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RADIO BROADBAND BEARER SYSTEM PRINCIPLES

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1. INTRODUCTION.

1.1 The rapid growth of the capital cities and major provincial cities and towns throughout Australia, and the extension of the telephone subscriber trunk dialling network, has produced a demand for large numbers of interstate and intrastate trunk telephone circuits and metropolitan junction telephone circuits. Most of trunk circuits and many junction circuits are derived using frequency division multiplexing (FDM) but time division multiplexing (TDM) using pulse code modulation (PCM) is being introduced and may be extended. Systems providing a large number of derived circuits, usually several hundred, are known as broadband carrier systems. Broadband carrier systems require large bandwidth (broadband) links for their transmission and these are provided via broadband bearers.

In addition to the requirement for telephony transmission, telephone circuits are used for telegraph signal transmission for the tress network providing the public telegram service, and the growing telex network which allows typed communications between subscribers. Also, the use of computers for automatic processing of information is increasing. The cost and computing capabilities of large high speed computers has lead to the use of centralised computers by some organisations. For convenience and speed of operation, data transmission facilities are required to provide for information transfer between different computers and between computers and remote data terminals. Low and medium speed data transmission facilities are normally provided via telephone circuits. High speed data transmission required wider bandwidths obtainable using broadband carrier systems. Telegraph and data transmission, therefore, is also causing a growth in the number of telephone and other wider bandwidth circuits provided by broadband links.

1.2 Television in Australia has also produced a need for broadband links. The major requirement is for the transmission of intrastate television programmes for the National Television Service. The majority of the programmes for this network originate in the Australian Broadcasting Commission Studios in the capital cities. The programmes are then distributed to capital city and regional transmitters via broadband links. For other programmes of national importance interstate broadband links are regularly required. In addition, television links are required by *"commercial"* television organisations and long distance transmission facilities for these organisations are provided by the Australian Post Office.

1.3 A link is defined as the connection which provides transmission facilities between two points, the signal at the output being essentially the same as that at the input. For telephony, the broadband link between two carrier system terminals is considered as providing a two way transmission path since both directions of transmission are required for a telephone communication. However, for television, where one direction of transmission provides the full information, the term link is used for a one way transmission system.

Broadband transmission systems normally provide independent transmission in each direction. In these circumstances, the term bearer is used to describe the equipment and propagation path for one direction of transmission. To improve reliability of a link, standby equipment can be used to provide additional bearers which can be switched in place of main bearers as necessary. It is possible, therefore, that a particular link may be provided via different bearers at different times. Normally a bearer is defined as providing a one way transmission system between adjacent bearer switching points. The preceding terms are examined further as necessary in this paper.

1.4 Broadband links can be provided by coaxial cable systems and by microwave radio systems. Suitable radio systems must operate in the microwave region, that is, the upper sections of the UHF range or in the SHF range, because of the bandwidth requirements for broadband telephony carrier systems and television signals. Three types of radio bearer systems can be operated in these frequency ranges. The majority of systems use direct transmission over terrestrial line of sight or near line of sight propagation paths between adjacent radio transmitters and receivers along the route. A second type of system uses line of sight propagation between two distant earth stations via earth satellite repeater. Satellite repeaters are used for international communications but, at present, are not used on a permanent basis for internal communications by the Australian Post Office. The third type of system makes use of tropospheric scatter of radio signals which occurs in the upper atmosphere. A limited number of such systems are operating in Australia but they are not in general use at this time.

Frequency modulation is currently used with all types of radio broadband bearers because the linearity required by FDM carrier systems, to prevent intermodulation distortion causing interference, is more readily obtainable using frequency modulation than it would be if amplitude modulation or phase modulation was used. Other forms of modulation may have advantages as bearers for PCM carrier systems in the future.

1.5 This paper summarises the characteristic of signals to be transmitted via radio broadband bearer systems and examines, in general terms, the equipment included in systems which operate over terrestrial line of sight paths. However, many of the techniques used for these systems are also applicable to satellite repeater and trophospheric scatter systems.

2. BASEBAND SIGNALS.

2.1 The signal at the input of a broadband link which is to be transmitted over a radio bearer to the output, is usually known as the *baseband* signal. A radio bearer must provide a channel with a frequency bandwidth which allows transmission of the baseband signal without significant degradation. The noise introduced by the bearer must also be kept below a specified minimum to prevent significant degradation. For a frequency division multiplexed telephony signal, it is important that a constant amplitude-frequency characteristic be maintained over the frequency band occupied by the signal so that each derived channel has the same transmission equivalent. Also, a good linearity is required to minimise intermodulation distortion which produces spurious interfering frequency components that appear as noise in the derived telephone channels. For television, the video signal waveform must be accurately maintained. To do this, in addition to a constant amplitude-frequency requirement over the signal bandwidth, the phase-frequency characteristic must be close to the ideal, particularly for colour television, so that there is practically the same time delay for each of the different frequency components of the signal. A similar requirement exists for PCM signals so that signal codes can be interpreted without error.

In this section we will examine FDM telephony carrier signals and television signals to determine the bandwidths required for transmission of these baseband signals. The signals are examined in more detail in other Technical Training Publications. At this time, radio systems are not in common use as bearers for PCM signals and these signals are not analysed in this paper. The examination of radio broadband bearer systems in following sections assumes either FDM telephony or television baseband signals.

2.2 FREQUENCY DIVISION MULTIPLEXED (FDM) TELEPHONY CARRIER SYSTEMS.

Many telephone channels can be transmitted via the one bearer by using frequency division multiplexing which involves translating each channel into a different section of the output frequency spectrum. The total bandwidth required is approximately proportional to the number of channels provided, and to the bandwidth of each channel. A channel provides one-way transmission only. Therefore, for a telephone circuit, a telephone channel is required in each direction. Radio systems provide separate bearers for each direction of transmission and the baseband signals for each bearer are assembled in the same manner.

In a broadband carrier system providing hundreds of telephone channels, the channels are normally translated and combined in standard patterns. Standardisation of carrier systems allows blocks of channels to be interconnected between systems without the need for them to be reconverted back to their original channel frequencies.

For a *basic telephone channel*, frequencies between *0.3 kHz and 3.4 kHz*, giving a channel bandwidth of *3.1 kHz*, are transmitted. Each telephone channel requires signalling information. This may be included in or may be outside the voice frequency band. For out-of-band signalling, a frequency of 3.825 kHz is normally used. The frequency spectrum occupied by the telephone channel is often indicated as in Fig. 1 and is considered as occupying a nominal 4 kHz bandwidth.

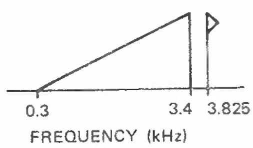


FIG. 1. BASIC TELEPHONE CHANNEL FREQUENCY SPECTRUM.

The combination of *12 telephone channels* in the frequency range of *60 kHz to 108 kHz*, a 4 × 12 = *48 kHz* band, is known as a *basic group*. Single sideband suppressed carrier amplitude modulation is used to translate each channel to its allocated position in this frequency range. The channels modulate separate carriers which are at 4 kHz spacings, the lower or inverted sideband of each carrier is selected and then all twelve sidebands are combined to occupy the frequency spectrum as indicated in Fig. 2a. The out-of-band signalling frequency allocations are not included in this diagram. Notice that the channels are inverted, that is, the lowest frequency of each channel becomes the highest frequency in the output frequency spectrum. Also notice that the channels are numbered from the high frequency end of the spectrum. The alternate symbol used to represent the spectrum of a basic group is included in Fig. 2b. In some equipment, channels are translated directly to their frequency range in the basic group. In other cases there is an intermediate sub-group stage and the basic group is produced from four sub-groups of three channels, three sub-groups of four channels or two sub-groups of six channels.

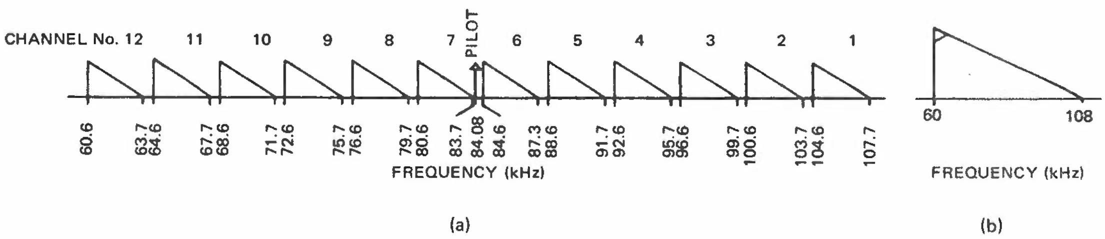


FIG. 2. BASIC GROUP FREQUENCY SPECTRUM.

To ensure that the overall transmission equivalent is maintained, it is often necessary to provide automatic supervision. This is obtained with the aid of a reference signal or pilot which is inserted between channels. If required a group pilot is included at a frequency of 84.08 kHz in the basic group frequency spectrum. At the receiving end, the level of the pilot signal controls the gain of an amplifier to provide regulation of the signal level.

In a similar manner to that used for individual channels, *five basic groups* are translated into separate group frequency ranges and when combined they form a *basic supergroup of 60 channels* with a frequency range of *312 kHz to 552 kHz*. The frequency spectrum occupied by each group in the basic supergroup is shown in Fig. 3 together with the alternate symbol for the basic supergroup. Notice that the groups in the basic supergroup and the basic supergroup are erect. If a supergroup pilot is required it is included at 411.92 kHz.

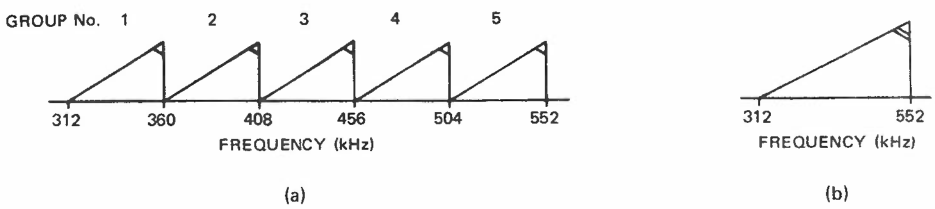


FIG. 3. BASIC SUPERGROUP FREQUENCY SPECTRUM.

By further modulation, *five basic supergroups* can be translated into different supergroup frequency ranges and combined to form a *basic mastergroup* of *300 channels* in the frequency range of *812 kHz to 2,044 kHz*. The frequency spectrum allocated to each inverted supergroup is illustrated by Fig. 4 which shows an 8 kHz adjacent supergroup separation. This allows for the separation of supergroups using practicable filters. The supergroup numbering included corresponds to the numbering of supergroups in a 960 channel (4 MHz) system. If it is required a pilot signal is included at 1,552 kHz.

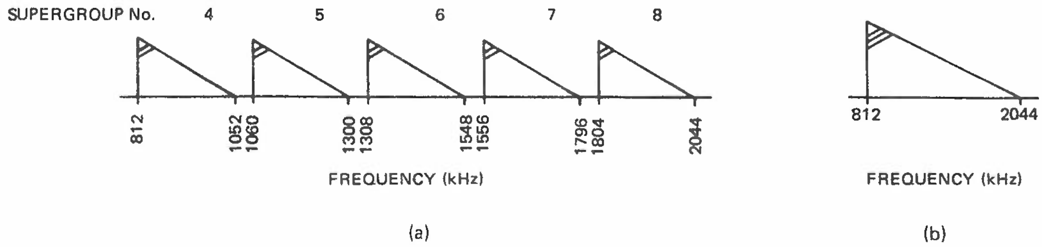


FIG. 4. BASIC MASTERGROUP FREQUENCY SPECTRUM.

A basic supermastergroup of *900 channels* is formed when *three basic mastergroups* are translated into separate mastergroup ranges and combined in the frequency spectrum of *8,516 kHz to 12,388 kHz* as shown in Fig. 5. An 88 kHz space is allowed between mastergroups which allows the mastergroups to be separated by practicable filters. The numbering of mastergroups in Fig. 5 corresponds to the numbers used for a 2,700 channel system produced by assembling mastergroups. Fig. 5 includes the symbol which represents a basic supermastergroup.

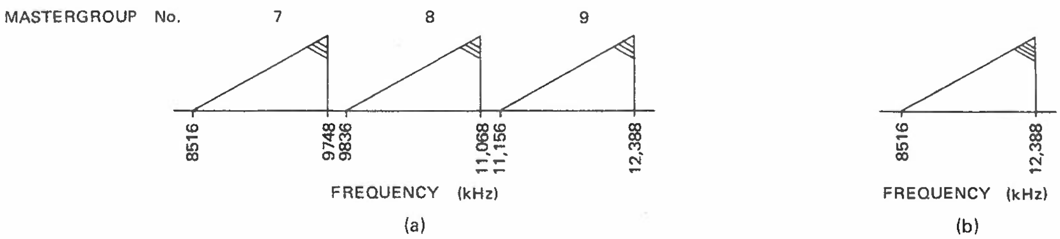


FIG. 5. BASIC SUPERMASTERGROUP FREQUENCY SPECTRUM.

2.3 TYPICAL BROADBAND CARRIER SYSTEMS.

The groupings as set out in para. 2.2 are used in various arrangements by typical broadband carrier systems. For example a *960 channel* or *4 MHz system* is normally provided by direct translation assembly of 16 supergroups into the frequency range of *60 kHz to 4,028 kHz* as illustrated in Fig. 6. Notice that, in this system, Supergroup 2 is the basic supergroup which is connected to the output without further frequency translation.

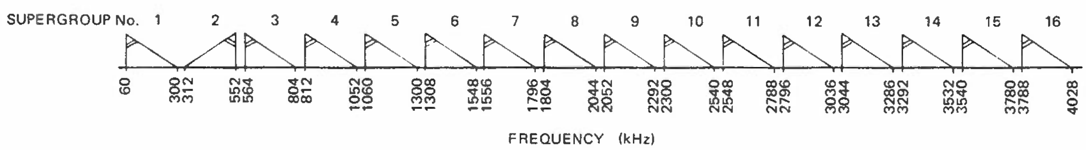


FIG. 6. 960 CHANNEL OR 4 MHz SYSTEM FREQUENCY SPECTRUM.

In some cases Supergroup 1 in Fig. 6 is not included and a 900 channel system is produced. The supergroup numbering is not changed. This arrangement is often used with coaxial cable bearer systems because it simplifies the equalisation of the cable when frequencies below 300 kHz are not to be transmitted.

A *1,260 channel* or *6 MHz system* can be produced by adding to a 16 supergroup 960 channel system, a mastergroup of 300 channels in the band above the frequency range used by the 960 channels. The frequency spectrum of such a system is illustrated in Fig. 7.

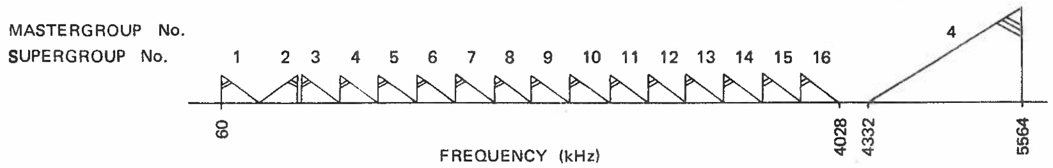


FIG. 7. FREQUENCY SPECTRUM OF 1,260 CHANNEL (6 MHz) SYSTEM.

Two methods of producing *2,700 channel* or *12 MHz systems* are shown by Fig. 8. In Fig. 8a, 900 channels, provided by direct translation of 15 supergroups, are combined with two supermastergroups which each contain three mastergroups or 900 channels. Fig. 8b shows 2,700 channels produced by three supermastergroups each of three mastergroups.

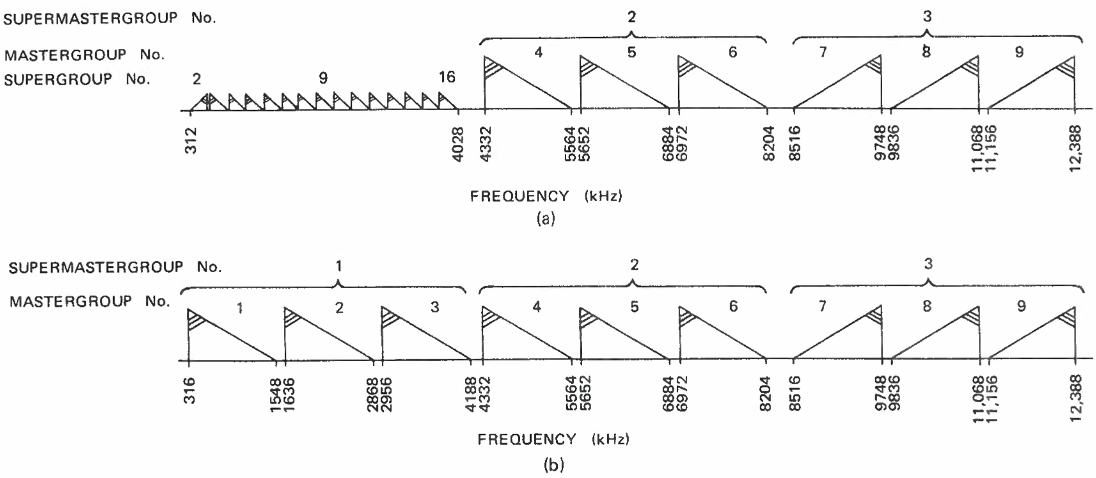


FIG. 8. FREQUENCY SPECTRUMS OF 2,700 CHANNEL (12 MHz) SYSTEMS.

The frequency bands occupied by carrier systems of typically available capacities are included in Table 1. The alternative frequency bands for some systems depend on the method of channel assembly. For example, for systems of 900 channels the bandwidth required is 312 kHz to 4,028 kHz if the channels are provided by direct translation of 15 basic supergroups as illustrated by supergroups 2 to 16 in Fig. 6, but is 316 kHz to 4,188 kHz if the channels are translated via basic mastergroup and basic supermastergroup stages to produce supermastergroup 1 of Fig. 8b.

NUMBER OF CHANNELS	FREQUENCY BAND OCCUPIED (kHz)
60	60 – 300
120	60 – 552
240	60 – 1,052
300	60 – 1,300
600	60 – 2,540
900	312 – 4,028 316 – 4,188
960	60 – 4,028
1,200	312 – 5,564
1,260	60 – 5,564
1,800	312 – 8,204 316 – 8,204
2,700	312 – 12,388 316 – 12,388

TABLE 1. F.D.M. BROADBAND CARRIER SYSTEM FREQUENCY BANDS.

2.4 MONOCHROME TELEVISION SYSTEM. In a television system the picture signal is produced by scanning each picture element in turn from left to right and from top to bottom to form a raster of approximately horizontal lines with an aspect ratio of 4 (horizontally) to 3 (vertically). In Australia, the complete picture is scanned by a 625 line raster formed by two interlaced fields. The picture frequency is 25 Hz and the field frequency is 50 Hz so that one vertical scan is completed in 20 ms. The line frequency and the frequency of the horizontal scanning signal equals the number of lines multiplied by the picture frequency; that is 625 × 25 = 15,625 Hz. This gives a complete line time of 64 μs. To allow for retrace of the scanning raster, the television signal includes horizontal and vertical blanking periods and, during these periods, horizontal and vertical synchronising information is included. Details of the timing and relative amplitudes of the resultant composite video signal are included in other Technical Training Publications.

2.5 VIDEO SIGNAL BANDWIDTH. The bandwidth required for transmission of a monochrome video signal depends on the resolution to be achieved. Resolution for a television system is defined as the number of alternate black and white lines (counting each separately) that can be reproduced in a distance equal to the picture height. Vertical resolution is related to the number of lines in the television system, but approximately 50 (25 lines per field) contain no picture information because they are used for the vertical blanking periods. Also, because of the scanning process and the finite scanning spot size, the expected resolution is only about 75% of the available number of lines. Therefore, the vertical resolution expected for the Australian Television is -

$$0.75\ (625-50) = 431 \text{ lines.}$$

For consistency of picture detail, the horizontal resolution is required to be the same as the vertical resolution. Because the aspect ratio (width : height) of the television picture is 4:3, the total number of lines to be resolved in the picture width is -

$$\frac{4}{3} \times 431 = 575 \text{ lines.}$$

Since the scene is scanned by a series of horizontal lines it is the horizontal resolution which determines the maximum frequency present in the signal. For a picture consisting of alternatively black and white vertical lines corresponding to the maximum required resolution, one cycle of signal is produced by two adjacent lines, one black and one white. Therefore, the maximum number of cycles of signal required in the picture interval of the line time is half the number of lines to be resolved in the picture width. It is sufficient for detail to be recognised that a sine wave at this frequency be transmitted by the system. Of the 64 μs line time, 12 μs is occupied by the horizontal blanking period so that the picture interval is 64-12 = 52 μs. Therefore -

$$\text{The high frequency limit of the video bandwidth} = \frac{\text{Maximum number of lines resolved in picture width}}{2 \times \text{picture interval}}$$

$$= \frac{575}{2 \times (64-12)}$$

$$= 5.53 \text{ MHz.}$$

The Australian Standards allow for a maximum video frequency for broadcasting purposes of not less than 5 MHz.

The frequency spectrum of a video signal consists of numerous frequencies. Because the picture repetition frequency is 25 Hz, a component is present at this frequency. However, it is normally small because the difference between two adjacent fields is normally small. A major frequency spectrum component is produced at the field rate of 50 Hz. Much of the television picture information and synchronising information recurs at the line frequency of 15,625 Hz. Significant components, similar to sideband components, appear at 50 Hz intervals on either side of the line frequency and its harmonics. In addition, the television signal contains a D.C. component. The D.C. component represents the average brightness of the scene to be transmitted and it varies for different pictures, giving a very low frequency component. Fortunately it is not necessary to transmit the D.C. component over a broadband bearer. The D.C. component and very low frequency amplitude variations can be restored when required by *clamping* a reference part of the signal (either the blanking level during the back porch intervals or the sync. tips) to a fixed potential. It is usually acceptable if an insignificant amplitude-frequency response reduction occurs at 50 Hz and the nominal low frequency limit of the bandwidth specified for television video signal transmission is usually slightly below this frequency, and normally 30 Hz.

2.6 PAL COLOUR TELEVISION SYSTEM. Colour television relies on the fact that colour pictures containing most possible colours can be produced by combinations of three primary colours. The system adopted for Australia is the PAL (phase alteration line) system which is a development of the NTSC (National Television System Committee, U.S.A.) system.

For colour television, the red, green and blue contents of the picture to be transmitted are separated using combinations of mirrors, prisms and filters. Each colour image is scanned using three separate monochrome camera tubes, and three separate colour signals are produced, one for each colour. These signals are normally designated R, G and B respectively.

Colour television systems are designed to be compatible with their related monochrome systems to enable monochrome television receivers to operate satisfactorily and reproduce a monochrome picture with colour transmissions from television broadcasting transmitters. Reverse compatibility is also required so that a colour television receiver will reproduce a monochrome picture when a monochrome television signal is broadcast. The colour video signal, therefore, includes a luminance signal corresponding to the picture signal of a monochrome video signal. The luminance signal (normally designated Y) can be obtained by combining the correct proportion of the red, green and blue colour signals. Alternatively, the luminance signal can be derived directly using a fourth camera tube in the colour television camera.

2.7 CHROMINANCE SIGNAL. The chrominance or colour information is not transmitted directly as the originally derived colour signals but is changed into two colour difference signals. These signals are the difference between the red signal and the luminance signal (R-Y), and the difference between the blue signal and the luminance signal (B-Y). Because the relationship between red, green, blue and luminance signals is defined, it is not necessary to transmit the green-luminance (G-Y) difference signal. This signal can be obtained by combining the correct proportions of the other two colour difference signals. Then each colour signal can be retrieved by adding the luminance signal to each colour difference signal; for example, (R-Y) + Y = R. The R-Y colour difference signal and the B-Y colour difference signal, when properly corrected to give the required relationship between the brightness of the scene and the signal voltage (gamma corrected) and presented at the specified relative levels, are normally known as V and U signals respectively.

It is required that the colour television signal should occupy a bandwidth no greater than that of the monochrome television signal. To achieve this requirement while still maintaining a high definition luminance signal, the colour information is transmitted as modulation of a colour sub-carrier located within the monochrome signal bandwidth. The modulated sub-carrier containing the colour information is known as the chrominance signal. To minimise the interference pattern produced on the picture tube screen by the chrominance signal, the colour sub-carrier frequency is selected to be towards the upper end of the video frequency band and a fixed relationship is maintained between it and the line frequency. For the Australian PAL colour television system, the colour sub-carrier frequency is approximately 4.43 MHz.

The chrominance signal is produced from the U and V signals. Because a viewer is not conscious of lack of colour in small details of a picture, a limited bandwidth for the colour information is acceptable. The bandwidths of the U and V signals are restricted using low pass filters with gradual cut-off (Gaussian) characteristics and 3 dB attenuation at 1.3 MHz. These signals then each modulate separate sub-carriers with the same frequency but with a relative phase of 90°. Suppressed carrier double sideband modulation is used. The outputs from the U and V modulators are combined to form the chrominance signal. A detailed analysis shows that the resultant chrominance signal is a sub-carrier which varies in amplitude and phase. The phase of the colour sub-carrier contains the hue (or colour) information and the amplitude of the sub-carrier contains the colour saturation (or purity of hue) information. Colour saturation is reduced by the addition of white to the pure hue making it pale or a pastel colour. If there is not colour, that is, the picture is all black, grey and white, there is not sub-carrier amplitude. In the PAL colour television system, the phase of the V sub-carrier is reversed in alternate lines. This allows phase errors introduced during transmission to be averaged between adjacent lines and their effect on the hue of the reproduced picture can be largely eliminated.

2.8 COMPOSITE COLOUR VIDEO SIGNAL. The composite colour video signal includes the luminance signal and the synchronising information of the monochrome video signal plus the chrominance signal. In addition, since suppressed carrier modulation is used to form the chrominance signal, the sub-carrier must be reinserted in the receiver to allow demodulation. To ensure synchronism of the reinserted sub-carrier, a reference colour sub-carrier signal (colour burst) is included in the horizontal blanking period following the horizontal sync. pulse. Details of the relative levels of the luminance and chrominance signals and the time and relative amplitudes of the resultant composite colour video signal are not included in this paper.

The modulation involved during the generation of the chrominance signal produces sideband frequencies on either side of the suppressed colour sub-carrier. Because of the bandwidth limiting of the colour information before modulation, the 3 dB points of the amplitude-frequency response of the chrominance channel are 1.3 MHz on either side of the colour sub-carrier frequency. This is illustrated by the broken line curve in Fig. 9. For broadcasting purposes, the composite colour video signal is limited in the television broadcasting transmitter to nominally 5 MHz. Therefore, the bandwidth of the broadcast composite video signal channel is from 0 to 5 MHz as illustrated by the full line curve in Fig. 9. Because of this, the upper sideband of the chrominance component of the video signal is cut off at nominally 0.57 MHz above the colour sub-carrier.

Though Fig. 9 indicates that the bandwidth requirements for both monochrome and colour television broadcasting are the same, it is desirable to avoid deliberate reduction of the upper sideband during transmission via a television bearer. Such a reduction would increase the overall asymmetry of the broadcast chrominance signal. Therefore, most radio broadband bearers have bandwidths which extend beyond 5.73 MHz so that significant sections of the chrominance signal bandwidth are not eliminated. Also, although the PAL television system is tolerant of phase errors, radio broadband bearers require good phase characteristics, particularly in the frequency band occupied by the chrominance signal, so that degradation of the broadcast television signal is minimised.

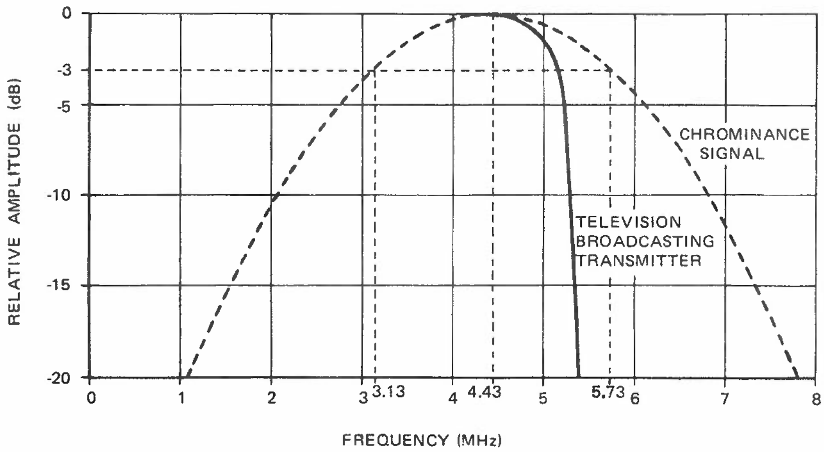


FIG. 9. COLOUR VIDEO SIGNAL BANDWIDTH.

The frequency spectrum of the luminance section of a composite colour video signal includes the same components as those present in a monochrome video signal. In addition, because, in the PAL television system, the phase of the chrominance information is changed in alternate lines, the same information can repeat every second line and the frequency spectrum of the chrominance signal has significant components at half line frequency intervals on either side of the chrominance sub-carrier. Detailed examination shows that, because of the chosen chrominance sub-carrier, the chrominance signal spectrum components interleave with the luminance signal spectral components. Further details are not included in this paper.

2.9 T.V. SOUND CHANNEL In addition to the video signals, a television system requires the provision of a high quality sound programme channels. Television broadcasting caters for an audio frequency bandwidth of 30 Hz to 15 kHz. This bandwidth is normally provided when the sound channel is provided in association with the video channel via a radio broadband bearer, but a reduced bandwidth is sometimes accepted.

3. BASIC LINE OF SIGHT RADIO BROADBAND BEARERS.

3.1 A radio broadband bearer system includes the main traffic bearers, any standby or protection equipment required to achieve the necessary reliability and the equipment needed to provide supervisory facilities and telephone circuits for maintenance purposes. The equipment required depends on the traffic requirements along the route. In a common arrangement, a radio bearer system on a particular route is required to provide a two way telephony link and a one way television link originating in the capital city. Development can be envisaged on a route with high traffic requirements in the Australian network that will give a need for two to four two way telephony links, one or two television links in each direction for programme exchange between main centres and a one way television link for programme distribution to regional television broadcasting transmitters along the route.

In this and following sections, block diagrams are developed to give an appreciation of the equipment required for a complete radio broadband bearer system operating over terrestrial line of sight propagation paths. The block diagrams examine the system as a whole but do not give details of individual sections of the equipment. It is assumed that the equipment is typical of that normally provided for modern main line installations.

3.2 BASIC RADIO BROADBAND BEARER SYSTEM. A basic radio broadband bearer consists of terminal transmitting and receiving equipment at each end and a number of repeaters placed at strategic sites at 30 km to 70 km intervals along the route. For television programme distribution, a bearer providing transmission in one direction is often all that is required. However, for telephony, independent bearers are required for transmission in each direction with separate baseband input and output connections as illustrated in Fig. 10. We will see in para. 3.17 that the bearers are not completely separated since it is normal for several transmitters and receivers to share a common aerial.

In the transmitting equipment in Fig. 10, a carrier is frequency modulated by the baseband signal. The transmitter output is radiated using a directional aerial. At the repeater, the received RF signal is amplified and translated to another frequency before being reradiated. The frequency translation is necessary to prevent interference between the RF output from the repeater and the much lower level RF signals received from the adjacent stations. The receiving equipment recovers the baseband signal from the modulated received signal.

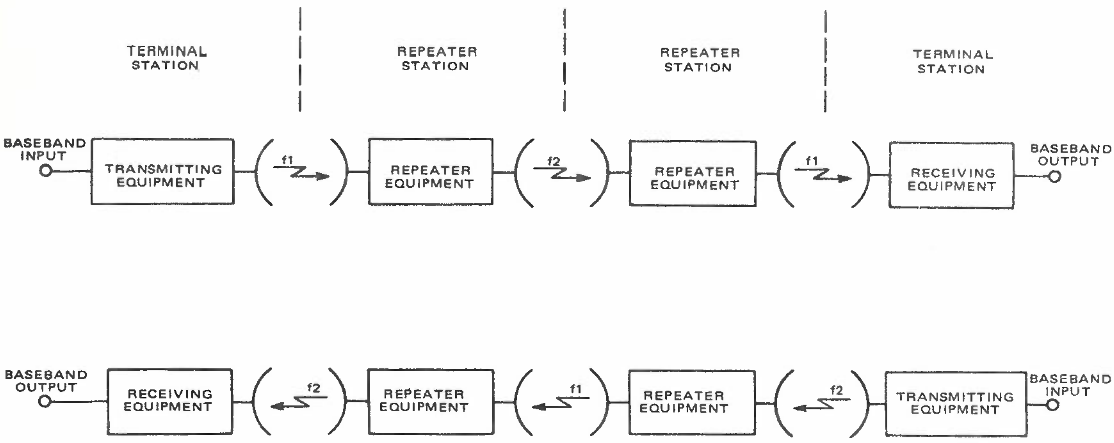


FIG. 10. BASIC RADIO BROADBAND BEARER SYSTEM.

In Fig. 10, two frequencies only (the minimum number practicable) are being used for all transmission paths. In this arrangement both the transmitted RF signals at one repeater have the same frequency, as also do both the received RF signals. Such a frequency plan gives many possibilities of interference because of propagation to other than the required station. The interference via some propagation paths can be reduced by the use of directional aerials and by selecting the location of stations on a route so as to prevent propagation overshoot from one path causing the signal to be received at another station further along the route. To further reduce the possibilities of interference, several transmission frequencies are often used, particularly with bearers having a large number of hops. The recommended standard frequency plans for a particular RF band give standard frequency shifts between the received and transmitted frequencies at a repeater station.

3.3 TERMINAL TRANSMITTING EQUIPMENT. There are two basic arrangements for the transmitting equipment at a terminal station. In one system (Fig. 11a) an RF oscillator is frequency modulated and then perhaps frequency multiplied and amplified to provide the transmitter power output. This technique is used, with frequency multiplication and amplification, in equipment for low capacity bearers in the UHF range and, without frequency multiplication and amplification, for mobile television bearers in the SHF range. The latter type of equipment was also used for some early short haul telephony broadband bearers.

The second basic arrangement for terminal transmitting equipment, which is illustrated by Fig. 11b, is used in most modern radio broadband beares of both main line and short haul systems. Frequency modulation is carried out at an intermediate frequency which, in almost all equipment currently available, is 70 MHz. Following the modulator a limiting amplifier is normally included to remove any amplitude modulation produced in the frequency modulator. The modulated intermediate frequency is converted to the final transmitted frequency by combining the intermediate frequency signal and the output of a local oscillator in the transmit mixer and selecting the desired output frequency. The transmit mixer and local oscillator combination is sometimes called an *up converter*. Amplification may or may not be provided after the transmit mixer.

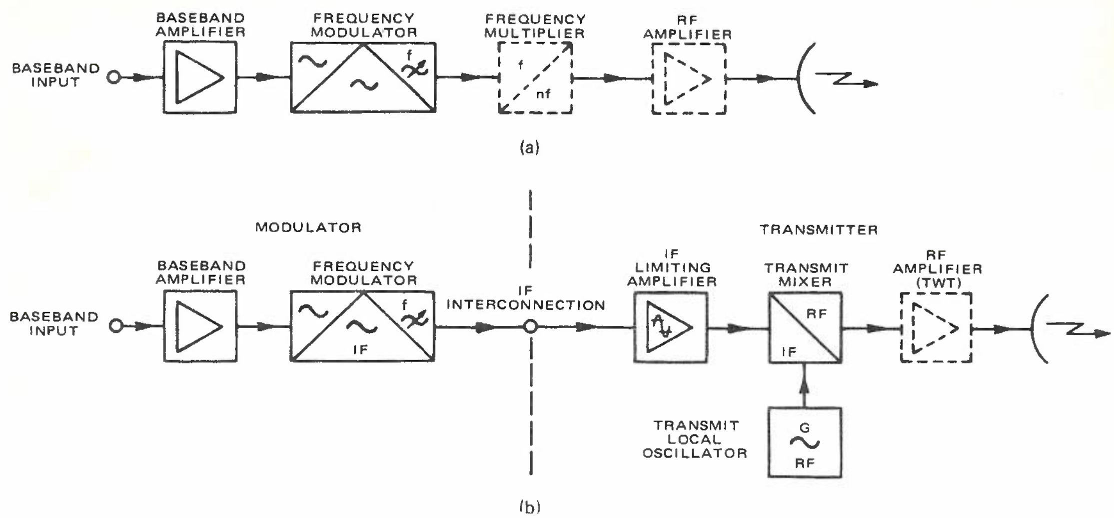


FIG. 11. TERMINAL TRANSMITTING EQUIPMENT.

Practical equipment is usually manufactured and mounted on racks or in units with a distinct division at the IF interconnection point in the block diagram as indicated by Fig. 11b. It is convenient to refer to the frequency modulator and its associated equipment as the modulator and to the transmit mixer, the RF local oscillator and the associated equipment as the transmitter. This designation will be used in the general system block diagrams in this paper.

3.4 TERMINAL RECEIVING EQUIPMENT. All radio broadband bearer receivers convert the incoming RF signal to an intermediate frequency where the majority of the amplification is provided. Fig. 12 shows a simplified block diagram of the receiving equipment at a terminal station. The incoming signal, in some cases amplified, is fed to the receive mixer. Here it is combined with the local oscillator signal to produce the intermediate frequency which is normally 70 MHz. The receive mixer and local oscillator combination is sometimes called a *down converter*. The following IF amplifier includes automatic gain control (AGC) so that a constant mean level is available at the IF interconnection point for a range of receiver RF input signal levels of at least 40 dB. The time constant of the AGC circuit is such that it can correct for receiver RF input signal level changes introduced by fading, but not for changes at baseband signal frequencies.

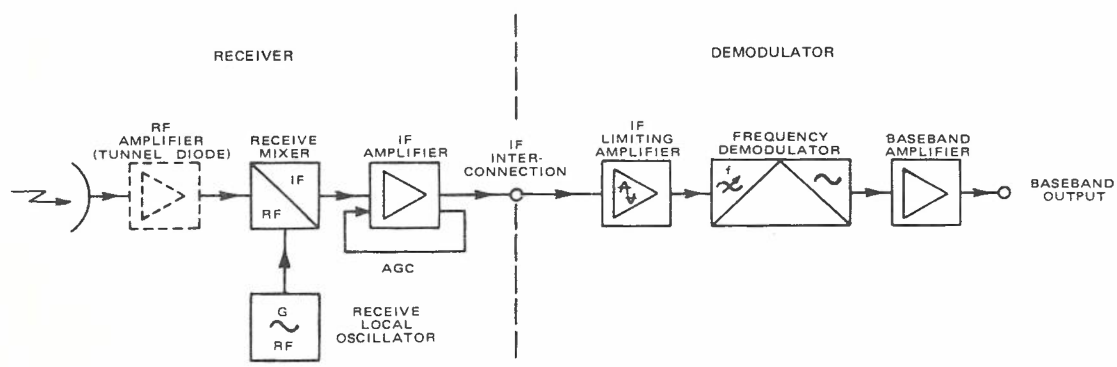


FIG. 12. TERMINAL RECEIVING EQUIPMENT.

With very low receiver RF input signal levels, the signal to noise ratio at the receiver output becomes very low and the bearer is unsatisfactory for service. The receiver IF amplifier includes a muting or squelch circuit which disconnects the output of the IF amplifier from the following equipment under these conditions. This prevents the receiver noise from causing equipment malfunction and possibly incorrect or misleading supervisory alarm indications.

After the IF interconnection point the IF signal is fed through a limiting amplifier. This removes rapid changes such as amplitude modulation at baseband signal frequencies produced by noise and interfering signals and by small errors in the amplitude-frequency characteristics of preceding RF and IF circuits. The information contained as frequency modulation of the IF signal is recovered in the frequency demodulator and, after amplification, provides the baseband output.

In some early equipment it was necessary to include an automatic frequency control (AFC) circuit in the receiving equipment to maintain the correct intermediate frequency. With modern equipment, the stability of the receive local oscillator and the received signal from the transmitter is such that this is not necessary.

In a similar manner to the transmitting equipment, the receiving equipment is divided at the IF interconnection point as shown in Fig. 12. The receive mixer, the AGC controlled IF amplifier and associated equipment is referred to as the receiver and this equipment is usually mounted on the same rack as the transmitter. The IF limiting amplifier, frequency demodulator and associated equipment is called the demodulator and is physically associated with the modulator.

3.5 BASIC REPEATERS. The object of a radio bearer repeater is to receive the incoming modulated RF signal, amplify it, and retransmit a modulated RF signal with a different frequency to that received so that interference is minimal. There are two general forms of radio bearer repeaters - demodulating and non-demodulating repeaters.

In a *demodulating repeater*, the baseband signal is recovered in the receiving equipment before being connected to the transmitting equipment where the modulated signal at the new frequency is generated. Such a repeater consists of terminal transmitting and receiving equipment connected back to back with the interconnection made at the baseband interconnection point as illustrated in Fig. 13a. This type of repeater is therefore sometimes called a *baseband repeater*. It is the only type of repeater possible with equipment using direct modulation of the carrier frequency (Fig. 11a).

In a *non-demodulating repeater*, the modulated signal at the required transmitting frequency is produced without the incoming RF signal being demodulated to recover the baseband signal. The most commonly used type of non-demodulating repeater provides the majority of the amplification at an intermediate frequency. It is identical with a terminal transmitter and receiver connected back to back at the IF interconnection point (Fig. 13b). Because of this, the repeater is sometimes called an *IF repeater*. Another type of non-demodulating repeater that is not in common use produces direct conversion from the incoming frequency to the required outgoing frequency. RF amplification is provided before and after the frequency converter as shown in Fig. 13c. This repeater is often known as an *RF repeater*.

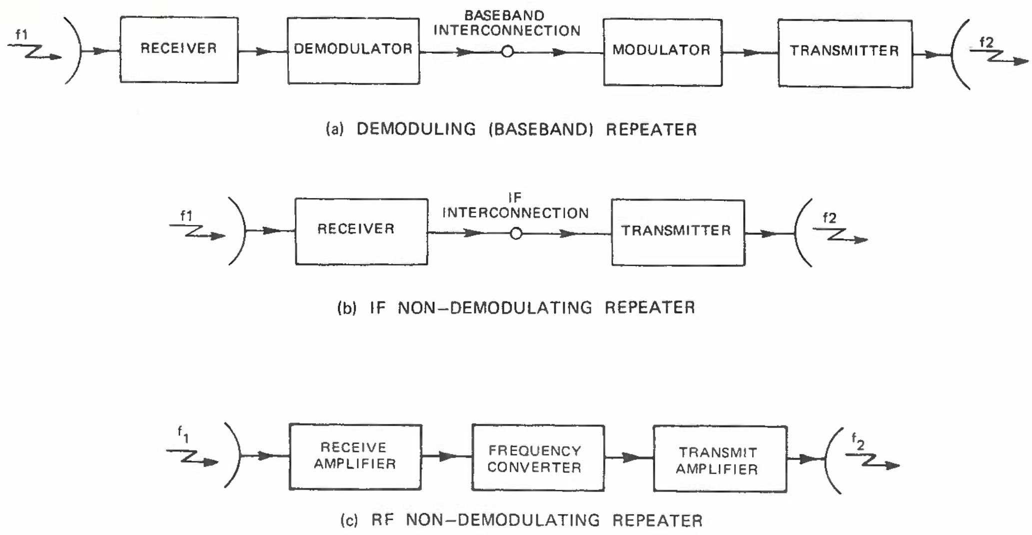


FIG. 13. BASIC REPEATERS.

