TWO WAY RADIO COMMUNICATION TRAINING PROGRAMS
FOR THE NATIONAL POLICE OF IRAN

FM RECEIVERS

Prepared By ZORIS L. WILKINS

US/AID PUBLIC SAFETY DIVISION

PREFACE

In my travols in the East and Far East I have noticed one thing in common about these countries, a desire for technical knowledge that is frustratod because of language barriers. In addition, most of the common technical words have no counterpart in these languages.

This book is number one of a series of three books especially written to assist translation and to give a type of technical assistance that will be useful for many years to come.

Zoris L. Wilkins
US AID - PSD

ACKNOWLEDGMENT

Permission has been granted (October, 1961) by Motorola Training Institute, U.S.A. to use portions of training material for U.S. technical assistance programs. (No charge will be made for a ny of this material, before or after translation.)

CHAPTER ONE

Progress today is greatly accelerated by the use of Electronics. The two most important uses of radio and electronics are:

1. The use of uncensored radio news broadcast to advise the people of world events at the moment these events occur. Also all aspects of local problems that the majority of the people will support or reject.
2. Public safety radio communications used in all modern police systems is designed for the suppression of crime, protection of individuals and national security.

This is written for the reader with limited mathematical background who is interested in studying the basic principals of electricity as applied to frequency modulated radio. As the beginning of this training manual is a review of previous studies, most detailed explanations are ommitted. However, basic items are mentioned and if forgotten should be looked up in a detailed manual or explained by your instructor.

Therefore, radio is a means of sending and receiving intelligence between distant points in a fraction of a second without the use of wires connecting these points.

It is important to know something about sound and sound waves before studying the principles of radio as there is a direct relation between sound and radio in radio communication.

Air in a place where no sound is made is said to be motionless. If a sound is made it sets the air in motion at one or more audio frequencies and these vibrations strike the ear drum and the ear drum will vibrate at this frequency causing the nerves to transmit the sensation of this sound to the brain. These vibrations are called sound waves. Sound waves are produced by mechanical vibrations of material in the medium of air. The strings of a violin or the radio cone of a speaker will send out sound waves. These waves will produce different sounds relative to the frequencies of the air vibrations. The tone of sound will vary directly with the frequency of the air vibrations set in motion by the sound source. The audio frequency range that can be heard by the average human ear is 20 cycles to a maximum of 20,000 cycles. All people do not hear the complete audio range but most people in varying degrees, can hear from 50 cycles to 10,000 cycles, the human voice is within the range of 75 cycles to 3,000 cycles.

Radio Waves

Audio waves and radio waves are similar in the fact that they are alternating frequencies. The difference is audio frequencies vary to produce different sounds and high frequency radio waves are controlled to a specific frequency (exact time interval). Varying audio waves are super imposed on the radio wave and therefore, the radio waves is a carrier of audio wave.

It should be noted that a radio transmitter besides being a carrier of information is a manufacturer of a specific desired frequency and a transformer of current into space (free space elections).

By referring to Figure 0 it is seen that an AC wave has completed a cycle after two alternations, one positive and one negative. It can also be seen that the maximum value in both directions are the same.

Velocity of radio waves

Audio waves travel at approximately 236 meters per second and are quickly absorbed by air, but radio waves travel at the constant rate of 186,000 miles per second. (300,000,000 meters per sec.) It must be noted, this velocity is regardless of frequency. Frequency denotes how many times each second the current changes from a positive direction to a negative direction as it travels thru space at the rate of 300,000,000 meters per second.

Example 1. Radio waves travel at 186,000 mps. What is their velocity in meters per second?

Miles per second	186,000	inches per meter	39.37
Feet per mile	5,280		
Inches per feet	12		

$$\frac{186{,}000 \times 5{,}280 \times 12}{39.37} = 300{,}000{,}000 \text{ per second}$$

Wave length or antenna length in inches above 50 megacycles

$$\frac{5904 \times .925}{\text{Freq. in Meg.}} = \tfrac{1}{2} \text{ wave in inches}$$

Antenna length in meters

$$\frac{300,000,000}{\text{Freq. in cycles}} = 1 \text{ wave length in meters}$$

$$\frac{300,000}{\text{Freq. in kilocycles}} = 1 \text{ wave length in meters}$$

$$\frac{300}{\text{Freq. in megacycles}} = 1 \text{ wave length in meters}$$

In the above samples you will note the use of the words cycles, kilocycles and megacycles. These words are associated with all electronics and radio as they are a means of making numbers smaller and easier to handle therefore, making problems easier to solve.

1 Cycle is 1 as explained in figure #1.
1 Kilocycle is 1,000 cycles
1 Megacycle is 1,000,000 cycles

Transmitting stations send out radio waves by the use of alternating currents and voltages at high frequencies. The electromagnetic and electrostatic fields produced by this means is called radio waves. The strength and frequency of the radio wave is dependent on the power and frequency producing it and it will vary directly with the source.

An (a.c.) alternating current will vary its direction at exact intervals and at each interval the current will go from zero to maximum then return to zero.

(Because an alternating current can be readily transformed from low to high or from high to low voltages it is possible to send large amounts of power at low current through wires of small diameter. It is cheaper to transmit an alternating current over great distances than a direct current, and for this reason it is the type of current used in industry, offices and homes.)

In radio receivers and transmitters, transformers are always a part of the unit so as to change the voltage to the designed requirement of the equipment. These requirements are usually higher and lower than the city voltage. This is accomplished by specially designed transformers that have connections on its output for both the low voltage and the high voltage. To operate the tubes used in mobile radio we need a high voltage as well as low voltage but the power available is a battery which is direct current. To transform this current it is necessary to change it to alternating current or interupted direct current. A simple coil with many windings is used so the instant the on-switch is closed the current starting from zero reaches maximum very rapidly, as this occurs a magnetic field is developed that separates the electric circuit connection, instantly the magnetic field colapses allowing the electric connection to again close. This happens many hundreds of times a second. This changing current passing thru the primary windings of a transformer in pulses from zero to maximum to zero will cause induction of pulsating current into the secondary of the transformer. This voltage is rectified and filtered to the high voltage direct current required.

Ohms Law

The flow of electricity through a circuit in many ways resembles the flow of water through pipes.

In the flow of water thru pipes we are interested in 3 things:

1. The cause of the flow (pressure)
2. The rate of flow in a given time
3. The factor regulating the flow (resistance)

The rate of flow is controlled by pressure. If the pressure is increased the flow will increase. If the pressure is decreased the flow will decrease. If there is no pressure there is no flow. The rate of flow therefore, is directly proportional to the pressure causing it to flow. If the resistance (friction of the walls of the pipe elbows angles etc.) is increased, the flow of water will decrease. If the resistance is decreased the flow of water will increase. Therefore, the flow of water is inversly proportional to the resistance of the pipes.

In the study of electricity we find we have three terms that compare with the flow of water:

Electric pressure is voltage
Rate of electric flow is current
Electric resistance is resistance

Ohms Law Formula

The electric equation found to determine the values of voltage current and resistance is equation 1, current $= \frac{\text{Voltage}}{\text{Resistance}}$. This is the Ohms Law formula.

Ohms law is the foundation upon which the study of all electronics is based. It is essential that this law be fully understood before a study of any one of the branches of electricity is attempted. Ohms law may be stated in 3 ways (Equation 1 - shown above) Equation 2 - Voltage - current x resistance, Equation 3 - resistance $= \frac{\text{Voltage}}{\text{current}}$.

The following conclusions can be established from a study of these three equations.

No. 1. - The current will increase if a voltage applied is increased or the resistance is decreased, and will decrease if the voltage is decreased or the resistance is increased.

No. 2.-- Higher voltage is required to force a larger current through a fixed resistance or to force a fixed amount of current through a higher resistance and a lower voltage is required if a smaller current is desired or if less resistance is used.

No. 3. - The value of any resistance will increase if the voltage applied is increased or the current is decreased, and the resistance will decrease if the voltage is decreased or the current is increased.

Fundamental Electrical Units

In every scientific subject there are definite units of measurement. It is necessary that we know these units in order to predetermine how a condition will change when any quantity of which it is made is varied.

In electrical work certain units have been adopted as standard by all countries of the world. As electricity and radio are both branches of the field of electronics the units used in electricity and radio are the same.

As current is the flow of electrons a brief explanation is necessary. A combination of protons and electrons are called an atom. All material is made up of atoms. The difference in material lies solely in the arrangement of its protons and electrons but all electrons are the same whether from an atom of copper, aluminum, or carbon. The difference or the reason these materials are different is an atom of copper has 64 protons, 35 fixed electrons and 29 orbital or free electrons, an atom of aluminum has 27 protons, 14 fixed electrons and 13 orbital electrons, carbon has 12 protons, 6 fixed and 6 free or orbital electrons. Scientist have learned that the center of an atom, called the nucleus, is positively charged and the electrons negatively charged orbit around the nucleus much the same as the earth and other planets orbit around the sun. In an ordinary conductor most of the electrons are revolving about their nuclei and ~~some~~ the orbital or free electrons are moving in their loose orbit. If this conductor were part of an electrical circuit, the free electrons would be attracted to the positive charged connection and the power source negative connection would furnish electrons thru this conductor to keep the electrons in balance. If the positive voltage was increased without increasing the size of conductor or wire, the wire or conductor would become hot. If the voltage was increased still more the conductor or wire would burn up.

Ampere

The effect produced by the flow of electrons through a conductor are all dependant on the amount flowing per unit time and not on the total amount of flow. For example, a quantity of electrons (several billions) may raise the temperature of a conductor 10 degrees if it flowed through the conductor for one second. If this same amount took one hour to flow through the same conductor the heat produced would total the same but the instant increase in temperature would be slight, as the same heat is spread over one hour, the instantaneous amount would be very small. It is therefore necessary to know the rate of flow rather than the amount of flow. As the number of electrons flowing for one second (6,280,000,000,000,000,000) is a large and unwieldly number so it is not used to denote the quentity of current per unit time. A practical unit has been established to denote this amount of electrons passing a given point per second. This large amount of electrons is shown on all meters as 1 and is called ampere.

The Volt

It has been shown that the free electrons in a conductor can be made to flow in a definite direction by applying a positive charge to one end of a conductor. This positive charge exerts a force on the electron and draws them to it. An electric force exists between any two bodies having different polarities of charge and this is called electromotive force, which is generally abbreviated as EMF. The practical unit of EMF is VOLT. Through common usage EMF is referred to as Voltage.

The Ohm

Certain materials has many free electrons and allow these free electrons to travel through it more easily, these materials are called Conductors. All material has varying amounts of resistance to the flow of current and can be measured by an Ohm-meter. This ohmmeter is calibrated to make the mathematical calculation based on the fact: one ohm is the opposition offered to the flow of one ampere under the pressure of one volt. (Inverse to conductors, resistance material has few free electrons and is used to control the flow of current.)

Power

Power is the rate of doing work per unit time. Therefore, we can express power by this formula power = $\frac{\text{Work done}}{\text{time}}$ or one watt = 1 volt x 1 ampere.

Electric symbols of resistance, volts and amperes (R, E and I) are used to determine power. The proper combination of these symbols to make the proper formulas are:

$$EI = W, \quad I^2R = W, \quad \frac{E^2}{R} = W$$

Example 1

If the final amplifier of a transmitter has one ampere flowing in the plate circuit and a pressure of 1000 volts, what is the apparent power in watts?

$E \times I = P \quad 1000 \times 1 = 1000$ watt apparent power

Example 2

What power is consumed by a circuit whose resistance is 80 ohms and has a current of 1.5 ampere?

