ROYAL SCHOOL OF ARTILLERY

BASIC SCIENCE & TECHNOLOGY SECTION
GUNNERY STAFF/CAREER COURSES

EM WAVE MODULATION

INTRODUCTION

1. Radio and radar systems are based upon the process of modulating EM waves. Radio is considered to be the process of voice communication. It may occur either in one direction only, as in commercial broadcast systems, or two way, as in military Command Communication and Control. Radio is necessary because it is impossible to communicate by voice over any great distance.

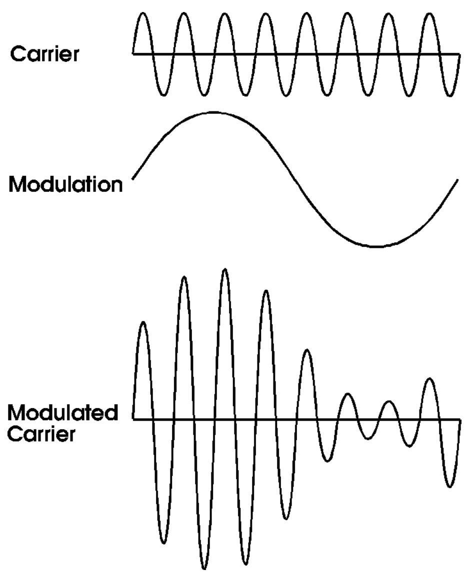


Fig.1. Amplitude Modulated Radio Carrier.

2. The process by which radio communication occurs is such that the longitudinal waves generated by voice are converted to a transverse form which can be made inherently more powerful. This signal is then transmitted as a transverse electromagnetic wave. At the receiver, arrangements are made for the required signal frequency to be selected, processed and converted from transverse to longitudinal form at the output. The longitudinal output device is normally a speaker or possibly headphones.

3. In some way it is necessary to superimpose the required message, or intelligence, upon the transmitted waveform, usually called the carrier. In electronic terms this means that the carrier must be modulated. Two major systems are currently in use, they are called the Amplitude Modulated (AM) and Frequency Modulated (FM) systems respectively.

THE AMPLITUDE MODULATED RADIO SYSTEM

4. In this system the intelligence is superimposed upon the carrier by modulating its amplitude at the required signal frequency. Fig.1, illustrates such a process where the modulating signal is at a single frequency of constant amplitude. In reality the voice signal is much more complex, being composed of many different frequencies, amplitudes and phases.

THE AM TRANSMITTER

5. Fig.2, shows the block diagram of a simple AM transmitter. It is comprised of four main elements. The Radio Frequency Oscillator, a Microphone, the Amplifier/Modulator and an Aerial,

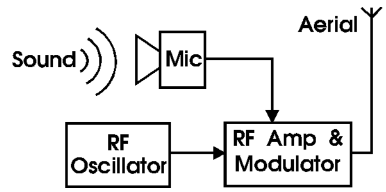


Fig.2. Simple AM Transmitter.

or Antenna as it is called in the USA.

6. The RF Oscillator is used to generate a carrier signal at the required transmission frequency. Its output is a constant frequency, constant amplitude waveform upon which the intelligence is to be superimposed.

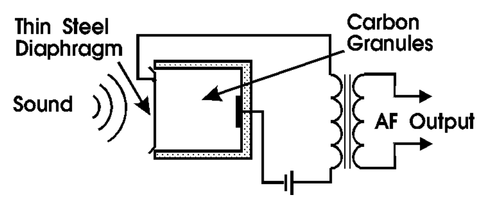


Fig.3. Carbon Granule Microphone.

7. The microphone is necessary to convert longitudinal voice waves into the transverse type required by electronic systems. There are many such devices, one of which, the Carbon Granule microphone, is illustated at Fig.3. Carbon granules have the property that their resistance falls as the material is compressed and increases as it is relaxed. Here the longitudinal voice wave is used to modulate the pressure on the granules via a diaphragm, so causing the circuit current to vary with the modulation in both intensity and frequency. The audio frequency signal is picked off at the transformer and delivered to the next stage as a transverse wave.

