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TECHNICAL TRAINING PUBLICATION

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EQUIPMENT COMPONENTS (2) - LINE TRANSMISSION

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1. INTRODUCTION.

1.1 Carrier equipment is composed of a number of different types of equipment components. In the general, these components are included in the carrier equipment to perform one or more of the following functions:-

- Translate signals from different sources into different frequency bands, so that they can be simultaneously transmitted over the same bearer.
- Separate signals of different frequency bands and direct them to the correct equipment.
- Ensure that signals are received with satisfactory intelligibility and quality.

Modulators and demodulators translate the signals into the required frequency bands, filters, and hybrid coils are used to separate signals, and components such as equalisers, amplifiers and voltage limiters, are included to ensure satisfactory quality and intelligibility of the received signals.

1.2 Modulators, hybrid coils, pads, attenuators and filters have been described in the course papers, "Amplitude Modulation - Line Transmission" and "Equipment Components (1) - Line Transmission". This paper describes the basic principles of some of the equipment components, such as equalisers, compandors, pre-emphasis and de-emphasis, and voltage limiters, which are used in carrier equipment to ensure satisfactory performance standards.

2. VOLTAGE LIMITERS.

2.1 A voltage limiter is connected across the input of each channel modulator in a carrier telephone system to prevent high signal voltage peaks from being applied to the modulators. The voltage limiter allows signals within the prescribed voltage limits to pass with little attenuation, but attenuates excessive signal peaks. Fig. 1 shows a signal containing excessive voltage peaks being applied to a voltage limiter. The output signal has the high peak values attenuated, but the remainder of the signal is unchanged.

The reasons for limiting the voltage of signals applied to channel modulators are:-

- For the satisfactory operation of a modulator the applied signal voltage must be considerably lower than the carrier voltage.
- Excessive signal levels from the modulator outputs could overload common equipment, such as line amplifiers, and produce non-linear distortion.

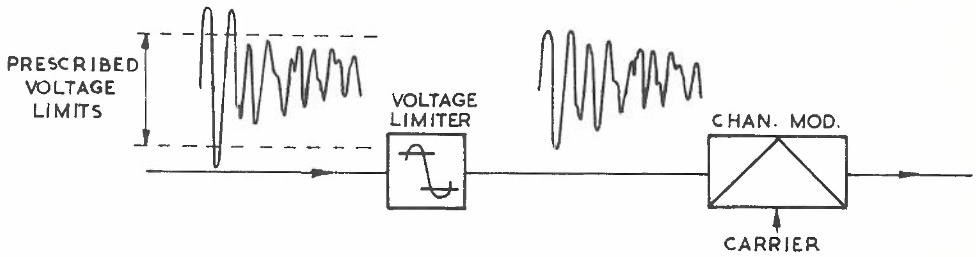


FIG. 1. VOLTAGE LIMITER.

2.2 The circuit of one type of voltage limiter is shown in Fig. 2. The neon lamp produces negligible loss to voltages within the prescribed limits. When the signal voltage becomes excessive, the neon lamp "strikes", or conducts, and its internal resistance drops sharply. The shunting effect produced by the conducting neon lamp reduces the voltage peaks to a value suitable for application to the modulator input.

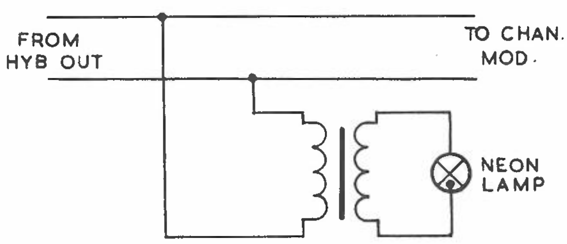
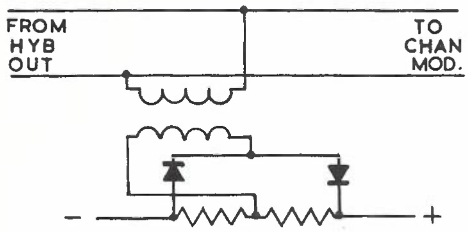
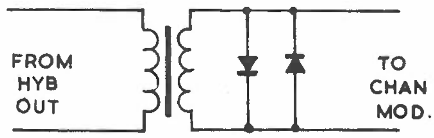


FIG. 2. VOLTAGE LIMITER - NEON LAMP TYPE.

2.3 The simplified circuit of a biassed diode type voltage limiter is shown in Fig. 3a. The voltage drop produced across the resistors by the d.c. supply is used to bias the diodes so that they offer a high impedance to signal votlages within the prescribed limits. Excessive signal voltages are larger than the bias voltage and cause the diodes to conduct. While the diodes are conducting they provide a low impedance shunt across the circuit and thus reduce the peak voltages to a suitable value for application to the modulator. Two diodes are used, to provide a path for each half cycle of A.C. signal.



(a) Biassed Diode Type.



(b) Silicon Diode Type.

FIG. 3. VOLTAGE LIMITERS - DIODE TYPE.

A voltage limiter employing silicon diodes is shown in Fig. 3b. The forward impedance of the diodes is very high to voltages within the prescribed limits. Excessive signal voltages cause the forward impedance of the diodes to decrease and provide a low impedance shunt across the circuit.

3. ATTENUATION EQUALISERS.

3.1 Transmission lines and many equipment components attenuate some frequencies more than others, and thus produce frequency distortion. When frequency distortion becomes excessive, the intelligibility of the received signal is reduced to an unacceptable quality. Attenuation equalisers are used to correct for the frequency distortion produced by the unequal attenuation versus frequency characteristics of either transmission lines, equipment components, or combinations of both.

Attenuation equalisers are divided into two main categories, these are:-

- PASSIVE ATTENUATION EQUALISERS, which are networks of inductors, capacitors, and resistors,
- ACTIVE ATTENUATION EQUALISERS, which consist of passive equalising networks in association with amplifiers. These types of equalisers are usually called "equalising amplifiers" or "slope amplifiers".

3.2 PASSIVE ATTENUATION EQUALISER. These networks introduce additional attenuation into the transmission path, but have an attenuation versus frequency characteristic which is opposite to that of the lines and/or equipment they are designed to equalise. The resultant attenuation of the equaliser plus the line and/or equipment is constant over the frequency range, thus reducing frequency distortion. Fig. 4 shows the principle of an equaliser designed to correct for the frequency distortion produced by an open-wire transmission line. Note that the transmission line attenuates the high frequencies more that the lower frequencies, whereas the attenuation equaliser attenuates the lower frequencies more than the higher frequencies. The total attenuation of the line plus the equaliser is constant over the entire frequency range. Since all frequencies are attenuated by the same amount, and equaliser has corrected for the frequency distortion produced by the line.

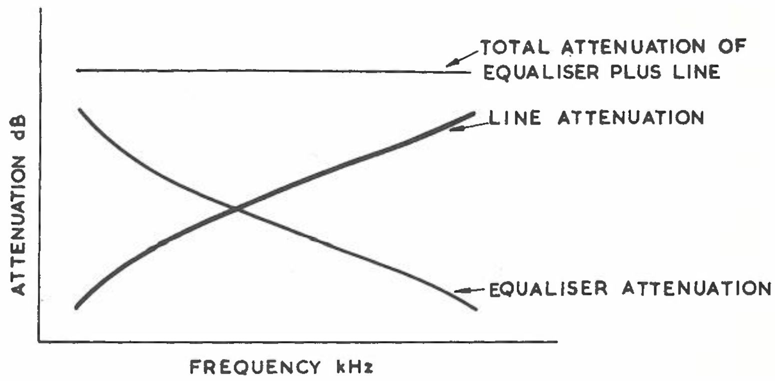


FIG. 4. PRINCIPLE OF PASSIVE ATTENUATION EQUALISER.

3.3 Fig. 5 shows a passive attenuation equaliser connection connected at the receiving end of a transmission line. All frequencies are restored to their original amplitude relationships by the equaliser, thus reducing frequency distortion at the amplifier input. The amplifier has sufficient gain to compensate for the total attenuation of the line plus the equaliser.

In many cases, the attenuation equalisers connected in transmission lines are designed to compensate for the unequal attenuation versus frequency characteristics of equipment components associated with the line, such as filters, as well as the line.

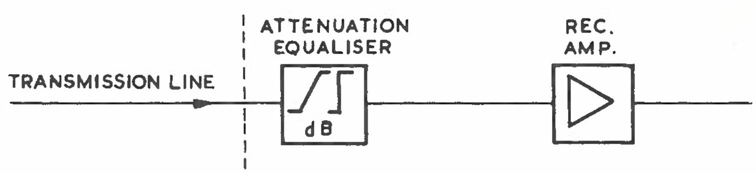
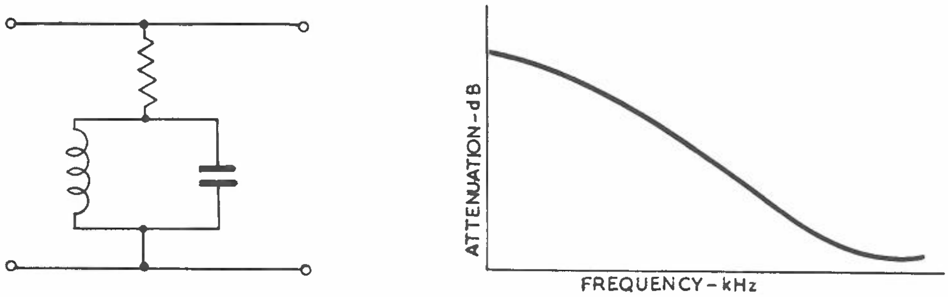


FIG. 5. TYPICAL APPLICATION OF A PASSIVE ATTENUATION EQUALISER.

Passive attenuation equalisers designed to correct for frequency distortion in transmission lines are usually adjustable in fixed steps. This enables the equaliser to be installed on any line which has characteristics within certain limits of a nominal value. Sections of the equaliser are strapped in or out, during installation, to suit the characteristics of the particular line on which it is installed.

3.4 As well as being used to correct for frequency distortion produced by transmission lines and their associated components, attenuation equalisers are also used to correct for frequency distortion produced by equipment components within the line transmission equipment, or the internal wiring between the equipment. These equalisers operate on the same principle as line attenuation equalisers, that is, they have reverse attenuation versus frequency characteristics to that of the equipment they are designed to equalise.