$I^2 \times R = W \quad 1.5 \times 1.5 \times 80 = 180$ watts

Example 3

What power is used by a circuit that has a resistance of 75 ohms and is connected to 15 volts?

$$\frac{E^2}{R} = \text{Watts} \quad \frac{15 \times 15}{75} = \frac{3 \times 15}{15} = 3 \text{ Watts}$$

Energy

Energy is the capacity to do work. The units for energy is therefore the same as work. The amount of energy in the universe is always constant, for, according to the law of conservation of energy, it can neither be created nor destroyed but can be changed from one form to another. A battery changes chemical energy to electrical energy. A generator changes mechanical energy into electrical energy. The energy of electric current will be the energy of moving electrons.

If we have a 100 watt lamp in a room and no current was flowing through its filament the lamp would not radiate light. No work would be done, and therefore no energy would be used. If electric current was caused to flow the lamp would radiate light and by using the formula $\frac{W}{e}$ Voltage 220, watts 100.

Example: $\frac{100}{220}$ = .454A or 454 Milliampers.

1 Millivolt = $\frac{1}{1000}$ of a volt

1 Milliampere = $\frac{1}{1000}$ of an ampere

The prefix Kilo means 1000 and it is used to designate large amounts of voltage and power.

1 Kilovolt = 1000 volts
1 Kilowatt = 1000 watts

Another unit of electrical power is the horsepower: 1 horsepower = 746 watts. The prefix Meg means one million 1,000,000 and is used to designate high resistance such as = 1 Megohm - 1,000,000 ohms.

Square Root

Previously Ohms law has been explained along with the formulas to find current, Voltage and Resistance and also the power formulas that are solved by the same simple mathematics. Now we will take up the two remaining power formulas that are solved by the use of square root.

1. $\sqrt{WR}$ = Voltage (V)
2. $\sqrt{\frac{W}{R}}$ = Current (I)

The process of deriving the square root can best be explained by working an example. Given the power and resistance we must find the voltage, as in the number 1 formula above we find that the power and resistance multiplied together we get the sum of 52805.3670. From this figure we must extract the square root which will be the voltage.

E = 52805.3670

1. Set down the number and divide the digits on each side of the decimal point into groups of two; start at the decimal point and work toward the left and then again from the decimal point and work toward the right. It is possible for the extreme left to have only one digit. If the extreme right group contains only one digit a zero is added so it will have two digits.

The number $\sqrt{52805.367}$

Example:

```
   2
 /5-28-05.36-70
  4
 /1
```

2. Find the largest number when multiplied by itself will go into the first group. In this example the group is 5 and the largest number that can be used is 2. We now write the 2 above the 5. Next double the root number 2 and place it under the 5. Its value is 4. Then substract the 4 from the 5 leaving a value of 1.

```
                    2 a
Example b -       /5-28-05.36-70
                   4
                4a/128
```

3. Now bring the next group of numbers down along side the remainder and draw a separation mark to the left of the 128. (Example b). Double that part of the square root already found and also place this number at the right of the 128 in the separator. This number placed in position as in example b, when multiplied by the combination (4a x a) that will give the largest number that will go into the remainder which is 128.

```
                    2   2
Example c -       /5-28-05.36-70
                   4
                42/128
                    84
                  _/44
```

This step is done by the trial and error method. By trying 3 we find 43 x 3 is 129 which is too large so we know we must use two. 2 x 42 is 84 and by looking at example c we see a remainder of 44.

5. Now we must bring down the next group (05) beside the remainder 44 and repeat the procedures as in example d.

```
                   2  2  9. 7  9 = Voltage
Example d -      /5-28-05.36-70
                   4
              42/128
                  84
             449/ 4405
                  4041
            4587/  36436
                   32109
           45949/   432770
                    413541
           ______/   19229
```

Double the root already found and find the largest multiplier that can be used. Continue until all numbers are filled above each group in the original numbers.

6. Notice that the decimal point in the root is placed exactly above the decimal point in the original number.

7. Should any of the divisors be too large to go into the remainder, a zero is placed in the root above that group and the next pair of numbers brought down. If it is desired to have more digits to the right of the decimal in the problems answer one or more pairs of digits can be added.

CHAPTER TWO

What is Frequency Modulation

Today almost all mobile two-way radio equipment uses frequency modulation rather than amplitude modulation. Therefore, if we are to think intelligently about the operation of present-day two way communication equipment we must thoroughly understand what is meant by frequency modulation - abbreviated F.M. The FM receiver is remarkably free from noise and adjacent station interference. Also the FM transmitter is more efficient in that it requires less power input for a given coverage than those used in AM (amplitude modulation).

FM is not particularly new. Not many years have passed, however, since it was first put to practical use. In 1939 the first successful state-wide mobile FM system was designed for the Connecticut State Police. Since then frequency modulation has been accepted universally as the best modulation method for mobile two-way communications systems.

Todays widespread use of FM demand that you, the technician, think in terms of FM as readily as you do in AM. One of the best ways to approach FM is to compare it to AM. Let us start with a quick review of AM and see how the two differ.

Amplitude Modulation

In any basic radio communications system consisting of transmitter and receiver, the transmitter produces and radiates a signal in the nature of high-frequency electromagnetic energy.

The receiver must select the desired signal and reproduce the message in its original form. Because low frequency audio cannot be radiated efficiently, a high frequency wave, called the radio frequency (R.F.) is used to carry the message to the receiver. That is the audio frequency is combined with this RF carrier, and in this manner the message reaches the receiver as part of the radiated signal. This process of combining the audio with the carrier is called modulation.

In modulating the carrier it is possible to alter the frequency or the amplitude.

It is also possible to alter phase of the carrier but as the FM receiver receives it the same as FM we will discuss it later. If the audio causes amplitude changes in the transmitted RF the system is known as "amplitude modulation". If the audio signal causes corresponding frequency changes in the transmitted RF, the process is called "frequency modulation".

The function of the receiver, whether AM or FM is to recover the original audio message from the carrier and reproduce it in the speaker.

Figure one is the block diagram of a simple AM transmitter. The RF carrier, generated in the oscillator stage, is constant in both frequency and amplitude. This RF carrier (represented by closely spaced waves) is amplified in the power amplifier and fed to the antenna, and then radiated into space. Something has happened however, to the steady

RF amplitude in the power amplifier stage, modulation has taken place. An audio voltage applied to the power amplifier at the same time as the RF has changed (modulated) the RF amplitude according to the amplitude of the audio signal. Lets see how this happens.

When sound waves strike the microphone diaphragm they are changed into corresponding audio voltages. These low frequency mike voltages are constantly changing both in amplitude and in frequency. This audio voltage is then applied to an audio amplifier (or modulator) where it is amplified to the level to properly modulate the power amplifier. Thus, there are two voltages applied at the same time to the power amplifier. One of them is a steady RF from the ascillator, the other is the audio (modulating) signal from the audio amplifier. Although the PA operates as an RF amplifier, its output is made to vary according to the amplitude of the audio signal. The audio signal is a low frequency alternating voltage. The positive half cycle increases the RF output, the negative half-cycle reduces the amplitude of the output. This means the amplitude of the RF output changes in exact accordance with the audio signal, while the frequency of the carrier remains unchanged, but the RF amplitude varies with the spoken message.

Amplitude Modulation

Compared to the AM system, the FM system makes more efficient use of the power taken from the primary power source. (The car battery in the mobile). The power output of the AM transmitter increases under modulation, to the extent that the power level at the peaks may be 4 times the power of the unmodulated wave. This means the level of the unmodulated carrier must be lower than the capabilities of the final output tube. Also because of the high current and voltage peaks the power supply and transmitter are bulky, heavy and costly. By comparison the FM transmitter operates at full power output at all times, its output power does not change with modulation. This greater RF power level means increased coverage for the same amount of power taken from the source. Also the FM transmitter is smaller lighter and more economical to build.

The AM Receiver

The desired RF Carrier reaches the antenna of the AM receiver (figure 1) together with carriers from other transmitters. The first action within the receiver is selection of the desired carrier from all the others. Because this RF voltage at the antenna is very weak it must be amplified. Figure one shows only one block diagram for the receiver RF Amplifier, but in the Communications receiver there may be more than one high gain stage. From the RF Amplifier this signal is applied to the detector, a device that reacts to amplitude changes. Since the amplitude of the RF wave is changing according to the spoken message at the transmitter, the detector output is an audio voltage corresponding to the audio wave form produced at the transmitter microphone. This signal is then applied to an audio stage, which amplifies it enough to reproduce the message in the speaker.

In connection with the detector's response to the amplitude variations, we should talk briefly about the noise voltages in the receiver itself. Almost all of these noise voltages are amplitude variations. Therefore, noise voltages reaching the AM detector will be heard in the speaker. These noise voltages may be (1) man made (2) natural noises from atmospheric disturbances (3) they may be generated within the receiver itself. We will study more about noise in a later session.

Figure 2 shows a very simple arrangement of a very simple type of FM transmitter. The ascillator serves the same purpose in the FM transmitter as it does in the AM transmitter, to generate the RF voltage of constant amplitude and frequency. There is a big difference, however, when an audio voltage is introduced. In an AM system the audio produces amplitude variations in the carrier, in an FM system the audio frequency produces frequency variations. Lets see how this happens. Figure 2 shows a simple oscillator with its frequency determined almost entirely by its inductance and capacitance of the tank circuit, (L and C). A condenser microphone is connected in parallel with the tank so it becomes a part of the total capacitance of the tuned circuit.

This type microphone is constructed of 2 metal plates, slightly separated from each other, forming a small capacitance. One plate is fixed the other is moveable. The moveable plate is the mike diaphragm. When it is moved back and forth by the sound waves, the space between the two plates varies, and the capacitance in parallel with the tuned circuit alters the total capacitance changing the oscillator frequency.

As the diaphragm moves closer to the stationary plate, the capacitance increases and the frequency decreases. When diaphragm moves away from the other plate the capacitance decreases and the frequency increases. Thus as the diaphragm continues to move back and forth a audio frequency modulated signal is produced.

Figure 2 shows the waveform of this FM signal in the oscillator plate circuit. The carrier frequency varies with the audio, but the amplitude remains constant. At certain points the waves are close together, representing a relatively high frequency. At other points the waves are further apart, representing a lower frequency. The plate circuit is tuned to the unmodulated oscillator frequency. The FM signal is coupled from the plate to the transmitting antenna.

Very little audio power is required in the FM transmitter illustrated in figure 2. This is another important characteristic of frequency modulation. Regardless of the total RF power output, only a small amount of audio modulating power is needed in an FM transmitter.

Extent of Frequency Change

While discussing frequency variation of the RF carrier, nothing has been said so far as to what extent the RF signal varies above and below the carrier frequency, nor has anything been said as to how often or at what rate the frequency changes. These factors are important and we must know how they are controlled by the audio signal.

Figure 3A shows a typical FM waveform which represents the output of the FM transmitter of figure 2. From the beginning of the waveform to "point 1" the FM frequency is constant. This is an unmodulated R.F. wave. Then it is modulated between 1 and 2, the RF increases in frequency - the waves are closer to-gether. (At 2 the RF reaches its highest frequency.) Between 2 and 3 it is returning to its average or unmodulated frequency. From 3 to point 4 the carrier swings below its average frequency, the lowest value occurring at point 4. At point 5 the RF has again returned to its normal unmodulated value, ending a complete FM cycle.