8. The RF carrier and AF modulation are both delivered to the Amplifier/Modulator stage. This circuit is effectively an amplifier which has the RF carrier as its input signal and the AF modulation varying the DC supply. As a result the output signal is a composite of both signals as previously shown, however, the signal is somewhat more complex than would appear from this and will be discussed more fully later in the text.

9. The modulated RF output from the Amplifier/Modulator is presented to the Aerial, which is cut to an appropriate length for the band of frequencies in use. This then radiates the transverse EM wave into the area surrounding it in a pattern deter-

mined by its construction.

THE TRF AM RECEIVER

10. The receiver comprises five elements as illustrated at Fig.4. They are the Aerial, RF amplifier, Detector, AF amplifier and loudspeaker. This type of receiver is called a Tuned Radio Frequency (TRF) receiver.

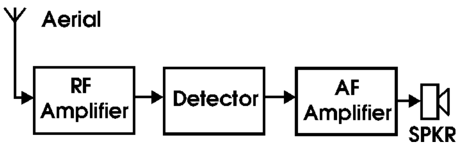


Fig.4. Tuned Radio Frequency AM receiver.

11. An aerial is necessary to maximise the signal component delivered to the RF amplifier. The aerial is 'tuned' by cutting it to a dimension approximately equal to one half wavelength at the carrier frequency. In many cases this would be of impossible length, so as long a piece of wire as possible is used.

12. The RF amplifier is frequency selective and 'tuned' to the appropriate frequency. This is achieved by the use of a parallel LCR circuit as the 'load'. Tuning of the receiver is carried out by variation of capacitance and selection of inductance.

13. The detector is used to pick off, or demodulate, the intelligence component from the received signal. It is a simple device employing few components and will be met later.

14. The AF amplifier is no different to those met previously in the course. It must amplify all the Audio signals, equally if possible, in order to reproduce the original voice wave. Its output is delivered to the loudspeaker in such a way that maximum power transfer takes place. This can often involve a transformer.

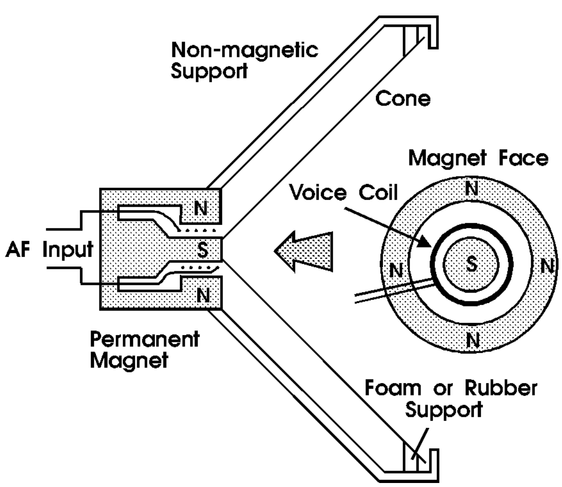


Fig.5. A Moving Coil Loudspeaker.

15. The loudspeaker is illustrated at Fig.5. It has the task of converting the transverse electronic signal into longitudinal sound waves for output. The principle by which it operates was met during the discussion on motors, ie. The current carrying conductor within a magnetic field. The conductor is wound around a cylindrical former located within the radial field emanating from the centre of the permanent magnet. When current flows in the coil, forces are generated which act axially along the centrally located pole. The axial movement is transferred to a cone of stiff fabric material, sometimes even plastic, which moves in and out creating the required sound.