3.5 SIMPLE PASSIVE ATTENUATION EQUALISER. Fig. 6a and 6b show respectively the circuit of a simple shunt type attenuation equaliser, and its frequency versus attenuation characteristic. At low frequencies the inductive-reactance is very low, and the value of R determines the maximum attenuation produced by the equaliser. As the frequency increases, the inductive reactance increases. This causes the shunt impedance of the equaliser to increase and reduce the attenuation of the equaliser. As the frequency rises further, the inductor and capacitor become resonant and offer maximum shunt impedance and, therefore, minimum attenuation to the signal. This is the frequency at which minimum attenuation of the equaliser occurs. Beyond this frequency the attenuation of the equaliser commences to increase again due to the effect of the decreasing capacitive reactance, but the equaliser is not usually operated beyond this point. In practice, the values of R, L and C are usually adjustable, so that the equaliser can be installed on any line having characteristics within certain tolerances of a nominal value.

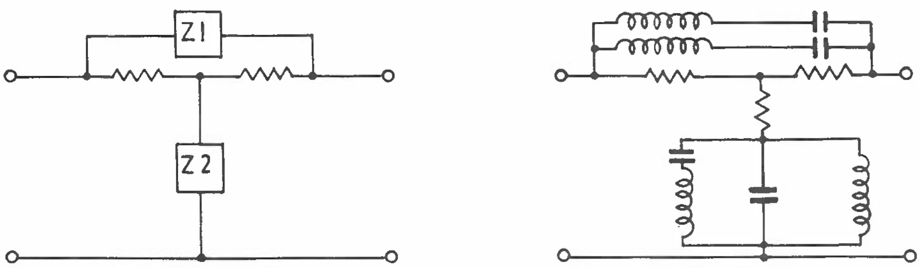


(a) (b)

FIG. 6. SIMPLE PASSIVE ATTENUATION EQUALISER.

3.6 Simple equalisers, similar to the type shown in Fig. 6, have the disadvantage that their impedance changes with frequency. In many line transmission equipment applications it is essential that the impedance of the equaliser remains relatively constant over the frequency range, to prevent an impedance mismatch and the resultant reflection problems from occuring. In these cases, more complex equaliser configurations are used, such as the bridged T type equaliser, which has a constant impedance over the frequency range for which it is designed. The basic configuration of the bridged T type equaliser is shown in Fig. 7a. The impedances Z1 and Z2 are networks of L, C, and R, which are designed for the particular application of the equaliser. Fig. 7b shows a practical application of the bridged T equaliser configuration.

Many different variations of the bridged T equaliser circuit, and also a number of other types of equaliser configuration, are used in practice.



(a) (b)

FIG. 7. BRIDGED T ATTENUATION EQUALISER.

3.7 ACTIVE ATTENUATION EQUALISERS. These are equalising amplifiers which have a gain versus frequency characteristic such, that when combined with the frequency response of the lines they are designed to equalise, a flat overall frequency response is obtained. For example, the effect of an equalising amplifier connected in the receiving end of a transmission line is shown in Fig. 8. The transmission line attenuates the higher frequencies more than the lower frequencies, and the equalising amplifier amplifies the higher frequencies more than the lower frequencies. When the attenuation of the line is substracted from the gain of the amplifier, the overall frequency response is flat, and frequency distortion is reduced. (Note, the gain of the amplifier has been shown in the lower quadrant of the graph for easy comparison with the attenuation of the line).

The change in attenuation with frequency of a transmission line is often referred to as the "slope" of the line. For this reason equalising amplifiers associated with transmission lines are often called "slope" amplifiers.

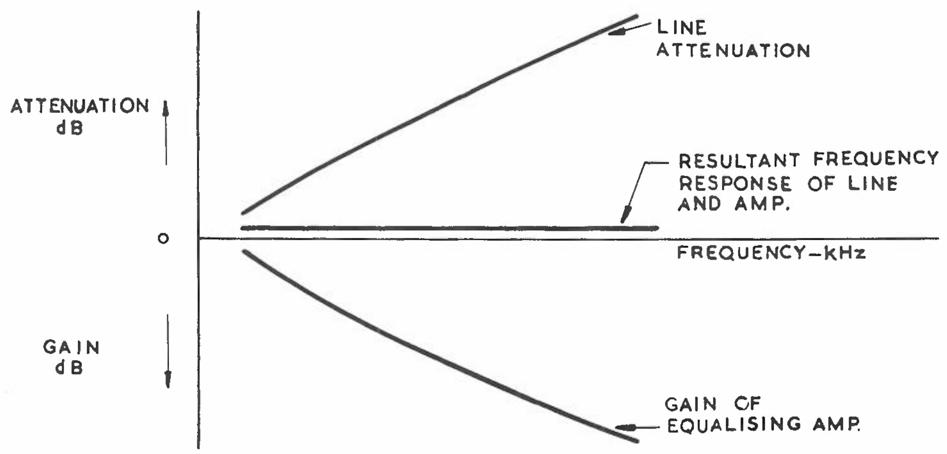


FIG. 8. PRINCIPLES OF EQUALISING AMPLIFIERS.

3.8 An equalising amplifier consists basically of an amplifier and an equalising network. The equalising network may be connected in series with the amplifier (Fig. 9a) or in the negative feedback circuit of the amplifier (Fig. 9b). The network is designed to have an attenuation versus frequency characteristic which causes the amplifier to amplify some frequencies more than others, and thus produce the required gain versus frequency characteristics.

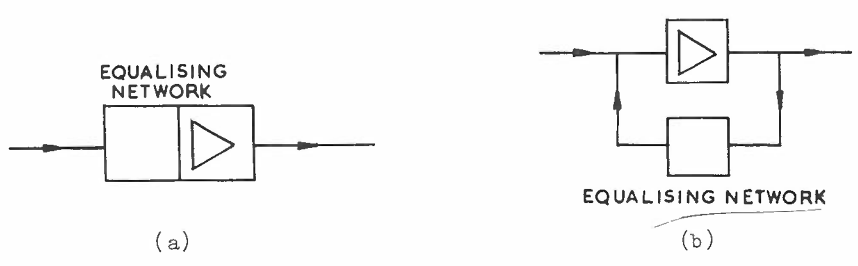


FIG. 9. BASIC EQUALISING AMPLIFIERS.

An example of a practical equalising amplifier with the equalising network connected to the negative feedback circuit is shown in Fig. 10. The values of the components in the equalising network may be varied during installation to suit the particular transmission line.

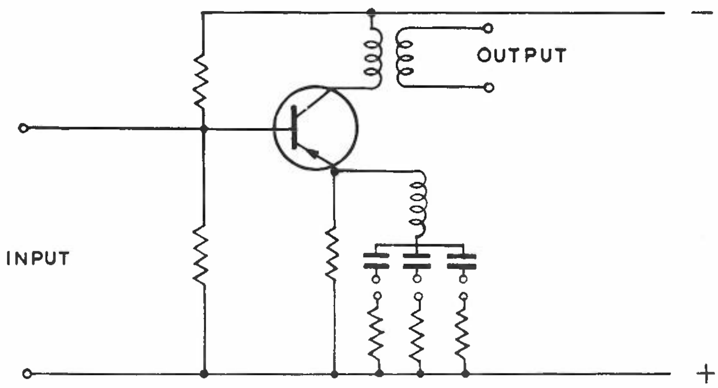


FIG. 10. EXAMPLE OF A PRACTICAL EQUALISING AMPLIFIER.

3.9 VARIABLE EQUALISER. Weather conditions cause the attenuation versus frequency characteristics (slope) of transmission lines to vary, particularly in open-wire lines. Fig. 11 shows typical attenuation versus frequency graphs of an open-wire line during dry and wet weather conditions. A fixed equaliser connected to the transmission line is only capable of compensating for the attenuation versus frequency characteristic produced by one type of weather condition. When weather changes produce variations in slope which are too large, a variable attenuation equaliser is used. The variable attenuation equaliser has its slope automatically varied, under the control of pilot regulation equipment, to compensate for changes in slope of the line.

Variable equalisers are also used in some types of line transmission equipment to compensate for changes in the frequency response of the equipment due to component ageing, and changes in ambient temperature.

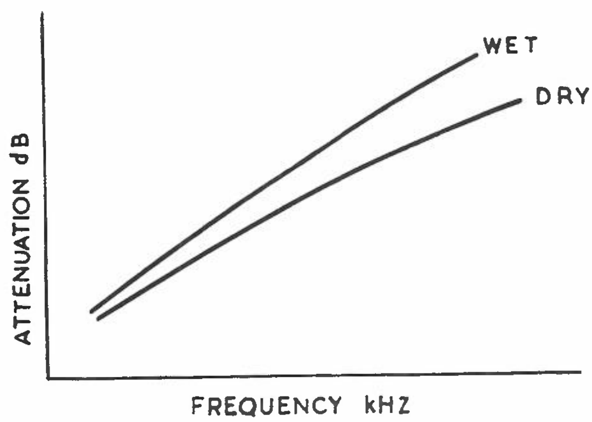


FIG. 11. EFFECT OF WEATHER CONDITIONS ON SLOPE OF OPEN-WIRE LINE.

4. DELAY EQUALISERS.

4.1 DELAY DISTORTION occurs when the component frequencies of a complex wave travel at different velocities through transmission lines and equipment. For example, assume that a complex wave containing two component frequencies (Fig. 12a) is applied to a circuit, and that the circuit causes the lower frequency to travel at a lower velocity than the higher frequency. The lower frequency will reach the circuit output later than the higher frequency (Fig. 12b); that is, the circuit delays the lower frequency for a longer period of time than the higher frequency. The difference in delay time between the two component frequencies in the output produces a change in their original phase relationship, which results in a change in the complex wave shape.

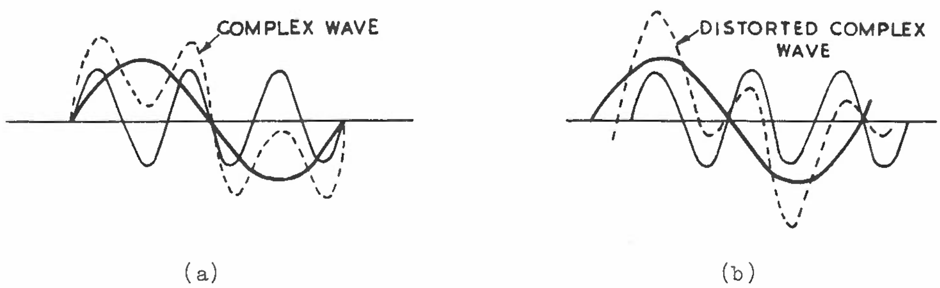


FIG. 12. DELAY DISTORTION.

Delay distortion has little effect on the intelligibility of speech, but has a considerable effect on telegraph, data, facsimile, and television video signals. For example, differences in the delay of the component frequencies of data pulses alter the shape of the pulses, and thus change the information being conveyed. If the delay is sufficiently large, some of the energy of a data pulse may be delayed to such an extent that it effects the following pulse.

4.2 ABSOLUTE DELAY is the total time required for a frequency to pass through a transmission path. The graph in Fig. 13 shows the absolute delay of each frequency in the pass range of a typical carrier telephone channel.