Now that we have seen the nature of the frequency modulated wave of figure 3A, lets inspect the audio voltage which is shown as the sine wave in figure 3A. Up to point 1 in the figure the audio voltage has zero amplitude and the corresponding RF voltage at that point is unmodulated. Between 1 and 3 the audio goes through a positive alternation, during this same period the RF frequency increases and returns to normal. At point 2 where the audio is maximum positive, the RF has its greatest frequency increase. Between 3 and 5 the audio changes polarity, so that it is now negative. The RF frequency between points 3 and 5 again varies but in the opposite "direction", that is it swings below its average frequency. From the audio sine wave in figure 3 A we see that every time the audio goes positive the RF frequency increases, every time the audio is negative, the frequency decreases.

The next question to consider is the effect of applying a stronger audio signal - (talking louder in the microphone.) Lets assume some definate value of frequency change in figure 3A RF wave-form. Suppose in 3A the frequency increases 500 cycles per second above and decreases 500 cycles below the unmodulated frequency. In a well designed system the modulation will vary twice as much or 1000 cycles per second above the unmodulated RF and 1000 cycles below the average RF value. By talking louder or amplifying the audio voltage we will have more frequency change in the RF carrier. A weak audio input does not cause as much frequency change as a strong one.

Rate of frequency change

Now that we know what determines the AMOUNT of carrier shift, the next problem is to consider the rate at which these frequency changes occur. - (Stated as the number of changes per second) we can determine the answer by figures 4 and 5. The sine wave in the middle of figure 4 shows the audio voltage producing the frequency change in the RF wave form. Assume the frequency of this audio wave is 1000 cycles a second. (CPS). Every time the audio goes positive the frequency increases and every time the audio goes negative the frequency decreases. If the audio has a 1000 cycles a second change the RF will change frequency, above and below average 1000 times. From this we learn that the audio frequency controls the rate of change of the RF. Lets see if this holds true, in figure 4 we assumed the audio to be 1000 cycles per second. In figure 5 we must have a lower audio frequency because it is longer for the same amount of time as shown on the time line. If one cycle took 2 times as much time for completion of the cycle, the frequency would be one half or about 500 cycles. Therefore, in an FM system, the frequency of the audio controls the rate of change of the carrier frequency.

Deviation

Thus far in talking about FM and frequency changes we have avoided a few terms commonly used by engineers and technicians. One often used term is "Center frequency". This is the mid frequency of the FM wave and corresponds to the unmodulated carrier. In figure 3A up to point 1 the RF is at its unmodulated frequency, and this is the center frequency. At point 3 and 5 the RF is again momentarily at center frequency.

"Deviation" is another frequently used term. This refers to the amount of frequency change higher and lower than the center frequency. In analyzing the frequency changes taking place we assumed 1000 cycles above and below center frequency. The deviation then is 1000 cycles. We usually write this "$\pm$ 1000 cycles", and say, "the deviation is plus and minus 1000 cycles". In practice the deviation of the average FM transmission is greater then 1000 cycles and is expressed in terms of kilocycles. We might expect to see $\pm$ 15 kilocycles. (KC) Note that the deviation bandwidth for a 15 KC deviation is 30 KC, this is the total frequency swing from 15 KC below center frequency to 15 KC above center frequency 15 + 15 = 30 KC.

Quick Review - What Have We Learned?

1. In the FM transmitter audio modulation causes the frequency but not the amplitude to change.

2. This change of carrier frequency above and below center frequency is known as deviation.

3. The amount of deviation is controlled by the strength (amplitude) of the audio signal.

4. The rate of change or number of deviations per second is determined by the frequency of the audio.

5. Deviation is expressed as ± KC.

6. Deviation bandwidth is the total swing and is twice the stated deviation. (Example ± 15 KC is 30 KC bandwidth.)

The FM Receiver

We have seen how an FM signal is generated and we know that the audio message is contained in the carrier deviations. In order to complete our system using frequency modulation, we now require a receiver which will recover the audio signal from the FM wave.

The fundamental difference is in the type of detector. The AM receiver has a detector that responds to amplitude changes. The detector in the FM receiver must be sensitive to frequency changes.

Figure 6 is a partial block diagram and simplified circuit of an FM Receiver. The incoming signal is an FM carrier and it is transferred from the Antenna to the RF Amplifiers. The operation of the RF Amplifiers in the FM receiver is the same as in the AM receiver. From the RF section the amplified signal is coupled to the FM detector by means of a transformer that has a tuned primary and two tuned secondaries. The primary is tuned to the center frequency but the secondaries are tuned to frequencies above and below center frequency respectively. Assuming a center frequency of 455 KC, secondary S1 may be tuned to 475 KC, which is 20 KC above center frequency, in which case S2 will be tuned to 435 KC which is 20 KC below center frequency. A load resistor R1 in series with a diode rectifier D1 is connected to secondary S1. During the positive alternation of the applied RF voltage, diode D1 conducts current in the direction shown by the arrows. This current produces a voltage across R1 which is approximately equal to the RF voltage in the S1 secondary. The RF filter capacitor across R1 maintains the resistor voltage at a DC value. Thus an incoming signal produces a voltage across R1 having the polarity indicated in figure 6 and an amplitude determined by the applied voltage.

Secondary circuit S2 is identical to S1 and operates in the same manner, the RF in the secondary being rectified to a DC voltage across R2. The two secondary circuits, however, operate independantely of each other the only common connection is at the resistors. As concerning the output, the voltage of R1 and R2 are in series with each other but have opposing polarities. The output will then be the differences of these voltages - Figure 7. shows what heppens when an FM signal is applied to the circuit. Figure 7A indicates that when the center frequency of 455 KC is present, the voltage of R1 and R2 are equal in value. This is true because the secondaries are off resonance by the same amount and the resulting voltage in the secondaries are equal. The output terminals A and B are at the same charge or potential. Since voltage is the difference between two charges or potentials, the voltage across A and B is zero! (A voltmeter connected across A and B of figure 7A would record zero voltage.) Thus for the FM detector zero output voltage occurs when the applied signal is at center frequency. The next step is to determine what happens when the signal varies above and below center frequency.

When the incoming signal swings above center frequency (we call this positive deviation), the frequency is higher than 455 KC and the tuned circuit of S1 is nearer to being in resonance with the incoming signal. Being nearer to resonance, the R.F. voltage in the tuned circuit increases and the resulting voltage across R1 must also increase. At the same time, the tuned circuit of R2 is further from resonance so the RF voltage of S2 decreases. This results in less voltage across R2.. In figure 7B we have assumed the voltage of R1 increases to 6 volts while that of R2 decreases to 4 volts. The difference between a and b is now 2 volts and a is positive with respect to b. Thus, when an incoming signal is above center frequency (positive deviation) the FM detector produces a positive output voltage.

When the incoming signal swings below center frequency (negative deviation) the condition of figure 7c occurs. At a frequency below center, S2 is nearer to resonance and produces the larger voltage. This time at R2. Secondary S1, on the other hand is further from resonance and its output voltage decreases. As assumed in figure 7c, the voltage across R2 increases to 6 volts while the voltage across R1 decreases to 4 volts. Again there is a difference of 2 volts between a and b but a is now negative in respect to b so the effective voltage is minus 2 volts.

To summarize, whenever the signal is at center frequency the output is zero. During a positive deviation of the signal the output becomes positive but for a negative deviation the output swings negative. Thus the FM detector is a device that converts frequency variations into changes of voltage.

At the FM transmitter the audio amplitude determines the amount of deviation while the frequency of this audio determines the rate of deviation. At the receiver this process must be reversed. That is the amount of deviation from the center that should determine the audio amplitude. (Amount of output audio voltage.) While the rate of deviation should determine the audio frequency. Lets see how this happens!

The amount of output voltage of figure 6 depends upon the difference, or the unbalance of voltages across R1 and R2. The resistor voltage depends upon the amount of RF voltage in the secondaries. The secondary voltages, in turn on how near the circuits are to being resonant with the incoming signals. For higher deviation the frequency is closer to resonance in one secondary and further from resonance in the other. This results in a greater difference in the resistor voltages and a higher voltage at the output terminals.

Thus, the higher the deviation, the higher the output voltage. This satisfies our first requirement. The AMOUNT of deviation determines the amount of output voltage, (audio amplitude).

Our second requirement is that the RATE of deviation determines the frequency of the output voltage. Every time the signal deviates from above center frequency to below center, the output changes from positive to negative, and vice cersa. The detector output thus changes polarity at the same rate that the frequency swings above and below center. Now we can see the recovered audio is exactly the same as the original audio that created the rate of deviation of the FM signal.

As we progress other differences between the FM receiver will be discussed. For this assignment however, the basic difference is in the type of detector used. The circuit in figure 6 is not used in present day receivers because there are several refinements introduced. This circuit does serve best to explain the principles involved in FM detection. Communications type FM receivers usually incorporate a circuit known as a "discriminator" for FM detection. As we shall see later the action is similar to that shown in figure 6.

At the beginning of this lesson we said one purpose of the assignment was to determine what is meant by FM. In addition, we indicated certain inherant advantages of FM. These advantages will now be discussed.

FM is more interference free

Almost all noise energy is characterized by its irregular amplitude variations. In the AM system the detector is designed to respond to amplitude variations. Little can be done at the detector to eliminate noise without sacrificing the desired signal modulation. Although circuits have been devised which seemingly distinguish the sharp peaked noise waveforms from the more even waveforms of the spoken message. These circuits, at best, leave alot to be desired and are only partially effective. Other types of amplitude limiting of noise pulses are successful to some extent but under adverse conditions the results are poor.

F.M. receivers incorporate special circuits known as "limiters" which drastically reduce or eliminate amplitude variations. This does not affect the audio message for infrequency modulation all of the intelligence is contained within the frequency deviations. Eliminating amplitude changes has no effect on frequency deviations. Thus the FM receiver by means of the limiter circuits, is free from almost all noise interference, this is probably the most outstanding advantage of FM.

FM signals are less sensitive to interference from other signals. For an AM system, a desired signal must be at least 50 to 100 times stronger than an interfering signal to over-ride the latter to the point where it causes no trouble. For an FM system however, interference free operation is often maintained with a ratio as low as 2 to 1.

The FM Transmitter is Efficient

The FM transmitter is more efficient than the AM transmitter. If a power tube has a rating of 60 watts the entire 60 watts can be utilized as carrier power in FM. The FM power, you will recall does not increase with modulation. The FM transmitter may work at maximum power at all times. In an AM system using the same tube, 20 watts must be reserved for audio modulation leaving only 40 watts for RF carrier powers. The AM transmitter is only 40 watts but the FM transmitter is 60 watts. Also where battery power is at a premium in mobile service, the ability to use all the power for the carrier means greater coverage. Furthermore, the additional power required to operate the higher power audio stages in AM is not required in FM!

Important Words.

AM Detector: A demodulator incorporated in an AM receiver which recovers the desired intelligence from the amplitude variations of the AM Carrier.

Amplitude Modulation: A system of modulating the RF carrier, whereby the amplitude of the radiated signal is made to vary in accordance with the modulating voltage, but the carrier frequency remains constant.

Carrier: RF energy of a specific frequency generated at the transmitter and radiated into space. The carrier when modulated, serves to transport the intelligence to the receivers.

Center Frequency: The term applied to the "average carrier frequency" of an FM wave. This center frequency is evident when the FM wave is undisturbed (in the absence of modulation).

Deviation: Frequency changes of the FM carrier, resulting from modulation. Deviation is expressed as the extent of frequency change from the center frequency.