THE SIGNAL SIDEBANDS

16. When the carrier is modulated by an audio signal it has the effect of generating other frequencies. For each modulating frequency, two other frequencies are generated one higher, or above, the carrier and the other lower, or below, the carrier. They are fc+fm and fc-fm respectively and are often called side frequencies. If a voice signal is modulating the carrier, many frequencies are involved, each of which has its own upper and lower side frequencies. Since the whole picture can be rather complex, the signal channel is often represented as a carrier plus sidebands as illustrated at Fig.6. It is important that the receiver being used to process the signal has adequate bandwidth (BW) so that none of the complex voice characteristics are lost.

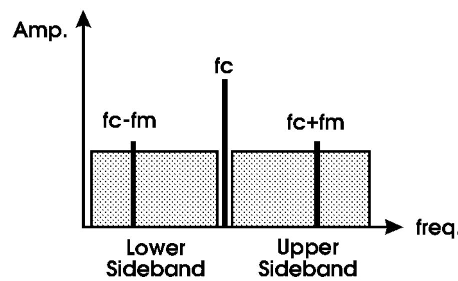


Fig.6. The Standard AM System Sidebands.

17. The main reason that European medium wave AM broadcasting has such a poor sound quality, is because in the early days of broadcasting a narrow bandwidth was specified, which resulted in the loss of higher frequency content. It was later realised that music in particular required a much wider bandwidth, up to about 15kHz. This is just not possible in the AM band. The other reason for the problem is that LCR circuit Q-factors of about 100-200 were necessary in order to extract the wanted signal from all others. Since BW=fo/Q and the rough centre of the AM band is 1,000kHz, BW=1,000,000/200. Which gives a maximum bandwidth of 5kHz. Thus since both sidebands must be allowed for, the highest frequency that can be processed is 2.5kHz. Poor even for voice, let alone music. In reality the bandwidths specified were even lower because of the stations at the lower end of the band. The modern FM system has solved this problem if only because of its natural wide bandwidth.

18. The TRF receiver can be used to good effect where the signal strength to be processed is high or a single channel is used. As soon as multiple stages of amplification, called Cascading, is required then problems with positive feedback causing oscillation and consequent 'howling' at the output occur. This is because when tuning is carried out in order to select a new station, all the frequency selective amplifiers must be tuned together. Hence, the tuning capacitors must be 'ganged' on the same tuning control shaft, this is the source of unwanted positive feedback.

'ganging' to get more amplification is overcome, because all the main amplifier stages are preset to a particular centre frequency and bandwidth. A typical AM 'superhet' block diagram is illustrated at Fig.7.

20. The frequency changer has two elements, the first is an oscillator, called the Local Oscillator, set up to beat with the incoming signals and the second is the mixer stage in which the beating is carried out and the difference frequency is formed. In order to ensure that all incoming signals are delivered to the fixed frequency amplifiers, called the Intermediate Frequency (IF) amplifiers, the LO must maintain the required frequency difference. eg, assume that the fixed frequency IFs are operating at 20kHz and that the signal frequency required is 100kHz. Then the LO must be tuned to deliver either 80kHz or 120kHz in order to form the difference. In most cases the higher of the two is used. Thus if the LO is tuned to 120kHz and beaten with the incoming signal at 100kHz the difference is

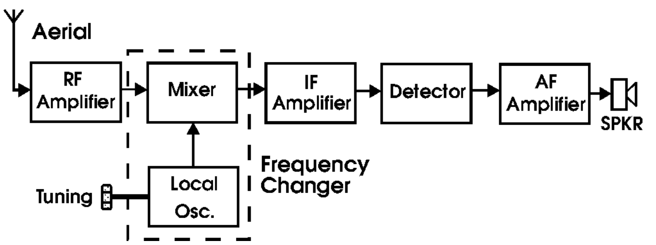


Fig.7. A SUPERHETERODYNE Receiver.

20kHz which corresponds to the IF requirement.
21. It is also true to say that signals of 140kHz would beat with the LO to produce the required difference of 20kHz, and thus cause interference. This effect is referred to as Second Channel interference and raising the IF frequency pushes this second channel further away from the band of interest. eg, if an IF of 500kHz is used then the LO must deliver 600kHz to beat with the incoming signal at 100kHz in order to form an IF at 500kHz. By selecting a high IF frequency the second channel has been pushed completely outside the band.