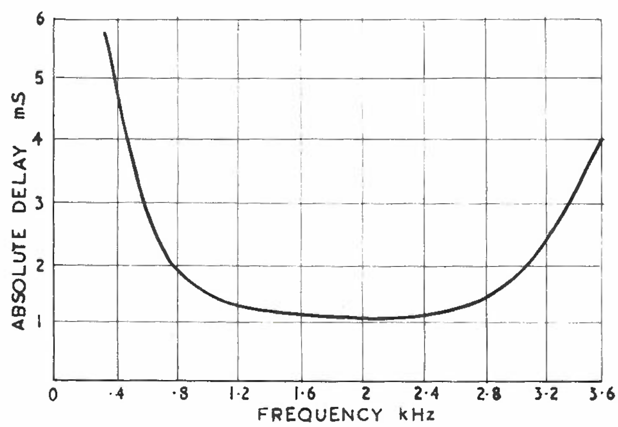


FIG. 13. ABSOLUTE DELAY.

4.3 DELAY EQUALISER. A delay equaliser is a network designed to make the absolute delay of a transmission path constant over the required frequency range. The delay equaliser introduces delay into the transmission path, but its delay versus frequency characteristic is opposite to that of the line and/or equipment it is designed to equalise. The total delay introduced by the delay equaliser plus the equipment and/or line is the same value for all frequencies. For example, Fig. 14 shows the principle of a delay equaliser connected in a carrier telephone channel. Note that the channel introduces minimum delay at the mid frequency and maximum delay at the end frequencies. The delay equaliser is designed to introduce maximum delay at the mid frequency and minimum delay at the end frequencies. The total delay introduced by the channel plus the equaliser is constant over the pass band of the channel, therefore delay distortion is reduced. (It should be noted that delay equalisers are not normally fitted to telephone channels used for speech transmission, but are fitted when the channels are used for such purposes as data, and facsimile transmission).

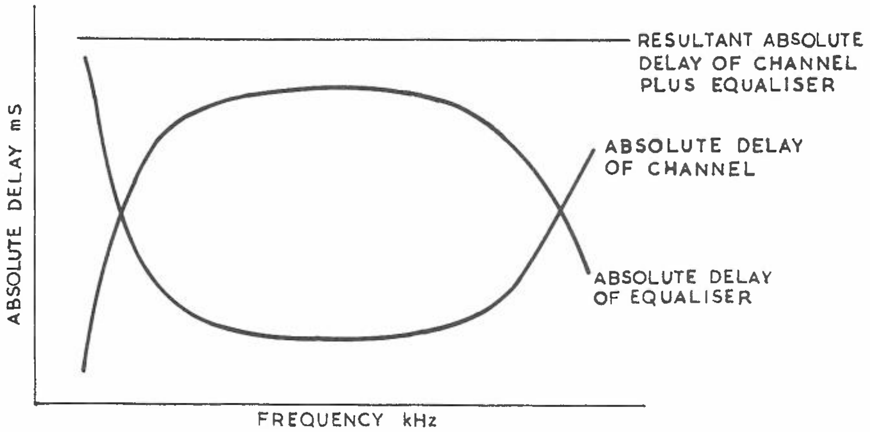
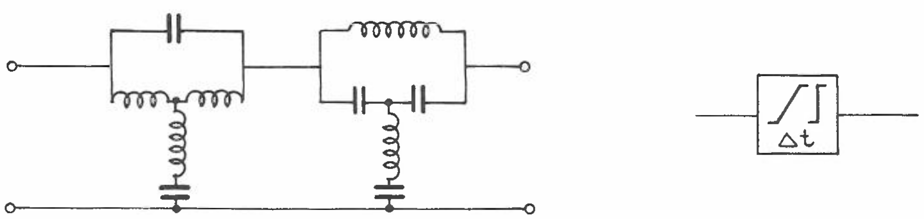


FIG. 14. PRINCIPLES OF DELAY EQUALISER.

Generally, delay equalisers contain a number of sections connected in series. Each of the sections is designed to correct for the delay distortion produced in a different portion of the frequency range. The combined effect of all the sections is to correct for the delay distortion produced over the entire frequency range required. An example of a delay equaliser circuit configuration containing two sections is shown in Fig. 15a, and the symbol used to represent a delay equaliser is shown in Fig. 15b.



(a) Practical Example. (b) Symbol.

FIG. 15. DELAY EQUALISER.

4.4 GROUP DELAY DISTORTION. The absolute delay of the combined go and return paths of a four-wire circuit can be measured relatively simply. The signal is fed over the go path to the distant terminal, where it is connected to the return path and fed back to the originating station. The combined go and return absolute delay is determined by comparing the received wave with that of the transmitted wave.

However, it is necessary to know the delay for one direction of transmission only to design a delay equaliser, and suitable absolute delay figures for this purpose are not always obtained by halving the go and return absolute delay. Also, because of the problems of providing a synchronised reference frequency at the distant terminal, it is not practicable to measure the absolute delay for one direction of transmission between two stations.

For this reason, complex test equipment has been developed to measure the relative delay over a transmission path. Basically, this equipment transmits a reference signal, and the signal to be measured, to the distant station, where the DIFFERENCE in delay between the two signals is measured. The reference signal is chosen from within the frequency band to be checked, and since its absolute delay cannot be measured, it is given a relative delay value of zero. All delay measurements obtained at the distant station are relative to the reference signal delay, and indicate the difference in time each signal takes to travel over the transmission path, as compared to the reference signal. The delay characteristic obtained by this method is referred to as the Group Delay Distortion of the transmission path.

The group delay distortion of a typical telephone channel is shown in Fig. 16. In this case, the frequency with the lowest delay (2000 Hz) has been chosen as the reference and is given the relative delay value of zero. The difference in delay time between this frequency and each other frequency in the range has been measured and plotted graphically. The graph shows that the 3000 Hz signal takes 500 micro-seconds more than the 2000 Hz signal to travel through this particular channel; that is, the 3000 Hz signal has a delay which is 500 micro-seconds more than the 2000 Hz signal.

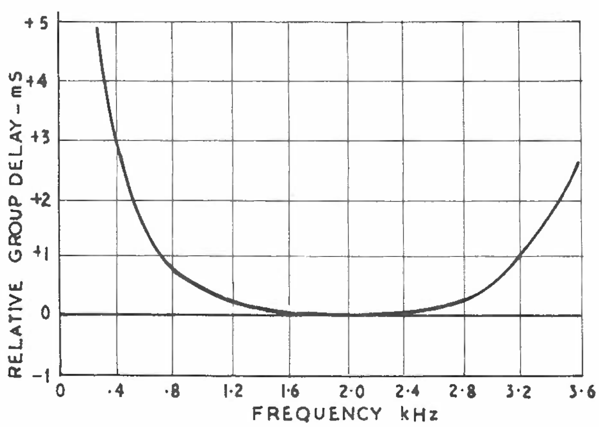


FIG. 16. GROUP DELAY DISTORTION.

4.5 In practice, a delay equaliser does not completly eliminate group delay distortion, but reduces it to an acceptable value. Fig. 17 shows the group delay distortion characteristics of a telephone channel equipped with a delay equaliser. Note that the relative group delay of all frequencies is within ±50 micro-seconds of the reference frequency.

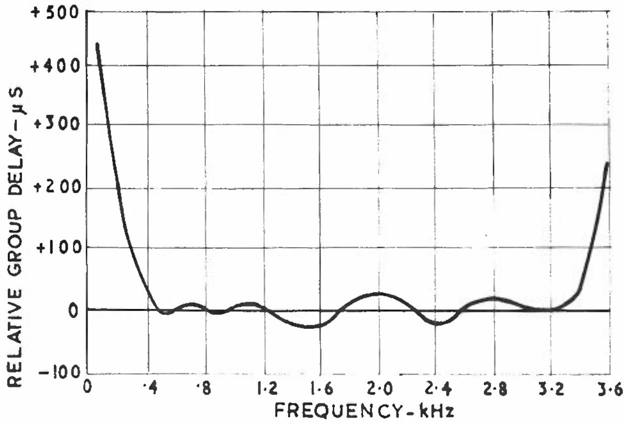


FIG. 17. GROUP DELAY DISTORTION OF AN EQUALISED TELEPHONE CHANNEL.

4.6 Group delay measurements may be made over any practical range of frequencies, for example, over the group, supergroup and television video frequency ranges. The measurements may be made for the purpose of:-

- Obtaining the relative group delay characteristics of the transmission path for the purpose of designing a suitable equaliser, or,
- To check that the group delay distortion introduced by a transmission path equipped with a delay equaliser is within the prescribed limits.

Fig. 18 shows the group delay distortion characteristic of a 5.8 mile coaxial television video link equipped with a delay equaliser.

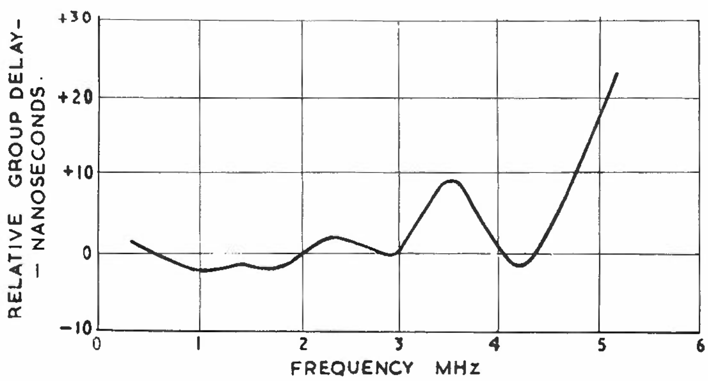


FIG. 18. GROUP DELAY DISTORTION OF A 5.8 MILE C.V. LINK.

5. LINE BUILDING OUT NETWORKS.

5.1 Generally, line transmission equipment is not "tailor made" for each individual route, but is mass produced. For this reason, each type of equipment is manufactured for a transmission line of nominal length and characteristics. The equipment is supplied with adjustable components, such as adjustable equalisers and amplifiers, so that it can be installed on lines which vary within certain limits from the nominal.

Situations occur, however, where it is necessary to install equipment on transmission lines which are shorter than the minimum length for which the equipment is designed. The characteristics of a shorter line are such that the equipment could not be adjusted to operate satisfactorily. In these cases "Line Building Out" networks may be used to extend the characteristics of a short line so that they fall within the required limits. Line building out networks consist of a number of sections in series, and each section is designed to simulate the characteristics of a particular length of line. During installation, the sections are strapped in or out until the required transmission characteristics are obtained for the line.

Fig. 19 is a block diagram showing the sections of a typical line building out network used in coaxial cable systems. Each section simulates the characteristics of a different length of line, and by suitable strapping, the length of the line can be increased electrically by 0.25 to 3.75 miles.