Deviation Bandwidth: The total frequency swing of the modulated FM wave. Numerically deviation bandwidth is equal to twice the stated deviation.

Electromagnetic wave: Radiant electric energy, such as that radiated from a transmitter antenna. Electromagnetic energy consists of an electric field and a magnetic field, both of which are essential for continued propagation of the wave. Light and heat are other examples of electromagnetic energy - - the difference, (radio energy, light energy) is in the wavelenght.

FM Detector: (Discriminator) A demodulator incorporated in an FM receiver, which recovers the desired intellignece from the deviations of the FM carrier. This is accomplished by converting the frequency variations into an audio voltage.

Frequency Modulation: A system of modulating the RF carrier, whereby the frequency of the carrier is made to vary in accordance with the modulating voltage, but the carrier amplitude remains constant.

Block Diagram Analysis

As we continue we will make use of several block diagrams of the communications receiver. We shall determine the purpose of each stage within the receiver and learn how each stage must function. After this, we shall be prepared to study the individual sections of the receiver. We will now confine ourselves with the single question, "what heppens"? The answer to "How is this accomplished"? will be taken up later. In this beginning studies power supply considerations will be obmitted as they will be taken up separately. This permits simpler diagrams, so that your attention can be confined to the particular circuit under discussion.

<u>Receiver requirements - The "Superhetrodyne"</u>

In order to provide interference - free operation a receiver must have three characteristics. Selectivity, sensitivity and fidelity.

Selectivity is the ability of a receiver to separate the desired signal from all others. The average receiver antenna may intercept hundreds of radio waves, each producing a voltage at its own frequency. All these RF voltages are transferred from the antenna to the receiver input and it becomes necessary to select the desired signal, rejecting all others, before any of these signals reach the detector. This is not accomplished in a single stage or in one circuit only. Many tuned circuits are required for this purpose. They all proceed the detector and they all have the same ultimate function, to select the desired signal.

Receiver sensitivity depends primarily upon the gain of the amplifier stages. Amplification alone, however, is not enough. When the received signal is very weak, it must undergo considerable amplification if the message is to be reproduced in the speaker with sufficient volume. In such cases it may be difficult or even impossible to hear the message because of noise interference from other stations. Sensitivity then, also depends upon the receivers selectivity and its ability to minimize noise. The true sensitivity of a receiver must be stated in terms of the weakest signal that can be applied at the input to produce a satisfactory output at the speaker. Fidelity in any receiver is its ability to reproduce a message which is free from noise, interference and distortion. (Any type of interference present in the output must be considered as a form of distortion.)

Because the superhetrodyne receiver exhibits excellent selectivity as well as sensitivity, most of the receivers today are of this type. In the superhetrodyne receiver incoming RF signals are converted to a lower frequency by means of a mixer. The mixer for this reason is sometimes called a "frequency converter". This lower frequency signal (still RF but called the "intermediate frequency of IF") is always the same for a given superhetrodyne. Let us, then, first review the operation of the familiar AM broadcast receiver before proceeding to the more intricate FM communications type receiver.

Simple Broadcast Receiver

Figure 8 is a block diagram of a simple AM receiver designed to operate within the broadcast band. The oscillator and mixer indicate that this is a superhetrodyne. To provide for converting the incoming RF to a lower frequency, a second RF signal is generated in the local oscillator stage, and this signal combines with the RF in the mixer to produce the intermediate frequency output. (IF)

Whenever two signals are combined (hetrodyned) in a non-linear device, such as a mixer, a number of new frequencies are produced, for our purpose only the "difference" frequency is used. A frequency of 455 kilocycles, (commonly used in broadcast receivers) is taken as the IF in figure 8. At the same time the receiver is tuned to a station, the oscillator is adjusted so that its frequency is 455 KC higher than the incoming RF.

For example, when we turn the receiver tuning knob to receiver a station, 720 KC, two things take place at the same instant. First, a tuned circuit between the antenna and mixer is tuned to the station, 720 KC frequency so that the maximum voltage from this station reaches the mixer grid, other stations are attenuated as far as possible. Second, the oscillator is adjusted to generate a signal of 1175 KC which is 455 KC higher than the station RF (720 KC).

The RF signal of 720 KC and the oscillator signal of 1175 KC are both applied to the mixer, and the difference or IF frequency becomes available in the plate circuit. Now, a most important factor in mixing two signals is that any modulation present on either or both of the applied signals will be present also in the IF output waveform.

Since the oscillator waveform in this case is unmodulated RF, the only modulation on the IF signal is the modulation of the incoming RF.

The advantage of selectivity, sensitivity and fidelity, which pertain to the superhetrodyne type of receiver, are the result of converting the RF to this lower frequency IF signal. Since the receiver's IF stages operate at the same frequency for all incoming signals, these stages have fixed tuned circuits, with controlled selectivity. All desired signals receive the same amount of amplification and are subject to the same degree of selectivity. The selectivity of the IF amplifier is much greater than would be possible at a higher frequency RF level. The problem of feedback too, becomes simplified, and the IF amplifier is more stable in operation.

While most of the selectivity in the superhetrodyne receiver is realized in the IF section, there must also be some rejection of unwanted signals at the RF level. Without RF selectivity the receiver will be subject to image frequency response.

Besides the desired RF another frequency - the image frequency - can combine with the oscillator voltage in the mixer stage to produce the IF frequency of the receiver. Thus, it is essential to reject undesirable signals before they reach the mixer, this is RF selectivity.

For broadcast receivers where the oscillator is always higher than the RF the image frequency will be 455 KC above the oscillator frequency. For higher frequency receivers (FM) the oscillator may operate below the RF, in which case the image frequency will be below the RF and the ascillator.

As an example of image frequency for the broadcast receiver, consider the previous example where the receiver is tuned to the station, 720 KC. With an IF of 455 KC the ascillator operates at 1175 KC. Now suppose that a strong station in the vicinity of the receiver is transmitting on a frequency of 1630 KC. If the signal from this transmitter reaches the mixer stage, not having been sufficiently attenuated in the tuned RF stage, it will hetrodyne (mix) with the oscillator to form a difference in frequency. The difference in frequency is, 1630 KC - 1175 KC which is 455 KC so it along with both modulations, will go into and through the IF stages to the speaker.

The separation between the image frequency and the RF to which the receiver is tuned is always equal to twice the IF frequency. Whether the image is above in frequency to the RF or below is determined by the oscillator. If the oscillator is above the RF, so is the image, if the oscillator is below, the image also will be below.

In the broadcast receiver the operation of 910 KC (twice 455 KC) for the image is satisfactory for the tuning range of the receiver. In order to provide good image rejection in high frequency receivers, the image must be further separated from the RF. This requires the use of a higher IF frequency.

The detector following the IF amplifier stage recovers audio signals from the amplitude modulated IF signal. For AM detection, the diode detector is the most practical since it is economical and has relatively little distortion. The audio voltage from the detector is too weak to operate the speaker, so an audio section is included to bring up the signal to a higher level.

The principal requirement of the detector and audio stages is that all distortion must be held to a minimum.

The basic FM receiver shown in figure 9 is not much different from the arrangement in figure 8. The oscillator, mixer, IF amplifier and audio sections are almost identical both in purpose and operation. The outstanding difference between the two receivers are (1) the type of detector required, and (2) the addition of a limiter stage in the FM receiver.

Because FM signals are transmitted in frequencies above 25 megacycles the tubes and circuits of the FM receiver differ somewhat from that of the AM broadcast receiver just described. Also in order to prevent image frequency response the IF is usually 10.7 megacycles instead of 455 kilocycles. The strength of the FM signal reaching the receiver is also less than in the AM receiver.

It is therefore necessary to have two or more stages of amplification in the IF section of the FM receiver. This additional amplification is also necessary for the proper operation of the limiter which follows the IF amplifiers. Before inspecting the limiters further lets look briefly at the FM detector. Most FM communications receivers make use of the discriminator, because of its relatively high audio output, sensitivity and its fidelity. This same discriminator however, is also affected by amplitude changes and its output will be noisy unless all amplitude variations have been eliminated from its input. Thus the signal to the discriminator must be free of any amplitude variations, noise pulsations in particular. It is the function of the limiter to provide just such a signal.

The effect of the limiter on the IF waveform is illustrated in figure 10.

The FM waveform at the left contains not only the desired signal, but many amplitude variations as well, most of them being made up by the sharp pulsations of noise voltage. The waveform at the right shows the FM output from the limiter. It will be noted in this output waveform that all amplitude variations have been eliminated. The amplitude of each cycle remains constant and the only remaining modulations consists of the frequency variations. These have not been disturbed by the limiter. Regardless of the strength of the incoming signal to the limiter, the output voltage cannot exceed certain limits which are designed into the limiting stage. Assumming that the IF amplifier's have sufficient gain, even the weakest signal at the antenna will result in a strong input to the limiter. This means all signals reaching the disciminator are equal in amplitude. The effectiveness of the limiter stage in reducing or eliminating amplitude variations from the signal depend directly upon the strengths of the signal applied to the limiter. In practice we say strong signals saturate the limiter. This action is considered more fully in a future lesson.

The FM detector (discriminator) of figure 9 recovers the audio intelligence from the incoming frequency deviations by converting these deviations into corresponding voltages. (The action is much the same as for the FM detector, figure 6.)

The discriminator audio output is then amplified in the audio section of the receiver and the message is reproduced in the speaker.

FM Communications receiver - The Double Superhetrodyne

FM was first used in the 30-40 megacycle range. and it took many years of research before FM was developed for use in 150-170 megacycles. Now FM is being used in the 450 megacycle frequency range.

We now call 24 to 54 megacycle frequency "low band" the 144-174 megacycle frequency, "High band". The 450 megacycle range is just called "450 mc".

Figure 11, is a block diagram showing a high band FM communications receiver designed to operate at 172 mc, but the same arrangement could be used in connection with a "low band" (24-54 mc) or a 450 mc receiver. The same general pattern will apply to any communications receiver regardless of its operating frequency. Notice there are two oscillators, two mixers and two I F sections. This type of receiver is called a double super-hetrodyne. The incoming RF is first converted to a high frequency IF for improved image frequency rejection, then the signal is again converted, this time to a low frequency IF to permit greater amplification and selectivity. We can best see the action and advantages of the double superhetrodyne by following the signal through the receiver.

Incoming signals from the antenna first encounter the RF amplifier stage. Because of the high frequency of the incoming signal it is not practical to expect a great amount of gain and selectivity in this stage. By careful designing this RF amplifier, satisfactory rejection of unwanted signals is possible, and the gain can be 5 times or more. Noise generation within this RF stage must be kept to the minimum because any noise generated in this RF stage would be amplified the same amount as the desired signal. Therefore, the properly designed RF amplifier is one that will amplify a maximum amount, which is just below the point of generating internal noise.

At the mixer the (172 MC) RF signal combines with the 160 mc signal from the oscillator to produce the first (or high frequency) IF of 12 mc. This comparatively places the image frequency far enough away from the channel frequency to be rejected in the tuned RF circuits with the oscillator operating below the RF. The image will be 12 megacycles below the oscillator frequency, or 148 mc.

The most important requirement for the oscillator is stability, and the most stable oscillator known today is the crystal controlled oscillator. Crystal oscillators at 160 mc are not practical at the present time for use in mobile equipment, so in our example (figure 11) we use 32 mc and the 5th harmonic of 32 is selected to provide the desired 160 mc signal. This receiver is designed to receive one frequency so the tuned circuits are semi-fixed tuned. (These circuits are only retuned by a technician to correct for aging components, after repair, or tube replacement). This type communications receiver has greater efficiency and circuit stability.