3.6 An advantage of a demodulating repeater is that the baseband is available at the repeater station and a section of the baseband can be dropped and inserted as required (see paras. 4.3 to 4.5). Access to the full baseband is not possible at a non-demodulating repeater station. However, a telephony bearer can provide a limited number of channels between a demodulating repeater station and other stations along the route by using the frequency band below that occupied by broadband telephony carrier systems. This frequency band is often termed the *sub-baseband*. For a television bearer, a limited number of channels that are accessible at a non-demodulating repeater are sometimes provided using sub-carriers in the frequency band above the baseband which is often called the *super-baseband*. The methods of providing these channels are examined in paras. 6.12 to 6.19.

A disadvantage of a demodulating repeater is that the demodulator and the following modulator introduce into the system, thermal noise, and also nonlinearity which produces intermodulation noise. This results in non-demodulating repeaters having a noise advantage over demodulating repeaters.

Demodulating repeaters are used at main centres only along a route where a significant portion of the bearer capacity is required for traffic to and from the centre. Intermediate repeaters are normally non-demodulating types and these are installed at the majority of stations.

The term demodulating repeater is normally used only when a direct baseband interconnection is made. If the baseband interconnection is made via telephony carrier equipment or television distribution or switching equipment, the receiving equipment and the transmitting equipment are effectively isolated. Under these conditions, the receiving equipment and the transmitting equipment are normally considered as being part of two independent terminals. Since the baseband interconnection is normally provided only when baseband access is required, the term demodulating repeater is rarely used with modern radio broadband bearers.

3.7 REPEATER EQUIPMENT. Demodulating repeaters or baseband interconnected terminals use the same equipment as shown in Figs. 11 and 12. A non-demodulating repeater of IF type includes a receiver and a transmitter as shown by the simplified block diagram in Fig. 14. The incoming signal is converted to the intermediate frequency. The AGC controlled IF amplifier maintains a constant mean level at the IF interconnection point independent of variations in the RF input signal level. This is necessary so that a constant output level is obtained from the transmitting section. This IF amplifier also provides muting which disconnects its output from the following equipment when the received RF signal is unusable. In addition, when muting occurs, an unmodulated carrier at the intermediate frequency is inserted in place of the normal IF signal to ensure correct operation of the following equipment. The IF limiting amplifier removes any amplitude modulation introduced by noise and the amplitude-frequency response irregularities of the RF and IF circuits. The intermediate frequency and the correct local oscillator frequency combine in the transmit mixer to produce the required output frequency. Notice that the transmit local oscillator frequency will differ from the receive local oscillator frequency. If the bearer is operating with a standard frequency plan, a standard frequency difference is required for that plan for a particular band.

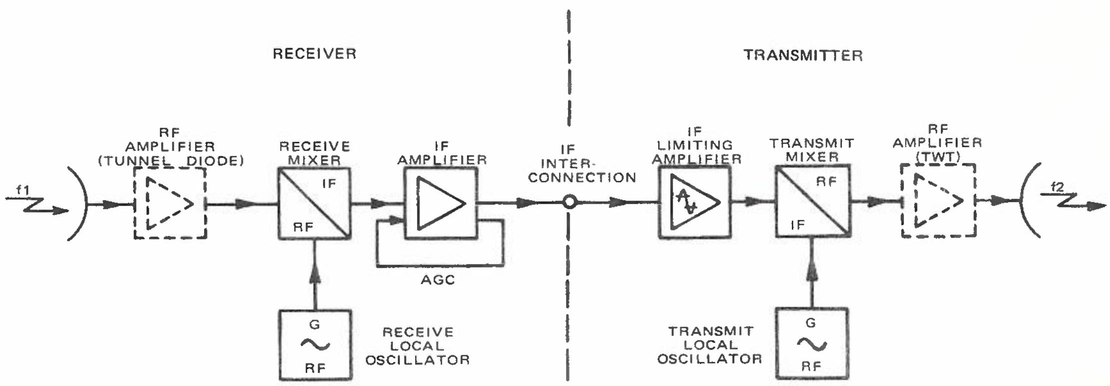


FIG. 14. IF NON-DEMODULATING REPEATER (SEPARATE LOCAL OSCILLATORS).

3.8 When independent local oscillators are used for the transmitter and the receiver of a non-demodulating repeater, the drifts in their frequencies can be such that a frequency error is produced in the difference between the repeater incoming and outgoing frequencies and this error can be cumulative in all non-demodulating repeaters between two demodulating stations. This results in an offset in the operating point of the signal on the frequency demodulator characteristic at the terminal and possibly an increase in the system nonlinearity. Assume, for example, that each local oscillator operates independently with frequencies suitable for the 4 GHz band. Fig. 15a illustrates the repeater frequencies when all are correct. In this condition, the received signal frequency (f1) mixed with the receive local oscillator frequency on the low side of the incoming signal (f1 - 70 MHz) gives the intermediate frequency (70 MHz). When 70 MHz is mixed with the transmit local oscillator frequency (f2 - 70 MHz), the transmitter output frequency (f2) is obtained.

If the stability of each local oscillator is ± 1 part in 10^5, the oscillators could change frequency by approximately -

$$\pm \frac{4000}{10^5} = \pm 0.04 \text{ MHz.}$$

Assume that the receive local oscillator is 0.04 MHz high (f1 - 70 MHz + 0.04 MHz). Then, since the local oscillator frequency is on low side of the incoming signal frequency, the intermediate frequency is 0.04 MHz low (70 MHz - 0.04 MHz). If the transmit local oscillator is at the opposite extreme of its allowable tolerance its frequency is 0.04 MHz low (f2 - 70 MHz - 0.04 MHz). The output frequency, which is the sum of the intermediate frequency and the transmit local oscillator frequency, is therefore 0.08 MHz low (f2 - 0.08 MHz). The frequencies for this operating condition are shown by Fig. 15b. Similar errors could be cumulatively added in other non-demodulating repeaters between demodulating stations.

The stability of the output frequency of each repeater transmitter is improved if the required difference between the repeater input and output frequencies can be maintained by keeping a constant difference between the transmitter and receiver local oscillator frequencies. Consider that the local oscillators have an accurately maintained frequency difference so that, if the receive local oscillator goes high in frequency, the transmit local oscillator also goes high by the same amount. This condition is illustrated by Fig. 15c. The receive local oscillator is 0.04 MHz high (f1 - 70 MHz + 0.04 MHz) and so the intermediate frequency is 0.04 MHz low (70 MHz - 0.04 MHz). Now, however, when the intermediate frequency is mixed with the high transmit local oscillator frequency (f2 - 70 MHz + 0.04 MHz), no error exists in the output frequency. The stability of the transmitter output frequency equals that of the receiver input frequency and cumulative frequency errors due to instabilities of repeater local oscillators are not produced. Notice, however, that the change in the intermediate frequency still occurs.

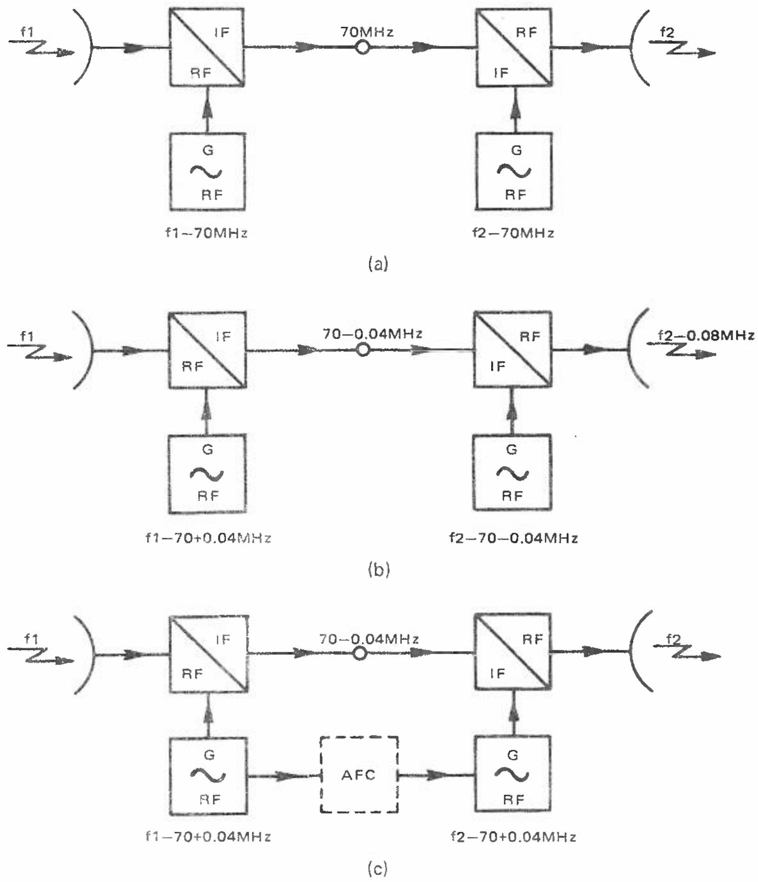


FIG. 15. REPEATER FREQUENCY STABILITY.

3.9 A constant frequency difference between the two local oscillators can be maintained by using an AFC system as suggested by Fig. 15c, but the normal method includes a shift converter and is illustrated by the block diagram in Fig. 16. From the receive local oscillator two outputs are derived using some form of splitting network. One output feeds the receive mixer. The second output at the receive local oscillator frequency, along with the output of the shift oscillator, is fed to the shift mixer. The shift oscillator frequency is equal to the magnitude of the difference between the repeater input and output frequencies ($|f1 - f2|$). Assuming that the receive local oscillator operates below the receiver input frequency at a frequency of f1 - 70 MHz, the output frequencies available from the shift mixer are the sum and difference of its input frequencies; that is, (f1 - 70 MHz) ± ($|f1 - f2|$). If f1 is greater than f2, the difference is the frequency required for the local oscillator input to the transmit mixer. This is -

$$f1 - 70 \text{ MHz} - f1 + f2 = f2 - 70 \text{ MHz}.$$

In Fig. 16 the stability of the transmitter output frequency is dependent on the stability of the shift oscillator. If the received frequency is correct, the frequency error at the output equals that of the shift oscillator. However, since the shift oscillator frequency is much lower than the required transmit local oscillator frequency, the transmitter output frequency stability (quoted as a proportion) is improved from that of the shift oscillator in proportion to the ratio of the two frequencies.

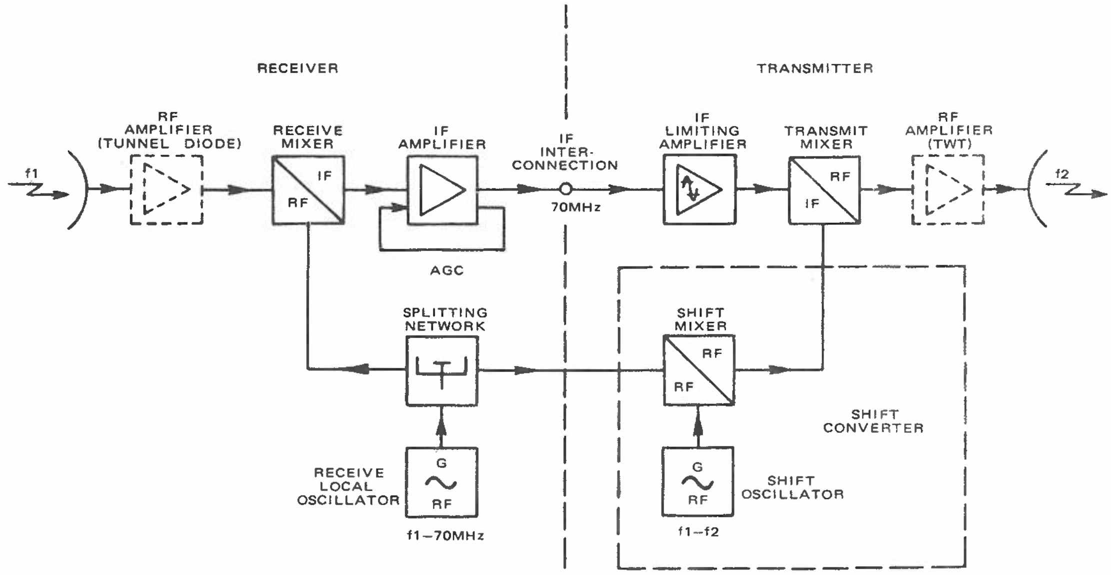


FIG. 16. IF NON-DEMODULATING REPEATER (SHIFT CONVERTER).

In some equipment the transmit local oscillator frequency is provided directly and a shift converter is used to obtain the receive local oscillator frequency. A reason for this is that the transmit mixer normally requires a higher oscillator power input than the receive mixer. However, most equipment now being supplied that uses the shift converter principle, operates as indicated in Fig. 16. This system has an advantage because it allows sub-baseband and super-baseband channels to be conveniently inserted at non-demodulating repeaters.

Though shift converter type IF non-demodulating repeaters have an overall frequency stability advantage, with modern eqiupment, adequate frequency stability can be obtained with IF non-demodulating repeaters using separate local oscillators. Both types of systems are in common use.

3.10 A simplified block diagram of a non-demodulating repeater of the RF type is illustrated in Fig. 17. The incoming signal is amplified in a low noise amplifier. A second amplifier includes fast acting AGC so that a constant output level is maintained for large variations in the input signal. The amplified received signal is then combined in a mixer with the output of the shift oscillator which operates at the difference between the repeater input and output frequencies (f1 - f2). This changes the received signal frequency (f1) directly to the required frequency for transmission (f2). A further amplifier provides the required power output. Because of the use of a shift oscillator in an RF non-demodulating repeater, the repeater's output frequency stability compares with that of an IF non-demodulating repeater using a shift oscillator (Fig. 16).

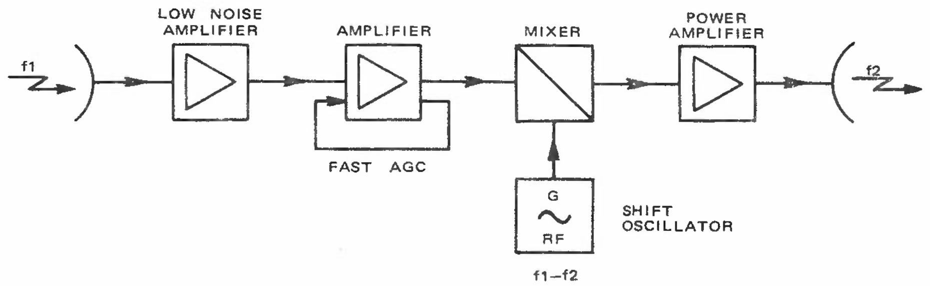


FIG. 17. RF NON-DEMODULATING REPEATER.

3.11 RADIO FREQUENCY BANDS. Within the UHF and SHF ranges, frequency bands are allocated for use by radio broadband bearers. The important frequency bands for terrestrial line of sight radio broadband bearers and the uses made of these bands are included in Table 2.

FREQUENCY BAND LIMITS (MHz)	GENERAL FREQUENCY BAND DESIGNATION	CHANNELS PROVIDED BY EACH BEARER IN BAND
1,700 – 1,900	Lower 2 GHz	60 – 120 telephony
1,900 – 2,300	2 GHz	300 – 1,800 telephony or television
3,770 – 4,200	4 GHz	300 – 1,800 telephony or television
5,925 – 6,425	6 GHz	600 – 1,800 telephony or television
6,425 – 7,110	Upper 6 GHz or 7 GHz	960 – 2,700 telephony or television
7,425 – 7,725	7.5 GHz	60 – 960 telephony or television
7,725 – 8,275	8 GHz	300 – 1,800 telephony or television
10,700 – 11,700	11 GHz	960 telephony or television

TABLE 2. RF BANDS ALLOCATED TO BROADBAND BEARERS.

The bandwidth required for transmission of the frequency modulated RF signal for a radio bearer depends on the RF signal deviation and on the bandwidth of the baseband signal. This is not analysed in this paper, but for typical systems with standard adjustments, the bandwidths required are approximately 17 MHz for a 960 channel telephony system and 24 MHz for an 1,800 channel telephony system.

Each of the allocated frequency bands is divided into RF channels in such a way as to make maximum use of the available frequency spectrum. Standard frequencies are used for the channels operating in any frequency band and these have been selected, to minimise the interference between different systems. Important factors taken into account to determine the RF channels were -

- Several RF channels may be required along a main route or on spur routes;
- It is normal for a common aerial to be shared by several transmitting and receiving RF channels;
- The RF channel spacing must allow channels to be separated without excessively complex filters;
- The frequencies should be selected to reduce the possibility of interference arising from spurious output of transmitters and receivers, and intermodulation products due to signals sharing common equipment such as waveguides and aerials.

In general, each band is divided into two sections with one half of the band being used for transmit frequencies and the other half being used for receive frequencies. This gives maximum frequency spacing between high level transmit and low level receive signals. In addition, horizontal and vertical polarisations of the radiated signals are used to assist in obtaining the necessary separation between channels.

3.12 As an example we will examine the frequencies for the RF channels derived in the 4 GHz band. The carrier frequencies for these RF channels and the approximate bandwidths occupied by bearers operating on these frequencies are illustrated by Fig. 18. Fig. 18a illustrates the normal RF channel allocation pattern (A) and Fig. 18b an alternative interleaved pattern (B). With reference to either Fig. 18a or Fig. 18b, the frequency band is divided into two by the nominal centre frequency, f0. Six RF channels for main line broadband bearers are allocated in each half of the band and these are designated 1, 2, 3, 4, 5, 6 and 1', 2', 3', 4', 5' and 6'. In addition, allocations are made for four auxiliary RF channels which are used as bearers for auxiliary systems providing services including supervisory and order wire facilities (refer Section 6). The approximate bandwidth occupied by each bearer is indicated by the rectangle which extends on either side of the channel carrier frequency. The polarisation of the transmission is changed for alternate channels. This is shown by alternate channels being drawn above or below the reference line and used as designated on the left of the diagram. For example, channels 1, 3 and 5 can be horizontally polarised and channels 2, 4 and 6 vertically polarised or vice versa. Notice that the frequency spacing between the carriers for adjacent RF channels in one half of the band is 29 MHz and a frequency spacing of 213 MHz exists between corresponding channels in each half of the band, for example, channels 1 and 1'.

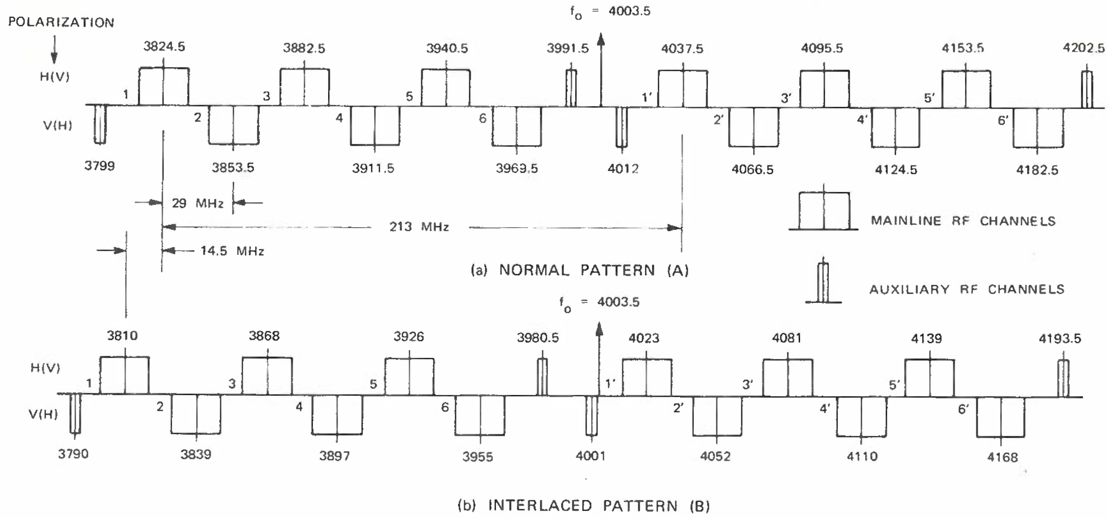


FIG. 18. RF CHANNEL ARRANGEMENT FOR 4 GHz BAND.

3.13 On a radio broadband bearer route, in one propagation path, frequencies in one half of the band are used for one direction of transmission and frequencies in the other half of the band for the opposite direction of transmission. Correspondingly numbered channels are used for associated bearers in each direction. For example, if channel 1' according to the normal frequency plan (A) is used from station V to station W in Fig. 19a, channel 1 is used for the bearer in the opposite direction. Horizontal polarisation could be used and this results in the RF channels between stations V and W being designated A1'H and A1H.

In a system using a two frequency plan following the principle outlines in para. 3.2 and Fig. 10, channel A1 is used for transmission from station W to station X and channel A1' for the return bearer. In addition, to reduce the possibility of adjacent path interference, it is usual to change the signal polarisation between adjacent propagation paths as indicated in Fig. 19a. This pattern is repeated for other stations along the route. As an alternative to the polarisation of Fig. 19a, on some routes the polarisation is reversed in each second propagation path to control interference produced when propagation path overshoot causes signals to be received by stations further along the route; for example, in Fig. 19a, when signals from station V are received at station Y.

Notice that, when a two frequency plan is used, the transmission frequency for each bearer shifts between correspondingly numbered channels in the upper and lower halves of the band at each station. Fig. 18 shows that, for the 4 GHz band, the frequency shift is 213 MHz. When additional bearers are required on a route, the same principle is applied for allocating other channels. In the 4 GHz band, RF channels with the same polarisation are allocated first in one propagation path (for example, channels 1', 3' and 5') before the system is extended to channels with the other polarisation. Fig. 19b illustrates six main line bearers being provided in each direction according to a two frequency plan using the normal allocation pattern in the 4 GHz band. This is the limit to the number of channels that can normally be provided in this band on one route but it may be possible to provide bearers on a route at right angles using frequencies according to the interleaved pattern.

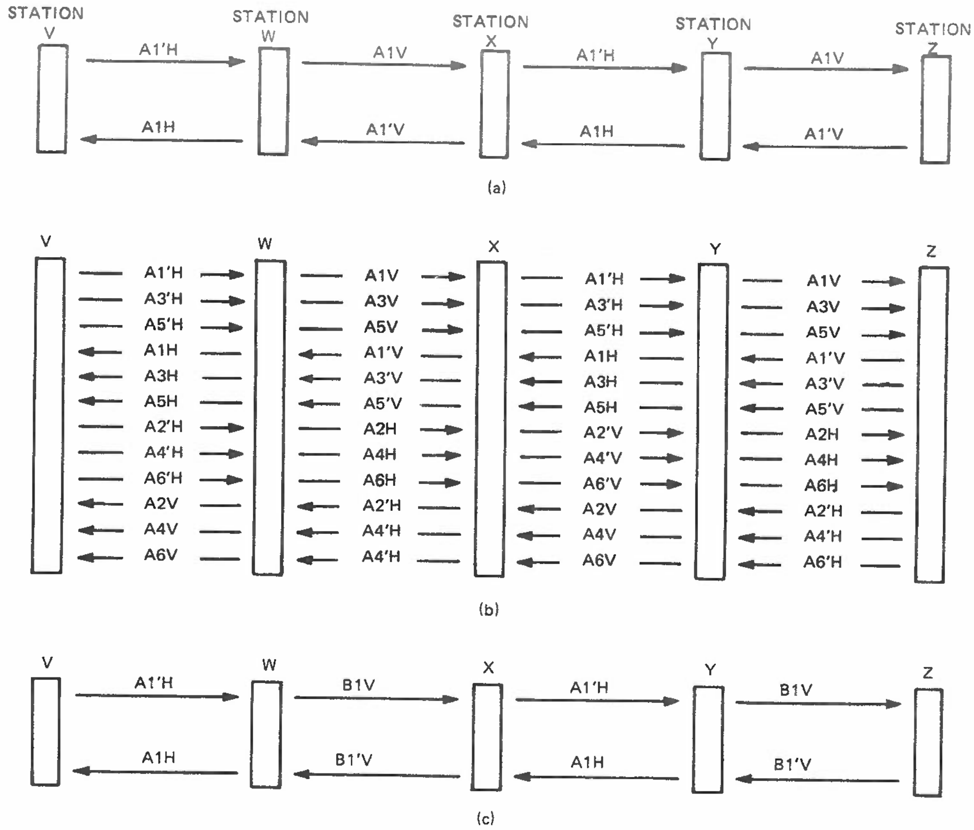


FIG. 19. TYPICAL RF CHANNEL ALLOCATIONS.

3.14 To reduce the possibility of interference between different propagation paths, several transmission frequencies are sometimes used for a bearer on a particular route. One example of a system using a four frequency plan is included in Fig. 19c. Between stations V and W, a bearer in each direction is provided using channels 1' and 1 according to the normal pattern (A). On the next section of the route between stations W and X, instead of using the same transmission frequencies, channels 1 and 1' of the interleaved pattern (B) are used. In this example, the polarisations of the RF signals are also changed in adjacent propagation paths. This pattern is repeated for other stations along the route and the same principle is applied when the system is extended to include additional bearers. Notice that the frequency shift that occurs between channel A1' and channel B1, which can be determined from Fig. 18, is 227.5 MHz (=213 + 14.5 MHz) and between channel B1' and channel A1 is 198.5 MHz (=213 - 14.5 MHz); that is, for a four frequency plan, a different frequency shift is required for each direction of transmission.

Particular sources of interference between propagation paths, and the frequency plans used to minimise the interference, are not examined further in this paper.

3.15 The frequency arrangements for RF channels in other bands used by radio broadband bearers follow similar principles to the 4 GHz band which has been used as an example. Details are not included in this paper but Table 3 summarises some information for comparison. Additionally, in the 6 GHz band correspondingly numbered channels in the two halves of the band operate with different polarisations.

FREQUENCY BAND	ALTERNATIVE PATTERNS	MAIN LINE RF CHANNELS IN EACH DIRECTION	AUXILIARY RF CHANNELS IN EACH DIRECTION	ADJACENT MAIN LINE RF CHANNEL SPACING (MHz)	FREQUENCY SHIFT BETWEEN CORRESPONDINGLY NUMBERED CHANNELS (MHz)
Lower 2 GHz	Normal and interleaved	6	–	14	119
2 GHz	Normal and interleaved	6	2	29	213
4 GHz	Normal and interleaved	6	2	29	213
6 GHz	Normal and interleaved	8	2	29.65	252
Upper 6 GHz or 7 GHz	Normal and interleaved	8	–	40	340
7.5 GHz (For short haul service)	7	3	–	49	161
8 GHz	Normal and interleaved	8	–	29.65	311.32
11 GHz	Normal and interleaved	12	2	40	530

TABLE 3. SUMMARY OF RF CHANNEL FREQUENCY ARRANGEMENTS.

3.16 RF CHANNEL MULTIPLEXING. Several radio broadband bearers are often required between major centres. In the UHF and SHF bands it is possible to design aerial and feeder systems with bandwidths wide enough to accommodate a number of RF channels. Both transmitters and receivers are usually connected to the one aerial. At this time it is not satisfactory to use one aerial and feeder system for all of the RF channels in one band, nor for RF channels in two different bands. For a fully allocated band on any propagation path two aerials are required at each end of the path for each band. It is normal to use one aerial for all transmitters of the band operating with the same polarisation and also for all associated receivers in the other half of the band. Another aerial is used for both directions of transmission for transmitters of the band operating with the alternate polarisation and for their associated receivers. For all bands except the 6 GHz band, this allows one monopolar (single polarisation) aerial to be used at each end of a propagation path when only a few bearers are required on a route, expanding to an additional aerial when the route capacity is increased to greater than half the maximum capacity of the band. For the 6 GHz band, the polarisation of associated transmitting and receiving channels requires a bipolar (dual polarisation) aerial and suitable feeders but the advantage that the initial requirement is for one aerial at each end of a propagation path, still applies.

A disadvantage of combining transmitters and receivers on the same aerial system is that all of the isolation must be provided by the RF channel multiplexing equipment. The alternative is to connect all transmitters in a band to one aerial and all receivers in the band to a second aerial at each end of each propagation path. This requires that all aerials for all bands be of the more expensive bipolar type and that all aerials be provided initially even when the number of bearers to be installed is limited. Also, the failure of either a transmit or a receive aerial causes the failure of all bearers on the route.

3.17 RF CHANNEL MULTIPLEXING EQUIPMENT. A basic block diagram of one method of connecting several transmitters and receivers to a common aerial is illustrated by Fig. 20. Other systems are also in use.

Included in Fig. 20 is a number of circulators. Circulators are coaxial or waveguide devices which perform a hybrid type function. The input or output connections of a circulator are normally called ports. Referring to any circulator in Fig. 20, input signals to port 1 appear at port 2 but not at port 3 and input signals to port 2 appear at port 3 but not at port 1, etc. The interpretation of the symbol is that the signal passes to the next port in the direction of the arrow but is not directly available at other ports.

In Fig. 20, the incoming signal from the aerial enters the aerial circulator at port 2 and appears at port 3 which is connected to the receive circulators. The signal fed in at port 1 of the first receive circulator comes out at port 2. Frequencies within the pass band of the branching filter associated with receiver 1 are selected and fed to the receiver. All other frequencies are reflected by the filter back to port 2 of the circulator where they are transferred to port 3. This signal now passes via ports 1 and 2 of the second receive circulator to the branching filter of receiver 2. Again the filter passes the frequencies required by the associated receiver and the remaining frequencies are reflected to proceed to the next circulator. The RF channel selection process continues for the other receivers.

On the transmitter side, the output of transmitter 4 enters port 2 of its associated circulator and appears at port 3. The signal passes via ports 1 and 2 of the circulator associated with transmitter 3 but is reflected by the transmit branching filter in the output of transmitter 3. Therefore, the transmitter 4 signal, along with the output of transmitter 3, is fed to port 2 of the third transmit circulator and the combined signal comes out at port 3. The signal continues in the same way through the other transmit circulators and the outputs of transmitters 2 and 1 are combined in turn with the other signals. The complete signal to be transmitted reaches the aerial via ports 1 and 2 of the aerial circulator.

Circulators are not ideal in that some of the power fed in at one port appears at a port where it should not. In the transmit circulators of Fig. 20, a small amount of the power input to port 2 appears at port 1. This finds its way, in some cases via other transmit circulators, to the termination attached to the fourth transmit circulator and is absorbed. Of the transmitter power input to port 1 of the aerial circulator, a small amount appears at port 3. This proceeds via the receive circulators and, being reflected by the receive branching filters, is finally dissipated in the termination of the fourth receive circulator. This termination also absorbs any spurious signals which are picked up by the aerial and are not with the bandwidths of the receive branching filters and, in addition, any spurious outputs from the receivers.

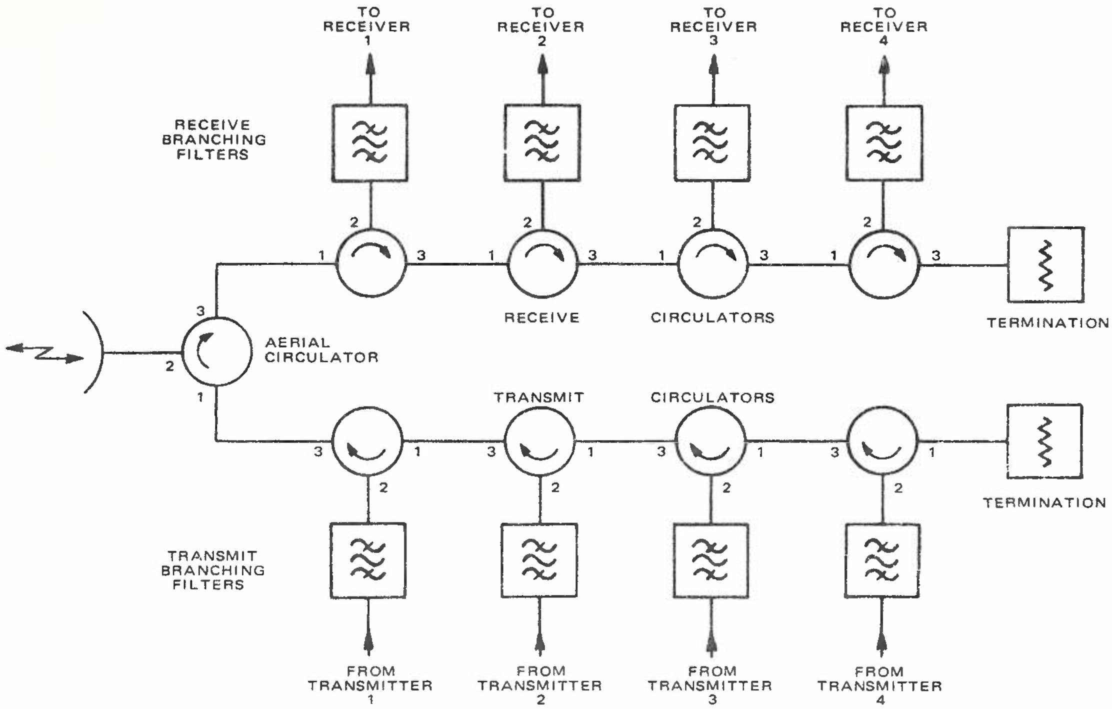


FIG. 20. RF CHANNEL MULTIPLEXING EQUIPMENT.

The block diagram in Fig. 20 is ideally suited to frequency bands in which transmitting and receiving channels use the same polarisation for the radiated signals. For the 6 GHz band, where transmitting and receiving channels use different radiated signal polarisations, the RF channel multiplexing equipment is generally the same as in Fig. 20 except that the aerial circulator is normally replaced by a polarisation filter and a bipolar aerial, with a circular waveguide feed from the polarisation filter, is used. The polarisation filter provides the initial separation between transmitting and receiving channels.

4. TRAFFIC CONNECTIONS.

4.1 TELEPHONY COAXIAL CABLE TAIL SYSTEMS. Telephony multiplexing equipment is normally installed in towns and cities close to the trunk exchange. However, because of propagation requirements, radio bearer stations are normally situated on suitable high land as close as is possible to, but usually not co-sited with, the multiplexing equipment. The separation between the multiplexing equipment and the radio bearer equipment is sometimes up to 16 km and it is necessary for the equipment to be linked with a suitable number of broadband bearers. Radio bearers are rarely suitable or economical for this requirement and it is normal to provide a multi-tube coaxial cable. The line equipment used with the coaxial cable is similar to the equipment normally associated with main coaxial cable bearers but, because of the relatively short transmission distance involved, pilot controlled gain regulation or variable equalisation is not included. The systems are often referred to as *coaxial cable tail* systems for the radio bearers.

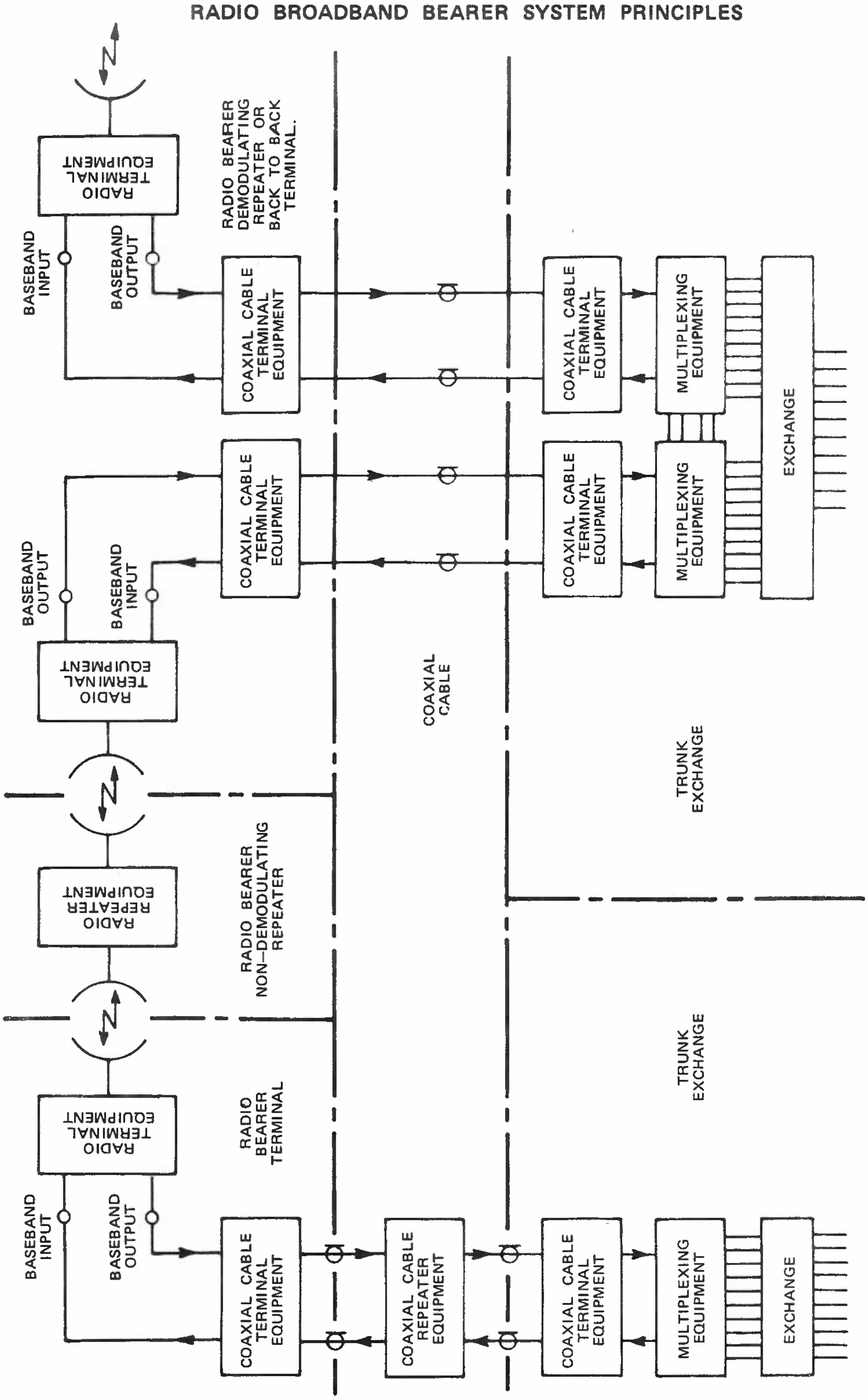


FIG. 21. INTERCONNECTION OF RADIO BEARER AND MULTIPLEXING EQUIPMENT.

Coaxial cable tail systems are required to interconnect broadband carrier and radio bearer equipment at terminal stations and at demodulating repeaters or back-to-back terminals along the radio route where some of the baseband channels are to be dropped and inserted to fulfil the telephony traffic requirements. Fig. 21 shows the location of coaxial cable tail equipment relative to exchange, multiplexing and radio broadband bearer equipment. The coaxial cable system operates on a four wire basis using a coaxial tube for each direction of transmission. Coaxial cable terminal equipment is located at each end of each cable; associated with the multiplexing equipment and at the radio bearer demodulating stations. If the cable route is long (greater than approximately 8 km for 4 MHz and 6 MHz systems) repeaters are located along the route. Power for the repeaters is usually fed via the inner conductors of the go and return coaxial tubes. For valve type equipment a 50 Hz a.c. power feed system is used. Equipment using transistors normally operates from a regulated constant direct current supply.

4.2 A simplified block diagram of the coaxial cable tail equipment at a radio bearer terminal station is included in Fig. 22. The equipment at other locations is similar. In Fig. 22 the baseband signal from the coaxial cable passes via the power feed filters to the *slope* amplifier. This amplifier has an amplitude-frequency characteristic designed to compensate for the cable characteristics between repeaters at standard spacings. The output of the slope amplifier provides the baseband input to the radio equipment. For cables shorter than the standard repeater spacings a building out network is included before the slope amplifier to make the cable appear electrically the same as the standard length. For the opposite direction, the radio equipment baseband output is connected to an amplitude-frequency response equaliser which compensates for the characteristics of the station cables. The following flat amplitude-frequency response amplifier feeds the coaxial cable via the power feed filters.

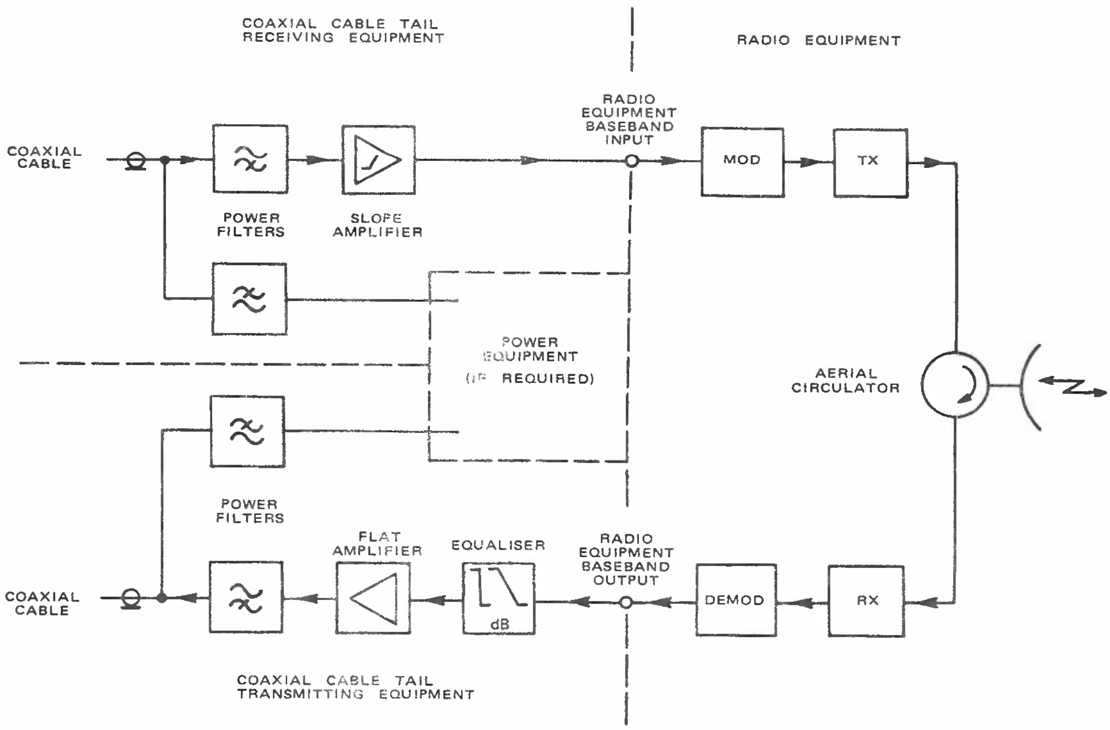


FIG. 22. COAXIAL CABLE TAIL EQUIPMENT.