22. If a very high IF frequency is used, the natural bandwidth, BW=fo/Q, is such that the range of frequencies processed is wider than necessary and the adjacent channels begin to interfere with the required channel. By selecting a lower IF

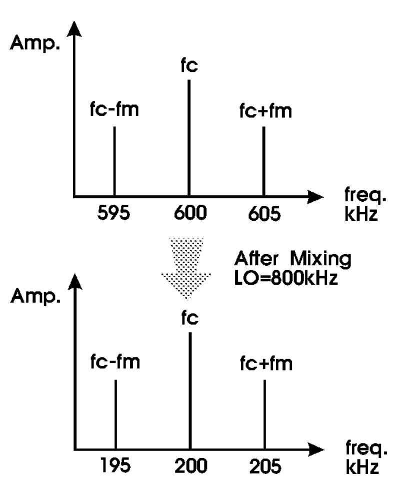
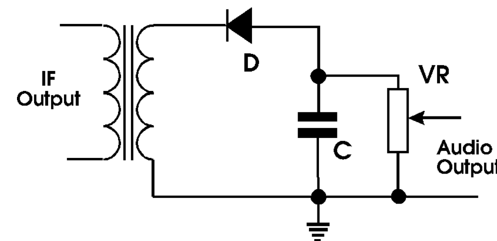


Fig.8. Preservation of AM Sidebands.

frequency this Adjacent Channel interference can be reduced. The reader will understand that the choice of IF frequency is very much a compromise between second and adjacent channel interference. In some military radio equipments two consecutive IF channels are used requiring two mixer stages. The first contains a high IF in order to eliminate Second channel interference and the second contains a low IF in order to eliminate Adjacent channel intereference. This forms the so-called Double Superhet receiver.

PRESERVATION OF SIDEBANDS

23. During the process of frequency changing, it is important that the intelligence content of the transmitted signal is retained. This means that the sideband content must not be lost in the frequency changing process, the diagram at Fig.8, will show that this is indeed the case. The carrier frequency is 600kHz and it has been modulated by a single frequency of 5kHz. The resulting side frequencies are illustrated, they are 605kHz and 595kHz respectively. This signal is now to be processed by a receiver employing an IF of 200kHz. Thus the required LO frequency will be 800kHz, which when beaten with 600kHz produces the IF centre frequency at 200kHz. At the same time 800kHz beating with 605kHz produces 195kHz and 800kHz beating with 595kHz produces 205kHz, as illustrated below. It can be seen from the diagram that the bandwidth of the original transmission has been maintained at the new lower frequency. However the upper and lower side frequencies have swapped sides, an effect called foldover, but none of



the signal message content has been lost.

THE DETECTOR

24. This stage is responsible for extracting the audio modulation from the RF signal emerging at the last IF amplifier. It is comprised of a diode followed by a CR network similar to that discussed during power supplies. A typical stage is shown at Fig.9. The diode rectifies the RF carrier, thus cutting it neatly in half, and the capacitor/resistor combination is selected so that the charge and discharge rate just enables the audio modulation to be followed. C charges through the diode and discharges through the resistor, which is shown at Fig.10. As a result any modulation is extracted and the following stage is supplied with the audio content only. A low pass filter can be added to remove the carrier content in much the same way that choke-capacitor smoothing was used in the power supply networks. The resistor can be made variable in order to act as a 'volume' control.