The 12 mc IF combines at the second mixer with the 12,455 mc signal from the second oscillator to produce the second or low frequency if signal of 455 kc.

Selective Filter

While the RF and first IF sections are efficient in rejecting the image frequency their relative selectivity at these high frequencies is not sufficient to reject signal of neighboring channels, which must be eliminated before they reach the discriminator. (FM detector). By employing this second IF, (455 kc) sharper selectivity becomes possible. However, before this 455 kc signal goes into the second IF (455 kc) it goes thru a "selective filter" which is between the second mixer and the second IF. (See Figure 11). This selective filter has many circuits tuned to bypass unwanted signals and pass only the 455 kc signal with its modulation deviation. This selective filter then passes this 455 kc signal to the second IF stages which have the sole function of amplifying the signal. These high gain IF stages provide far more amplification than minimum gain required, thus introducing a reserve gain, which is essential for continued receiver sensitivity over a prolonged period.

Limiter section

Following the second IF section are two limiter stages, (see figure 10) which eliminate the amplitude and noise pulsations which may be present.

The Discriminator

The input to the discriminator is then a pure FM signal containing only deviations introduced to the signal at the transmitter.

The discriminator recovers the audio component from the FM variations and this audio voltage is applied through two audio amplifier stages to the speaker.

Squelch

In a commercial broadcast receiver, the transmitter carrier is present even though modulation may be temporarily discontinued. In the case of the communications receiver the situation is different. The carrier is present only when a message is being transmitted. In the absence of any RF carrier to provide this quieting, noises entering the receiver causes an objectional noise in the speaker. This is particularly bothersome when the receiver must be constantly monitored. A squelch circuit quiets the receiver between transmissions by preventing the noise voltage from passing through the audio stages and reaching the speaker.

As shown in figure 11, the squelch system operates into the first audio amplifier, preventing that tube from functioning. In the absence of an incoming signal, the noise cannot get through the audio stages to the speaker.

The squelch circuit controls the bias on the audio amlpifier so that it operates only when a signal is coming in. At other times when there is no signal the audio stage is biased beyond cutoff and no sound comes from the speaker.

Two Frequency Operation

Certain applications require the communications receiver to operate on either of two frequencies. This can be accomplished by having two oscillators at the first mixer in place of one. It is not advisable to have these two oscillators operate at the same time in an effort to receive two signals at the same time because the mixing of the signals and oscillators would allow unwanted signals to mix in the mixer possibly producing a difference frequency that would also pass through the 12 mc IF.

Summary

Since the FM receivers use the superhetrodyne circuits commonly found in AM receivers, most of the stages of the FM receiver operate in the same manner as those in the AM receiver.

The two receivers differ as to the type of detector amployed. The detector in the AM receiver must respond to changes of carrier amplitude, the FM detector (discriminator) must respond to changes of carrier frequency.

In order to prevent urdesirable amplitude variations from reaching the discriminator, limiters are used immediately ahead of it. Also sufficient input voltage must be provided by the RF and IF amplifiers, so the limiters will be able to limit the lowest as well as the highest voltage peaks and a uniform noise free voltage will be presented to the discriminator with only the "frequency variations" (modulation) present.

For maximum frequency stability oscillators are crystal controlled.

Without squelch the high gain communications receiver is very noisy between transmissions. The squelch circuit however, disables the audio section of the receiver during the times when there is no carrier present, and prevents noise from reaching the speaker. As soon as the carrier is received, the squelch circuit becomes inoperative and the receiver performs normally.

Because of the high frequency of incoming signals, the tuned circuits of the RF and IF stages cannot reject all of the unwanted frequencies, this task is performed in the low frequency section of the receiver. The highly selective filter immediately following the second mixer rejects all signals except those of the operating channel, permitting only the desired signal to pass through the last IF section to the detector.

Important words used in this chapter:

Image frequency: That undesired frequency that combines with the local oscillator at the mixer to produce a difference frequency equal to the IF frequency. The image frequency is always spaced from the desired frequency by an amount equal to twice the value of the IF frequency.

Limiter: The limiter is an amplitude controlling device. When the input signal reaches a certain amplitude, the output voltage has reached a maximum value beyond which it cannot increase, regardless of more increase in the input.

Oscillator: A device that generates A.C. As used in the superhetrodyne receiver, the oscillator provides an additional R.F. signal which mixes with the incoming signal to produce a difference lower frequency.

Selectivity: The ability of a receiver to discriminate between radio waves having different carrier frequencies. Good selectivity of a receiver depends upon the efficiency of its tuned circuits to pass a desired frequency with sufficient attenuation to all others.

Sensitivity: The ability of a receiver to respons to weak signal.

Squelch: A circuit that silences the speaker between transmissions of messages.

CHAPTER THREE

We will now analyze the complete operation of the various stages within the receiver, beginning in this chapter with the RF amplifier stage.

Requirements of the RF Stage

RF stages are used extensively in receivers up to 170 megacycles. Where an RF stage is used, efficient operation depends on (1) to reject interfering signals as far as possible by incorporating sharp RF selectivity and (2) to establish the best possible signal to noise ratio at the mixer input. The undesired signal which must be rejected include the image frequency, the frequency that is the same as the receiver IF, and all others that might cause interference.

While circuits that are effective in rejecting undesired signals, they also cause some loss of the desired signal. The gain of the RF amplifier, however, more than compensates for this loss with the result that the amplified signal delivered to the mixer stage has a better signal to noise ratio.

In the design of the RF stage particularly in the choice of the RF tube, attention must be given to the amount of noise generated in the RF stage itself. Unless this noise is held to a minimum the signal-to-noise ratio will not be increased and the receiver sensitivity would not be good.

The RF stage must also provide an impedance match between the antenna and the RF stage tube grid. This impedance match will isolate the antenna from the local oscillator. (If the antenna went direct to the mixer the oscillator RF could pass to the antenna and radiate interference to nearby receivers.)

Signal to Noise Ratio

Small signal voltages entering the receiver must compete with any noise voltage in the receiver. The total noise whether internal or external limits the minimum signal voltage that can be successfully received. It therefore is important to have some means of comparing the strength of the signal with that of the noise.

The expression "signal-to-noise ratio" which is usually abbreviated "s/n ratio" is used to compare the strength of the desired signal with the noise voltages present in a particular circuit. The s/n ratio is most important at the input of the receiver, where the signal level is the lowest. Unless the incoming signal voltage is greater than the noise voltages, satisfactory reception is not possible. The amount of noise present at the receiver input combined with the noise generated within the receiver input circuits, determines the weakest useable signal.

While the RF stages generates a certain amount of internal noise, the mixer which follows is an even greater offender in this respect. Unless the signal gets the required amplification in the

RF stages the relatively high noise level of the mixer would limit the receiver's sensitivity.

Because noise plays such an important part in determining the overall performance of the receiver, let us discuss it briefly before proceeding.

Noise Sources and Noise Frequencies

Noise may be either external or internal, whether it is manmade, natural or generated within the receiver itself. It may be either impulse or random noise according to its waveform, and it may be classified to some extent as to frequency.

Noise may enter the receiver from some external source, in which case it may be man-made or due to natural causes. Noise also may be internal in origin, since it may be generated within the receiver circuits and their components. Noise, particularly man-made noise is not distributed uniformly throughout the frequency spectrum. Impulse noise is most bothersome at frequencies from approximately 15 megacycles to 160 megacycles, while random noise can appear at any frequency.

Man-made noise

Man-made noise falls within two general classifications just mentioned, impulse and random noise. Impulse noise consists of sharp pulses of RF voltage which produce audible sounds in the apeaker. The most common source of pulse noise is the ignition systems of cars. Because two-way radio is mostly vehicular, impulse noise is a major problem.

The second kind of man-made noise, (random noise) is more continuous in nature. It appears as a broad band of many pulses which bear little or no relation to each other. Such noises are produced by rotating electrical machinery, automotive generators, regulators, high voltage power transmission lines, gas rectifiers and similar devices.

Natural Noise

Natural noise coming from various sources frequently proves disturbing to radio communications. These noises also can be impulse or random type. Perhaps the most familiar example of natural noise is that produced by lightning discharge. This type is not entirely due to local storms, it frequently originates in tropical storm centers and then it radiates as a radio wave to many parts of the earth. The highest noise level is usually highest in our summer months. Fortunately the intensity of this noise is less above 40 mc. Some noises are attributed to sun spots and other natural phenomena.

Receiver Noise

In addition to man-made and natural noises entering the receiver from outside, noises are also generated in the receiver itself. Almost all noises generated in the receiver is random type for they are continuous, have no specific waveform and cover a wide range of frequencies.

One source of receiver noise is the irregular motion of electrons in any current passing through a conductor. The erratic motion of electrons causes small variations in current and a corresponding change in voltage. This is called "fluctuation noise" and has no specific waveform or frequency.

Another source of noise is the normal but random motion of atoms and electrons. These particles make up all matter. They are always in violent motion and their activity increases with temperature increase. The resulting noise (designated as thermal noise) is present in any circuit that has resistance.

The amount of noise generated in the input circuit of a receiver is determined by the bandwidth and impedance of the circuit. A circuit designed to operate on a wide band of frequencies and having a high impedance (resistance) generates more noise than a circuit with a narrow band acceptance and a low impedance.

Tubes also produce noise due to their distinct actions inside the tube.

1. Electrons leave the cathode at irregular intervals and with random velocity. Their arrival at the plate is also irregular and causes noise pulsations in the plate circuit this is known as the "shot effect".

2. Electrons leaving the cathode of a pentode or other multi-element tube form separate currents on their way to the plate and screen. This division of electron stream is a source of noise and is most noticeable in tubes which has a number of positive grids. Such a division of cathode current does not take place in triodes so these tubes are not subject to this effect.

3. Another source of noise generated within the tube is due to electrons passing close to the control grid on their way to the plate. Small noises are induced in the grid circuit and add to other noises present.

Of all tube types, the triode is the quietest. The sharp cutoff pentode is next best, followed by the remote cutoff pentode and multi-element tubes in that order. Regardless of the tube used, noise can be minimized by establishing a low value of cathode current.

Amplification Requirements

Because the mixer has a high noise level, the signal must be strong when it reaches this stage. The high noise level at the mixer is due to many factors. First, the oscillator multiplier section generates noise, and this noise reaches the mixer along with the desired oscillator signal. Second, the mixing of two different frequencies causes additional variations in the electron stream in the tube - which in turn means more noise. In addition, the conversion efficiency of any tube is low compared to the same tube used as an amplifier. The lower available output voltage at the IF frequency means a relatively low signal to noise ratio. The RF section of the receiver must provide the necessary gain in order to have a satisfactory signal to noise ratio at the mixer.

Below 200 megacycles a single well designed RF stage of amplification using a pentode tube is preferred to two triode tube stages. The pentode will give about the same gain as two triodes.

At higher frequencies (above 200 megacycles) the pentode becomes less satisfactory, and at these frequencies triode tubes are generally used. They must be neutralized however, or used as a grounded grid amplifier.

If all the noise generated in the RF is kept to a minimum and at the same time, the incoming signal is amplified so that the signal-to-noise ratio is satisfactory the RF amplifier will have fulfilled one of its important requirements.

Intermodulation

Intermodulation requires two or more frequencies which combine to produce a signal at the channel frequency.