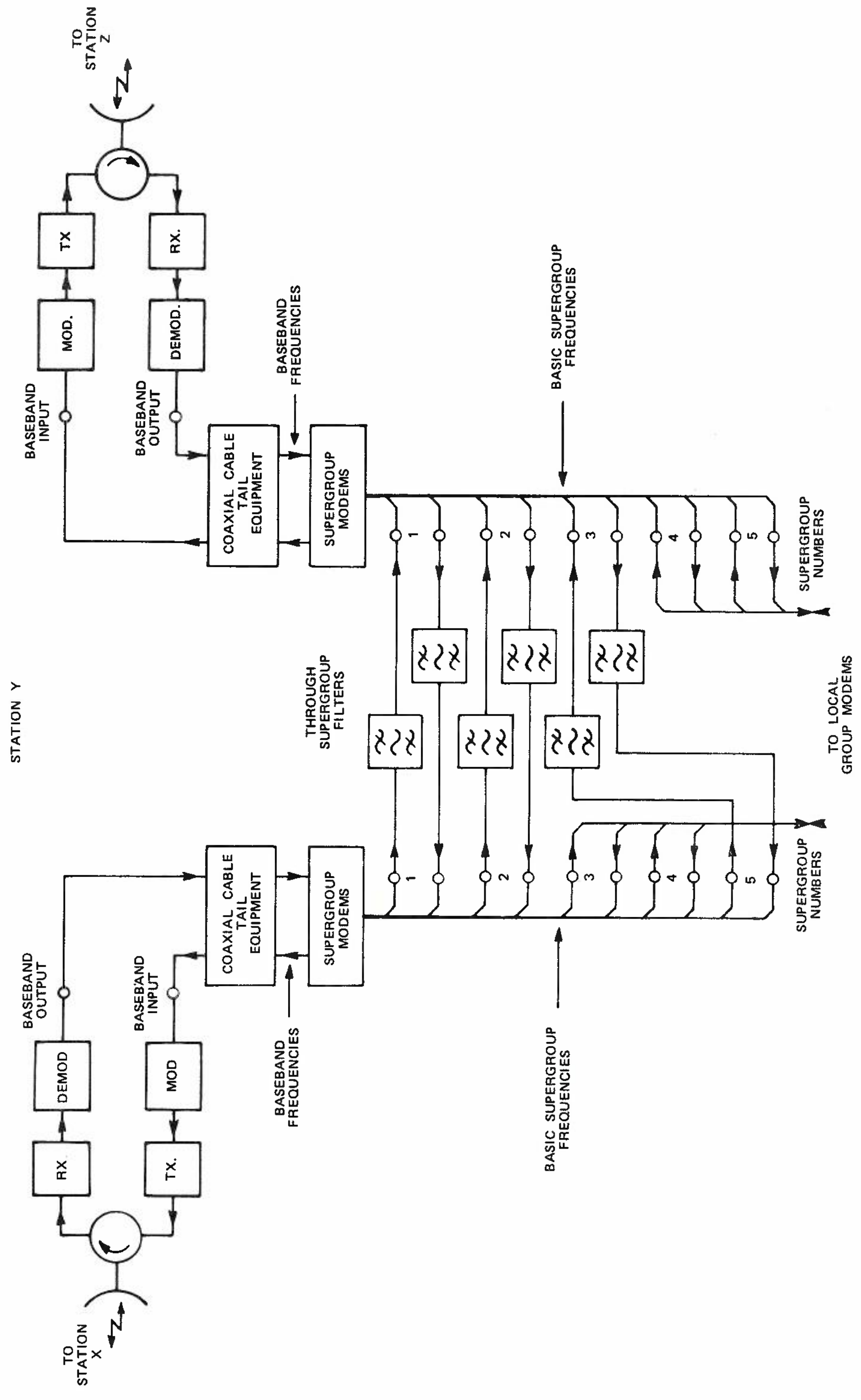


FIG. 23. BASIC SUPERGROUP INTERCONNECTION.

4.3 TELEPHONY CHANNEL BRANCHING. On a broadband bearer route, demodulating stations are included where it is required to make a number of circuits available to satisfy the telephone traffic requirements. Because of the standardisation of the frequencies for groups, supergroups and mastergroups etc., it is not necessary to convert the baseband back to individual channels and then reassemble the baseband, when blocks of circuits are to be through connected at the station. Interconnections can be made between any corresponding points in the baseband terminal equipment; for example, between points where basic group frequencies are present or where basic supergroup frequencies are present.

To illustrate the interconnection of basic supergroups at a demodulating station, assume that a link between terminal stations X and Z includes a demodulating repeater or back-to-back terminals at intermediate station Y. Assume also that the bearer system is able to provide 5 supergroups between adjacent demodulating stations. A basic block diagram showing one way of using the supergroups that are available at station Y is included in Fig. 23. The baseband inputs and outputs of the radio equipment for the bearers to and from both stations X and Z are extended to the broadband carrier equipment via a coaxial cable tail and its associated equipment. Since the complete baseband is processed by the broadband carrier equipment, the radio equipment at station Y is operating as two independent radio terminals.

The supergroup modems of the broadband carrier equipment separate the individual supergroups and translate them to the basic supergroup range and vice versa. The basic supergroups corresponding to supergroups 3 and 4 from station X are connected to group modems and then, as required, to channel modems. In the opposite direction supergroups 3 and 4 are derived from the basic supergroup outputs of the group modems at Y. Therefore, two supergroups (120 channels) are provided between stations X and Y. In a similar manner, two supergroups (supergroups 4 and 5) are provided between stations Y and Z. The remaining supergroups are interconnected between supergroup modems via through supergroup filters as basic supergroups. The filters are necessary to eliminate adjacent supergroup frequencies which are not effectively removed by the filters in the supergroup modems. If not removed, these frequencies would cause adjacent supergroup interference. Fig. 23 shows that supergroups 1, 2 and 5 between stations X and Y are interconnected with supergroups 1, 2 and 3 respectively between stations Y and Z. Therefore, three supergroups (180 channels) are provided between stations X and Z. Interconnection at the basic group point can be arranged using through group filters in a similar manner. The system illustrated by Fig. 23 is completely flexible and allows supergroups to be routed or interconnected in any way. Disadvantages are that a relatively large amount of broadband carrier equipment is required and this introduces both thermal and intermodulation noise into the telephony channels.

4.4. The noise introduced into through connected circuits by telephony carrier equipment can be eliminated by direct through connection of the baseband with branching provided for only those blocks of channels necessary for local traffic. Facilities are available so that, at demodulating stations, supergroups can be dropped for one direction of transmission and corresponding supergroups can be inserted for the return direction of transmission. In a basic arrangement, branching is achieved by using hybrids and the dropped channels are not eliminated from the baseband. Therefore, the supergroups involved are not available for use on the remainder of the route. However, by including suitable band stop filters, the dropped supergroups can be eliminated from the through baseband and these supergroups *replenished* and used again along the continuation of the route. Band stop filters with adequate rejection to allow replenishment are available for supergroups 1 and 2 only, as separate supergroups. However, high or low pass filters are sometimes used to provide satisfactory elimination of blocks of supergroups at the lower or upper ends of the baseband. Because of the cut-off characteristics of these filters it is sometimes necessary to sacrifice the further use of the supergroup which coincides with the filter cut-off frequency.

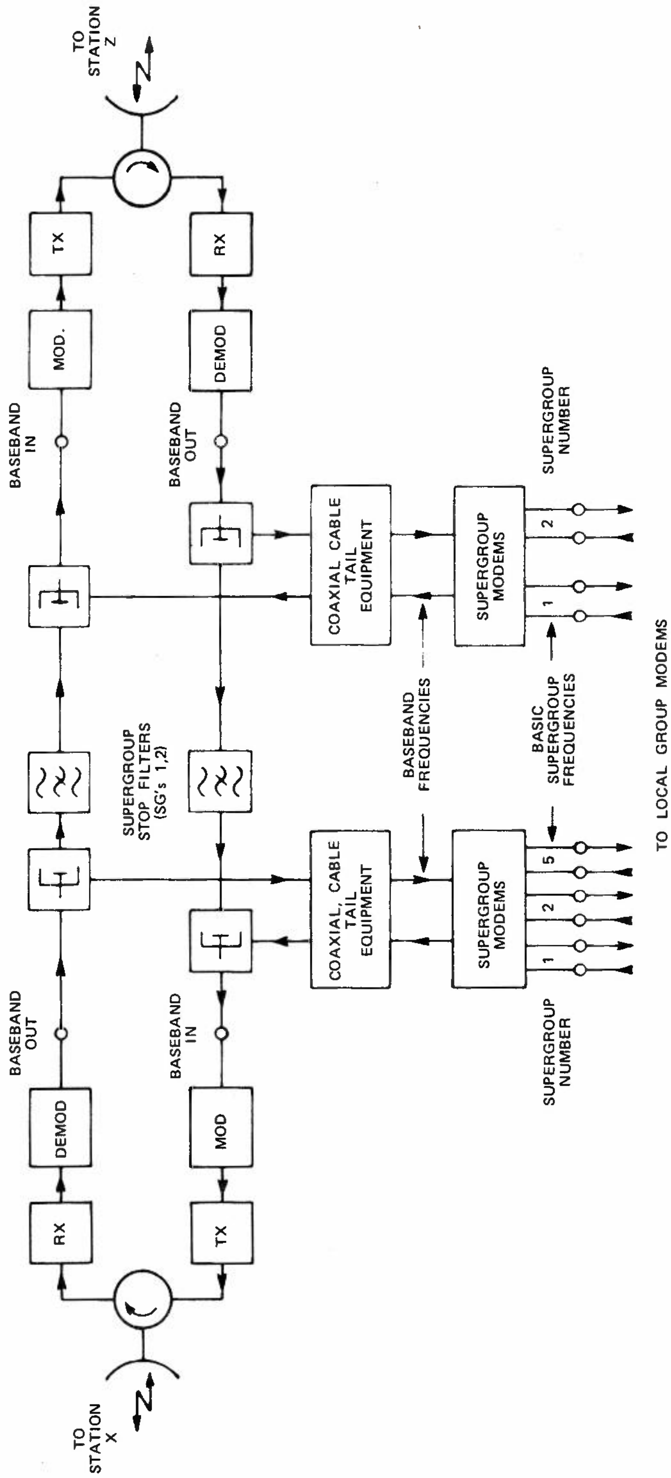


FIG. 24. SUPERGROUP BRANCHING.

The basic block diagram in Fig. 24 corresponds to station Y of the preceding example modified to provide direct through connection of some supergroups and branching of others. The hybrids and supergroup filters are located in the radio bearer station. The baseband outputs of the demodulators for each direction of transmission are connected to hybrids. One output of each hybrid is fed via the supergroup stop filters to the baseband input of a modulator for transmission on the next section of the route. In this example, with supergroup stop filters for supergroups 1 and 2 in circuit, the remaining supergroups (supergroups 3, 4 and 5) are directly through connected. The second output from each of the preceding hybrids is fed via the coaxial cable tail equipment to the supergroup modems. For the opposite direction of transmission the signals produced at the output of the supergroup modems are transmitted to the radio bearer station via the coaxial cable tail equipment where they are combined with the through supergroups using hybrids. For transmission between stations X and Y, the system includes supergroup modems for supergroups 1, 2 and 5. Because of the inclusion of supergroup stop filters for supergroups 1 and 2, these supergroups can be replenished for independent transmission between stations Y and Z. However, because no filter is included to eliminate supergroup 5, supergroup 5 is not available for use on this section of the route. In summary, supergroups 3 and 4 (120 channels) are provided between stations X and Z, supergroups 1, 2 and 5 (180 channels) between stations X and Y and supergroups 1 and 2 (120 channels) between stations Y and Z. Notice that, in Fig. 24, the bearers between stations Y and Z are not used to their maximum capacities.

In Fig. 24 no filters are included to prevent supergroup 5 from station X to station Y from continuing on to station Z even though it cannot be used on this latter section of the route. Although this arrangement is normal for coaxial cable bearers, it has the disadvantage that the bearer from station Y to station Z is loaded with unnecessary traffic which could introduce unnecessary intermodulation noise. To prevent this, filters which are adequate to reduce the bearer traffic loading but not adequate to allow replenishment, can be included to stop through connection of the unnecessary supergroups. This procedure is often used with radio bearers to improve the noise performance though it does not increase the bearer usage.

4.5 Combinations of the preceding and other similar methods for connecting blocks of telephone circuits allow considerable flexibility in allocating the usage of a bearer to suit traffic requirements.

4.6 TELEVISION PROGRAMME DISTRIBUTION. Radio bearers are used extensively for the relay of television programmes. As an example of the equipment involved in television programme transmission, Fig. 25 illustrates a basic television programme distribution system from a metropolitan studio to regional television transmitters. This is typical of the National Television Service for which the majority of programmes are produced in the capital city studios. The television programmes between the studios and the radio bearer terminal for interstate or intrastate relay are routed via a television operating centre (TOC) which is normally located in the vicinity of the telephony multiplexing equipment in the trunk exchange. The television operating centres provide facilities for switching and monitoring of the television programmes. The distances involved in the route between the studios and the radio bearer terminal station are normally short enough to allow video signals to be transmitted in the video band over coaxial cables. The interstice pairs of the coaxial cable normally provide the programme lines for the audio signal.

Radio systems used as television links usually provide both video and audio channels of the television programme. The two signals are combined in equipment which is often known as a sound and vision combiner, to provide the television baseband signal for the radio bearer. At the remote terminal, the individual signals are recovered in a sound and vision separator. This equipment is examined further in para. 4.9.

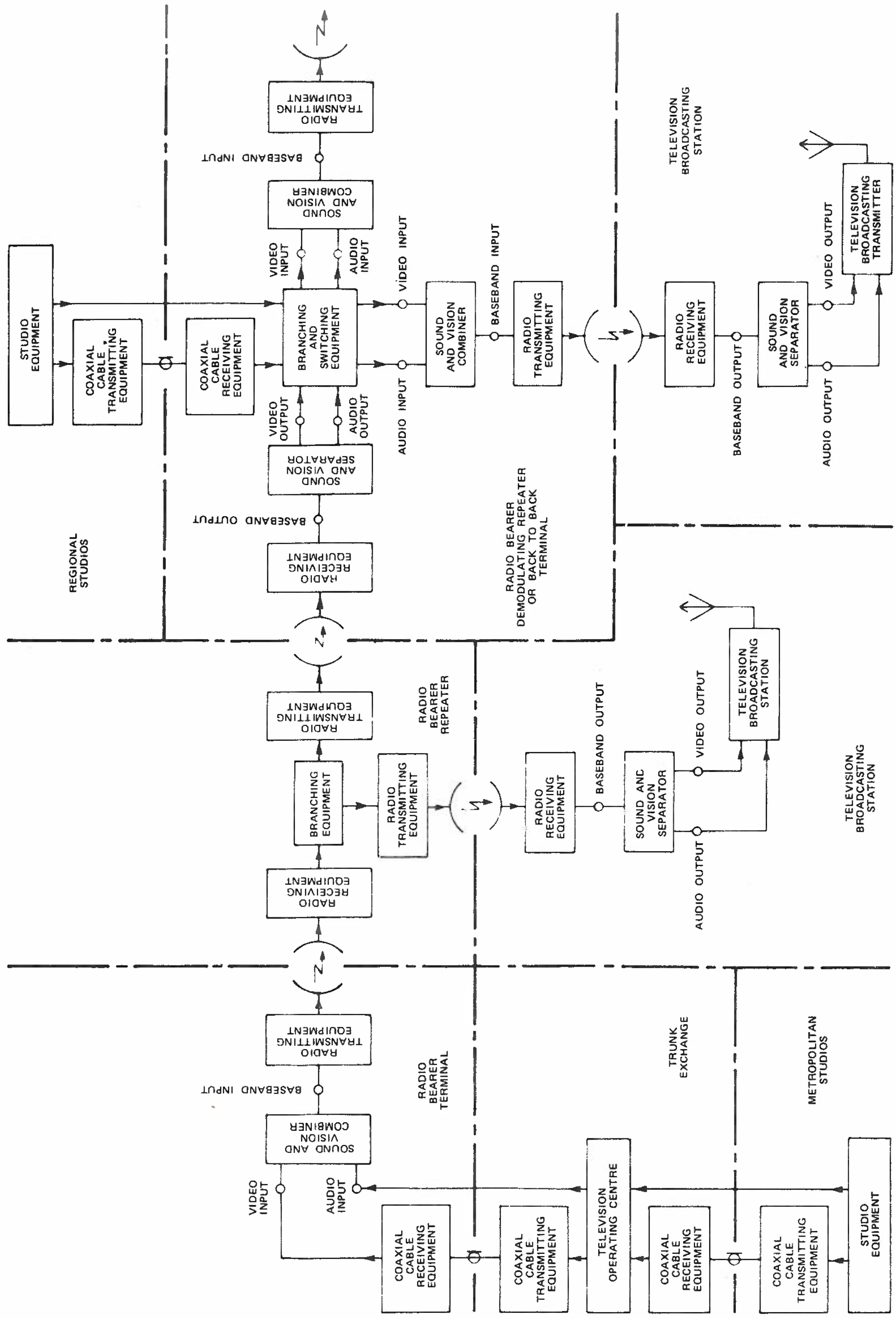


FIG. 25. TELEVISION PROGRAMME DISTRIBUTION.

For most of the time each regional television broadcasting transmitter receives the same programme. Since many of the television broadcasting stations are located on or near a main broadband bearer route, in such circumstances, it is normal to use a common bearer for the programme to all of the stations. The programme is branched as required and connected either directly or via *spur* bearers to the television broadcasting transmitters. Methods used to provide branching are included in paras. 4.10 to 4.12. If a spur bearer is required, between the main bearer route and the television broadcasting station, radio bearers are ideally suited since both the television broadcasting and radio bearer stations are normally sited on hill tops.

Regional studios are provided in some centres and in these centres, switching is also required. Usually the individual video and audio channels are recovered for switching purposes. A regional switching centre can be located with the studios or the local trunk exchange, but it is often convenient to include the switching equipment in the radio bearer station, as shown in Fig. 25, with the switching remotely controlled from the regional studios. The regional studios and the switching equipment are linked by coaxial cable video systems and audio programme lines.

4.7 SHORT COAXIAL CABLE SYSTEMS FOR TELEVISION. For direct transmission of video signals over a coaxial cable, considerable care is needed to equalise the cable so that excess waveform distortion is not introduced on to the video signal. However, the main difficulty is interference introduced into the coaxial cable. Because of the construction of coaxial tubes in a coaxial cable, the outer conductor provides good shielding at high frequencies and interference or crosstalk between adjacent tubes and other cables at high frequencies is very small. However, the effectiveness of the screening produced by the outer conductor is decreased at low frequencies and is ineffective at mains power supply frequencies. Low frequency interference is produced largely by the introduction of longitudinal currents into the cable, that is, currents in the same direction in both the inner and outer conductors of the coaxial tube. These currents, induced into the cable or generated by the difference in the earth potential between the ends of the cable, are illustrated in Fig. 26a. This shows that the longitudinal current in the centre conductor flows through the output termination, thus causing interference.

There are a number of ways by which the interference introduced into coaxial cables can be reduced. The important methods are -

- By providing wideband isolating transformers at the ends of the coaxial tube and not earthing its outer conductor (Fig. 26b). This method is usually very effective. The difficulty lies in the design of the transformers with a full video bandwidth and effective electrostatic shielding between primary and secondary windings.

- By providing longitudinal coaxial inductors. These are constructed by winding a coaxial cable on a core of magnetic material as illustrated by Fig. 26c. To achieve satisfactory results at low frequencies, high inductances, requiring physically large ferrite cores, are necessary. A typical low frequency longitudinal coaxial inductor has an inductance of 0.35 H and a volume of approximately 0.025 cubic metre. If the coaxial inductors are to be effective at high frequencies only, their inductances and physical sizes can both be acceptably small.

- By clamping of the sync. or back porch periods of the video signal to a reference level. This method attempts to remove the effect of the interference rather than to eliminate the cause, but is useful at low frequencies, particularly for 50 Hz interference. However, clamping cannot completely remove interference and can, itself, produce some waveform distortion.

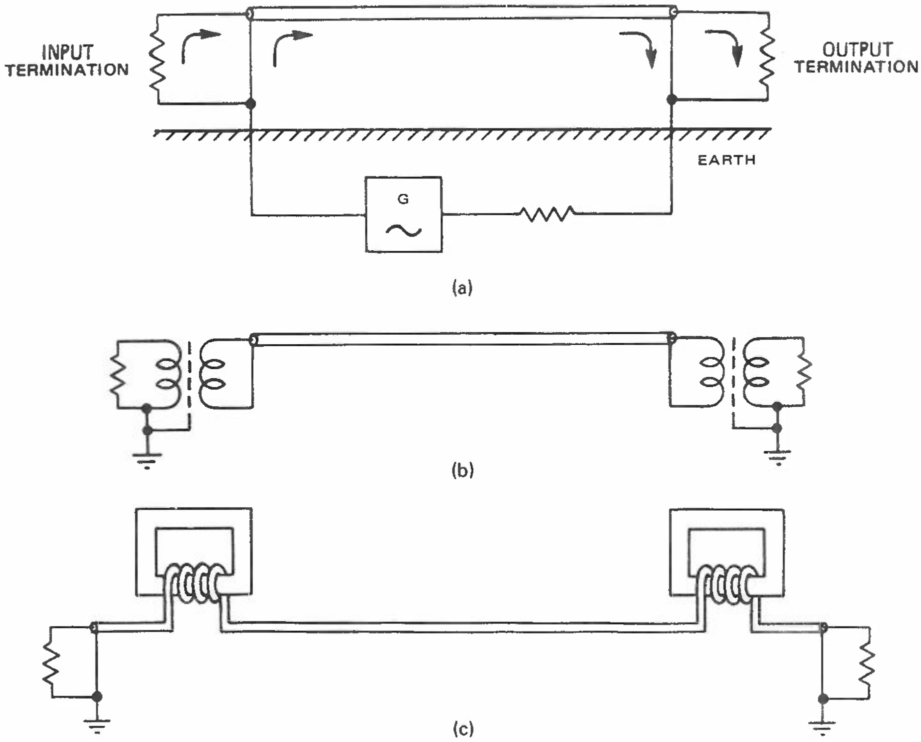


FIG. 26. LONGITUDINAL CURRENT SUPPRESSION IN COAXIAL CABLES.

- By cancelling the interference with a similar signal of opposite phase. Since the interference will normally vary with time and is dependent to a large extent on the varying loading of power circuits, long term complete cancellation cannot be achieved.

4.8 The direct video coaxial cable systems installed in Australia use isolating transformers combined with longitudinal inductors to give a further improvement at high frequencies. In addition, the valve type equipment includes clamping of the peaks of the sync. pulses of the video signal. A simplified block diagram of a coaxial cable video system is included in Fig. 27. The transmit terminal includes only an isolating transformer and a longitudinal coaxial inductor. At the receiving terminal, the underground coaxial tube is terminated using a longitudinal coaxial inductor and an isolating transformer. To achieve the required interference suppression, special attention is paid to earthing arrangements and shielded coaxial cable is used within the buildings. Also, the sheath of the underground cable is earthed but the outer conductor of the coaxial tube is isolated from earth.

The equalising amplifier following the isolating transformer has gain and amplitude-frequency characteristics which are adjustable to compensate for the characteristics of cables up to approximately 10 km. The delay equaliser is used to correct for group delay errors introduced by the system. The output amplifier includes a keyed clamp. The electronic switch of the clamp circuit is conducting during the sync. pulse period. This causes the sync. pulse peak to be established at a reference potential and so removed remaining low frequency interference. If the video cable link is greater than approximately 10 km, a repeater, consisting of a transmit and receive terminal back to back, is used.

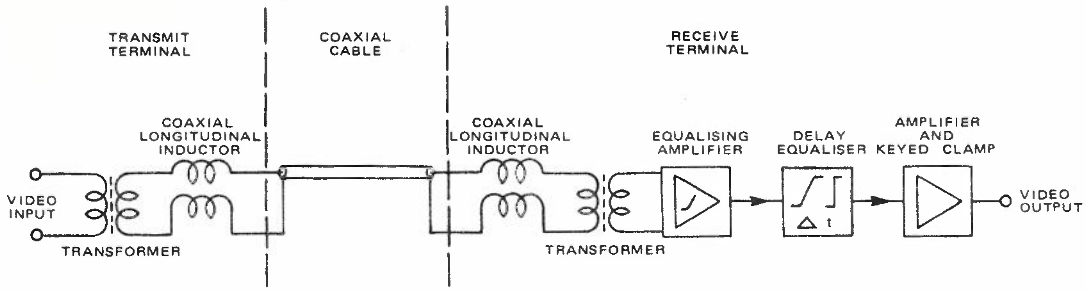


FIG. 27. VIDEO COAXIAL CABLE SYSTEM.

4.9 TELEVISION BASEBAND SIGNALS AND EQUIPMENT. The sound and vision combiner that is used to derive the television baseband signal at the transmit terminal of a television bearer is illustrated by the simplified block diagram included in Fig. 28b. The sound channel is derived by using a 7.5 MHz sub-carrier which is frequency modulated by the audio signal. The modulated sub-carrier is combined with the video signal using a hybrid network. A 7.5 MHz band stop filter is included in the video input circuit to eliminate any input signals appearing in the band required by the derived sound channel. The combined signal is the television baseband signal which occupies the frequency bands illustrated by Fig. 28a. This signal is fed to the modulator of the bearer.

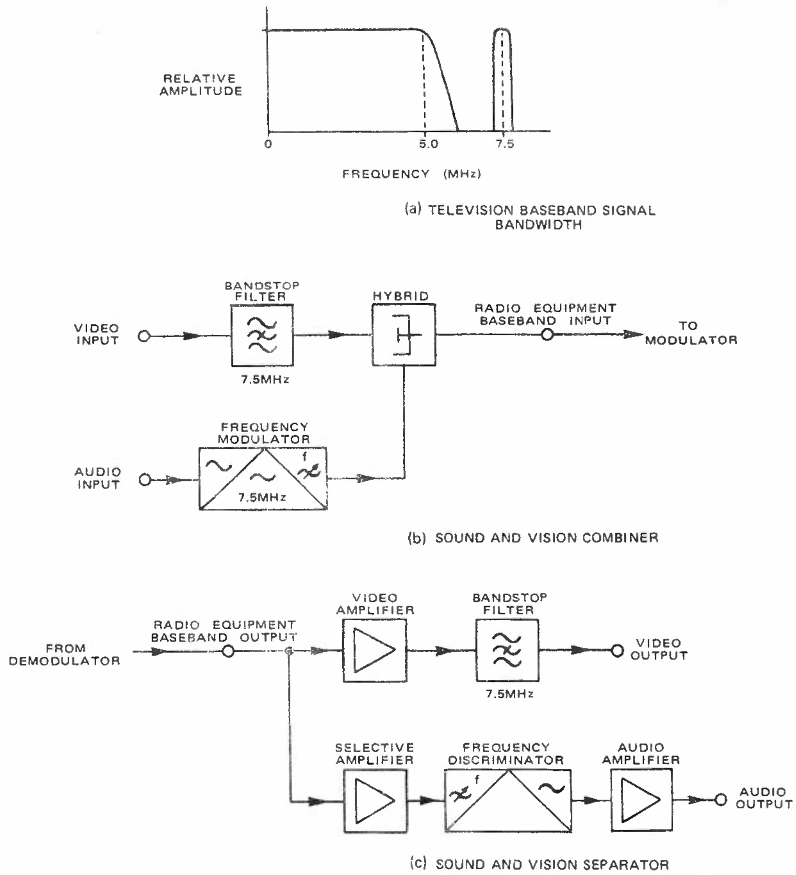


FIG. 28. TELEVISION BASEBAND SIGNALS AND EQUIPMENT.

The receiving terminal television baseband equipment includes a sound and vision separator (Fig. 28c). In this equipment the 7.5 MHz modulated sub-carrier is selected by an amplifier and the audio signal recovered in frequency demodulator. A 7.5 MHz band stop filter eliminates the sound sub-carrier from the baseband signal to recover the video signal.

4.10 TELEVISION BEARER BRANCHING. Branching of television programmes from the main bearer to feed the spur bearers to the television broadcasting transmitters can be carried out at the basic channel frequencies by converting the baseband output at a television bearer demodulating repeater back to the video and audio frequencies. These signals are then *split* to provide video and audio signals for both the main and the spur bearers (Fig. 29) and for local television broadcasting transmitters, if necessary. Multiple output video distribution amplifiers (VDAs) are usually used for video signal branching, and high input impedance amplifiers bridged across a common input termination are often used for audio signal branching. Branching at the channel frequencies is usually restricted to major regional centres where regional programmes are originated and switching is required.

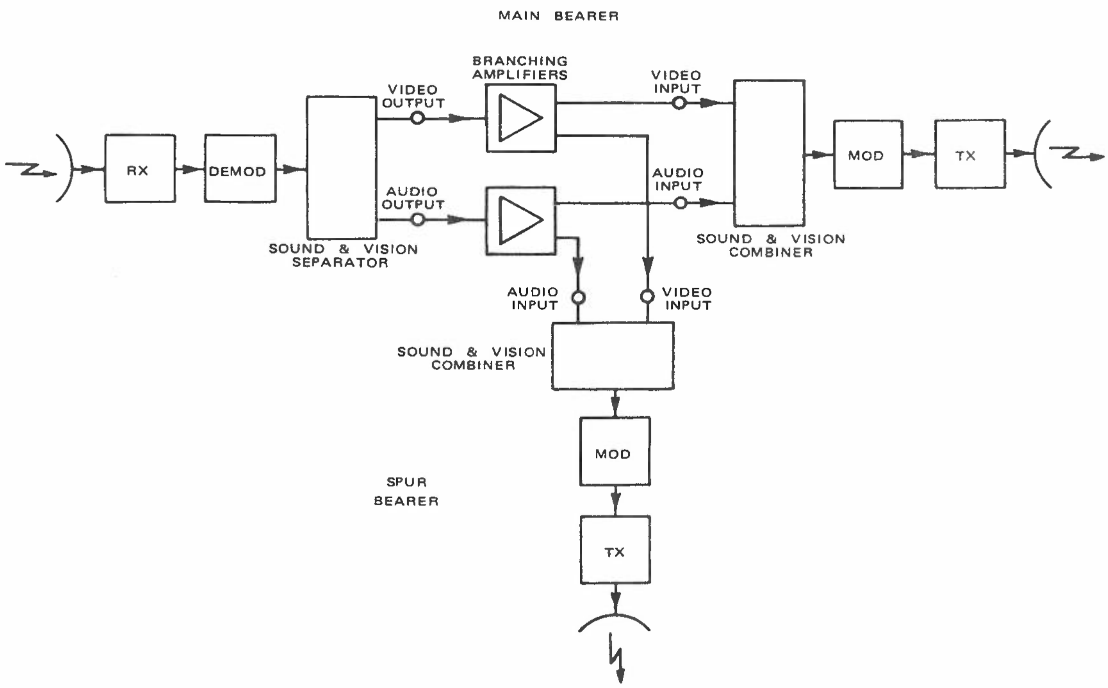


FIG. 29. TELEVISION BEARER VIDEO AND AUDIO BRANCHING.

4.11 If individual switching of video and audio signals is not required at the branching station, the complete television baseband at a demodulating repeater can be through connected or branched as shown in Fig. 30. The baseband output of the demodulator is connected to a multiple output video distribution amplifier to provide baseband branching. One output provides the through connection of the signal for the main bearer and a second, the signal for the spur bearer. If a television broadcasting transmitter is located at the radio bearer station, or if video and audio testing facilities are required, an additional output of the VDA is fed to a sound and vision separator to recover the video and audio signals. The elimination of the sound and vision separators and combiners for through connected signals removes a possible source of noise and distortion.

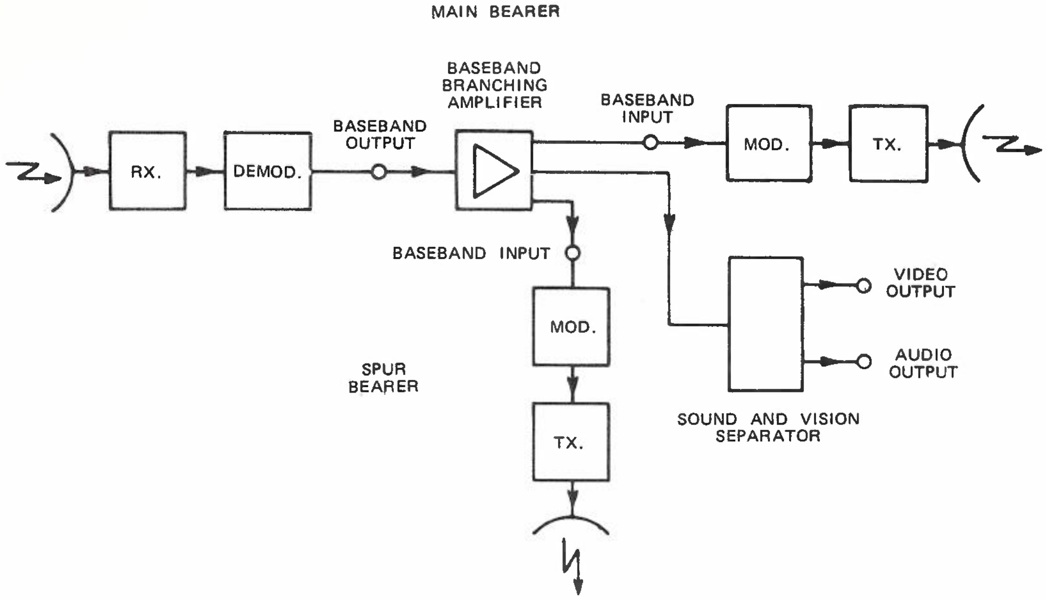


FIG. 30. TELEVISION BEARER BASEBAND BRANCHING.

4.12 Television programme branching can also be carried out to advantage at non-demodulating repeaters at the intermediate frequency. Fig. 31 illustrates a non-demodulating repeater for a television bearer using IF branching to a spur bearer. From the output of the repeater receiver two IF signals are derived in an IF branching amplifier. One output continues to the transmitter of the main bearer and the other provides the input to the transmitter of the spur bearer to the television broadcasting station. If a video and audio output is required to feed a local television broadcasting transmitter, or for test purposes, an additional IF branching amplifier followed by a demodulator and a sound and vision separator is installed as shown in Fig. 31. Since branching does not involve demodulators and modulators or sound and vision separators and combiners, degradation of both the video and audio signals is minimised.

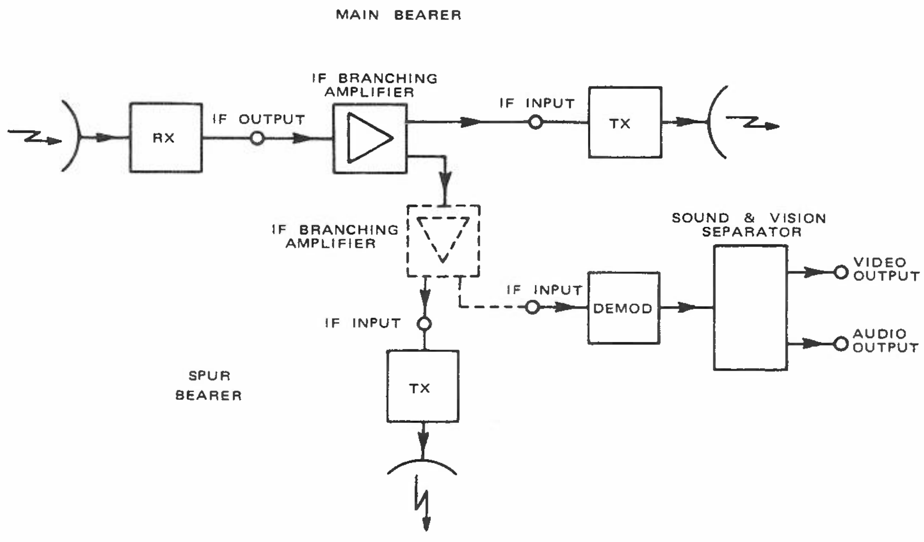


FIG. 31. TELEVISION BEARER IF BRANCHING.

5. METHODS OF IMPROVING RELIABILITY.

5.1 RELIABILITY. The large number of channels provided by each telephony link and the importance of television links for programme distribution means that services will be severely disrupted if a bearer failure occurs. To provide a high grade of service, the out of service time of bearers must be kept to a minimum.

Bearer out of service time or interruption can result from complete failure of the bearer, from degradation of its transmission performance, in particular, from its signal to noise ratio decreasing below a specified minimum standard, or from a planned removal of the bearer from service for maintenance purposes. Complete failure is normally caused by the power supply or the equipment. However, it can also be produced by a deep fade during which the received RF level is low enough to cause receiver muting. Degraded performance results from equipment deterioration and from fading which does not cause receiver muting.

The effect of a bearer interruption depends on the traffic operating over the bearer. An interruption of the order of 10 μs will affect the operation of high speed data circuits derived over the bearer. However, an interruption of 10 ms does not greatly degrade telephone speech. Interruptions of less than approximately 5 s are usually classified as *short* interruptions. For example, short interruptions may be caused by switching. Longer interruptions are classified as *outages* and the causes are recorded as *faults*.

To reduce the outage time of a bearer to a minimum, the bearer requires a high *reliability*. Reliability is the probability that the system will carry traffic for the specified period with a performance which is satisfactory for service. Reliability specifications allow prediction of whether or not a system will operate for the duration of a communication or programme; for example, for the duration of a particular telephone call, for communication with a manned space capsule for the duration of the mission, or, for the duration of a *live* television programme.

5.2 AVAILABILITY. While reliability indicates the chance that a system will operate satisfactorily for a specified period, a more practical way of indicating the quality of service provided by a system is by its *availability*. Availability is the probability that a system, when required, will provide a performance which is satisfactory for service. It therefore indicates the percentage of the required time that the system is expected to be able to provide the required service. Availability can be applied to a link in continuous use, or to a link used for limited periods in a day, such as is required for interstate exchange of television programmes.

Ideally a system should introduce no interruptions which would result in 100% availability. This is difficult to achieve in a practical situation. Availability depends on the reliabilities of the power supply, the bearer equipment and the propagation path and, in addition, on the effectiveness of the maintenance programme, the time taken to repair any faults and the outage time caused by human error. A typical target for availability of a link provided via a radio bearer system over a period of a year is 99.9%. Such an availability allows an outage time of 0.1% corresponding to 8.76 hours in a full year. This outage time includes outages due to all causes which may originate anywhere along the bearer route.

A particular availability can result from either one long outage or numerous small outages. Long and short unplanned outages have distinctly different origins. Equipment faults, particularly at remote unstaffed locations, require that staff be transported to the station and that the fault be diagnosed and cleared. Several hours may elapse before the bearer can be restored to service. Therefore, equipment faults tend to cause long bearer outage times and, to achieve a particular availability, must not occur very often. By contrast, fading is likely to cause outages of short duration and a particular availability would allow many such failures.

5.3 Equipment failure is minimised by design, by the manufacturers, of equipment with acceptable reliability within economic limits. Improvements in reliability are obtained by selecting components which meet rigid standards during manufacture and testing and by operating these components below their maximum dissipations. Equipment power supply failure is minimised by using no-break supplies, often battery power supplies with modern solid state equipment. In addition, propagation paths are engineered so that the probability of bearer failure, because of fading, is reduced to an acceptable value.

Though equipment can be manufactured which gives a high reliability, faults will still occur and, for a system in which no duplicated equipment is provided, the system will be out of service until repairs are effected. If the average time to repair a fault is four hours, and assuming all outages are caused by equipment faults, only two faults per year can be allowed for an availability of 99.9%. In a system of 60 hops (corresponding to 2400 km when the average hop is 40 km) this allows an average of only one fault on each hop every 30 years!

The most economical way to achieve high availability is by including redundancies in the system; that is, something additional to the essential which will provide an alternate method of operation should parts of the system fail. This approach can be used to reduce outage times due to both equipment faults and propagation difficulties.

One method is to include additional equipment which is normally on standby but automatically replaces the normal equipment when this is not working satisfactorily. Though a failure occurs the bearer system continues to provide the link via the standby or protection equipment with little or no loss of traffic time. Faults in equipment tend occur at random and, therefore, faults in the normal and the 'redundant' equipment occur independently. Because there is little possibility that both sets of equipment will be out of order at the same time, the overall system availability is increased greatly.

A second method of adding redundancy attempts to prevent failures due to fading by establishing two or more largely independent propagation conditions between two adjacent stations. This system is known as diversity operation (see para. 5.5).

5.4 While system availability is improved by system design and by including redundancies, the high grade of service can only be maintained if a fast, efficient maintenance organisation is available to clear equipment faults. If either the normal or redundant part of the system is out of service, the system is operating without protection and a further failure will cause the complete system to fail. It is worth noting that approximately one third of all outages are caused by human error so that effective training is required and considerable care is necessary when working on broadband bearer equipment. Remember that, if a bearer is interrupted, hundreds of telephone channels, some possibly carrying telegraph or data traffic, or a television programme may be put out of service. No equipment may be removed from service for maintenance or testing without permission from the control station.

A typical staffing arrangement for a radio broadband bearer network includes continuous staffing of State capital city control stations and 'officer hours' staffing of other section control stations in the State. Outside normal duty hours, the staff is called on duty as required. The section control stations are typically at approximately 300 km intervals along a route, usually standby or protection bearer switching stations and often, also, the demodulating stations. Other stations, mainly non-demodulating repeaters, are unstaffed. 'First in' maintenance at unattended stations is often carried out by calling on staff of telephone exchange or line transmission stations in the local district to reduce maintenance delays due to the travelling time incurred by specialist maintenance staff.

From the equipment point of view, it is necessary to provide staff with adequate facilities for remotely supervising and controlling the operation of unstaffed stations. Also suitable communication facilities must be provided between stations. Collectively, the supervisory, control and communication or order-wire channels are often known as service channels. These channels are made available by the auxiliary system which incorporates an auxiliary bearer provided by either an auxiliary radio system or by using the frequency band below the main traffic band of a main telephony bearer or above the video band of a television bearer.

5.5 DIVERSITY OPERATION. The level of the signal at the input of each receiver for each hop of a radio bearer varies with propagation conditions. The signal level fading is usually produced by ducting or by signals arriving out of phase at the aerial after travelling via multiple propagation paths of different lengths and producing multi-path fading. On any individual propagation paths where fading is likely to cause excessive bearer interruptions, considerable improvement can be obtained by using diversity operation. For diversity operation, two or more slightly different propagation conditions are arranged so that it is unlikely that both or all transmission paths for the particular hop will experience a fade at the same time. Two systems are important for radio broadband bearers; space diversity and frequency diversity.

Space diversity involves the use of two (or sometimes more) aerials at the receiving end of a propagation path. For terrestrial line of sight radio bearers, the aerials are spaced vertically on the mast by about 5 to 20 metres depending on the propagation path length and the likely cause of the fading. The spacing is selected so that, for the majority of the time, the signals received by the aerials fade independently. Space diversity gives a substantial improvement in system reliability on paths subject to severe fading. Reductions by a factor between 100 and 1000 in outage times due to fading can be achieved.

Assuming two aerials operating as part of a space diversity system, the receiving equipment must be able to select the better of the signals from the aerials, or combine them in such a way as to make optimum use of the available signals. The most favoured system uses two independent aerial feeders and receivers. The IF output of the receiver with the better output signal to noise ratio is selected with a switch and fed to the IF interconnection point as shown in Fig. 32a. The system can be used at both demodulating and non-demodulating stations. The IF switching is usually electronic to obtain a fast change-over so that the interruption to the bearer is minimised. Typically the interruption due to electronic IF switching is 1 μs to 10 μs. In most cases, the switching is initiated by sensing the receiver with the greater input signal. This receiver normally has the better signal to noise ratio. Alternatively, the output of each receiver is demodulated and the noise level measured in a frequency band above the traffic band to determine the receiver to be selected.

The circuits determining diversity switching are normally arranged to have some *hysteresis*. Typically, for a system with switching determined by the receiver input level, if receiver A has been selected, the signal available to receiver B must exceed that existing at receiver A by approximately 6 dB before switching will occur and vice versa. This eliminates unnecessary switching when the input signals to both receivers are approximately equal.

Another method of using space diversity signals combines the signals from both aerial feeders in an RF phase combiner to provide the input to a single receiver (Fig. 32b). It is necessary to arrange that the two signals are combined in phase and, to do this, the lengths of the aerial feeders are equalised and one aerial feeder includes a variable phase shifter which is controlled by phase detecting circuitry.