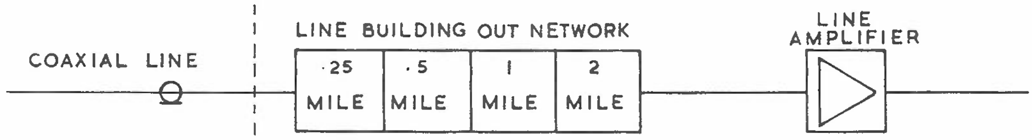


FIG. 19. LINE BUILDING OUT NETWORK.

To prevent a mismatch from occuring between the network and the line, a line building out network must simulate the line characteristics in all respects. For this reason the circuit design is very complex. Fig. 20 shows the circuit configuration of a typical line building out network section which is designed to simulate the characteristics of 0.25 miles of coaxial cable.

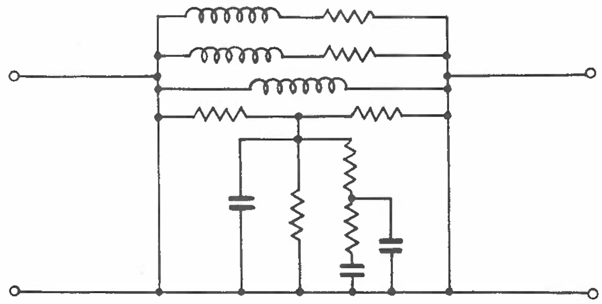


FIG. 20. LINE BUILDING OUT NETWORK SECTION (0.25 MILES OF COAXIAL CABLE).

6. COMPANDORS.

6.1 One of the requirements of good quality transmission circuits is that the noise level, as compared to the signal level, should be kept as low as possible. When the signal to noise ratio is not satisfactory, the noise in the circuit tends to mask the received signal and reduce its quality to an unacceptable value.

Generally, the design of modern line transmission equipment, and line construction methods, are of such a standard as to maintain a satisfactory margin between the signal and the noise. However, occasions occur where excessive noise exists in equipment or transmission lines, and the refinements and alterations necessary to reduce the noise to an acceptable value are considered uneconomical or impracticable. In these cases, compandors are often used to improve the signal to noise ratio. Through the use of compandors, satisfactory voice transmission can often be achieved over circuits which would otherwise be unsuitable because of excessive noise.

6.2 SIGNAL VOLUME RANGE. The volume (or dynamic) range of a signal is the difference, expressed in decibels, between the maximum and minimum power levels of the signal. The average talker produces a volume range of approximately 30 dB, but the difference between the weakest syllable of a soft talker and the loudest syllable of a lound talker may be as high as 60 dB (Fig. 21). Audio programme signals have an average volume range of approximately 50 dB, but this may extend up to 75 dB for the music produced by a symphony orchestra.

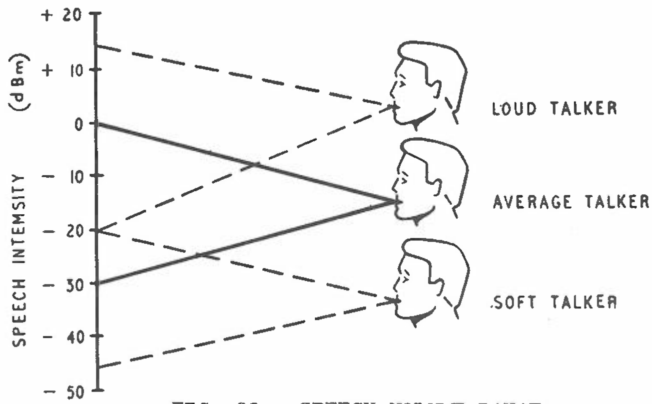


FIG. 21. SPEECH VOLUME RANGE.

In practice, the maximum volume range transmitted through line transmission equipment is approximately 50 dB, ranging from -40 dBm0 to +7 dBm0 for telephone circuits, and from -31 dBm0 to +18 dBm0 for audio programme circuits. This volume range is determined by the maximum and minimum levels which can be satisfactorily transmitted over the transmission path, and is sufficiently wide to give satisfactory quality to the listener. The limits to the volume ranges are chosen so that:-

- The highest level transmitted will not overload amplifiers, or induce excessive crosstalk into neighbouring circuits.
- The lowest level transmitted will have a satisfactory margin between it and the noise level existing on the circuit.

6.3 NOISE LEVEL. Control of the noise level in circuits needs careful planning. A certain amount of noise in circuits is unavoidable, but its level is generally kept below the prescribed maximum value by careful repeater spacing and the use of such techniques as line transpositions, the selection of suitable frequency bands for transmission over the route, good circuit design, etc. Ideally, for the satisfactory transmission of signals, the noise level should be at best 10 dB lower than the minimum signal level transmitted.

6.4 EFFECT OF EXCESSIVE NOISE LEVEL. Sometimes conditions exist which would produce excessive noise on circuits operating over a route. For example, it may be necessary to install a carrier system on a route which requires extensive transpositions and reconstruction in order to reduce the noise to an acceptable value, but these alterations are considered uneconomical or impracticable. Fig. 22 is a power level diagram showing the effect that the excessive noise produced by this type of line has on a telephone circuit operating over a carrier channel installed on the line. A V.F. signal with an average volume range of 30 dB (ranging from -30 dBm to 0 dBm) is being transmitted over the channel, and the line has an excessive noise level of -50 dBm. The low level signal is amplified to a level of -13 dBm in the carrier transmitting equipment, but due to the 40 dB line attenuation it reaches the receiving terminal at a level of -53 dBm, which is 3 dB below the noise level. Since both the received signal and the noise are amplified in the carrier terminal, the noise reaches the listener at a level 3 dB higher than the low level signal. This circuit, therefore, does not meet the requirements of having the noise level 10 dB lower than the minimum signal level.

One method of improving the signal to noise ratio on circuits operating over a carrier system installed on this type of line is to use compandors in the terminal equipment.

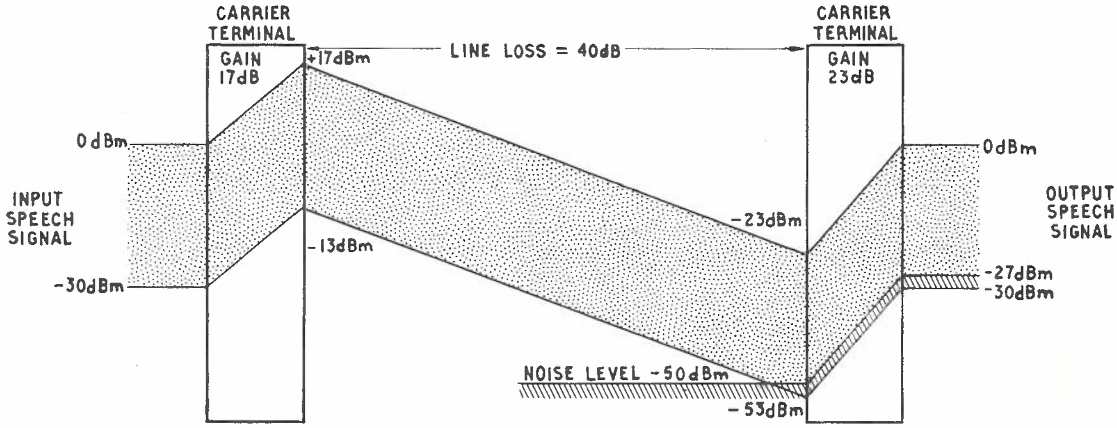


FIG. 22. EFFECT OF EXCESSIVE NOISE LEVEL.

6.5 FUNCTION OF THE COMPANDOR. A COMPANDOR is a combination of a volume range COMpressor and a volume range exPANDOR. The compressor is connected in the channel input, at the transmitting terminal, and compresses signals by imparting gain to low level signals and loss to high level signals. (Fig. 23). The expandor is connected in the channel output, at the receiving terminal, and performs the opposite function of restoring the signals back to their original volume range. Usually, the compressor reduces the volume range of signals by a ratio of 2:1, and the expandor increases the volume range by a ratio of 1:2. In the example shown in Fig. 23, the compressor reduces the 50 dB input volume range to a volume range of 25 dB, and the expandor restores the compressed range back to the original value.

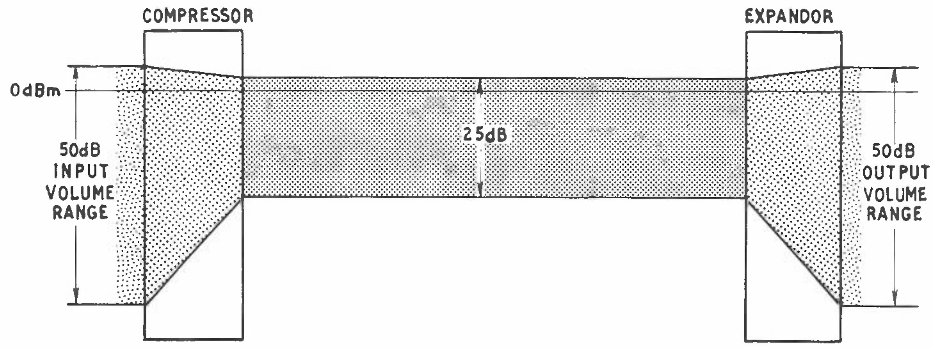


FIG. 23. COMPRESSION AND EXPANSION ACTION OF A COMPANDOR.

By raising the level of low level signals, the compressor allows them to be transmitted over the channel with a greater margin above the noise level. Also, the compressor attenuates the high level signals, and prevents these from overloading transmission equipment.

6.6 NOISE ADVANTAGE. The noise advantage obtained by installing a compandor in the channel used in Fig. 22, is shown in Fig. 24. The -30 dBm low level signal is fed into the compressor, where it is amplified to a level of -15 dBm. The carrier equipment transmitting amplifier further raises the signal level to +2 dBm, for transmission to the distant station. Because of the 40 dB line attenuation, the signal reaches the receiving carrier terminal at a level of -38 dBm; which is a much higher level than that received on the channel without compandors, in Fig. 22.

The noise level on the line at the receiving terminal is still -50 dBm. Both the received signal and the noise are amplified 23 dB by the carrier terminal receiving amplifier, so the received signal enters the expandor with a level of -15 dBm and the noise enters the expandor with a level of -27 dBm. If the expandor attenuates both the signal and the noise by a ratio of 1:2, the signal has a level of -30 dBm at the expandor output, and the noise has a level of -54 dBm. The low level signal now has a margin of 24 dB above the noise level, which is a big improvement on the margin of 3 dB below the noise level obtained in the channel without a compandor in Fig. 22.