This can best be explained by an example. Consider a receiver designed to operate on 152 mc. Two unwanted signals, 152.12 mc 152.24 mc. are at the antenna, and these two signals can possibly combine in the mixer stage to produce a signal of 152 mc., Here is how this can happen. We know that among the additional frequencies created in the mixer stage will be the second harmonic of any incoming signal. Now the second harmonic of 152.12 mc. is 304.24 mc. This frequency combines with the 152.24 mc. to produce 152. mc. (The operating frequency of the receiver.) Any modulation present on either of the two frequencies will modulate the new frequency and be heard in the speaker.

Intermodulation occurs only when the signals causing this condition are transmitting at the same time. From extensive investigations it is found the percentage of time these signals are transmitting at the same time is small. Also, these exact multiplications and mixing of frequencies usually occur only in an area where all radio frequencies are being used.

The RF Input Circuit Impedance Matching

It is common to call the circuit between the antenna transmission line and the RF grid the "input circuit". This circuit has two basic functions. First, being a tuned circuit it must provide some selectivity. Second, in order to transfer maximum energy from the transmission line to the RF grid it must match the impedance of these circuits. The antenna transmission line usually has an impedance of 50 ohms at the channel frequency. Thus as far as the transmission line is concerned, the input circuit must appear to be 50 ohms. This circuit forms a parallel tuned circuit between the grid and ground, and a parallel tuned circuit usually has a high impedance.

An impendance match may be effected several ways. One of the most common makes use of a transformer in which the primary winding impedance matches that of the input, while the secondary impedance is that required in the RF grid. Another method is to use a single coil, but to connect the input to a low impedance tap on the coil.

The one used in Figure 12 employs still another approach to the problem of impedance matching. Here the input is connected between two series connected capacitors, which themselves are part of a grid tank circuit. This arrangement allows a step up of voltage in the same manner as if a tapped coil were used. The value of input capacitor is selected so that at its operating frequency its impedance is about 50 ohms. Therefor the input impedance is 50 ohms.

The grid circuit sees a parallel tuned circuit between grid and ground, and this offers the required high impedance. For figure 12 the step up in voltage from the antenna to the grid of the RF tube is about 5 times, which means an improvement in the signal to noise ratio. The signal is increased 5 times while the noise remains unchanged.

The RF Amplifier Plate Circuit

The plate circuit of figure 12 is rather unusual because it makes use of three highly efficient tuned circuits. These tuned circuits are critically coupled to provide maximum gain and frequency selection. Whenever several tuned circuits are used, the coupling between them greatly effects both the selectivity and the amount of signal voltage at the output. With transformers the interaction of the coils (mutual induction) determines the amount of coupling. For the plate circuit of figure 12 the degree of coupling is determined by the value of capacitors between the tuned circuits.

With a small degree of coupling, tuned circuits react at their natural frequency and their selectivity is very good. As the coupling is increased, the output voltage continues to increase up to a certain point ("called critical coupling") beyond which there is no further increase in output voltage. Increasing the coupling up to the "critical coupling" point increases the bandwidth a small amount. Beyond critical coupling, however, the bandwidth increases rapidly. This is called overcoupling and causes poor selectivity. In addition the output voltage will be lower than the maximum value established at critical coupling. It is important to employ critical coupled circuits to obtain good selectivity and sensitivity.

In addition to critical coupling it is important to use circuits having a high Q, for this determines their ability to reject unwanted signals. High Q gives much better selectivity than those with a low Q. At high frequencies such as found in communications receivers, the Q of the coil and the degree of the loading determine the Q of the tuned circuit. The Q of the coil is the ratio of its reactance to its resistance. (As a formula, Q = 2x3.1416xFxL÷R, where R is the resistance to the high frequency current traveling on the surface of the conductor.)

The coils of some receivers are made from silver plated ribbons having a large surface area. This reduces the R and produces a high Q. The three critically coupled high Q tuned circuits in the RF stage of figure 12 provide excellent selectivity, rejecting the image frequency as well as many other signals that might cause interference. At this frequency (152 mc) it is impossible to reject all signals on the neighboring channels but these are eliminated by the selective filter in the last IF section.

The RF Stage as a Class A Amplifier

When it is necessary to secure good amplification with a minimum of distortion we use Class A amplifications. The signal voltage must not drive the grid positive with respect to cathode, causing grid current. The tube is operated as near as possible to the center of the straight portion of its characteristic curve. A typical Class A amplifier "characteristic curve" is shown in figure 13. (The amplification is slightly exagerated for explanation purposes.)

Plate current is plotted on the vertical axis and the grid voltage on the horizontal axis. The tube bias should be at the center marked X on the curve. The incoming signal to the RF grid, at the bottom of the figure, varies the total grid voltage and operates the tube between points A and B on the curve. Plate current varies between A and B. If the operation is linear the output wave shape is an exact duplication of the RF grid voltage. However, the amplification will be greater than the input, the exact amount depending on the gain of the tube.

Looking again at figure 13 two important things can be seen. (1) If the input signal is reduced the output signal will also be reduced. (2) If the grid bias is changed more negative the operation of the RF input will be on the lower curved portion of the characteristic curve and distortion again occurs on the upper curved portion of the tube characteristic curve.

Automatic gain control

Automatic gain control or "AGC" as it is usually referred to, lowers the amplification or gain of the RF stage when a strong signal is received. The grid of a "limiter stage" has a negative voltage that goes more negative with a strong signal. A small part of this voltage that is more negative with a strong signal, is rectified, filtered and used to keep the RF grid at the proper bias on strong signals. Because the limiter grid is comparitively negative even on a weak signal, it is important that this AGC does not further reduce a weak RF signal. This is realized by taking the proper amount of positive voltage from the IF screen grid to balance or cancel this idling negative voltage coming on the AGC line. Therefore this AGC negative voltage will overcome the positive balancing voltage only on strong signals. This is called "delayed" AGC because the action is delayed until the RF signal reaches a certain level.

Important Words used in this Chapter

Automatic gain Control: A method of controlling the overall amplification of a receiver by varying the gain of one or more stages inversely with the strength of the incoming signal. When used with two way FM receivers, AGC is highly effective in reducing intermodulation.

Delayed AGC: An AGC system where weak signal are prevented from producing any AGC action.

Impulse noise: Those noise voltages which have very sharp peak amplitudes and which occur at irregular intervals. The most common is the ignition systems of gasoline engines.

Insertion loss: The attenuation of the desired signal by some circuit element, such as a tuned circuit.

Intermodulation: A type of interference in receivers, whereby two or more unwanted signals combine to create a new frequency corresponding to the channel frequency of the receiver.

Noise: As used in the electronic industry, noise refers to spontaneous and irregular variations in voltages and currents. Noise voltages are characterized by the absence of uniformity in both wave form and frequency. When such noise voltages are reproduced by the speaker, the resulting sound is equally irregular and is "noise".

Random noise: This noise is more continuous in nature and has a more uniform amplitude. (Compared to impulse noise) nearly all noise is random type.

Signal-to-noise ratio: A comparison of the amplitude of the desired signal to the amplitude of the noise voltage present.

CHAPTER FOUR

The High Frequency Oscillator

The basic function of any oscillator is to change the DC energy from the power supply into AC energy at a specific frequency. Many types of oscillators have been developed to meet a variety of requirements. The most important of these requirements in regard to communications receivers is stability. The "colpitts" type oscillator, which can be readily adapted to crystal control, appears to be the most popular for high frequency communications.

The operating frequency of an oscillator is that frequency producing a net zero reactance of all the circuit components. Any circuit changes caused by varying voltages or aging of tubes necessitates a frequency adjustment to keep the reactance at zero, (or oscillator on exact frequency). Because of the high Q and steep resonant curve of a crystal, it takes a large change in reactance to cause a small change in crystal frequency. Regardless of how or why a frequency change takes place, it is undesirable and may rander the receiver to be inoperative. Assuming the frequency drift is small (and it usually is), it is possible to bring the oscillator back on frequency by varying a small capacitor (figure 14) in series or in parallel with the crystal. This is called "warping".

If a receiver uses an oscillator-multiplier operating at the 5th harmonic, the change of frequency is 5 times greater at the mixer than at the oscillator section. As an example, in figure 14, a change of 2 KC at the oscillator frequency would produce a change of 10 KC at the mixer. This in turn would allow a 10 KC change in the 12 MC I F.

The effect of temperature on a crystal

The natural frequency of a crystal is influenced to an appreciable degree by the temperature at which it is operated. The extent and character of this temperature-effect is determined by the manner in which the crystal is cut from the natural quartz, the shape and size, the precision of grinding and the characteristic of the crystal material itself. The frequency change is expressed in number of cycles changes for each million cycles of crystal frequency for each degree centigrade variation in temperature. This change is in cycles per second and is termed the temperature coefficient of frequency.

A positive coefficient means that the crystal frequency increases with temperature increase and a negative coefficient means the crystal frequency decreases with an increase in temperature. Thus for the highest degree of stability in a crystal oscillator, it is necessary to keep the crystal at a constant temperature.

To meet the rigid requirements of modern communications, crystals of the lowest temperature coefficient are used. Also these crystals are enclosed in a sealed electric oven that is thermostatically controlled at a specific temperature. The temperature of this "crystal oven" is maintained higher than the summer operating temperature of the equipment. If it is cold or hot weather; the crystal is operating at this fixed temperature. This allows the overall operational stability of the receiver to be within .0005 percent. Comparing this accuracy with distance, this is an accuracy to within three centimeters in three kilometers. (One in. two miles.)

Aging in Crystals

This refers to a natural change of frequency that takes place over a period of time. All crystals age to some degree, and this usually occurs during the first few months the crystal is used. After the aging period, crystals are likely to maintain a stable frequency for the rest of their natural life. Aging in crystals may be accompanied by a deteriation in activity. If crystal activity drops as much as 25 percent during the initial aging period it is possible that the crystal has some contamination or natural flaw.

Contamination results when foreign matter accumulates on the crystal. This may seriously affect the crystal's operation as to both, frequency and activity. Because modern crystals are "plated" there is no practical field repair suggested, and such crystals should be returned to the factory for service.

The High Frequency Mixer

Since the mixer output voltage depends largely upon the impedance presented to the IF signal current in the plate circuit, it is desirable that this plate circuit be highly selective.

A typical mixer, with an input of 172 mc is shown in figure 14. The oscillator voltage at 160 mc is injected into the cathode circuit. The 1.25 volt bias developed across the cathode resistor operates the tube a t the lower portion of its characteristic curve. A triode is used so that the noise generation will be low, and the three high, critically coupled tuned circuits in the plate provide maximum IF signal output with good selectivity.

Does Hetrodyning affect Deviation?

The question of deviation always arises in connection with mixer action and the resulting IF signal. We can best explain this by using an example. Assume the incoming signal of 172 mc has a deviation of plus and minus 15 kc. This means the RF swings 15 kc above and 15 kc below center frequency. The incoming RF is not the constant frequency of 172 mc, but varies between 171.985 and 172.015 mc.

When the RF frequency is at center, or 172 mc it combines with the constant 160 mc oscillator frequency to produce the center IF frequency of 12 mc. When the RF is 171.985 mc it again combines with 160 mc signal but the difference is now 11.985 mc.

Similarly, when the RF is 172.015 mc, the difference frequency is 12.015 mc. The IF frequency varies between 11.985 and 12.015 mc, which is a deviation of plus and minus, 15 KC. From this we can see that the mixing action has no affect on the modulation deviation, the resulting IF has the same deviation as the applied RF.