Two other methods of making use of space diversity signals are illustrated by Figs. 32c and d in which the IF and baseband outputs of receiving equipment respectively are combined. These techniques, though not used in currently installed terrestrial line of sight systems, have been used separately with two receivers and in combination with four receivers, for tropospheric scatter systems which invariably suffer from deep fading. Baseband combiners, which are suitable for use with telephony bearers but not television bearers, are examined further in para. 5.11.

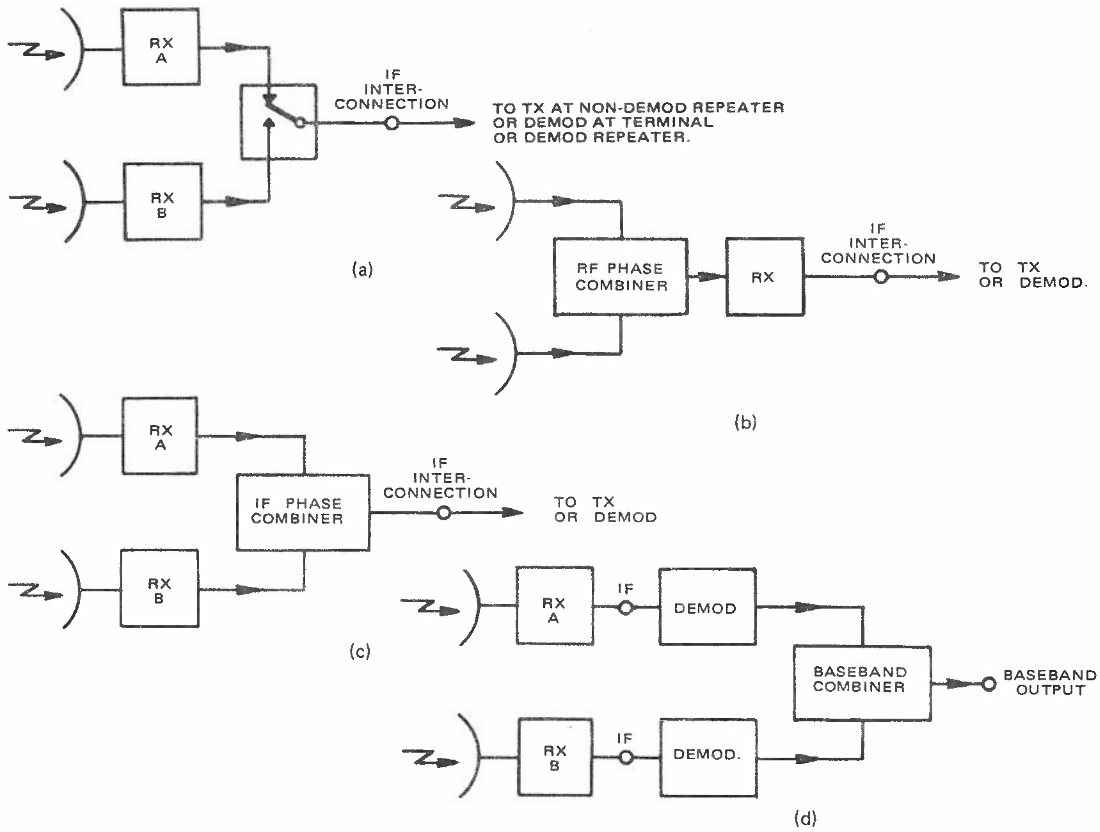


FIG. 32. DIVERSITY OPERATION.

In a system using frequency diversity, the bearer between adjacent stations is provided by selecting the better of two or more radio transmission systems operating over the same path on two or more different frequencies. This tends to produce independent fading conditions, particularly if the spacing of the two frequencies is significant. A disadvantage of frequency diversity is that both the transmitting and receiving equipment must be duplicated.

The transmitters operating on each frequency are modulated by the same baseband signal. Receivers are provided for each frequency and the receiver with the better signal to noise ratio is selected using the techniques illustrated in Figs. 32a, c or d. In terrestrial line of sight bearer systems, the provision of a protection bearer (para. 5.6), using frequencies on each hop that are different from those of the main bearer, provides a small improvement due to frequency diversity operation, though it is not included for that purpose alone. Tropospheric scatter radio bearer systems, however, often use frequency diversity, in many cases combined also with space diversity.

5.6 PROTECTION BEARERS. To provide protection against equipment failure we could duplicate all units of equipment and switch individual units to replace failed items. If this principle is applied to radio broadband bearers, transmitters and receivers are duplicated by standby equipment operating on the same frequency. Any faulty equipment is replaced by switching the standby equipment into service at each station as necessary. Although such a system gives greatest flexibility, it has several disadvantages which make it unsuitable for use. These are -

- Mechanical waveguide switches are required at the outputs of transmitters and possibly at the inputs to receivers which results in slow switching;
- Interference between two sets of equipment operating on the same frequency is difficult to prevent;
- To achieve full flexibility, supervisory equipment is required for each unit duplicated;
- The standby equipment is not available for testing on an overall basis.

An alternative to the duplication and switching of individual equipment units is to provide an additional radio bearer, as a standby or protection bearer, for each direction of transmission along the complete bearer route. For each hop, the protection bearer operates in the main bearer band but on a different frequency. In case of failure of any part of the main equipment, significant interruption is prevented by transferring the traffic to the standby or protection bearer. Normally one protection bearer is adequate for up to at least five main bearers, though the arrangement depends on the design of the system and the reliability to be achieved. Equipment is available offering switching facilities for one protection bearer to be shared by up to seven main bearers (one for seven system) and for two protection bearers to be shared by up to six main bearers (two for six system).

A system using separate protection bearers has a number of advantages -

- Each protection bearer, when not in use, can be automatically monitored to ensure that it is in an operating condition and available for immediate service. The monitoring is similar to that used on the main working bearers.
- Maintenance and performance testing of each protection bearer can be carried out between adjacent switching stations when the bearer is not required to replace a faulty bearer.
- Maintenance and performance testing of a normally working bearer can be carried out by purposely switching the traffic to the protection bearer.
- The protection bearers can be used on an occasional basis to provide a non-priority television bearer in each direction. For this service, should a protection bearer be required for its basic requirement of providing protection against failure of a main bearer, the television signal is removed.
- Some measure of protection against failure caused by fading exists since the protection bearer is operating on a different frequency from the main bearer in each hop and there is a reasonable chance that, if a main bearer fails because of a deep fade in one hop, a similar fade will not be occurring at this time in any of the propagation paths of the protection bearer. The effectiveness of this frequency diversity reception is normally improved with an increase in the frequency difference between the main and the protection channels. Therefore, the protection bearer is normally allocated the lowest of the available frequencies in a band and the most important main bearer, the highest. Even so the proportional frequency difference is small and a number of propagation paths are involved so that only small reductions in outage time (by a factor of 3 to 5) result from the frequency diversity of main and protection bearers.

5.7 SWITCHING SECTIONS. When a bearer system incorporates protection bearers, a failure of a main bearer in one direction causes this bearer to be completely replaced by its protection bearer between two adjacent switching stations. The substitution of the standby equipment is not done by replacing individual terminals or repeaters. However, on a long route involving many non-demodulating and demodulating repeaters, if switching was carried out only on an end-to-end basis, there would be considerable chance that both a main bearer and its protection bearer would be inoperative at the same time. A compromise is required between the flexible switching at each station and switching of a complete route. Therefore, in practice, long bearer routes are divided to produce switching sections with lengths that give the required reliability without adding excess switching equipment. In most cases the switching stations are also the demodulating repeater stations but, in some cases, switching may be necessary at intermediate non-demodulating repeater stations. Typically, a switching section includes the equipment at demodulating switching stations at each end and four to six immediate repeaters, where demodulating repeaters are located fairly closely in well populated areas. However, longer switching sections including more repeaters have been used for some radio bearer systems.

With a broadband bearer route divided into switching sections, the protection bearer for one switching section is brought into service completely independently of other switching sections. Also the switching of a protection bearer in one direction is independent of the associated bearer in the opposite direction.

An idea of the independence of switching of the protection bearers of a radio broadband bearer system is illustrated by Fig. 33. The bearer system, under normal conditions, is represented by Fig. 33a. The system provides a telephony (TP) link via bearers for each direction of transmission and a television (TV) link allowing one direction of transmission between the terminals. The complete route is divided into two switching sections and a protection bearer, indicated by the broken lines, is provided in each direction for each switching section. Each switching section includes a number of repeater stations. For normal conditions, the switching equipment arranges that all traffic is using its normal or main bearers as shown by the broken lines in the switching equipment.

An example which illustrates the flexibility of the bearer system switching equipment is shown by Fig. 33b. The broken lines indicate the connections that are provided by the switching equipment. The telephony bearer from station X to station Y is operating normally. However, the television link from station X to station Y is provided by the protection bearer and the protection bearer from station Y to station X is being used for telephony. From station Y to station Z, telephony is using the protection bearer and the television link is provided via its normal bearer. Also, in the opposite direction from station Z to station Y, telephony is operating over its normal bearer. The protection bearer from station Z to station Y is not in use. Fig. 33, therefore, illustrates that, because of the protection bearer switching, a particular broadband link can be provided via different bearers at different times.

5.8 BEARER AND SITE NUMBERING. In many cases the term radio bearer is loosely used to describe the equipment which provides a one-way broadband channel between any two terminals. However, for identification in practical radio bearer systems, a radio bearer is considered as the equipment which provides one broadband channel for one direction of transmission between adjacent protection bearer switching stations. This applies even if the switching is provided at a non-demodulating repeater and the baseband is not recovered.

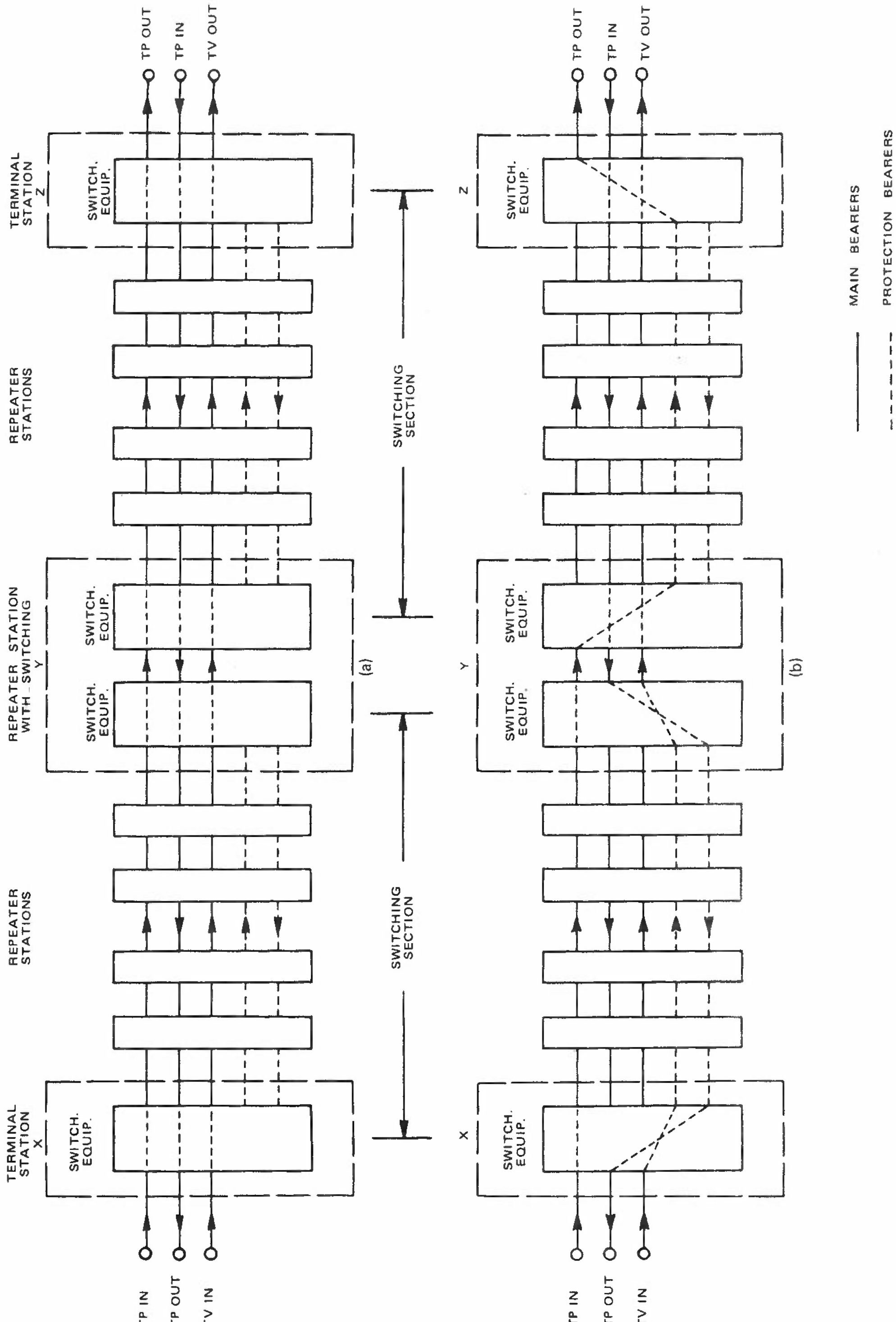


FIG. 33. SWITCHING SECTIONS.

For convenience when recording bearer service reports and for simplicity when records are processed using digital computers, each bearer and each radio communications site is identified by a number. Computer programmes are available to sort the information from service reports and to present the data in several forms which allow analysis of faults and activities at particular sites, on particular bearers or on particular routes. Bearer numbers are normally allocated in groups to the bearers in a particular switching section between adjacent switching stations. Considering the complete bearer route, odd numbers are assigned to bearers providing transmission from the southern terminal towards the northern terminal and even numbers for bearers providing transmission in the opposite direction. This rule applies even when the route is approximately east-west. For a particular section of a route, consecutive numbers are usually allocated in numerical order to protection, telephony and television bearers respectively. Auxiliary radio bearers (para. 6.13) are normally assigned numbers in a similar manner but in a separate group.

5.9 SWITCHING OF BROADBAND BEARERS. Switching of main bearers and their protection bearers in a radio broadband bearer system involves fault detection and recognition of the switching requirement, control of the switching operation, bridging of the protection bearer across the main bearer at the transmitting end and, finally, switching of the traffic path at the receiving end. The switching at the receiving end is simply the changeover or transfer of the traffic output connection from the main bearer to the protection bearer, or vice versa when the system is returned to normal. The actual changeover time of this switching is known as the *transfer* time. The total switching cycle, from the time the bearer is degraded sufficiently to initiate the switching cycle to the time when the traffic is transferred and normal quality is restored, is known as the *operate* time.

If a catastrophic failure occurs, the interruption to the traffic equals the operate time. However, bearer switching can be initiated by the increase in the noise level at the output of a receiver, which results during an RF signal level fade, rather than by a catastrophic failure. If the operate time and the noise level which initiates switching are properly proportioned considering the maximum fade rate, the traffic will be transferred to the protection bearer before the main bearer becomes unusable and the traffic interruption is limited to the transfer time of the receive end switching.

Bearer switching can be carried out at either the baseband or at the intermediate frequency points in the equipment. Baseband switching in currently installed equipment normally uses mechanical relays, often reed relays, designed to maintain the 75 ohm characteristic impedance of the baseband distribution cables. A disadvantage of relay switching is that the transfer time is typically 0.5 to 2 ms. However, some recent relay switching systems provide make-before-break operation which eliminates any interruptions during traffic transfer. For successful make-before-break operation, the levels and phases of the two baseband signals must be the same to prevent interferring transients during the traffic transfer time. For IF switching, electronic switches are often used, normally involving forward and reverse biassed diodes. The transfer time using electronic switches is typically 1 to 10 μs. Electronic IF switching has the advantage of fast switching times but often the facilities provided for bearer testing are not as convenient as those provided by baseband switching systems. Electronic baseband switching, while available and providing fast switching, is not in common use at this time. This is because relays provide adequate performance and because electronic switches have the disadvantages that their power consumption is high, they can cause intermodulation under normal operation and it is difficult to achieve adequate isolation between switched circuits. At this time the A.P.O. favours baseband switching using mechanical relays.

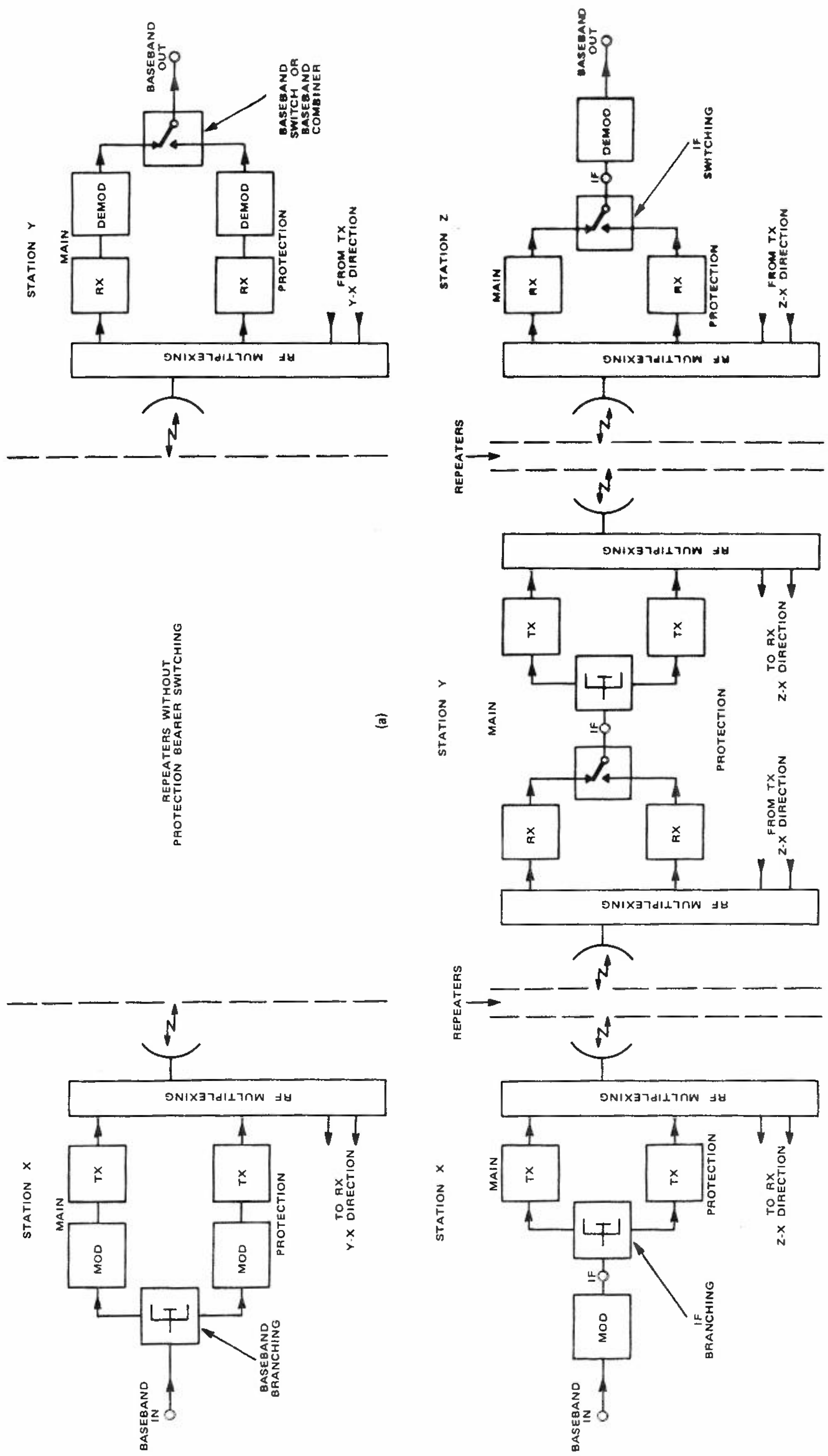


FIG. 34. TWIN PATH BROADBAND BEARER SWITCHING.

5.10 TWIN PATH BEARER SWITCHING. The most basic arrangement for a broadband bearer system is one consisting of a main bearer and a protection bearer. Such a system, often known as a twin path system, allows the traffic to be connected to both main and protection bearers at all times. Switching at the receiving end, to effect the changeover of the traffic path from the main bearer to the protection bearer, can be carried out at either baseband or intermediate frequency points. Fig. 34a illustrates one transmission direction for a bearer system using baseband switching which can be carried out at demodulating stations only. Normally the branching of the bearer at the transmitter is also at a baseband point.

In Fig. 34b, branching at the transmitting end and switching at the receiving end is carried out at the intermediate frequency. I.F. switching allows switching at non-demodulating repeaters if required as at station Y in Fig. 34b. Since the modulators and demodulators in Fig. 34b are not included in the main switching system, additional modulators and demodulators and associated switching are often included to duplicate these units. It is also possible to mix baseband and IF switching on the one route. As an example, baseband branching and switching can be used at demodulating stations and IF switching at non-demodulating stations. This corresponds to station Y of Fig. 34b being located between stations X and Z of Fig. 34a.

With two bearers, and only one in operation at any one time, there is no need for either bearer to be given preference and designated the main bearer. The system can be bistable with a changeover occurring only when the working bearer fails. However, since most switching systems are designed for more than one working bearer per protection bearer, this bistable arrangement is rarely used.

5.11 BASEBAND COMBINERS. In a twin path system, the baseband switch at the receiving equipment output (Fig. 34a) can be replaced by a baseband combiner. Instead of a baseband switch selecting the output of the required receiver, the signals from both receivers are added together to produce the combiner output signal. Baseband combiners have an advantage that they can produce a small improvement in the signal to noise ratio of the system. However, a more important advantage is that baseband combiners allow traffic transfer between bearers without interruption, whereas normal baseband switching produces an interruption during the changeover time of the receive end switching. Mainly because of the latter advantage, baseband combiners are used with some twin path telephony bearer systems. However they are not satisfactory for use with television bearers.

Baseband combiners can be designed to add the two input signals in a linear manner or, alternatively, in proportions which depend on the relative signal to noise ratios of the receiver output signals. The two types of combiners differ in the way they affect the signal to noise ratio of the bearer system. Assume that both the main and the protection bearers are operating, at a particular time, with equal signal to noise ratios. With either type of combiner, for these conditions, when the outputs of the two bearers are combined, the signals add in phase to give a voltage equal to twice the individual bearer output voltages and a power four times that of a single bearer. However, the noise components of the outputs are uncorrelated, that is, they vary independently for each bearer, and they add on a power basis to give a noise power only twice that of a single bearer. Therefore, the combining of the signals has produced a 3 dB improvement in the system signal to noise ratio. This improvement decreases when the signal to noise ratios of the individual bearers are not equal.

For a linear combiner, which effectively adds directly the output of the two bearers, the signal to noise ratio of the combined signal equals that of the better bearer when the signal to noise ratios of the two bearers differ by 4.77 dB. For greater signal to noise ratio differences, the signal to noise ratio of the combined signal is less than that of the better bearer; it can never be more than 6 dB greater than that of the poorer bearer. Therefore, in practice, linear combiners normally include switching which disconnects the bearer with the lower signal to noise ratio for signal to noise ratio differences greater than 4.77 dB. Then the signal to noise ratio of the combiner output is never less than that of the better bearer. A similar effect is achieved with a *ratio squared* baseband combiner which adds to the outputs of the two bearers in inverse proportion to the square of the ratio of their noise outputs. As the signal to noise ratio difference between the two bearers increases, the combiner takes a greater proportion of the signal from the better bearer and a smaller proportion from the poorer bearer. Therefore, for large signal to noise ratio differences the signal to noise ratio of the combined signal approaches that of the better bearer. Both methods of combining are used in practical equipment.

5.12 MULTIPLE BEARER SWITCHING.

When a protection bearer is shared by a number of main bearers, switching must be included at both ends of the switching section. Again, the switching can be carried out at either baseband or intermediate frequency points. The equipment used to provide the switching facilities is often called a multi-line switching system. The functional operation of a system in which three main bearers use IF switching to share a common protection bearer is shown by Fig. 35.

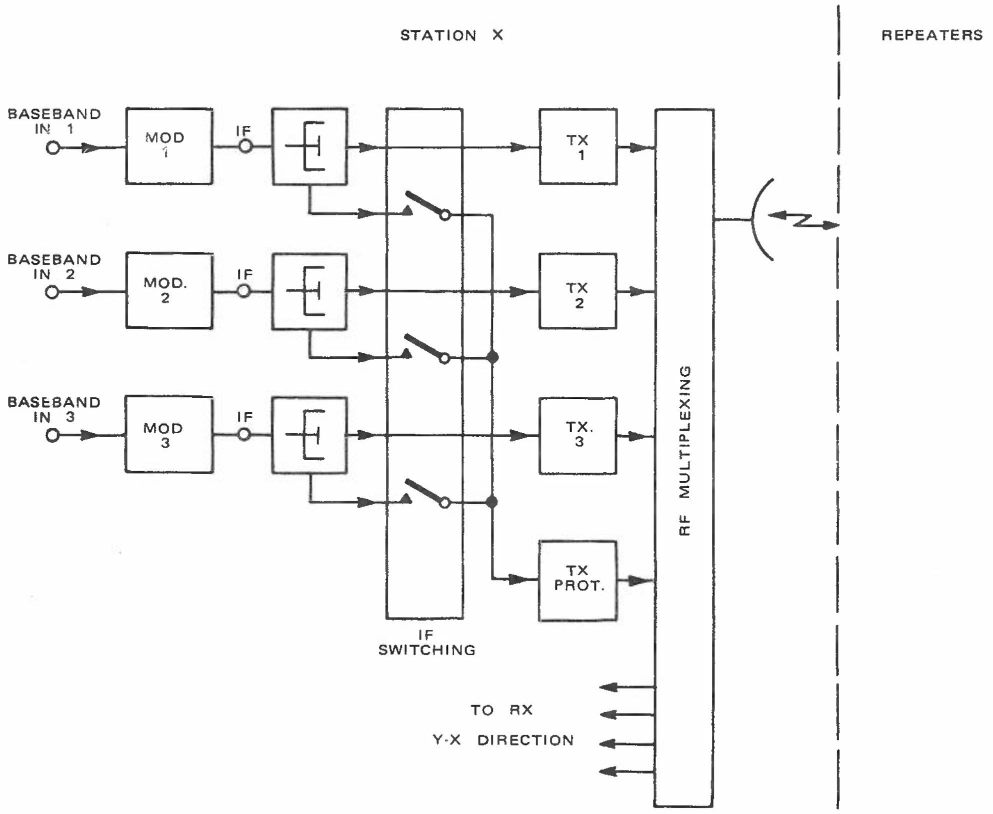


FIG. 35. IF PROTECTION BEARER SWITCHING.

The IF output from each modulator is split so that any modulator output can be connected, via the transmitting end switching, to the protection bearer transmitter input without being removed from the main bearer. This allows monitoring of the main bearer to continue so that its return to normal operation can be sensed. It also minimises the duration of traffic interruptions when switching is initiated by degradation of the bearer noise performance rather than by a complete failure. Traffic transfer is completed by the operation of the correct receiving end IF switch.

The control circuits for the transmitting and receiving end IF switching ensure that only one modulator and one demodulator can be connected to the protection bearer at any one time. Also, the switching is arranged so that correct terminations are maintained on all circuits. At non-demodulating repeater IF switching stations, switching is similar to that shown in Fig. 35 but the receiving end switching outputs are connected to the transmitting end switching inputs at the IF interconnection points.

Broadband bearers for telephony and television differ in some respects; for example, input and output levels, deviation sensitivity, pre-emphasis and de-emphasis and sometimes pilot frequencies. However, this does not add any complications to systems using IF switching. All that is necessary is for the modulator, the demodulator and the associated baseband equipment to be selected and adjusted for its intended purpose.

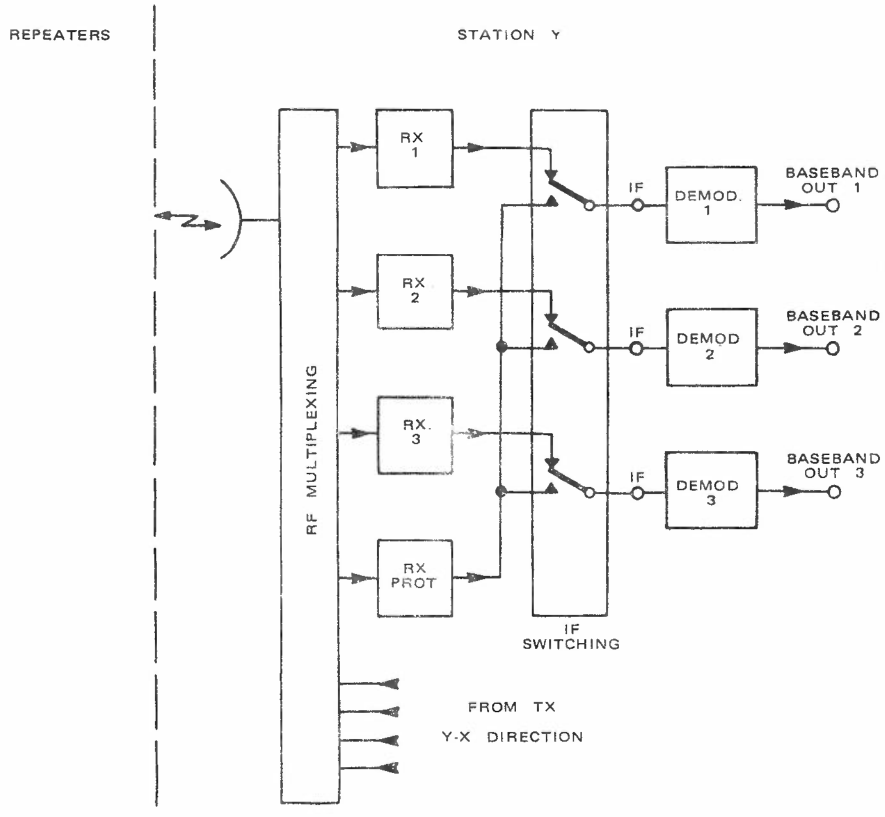


FIG. 35. (CONTINUED FROM PAGE 48).

5.13 For baseband switching in a system involving both telephony and television main bearers, suitable modulators, demodulators and associated baseband equipment can be selected for the main bearers. However, the modulator and demodulator of the protection bearer must be arranged to operate with either telephony (TP) or television (TV) signals.

Fig. 36 shows a system using baseband branching and switching. The protection bearer includes a modulator with two independent baseband inputs. Internal switching, operated at the same time as the main baseband switching, selects the input which gives the correct equipment and adjustments for the protection bearer traffic. Similar arrangements are necessary at the output of the demodulators.

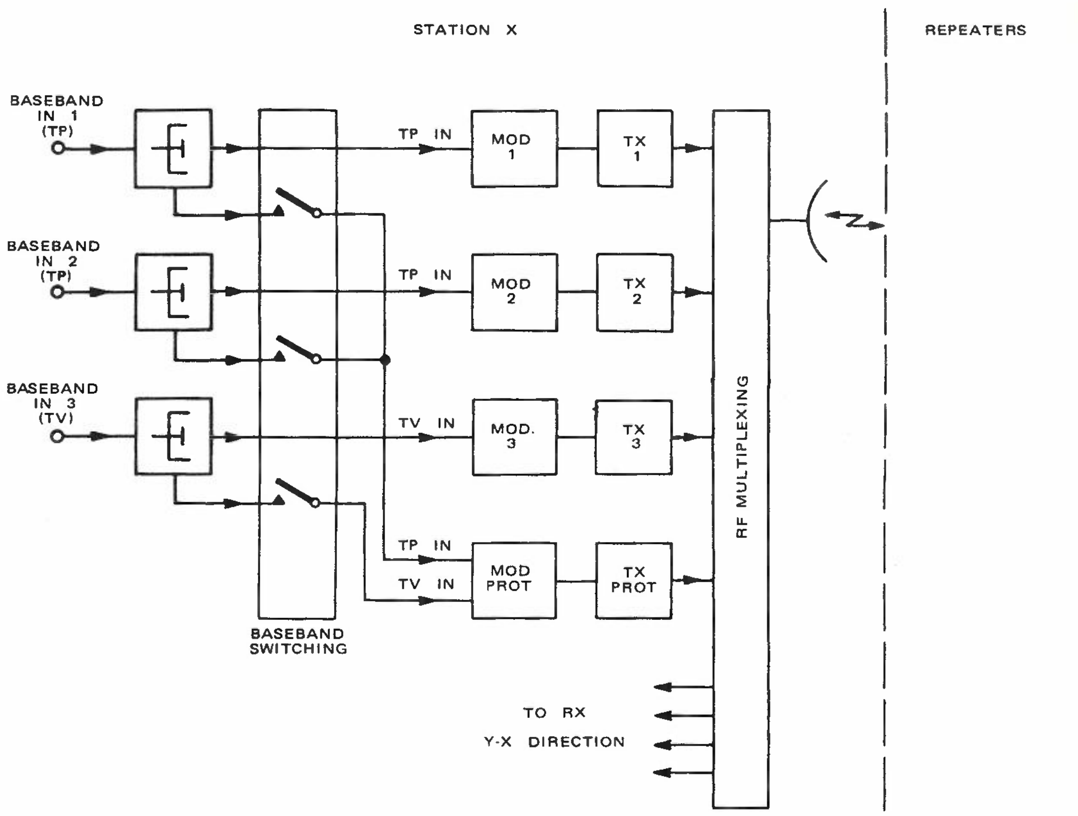


FIG. 36. BASEBAND PROTECTION BEARER SWITCHING.

In other respects the operation is similar to that of an IF switching system. When switching is required, a split of the baseband signal is fed via the transmitting end baseband switching to the protection bearer and the traffic transfer is completed by the operation of the correct receiving end baseband switch.

In an alternative arrangement, to allow the protection bearer to operate with either telephony or television traffic, all modulators and demodulators are of the same type designed and adjusted for telephony signals. To compensate for the differences in the characteristics required for telephony and television signal transmission, a difference equaliser is included between each television baseband input and the transmitting end protection bearer switching and between the receiving end protection bearer switching and each television bearer output. Such a system is used for the television link provided by the system in Fig. 37.

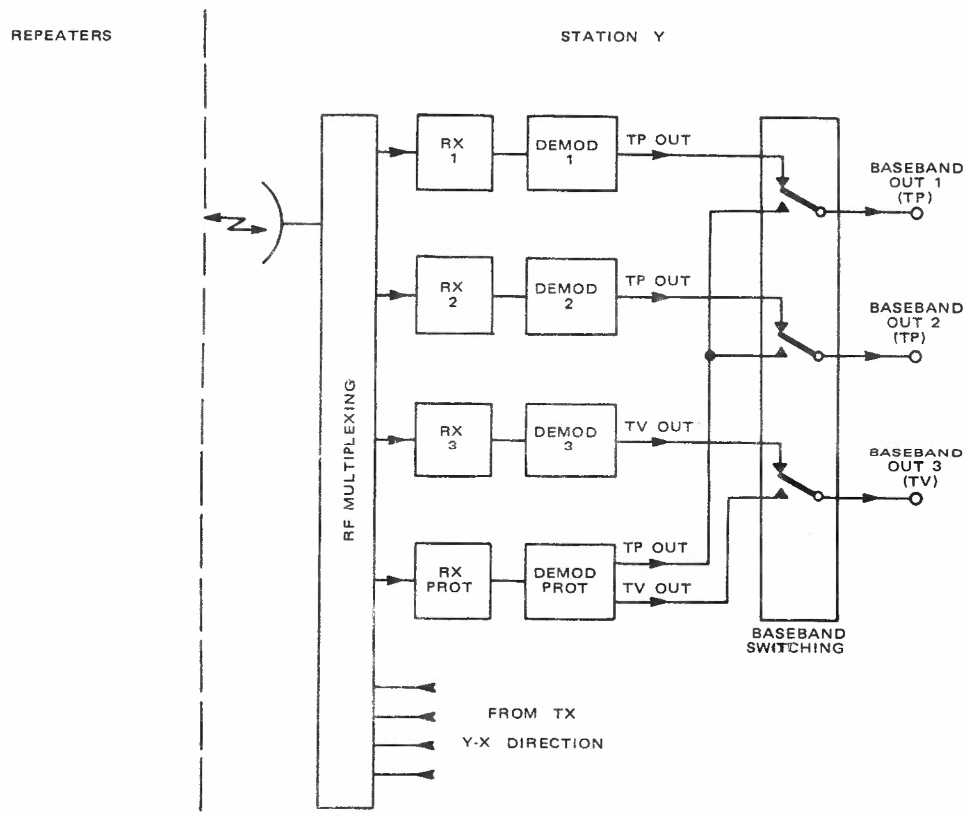


FIG. 36. (CONTINUED FROM PAGE 50).

5.14 NON-PRIORITY TELEVISION BEARER. When all main bearers are operating normally, the protection bearer is idle and can be used for other purposes as long as it is immediately available for its initial purpose of protecting against failure of any main bearers. A link provided in this way is sometimes known as a *phantom* link. Such a link is suitable for occasional non-priority television programmes, but interruption to the transmission must be accepted should a failure of a main bearer occur. Only in special cases of programmes of national importance might this interruption be prevented.

Facilities for occasional non-priority television transmission using the protection bearer can be made available with either baseband or intermediate frequency switching. Baseband switching is preferred. Suitable account must be taken of the differences between telephony and television bearers.

The block diagram in Fig. 37 shows the switching facilities of a twin path system with baseband switching and provisions for occasional non-priority television (NP TV) traffic over the protection bearer. This bearer system uses the same types of modulators and demodulators for each bearer with different equalisers for television transmission as examined in para. 5.13.

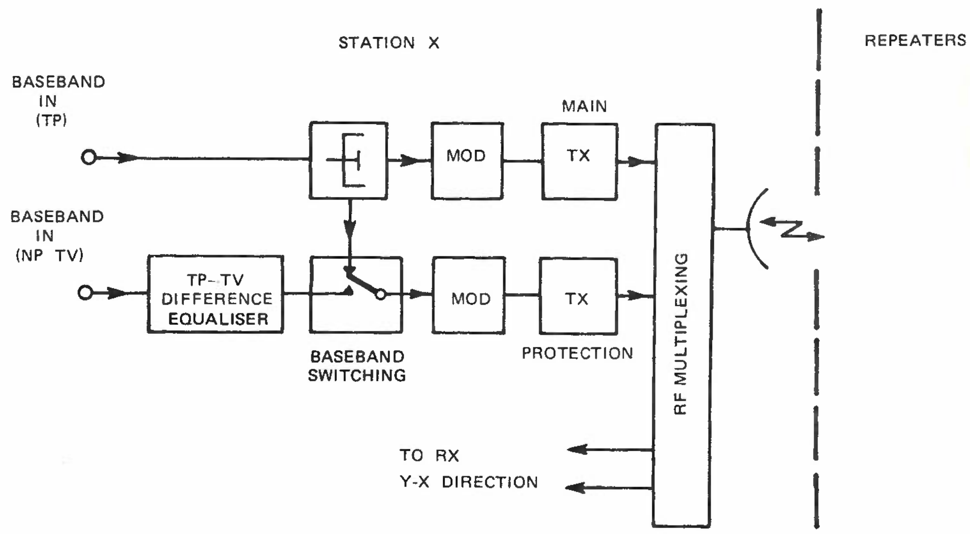


FIG. 37. NON-PRIORITY TELEVISION BEARER.

5.15 SWITCHING CRITERIA. It is necessary to provide some means of determining that each broadband bearer is working satisfactorily to assess the need for protection bearer switching. The protection bearer switching sequence can be initiated either by complete failure of a main bearer or by a main bearer being excessively noisy.

The A.P.O. philosophy for protection bearer switching is that switching should reduce traffic interruptions to an absolute minimum. Therefore, to reduce interruptions due to the switching transfer times, bearer switching should be carried out only when a bearer failure occurs or is expected. It should not be used to improve the quality of transmission when the main bearer has been degraded by a marginal increase in noise due to fading. To achieve this objective the noise sensing circuits are adjusted so that they sense potential failure. They do not initiate switching until the noise level has increased to a value equivalent to that produced when one receiver in a switching section is about to fail because of an RF signal fade; that is, muting is about to occur. This procedure makes effective use of a large RF signal level range, limits the number of short interruptions to important traffic, reduces the possibility of simultaneous fading affecting two or more bearers and gives a high availability of the protection bearer for non-priority traffic.

An exception to the preceding practice occurs with twin path systems using baseband combiners (para. 5.11) where the transfer of the traffic from one bearer to the other occurs gradually over a signal to noise ratio difference range of ±5 dB approximately. Notice that the philosophy of minimising protection bearer switching is opposite to that of diversity systems (para. 5.5) which attempt to prevent signal degradation by switching with an RF signal level differential of approximately 6 dB.

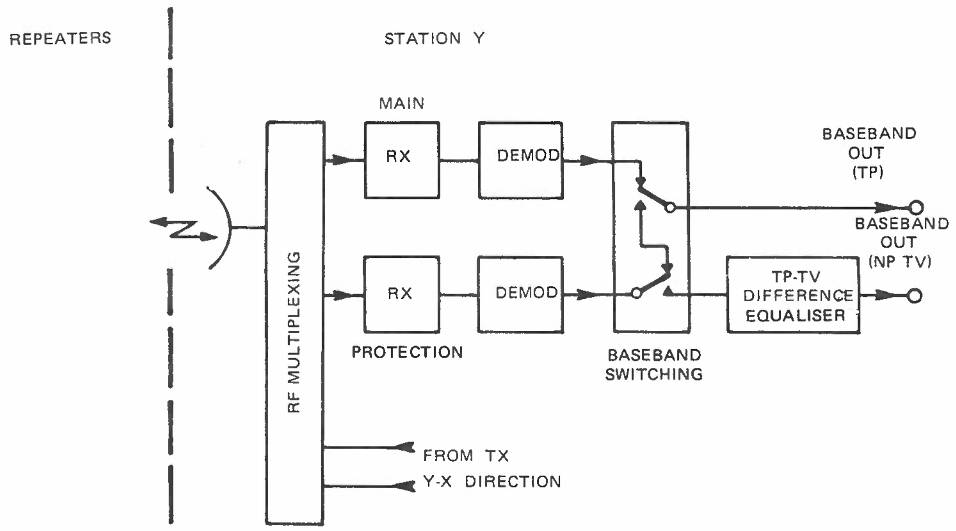


FIG. 37. (CONTINUED FROM PAGE 52).

5.16 So that the operation of each bearer can be monitored, a continuity pilot signal with a frequency outside the baseband frequency range is injected at the baseband input to each switching section. The basic terminal transmitting equipment block diagram for a twin path system in Fig. 38 shows the injection point of the pilot oscillator. This applies for both baseband branching (full line) and IF branching (broken line) to the protection bearer. A pilot stop filter is included to remove any signals, including remaining pilot or noise signals originating in preceding equipment, from the band around the pilot frequency. This is necessary since the performance of each bearer is assessed by measuring the noise level in this band.