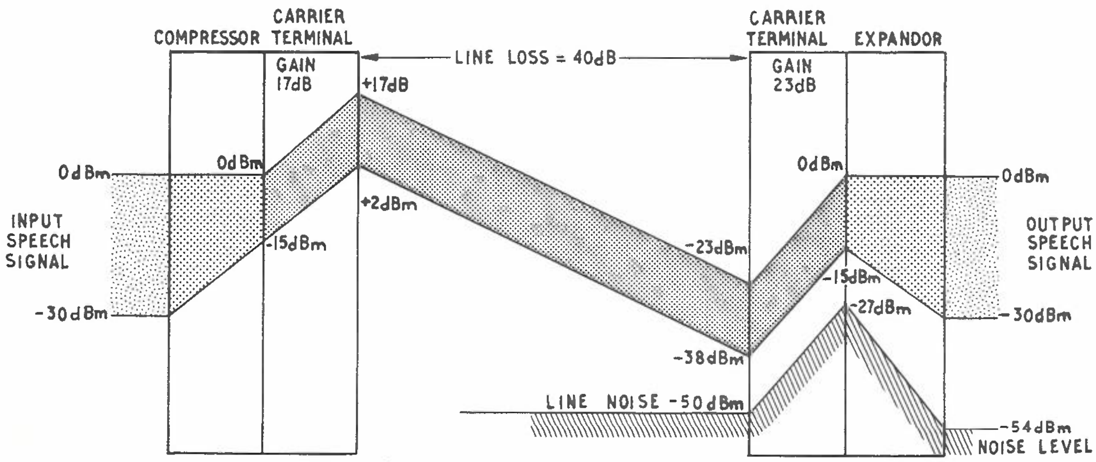


FIG. 24. NOISE ADVANTAGE GAINED BY INSTALLING COMPANDORS ON NOISY CIRCUITS.

6.7 COMPRESSION AND EXPANSION RATIO. The ratio of the input to output volume ranges of a compressor is called the COMPRESSION RATIO. For example, a compressor having an input volume range of 50 dB and an output volume range of 25 dB has a compression ratio of 2:1 (or 2). The compression ratio must always be greater than 1, for compression of the signal to occur.

Selection of the correct compression ratio is important. If the compression ratio is too high the companding action may produce distortion. If the compression ratio is too small, the volume range may not be compressed enough to give sufficient signal to noise improvement. A compression ratio of 2 (or 2:1) is commonly used, and provides a satisfactory performance on most circuits.

The "EXPANSION RATIO" is the ratio of the input to output volume ranges of the expandor. The expansion ratio is the inverse of the compression ratio, and is always less than 1. For example, if the compression ratio of a compandor is 2(2:1) the expansion ratio is ½(1:2). (Sometimes the expansion ratio is expressed as the ratio of the output to input volume ranges of the expandor, so that the compression and expansion ratios can be expressed as equal values).

6.8 COMPANDOR CHARACTERISTIC. The volume range over which companding action occurs in a compandor is called the COMPANDING RANGE. Since line transmission equipment is designed to transmit a volume range of approximately 50 dB, compandors used on this equipment should have a companding range of 50 dB. Distortion could occur if the companding range is less than the volume range to be transmitted.

The characteristic of a typical compandor having a companding range of 50 dB and a compression ration of 2:1 is shown in Fig. 25. There is always one signal level in the companding range which is not effected by the compandor action. This level passes through the compressor and expandor with zero, loss or gain, and is known as the UNAFFECTED LEVEL (or focal point) of the compandor. For exmaple, the unaffected level of the compandor shown in Fig. 25 occurs at 0 dBm. Compression and expansion of the signals transmitted through the compandor occurs around the unaffected level, or focal point.

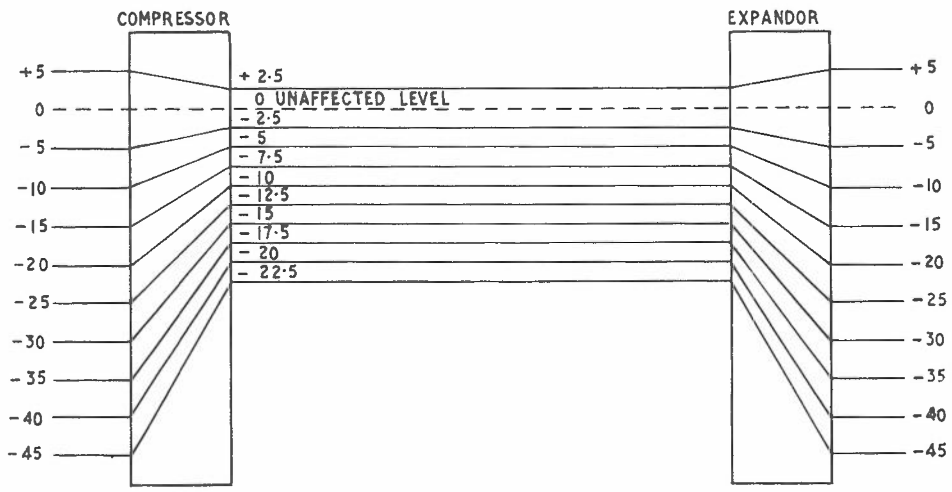
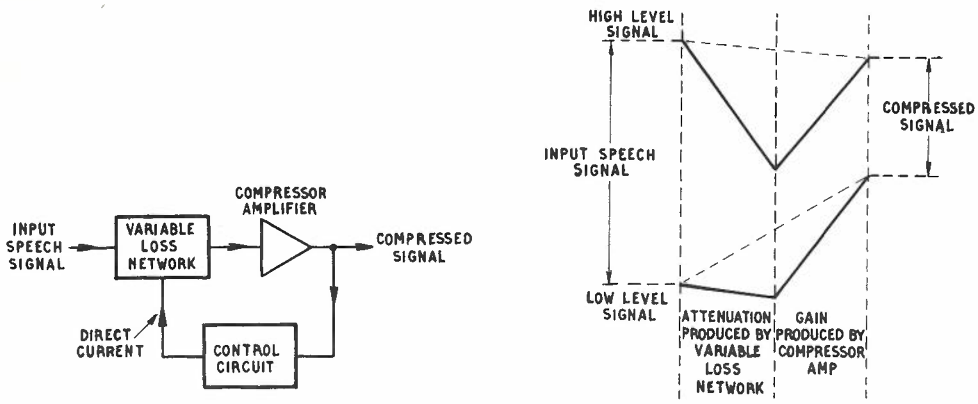


FIG. 25. CHARACTERISTIC OF A COMPANDOR.

6.9 COMPRESSOR – BASIC OPERATION. The compressor contains a variable loss network, an amplifier, and a control circuit, connected as shown in Fig. 26a. Signals entering the compressor pass through the variable loss network, and then the amplifier. Portion of the signal output from the amplifier is fed to the control circuit, where it is rectified. The direct current produced by the control circuit is fed to the variable loss network where it is used to control the attenuation this network offers to the signal. The value of the direct current, and the resultant attenuation it produces in the variable loss network, is directly proportional to the signal level.

When a low level signal is applied to the compressor, the control circuit produces a small value of direct current which causes the variable loss network to offer a low attenuation to the signal. When a high level signal is applied to the compressor, the d.c. produced by the control circuit increases, causing the attenuation offered by the variable loss network to increase. The variable loss network, therefore, offers high attenuation to high level signals and minimum attenuation to low level signals. (Fig. 26b). The compressor amplifier sets the compressed signal to the correct level at the output of the compressor. The power level diagram in Fig. 26b shows how the combined effect of the attenuation in the variable loss network, and the gain of the compressor amplifier, produces the correct compression of the input volume range.



(a) Block Diagram of a Compressor. (b) Power Level Diagram of a Compressor.

FIG. 26. BASIC OPERATION OF A COMPRESSOR.

6.10 COMPRESSOR – SIMPLIFIED CIRCUIT. A simplified circuit of a typical compressor is shown in Fig. 27. The input speech signals are fed through the variable loss network and the compressor amplifier. Portion of the compressor amplifier output is fed to the control circuit, where it is rectified by diodes SC1 and SC2. The d.c. produced from the control circuit is applied to SC3 and SC4 in their forward or conducting direction. The value of d.c. produced from the control circuit determines the forward bias applied to SC3 and SC4, and therefore, the value of the shunting impedance (or attenuation) they provide across the signal path.

High level signals produce a large d.c. from the control circuit which provides a high forward bias to diodes SC3 and SC4. This high forward bias lowers the shunt impedance of SC3 and SC4 and the variable loss network offers maximum attenuation to the high level signal.

Low level signals produce a small d.c. from the control circuit consequently, only a small forward bias is applied to SC3 and SC4. The shunt impedance offered by SC3 and SC4 is increased, and the variable loss network offers minimum attenuation to the low level signal.

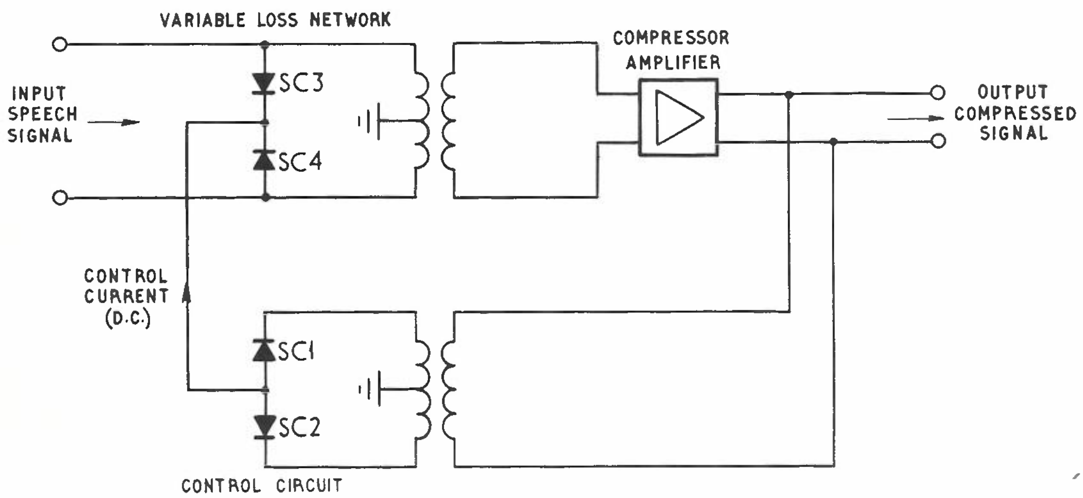
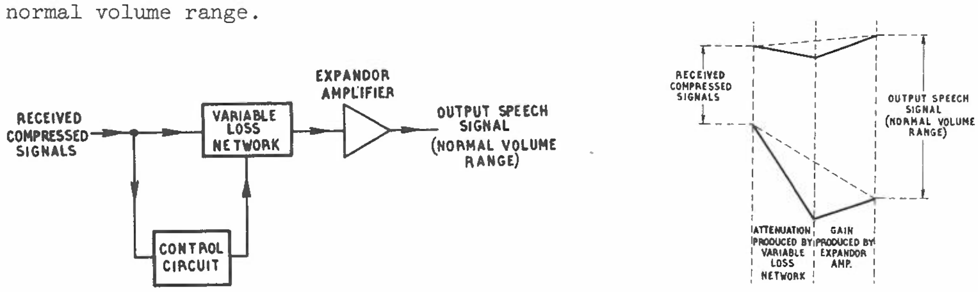


FIG. 27. SIMPLIFIED COMPRESSOR CIRCUIT.