AUTOMATIC GAIN CONTROL

25. EM waves are subject to varying conditions during transmission which can lead to fading at the receiver. This means that the volume level seems to be rising and falling over a given period of time. Since the average level of the rectified RF signal at the detector is representative of the signal strength, a portion

of the diode output is taken and its average level used to control the gain of the IF amplifiers. This is achieved by the use of yet another CR combination in which the DC level developed across the capacitor is fed back to control the gain. Now, as the average RF level increases, the rise in feedback voltage reduces the gain of the IF amplifiers, bringing the RF signal back to its previous level. On the other hand, if the RF level falls, the fall in feedback voltage increases the gain of the IF amplifiers, bringing the RF signal back to its previous level again. Obviously there is a limit to the range over which AGC can operate

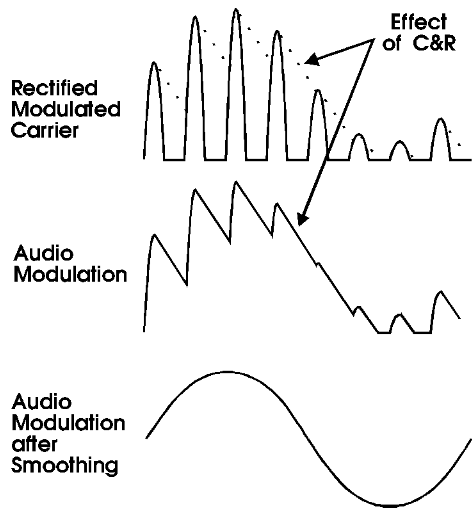


Fig.10. Detector Waveforms

and once outside that limit some fading will be experienced, however it is generally successful in most radio systems.

THE FREQUENCY MODULATED RADIO SYSTEM

26. This system has substantially replaced the older AM radio system as far as local radio is concerned and in the military sphere a steady changeover has been going on over a few years. It should be realised at the outset that system coverage area is limited because of the frequencies used, ie, VHF band,

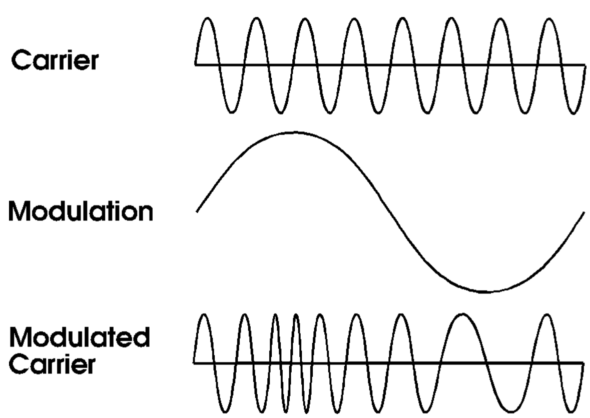


Fig.11. Frequency Modulated Radio Carrier.

giving poor range for given transmitter power. On the other hand this has the advantage of making it very much a local system.

27. The AM system conveyed the intelligence of the signal by varying the magnitude of the carrier but holding its frequency constant. The FM system conveys the intelligence by holding the amplitude of the carrier constant but varying its instantaneous frequency. The diagrams at Fig.11, illustrate the FM system.

DEVIATION OF FREQUENCY

28. As can be seen from the diagram, the carrier frequency changes are dependent upon the ‘loudness’ or amplitude of the modulating signal, the amount by which the carrier changes is called the Deviation of Frequency. Clearly, a limit must be set for the maximum loudness permitted by the system, this limit is called the MDF, Maximum Deviation of Frequency. For standard FM broadcasting systems it is of the order 0.1% of the

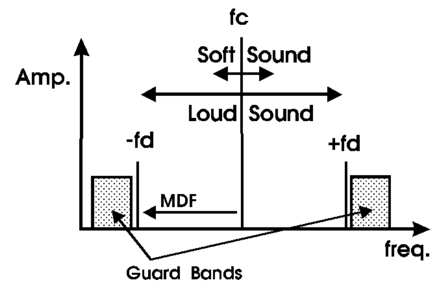


Fig.12. FM System Sidebands.

carrier, sometimes called resting, frequency. It will be apparent that there must be an upper MDF and a lower MDF.