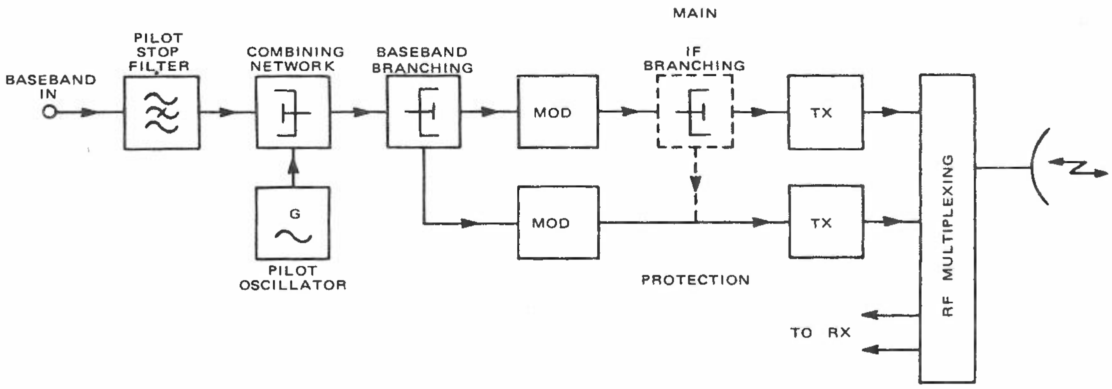


FIG. 38. PILOT INJECTION.

The recommended pilot frequencies are included in Table 4. The use of the alternative frequencies for a particular system depends on the manufacturer. For example, for a 960 channel telephony link, the lower frequency (4,715 kHz) is suitable but, if the same bearer system is to be used to provide a television link, an 8.5 MHz pilot is required. The manufacturer may then decide to use the higher pilot frequency (8.5 MHz) for both telephony and television bearers for standardisation, or he may take advantage of the different pilot frequencies to identify the traffic connected to the protection bearer.

BASEBAND TRAFFIC	CONTINUITY PILOT (kHz)
60 Channel telephony	304 or 331
120 Channel telephony	607
300 Channel telephony	1,499, 7,000 or 8,500
600 Channel telephony	3,200 or 8,500
960 Channel telephony	4,715 or 8,500
1,200 Channel telephony	6,199 or 8,500
1,800 Channel telephony	9,023
2,700 Channel telephony	13,627
625 line television	8,500

TABLE 4. CONTINUITY PILOT FREQUENCIES.

Some manufacturers use a different pilot frequency (for example, 8 MHz) for the idle protection bearer so that, at the receiving end, they can easily identify when the traffic of a main bearer has been connected to the protection bearer by the change in the pilot frequency. Another method used to identify an idle protection bearer is to amplitude modulate the protection bearer pilot with a low frequency signal (13.5 kHz) when the bearer is available to accept traffic.

5.17 Bearer operation is monitored by sensing, at the receiving end of each bearer immediately preceding the switching equipment, the level of the pilot signal and the magnitude of the noise in a frequency band in the vicinity of the pilot frequency. Note that sensing must be carried out before the switching point. For baseband switching the pilot and noise receivers or quality detectors are connected at the baseband outputs of the receiving equipment as illustrated by Fig. 39a for a twin path system. For IF switching, a split of the IF signals immediately preceding each switching point is demodulated in a pilot demodulator to recover the baseband signal and, in particular, the pilot signal, which is fed to the pilot and noise receiver (Fig. 39b).

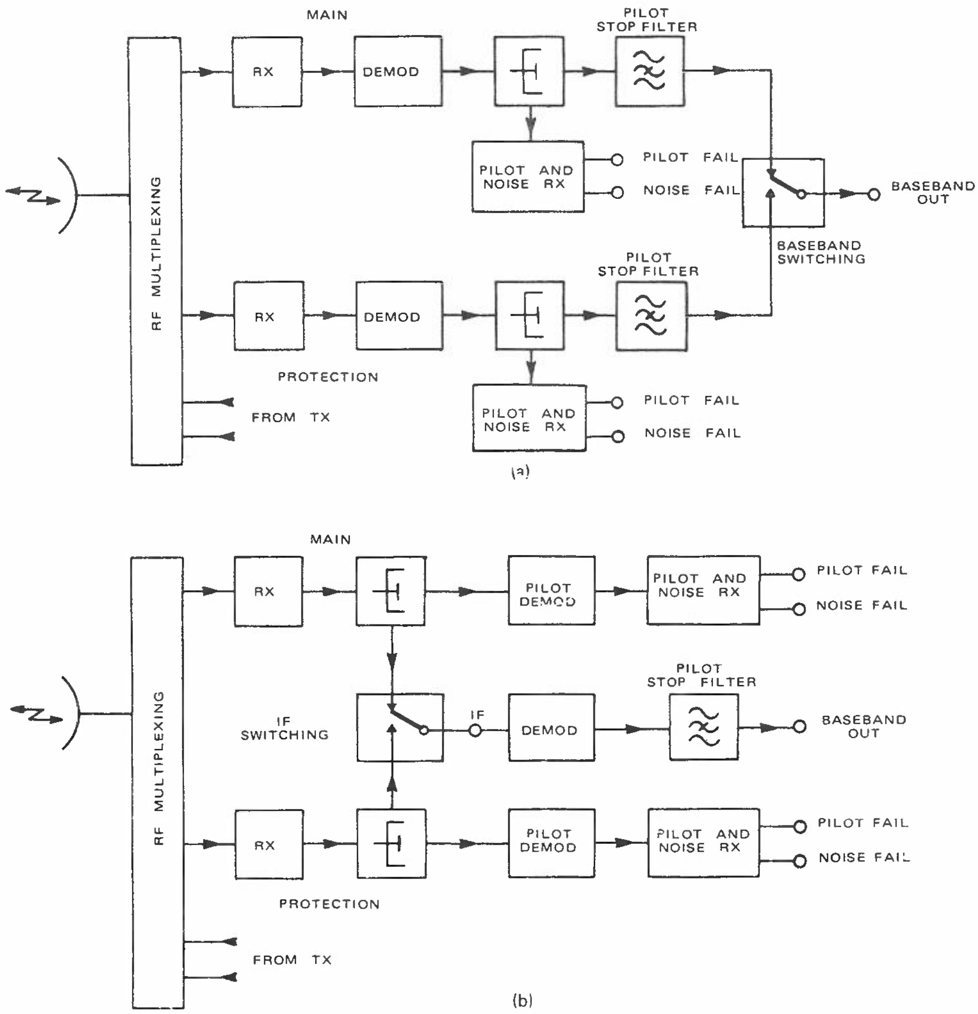


FIG. 39. PILOT AND NOISE RECEIVERS.

A band stop filter in the traffic path at a baseband point prevents the pilot from appearing at output at both terminal and demodulating repeater switching stations. At terminals, this prevents the radio bearer continuity pilot from being fed to the broadband carrier terminal equipment. At repeaters, it prevents the pilot and the noise in the adjacent band from being fed to the next switching section. For the following switching section, a new pilot signal is injected at the baseband input to the transmitting equipment.

At non-demodulating switching stations with IF switching, the pilot and noise receivers are connected as at demodulating stations with IF switching (Fig. 39b). However, because the output of the IF switching is connected to a transmitter without demodulation (refer to Fig. 34b), the pilot cannot be removed and re-inserted again for the next section of the route. The same pilot is monitored at the following switching point. Assume a system consisting of a near terminal, station X, a non-demodulating repeater, station Y, with IF protection bearer switching, and a remote terminal, station Z. A bearer failure between stations X and Y, giving a pilot fail signal at station Y, will, slightly later depending on the propagation time between stations Y and Z, be detected as a pilot failure at station Z. Switching is initiated at station Y, but because no fault exists between stations Y and Z, some means of preventing switching of this section must be included. Manufacturers use different techniques including -

- Sending a control signal from station Y to station Z to inhibit switching in the Y to Z section;
- Checking for correct operation between stations X and Y before the Y to Z section is switched, and,
- For complete failure of both main and protection bearers, connecting a pilot modulated IF carrier to the transmitter at station Y instead of the receiver output from the failed section so that the Y to Z section can be independently monitored for correct operation.

The pilot and noise receivers monitoring the quality of the bearers provide a pilot fail signal when the amplitude of the pilot decreases from its normal level by a preset amount, usually in the range of 3 dB to 6 dB. The noise fail monitoring circuits are adjusted to give a noise fail signal when the bearer output signal to noise ratio falls below a pre-determined value. The value depends on the bearer capacity and is usually a signal to noise ratio of 37 dB to 49 dB weighted in a test channel at the high frequency end of the baseband. The signal to noise ratio which produces the noise fail signal to initiate switching is chosen to allow at least a 4 dB margin so that, with fast RF signal level fades up to 100 dB per second, the bearer switching operation will be completed before the bearer fails either because of receiver muting or because the signal to noise ratio in the worst telephony channel is less than 30 dB unweighted (32.5 dB weighted). The method of deriving the preceding values is not examined in this paper.

5.18 The circuitry which automatically controls the switching of traffic from a failed main bearer to the protection bearer is such that priorities can be allocated when two or more bearers share a common protection bearer. The A.P.O. requires that one regular bearer be given priority over others for access to the protection bearer and that other regular non-priority bearers are equal but take preference over occasional non-priority television programmes (or test signals) being transmitted via the protection bearer. Under these circumstances, when the protection bearer is not being used for traffic, the first bearer to fail, because of pilot or noise, seizes the protection bearer and the traffic transfer from the main bearer to the protection bearer is effected. If, because of a main bearer failure, the protection is being used to provide a non-priority link and, subsequently, a priority bearer fails because of pilot or noise, then the non-priority traffic is returned to its normal bearer and the priority traffic takes over the protection bearer.

However, if any non-priority link has seized the protection bearer and a failure occurs of another non-priority link, then no change takes place. Also, if the protection bearer is being used for an occasional non-priority television programme and any main bearer fails, then the traffic of the main bearer displaces the occasional non-priority traffic from the protection bearer. If a main bearer failure has caused the traffic to be transferred to the protection bearer and, following this the main bearer returns to normal, the traffic is then returned to the main bearer. This leaves the protection bearer available for use, if required, for other traffic. In a bearer system combining both telephony and television bearers, priority is allocated to a telephony bearer.

Many protection bearer switching systems presently installed operate with priority arrangements different from those previously outlined. In a typical arrangement, the priority is allocated in order of bearer numbering with the highest priority bearer being the number 1 bearer on the route. Telephony bearers are given priority over television bearers by allocated telephony traffic to the lower number bearers. Also, complete failure of a bearer, indicated by a pilot fail signal, is given priority over degradation of the bearer which produce a noise fail signal. This means, for example, that complete failure of a television bearer has priority over noise failure of a telephony bearer and noise failure of telephony bearer 1 has priority over noise failure of telephony bearer 2.

With the philosophy that a noise failure is used only as an early indication of a complete failure, it is not desirable for pilot failure of any bearer to have preference over noise failure of a priority bearer. However, the differences between the two priority systems are of little practical consequence since, setting the noise detectors to indicate a failure when receiver signal levels are only slightly above the muting level, gives a large range of acceptable receiver signal levels and reduces the possibility that two bearers will fail simultaneously as a result of fading.

We will see in para. 5.19 that, when switching is to be carried out, control signals are sent between the stations at each end of the switching section. These signals are sent over a channel provided by the auxiliary system. If the control channel should fail, the bearer traffic remains on the bearer that it occupied before the control channel failure, independent of later changes in the status of the main and protection bearers.

5.19 SWITCHING SEQUENCE. The pilot and noise fail signals, indicating the quality of the bearers, are fed to the receiver switching logic and control circuitry. Here, the signals and the failure priorities determine the switching that is required.

The simplest switching arrangement is the twin path system in which the traffic is connected to both bearers at all times (Fig. 34). If a failure occurs on the main bearer, the receiver switching logic and control circuitry checks the quality of the protection bearer and, if it is satisfactory, control signals cause transfer at the receiving end. No control signals are required between switching stations.

For a system with more than one main bearer, or with provision for occasional non-priority television on the protection bearer, switching is required at both ends of the switching section (Fig. 35, 36 and 37) and control signals are required between switching stations. The control signals are often voice frequency tones with frequencies the same as those standardised for voice frequency telegraph systems; that is, odd multiples of 60 Hz. However, to obtain wider bandwidth control circuits, which reduce the operating times of the control circuits, higher frequency control tones are sometimes used in modern equipment. The control tones are used singly, or in combinations, and by either their presence or a shift in their frequencies, to initiate the required control functions.

Fig. 40 illustrates the equipment at two baseband switching stations for one direction of transmission of a radio broadband bearer system. In this example, the control tones are transmitted via an auxiliary system incorporating an auxiliary radio bearer operating in the same frequency band as the main bearers. Auxiliary systems and alternate auxiliary bearers are examined in para 6.12 to 6.19. Fig. 40 also assumes a system which uses a protection bearer pilot signal different from that of the main bearers. It could have a different frequency or it could include a low frequency (13.5 kHz) amplitude modulation as a marker signal. The following examination is intended to show the principles of protection bearer switching, without representing any particular manufacturer's equipment.

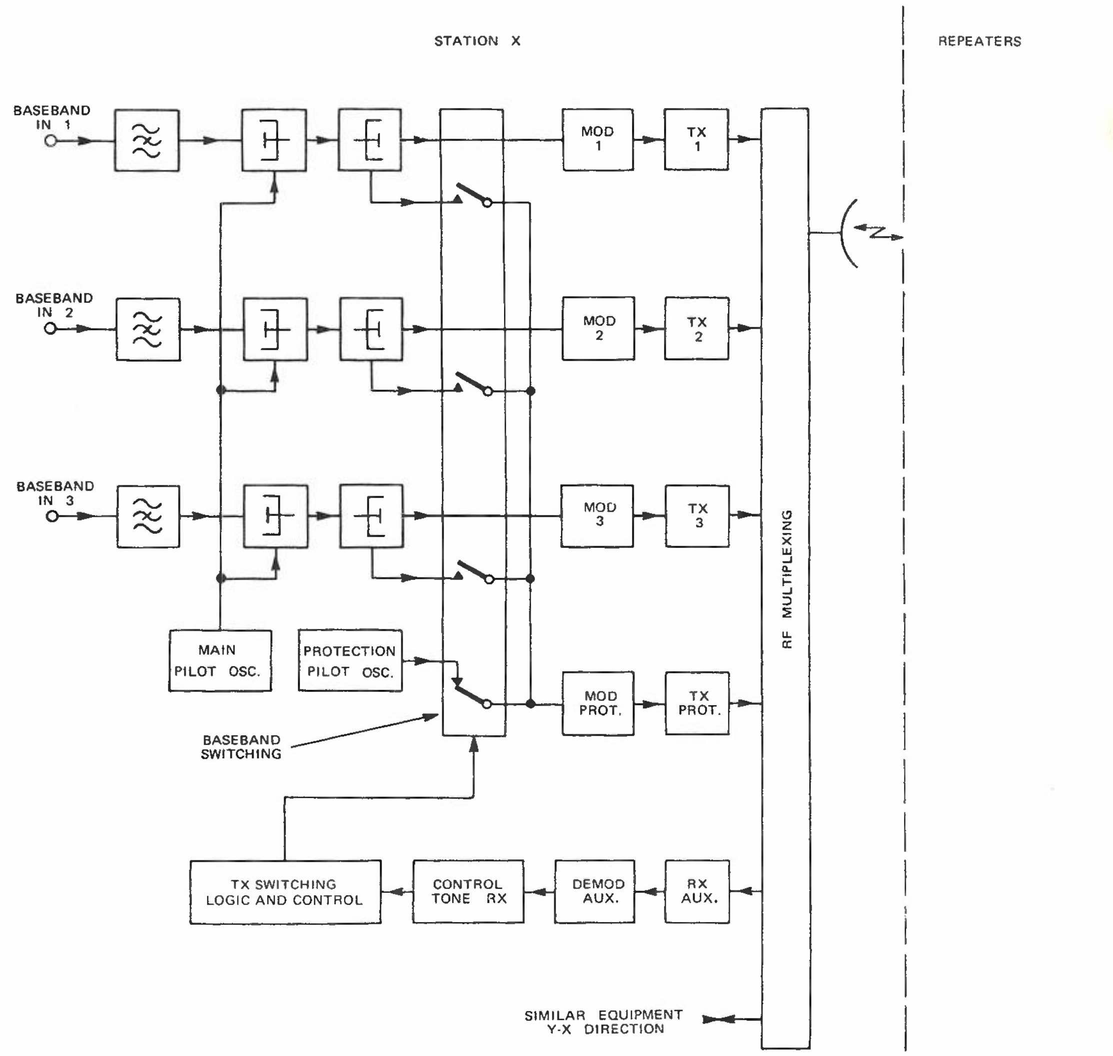


FIG. 40. PROTECTION BEARER SWITCHING CONTROL SYSTEM.

Under normal conditions, no pilot or noise fail signals are produced at the output of the pilot and noise receivers. The receiver switching logic and control circuitry indicates this to the control tone generators and a control tone is sent via the auxiliary system to the transmit end of the system. The control tone receiver detects the particular tone and the transmitter switching logic and control circuitry identifies that the system is normal; that is, the auxiliary system is working and no switching is required. If the protection bearer is idle and operating satisfactorily, its pilot and noise receiver detects the presence of the special protection pilot signal and passes this information to the logic circuitry.

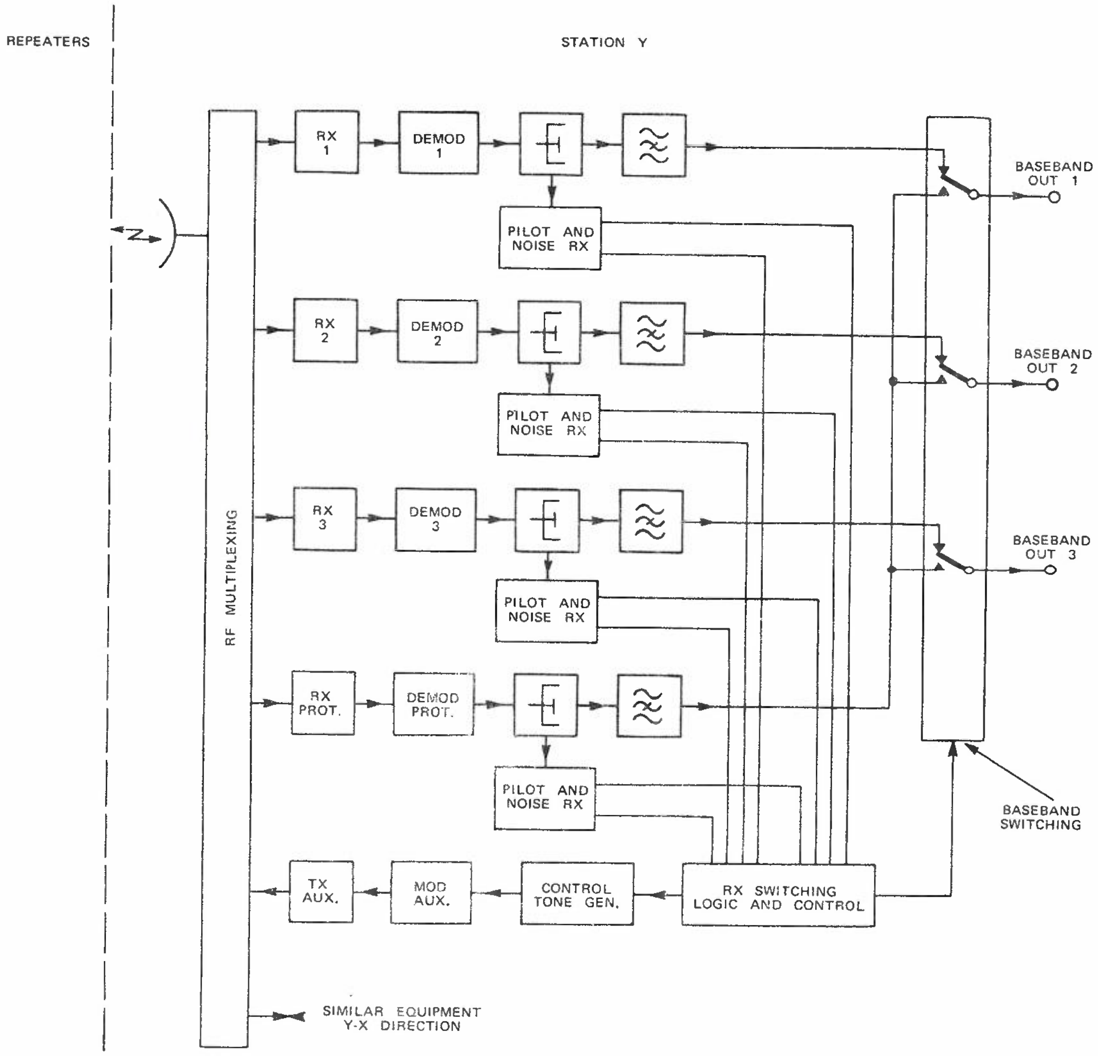


FIG. 40. (CONTINUED FROM PAGE 58).

Assume now that a main bearer, for example, bearer 2, is degraded sufficently to produce a noise fail signal. This signal is fed to the receiver switching logic and control circuitry at station Y where availability of the protection bearer, considering bearer priorities, is checked. With the protection bearer available, a combination of control tones is sent via the auxiliary system to station X. The tones indicate to the transmitter switching logic and control circuitry that bearer 2 is to be replaced by the protection bearer. A different combination of tones is used for each switching condition.

The transmitter switching logic and control circuitry causes the protection pilot to be removed and a split of the traffic at the baseband input 2 is connected to the protection bearer. The traffic is still connected to bearer 2. At the receiving end, the protection bearer pilot and noise receiver detects the pilot frequency change to that of a main bearer or the absence of the pilot marker signal, showing that baseband 2 traffic is available. Given this information, the receiver switching logic and control circuitry causes the protection bearer to be connected to baseband output 2 so finally replacing bearer 2.

In the preceding operating sequence, the successful operation of the transmitting end switching is detected at the receiving end by the change in the pilot signal. An alternative method of indicating that the transmitting end switching has been completed is to send a confirmation control tone from station X to the receiver switching logic and control circuitry at station Y via the auxiliary system which is provided for control of switching of the Y to X main bearers.

The switching circuits at both switching stations have a locking characteristic and they will remain in the switched state until a control signal changes that state. As indicated in para. 5.18, if the auxiliary system should fail, the traffic will remain on the bearer it occupied before the control path failure. The bearer switching logic and control circuitry is disabled when the auxiliary system, which may be monitored by using an auxiliary system continuity pilot signal, is not operating correctly.

Notice that, when switching is initiated by noise, the traffic is degraded for the total operate time, but the traffic interruption is only that introduced by the change-over of the output switching; that is the transfer time. Under normal operating conditions it is expected that a noise fail indication will be followed closely by a pilot fail indication, but this will occur after the traffic transfer has been completed. However, if a catastrophic failure of the main bearer occurs, as indicated by a sudden pilot failure, the traffic interruption is the total operate time including detection and recognition of the pilot failure, control of the switching sequence and receiving end switching to finally effect the traffic transfer.

When main bearer 2 returns to a satisfactory operating condition, the noise fail signal, and also the pilot fail signal if initiated, ceases to be produced. This causes the baseband output 2 to be reconnected to bearer 2 again with an interruption equal to the transfer time. It also causes transmission of the intial 'system normal' control tone to station X and the transmitting equipment switches return the protection bearer to the idle condition.

5.20 Assume that bearer 2 is a non-priority bearer and that it is still unserviceable with its traffic being carried by the protection bearer. Now, a failure occurs of a bearer that has been allocated priority. For example, assume that bearer 1 is the priority bearer and a pilot failure signal is produced by its pilot and noise receiver. The receiver switching logic and control circuitry identifies the priority and immediately returns the baseband 2 traffic to bearer 2. At the same time, the 'system normal' control tone is sent to station X and the protection bearer is temporarily returned to the idle condition. When it has been proved idle by the arrival of the special protection bearer pilot signal at station Y, a control tone combination is sent to station X and a split of baseband 1 traffic is connected to the protection bearer. The arrival of the main bearer pilot signal at the receiving end of the protection bearer causes switching of the protection bearer to baseband output 1 and the protection bearer is now being used for baseband 1 traffic.

Because of the need to free the protection bearer before it is available to replace the priority bearer, the bearer switching operate time is longer than when the protection bearer is idle. Therefore, a greater traffic interruption occurs in the case of a catastrophic failure. If the priority bearer failure is detected as a noise fail condition, the traffic interruption usually remains equal to the transfer time of receiving end switching.

5.21 OPERATE TIME. The operate time of the protection bearer switching system depends on propagation times between control stations, time delays introduced by the pilot and noise receivers and the control channels, switching times of logic and control circuitry and the transfer time of the receiving end output switching. It also depends on the availability of the protection bearer at the required switching time.

The approximate operate time can be determined by estimating the delays introduced by the different sections of the operation. If the propagation path length between two switching stations is 300 km (187.5 miles), at the speed of light (3×10^8 m/s), the propagation time is 1 ms. This means that, each time a signal passes from one end to the other of a switching section, a 1 ms delay is introduced. Both pilot and noise receivers and control channels introduce time delays because of their phase-frequency characteristics, their restricted bandwidths, and the time constants of their associated detectors. Typically, the operating time of a pilot or noise receiver is approximately 1 ms. For control channels using low frequency control tones and a narrow bandwidth (for example, 200 Hz bandwidth), the delay introduced is typically 5 ms. With higher control tone frequencies and a bandwidth of say 2 kHz, the delay introduced is typically 0.5 ms. To provide the locking feature of bearer switching systems, either electro-mechanical (for example, magnetic latching relay) or electronic (bistable multivibrator) systems can be employed. The operate time of magnetic latch relays is typically 8 ms but multivibrator operate time can be of the order of microseconds. Delays introduced by electronic logic circuits are also of the order of a few microseconds, depending on design, but longer delays are produced if relays are involved in the control circuitry.

An estimation of the propagation, control and switching times which combine to make up the operate time for bearer switching when the protection bearer is available, is included in Table 5. The two examples in Table 5 are typical figures for extreme conditions. Combinations of both examples occur in practice; for example, narrow bandwidth control channels and electronic switching.

CONTROL STATE	TIME (ms)	
	NARROWBAND CONTROL CIRCUIT ELECTRO–MECHANICAL SWITCHING	WIDEBAND CONTROL CIRCUIT ELECTRONIC SWITCHING
Recognition of pilot or noise failure	1	1
(Times for freeing of protection bearer)	(See Table 6)	(See Table 6)
Logic circuit operation and switching of control tones to auxiliary system	1	0.1
Propagation of control tones to transmitting end.	1	1
Delay due to restricted channel bandwidth and recognition of control tones	5	0.5
Operation of logic circuit and locking circuit.	8	0.01
Bearer switching at transmitting end	2	0.01
Propagation of traffic to receiving end via protection bearer	1	1
Recognition of arrival of pilot and logic and control circuit operation	1	1
Bearer switching at receiving end.	2	0.01
Operate time (Total)	22	4.63

TABLE 5. OPERATE TIME (PROTECTION BEARER FREE).

Notice that the receiving end bearer switching, which determines the transfer time, is significantly less than the total operate time. However, an interruption equal to the operate time should occur only following a catastrophic failure of a bearer which is switched at each end. This is acceptable since such failures do not occur very often. In practice, most bearer failures are not instantaneous and switching is initiated by detection of a noise failure, usually produced because of RF signal level fading. However, even catastrophic failures may not be instantaneous if they involve cooling of thermionic valves or discharge of power supply capacitors.

During a rapid fade, the rate of signal level reduction is usually not greater than 100 dB/second. With this rate of fade, during a bearer switching operate time of say 20 ms, the signal level will fall by 100 × 0.02 = 2 dB. The signal to noise ratio of a bearer under fade conditions is directly dependent on the RF signal level. Therefore, during the operate time, the signal to noise ratio is degraded by 2 dB - a satisfactory condition. Notice that this is within the 4 dB noise margin which is allowed when the setting for the noise detector is determined (para. 5.17). Therefore, for twin path systems and for bearers switched at each end with the switching initiated by a noise failure, as occurs for most protection bearer switching, the traffic interruption is equal to the transfer time.

Table 5 shows that a significant improvement in the operate time can be gained by using wider bandwidth control channels and electronic control and locking circuitry. However, for a noise failure when the protection bearer is available, this improvement is of little consequence.

5.22 When the protection bearer is occupied by non-priority traffic, additional time is involved in removing this traffic before the bearer can be used to replace a priority bearer. An estimate of the additional operate time, that is required to free the protection bearer, is included in Table 6.

CONTROL STATE	TIME (ms)	
	NARROWBAND CONTROL CIRCUIT ELECTRO–MECHANICAL SWITCHING	WIDEBAND CONTROL CIRCUIT ELECTRONIC SWITCHING
Recognition of pilot or noise failure (priority bearer)	(See Table 5)	(See Table 5)
Logic operation and switching of "System Normal" control tones to auxiliary system	1	0.1
Propagation of control tones to transmitting end	1	1
Switching of bearer to normal at receiving end (coincident with above two items)	(2)	(0.01)
Delay due to restricted channel bandwidth and recognition of control tones	5	0.5
Release of locking circuit	8	0.01
Switching of protection bearer to standby at transmitting end	2	0.01
Propagation of protection pilot to receiving end via protection bearer	1	1
Recognition of protection pilot	1	1
Remainder of control and switching sequence.	(See Table 5)	(See Table 5)
Operate time (Additional to Table 5). (Total)	19	3.62

TABLE 6. ADDITIONAL OPERATE TIME (PROTECTION BEARER OCCUPIED).

The times in Table 6 assume that it is necessary to ensure that the bearer is returned to the standby condition before being switched to the priority traffic. Operating times can be reduced if this double control operation is not used as is the case in some equipment.

5.23 MANUAL CONTROL OF BEARER SWITCHING. For normal operation, the switching of the protection bearer is automatic. However, for test and maintenance purposes, it is necessary to provide manual control of the switching. Manual switching usually has facilities for -

- Transferring of the traffic of any main bearer to the protection bearer to allow maintenance or testing of the main bearer;

- Preventing the switching of any main bearer (main bearer lockout) or, a function which achieves the same purpose for all bearers at once, preventing the protection bearer from being made available for switching (protection bearer lockout). Lockout of one main bearer can be used to override the priority of that main bearer. Lockout of all main bearers or protection bearer lockout is used for maintenance or testing of the protection bearer and to allow occasional television of national importance to have priority use of the protection bearer.

Therefore, the manual control switches for each main bearer include positions for three functions -

- Normal automatic operation;
- Traffic on protection;
- Bearer lockout.

In most cases manual switching, causing a main bearer to be replaced by the protection bearer, is initiated from the receiving end control station. However, in some cases, switching may require attendance at both ends or may allow the switching of the bearers in both directions from the one control station.

Though switching is initiated manually, most equipment requires that the protection bearer be proved to be working satisfactorily before switching is completed. The method of arranging the switching depends on the equipment manufacturer. One method simulates a pilot fail on the bearer to be switched and inhibits any priority failures to prevent these from overriding the manual switching. Switching of the bearer is then carried out in the normal automatic manner. Alternately, the manual control can be carried out in two stages. Firstly the control tones are sent to the transmitting end initiating paralleling of the input of the protection bearer with the main bearer and then the receiving end transfer is produced locally. The traffic is returned from the protection bearer to its normal bearer by returning the switching to allow automatic operation. The traffic time lost during manual switching corresponds to the transfer time. Bearer lockout can be obtained by overriding the bearer fail signals thus preventing them from initiating the switching control circuitry.

5.24 When testing is being carried out on a bearer, it may occur that a bearer carrying traffic fails. For example, while the protection bearer is being tested a main bearer fails or, while a main bearer is being tested with the traffic being carried by the protection bearer, the protection bearer fails. Under these circumstances, the testing procedure is normally immediately interrupted and the bearer under test returned to service as quickly as possible to minimise the traffic interruption. The interruption depends on the time required to return the system to normal, which depends on the way that the test equipment is connected to the bearer.

For overall testing of a bearer, the method of connecting the test equipment varies with the type of equipment. In some cases the test points for overall bearer testing are incorporated with the bearer switching so that, should a bearer fail, the test equipment is isolated from the bearer being tested and this bearer made available for normal traffic. In other cases, patching of the test equipment into circuit isolates the bearer from its normal traffic connections. To restore the bearer under test to normal operation requires the removal of patching and the traffic time lost could be seconds, depending on the skill of the operator.

At all times while carrying out testing, the procedure for returning the system quickly to normal should be kept in mind and immediate action taken in case of a bearer failure.

5.25 BEARER SWITCHING SUPERVISORY INDICATIONS. Protection bearer switching circuits provide lamp displays indicating the conditions of the bearers. These may be in matrix form but, for ease of interpretation at main control stations, they may be arranged on a mimic diagram of the route. Local displays are controlled directly from the switching control circuitry, but remote displays are obtained with the aid of remote supervisory systems which are examined in paras. 6.1 to 6.3. Remote supervisory equipment can be provided especially for indicating the conditions of bearer switching circuits, but most systems use a common supervisory system for supervision of both bearer switching and other alarm conditions.

Bearer switching supervisory displays normally indicate -

- The bearers that are working;
- The bearers that have failed;
- The cause of the failure (pilot or noise);
- The traffic occupying the protection bearer;
- Bearer lockouts;
- Auxiliary system failure;

And if modulator and demodulator switching is included -

- Modulator or demodulator failure;
- Traffic using spare modulator or demodulator.

Remote displays may be restricted by combining or eliminating some of the available indications.

6. SUPERVISORY, REMOTE CONTROL AND AUXILIARY SYSTEMS.

6.1 SUPERVISORY SYSTEMS. Broadband bearer system reliability is improved by including automatically switched protection bearers. However, when a fault occurs, it must be cleared quickly if the high system availability is to be maintained. For a system with one protection bearer, when one bearer is faulty, no redundant equipment is available and a further bearer failure in the same switching section will cause loss of traffic for an extended period until one of the faults is cleared. Because most radio communications stations are unstaffed, diagnosis of the general cause and location of the faults in a short time is possible only if adequate remote supervision of the operation of the equipment is available.

Extensive monitoring of all equipment to provide supervisory information for expert staff at control stations allows initial maintenance, particularly by unit replacement, to be carried out, under direction, by staff with a limited diagnostic ability. However, a compromise must be reached between the cost of supervisory equipment and that of initial maintenance staff of a high calibre. Currently installed equipment monitors, for remote supervision, only the more important parameters of the system because of the availability of high trained technical staff within easy reach of the normally unstaffed station. The equipment is normally monitored on a satisfactory/unsatisfactory basis to provide the information for transmission to the control station. Many additional monitoring facilities, for example, metering of currents and voltages, are included in the bearer equipment for detailed local maintenance. It is possible to accurately convey analogue measurements of equipment parameters from a remote station to a control station by converting the analogue values into digital form for transmission. However, this is not normally done at this time.

At control stations, the supervisory information can be displayed by lights that are coloured to indicate the urgent or non-urgent nature of the supervised conditions. Audible alarms are provided to draw attention to abnormal conditions. In some cases a complete lamp display is continuously available to indicate the status of all supervised items at each remote station. For other systems, only simplified information is displayed continuously; for example, the status of each bearer and the stations initiating alarms. When detailed supervisory information is required this can be obtained, if facilities are provided, by either manual or automatic interrogation of the relevant station. The detailed supervisory information for the interrogated station can then be provided using a single detailed display.

As an alternative or in addition to a lamp type display, particularly at main control stations, supervisory information may be recorded in typed form by a teleprinter. To provide this facilitiy, a small digital computer or processor is required to convert the supervisory information received at the control station into a form suitable for printout. Typical information recorded includes the times, locations and types of faults, bearer switching operations and traffic interruptions.

6.2 Supervisory indications at two different levels are sometimes provided for broadband bearer systems. Some control stations have responsibility for only the small section of the route in their vacinity. These stations are provided with facilities for fairly detailed supervision of each station under their direct control. Typical detailed supervisory indications extended to control stations and the number of indication involved are included in Table 7. The table also shows whether the information is to provide an urgent or non-urgent alarm or is for general information about the system and requires no immediate action.

GROUP	SUPERVISORY INDICATION	ALARM PRIORITY OR SUPERVISORY INFORMATION	NUMBER OF INDICATIONS
Bearer Transmission Equipment	Transmitter fail (power output low) Receiver fail (muting)	Urgent Urgent	Each bearer for each station under direct control
Bearer Switching	Bearer fail Pilot fail Noise fail Traffic on protection Bearer lockout Modulator fail Spare modulator operating Demodulator fail Spare demodulator operating	Urgent Information Information Information Information Urgent Information Urgent Information	Each bearer for adjacent switching sections (If modulator and demodulator switching included)
Power Equipment	Mains power fail Emergency generator operating Urgent power fail (e.g. mains power fail but generator not operating) Battery voltage low Battery voltage high Fuel low Fuel empty	Non-urgent Information Urgent Urgent Urgent Non-urgent Urgent	Each station under direct control
Miscellaneous	Waveguide pressure Temperature Illegal entry Alarms local	Non-urgent Non-urgent Urgent Information	Each station under direct control

TABLE 7. TYPICAL DETAILED SUPERVISORY INDICATIONS.

At capital city or other main control stations accepting responsibility for a large section of a bearer network, in addition to the detailed supervision of the stations directly under its maintenance control, a less detailed picture of the operation of all bearers in the area is sometimes given. The simplified overall supervisory indications, if provided, are derived from the detailed information available at minor control stations. Typical simplified overall supervisory information indicates -

- A bearer failure, its number and the route section affected;
- Stations initiating alarms and whether they are urgent or non-urgent.

This approach limits the amount of information to be transmitted to the main control stations but gives sufficient information to initiate call-out of local maintenance staff when the alarms occur outside normal duty hours of these stations.

6.3 Some of the supervisory indications in Table 7 interact and must be interpreted. Assume that a transmitter fail alarm is given at one station. If the failure is caused by a small reduction below normal of the transmitter power output, the RF signal level at the following receiver may be adequate and the bearer could still operate satisfactorily. However, if the transmitter fail alarm results from a complete failure, the lack of RF signal at the next station will cause receiver muting, a receiver fail alarm, a pilot fail is detected and the bearer failure indicated. If the protection bearer is available, the traffic is transferred to the protection bearer and a supervisory indication given. Of all of the indications given, the initiating cause is the transmitter failure which can be interpreted from the display.

The interpretation of the interaction of the detailed supervisory information can be carried out automatically and only the relevant information displayed or printed if a small digital computer or processor is associated with the supervisory equipment. Such a processor, in addition to providing a data logging function (para 6.1), can perform calculations to determine bearer availability and other statistical data. Also it can be associated with the bearer switching equipment to allow more flexible use of this equipment. At this time, data logging facilities are being included with some radio broadband bearer systems, but advantage has not been taken of the full capabilities of a processor.

6.4 REMOTE CONTROL Control stations often require a limited number of manual remote control facilities to allow them to carry out operations at distant station, thus supplementing or overriding automatic controls. Typical remote control functions are -

- Start emergency generator;
- Stop emergency generator;
- Cancel or reset alarms or overloads;
- Initiate switching that is not part of the normal protection bearer switching system.

6.5 SUPERVISORY AND REMOTE CONTROL EQUIPMENT. At each remote station, supervisory equipment is provided to translate the supervisory information so that it can be sent via the auxiliary system. At control stations, the information is interpreted to provide the supervisory display. In the opposite direction, similar equipment provides for the transmission of remote control information from control keys at the control station to initiate the control function at the remote station. A possible difference is that the remote control signals often include additional facilities for error detection to prevent accidental or incorrect operation of controls if errors are introduced by interferring signals during transmission.

At any one control station, all of the indications from all supervised stations represents a rather large number. Because of the nature and the use of the supervisory data, high speed data circuits are not required. With suitable equipment all of the information required can be transmitted via one or two telephone channels (≈ 4 kHz bandwidth each) provided by the auxiliary system. However, it may take as long as several seconds (depending on the number of supervisory indications transmitted from each station and the method of transmission) for the supervisory display to be updated following a change in status of the equipment. The small number of different control functions required for any particular remote station can be provided without a significant delay.

A number of methods can be used to convey supervisory information from a remote station to the control station or control information in the opposite direction. Some of the interacting factors which define the differences between systems are -

- The method of identifying the supervised or controlled station;
- The method of encoding the supervisory or control information for transmission;
- The type of transmission used for the encoded supervisory or control information;
- The method of initiating the transmission of the supervisory information;
- The transmission speed;
- The type of display information provided;
- The time taken to update the supervisory display;
- The supervisory information memory and resetting facilities;
- The facilities and methods used for error detection, particularly for control information.

The facilities and techniques of only a few of the possible systems will be examined briefly in this paper.

6.6 In one supervisory system, a unique voice frequency is used to identify each of the remote stations. The signals from the remote stations along a route are progressively connected to a common telephony channel for transmission to the control station. When a fault occurs at a remote station, the station identification tone from that station causes the lamp for that station to light. The remote station can be interrogated manually by sending the appropriate interrogation tone from the control station. The outstation then returns the tone or tones corresponding to any fault conditions. A different frequency is allocated for each supervisory indication, but these frequencies are shared by all stations of a particular supervisory system.

Notice that, for a supervisory system requiring interrogation from the control station, transmission facilities are required in each direction. The channel to the remote station, however, can be used for control signals. The required remote station is identified by the interrogate tone and additional tones determine the control function to be carried out.

The preceding type of supervisory system is not favoured at this time. Although the supervisory information is available without delay, the number of stations and the number of supervisory indications that can be provided using one telephone channel is very limited.

6.7 Most of the supervisory and control systems currently installed assemble the supervisory or control information in time division multiplex (TDM) form for transmission as modulation of a carrier signal. This is done by scanning each supervised item or control key in turn. For remote station identification, a different carrier frequency is allocated to each station sharing a common telephony channel. Therefore, each remote station is provided with a separate data or telegraph channel for transmission of supervisory or control information between the remote station and its control station.

Some early systems used amplitude modulation of the supervisory system carrier frequencies by the TDM information. However, most modern systems use frequency modulation (sometimes called frequency shift keying, FSK, when associated with digital information). Supervisory and control systems of this type normally transmit data with a signal of approximately 50 bauds. For this transmission speed, the carrier frequencies allocated are normally those standardised for voice frequency telegraph carrier systems (odd multiples of 60 Hz). Also, for systems using FM, the carrier is normally shifted ± 30 Hz by the TDM signal. This allows 24, 50 baud data channels to be provided via a single telephony channel. Therefore, a telephone channel in each direction can provide the transmission facilities for supervision and control of 24 remote stations.

Supervisory and control systems which transmit information using time division multiplexing vary in the way that transmission of the information is initiated. Typical methods used by the preceding TDM systems, which operate with a separate slow speed data channel for each remote station, are -

- The information is transmitted automatically only following a change of status of the supervised equipment, for example, when a fault occurs, or when a control key is operated. Each supervised item or control key is usually scanned twice to allow the received signal to be checked for errors. Such a system normally provides facilities for manual interrogation of remote stations for checking of the equipment status at any time. Fault initiated scanning is normally used for circuitry designed around electro-mechanical supervisory systems. The technique is also used for some remote control systems.

- The information is transmitted continuously. For supervision, the items are continuously scanned so that the supervisory display is automatically updated at each scan. For control, the information is transmitted while the control key is operated. Continuous scanning is used by the majority of equipment at this time which incorporates electronic scanning.

6.8 As an example of the general form of supervisory and control equipment, Fig. 41 shows a basic block diagram of a supervisory system using time division multiplexing, continuous scanning and frequency modulation of the remote station supervisory carrier frequency. In Fig. 41a the inputs from the items to be supervised are scanned in turn using a number of gating circuits. This corresponds to converting the parallel input supervisory information into serial form. The generation of the TDM waveform is completed in the waveform encoder. This unit produces a pulse waveform which has one of its parameters modified, at times corresponding to the scanning of each input, in accordance with the supervisory information. To obtain the correct display at the receiving end, the receiver decoder must be synchronised with the transmitter encoder. A synchronising signal must be included as part of the transmitted waveform. This signal is generated by the input scanning gate control circuit and combined as part of the output waveform from the encoder. This waveform, containing both supervisory and synchronising information, causes frequency modulation of the internally generated supervisory system carrier frequency which is fed to the auxiliary system via a band pass filter. At other remote stations on the same section of the bearer route, the outputs of similar equipment, each operating with a different carrier frequency, are commoned into one telephony channel provided by the auxiliary system.