6.11 EXPANDOR — BASIC OPERATION. The block schematic diagram of a basic expandor is shown in Fig. 28a. The function of the expandor is to restore the compressed received signal back to its original volume range. Portion of the received compressed signal is fed to the control circuit, which produces a direct current. The attenuation of the expandor variable loss network is inversely proportional to the level of the direct current produced by the control circuit (which is opposite to that of the variable loss network in the compressor).

In this way low level signals are attenuated more than high level signals, and the signals are restored to their original volume range. (Fig. 28b). The expandor amplifier produces sufficient gain to set the output signals at their correct level. The power level diagram in Fig. 28b shows how the combined effect of the variable loss network attenuation, and the amplifier gain, restores the signal back to its normal volume range.



(a) Block Diagram of an Expandor. (b) Power Level Diagram of Expandor Operation.

FIG. 28. BASIC OPERATION OF AN EXPANDOR.

6.12 EXPANDOR — SIMPLIFIED CIRCUIT. A simplified circuit of a typical expandor is shown in Fig. 29. Portion of the incoming signal is rectified by diodes SC1 and SC2 in the control circuit. The D.C. produced from the control circuit is connected to the midpoint of the transformer in the variable loss circuit, and controls the forward bias applied to diodes SC3 and SC4.

High level signals cause the control circuit to produce a large d.c. which provides a high forward bias to SC3 and SC4. This decreases the impedance of SC3 and SC4, and little attenuation is offered to high level signals by the variable loss network. Low level signals produce a small d.c. from the control circuit and, therefore, small forward bias to SC3 and SC4. The impedance of the varaible loss network is increased and the low level signal is greatly attenuated.

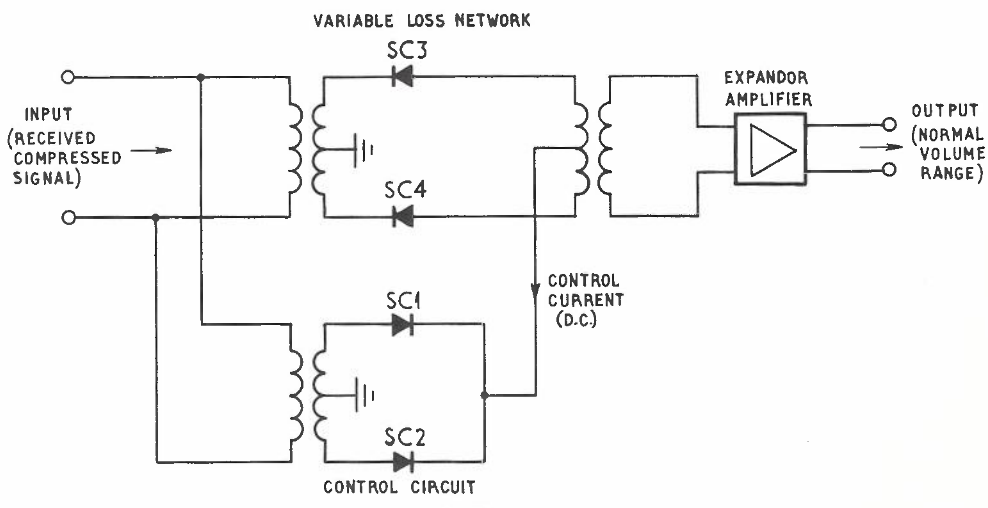


FIG. 29. SIMPLIFIED EXPANDOR CIRCUIT.

6.13 POWER LEVEL DIAGRAM OF COMPANDOR IN A CARRIER CHANNEL. Fig. 30 is a power level diagram showing the combined effects of the compressor and expandor variable loss networks, and amplifiers, when connected in the circuit provided by a carrier channel which also contains amplifiers. The dotted lines show the actual characteristics of the compandor.

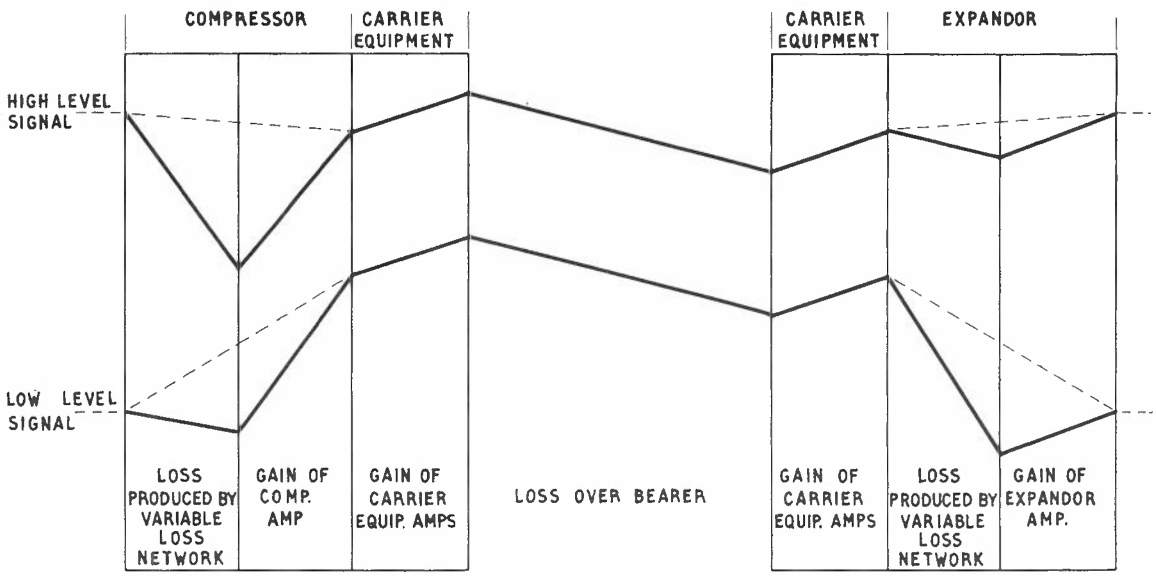


FIG. 30. POWER LEVEL DIAGRAM OF A COMPANDOR AND CARRIER EQUIPMENT.

6.14 The Symbols used to represent a compressor and expandor are shown in Fig. 31.

(a) Compressor. (b) Expandor.

FIG. 31. COMPRESSOR AND EXPANDOR SYMBOLS.

6.15 APPLICATIONS OF COMPANDORS. Compandors are used in the following applications:-

- PHYSICAL TELEPHONE CIRCUITS. Compandors are used on some physical V.F. circuits to compensate for the effects of power line induction and noise induced from other sources. Also, they may be used on some older circuits, which have fallen below transmission standards, to restore them to satisfactory quality.

- CARRIER TELEPHONE SYSTEMS. Compandors are employed in some carrier telephone systems to reduce the effects of crosstalk, and improve the signal to noise ratio of circuits operating over the channels. For example, compandors are used in Rural Carrier Telephone systems, which have a wide application in Australia. These systems operate over lines which are only lightly transposed and have a minimum of upgrading. Carrier systems may not operate satisfactorily over these lines without the use of compandors.

- PROGRAMME CHANNELS. Generally, the modern line transmission equipment provided for relaying radio programmes transmits the required volume range with satisfactory quality. However, if a programme channel is not giving a satisfactory signal to noise ratio, or distortion is being produced by high level signals overloading amplifiers, it is sometimes necessary to connect compandors in the channel.

6.16 LIMITATIONS OF COMPANDORS. Compandors are only effective in reducing the noise which is generated within, or induced into, the equipment or line. They cannot reduce noise which is received along with the signals at the input to the circuit.

A limited use is made of compandors in Australia because it is undesirable to have more than two compandors connected in tandem. For this reason, compandors are used only where special circumstances require their particular advantages, or in systems, such as rural carrier systems, where a distinct economical advantage is obtained.

7. PRE-EMPHASIS AND DE-EMAPHSIS.

7.1 PRE-EMPHASIS AND DE-EMPHASIS IN AUDIO PROGRAMME EQUIPMENT. The human ear is very sensitive to noise in audio programmes in the high frequency region around 5 kHz. For this reason it is desirable to obtain a high margin between the levels of the higher frequency signals and the basic noise.

The margin between the high frequency signal and the noise cannot be increased by raising the level of the complete audio programme signal at the transmitting station, because a limit exists on the maximum power which can be satisfactorily transmitted. If the maximum permissable transmission level is exceeded, intermodulation noise and crosstalk problems occur.

Pre-emphasis and de-emphasis can be used in programme channels to improve the margin between the higher frequency signals and the noise. The pre-emphasis unit, which is installed in the transmitting equipment, offers greater attenuation to the lower frequencies than to the higher frequencies (Fig. 32). As a result, the higher frequencies are transmitted at a higher level than they would be normally, and reach the receiving equipment with a greater margin above the noise.

The pre-emphasis network, by attenuating the lower frequencies more than the higher frequenices, introduces frequency distortion into the signal. For this reason, a de-emphasis network is necessary in the receiving equipment. The de-emphasis network has an attenuation versus frequency characteristic which is exactly opposite to that of the pre-emphasis network, that is, it attenuates the higher frequencies more than the lower frequencies, and so restores the frequency components to their original relative levels.

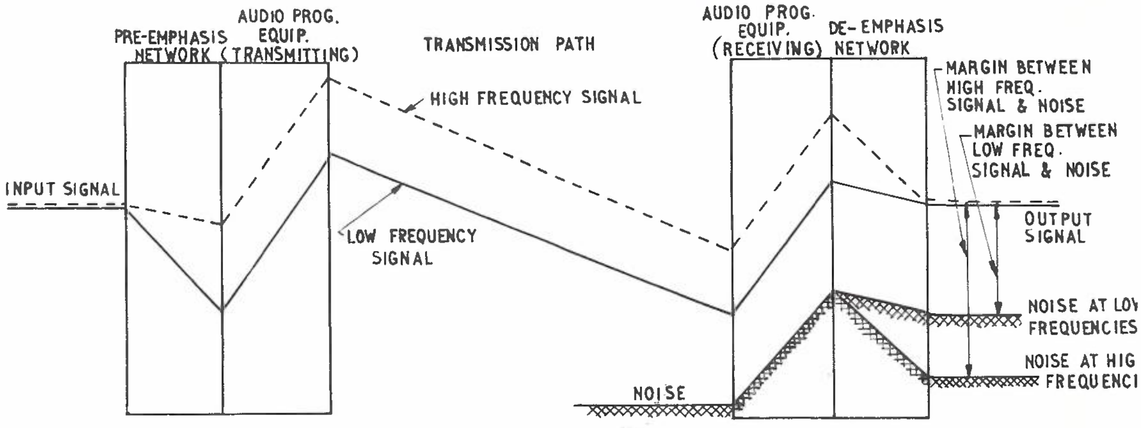


FIG. 32. PRINCIPLES OF PRE-EMPHASIS AND DE-EMPHASIS IN AUDIO PROGRAMME CHANNELS.