29. The spectral content of an FM signal is most complex, however, the simple diagram at Fig.12, illustrates the operational use of a single FM channel. The Guard Band should be noted, within which no transmission is permitted, in this way adjacent channel interference is eliminated. The bandwidth requirement for FM is very wide, this can be met quite easily at the frequencies in use, commercial radio uses 88-108MHz, because at say 50MHz with a Q of 100 then BW=fo/Q, giving a BW of 500kHz. This is enormous when compared to the AM frequency band and indicates why the FM system has natural high quality voice and music. A much higher Q can be used making the channels even more selective.

FREQUENCY OF DEVIATION

30. This is a most distressing term when it is first met because of the obvious clash with Deviation of Frequency. It is probably better thought of as Rate of Deviation. The term is meant to convey how increasing the frequency of modulation at a given amplitude does not change the amount of deviation of frequency, merely the rate at which it occurs. Thus a doubling of modulating frequency means that two complete cycles of carrier deviation are passed through in the same time as one cycle was passed through at the lower frequency. Hence, the frequency of deviation has increased.

THE FM RECEIVER

31. Since the FM system does not vary the carrier amplitude, a standard AM detector system for removing the audio modulation from the carrier is not going to work. Clearly some other system is required within the receiver for modulation extraction. The stages which take the place of the detector are illustrated in the block diagram at Fig.13, below. The receiver is in effect a standard superhet, however, the detector is removed and a limiter/discriminator combination takes its place.

THE LIMITER

32. This device is merely intended to remove any amplitude modulation which has been produced during transmission, such modulation can have severe distorting effects within the

receiver and must be eliminated. The limiter is in effect a standard IF amplifier which has been slightly overdriven, this

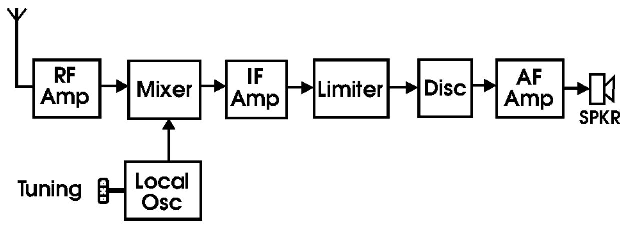


Fig.13. The FM Receiver

means that it clips the IF signal at the required amplitude. Hence amplitude modulation is removed at the expense of slight frequency distortion which is almost unnoticed.

THE DISCRIMINATOR

33. The discriminator is used to remove the audio modulation from the frequency modulated carrier. A number of different types are available. One of the more simple devices which are commercially available is discussed with reference to the diagram in Fig.14. It is merely called a Frequency Discriminator. The input to it is derived from the parallel tuned circuit associated with the last IF stage, which forms the limiter. This

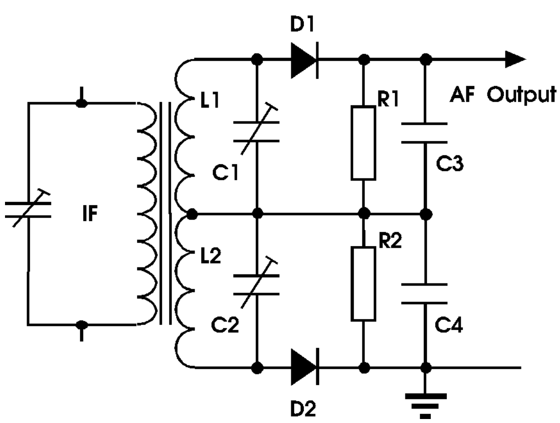


Fig.14. A Frequency Discriminator.

is tuned to the IF centre frequency with adequate bandwidth for the signals being processed. Transformer coupling is used to deliver the signal into the frequency discriminator stage.