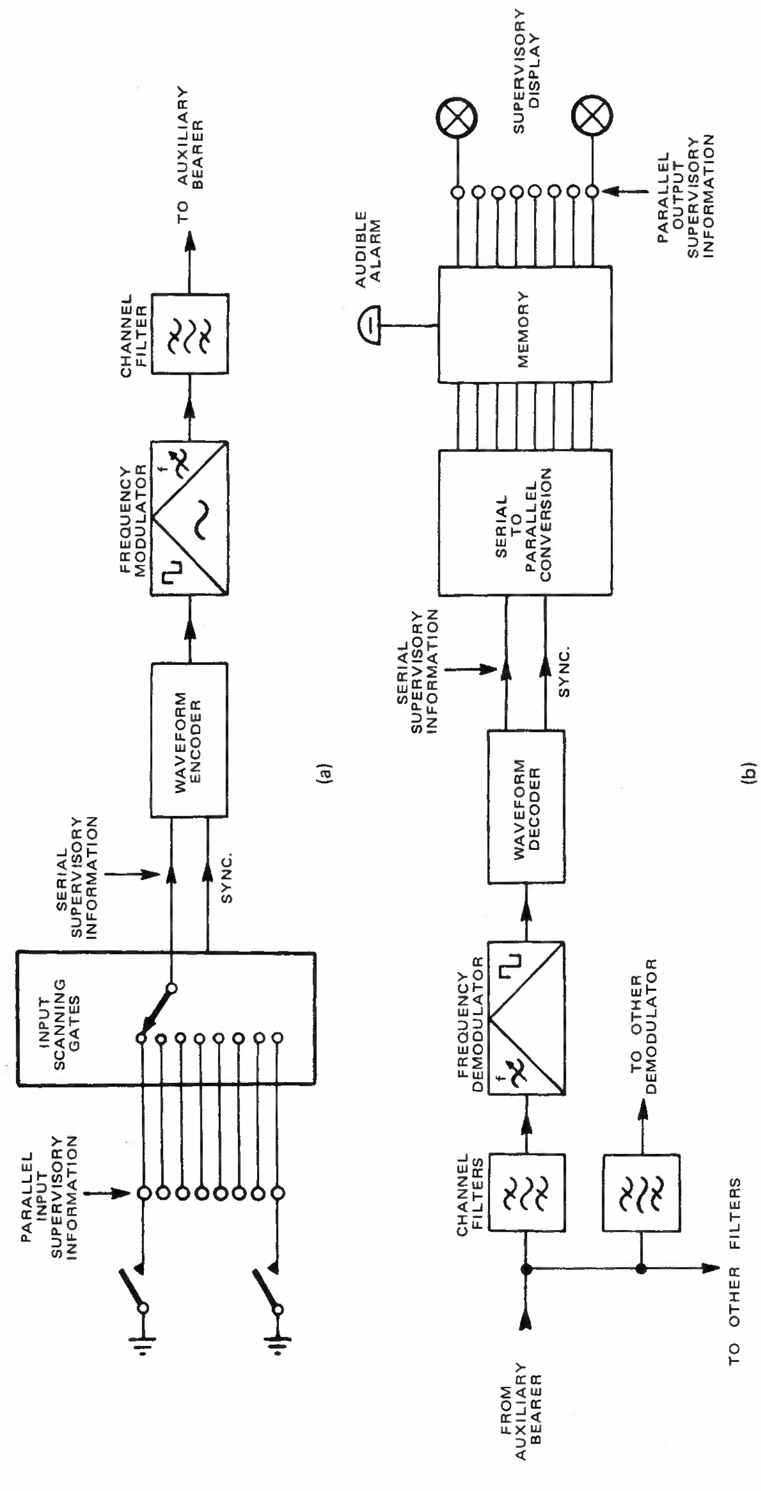


FIG. 41. SUPERVISORY EQUIPMENT.

At the receiving end (Fig. 41b), the transmissions from each remote station sharing a common telephony channel are separated using band pass filters. Each filter output is demodulated to recover the TDM signal. This signal is decoded to obtain the synchronising and supervisory information. The supervisory information is converted from serial to parallel form using either a number of gates or a shift register. The synchronising information controls the timing of the serial to parallel conversion to ensure that channel 1 of the TDM signal appears at number 1 output. The parallel supervisory information is transferred to the memory circuits which are normally either magnetic latch relays or bistable multivibrators. A memory is necessary for each output because the information for each channel of a TDM system is available for only a small period of each scanning cycle. The outputs from the memory circuits are used to light display lamps and to sound audible alarms as necessary. Typical systems cater for up to 64 binary supervisory indications.

6.9 To generate the TDM waveform of a supervisory system, the supervisory information causes some characteristic of a pulse waveform to be modified. Two different methods which are used in slow speed continuous scanning supervisory equipment can be compared by examining the variation of frequency with time of the signal fed to the auxiliary system. Examples of typical signals are illustrated by Fig. 42.

In one system the output from the modulator is switched between two frequencies and information is transmitted by modification of the duration of each tone pulse. At a time when the scanned input is normal, the equipment transmits a frequency of f + 30 Hz for 20 ms. This is followed by the transmission of a frequency of f - 30 Hz for 20 ms except during the synchronising interval when the low frequency extreme of the TDM FM waveform is 'stretched' to 50 ms. The signal for a 'no fault' condition on all inputs is shown in Fig. 42a. With the times shown, the time for one scan during a 'no fault' condition for a system scanning 16 inputs is 670 ms. When a fault occurs and a supervisory indication is given, the high frequency section of the waveform corresponding to that input is 'stretched' to 50 ms. In Fig. 42a, 'fault' supervisory indications are given for inputs 4, 7, 8 and 15. Notice that the time for one complete scan of the input is lengthened when 'fault' information is transmitted.

A second system uses three different frequencies to indicate 'no fault', 'fault' and 'synchronising' conditions. For a time slot corresponding to an input with a 'no fault' condition, the TDM FM signal has a frequency of f + 30 Hz for 18 ms and then returns to a frequency of f for 18 ms. Therefore, for a 'no fault' condition on all inputs (Fig. 42b) the TDM FM signal switches between the frequencies f and f + 30 Hz at 18 ms intervals while the inputs are being scanned. To include the synchronising information, the signal is prevented from switching to f + 30 Hz for one time slot and remains at frequency f for a total of 54 ms. The time for one scan of 16 inputs using the times shown is 612 ms. A 'fault' condition is indicated by causing the supervisory carrier frequency to switch to f - 30 Hz for 18 ms instead of to f + 30 Hz. Therefore, a frequency of f + 30 Hz, at the time allocated to a particular input, indicates a 'no fault' condition and f - 30 Hz indicates a 'fault' condition. The scan time is not changed by a change in the supervisory information. In this system the validity of the message is verified by checking that each scan between the synchronising intervals contains the correct number of pulses. If any scan does not, the information for that scan is rejected.

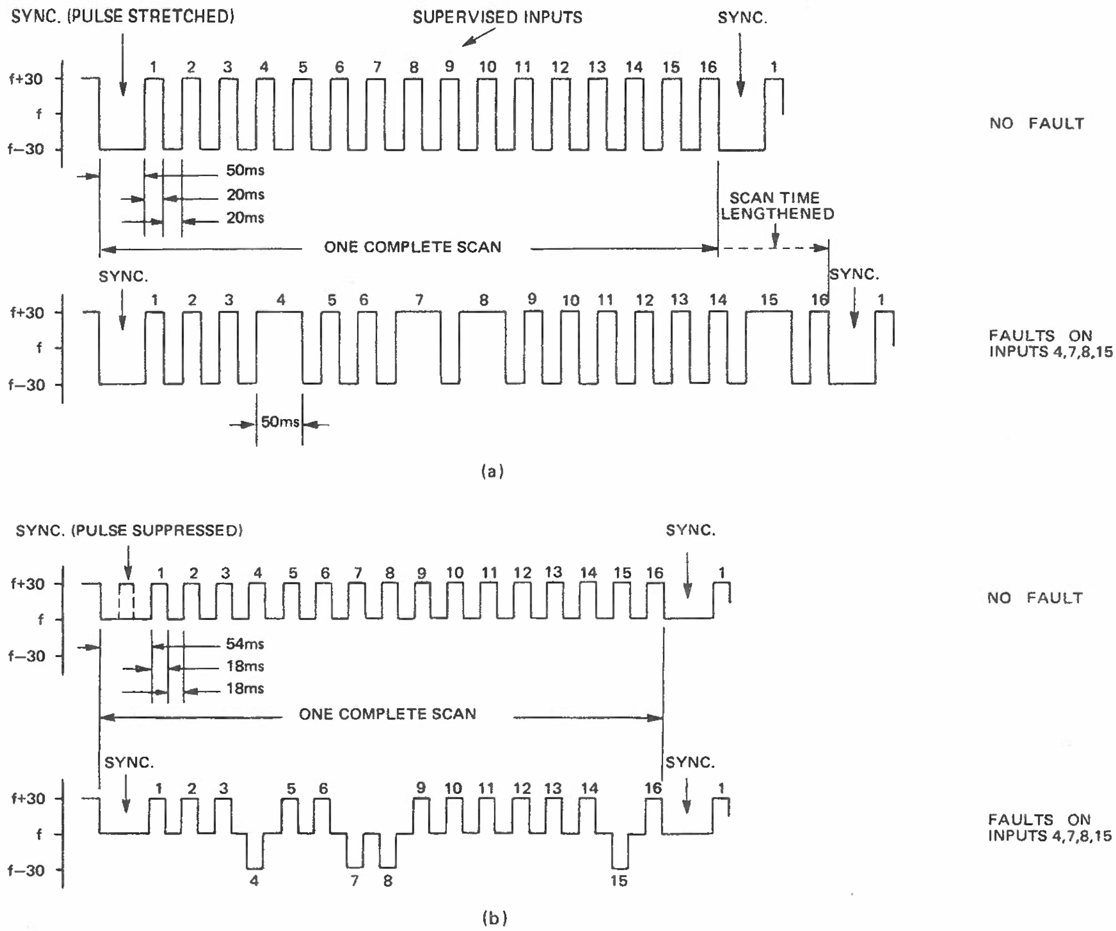


FIG. 42. SUPERVISORY SYSTEM WAVEFORMS.

6.10 An additional type of supervisory and control system also transmits the supervisory and control information between remote and control stations in TDM form. However, instead of a separate data channel being allocated to each station, a common data channel is shared by all stations of the system. Each remote station is identified by a binary coded address. The stations are automatically interrogated sequentially and cyclically by the control station which transmits data messages containing synchronising information and the address of the remote stations to be interrogated. The interrogated remote station then replies with the synchronising information, its identifying address and the supervisory information. To send control signals, the interrogation cycle is temporarily interrupted but resumed again when the transmission of the control signal is completed. The automatic interrogation cycle is also interrupted if manual interrogation of a particular station is required.

Because of the sequential interrogation of the remote stations, the data transmission speed needs to be greater than for systems using individual data channels to allow the supervisory display to be updated at acceptable intervals. Typically, data is transmitted using a 200 baud signal, though the equipment available can operate at discrete speeds between 50 bauds and 2,400 bauds. The latter speed requires the full bandwidth of a telephony channel for transmission.

Important features of this supervisory and control system are its flexibility and the facilities included to detect errors. Flexibility results from the use of binary coded addresses for remote stations. This allows the number of stations in a system and the interrogation cycle to be readily changed. A number of different methods are included for error detection. To illustrate these we will examine briefly the structure of a typical data message corresponding to one transmission to or from a remote station.

The interrogation and control messages from the control station and the supervisory information messages from the remote stations are all of the same duration. Each message is a continuous binary signal which is divided into 8 channels each of 14 bits. The first channel contains the synchronising information, the second the address code, and the remaining 6 channels are available for transmission of supervisory or control information (Fig. 43a). The synchronising channel contains a code configuration (Fig. 43b) which must be received without error before the following part of the message is accepted. In channels 2 to 8, 10 of the available bits are used for significant information and the remaining 4 for checking purposes.

For the address channel, the 10 significant bits are divided so that 5 bits are used for the units digit and 5 bits for the tens digit of the remote station address. This allows for 100 addresses from 00 to 99. The code used for each digit of the address is arranged so that 2 of the 5 bits are always '1s'. This provides one method of checking the address code for errors. Details of the code are not included in this paper. Of the check bits, 3 are designated transition check bits. These bits, bits 4, 8 and 13, always have the opposite value to the immediately preceding bits. Fig. 43c illustrates the signal in the address channel for a typical address. The units digit is conveyed by bits 1, 2, 3, 5 and 6, bits 2 and 5 being '1s' in this example. Transition bit 4 is '1' because bit 3 is '0'. The tens digit is conveyed by bits 7, 9, 10, 11, 12 which determines the values of the transition bits 8 and 13. Bit 14 is used for a parity check of the channel information. The parity bit is arranged so that total number of "1s" in the signal for the channel is odd.

In the 6 information channels, the check bits are used in the same manner as in the address channel. The 10 significant bits per channel provide for a corresponding number of on/off supervisory indications. The signal for a typical channel containing supervisory information is included in Fig. 43d. For an interrogation signal, the information channels contain no significant information. For a control signal, control information is sent in the information channels in a coded form similar to the coded address. This allows the validity of the control code to be checked in the same manner as is the station address.

As an additional check of signal for distortion and interference, the equipment checks that all transitions of the received signals occur within specified limits of their correct timing.

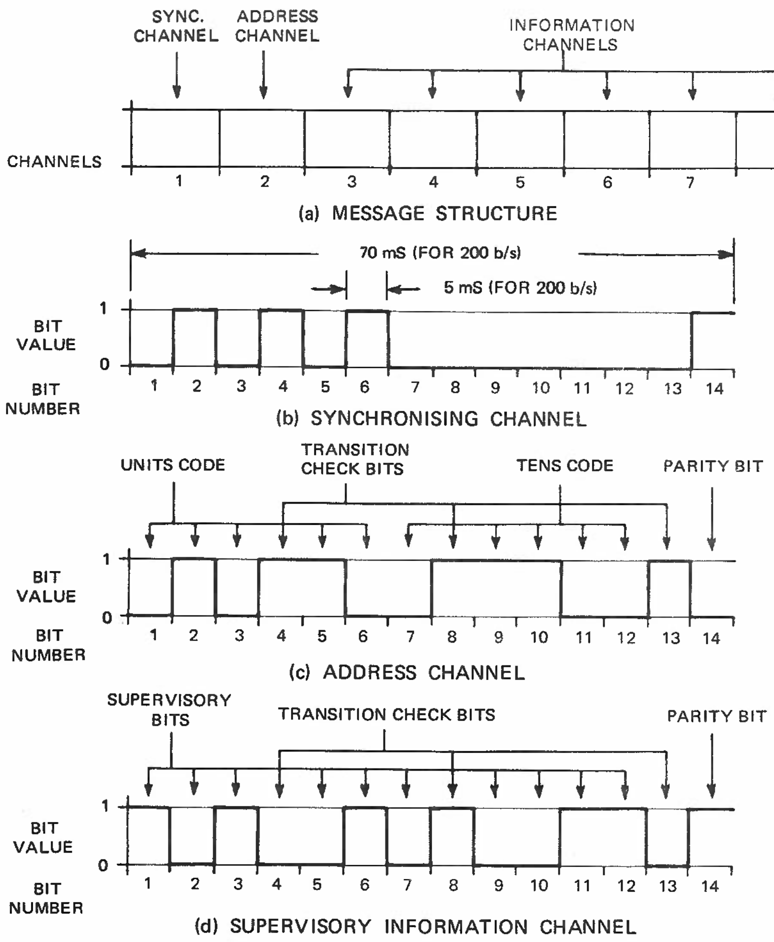


FIG. 43. SUPERVISORY SYSTEM WAVEFORMS.

6.11 ORDER-WIRES. For maintenance purposes, communication channels are required between stations. The following order-wires are usually provided -

- An omnibus (party line) circuit connecting adjacent control stations and the intermediate repeaters;
- An omnibus circuit, often known as the express order-wire, connecting each control station on a route;
- An omnibus circuit connecting the television programme centre with the metropolitan and regional television stations, but also available at the radio bearer control stations.

The order-wire terminating equipment provides facilities to allow selective calling on each order-wire. The channels are assembled by the auxiliary system using frequency division multiplexing and transmitted over the auxiliary bearer.

6.12 AUXILIARY SYSTEM. On a radio broadband bearer route, an auxiliary system is required to provide circuits for service channels which transmit -

- Protection bearer switching control tones;
- Supervisory system signals;
- Manual remote control signals;
- Communications or order-wire signals.

The auxiliary system consists of frequency division multiplexing equipment and a suitable two way link. The link can be provided by an auxiliary radio system operating either in the same frequency band as the main bearers or in a separate band from the main bearers usually in the VHF or UHF ranges. Alternatively, the link can be provided by main telephony links by using the frequency band below that required by the broadband telephony carrier system (below 60 kHz); that is the sub-baseband. The auxiliary link can also be provided in the frequency band above that occupied by the main baseband signal; the super-baseband. The super-baseband is sometimes used with television links and is the only alternative to a separate auxiliary radio system on routes which provide for television programme distribution only.

Until the late 1960s, an auxiliary radio system was normally provided as part of the auxiliary system. However, from the late 1960s most radio broadband bearer routes constructed use the sub-baseband of the main telephony link as the link for the auxiliary system. On a limited number of routes providing television programme distribution only, the super-baseband is used as the auxiliary link. Compared with auxiliary systems using the sub-baseband, auxiliary systems operating in the super-baseband use similar techniques but are often considerably simplified. Such systems are not specifically examined in this paper.

The frequency division multiplexing equipment of the auxiliary system normally follows conventional telephony carrier system techniques. In some cases, the voice frequency band of the link (300 Hz to 3.4 kHz) is used to provide one of the required channels. Control and supervisory signals can be generated, using carrier frequencies in the voice frequency range, and then allocated to a derived telephony channel of the multiplexing equipment where they are translated into a higher frequency band to be sent via the auxiliary link. Another technique is to generate control and supervisory signals using the final carrier frequencies that are to be fed to the auxiliary link. They are then combined, using normal filter methods, with other derived channels. This eliminated the need for multiplexing channel equipment.

Along a radio broadband bearer route, each station requires order-wire facilities and also the facilities for transmitting the supervisory system signals and receiving manual control signals. If the auxiliary link is provided by auxiliary radio bearers, the protection bearer switching control tones are required at main bearer switching stations only. However, when the sub-baseband is used for the auxiliary system, switching control tones may be required at intermediate stations also, to initiate sub-baseband switching (para. 6.17). The preceding requirements make it necessary for the auxiliary system to provide demodulating and modulating facilities at each station. Because of this and because the auxiliary link often provides a wider bandwidth than is necessary for the control tones, supervisory signals and order-wires, it is possible, with some restrictions (see para. 6.20), to use the auxiliary system to provide a limited number of telephony channels between main bearer non-demodulating stations. These channels can be used as subscriber or minor trunk circuits for the public telephone network.

6.13 AUXILIARY SYSTEM USING AUXILIARY RADIO BEARERS. Fig. 44 illustrates the equipment at a radio bearer terminal station for an auxiliary system incorporating auxiliary radio bearers. The auxiliary radio bearers in this example are operating in the same frequency band as the main bearers and share a common aerial with these bearers. Typical channels provided by the auxiliary system are shown in Fig. 44. Those channel inputs shown by broken lines are not required or provided by some equipment.

The signals from the supervisory, control and order-wire equipment (and minor trunk and subscribers' equipment if applicable) are connected to the transmit multiplexing equipment where they are translated into a frequency division multipled form. The output of this equipment is fed via a modulator to the transmitter. Either frequency or phase modulation may be used depending on the equipment manufacturer.

The RF signal of the return bearer is demodulated and the individual channels recovered in the receive multiplexing equipment. Similar equipment to that at a terminal is used at control stations along the route. Here, however, some channels, such as the order-wires interconnecting control stations and television stations, are made available locally and then through connected to the next section of the route.

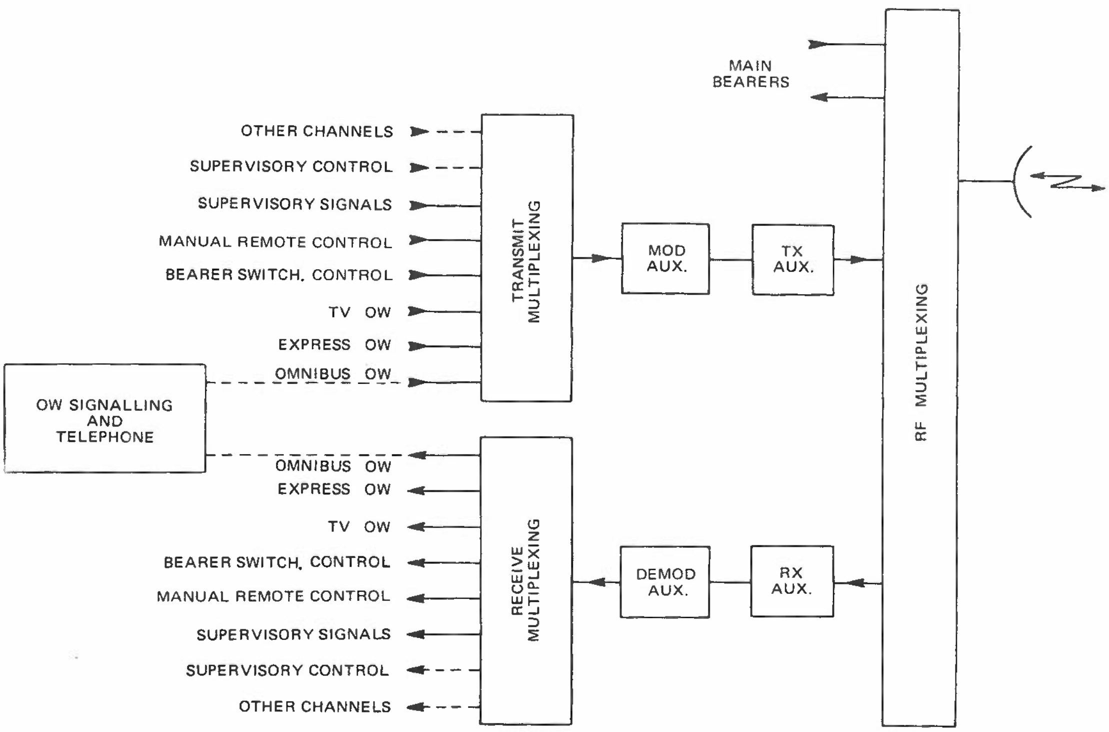


FIG. 44. AUXILIARY SYSTEM USING AUXILIARY RADIO BEARERS (TERMINAL).

6.14 At non-demodulating repeater stations, only a limited number of channels is required and it is not necessary to fully equip the multiplexing equipment. Through channels are interconnected without passing through the multiplexing equipment. Fig. 45 shows the equipment at a repeater station for a typical auxiliary system operating over auxiliary radio bearers. The necessary interconnections at the repeaters are provided using a number of hybrid units. These units provide splitting and combining but prevent undesirable feedback paths.

The auxiliary bearers in each direction are demodulated and the outputs split using hybrids. One output from each demodulator hybrid is fed via another hybrid to a modulator connected with the auxiliary transmitter for the next transmission section. This provides the through connections at the auxiliary radio system baseband for all channels. The remaining outputs from the two demodulator hybrids are combined and fed to the receive multiplexing equipment. This equipment provides for the dropping of all necessary channels in both directions, such as manual remote control signals, the order-wire for that control section and, in some equipment, control signals for the supervisory equipment.

The channels originating at the repeater, that is, the supervisory signals and the order-wire, are fed to the transmit multiplexing equipment. The multiplexed output is split and fed to each modulator after being combined with the signals from the respective demodulators. Notice the use of the same multiplexing equipment for both directions of transmission in this example. This allows supervisory and order-wire signals to be sent in each direction towards both adjacent control stations and allows reception of manual remote control signals from either of the adjacent control stations and monitoring of the order-wire signals received from either direction.

6.15 AUXILIARY SYSTEM USING SUB-BASEBAND LINK. An auxiliary system in which the auxiliary link is provided by the sub-baseband frequency spectrum of a telephony link is illustrated by Fig. 46. The radio system includes a protection bearer operated on a twin path basis with the main bearer. Along with the main telephony traffic, the sub-baseband traffic is normally transmitted via the main bearer, but is transferred to the protection bearer in case of main bearer failure.

The sub-baseband output of the transmit multiplexing equipment is split to provide independent outputs for the main and the protection bearers. Each output is combined in a filter group with the main telephony signal and fed to its respective modulator. If the radio bearer system is larger than a twin path system and requires transmitting end switching, this is carried out at point A when the protection bearer is used for telephony traffic and at point B when it is used for television traffic. Because of the lower limit of the television signal frequency spectrum, the sub-baseband signal must be disconnected before the protection bearer can be used for television traffic.

In the receiving section of the terminal in Fig. 46, the bearers are switched at baseband in the normal manner and the sub-baseband separated from the main telephony traffic in a filter group. In some cases, the sub-baseband may be separated from the main telephony traffic at the output of both the main and the protection bearer demodulators and switched independently from the main telephony traffic. Sub-baseband traffic can also be included on main bearers incorporating intermediate frequency switching.

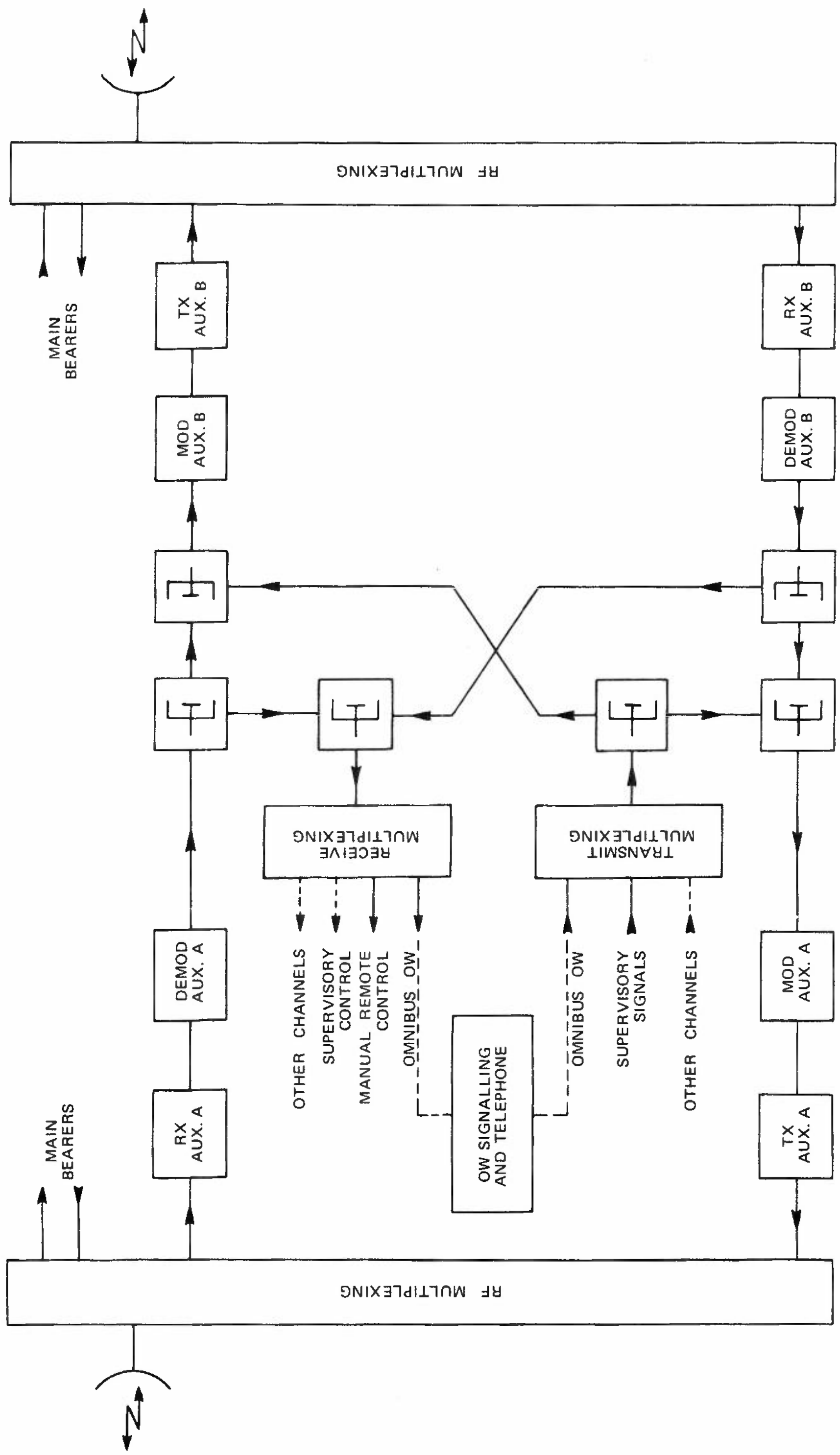


FIG. 45. AUXILIARY SYSTEM USING AUXILIARY RADIO BEARERS (REPEATER).

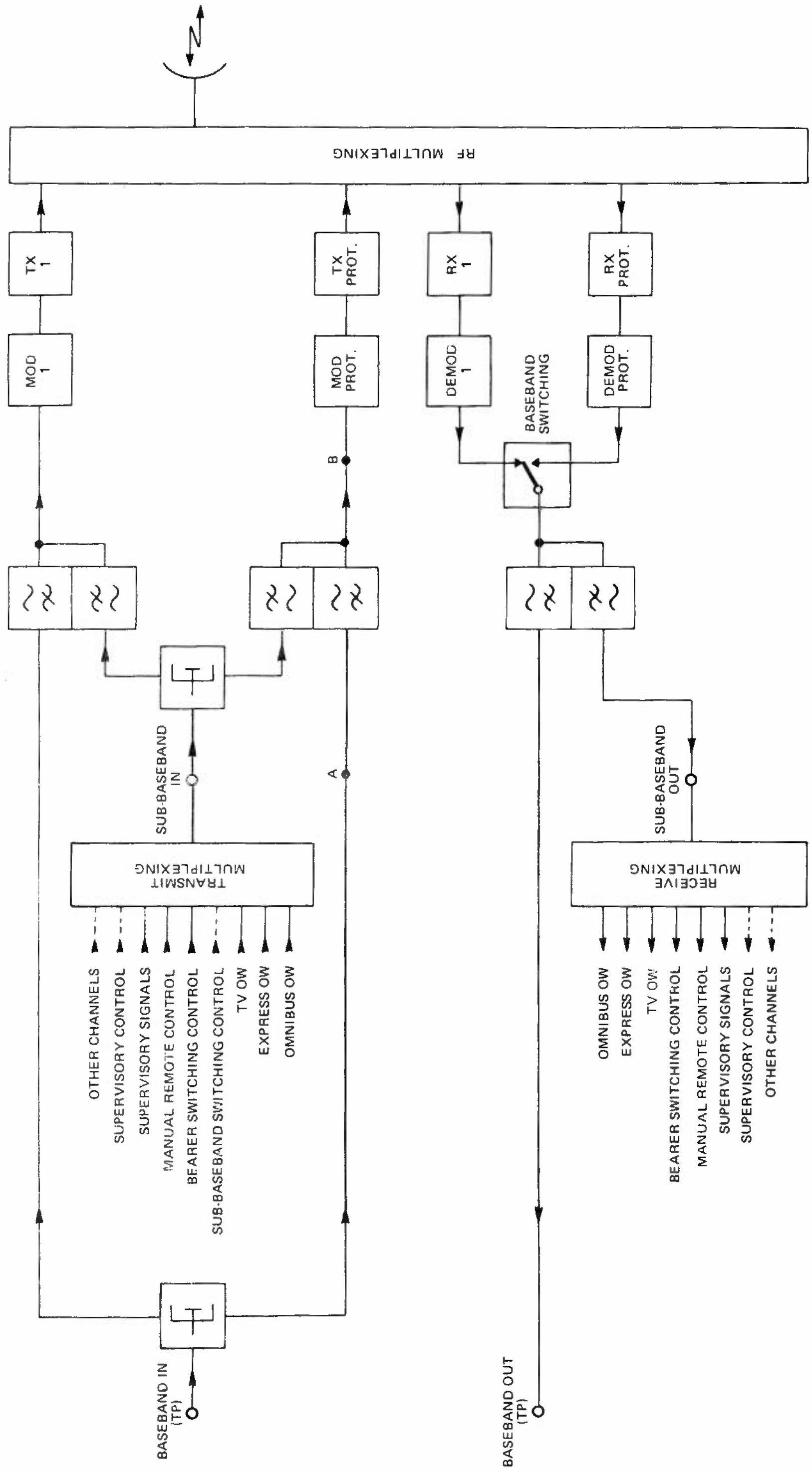


FIG. 46. AUXILIARY SYSTEM USING SUB-BASEBAND LINK (TERMINAL).

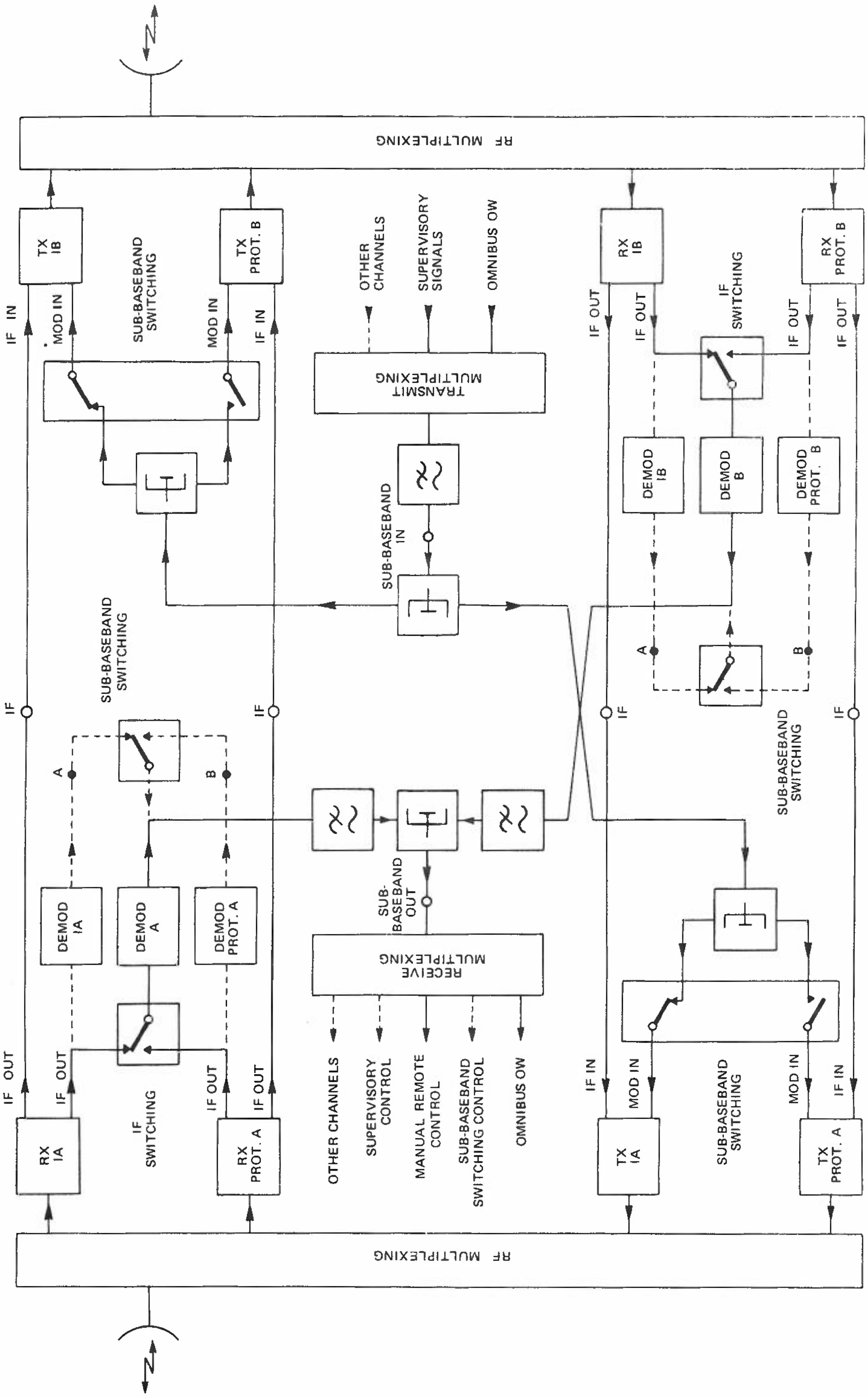


FIG. 47. AUXILIARY SYSTEM USING SUB-BASEBAND LINK (REPEATER).

6.16 At non-demodulating repeater stations it is necessary to demodulate the output of the receivers to make available the required auxiliary system channels. Also, modulation facilities must be provided to allow local signals to be combined with the through information at the repeater. Further, switching between main and protection bearers, co-ordinated with the switching at the terminals, must be provided.

Fig. 47 shows a typical repeater with sub-baseband link facilities. Each receiver provides two outputs at the intermediate frequency. One output from each receiver is through connected to its respective transmitter for the next section of the route. The other outputs from the receivers are connected to IF switches which select the working bearers in each direction. The intermediate frequency signals from the switches are demodulated and the sub-baseband traffic selected using low pass filters. The sub-baseband signals from the receiving equipment in each direction are combined to provide the sub-baseband output. This is fed to the receive multiplexing equipment where the required auxiliary system channels are recovered. Instead of intermediate frequency switching and a common sub-baseband demodulator, separate demodulators for main and protection bearers can be used along with sub-baseband switching as shown by the broken line section of Fig. 47.

The auxiliary system signals originating at the repeater are fed to the transmit multiplexing equipment. A low pass filter ensures that no frequencies outside the sub-baseband frequency range are fed to the repeater sub-baseband input. The sub-baseband signal is split to provide signals for the bearers in each direction. Further splitting and switching feeds the sub-baseband signal to the modulator input of the main bearer in each direction with the facility for change-over to protection bearer in case of main bearer failure.

6.17 The switching of the sub-baseband traffic between main and protection bearers, at terminals and demodulating repeaters, is carried out either by the main bearer switching or by separate sub-baseband switches controlled by the same signals as those for the main bearer switching.

At non-demodulating repeater stations, additional facilities are required to control the switching (Fig. 47) of the equipment provided for the sub-baseband traffic. One method produces a control tone at the receiving end of the main bearer switching section when the receive end switching completes the transfer of the traffic from the failed main bearer to the protection bearer. This tone is fed via the auxiliary system to non-demodulating repeaters in the switching section to control the IF or sub-baseband switching of the sub-baseband link equipment. Switching occurs only for the equipment associated with the direction of transmission in which the main bearer failure has occurred and not for the opposite direction of transmission. Notice that, for a bearer failure in one direction, the switching control tone is sent via the bearer in the opposite direction. This applies to the control tones for both the main bearer switching at the transmit end of the switching section and the sub-baseband bearer switching at the repeaters.

In another system the sub-baseband link switching requirements are determined locally at each repeater. This system is most suitable when sub-baseband switching is used at the sub-baseband demodulator outputs as shown by the broken line sections of Fig. 47. Pilot detectors are connected to the equipment at points A and B to establish the satisfactory operation of the bearers. The switching of both the sub-baseband demodulator outputs and the transmitter modulator inputs is controlled by the failure of the pilot on the main bearer and by the presence of the correct pilot on the protection bearer.

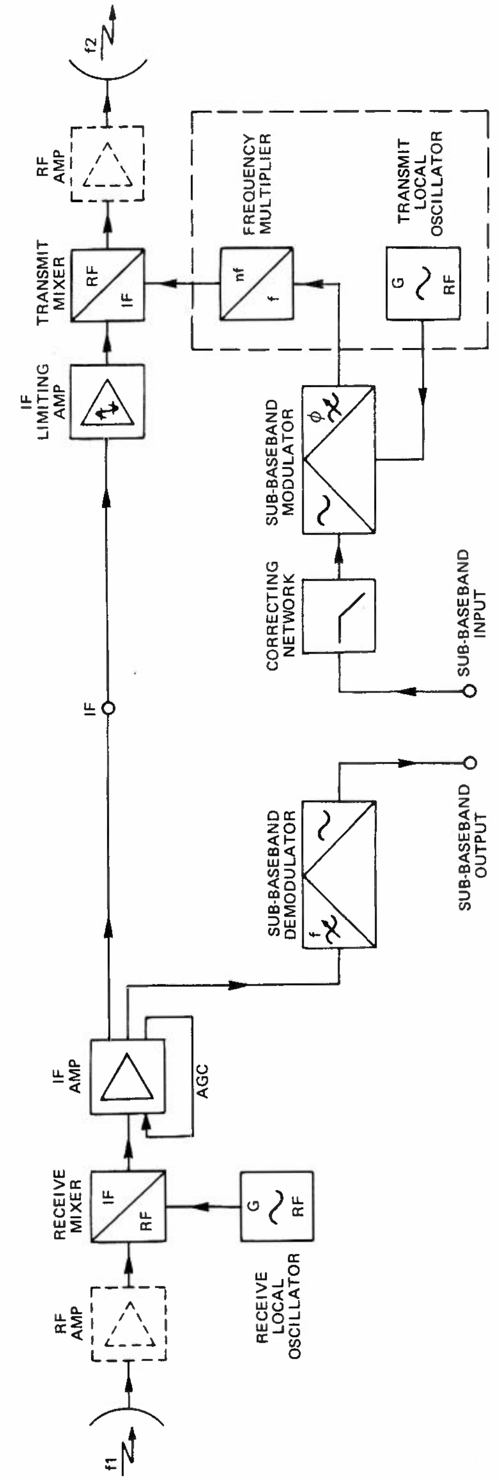


FIG. 48. IF NON-DEMODULATING REPEATER WITH SUB-BASEBAND FACILITIES.
(SEPARATE LOCAL OSCILLATORS).

6.18 At radio bearer terminals, the combined main telephony traffic and the sub-baseband signal cause frequency modulation of the broadband bearer carrier frequency. To be compatible, the sub-baseband signal input to the repeater transmitters must also cause frequency modulation of the carrier. Most equipment achieves this by producing frequency modulation of the transmit local oscillator of an IF non-demodulating repeater.

The IF non-demodulating repeater in Fig. 48 has separate local oscillators and facilities to provide a sub-baseband link. Switching equipment for the sub-baseband link is not included. One output of the receiver IF amplifier feeds the sub-baseband demodulator to provide the sub-baseband output. To provide for modulation by the sub-baseband input, the output of the transmit local oscillator, typically at approximately 10 MHz, is connected to a phase modulator. The sub-baseband input to the transmitter is fed via a correcting network to the phase modulator. The correcting network has an amplitude-frequency response inversely proportional to frequency. This compensates for the differences between phase modulation and frequency modulation and results in the signal at the output of the phase modulator being equivalent to the local oscillator, frequency modulated by the sub-baseband input. This output is frequency multiplied to the required frequency (normally f2 ± 70 MHz) before being fed to the transmit mixer. The mixing of the frequency modulated IF signal from the receiving section with the frequency modulated local oscillator produces a resultant signal that is frequency modulated by both the through traffic and the repeater sub-baseband input.