Summary

1. The purpose of this portion of the receiver is to deliver an interference free signal with high S/N ratio to the second mixer.

2. The high frequency crystal is temperature controlled for maximum stability.

3. The crystal oscillator, can be altered to compensate for the natural aging of the crystal. This is usually accomplished by means of a small variable capacitor.

4. The mixer hetrodynes (mixes) the RF and the oscillator signals to provide the difference IF frequency.

5. The hetrodyning process in the mixer does not change the deviation characteristics of the signal. The deviation of the IF signal are identical to those of the incoming RF.

6. The IF amplifier provides high gain and sharp selectivity.

Important words used in this Chapter

Aging: As applied to quartz crystal used in the oscillator. Aging is a natural change in crystal frequency evidenced over a period of time.

Crystal Controlled Oscillator: An oscillator that makes use of a quartz crystal to provide a high degree of stability.

Harmonic Frequency: A frequency which is a whole number multiple of the fundamental frequency.

Piezoelectric Effect: A natural phenomenon associated with certain crystals. When a voltage is applied across its faces it distorts mechanically.

Quarts Crystal: A silica material which exhibits piezoelectric properties. Its most important use in the electronic industry is in conjuction with an oscillator as a frequency controlling device.

Warping: This is the changing of the frequency of a crystal controlled oscillator so that it operates exactly at the required frequency.

CHAPTER FIVE

The Second Mixer Oscillator and IF Stages

In this lesson we will be concerned with (1) Rejection of all remaining signals except those of the desired channel. (2) Provide a large amount of amplification ahead of the limiters.

The Low Frequency Oscillator

In order to provide for the required selectivity and amplification, the high frequency IF signal of 12 mc must be converted to a low frequency IF of 455 kc. (.455 mc) (which is used for the low IF of most communications receivers.) This requires another mixer and oscillator combination. Figure 15 shows a typical circuit. With an IF of 12 mc, in order to secure a 455 KC second IF the second oscillator must be either 455 KC above or below 12 mc. As shown in figure 15, the oscillator in our example is 12.455 mc which is 455 KC above the 12 mc incoming signal. To insure maximum stability, the second, or low frequency oscillator is crystal controlled. Because of its comparatively low frequency, the slight frequency change due to any temperature change has no appreciable effect on the receiver operation. Therefore, the oscillator design is less complicated and it is not necessary to use a constant temperature oven.

In figure 15 the crystal acts like a parallel tuned circuit controlling the frequency of operation. Feedback to keep the crystal oscillating is obtained by connecting the cathode to the junction of the two capacitors connected in parallel to the crystal. The oscillator voltage is injected into the mixer stage grid through capacitor C1. The oscillator plate is bypassed to ground and has no active part in delivering the oscillations to the mixer stage.

The Second Mixer

Two distinct inputs, the 12 mc IF signal and the 12.455 mc oscillator voltage are applied to the second mixer. The heterodyning action, or "beating together" of these two inputs produces a difference frequency of 455 KC at the output of the second mixer. (There is also the sum of these two frequencies 24.455 but it is rejected because the output is tuned to 455 KC,) while the second mixer stage is operated in class A to minimize the generation of any undesired frequencies there is a satisfactory output at the 455 KC second IF frequency. To provide a large voltage at the 455 KC, the plate load of the second mixer must present a high impedance at this frequency. At the same time it must present a low impedance to all undesired frequencies.

Obtaining Selectivity

When we remember that all the intelligence we want to hear is contained in the side-bands rather than at the center frequency, we can appreciate the statement that the bandwidth of the last IF must accomodate all of the incoming energy. Also since the AM deviations possibly may extend plus or minus 15 kc each side of center frequency, a frequency response which is both broad and flat is essential. Beyond this flat top response, however, a sharp attenuation is required in order to eliminate other signals.

In the best equipment a bandpass filter that is tuned at the factory to pass a required frequency and sealed so that it cannot be jarred out of adjustment or tampered with by an unexperienced person. (It would require special equipment and knowledge to readjust a bandpass filter.)

Because there is always some loss due to resistance, all filters attenuate the signal to some extent because there is no amplification. Attenuation of the desired frequency is called "insertion loss". The input and output impedance must be held constant and they must match the impedance of the terminating circuits. By maintaining a constant impedance match there is no reflections and the only losses are those due to resistance.

At the output of this bandpass (passive) filter we have only the desired signal to be delivered to the limiter stages. This we will take up in the next chapter.

Introduction to Decibels

There is probably no field of electronics today which makes more use of the decibel than does the two way communications.

Overall gain, selectivity curves, noise levels and many others are all expressed in decibels levels, gains or losses. The service man must have a good knowledge of decibels, abbreviated db, in order to perform his duties intelligently. The decibel is often concerned with sound intensities, and there is a direct relation in our hearing to the decibel. Thus, we have a convenient starting place for this discussion.

The physicist defines sound in terms of wave motion that take place in air. From the physiological standpoint sound is the sensation produced in the ear by such wave motion. There is a difference in the amount of sensation as recorded by the ear as compared with the amount of energy used to produce these sound waves. In other words our ears are neither reliable nor efficient in distinguishing between sound intensities. For example, will 10,000 people shouting sound 100 times louder than 100 people shouting? The answer is no. The difference to our ears is about 20 times louder. There are many such examples that illustrate the non-linear hearing characteristics of the human ear.

The specific relationship between the amount of sound energy and the intensity of what we hear is conveniently expressed in terms of decibels. The decibel is said to be the smallest change in sound intensity that the human ear can detect.

The conditions must be ideal, or a change in sound intensity of one decibel may not be noticeable. This is rather nontechnical definition but it illustrates how the decibel is used. Decibel is written, db.

As a further example in compa ring sound levels, a sound producing device increasing to twice its original power output produces a 3 db increase in intensity. Any time power is doubled it represents an increase of 3 db. Should the power be reduced by one half its original value, there will be a 3 db loss, the power is said to be "down 3 db." This 3 db relationship holds true whether the level is but a small portion of a watt or many thousand watts. For example, assume the power from a speaker is increased from 1 to 2 watts. This is a 3 db change. On the other hand, when the power output from a commercial broadcast station is increased from 10,000 to 20,000 watts the increase again is just 3 db. In the first instance it required only 1 watt to double the power and produce a 3 db gain, in the second case, 10,000 watts were required to cause a 3 db increase.

The exact amount of db change is usually found by means of logarithms. Where two power levels are concerned, the formula is: (1) db = 10 times the log of P1/P2.

Where voltages or currents are being considered the formula is: (2) db = 20 times the log of E1/E2 or (I1/I2).

In using either of these formulas place the larger number in the numerator in order that the ratio will be larger than 1.

If amplification has taken place, the answer is said to be a db gain, if there has been some attenuation, the result is a db loss.

Example 1. Find the db change for a power increase from 5 watts to 10 watts. Using formula (1) db = 10 times the log of 10/5, or 2. From a log table the log of 2 is .3010. Substituting, db = 10 times .3010 or a 3.01 db increase.

If the power had been reduced from 10 to 5 the solution would be the same but it would be a 3.01 db loss.

Example 2. Find the db change when the voltage in a circuit is reduced from 16 to 2 volts.

Using formula (2) db = 20 times log 16/2 (20 times log of 8). The log of 8 is .9031, and the db loss is 20 times .9031 or about 18 db.

The convenience of using decibels may not be apparent in the foregoing examples, but consider the problem of determining the total gain (amplification) of a communication receiver where the gain might well be 1,000,000. Without decibels, the gain of each separate stage is determined, and then the gain of each separate stage must be multiplied. When the gain of each stage is given in terms of the equivalent db, the separate db resultants are added or subtracted.

The db also eliminates the use of large and unwieldy numbers. Lets take as an example the receiver having a gain of 1,000,000. What is the db gain? Fortunately we do not have to resort to mathmatics when a table such as shown below is available.

Current or voltage ratio	db change
10	20
100	40
1,000	60
10,000	80
100,000	100
1,000,000	120

Power ratio	db change
10	10
100	20
1,000	30
10,000	40
100,000	50
1,000,000	60

From this we see that each time the voltage is increased 10 times, there is a 20 db gain.

Each power increase of 10 times, is a 10 db gain. It is interesting to note that the voltage or current change ratio is always exactly twice the corresponding db power change.

To say that the power of a transmitter has increased one watt does not tell us very much unless we also know the power level before this change took place. When the increase occurs for a low power device having but one watt of power originally the increase of one watt means doubling the power and a 3 db increase.

Should the same increase of 1 watt occur in a transmitter with an original output of 20 watts, the power will now be 21 watts. The effective increase is only about .2 db and will not be noticeable. (1) An increase or decrease can always be accurately stated in terms of decibels, for this is always a comparison of two levels and automatically indicates the effective increase.

Including the latter statement, here are some more things to remember about decibels.

2. An increase of power to twice (or one half) the original value is a 3 db change.

3. Each change of power by 10 times, means a 10 db change.

4. Each change of voltage or current of 10 times is a 20 db change.

5. Our ears are not linear devices, but hear differences of intensities according to db changes in power levels.

6. Where the reference levels are not specified, .001 watt across 600 ohms is assumed. (Zero db is .001 watt.)

The db meter dial markings are actually voltage readings calibrated according to power level. (Some meter dial scale, unlike number 6 above, use .006 watt across 500 ohm line for zero db reference.)

Important words used in this chapter

Critical coupling: The amount of coupling between tuned circuits which allows for maximum output voltage, but which retains relatively sharp selectivity.

Cutoff Frequency: As applied to filters, the cutoff frequency is the midpoint between the attenuated band of frequencies, and the passed band of frequencies.

DBM: A decibel reference level in which .001 watts across 600 ohms equals zero dbm. All power levels may then be stated with respect to this 1 milliwatt reference.

Decibel: A standard unit of comparison between two levels of sound intensities or electrical power. A decibel is sometimes defined as "the smallest change of sound intensity the human ear can distinguish".

Filter: A frequency selective device in which certain frequencies are allowed to pass, but other frequencies are attenuated.

Insertion loss: Attenuation of the desired signal (due to resistance) in a passive filter. This loss is usually stated in decibels.

CHAPTER SIX

The Limiter

The noise free reproduction of the weak signals by the FM communications receiver is made possible by the operation of its limiters.

While the discriminator is designed to respond to the incoming deviations of the applied signal, it is also sensitive to amplitude variations -- and the dominant characteristic of all noise energy is its amplitude irregularity. Thus, by using properly designed limiters to deliver a constant amplitude signal to the discriminator, a relatively noise-free reception of FM signals is realized.

Limiter Action

The incoming signal contains many irregular amplitude variations in addition to the desired frequency modulation. Most of the noise energy is concentrated on the peaks of this signal. To eliminate this noise energy from the signal, only a small portion of incoming positive cycle is used. This is realized by using a low plate and screen voltage (50 v) with capacitor coupling and grid leak bias.

The limiter has upper and lower limits regardless of the amplitude of the applied signal, the output can never exceed these limits. Using a large resistor in series with a strong signal input, one half of each cycle is attenuated, and the other half cycle drives the tube beyond the upper portion of its characteristic curve which is saturation, this cuts off the peaks of the output pulses. As we are using only a portion of a cycle that has been limited or clipped we can see the noise is greatly reduced. To be sure that all noise is removed, we use at least one more limiter stage.

As we are only interested in deviation of frequency which contains the intelligence, we now can realize that the output of the total limiters are exact reproductions of the input signal only in regard to frequency. All amplitude variations have been removed leaving only a precise coding as to frequency variations.