34. The two secondary resonant circuits, L1C1 and L2C2 are tuned so that one response peaks slightly above the carrier frequency and the other slightly below as shown in Fig.15. The peaks of response must occur outside the upper and lower MDFs respectively and the crossover point is at exactly the carrier frequency.

35. D1, R1 and C3, rectify the RF signal across C1, as do D2, R2 and C4 for the signal across C2. The diode current paths are such that the top end of R2 is negative with respect to its bottom end and the top end of R1 is positive with respect to its bottom end. Hence, if the signals across C1 and C2 are identical in magnitude, ie, at the carrier frequency (Centre IF), then the PD across R1 is identical to the PD across R2 and the output is zero Volt.

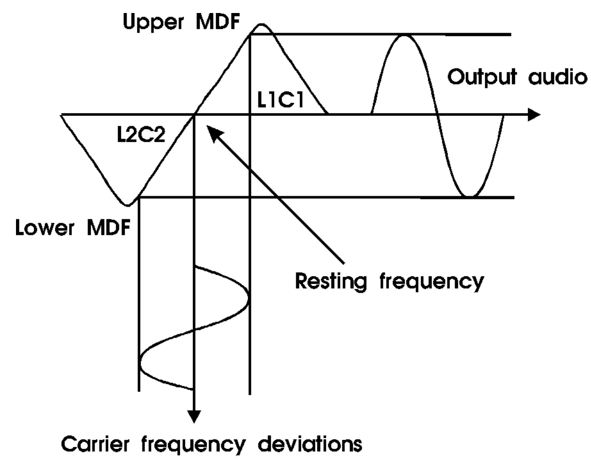
36. When the carrier frequency is deviated above the centre, or resting, frequency the response from L1C1 rises producing a larger signal across C1 which is rectified producing a larger PD across R1. This causes the output voltage to go positive, since VR1 is now greater than VR2.

37. When the carrier frequency is deviated below the centre frequency the response from L2C2 rises whilst L1C1 has fallen. This produces a larger signal across C2 which is rectified producing a larger PD across R2. The top end of R2 is now more negative and the output voltage goes negative, since VR2 is now greater than VR1 but of opposite sign.

38. As the audio modulation swings the carrier above and below the resting frequency the output voltage from the discriminator swings above and below zero volts. The output voltage is varying at the audio frequency with amplitude determined by the deviation of the carrier, in other words as the original modulation.

AUTOMATIC FREQUENCY CONTROL

39. If the receiver is slightly off tune, ie, the LO is not exactly at the correct frequency to place the carrier at the IF, but may be slightly above or below it. Then the response from the discriminator will not be above and below zero volt, but will be above and below some small DC potential proportional to the displacement of the carrier from the centre tuned point. This DC is now fed back to a VARACTOR DIODE in the LO tuned circuit, where its capacitance is altered by the DC level and caused to retune the LO to the correct frequency. As soon as that point is reached the carrier returns to the centre of response, the discriminator

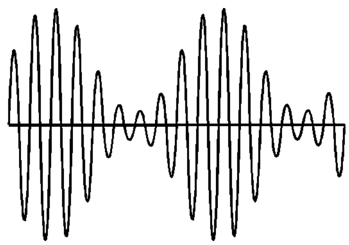


output no longer contains a DC element and the receiver is automatically maintained at the correct frequency for the station being worked.

SELF TEST QUESTIONS

Each question has a single fully correct answer. Check all of the options carefully before making your choice.