The attenuation versus frequency characteristics of typical pre-emphasis and de-emphasis networks used in audio programme channels are shown in Fig. 33.

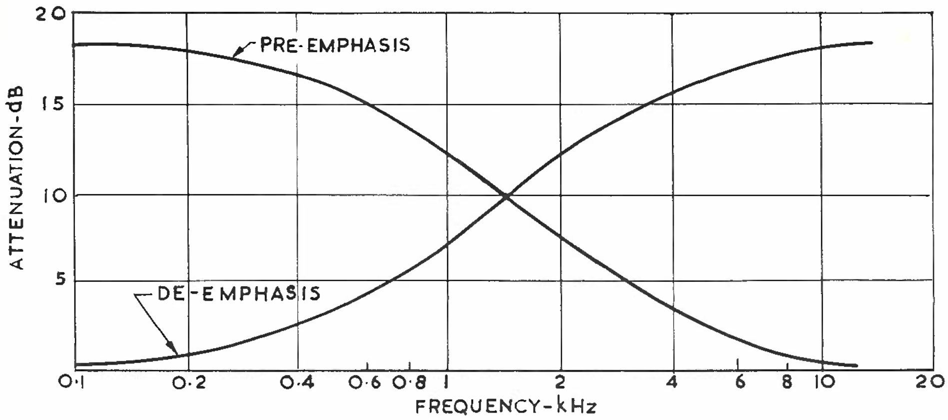
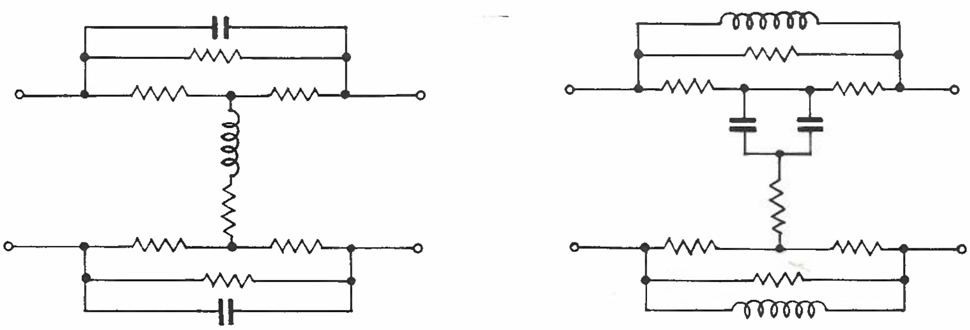


FIG. 33. AUDIO PROGRAMME PRE-EMPHASIS AND DE-EMPHASIS CHARACTERISTICS.

The circuit configurations of a pre-emphasis and de-emphasis network used in a typical programme carrier system are shown in Fig. 34. Note that where capacitors are used in series arms of the pre-emphasis network inductors are used in the de-emphasis network, and so on.



(a) Pre-emphasis Network. (b) De-emphasis Network.

FIG. 34. TYPICAL PRE-EMPHASIS AND DE-EMPHASIS NETWORKS.

7.2 PRE-EMPHASIS AND DE-EMPHASIS IN CARRIER TELEPHONE EQUIPMENT. Generally, transmission lines attenuate higher frequencies more than lower frequencies. If a high frequency signal and a low frequency signal of the same level are applied to the input of a transmission line, the high frequency signal will reach the output at a lower level than the low frequency signal. This means that the received high frequency signal has a smaller margin above the noise than the low frequency signal. Fig. 35 is a simplified block diagram showing a high frequency signal component, and a low frequency signal component, being applied at the same level to the input of a transmission line. The high frequency component is attenuated to such an extent by the line that an unsatisfactory margin exists to the noise.

Carrier telephone systems which transmit wide frequency bands (For example, 1260 channel systems) have the higher frequencies attenuated to such an extent by the transmission line that an unsatisfactory margin between the signal and noise levels could exist.

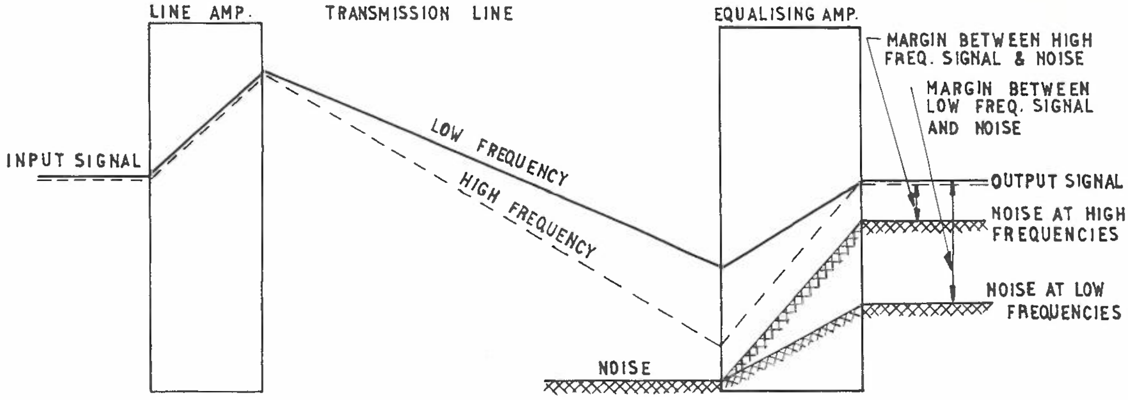


FIG. 35. UNSATISFACTORY MARGIN BETWEEN HIGH FREQUENCIES AND NOISE (CARRIER TELEPHONE EQUIPMENT).

Pre-emphasis is used in some broadband carrier telephone systems to:-

- Improve the margin between the high frequency signal components and the basic noise, and,
- Reduce intermodulation noise at the high frequency end. This noise is caused by the products of intermodulation of the lower frequencies.

Fig. 36 is a simplified power level diagram showing the principles of pre-emphasis and de-emphasis networks in this application. The pre-emphasis network offers greater attenuation to the lower frequencies than to the higher frequencies. Consequently, the higher frequencies are transmitted at a higher level than they would be normally, and reach the receiving equipment with a greater margin above the noise. Because the lower frequencies are transmitted at a lower level the intermodulation products arising from them are at a lower level.

In receiving equipment, the signal passes through the attenuation equaliser and receiving amplifier, and is applied to the de-emphasis network. The de-emphasis network has opposite characteristics to the pre-emphasis network and restores all frequencies back to their original relative levels.

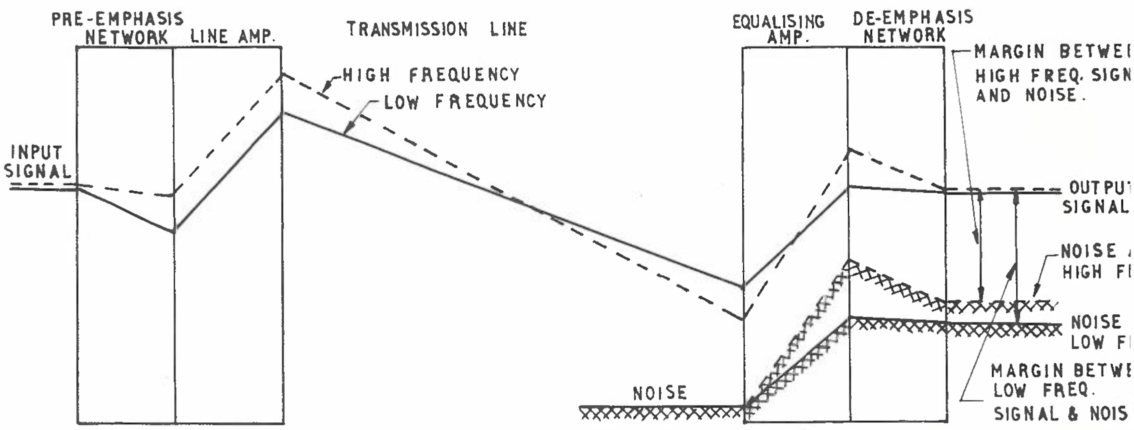


FIG. 36. PRINCIPLES OF PRE-EMPHASIS AND DE-EMPHASIS IN CARRIER TELEPHONE SYSTEMS.

The attenuation versus frequency characteristics of typical pre-emphasis and de-emphasis networks used in carrier telephone coaxial line equipment are shown in Fig. 37. Note that the characteristic of the de-emphasis network is the reverse to that of the pre-emphasis network.

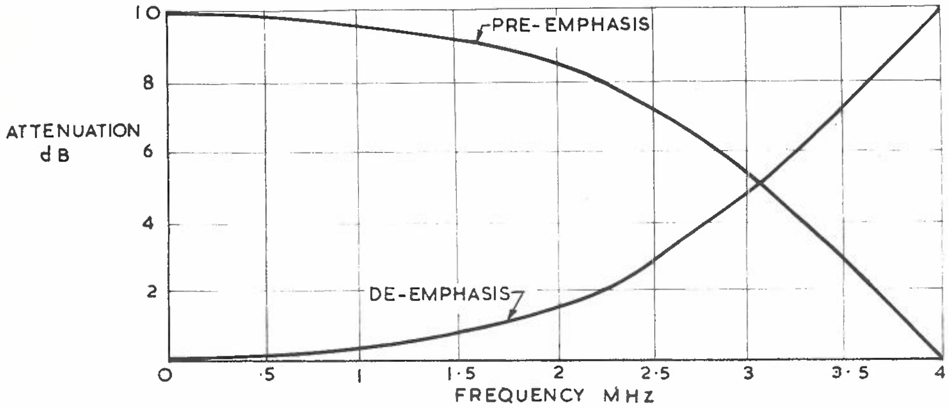


FIG. 37. TYPICAL PRE-EMPHASIS AND DE-EMPHASIS CHARACTERISTICS. (BROADBAND CARRIER TELEPHONE SYSTEM).