6.19 In a non-demodulating repeater which uses a shift converter to produce the local oscillator feed to the transmit mixer (but not the receive mixer), the transmit local oscillator signal can be frequency modulated by modulating the shift oscillator. This can be done by including a phase modulator, with a correcting network to produce frequency modulation, similar to that included in Fig. 48, between the shift oscillator and the shift mixer of Fig. 16. Alternatively, the shift oscillator can be frequency modulated directly, as indicated in Fig. 49.

Using some standard frequency plans for RF channels, the same shift frequency is required at a repeater for the bearers for each direction of transmission. For such a repeater, the same frequency modulated shift oscillator can be used to feed the shift mixers of both the main and the protection bearers in both directions as required. The modulated shift oscillator is distributed from point A in Fig. 49 and switched in place of a fixed frequency shift oscillator as necessary. The sub-baseband input distribution and switching of Fig. 47 is then not required but is replaced by a similar modulated shift oscillator distribution.

6.20 When the sub-baseband traffic is injected at a repeater, the mixing of the through frequency modulated signal and the frequency modulated local oscillator signal produces a complex spectrum of frequency components. So that the spurious frequencies, which appear as noise in the main telephony baseband output, are kept within the required limits, the number of channels in the sub-baseband and the frequency deviation produced by them is purposely kept to a minimum. This limits the number of channels that can be provided in the sub-baseband for subscriber and minor trunk services.

Non-demodulating repeaters, while allowing dropping and inserting of sub-baseband traffic, do not allow any channels to be dropped and the same channel to be replaced with different traffic. All channels are through connected independent of dropping and inserting arrangements. Therefore, any channel allocated for use as a subscriber or minor trunk service between any two stations in a section between demodulation stations, cannot be used at other stations, except on a party line basis.

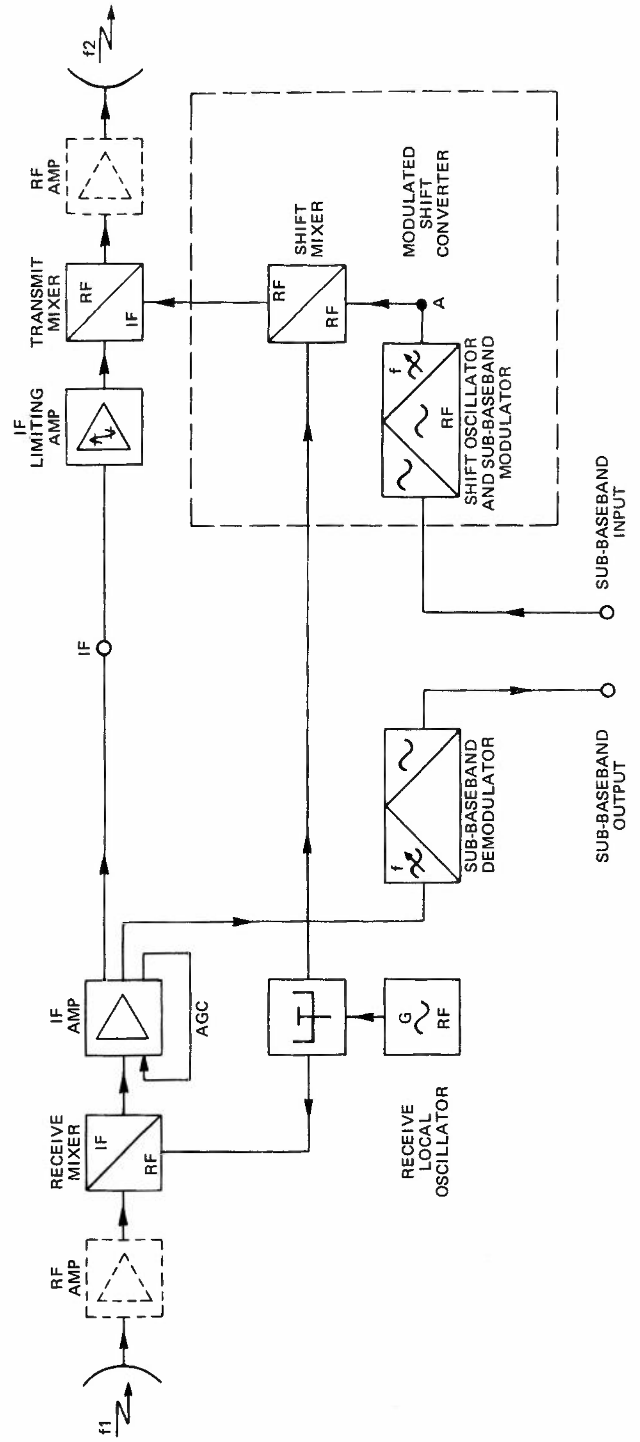


FIG. 49. IF NON-DEMODULATING REPEATER WITH SUB-BASEBAND FACILITIES. (SHIFT CONVERTER).

7. TYPICAL RADIO BROADBAND BEARER SYSTEMS.

7.1 In preceding Sections, the facilities provided by radio broadband bearers have been examined individually with only a limited amount of associated equipment included in the diagrams. In this Section, basic block diagrams of typical systems for typical stations are included. The main features of the systems are stated but full explanations of their operation are not given. It is left to you, the student, to interpret the operation of the block diagrams from a knowledge of the information given in the preceding Sections. Though the block diagrams are modelled on particular systems using particular brands of equipment, the techniques, in most cases, are applicable to many systems.

For some of the figures, styles of drawing based on those used by the equipment manufacturers are maintained so that you can become familiar with different drawing layouts and symbols. A symbol that is included and needs clarification is the switch symbol shown in Fig. 50. The connections implied by the symbol are included in Table 8.

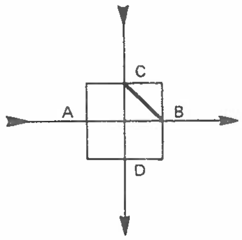


FIG. 50. SWITCH SYMBOL.

CONDITION	CONNECTIONS
SWITCH NORMAL	A TO B AND C TO D
SWITCH OPERATED	C TO B AND A TERMINATED

TABLE 8. SWITCH CONNECTIONS.

7.2 TYPICAL BEARER SYSTEM (A). The block diagrams in Fig. 51 to 55 show the equipment at four stations of a typical radio broadband bearer system. The system provides a two-way link for a 600 channel telephony carrier system and a one-way link for television traffic, including the sound channel on a 7.5 MHz sub-carrier, from the capital city terminal to regional television broadcasting stations. An example of branching of the television bearer, at the intermediate frequency, to spur television bearers, is provided by the demodulating repeater station (Fig. 52). A protection bearer is provided in each direction. This is switched to replace the main bearers at baseband, using reed relays, except at switching stations incorporating television IF branching (Fig. 52). Here IF switching, using diode electronic switching, is provided to allow the protection bearer to be used in place of the main television bearer. To inhibit unnecessary switching of the bearer section following the IF switching point, an IF oscillator, modulated by an 8.5 MHz pilot signal, is switched into circuit by the bearer switching control equipment. Under normal conditions the protection bearer is connected on a twin path basis with the main telephony bearer to reduce the switching operate time involved for telephony main bearer replacement. The protection bearer modulator has independent telephony and television inputs (Fig. 51) and internal switching caters for the different requirements for the two forms of traffic. Similar arrangements are provided at protection bearer demodulator outputs with baseband switching of both telephony and television traffic (Fig. 55). On the television spur route, a protection bearer is provided which is operated on a twin path basis with the main bearer and switched at the receiving terminal located in the regional television broadcasting station.

Correct operation of the bearers is monitored with the aid of continuity pilot signals. The main telephony bearer uses the standard continuity pilot frequency for 960 channel bearers of 4.715 MHz. Under normal conditions this pilot is also present on the protection bearer. The standard 8.5 MHz pilot is used for the television bearer. When the protection bearer is used for television traffic, the telephony pilot is disconnected along with the telephony traffic and replaced by the 8.5 MHz television pilot. Each bearer is monitored at the receiving end before the switching point, by pilot and noise detectors. The noise is measured in the band on either side of the pilot frequency. A pilot detector for 4.715 MHz is connected at the output of each telephony demodulator and at the telephony output of each protection demodulator (Fig. 55). Each television demodulator output and the television output of each protection demodulator is monitored by a 8.5 MHz pilot and noise detector. At switching stations with television IF branching (Fig. 52), the monitoring, which must be before the IF switching, is carried out by 8.5 MHz pilot and noise detectors associated with pilot demodulators which are connected to the IF outputs of the television and protection receivers.

The system incorporates an auxiliary radio bearer in each direction as part of the auxiliary system. The transmitters and receivers of these bearers, and those of the main and protection bearers, share a common aerial. Space diversity reception is provided at some stations. For this purpose an additional diversity receiving aerial, spaced vertically on the tower from the main aerial, is provided. Combining of the main and diversity signals is carried out at RF as illustrated by the non-demodulating repeater in Fig. 54. To achieve correct combining, the main and diversity aerial feeders are adjusted to equalise their lengths. Also, the diversity signal is phase modulated by a low frequency signal using a ferrite modulator. This allows the phase shifters and associated control circuitry of each diversity channel to sense and adjust the phase of the diversity signal so that it is in phase with the main signal with which it is to be combined.

The auxiliary system is divided to operate over two different links. The auxiliary radio bearers are used for the omnibus order-wire connecting all stations in a switching section, the bearer switching control signals, bearer status indications, supervisory signals and manual remote control facilities. An express order-wire linking control stations which are also demodulating stations and switching stations and a television order-wire linking these stations and the television broadcasting stations are operated using the sub-baseband of the main telephony link. Since the latter order-wires are required at demodulating stations only, no sub-baseband modulation and demodulation facilities are required at non-demodulating stations. At demodulating stations, the sub-baseband is combined separately with the telephony traffic to the main and protection bearers. The switching in the modulator from telephony to television disconnects the sub-baseband traffic when the protection bearer is used for television traffic. At the receiving end of the bearer, the sub-baseband is separated from the main telephony traffic after the baseband switching and no separate sub-baseband switching is required. At demodulating stations, the express and television order-wires are through connected using hybrid units so that the facilities are available locally.

The auxiliary radio bearers are demodulated at each station including at main bearer non-demodulating stations. At demodulating stations along the route, separate multiplexing equipment is used for the bearers of the sections in each direction. The only channel requiring through connection, with local dropping and inserting facilities is one used for overall supervisory signals to the main control station. At non-demodulating stations, the multiplexing equipment is common for signals in each direction so that order-wire and sectional, control and supervisory signals are received from and transmitted in each direction.

The bearer switching requirements are determined by the logic circuitry and separate frequencies for each switching function are transmitted via an auxiliary system channel to the remote switching station. Similar frequencies are used on a separate channel of the auxiliary system to provide a display, at switching stations, of the status of the bearer switching. This display is independent of the supervisory system used for extension of fault supervisory indications.

The sectional fault supervisory system is a fault initiated scanning system. A discrete frequency is allocated to each supervised station to allow identification of the origin of supervisory signals by the equipment at the control stations; that is, each station has a separate data channel for supervision information. However, all stations in a section share the same channel of the auxiliary system. A fault at a remote station is indicated to the control station by a shift in the stations supervisory channel frequency. If the equipment at the control station is ready to receive the supervisory signal, a supervisory control signal is returned to the remote station. The equipment at the remote station scans the monitoring points and produces a time division multiplexed waveform with faults indicated by extended pulse durations for these time slots. The TDM waveform frequency modulates the station supervisory channel frequency being transmitted to the control stations. The supervisory information for all stations in a switching section is transmitted to the control stations, which are also the switching stations, at each end of the section. Each control station receives supervisory information for all stations in the section including that for the remote control station.

Manual remote control is provided by equipment associated with the supervisory system. The supervisory signals, supervisory control signals and manual remote control signals use different frequencies to share the same two-way telephony circuit provided by the auxiliary system. However, each control station is allocated only one frequency for manual remote control. This signal is frequency modulated by the control information which is contained in a waveform of short and long duration pulses, coded to include both the control function and the address at which the control is to be performed. Therefore, manual remote control of all stations is carried out using one data channel.

Overall supervision of the bearer route is available at the main control station (Fig. 51). The required supervisory information is derived from the sectional supervisory information at each remote control station. This information is assembled in TDM form and transmitted, by frequency modulation of a frequency allocated to each control station, over a channel of the auxiliary system. The overall system is fault initiated and operates in a similar manner to the sectional supervisory system.

7.3 TYPICAL BEARER SYSTEM (B). Figs. 56 to 58 show the arrangement of equipment at three stations of a typical radio broadband bearer system. The system provides a 1200 channel two-way telephony link and a one-way link for distribution of a television programme to regional television broadcasting stations along the route. A protection bearer in each direction is included and each is switched at baseband to replace the telephony and television bearers as required. Non-priority television programmes can be transmitted via the protection bearers. Under normal conditions the protection bearers are connected for telephony to the telephony test inputs and outputs, but they are through connected at demodulating stations along the route (Fig. 57), by operation of the correct non-priority television control key, to provide the non-priority television facility over the complete route.

At each station, a common aerial is used by both the transmitters and the receivers for all bearers on each path. The order of connecting equipment to the RF multiplexing equipment is varied to maintain approximately equal overall losses for each bearer.

Some stations include space diversity reception using an extra receive only aerial spaced vertically on the tower from the main aerial. Separate diversity receivers are provided and connected to the diversity aerial. They are switched in place of the main receivers at IF. The IF output is provided from the receiver with the greater RF input. A hysteresis of about 6 dB is included.

So that the bearers can be monitored for correct operation, pilot signals are included. A pilot frequency of 6.199 MHz, the standard for a 1200 channel system, is used on the telephony bearers and the standard 8.5 MHz pilot frequency is used for the television bearer. The protection bearers transmit a pilot frequency of 9.023 MHz (1800 channel system frequency) when idle or used for non-priority television. When they are carrying the traffic of a main link the idle pilot is replaced by the pilot accompanying the main traffic. The pilot signals are monitored by pilot and noise detectors at the receive end of each bearer. The noise is measured in a 6 kHz band 50 kHz above the pilot frequency instead of in the band on either side of the pilot frequency. No noise detector is associated with the 9.023 MHz pilot. When idle, the protection bearer is monitored using the 9.023 MHz pilot detector and the 6.249 MHz noise detector; when operating as a non-priority television bearer, it uses the 9.023 MHz pilot detector and the 8.55 MHz noise detector; when used to replace the telephony bearer, the 6.199 MHz pilot detector and the associated 6.249 MHz noise detector is used and when replacing the television bearer, the 8.5 MHz pilot detector and the associated 8.55 MHz noise detector is used. (For the protection bearer in the direction which has no regional television bearer, the 8.5 MHz pilot detector is provided to obtain the 8.55 MHz noise detector but the pilot detector is not used).

The logic system determines the switching requirements and controls the transmit end switching by using control tones transmitted via the auxiliary system. The baseband switching is accomplished with reed relays but achieves relatively high speed operation because of the use of wideband control channels.

Along this particular route the regional television broadcasting transmitters are located in the same building as the radio bearer equipment. Therefore no television spur bearers are required. At demodulating stations along the route (Fig. 57) the television baseband signal, including the video signal and the sound signal on a 7.5 MHz sub-carrier, is fed to a branching amplifier. One output of this amplifier is connected directly to the modulator of the bearer for the next section. The second output feeds the sound and vision separator which recovers the video and audio signals for the television broadcasting equipment. At non-demodulating repeaters where television signal dropping is required (Fig. 58), the IF signals from both the television and protection bearer receivers are split. One output, in each case, continues to the transmitter for the next hop of the system. The other output, in each case, is demodulated. Pilot and noise detectors and associated logic circuitry connected to each demodulator output determine the switching of the demodulators to the sound and vision separators.

The auxiliary system operates over a link provided by the sub-baseband of the main telephony link. At demodulating stations the sub-baseband traffic from the multiplexing equipment is combined separately with the inputs to the telephony and protection modulators. Switching of television traffic to the protection bearer is so arranged that it disconnects the sub-baseband traffic. In the receiving section of a demodulating station, the sub-baseband traffic is switched along with the main traffic since separation of the two follows the baseband switching. Demodulating stations along the route use separate multiplexing equipment for the sections in each direction. At non-demodulating repeaters (Fig. 58) second outputs from the telephony and protection bearer receivers are demodulated. Switching selects the outputs of the demodulators connected to the bearers being used for the main telephony traffic for each direction, by sensing the presence of a 6.199 MHz pilot signal.

The sub-baseband signals from each direction are combined to provide the sub-baseband output to the multiplexing equipment. The sub-baseband input from the multiplexing equipment at non-demodulating repeaters frequency modulates a common shift oscillator which is distributed to both the telephony and protection bearer transmitters in each direction. It is switched to connect it to the bearers occupied by the telephony traffic in place of fixed frequency shift oscillators.

Supervision of the conditions of the equipment at each station, and the status of the bearers at switching stations, including bearer switching, is, for the complete route, extended to the main control terminal (Fig. 56). Limited remote supervisory displays are provided at some other demodulating and switching stations (Fig. 57) but not at all of them. No manual remote control facilities are provided except those included as an integral part of the bearer switching. The supervisory equipment uses pulse width modulation to include the information in the time division multiplexed waveform produced by scanning of the supervised points. The TDM waveform at each station frequency modulates a voice frequency carrier which identifies that station and, therefore, provides a separate data channel for each station. Because of the number of stations on the route, two telephony channels of the auxiliary system are allocated to the supervisory system. At demodulating stations where a local supervisory display is required, a hybrid unit is included (Fig. 57). This provides for through connection of the channels between the two sets of multiplexing equipment and also for dropping and inserting of supervisory signals.

An omnibus order-wire connects all stations and an express order-wire connects all demodulating and switching stations. Order-wire signalling uses out-of-band tones. At demodulating stations, the order-wire terminating equipment provides for through connection and branching as well as the telephone circuit and signalling facilities.

7.4 TYPICAL BEARER SYSTEM (C). Block diagrams of a terminal and a non-demodulating repeater station of a radio broadband bearer system are included in Figs. 59 and 60. The system is engineered to provide a 600 channel two-way telephony link and a one-way television link to regional television broadcasting stations. A protection bearer is provided in each direction and these bearers are substituted for the main bearers, as required, if they should fail. Non-priority television facilities are provided by the protection bearers. The switching of a protection bearer in place of a main bearer is carried out at the intermediate frequency using diode electronic switches. Some non-demodulating repeaters are also switching stations using IF switching (not illustrated by Fig. 60). Because the bearer switching at the intermediate frequency does not protect against failure of modulator and demodulator equipment, this equipment is duplicated for main links and the duplicate equipment is switched to replace the main equipment when a failure is sensed. The IF output of modulators is switched using diode electronic switches and the baseband output of demodulators is switched using reed relays. At the receiving end of a television main bearer (not shown in Fig. 59) the equipment is similar to that provided for non-priority television except that the demodulator is duplicated and switched at baseband, before sound and vision separation, in a similar manner to that shown for the telephony bearer.

All main bearers are monitored using 8.5 MHz continuity pilot signals. When idle, or used for non-priority television, each protection bearer uses an 8.0 MHz continuity pilot signal for monitoring and identification. This is replaced by an 8.5 MHz main bearer pilot when a protection bearer is used for main traffic. Since the bearer switching is at the intermediate frequency, to allow monitoring on the input side of the receive end switching, pilot demodulators are required to recover the baseband signals from the outputs of the receivers. These signals are fed to the pilot and noise detectors.

The noise detectors measure the noise outputs of the pilot detectors and, therefore, effectively measure the noise in the frequency bands on either side of the pilot frequencies. The main bearer pilot end noise detectors operate at 8.5 MHz. For the protection bearers, both 8.5 MHz and 8.0 MHz pilot detectors are included. A noise detector is provided for information purposes only since, with the protection bearer occupied by main traffic, no further switching is possible even if the protection bearer becomes noisy.

The required bearer switching is determined by the logic and control equipment. It senses pilot and noise failures and takes into account bearer priorities. Switching control to the transmit end of the bearer switching section is extended via the auxiliary system. The control signal is in the form of a code of two out of five voice frequency tones. At IF switching stations, unnecessary switching of the next section is prevented by sending an inhibit control signal to the next switching station via the auxiliary system channel allocated to bearer switching control tones.

Monitoring of the operation of the main bearer modulators and demodulators is also carried out with the aid of the continuity pilot. In each modulator, as a by-product of the automatic frequency control system, a baseband output is derived. The baseband output of each main bearer modulator is fed to an 8.5 MHz pilot detector. Detection of a failure of a main modulator, by the loss of the pilot signal, causes changeover to the spare modulator. Similar pilot detectors at the output of the main bearer demodulators sense pilot failures at these points and initiate changeover to the spare demodulators. The operating levels of the separate pilot detectors for bearer, modulator and demodulator switching are graded so that the separate logic circuitry can interpret correctly the part of the system that has failed.

At each station, both the transmitters and the receivers for each path share a common aerial. The RF multiplexing order is arranged so that each bearer suffers a similar multiplexing loss. Some stations use space diversity reception which requires an additional diversity aerial and associated receiver RF multiplexing equipment. Diversity receivers independent of the main receivers are used and switching is carried out at the intermediate frequency output of the receivers. The output is taken from the receiver with the greater RF input, this receiver normally giving the better signal to noise ratio. The RF input to the idle receiver must exceed the RF input to the operating receiver by about 6 dB before switching is initiated.

The auxiliary system link is provided by the sub-baseband of the main telephony link. At demodulating stations, the sub-baseband input is combined with the main telephony input to both main and spare modulators to allow the circuit to be maintained should modulator change over occur. The intermediate frequency switching of the bearers at each end of a switching section automatically transfers the sub-baseband traffic to the protection bearer along with the main telephony traffic in case of main bearer failure. Following the demodulators, the sub-baseband is switched independently from the main telephony traffic, but the same logic circuitry controls both sets of switches. Sub-baseband demodulation and modulation facilities are required at non-demodulating repeater stations. These facilities are transferred from the main telephony bearer to the protection bearer in case of main bearer failure. The switching is initiated from the receiving end of the switching section using a control tone over the bearer switching channel of the auxiliary system. To obtain the sub-baseband output, the main and protection bearers are branched and switched at the IF output of the receiver and fed to a demodulator. The sub-baseband signals from the demodulators in each direction are combined before being fed to the sub-baseband output and the common multiplexing equipment. The sub-baseband input from the multiplexing equipment feeds the transmitters in each direction. Switching selects the modulator input to either the main or the protection transmitters. The sub-baseband traffic is injected by phase modulation of the transmitter local oscillator. Pre-correction at the modulator input provides compensation to obtain a frequency modulated output from the phase modulator.

The auxiliary system incorporates two largely independent multiplexing systems. One is used for the service channels providing bearer switching control, omnibus order-wire, supervisory and manual remote control facilities. The other provides facilities for wayside telephone channels, but, where necessary, is also used for additional order-wires; for example, an express and a television order-wire. The equipment for the wayside channels is provided as necessary, to serve the local and trunk telephone circuit needs of towns between demodulating repeaters.

The supervisory system extends the information on faults at each station and the bearer status from switching stations to the stations at each end of the switching section. In addition, the full supervisory information is extended to the main control station from all stations for which the main station is responsible. Control facilities are provided from the stations at each end of a switching section and also limited control facilities from the main control stations. To provide the extension of the order-wire, supervisory and control facilities to main control stations, the necessary auxiliary system channels are through connected at demodulating stations along the route (not shown in Fig. 59). Hybrid units are included to provide dropping and inserting facilities.

The supervisory system at each station uses continuous scanning to encode the information from the monitoring points into time division multiplexed form. The TDM information frequency modulates a voice frequency carrier allocated to each monitored station and provides each station with a separate supervisory data channel. Because of the number of stations monitored, two telephony channels are required to accomodate the required number of supervisory channels. One channel is allocated to near stations where supervisory information is transmitted in each direction and the second channel to distant station sending supervisory information to the main control station. The supervisory information is coded and modulates the supervisory channel frequency to produce the type of waveform illustrated in Fig. 42b. With the carrier frequency identified as f_o, no fault in a particular time slot is indicated by a frequency shift to f_o + 30 Hz and a fault by a frequency shift to f_o - 30 Hz. Between time slots and during synchronising periods the frequency transmitted is f_o.

The manual remote control system uses similar equipment to that of the supervisory system. The main difference is that the carrier, frequency modulated by the coded TDM signal indicating the control function, is sent only while the control key is operated. As for the supervisory system, near stations are allocated a telephony channel in each direction to allow control from stations at each end of the switching section. Control from the main control station to distant stations is carried by the return channel of the circuit which is used for distant station supervisory signals.

7.5 TYPICAL BEARER SYSTEM (D).

Figs. 61 and 62 show block diagrams of the terminal and a non-demodulating repeater of a typical radio broadband system bearer. The system provides a two-way link for 1,800 telephony channels and a one-way link for television programme distribution to regional television broadcasting stations. The television link provides for direct transmission of the video signal and transmission of the audio signal on a 7.5 MHz sub-carrier. A protection bearer is provided in each direction, with switching for main bearer replacement being carried out at baseband. Facilities are included for non-priority television transmission via the protection bearers. The modulators and demodulators for all bearers have pre-emphasis and de-emphasis characteristics, and are adjusted, for telephony operation. Equalisers with the input and output equipment of television links compensate for the differences between telephony and television links.

The broadband bearers of this system operate in the upper 6 GHz band. At each station, the transmitters and receivers for all broadband bearers between adjacent stations share a common aerial. A bipolar aerial is used although this is not an essential requirement of RF channels in the upper 6 GHz band. Horizontal polarisation is used for transmission and vertical polarisation for reception or vice versa.

Circular waveguide is used for the vertical waveguide run on the mast to allow propagation of the combined transmit and receive signals. The two directions of transmission are separated by a polarisation filter mounted at the bottom of the mast. The polarisation filter forms part of the RF multiplexing equipment. It is connected to the remainder of the RF multiplexing equipment by eliptical waveguides. The order of connection of the channels in the RF multiplexing equipment is reversed in adjacent stations to equalise the losses of the bearers on the route (compare Figs. 61 and 62). Fig. 62 also shows that the RF channels are allocated according to a two frequency plan.

The baseband switching in this system uses coaxial reed relays. In the transmitting equipment, a branching amplifier provides the signal to feed the protection bearer. In the receiving equipment, the switching is preset with one set of relays, but the actual transfer of the traffic is carried out by a make before break switching system. During the transfer time of approximately 1 ms, both the main and protection bearers operate in parallel. Therefore, there is no interruption to the traffic for a prepared changeover such as one initiated by a noise failure or by manual control. The switching is arranged so that levels remain constant and impedances matched during the traffic transfer. However, it is essential that the propagation times via both the main and protection bearers are the same. The bearers are equalised so that the phase difference at the highest baseband frequency is less than 30°.

For monitoring of the performance of each bearer, a 9.023 MHz (1,800 channel) pilot is injected in the input equipment. The protection bearer is identified by amplitude modulating its pilot with a 13.5 kHz marker signal. The pilot for each bearer is monitored at the output of each demodulator. The pilot detector provides a pilot fail indication for a predetermined reduction in the pilot level. An output in the audio frequency band corresponding to the amplitude modulation of the pilot is also produced. The 5 to 11 kHz band is selected and the amplitude of this signal used as a measure of the bearer noise performance. On protection bearers, the 13.5 kHz component is also selected and detected. The presence of a 13.5 kHz marker signal indicates that the protection bearer is idle.

Bearer switching requirements are determined at the receiving end of the system based on the information from the pilot, noise and marker detectors. Switching control signals are transmitted continuously to the transmitting end switching logic and control circuitry. The required switching information is transmitted as a 60 Hz shift of the corresponding control tone. The control tones are conveyed by the sub-baseband of the telephony link. The sub-baseband is not used for any other purpose and so it is not necessary for it to be made available at non-demodulating repeaters. At demodulating stations, the sub-baseband is transferred between main and protection bearers along with the main telephony traffic.

Order-wire and supervisory information is transmitted using auxiliary radio bearers. However, in the upper 6 GHz band, no provision is made for auxiliary radio bearers. Therefore, the auxiliary radio bearers operate in a different band with aerials separate from those of the main bearers. The 450 MHz band has been selected. The auxiliary bearers are demodulated at each station. Branching equipment provides through connection as well as the required connection to the local multiplexing equipment. Common multiplexing equipment is used for the routes in each direction.

Supervisory information from each station and bearer status information from switching stations is extended to the control station using a continuous scanning supervisory system. Information is included in the TDM waveform by changing the duration of the corresponding pulse. The TDM waveform is transmitted as frequency modulation of a voice frequency carrier. A different carrier frequency, providing a separate data channel, is allocated to each station. All stations share a common telephony channel. No manual remote control facilities are provided.

8. TEST QUESTIONS.

1. *What voice frequency band is transmitted by a carrier system?*

2. *In a FDM carrier system, how many channels are combined to form -*

   (i) A group,

   (ii) A supergroup,

   (iii) A mastergroup,

   (iv) A supermastergroup?

3. *What are the frequency spacings of the carriers for adjacent channels of a basic group?*

4. *State the limits of the frequency bands occupied by carrier systems with channel capacities of -*

   (i) 600, (ii) 960, (iii) 1,200, (iv) 1,800.

5. *The Australian television system is a ..(i).. line system with a picture frequency of ..(ii).. Hz. Therefore, the vertical scanning frequency is ...(iii)... Hz and the horizontal frequency ...(iv)... Hz.*

6. *What are the limits of the video bandwidth required for the transmission of television signals?*

7. *In a colour television system, the picture is reproduced by using combinations of three primary colours, ..(i).. , ...(ii)... and ..(iii).. . So that the colour television system is compatible with the monochrome television system, the signals for the three primary colours are combined in the correct proportions to produce the ..(iv).. signal. The colour information is transmitted on a sub-carrier of approximately ..(v).. MHz. The sub-carrier amplitude is dependent on the ..(vi).. of the colour and the sub-carrier phase is dependent on the ..(vii).. of the colour. In the PAL colour television system the sub-carrier ..(viii).. is changed in alternate lines to reduce the effect of poor transmission performance on the ..(ix).. of the reproduced picture. The bandwidth required for transmission of a colour video signal is -*

   {less than / equal to / greater than} - that required for a monochrome video signal.

8. *What form of modulation is used by radio broadband bearers?*

9. *What is the typical spacing of the repeaters for a line of sight radio broadband bearer?*

10. *(i) Draw a basic block diagram of the transmitting equipment for the terminal of a radio broadband bearer in which modulation is produced at an intermediate frequency.*

    (ii) Explain briefly the operation of the transmitting equipment in (i).

8. TEST QUESTIONS (CONTD.)

11. *With the aid of a basic block diagram explain briefly the operation of the receiving equipment of a radio broadband bearer terminal.*

12. *Explain briefly what is meant by -*

    (i) Demodulating repeater,

    (ii) Non-demodulating repeater,

    (iii) Baseband repeater,

    (iv) IF repeater,

    (v) RF repeater.

13. *Draw a block diagram of a shift converter type non-demodulating repeater.*

14. *List the generally used designations for the radio frequency bands used by radio broadband bearers.*

15. *In the 4 GHz band what is the frequency spacing between -*

    (i) RF channels 4 and 4' of the normal channel arrangements;

    (ii) RF channels of adjacent bearers in the same direction in the one hop;

    (iii) Incoming and outgoing RF channels of the main bearers for each direction of a two-way link at one repeater, when a four frequency plan is used?

16. *Describe how equipment can be arranged to allow the transmitters and receivers of several radio broadband bearers to share a common aerial.*

17. *What form of bearer is normally used for the connection between the carrier equipment and a separately located radio broadband bearer station?*

18. *Explain briefly two methods which can be used at a demodulating repeater station to provide for both through and local main telephony traffic.*

19. *Describe four methods which can be used to reduce the effect of interference on a co-axial cable television bearer operating at normal video frequencies.*

20. *How is the audio channel normally provided by a radio broadband bearer which is used for television programme distribution?*

21. *Under what circumstances would baseband branching of a television programme be used in a television distribution system?*

22. *Draw a block diagram to show how a television bearer may be branched at the intermediate frequency to feed a spur bearer and also to provide video and audio signals to local broadcasting equipment.*

23. *Define -*

    (i) Reliability,

    (ii) Availability.

8. TEST QUESTIONS (CONTD.)

24. What is the likely difference in the characteristics of a bearer interruption caused by fading and one caused by equipment failure at an unstaffed station?

25. What is meant by -

(i) Space diversity operation,

(ii) Frequency diversity operation?

26. A space diversity system operates with two separate receivers switched at the intermediate frequency. How is the need for switching normally sensed and under what conditions is switching initiated?

27. List four advantages of providing protection bearers instead of other forms of redundancy.

28. For service reporting, bearers are allocated numbers. For bearers carrying traffic from the southern terminal of a route to the northern terminal, ...(i) numbers are used. A separate number is given to each bearer between adjacent -

(ii) { terminal stations. / demodulating stations. / switching stations. / control stations. }

29. Bearer switching can be carried out at either baseband or intermediate frequency points. Baseband switching normally uses .....(i) switches and IF switching normally uses ....(ii) switches. In case of a failure due to increased noise, the traffic time lost is dependent on the ....(iii) time. For a catastrophic failure, the traffic time lost is dependent on the .....(iv) time. Using electromechanical relays, the minimum traffic interruptions is typically ....(v) to ....(vi) seconds. By comparison, the minimum interruption using electronic switches is typically ......(vii) to ......(viii) seconds.

30. (i) What is a "twin path" radio broadband bearer system?

(ii) Draw a basic block diagram of a "twin path" radio broadband bearer system using IF branching and IF switching. Show equipment for one direction of transmission at transmitting and receiving terminal stations and at a switching non-demodulating repeater.

31. (i) State two advantages of using baseband combiners in a twin path telephony bearer system.

(ii) What is a disadvantage of linear baseband combiners?

(iii) How can the disadvantage of linear baseband combiners be overcome?

32. When a number of bearers share a common protection bearer, switching is included at both ends of the system. However, when the traffic is connected to the protection bearer, it is not disconnected from the main bearer. Why is this done?

8. TEST QUESTIONS (CONTD.)

33. *Draw a block diagram to show how a protection bearer can be used for the transmission of non-priority television programmes.*

34. (i) *What is the purpose of a continuity pilot on a radio broadband bearer?*

(ii) *What parameters are used to determine the need for bearer switching?*

(iii) *What happens to the conditions of the bearer switching if the bearer switching control channel fails?*

35. *Draw a basic block diagram of two baseband switching terminals of a radio broadband bearer system for one direction of transmission. The system includes two main bearers and a protection bearer. Show pilot injection, pilot and noise receivers, the switching functions provided, and the control equipment necessary for bearer switching.*

36. *With the aid of a block diagram (Fig. 40), describe the sequence of events which occur when -*

(i) *The protection bearer is idle and operating satisfactorily, and a main bearer fails.*

(ii) *The protection bearer is carrying traffic and a failure of a priority main bearer is sensed.*

37. *List in detail, the factors which determine the time that traffic is interrupted because of a catastrophic failure of a priority bearer when the protection bearer, at the time of the failure, is occupied by other traffic.*

38. *What manual control facilities are normally provided as part of a bearer switching system?*

39. *What information is given by a typical detailed remote supervisory display?*

40. *Draw a basic block diagram of the transmitting and receiving equipment for a remote supervisory system, and explain briefly its operation.*

41. (i) *What methods of multiplexing are normally used for combining the remote supervisory information -*

(a) *At a particular station,*

(b) *From adjacent repeaters in the same switching section?*

(ii) *What method of modulation is normally used for the remote supervisory information from a supervision station?*

(iii) *With an illustration, show one form of signal that is fed to the auxiliary system from a remote supervisory sytem.*

42. *State the order-wire facilities usually provided for a radio broadband bearer system.*

43. (i) *What channels are normally provided by the auxiliary system of a radio broadband bearer system?*

(ii) *How can the link for the auxiliary system be provided?*

8 TEST QUESTIONS (CONTD.)

44. *Using a block diagram, show how the service channels at a main bearer non-demodulating station are interconnected with the auxiliary radio bearers in each direction.*

45. *Draw a basic block diagram to illustrate how the equipment at broadband bearer demodulating stations is arranged in order to provide a sub-baseband auxiliary link.*

46. *With the aid of a block diagram (Fig. 47), describe the operation of the equipment providing the service channel facilities at a non-demodulating repeater station when the auxiliary link is provided by the sub-baseband of the telephony link.*

47. *Use a block diagram to show a method by which the sub-baseband traffic can be dropped from and inserted into the bearer at a non-demodulating repeater.*

48. *From the block diagrams included in Fig. 51 to 62 or any system block diagrams of installed equipment in your area, describe the facilities and operation of a typical radio broadband bearer system.*

49. *A broadband bearer route provides two telephony bearers and a protection bearer in each direction, and a television bearer in one direction for regional television programmes. The bearers are numbered as in Table 9.*

BEARER NUMBER	NORMAL TRAFFIC	
101	Protection	A to B
102	Protection	B to A
103	Telephony 1 (TP1)	A to B
104	Telephony 1 (TP1)	B to A
105	Telephony 2 (TP2)	A to B
106	Telephony 2 (TP2)	B to A
109	Television (TV)	A to B
201	Auxiliary	A to B
202	Auxiliary	B to A

TABLE 9. BEARER NUMBERING.

8. TEST QUESTIONS (CONTD.)

Complete Table 10 to indicate the automatic switching that occurs and the traffic that occupies the protection bearer for each event shown. Include also the approximate traffic time lost due to bearer out-of-service or switching. Assume electromechanical switching at baseband with an interruption during the transfer time. Also, assume that priority is allocated to bearers in each direction in bearer number order, so that telephony bearers have priority over television, and a pilot failure in any bearer has priority over a noise failure.

TIME	BEARER	EVENT	BEARER SWITCHING	TRAFFIC ON PROTECTION		TRAFFIC TIME LOST				
						TP1		TP2		TV
				A TO B	B TO A	A TO B	B TO A	A TO B	B TO A	A TO B
0800	All	Normal	–	Nil	Nil					
0810	106	Pilot Fail	TP 2 B to A to 102	Nil	TP2				20 ms	
0820	109	Pilot Fail	TV A to B to 101	TV	TP2					20 ms
0830	103	Noise Fail								
0832	103	Normal								
0840	105	Pilot Fail								
0845	109	Normal								
0850	104	Pilot Fail								
0900	103	Pilot Fail								
0903	103	Normal								
0910	106	Normal								
0920	105	Normal								
0925	104	Normal								
0930	103	Noise Fail								
0935	202	Fail								
0936	103	Normal								
0940	109	Pilot Fail								
0945	202	Normal								
0950	109	Normal								

TABLE 10. A BAD MORNING?

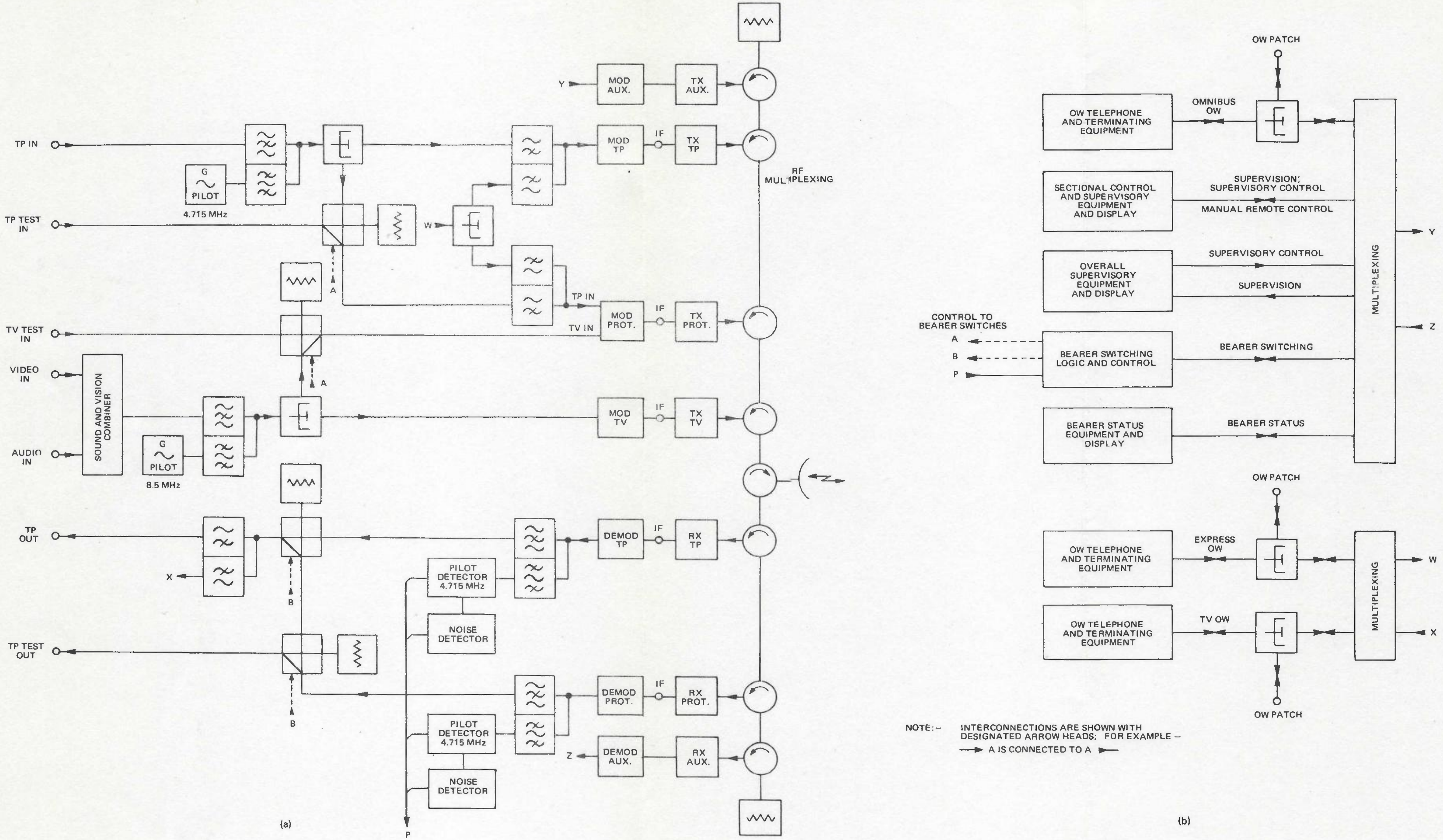
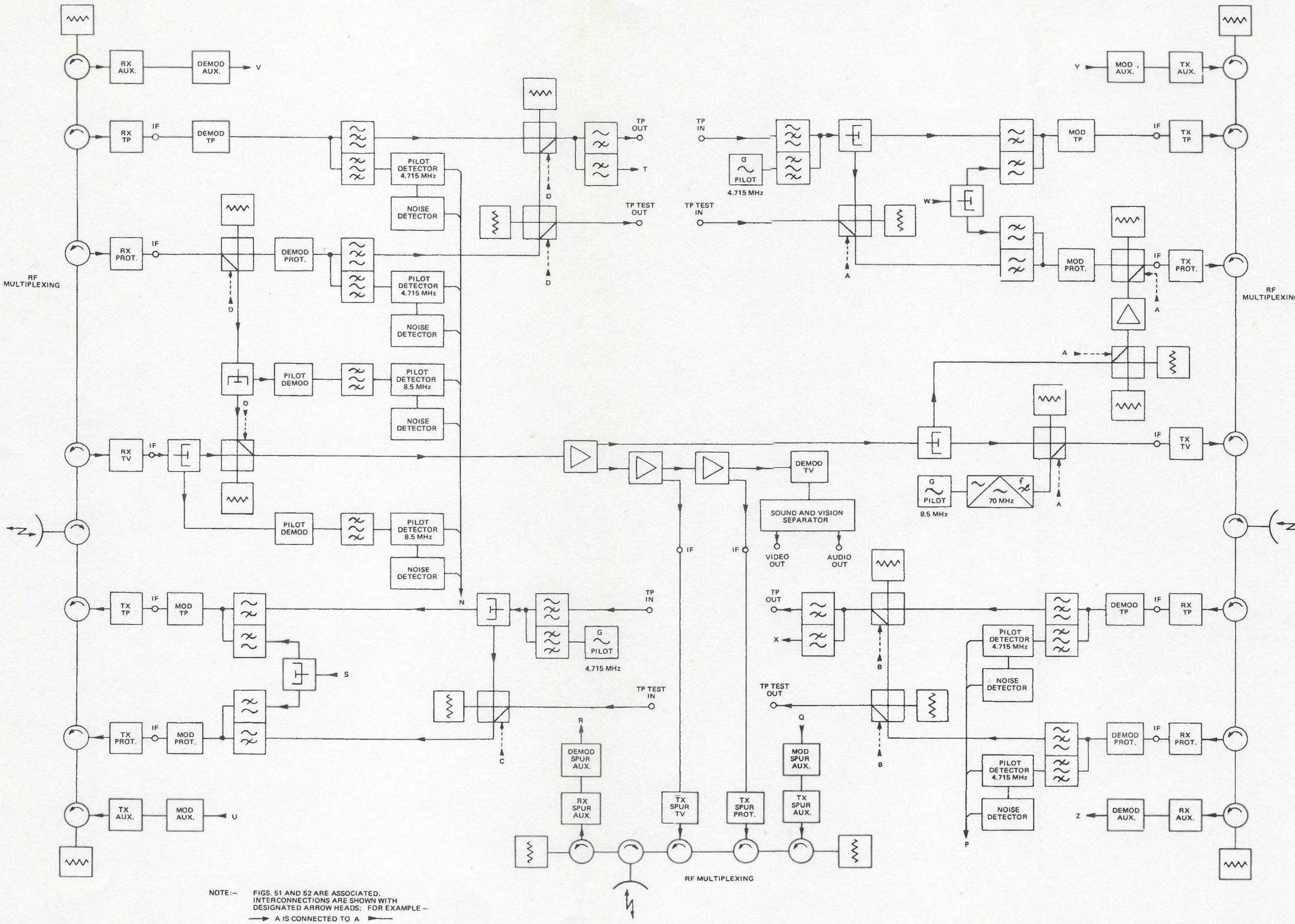


FIG. 51 TYPICAL BEARER SYSTEM (A)
(TERMINAL X)



NOTE:– FIGS. 51 AND 52 ARE ASSOCIATED. INTERCONNECTIONS ARE SHOWN WITH DESIGNATED ARROW HEADS; FOR EXAMPLE – → A IS CONNECTED TO A ←

FIG. 52. TYPICAL BEARER SYSTEM (A) (BACK-TO-BACK TERMINALS WITH TELEVISION BRANCHING - TRANSMISSION EQUIPMENT).