1. The following diagram illustrates a type of modulated carrier used in radio. The particular system of which it forms part is called:-

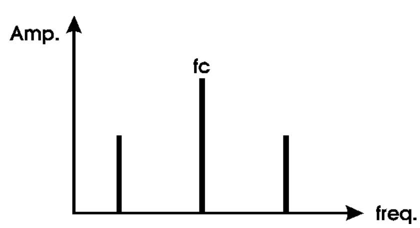


a. AM
b. PM
c. FM
d. QM

2. A certain radio system employs a TRF receiver for single channel reception at long range. The reason that such a receiver would not be used when many different stations, in a given band, may need to be selected, is because:-

a. AGC circuits cannot be designed to cope with all of the various RF signal levels
b. ganged tuning would be required, leading to positive feedback and howling
c. it is impossible to acquire the necessary bandwidth at the higher frequencies
d. the aerial system becomes too complex

3. The following diagram illustrates the RF signal from a simple amplitude modulated transmitter. The diagram shows that



the:-

a. RF signal contains only two frequencies, the carrier and the modulating signal
b. carrier signal is being modulated by three different frequencies
c. carrier signal is being modulated by two different frequencies
d. carrier signal is being modulated by a single fre quency

4. A superheterodyne receiver is one in which:-

a. a frequency changer is employed
b. AGC cannot be used
c. an IF is formed at the transmitter carrier frequency
d. double sideband reception is not possible

5. A superhet receiver uses a 10.7 MHz IF and is required to process an incoming RF signal at 88.5 MHz. The local oscillator may be tuned to:-

a. 77.8 MHz
b. 99.2 MHz
c. either 77.8 MHz or 99.2 MHz
d. none of the above frequencies

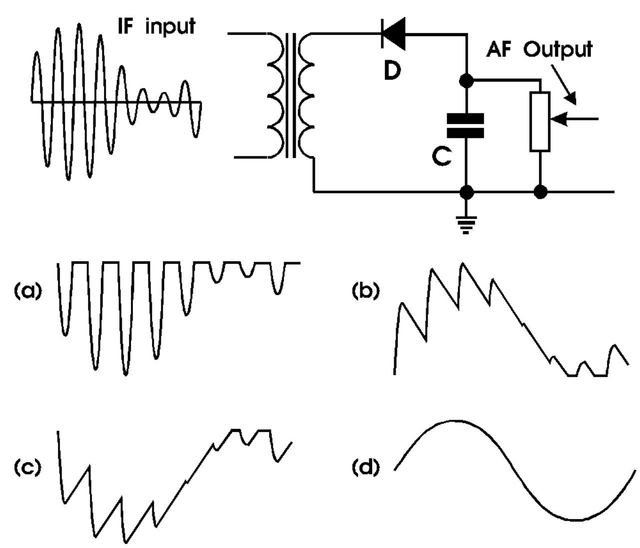
6. One of the problems produced when using high gain receivers in radio and radar systems, is that interference between channels can occur. Adjacent channel interference is caused by:-

a. other transmitters physically located too close to the receiver being interfered with
b. other transmitters operating at the second fre quency which can mix with the LO and form the IF
c. not using a frequency changer stage in the receiver
d. the receiver bandwidth being too wide

7. A simple AM transmitter is operating at a carrier frequency of 150 kHz and is modulated by a single frequency of 3 kHz. The receiver LO operates at 200 kHz to form an IF centred on 50 kHz. In order to receive all of the transmitted RF, the bandwidth of the IF stages must be at least:-

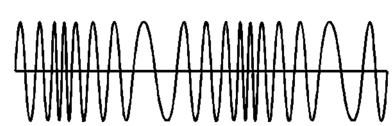
a. 6 kHz
b. 3 kHz
c. 150 kHz
d. 200 kHz

8. The following diagram shows the detector stage of an AM radio receiver. If the capacitor, C, was removed from the circuit



the output waveform would take the form given by:-

9. The following diagram illustrates a type of modulated carrier used in radio. The particular system of which it forms part is called:-



a. AM
b. PM
c. FM
d. QM

10. An FM receiver employs a frequency discriminator to remove the audio signal from its RF carrier. In such a circuit:-

a. the size of the output voltage is proportional to the deviation of the carrier from its centre frequency
b. two tuned circuits are employed, both working above the carrier frequency
c. the size of the output voltage is proportional to the rate of carrier deviation from its centre frequency
d. two tuned circuits are employed, both working below the carrier frequency