8. ECHO SUPPRESSORS.

8.1 ECHO. Echo occurs in telephone circuits when a mismatch at some distant point causes portion of the transmitted energy to be returned to the talker. In four-wire telephone circuits, echo is created primarily at the far end of the circuit, where the hybrid coil converts four-wire operation to two-wire operation (Fig. 38). Theoretically, an infinite loss should exist across the hybrid, and it should return no energy to the talker. In practice, however, a finite loss always exists across a hybrid, causing some of the received energy to be returned to the talker via the return path of the four-wire circuit.

The loss across hybrid is caused by the following factors:-

- The impedance connected across the hybrid line terminals varies, depending on such factors as the length of the subscribers line, the type of subscribers equipment, etc., and the best balance that can be achieved is by using a compromise balance network. Since the balance network is designed to provide the best match possible for the range of impedances which may be connected to the two-wire line, some lack of balance occurs on a majority of connections.
- The construction of the hybrid coil is not perfect. For example, it is not possible to have perfectly balanced windings, and capacitance unbalance always exists between the windings.

Echo is also caused by energy being reflected from impedance mismatches occuring at other points in the two-wire section of the connection, but mismatch (unbalance) at the hybrid is the principle cause of echo.

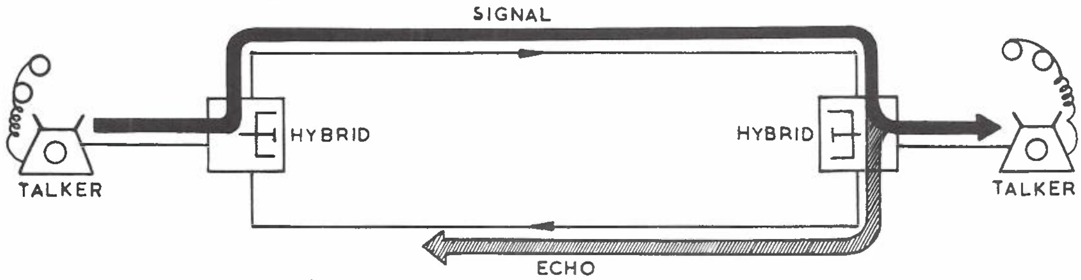


FIG. 38. ECHO IN FOUR-WIRE CIRCUITS.

8.2 Telephone echo causes the speaker to hear his own voice, as an echo, in the telephone receiver. The echo is delayed by the transmission delay around the circuit loop, that is, by the total delay of the "go" and "return" paths of the circuit. When the delay around the circuit becomes excessive, the echo produces an unnatural effect which becomes objectionable to the talker.

In practice, the maximum "round-trip" delay permitted on a circuit, before echo is considered to be objectionable, is 45 milliseconds. This delay corresponds to a carrier circuit of approximately 2400 miles in length. When this distance is exceeded, and the round trip delay of a circuit exceeds 45 milliseconds, it is desirable to use echo suppressors in the circuit.

8.3 PRINCIPLES OF ECHO SUPPRESSION. Fig. 39 is a simplified diagram showing the basic principles of echo suppression. When subscriber A talks, portion of the received signal is rectified by the "receive speech detector" in terminal B. The d.c. produced by the receive speech detector operates the "echo control switch". The echo control switch open-circuits the transmit path of terminal B, and blocks the echo from being returned to the talker at A.

Similarly, when subscriber B talks, the receive speech detector at terminal A operates the echo control switch at A. The echo control switch open-circuits the transmit path of terminal A and prevents echo from being returned to the talker at B.

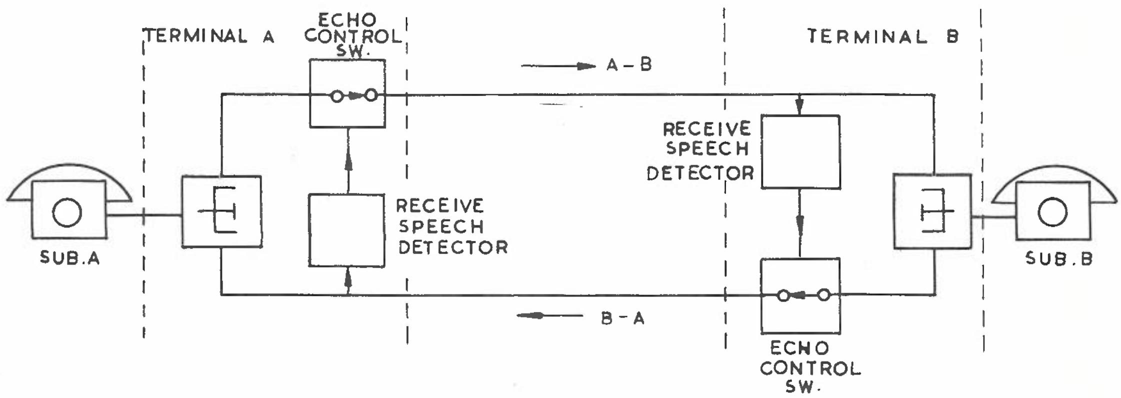


FIG. 39. PRINCIPLES OF ECHO SUPPRESSION.

8.4 BASIC ECHO SUPPRESSOR. The simple echo suppressor shown in Fig. 39 has the disadvantage that while one subscriber is talking, the other subscriber cannot "break-in" or interrupt, because their transmission path is open-circuited by the echo control switch. Fig. 40 shows the basic block schematic diagram of a typical modern echo suppressor which provides facilities for a subscriber to interrupt, or break-in, while the other subscriber is talking.

When only one subscriber is talking, complete echo suppression is provided by opening the transmit path of the circuit at the far end, as described in para. 8.3. For example, when subscriber A talks, portion of the speech signal is connected to the transmit speech detector at terminal A, and portion to the receive speech detector at terminal B. The output of the transmit and receive speech detectors are connected to the "differential devices" at each terminal. The differential device at terminal A has no effect at this stage, but the output from the differented device at terminal B operates the echo control switch. The echo control switch open-circuits the transmit path of terminal B and prevents the echo from being returned to the talker at A.

When two subscribers are talking, partial echo suppression is achieved by inserting pads into the circuit, and releasing the echo control switch. The pads are connected into both the transmit and receive sides of the circuit, and cause the echo to suffer twice as much loss as the signal. For example, if subscriber B commences to talk while A is talking, B's speech signal is connected to the transmit speech detector at terminal B, and then compared in the differential device with the signal received from A. When B's speech energy reaches a sufficient magnitude, compared with the signal received from A, the differential device releases the echo control switch at B, permitting B's signal to be transmitted to A. The differential device at B also switches pads into the transmit and receive paths at B. At terminal A, portion of B's signal is connected to the receive speech detector and causes the differential device to connect pads into the transmit and receive paths at both terminals. When either talker ceases, the circuit returns to the normal condition of a single talker.

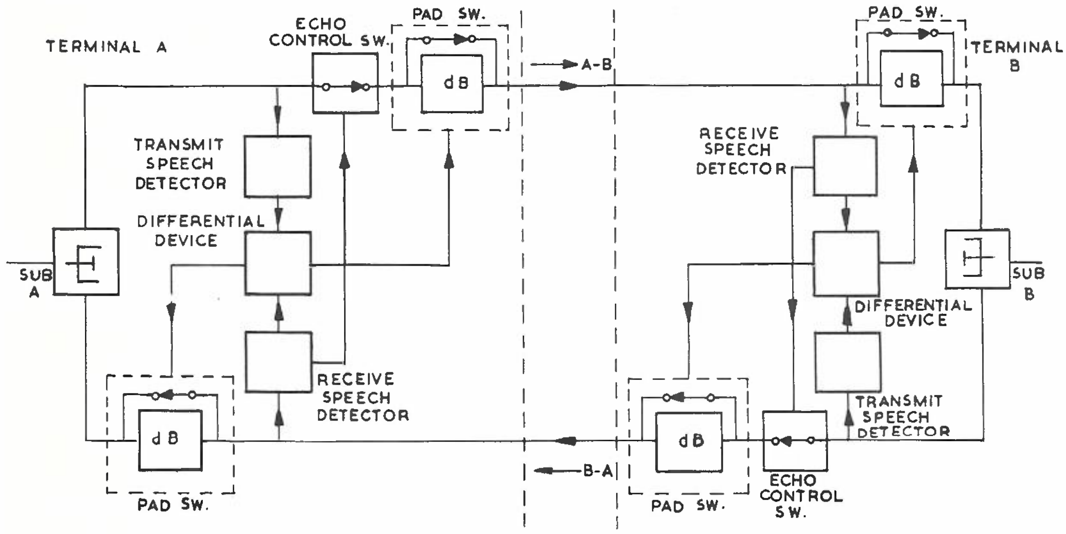


FIG. 40. BASIC ECHO SUPPRESSOR.

9. TEST QUESTIONS.

1. *State two reasons for limiting the voltage of signals applied to carrier equipment.*
2. *Sketch a neon lamp type voltage limiter and briefly explain its operation.*
3. *Briefly explain why it is necessary to use attenuation equalisers in line transmission equipment.*
4. *With the aid of simple graphs explain how a passive attenuation equaliser corrects for the frequency distortion produced in a transmission line.*
5. *With the aid of simple graphs explain how an active attenuation equaliser corrects for the frequency distortion produced in a transmission line.*
6. *Fig. 10 is a circuit of an active attenuation equaliser; briefly describe its operation.*
7. *With the aid of sketches explain how delay distortion is produced in transmission equipment.*
8. *What is "absolute delay"?*
9. *Sketch the absolute delay characteristics of a typical telephone channel.*
10. *What is the function of a delay equaliser?*
11. *Sketch the "group delay distortion" characteristic of a typical telephone channel.*
12. *State two reasons why it may be necessary to measure the group delay characteristics of a circuit.*
13. *Briefly describe the function of "line building out networks".*
14. *What is the maximum volume range (approximately) transmitted through line transmission equipment?*
15. *What conditions determine the limits of the maximum volume range?*
16. *With the aid of simple power-level diagrams show how a compandor can improve the margin between the signal and the noise.*
17. *Explain the terms "compression ratio" and "expansion ratio", as applied to compandors, and state typical values.*
18. *Sketch a simplified block diagram of a compressor and explain its operation.*
19. *What is the "unaffected level" of a compandor?*
20. *Discuss some typical applications of compandors in the communication network, and also their limitations.*
21. *Why is it sometimes necessary to use pre-emphasis and de-emphasis in:-*
    - *(a) Audio programme equipment?*
    - *(b) Broadband carrier telephone equipment?*

TEST QUESTIONS (CONT.D)

22. *Sketch the attenuation versus frequency characteristics of typical audio programme pre-emphasis and de-emphasis networks.*

23. *With the aid of a simple sketch explain how echo is produced in a four-wire circuit.*

24. *With the aid of a sketch explain the principles of an echo suppressor when:-*

    (a) One subscriber is talking.

    (b) Both subscribers are talking.

END OF PAPER

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