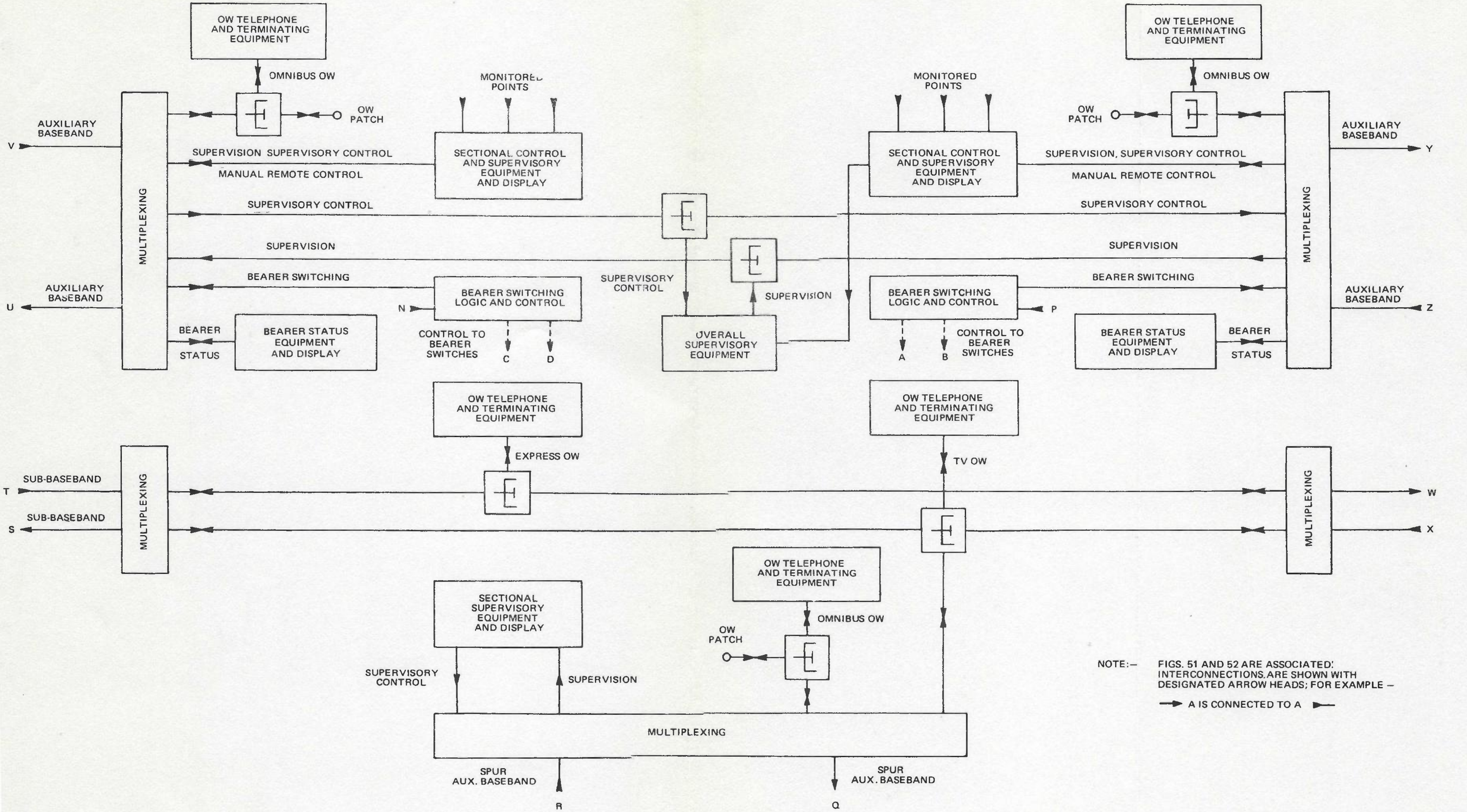
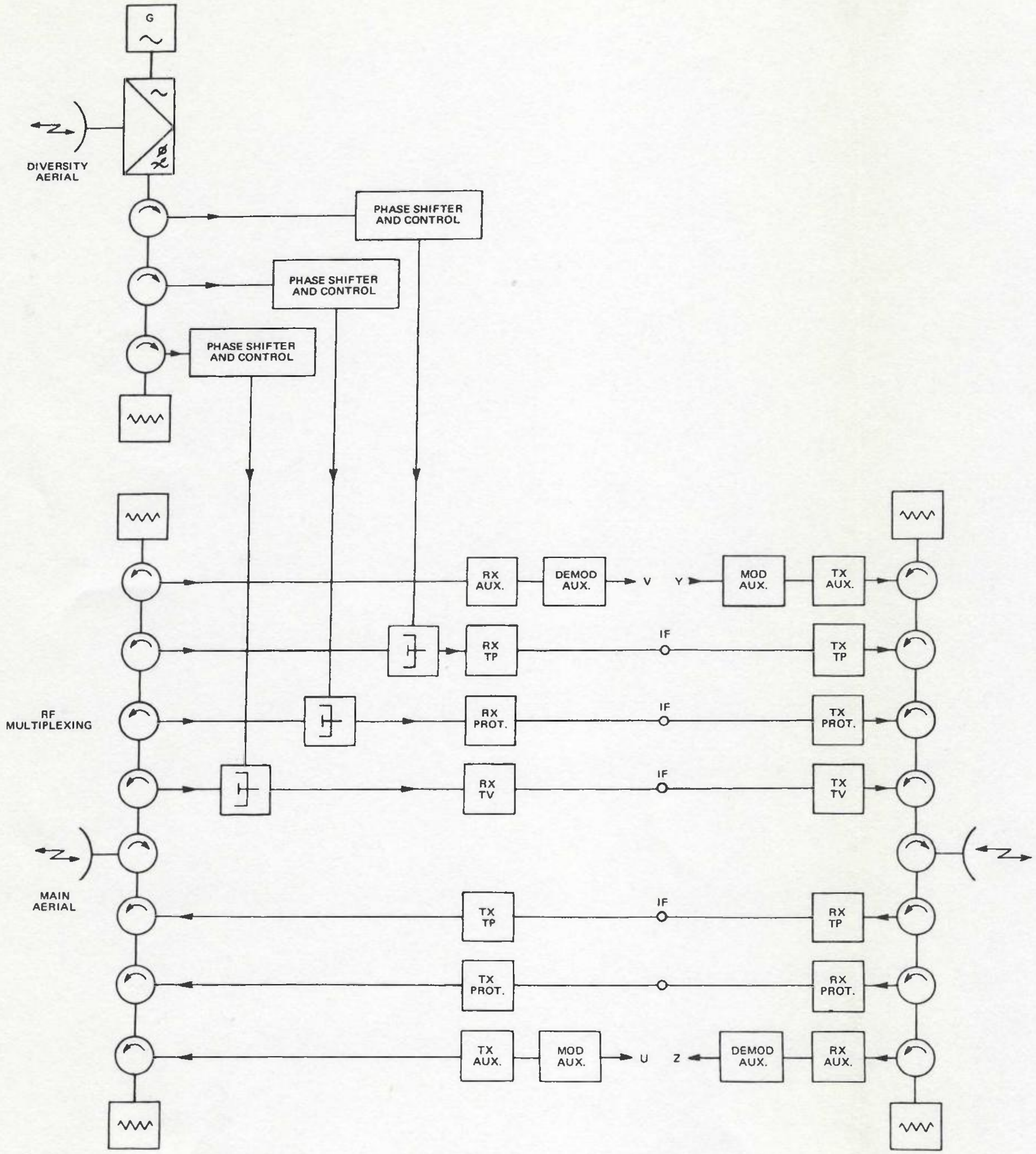
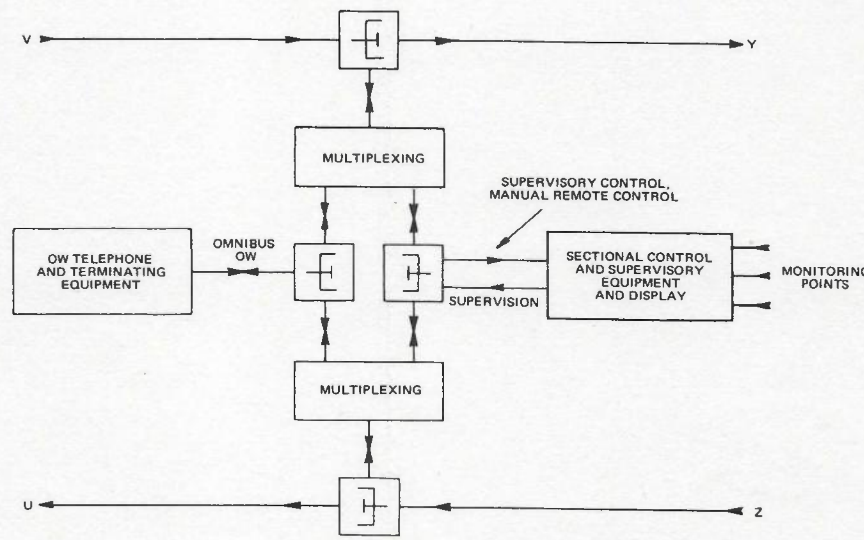


FIG. 53. TYPICAL BEARER SYSTEM (A) (BACK-TO-BACK TERMINAL WITH TELEVISION BRANCHING - SUPERVISORY AND AUXILIARY EQUIPMENT).



(a)



NOTE:– INTERCONNECTIONS ARE SHOWN WITH DESIGNATED ARROW HEADS; FOR EXAMPLE – A IS CONNECTED TO A

(b)

FIG. 54. TYPICAL BEARER SYSTEM (A)
(NON-DEMODULATING REPEATER WITH DIVERSITY RECEPTION).

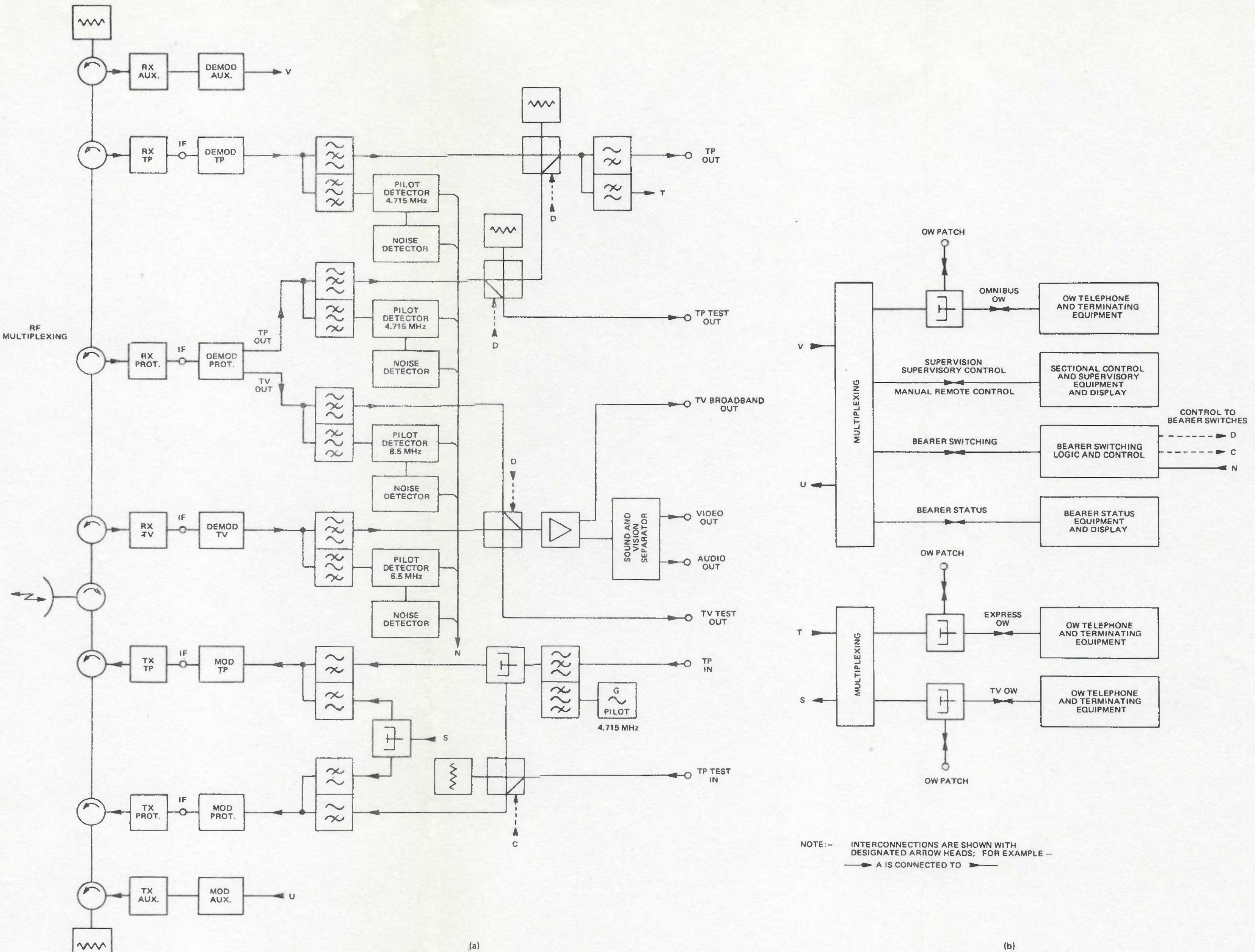


FIG. 55. TYPICAL BEARER SYSTEM (A)
(TERMINAL Y).

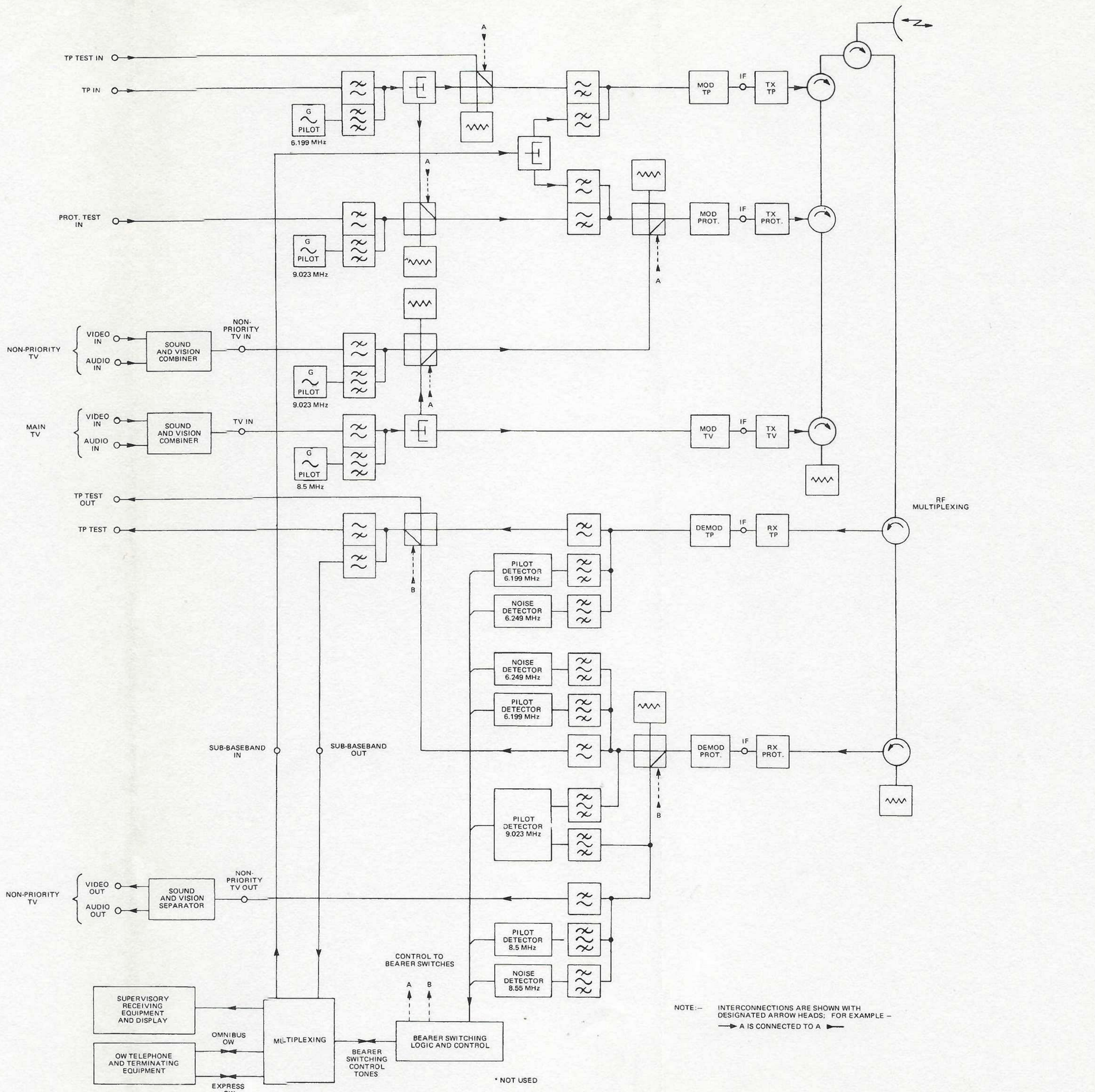


FIG. 56. TYPICAL BEARER SYSTEM (B) (TERMINAL).

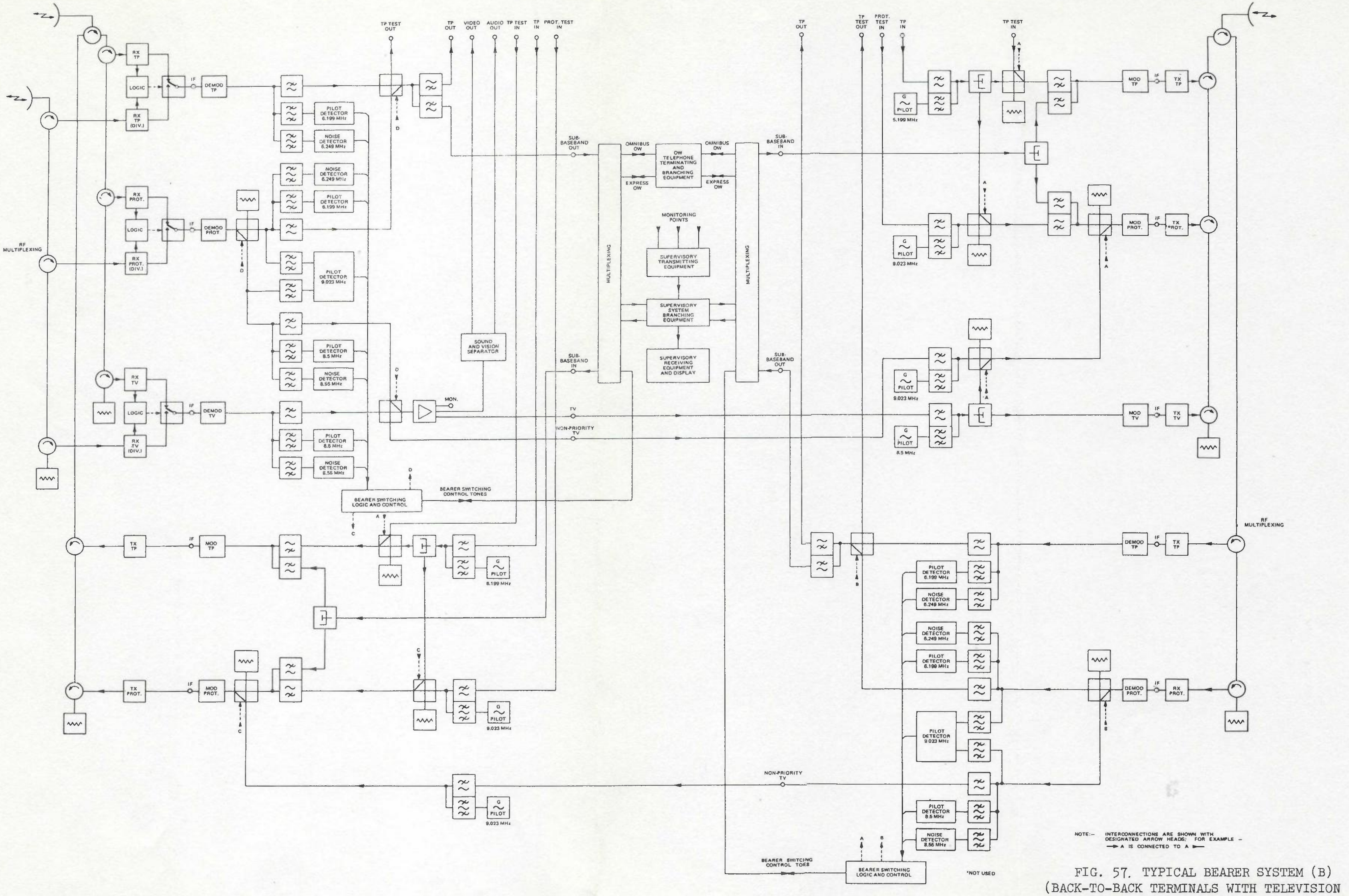


FIG. 57. TYPICAL BEARER SYSTEM (B)
(BACK-TO-BACK TERMINALS WITH TELEVISION BRANCHING AND DIVERSITY RECEPTION).

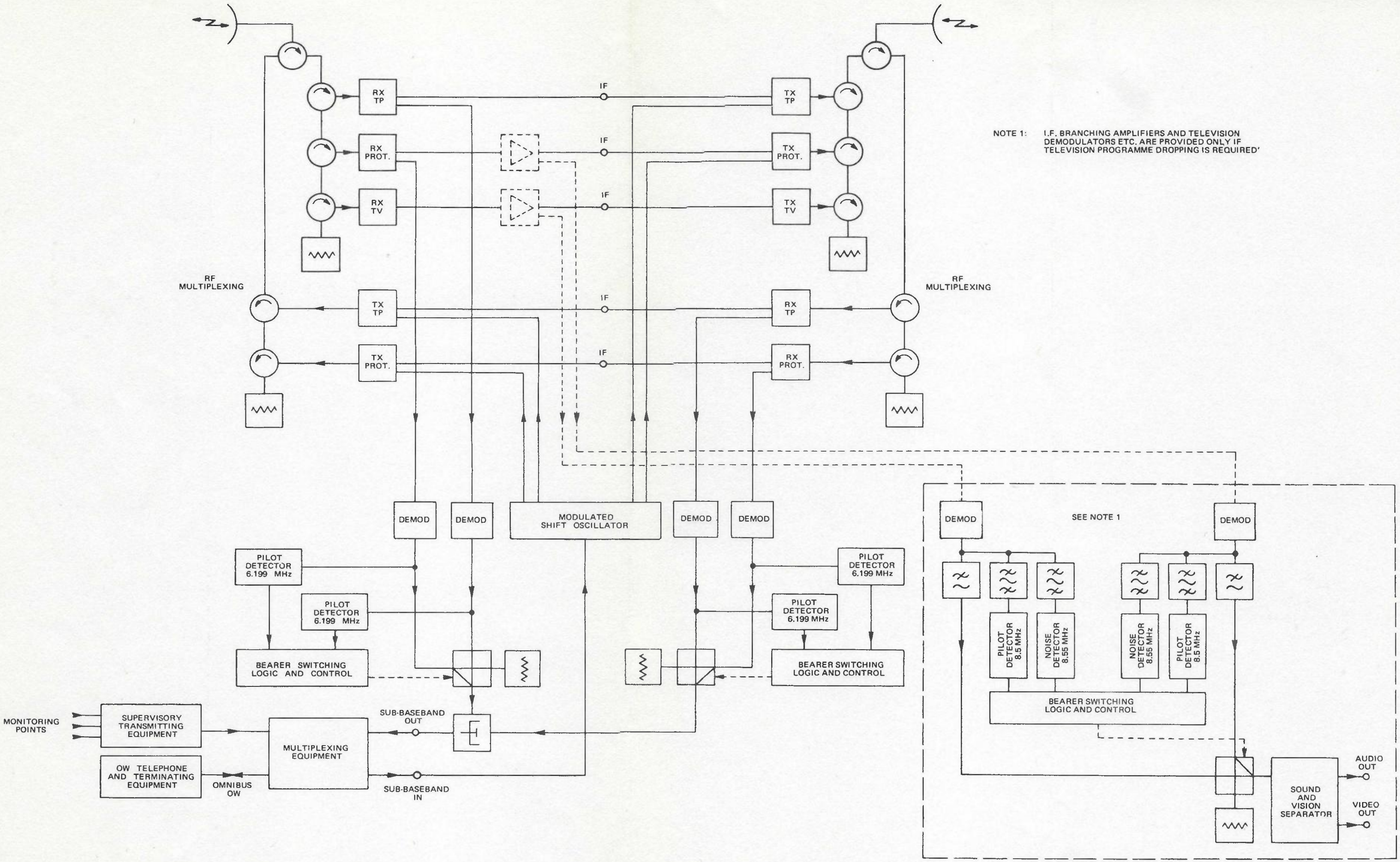


FIG. 58. TYPICAL BEARER SYSTEM (B)
(NON-DEMODULATING REPEATER
WITH TELEVISION BRANCHING).

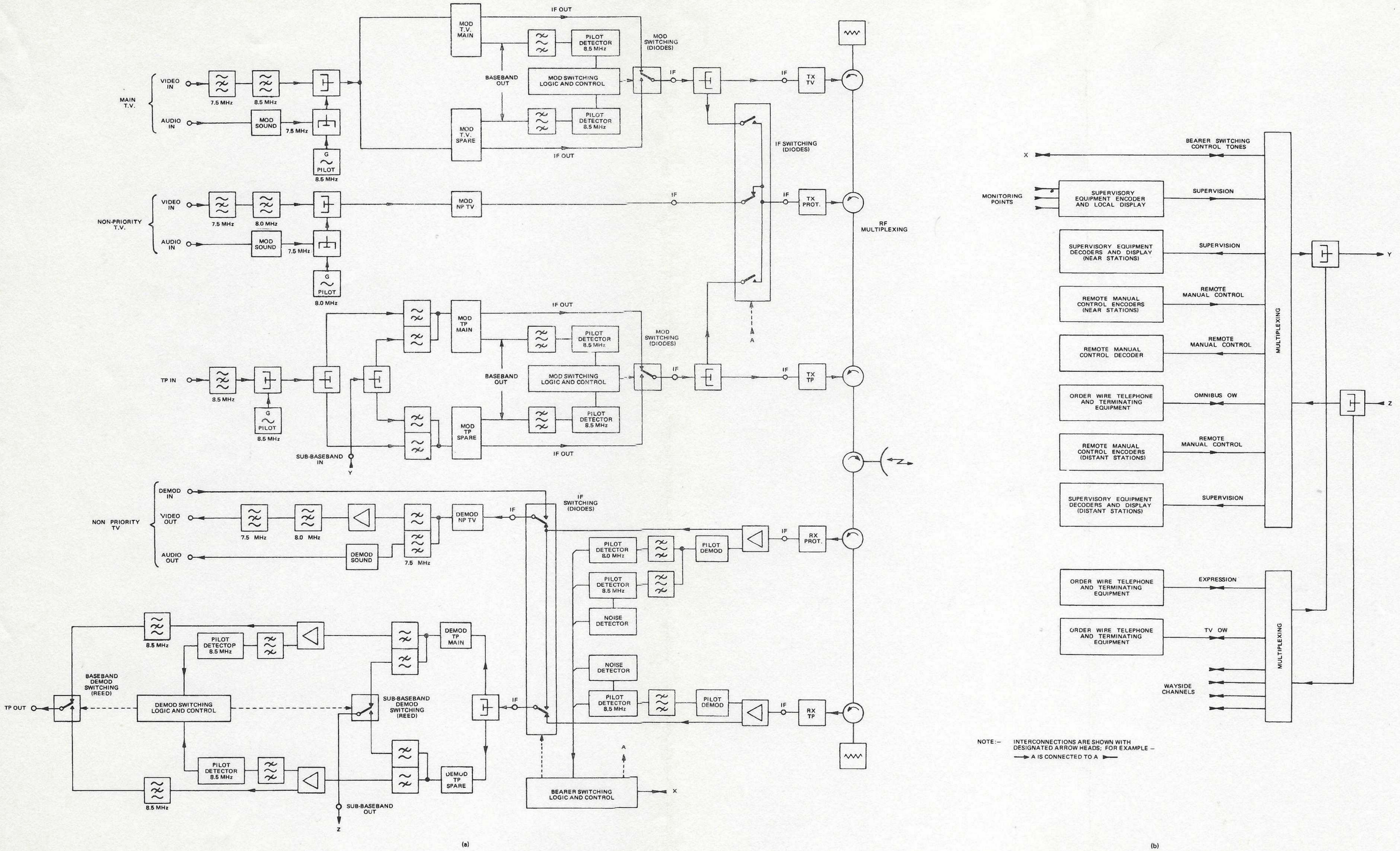
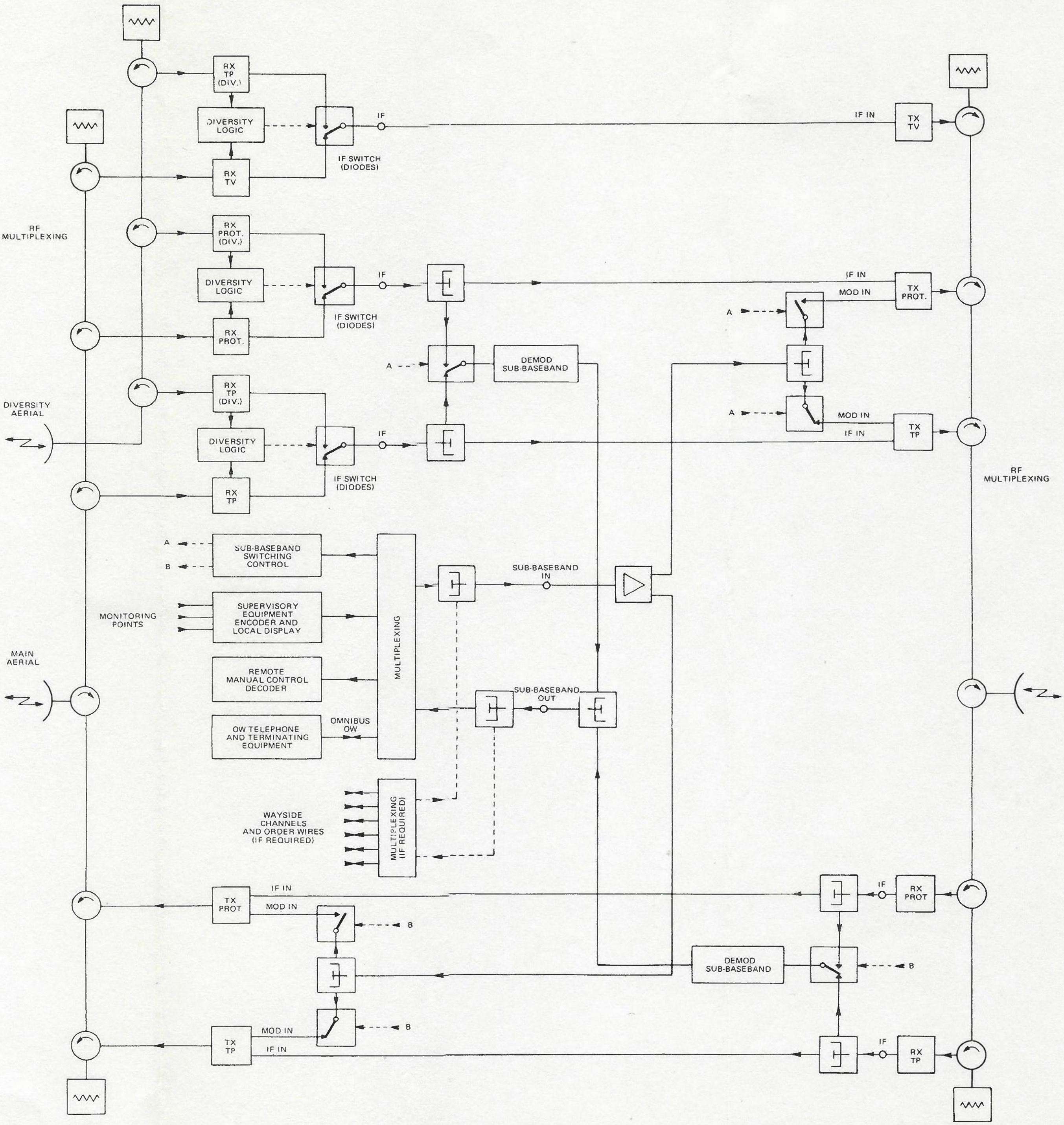


FIG. 59. TYPICAL BEARER SYSTEM (C) (TERMINAL).



NOTE:– INTERCONNECTIONS ARE SHOWN WITH DESIGNATED ARROW HEADS; FOR EXAMPLE – → A IS CONNECTED TO A →

FIG. 60. TYPICAL BEARER SYSTEM (C) (NON-DEMODULATING REPEATER WITH DIVERSITY RECEPTION).

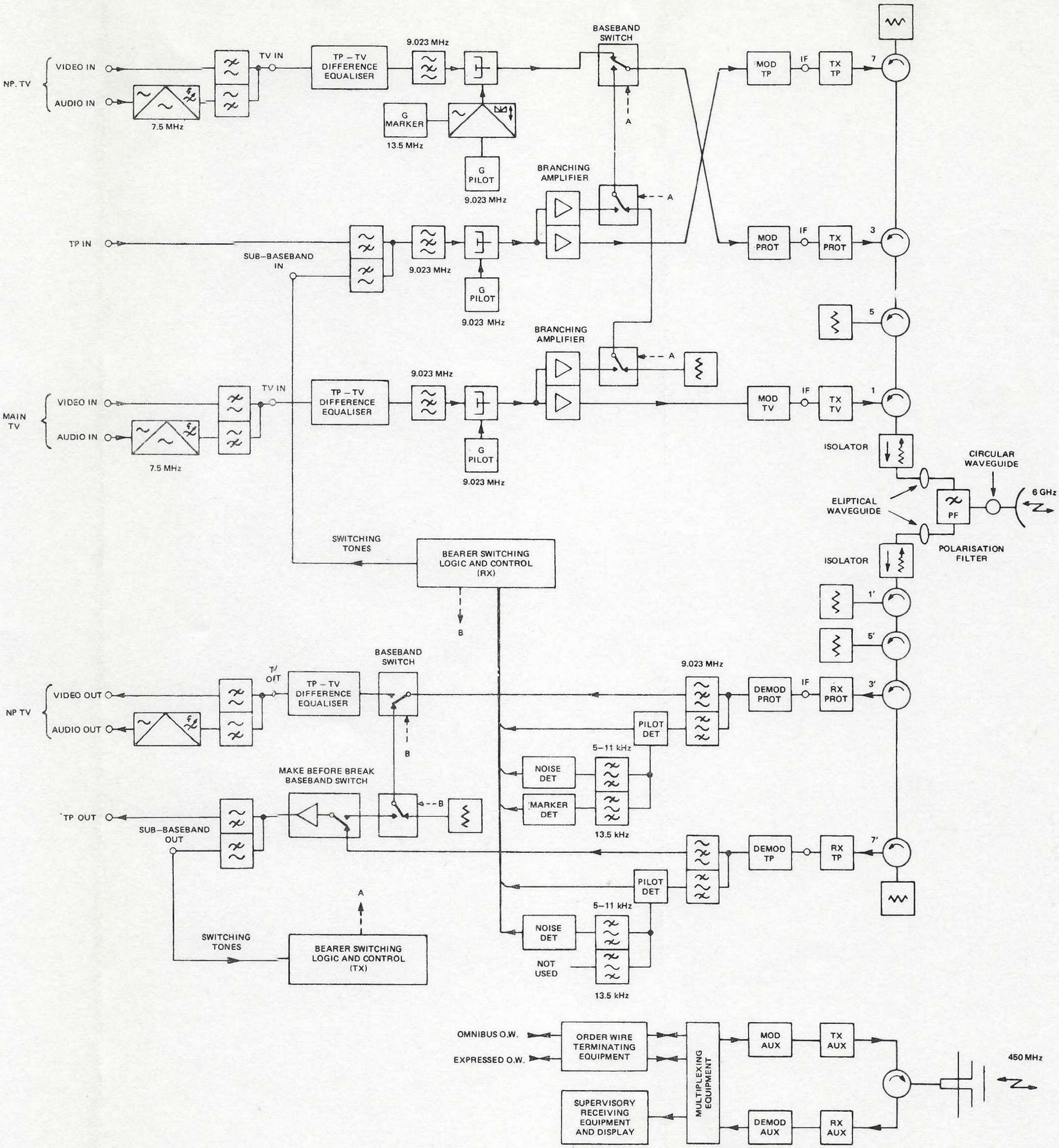


FIG. 61. TYPICAL BEARER SYSTEM (D) (TERMINAL).

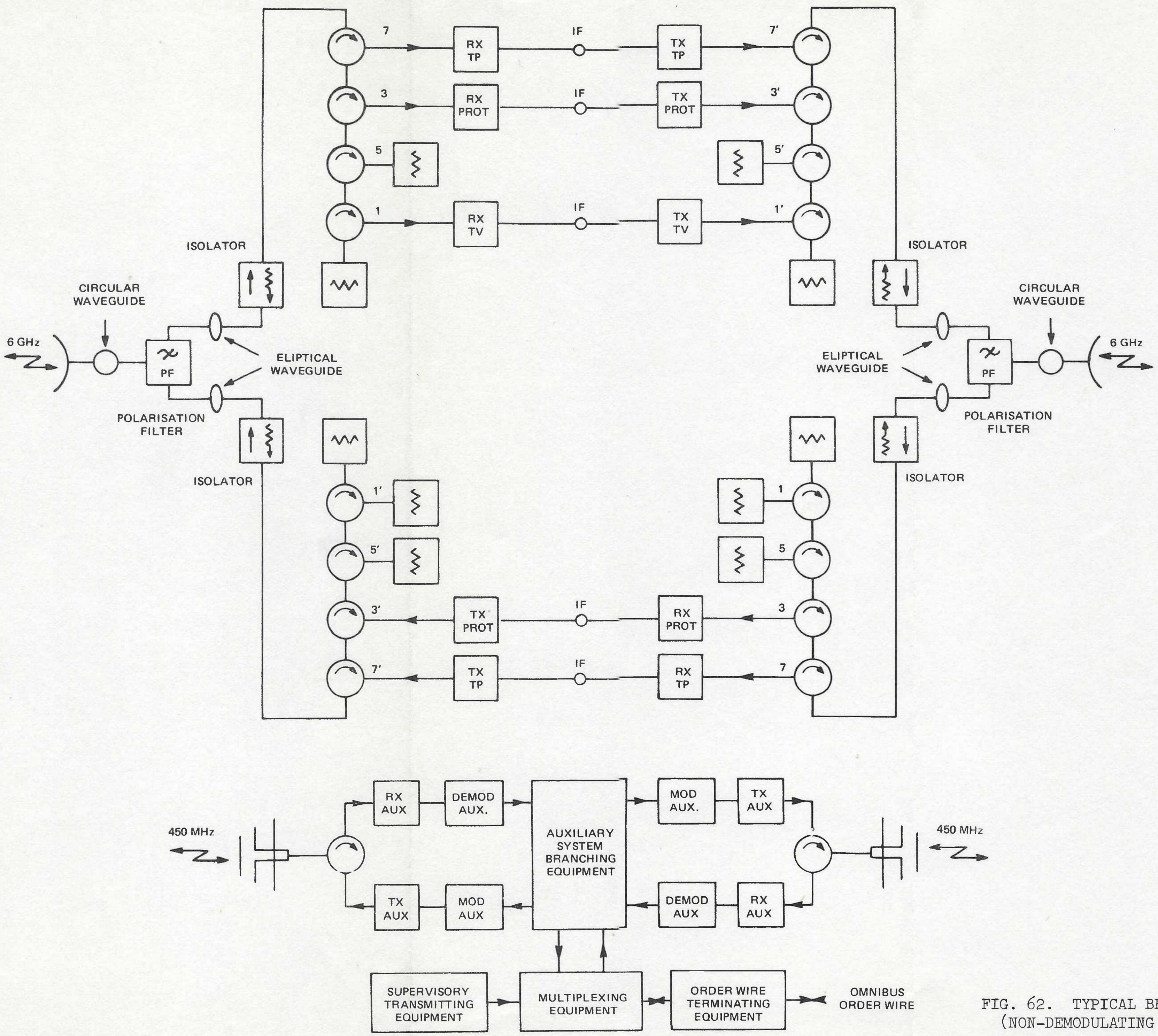


FIG. 62. TYPICAL BEARER SYSTEM (D)
(NON-DEMODULATING REPEATER).

END OF PAPER