A typical circuit employing two limiter stages uses resistance coupling between the stages. This type coupling eliminates the use of transformers which is very difficult to align where limiters are in saturation and the adjustment of the circuit to resonance do not cause any additional increase in output voltage.

Low value of supply voltage and grid-leak bias are used in both limiter stages.

The first limiter stage, with no signal applied has an initial bias of 25 volts due to noise, with a signal applied, this bias increases. The stronger the signal the higher the voltage produced, until the point of maximum bias - about 60 volts - is reached. At this point the maximum possible signal will be reaching the grid, due to the saturation in the plate - circuit of the preceeding stage.

The second limiter stage with noise applied, has an initial bias of approximately 20 volts with a signal applied, this bias does not noticeably increase. This indicates that the plate of the first limiter is already saturated by noise and the signal produces little or no increase in voltage from this stage. The signal voltage merely replaces the noise voltage in the output.

Strong signal are limited to some extent even before they reach the first limiter. It will be recalled that the last IF stage does not use cathode bias but has a grid-leak arrangement which provides some limiting action. When a signal is strong enough to exceed the straight portion of the operating curve, reaching the points of cutoff and saturation, the last IF stage operates as a limiter so that, in effect, a well designed receiver has 3 limiter stages on strong signals.

Inversely the weakest signal to be received has only about .5 microvolts at the antenna, the total amplification preceeding the first limiter must be at least 4,000,000 times, to provide a two volt signal at the limiter input. With a strong signal input the amplification is greater than needed but as we have a constant amplitude from the limiters this strong signal guarantees a noise free voltage at the discriminator. With a very weak signal at the antenna, the high amplification of the stages ahead of the limiter will still provide an understandable signal.

While we understand that the output of the second limiter of the FM receiver has a constant amplitude, it is important to investigate the nature of its waveform in the absence of a signal.

Because of the very high gain of the entire receiver, particularly in the last IF section, the small noise voltage generated in the RF stages becomes large voltages at the limiter. For this reason the last limiter is always in a state of saturation. Thus, the limiter output, despite the absence of signal, consists of noise voltages having a constant amplitude. When this waveform is applied to the discriminator the receiver becomes very noisy. This noise output from the discriminator is mainly due to the irregular frequency pattern of the noise waveform rather than to any amplitude changes.

When a carrier is received it "replaces" the noise energy in the output of the limiter. Because of the amplitude limiting ability of the stage, the noise energy of the plate circuit of the last limiter is reduced. Instead of the irregular frequency of the noise pulses, the plate current pulses now correspond to transmitted signal coming from the last IF. These pulses of plate current through the primary of the discriminator transformer cause an oscillatory current, which results in a sine wave (a signal pulse introduced into a transformer primary produces a sine wave at the exact frequency in the secondary). This oscillating current will correspond exactly with the frequency modulation deviations. Also, it is of constant amplitude and is free of noise. The completeness by which the signal replaces the noise depends upon the strength of the signal itself. The exact amount of noise replacement is usually referred to in terms of resulting "quieting".

<u>Summary</u>

Amplitude modulation, particularly noise energy, is eliminated from the FM signal by the operation of limiters ahead of the discriminator stage. With low operating voltages on the plate and screen grid, plate current saturation takes place rapidly. Grid leak bias is used to operate the tube on the desired portion of its characteristic curve for all levels of applied signal.

To obtain good limiting action, the amplitude of the input signal to the limiter must be appreciable, there must be a high order of amplification in the stages preceeding the limiter. Limiting action by removing both negative and positive peaks from the signal, eliminates most of the noise voltages from the signal.

After limiters reach a condition of saturation, the output voltage no longer increases with signal strength.

A constant grid leak bias at any grid circuit means that the plate current of the preceeding stage has reached saturation.

The last limiter in a receiver is saturated with or without a signal being received, without a signal the noise voltage output has a nearly constant amplitude due to the action of the last limiter.

A signal replaces the noise in the output, the amplitude remains constant.

Important Words

Cascade: Two or more stages arranged so that the output of one is applied to the input of the other. (Word not used in this chapter.)

Grid leak bias: A biasing method whereby the grid is made negative by an amount dependant upon the strength of the applied signal. An RC circuit combination in the grid circuit develops this biasing voltage when the signal drives the grid positive with respect to cathode.

Plate Limiter: The stage immediately preceeding the discriminator, the plate limiter provides an output having a constant amplitude. A strong input signal is required to swing the limiter plate current between cutoff and saturation, thereby limiting the signal amplitude and providing good noise quieting.

Quieting: The decrease in noise reproduced by the FM receiver when a signal is received. Receiver quieting is the result of limiter action.

Saturation: An operating condition of a vacuum tube in which the plate current is a maximum value for the established operating voltages and plate load. Once a tube has reached saturation, the plate current cannot increase further, regardless of signal amplitude.

20 Db Quieting: A standardized term in two way communications, this amount of quieting is used in conjunction with receiver sensitivity. Thus sensitivity may be stated as a minimum signal voltage at the receiver input terminals, required to produce a 20 db reduction in noise at the receiver utput. (10 to 1 voltage ratio.)

CHAPTER SEVEN

The Discriminator

All FM receivers incorporate some circuit device to convert the incoming deviations of the IF signal (which contains the audio message to be reproduced) into voltage variations. The two most popular of these circuits are the discriminator and the ratio detector. The discriminator which at the present is best suited for the needs of the communications receiver is the one described in this chapter.

Because the action of the discriminator depends upon several phase relationships between existing RF voltages, it is often regarded as somewhat more intricate than other circuit found in FM receivers. For this reason it is probably the least understood.

It is not necessary to have a thorough knowledge of "vectors". However, a knowledge of vectors would be of great help to understand this circuit.

If you have not had the opportunity to make use of vectors in the past you will find this following section helpful.

Plain Vector

Many things that we weigh and measure are described in terms of pounds, feet or gallons. Because of their nature we do not require any further data about these things, the information is complete. Other quantities require that their direction be given before we can make useful application of the information. For example, the airplane pilot must know the direction of the wind as well as the velocity. In operating his plane the pilot must take into account the wind direction or he will not fly a straight path to his destination. He may even end up in the wrong place. This wind must be stated in terms of both direction and magnitude.

Many electrical forces too, must be stated in terms of both direction and magnitude before we can make intelligent use of them. The "vector" is a convenient device which can be used to describe both magnitude and direction of forces.

A vector is a straight line drawn to a certain length and in a specific direction. In any vector diagram, a vector must have a common starting point, known as "origin".

A vector system is drawn by a horizontal line and a vertical line. The horizontal line is the X axis with zero° at the right end and 180 degrees at the left end. The vertical line (Y axis) crosses the horizontal line in the center and the top is marked 90 degrees and the bottom marked 270 degrees. Where the lines cross is the "point of origin". Now we have 4 quadrants (quarters) each 90 degrees. (Vectors above the X axis are positive, below are negative.)

In alternating current, vectors are thought of as being in constant rotation, moving counter clockwise at a specific relation to time (frequency). It is permissible however, to "stop" the vector at any instant to consider phase angles and analyze what is happening in the circuit. Example (1) We have two alternating voltages in a circuit. One is 50 volts at zero degrees, the other is 50 volts at 180 degrees. Starting at the crossover point of the xy axis we draw a line out toward zero on the X axis, a specific distance for each volt. We do the same in the 180 degree direction and we see they are exactly the same magnitude but the direction is such that one must subtract from the other. Thus, we find the result is zero volts. In other words these voltages cancel each other. When two voltages are said to be 180 degrees out of phase, and they are equal magnitude, the resultant magnitude will be zero

In AC practice we use "phase" todescribe the relative directions of separate forces. Example (2) We have 2 alternating voltages. One voltage is 15 volts at zero degrees, this is on the horizontal X axis. The other voltage is 15 volts at 90 degrees, this is on the y axis. Now we use a scale which is an equal amount for each volt. We make a line at the degree angle the length of this 15 volt scale. By drawing a line from the termination end of the 90 degree voltage exactly parallel with the voltage at zero degrees and another line from the zero degree voltage and exactly parallel to the other voltage angle until these two lines intersect forming a parallelogram. At this point of intersection we draw a line back to the xy axis (point of origin) we now have a resultant phase angle and by using the voltage scale we can determine the resultant voltage which is about 22 volts at 45 degrees.

It is apparent that the above resultant sine wave is not the added sum of the two voltages but the phase difference sum. This can be solved by completing a parallelogram. Regardless of the phase angle of two voltages or two currents, a line drawn from the termination of one value exactly parallel with the other phase and a line from the other value termination, in parallel with the first - the intersection of these lines back to point of origin will be the resultant angle and value of voltage or current.

Deviation and Discriminator Output

A simple discriminator circuit was shown in an early chapter. This circuit has a transformer with a single coil primary from the last limiter but a double coil secondary. One of the two coils is tuned to accept 15 kc above the 455 IF and the other secondary coil is tuned to accept 15 KC below the 455 IF frequency.

(1) We have said, the audio amplitude controls the amount of deviation. By this we mean, up to a controlled point, the more volume at the transmitter microphone the more the frequency will change from center frequency. This exact condition

is at these 2 transformer coils in the receiver discriminator. One coil winding will accept 15 KC above center frequency, the other will accept 15 KC below center frequency. As the voltages from these two transformer coils are connected each to a separate diode, capacitor and resistor, with the resistors in series, it is apparent this voltage will be rectified. The higher the frequency goes above and below center frequency the higher this positive and negative voltage will be so a higher voltage will be present at the output. This amplitude will establish the magnitude of the output. (2) Also we have said the audio frequency determines the rate of deviation above and below center frequency within the deviation limits established by the audio volume. To explain this further we can better use an example: Assume an FM transmitter produces a maximum deviation of plus and minus 15 KC while using an audio frequency tone of 1000 cycles. At the receiver this maximum deviation will establish maximum rectified voltage at the receiver discriminatr output and the rate or number of excursions from center frequency will be 1000 times per second. In the output of the discriminator we find this rectified output voltage must change from positive to negative at the exact audio rate of 1000 times per second so we realize a 1000 cycle audio sine wave at maximum amplitude.

Let us summarize at this point:

Without deviation being present (carrier only) at the secondary of the discriminator transformers, any center frequency voltage present in one of the two discriminator transformer windings will also be present in the other transformer winding. Because of the effect of the components in the discriminator circuit, these two center frequency voltages, because of the resultant phase angles, will result in zero voltage output.

Now we should be able to understand that with voice modulation, varying amounts of frequency change, and the rate of this change introduced by audio will cause a variety of complex phase relationships in the discriminator input. The discriminators circuits transposes these phase differences back to the original audio.

It must be mentioned that FM systems use preemphasis to improve the signal to noise ratio at the higher voice frequencies. To restore the discriminator output to normal, a deemphasis network is required. To have proper balance between the audio frequencies, the amount of deemphasis in the receiver must correspond to the preemphasis introduced by the transmitter.

Important Words

Discriminator: A type of FM detector which recovers the audio component from the deviations of the applied FM signal.

Phase: As used in AC, phase refers toany instantaneous time within the AC cycle. Because time is usually measured in the degree of angular rotation, phase is designated in degrees, (0 to 360).

Phase Detector: An FM demodulator or detector, its operating depending upon a changing phase relationship between the operating voltages within the circuit. As the incoming signal deviates from center frequency, these voltages change in phase to accomplish the required detection.

Phase Difference: Phase angle, or Phase Displacement: A comparison of the instantaneous phases of two AC voltages or currents.

CHAPTER EIGHT

Squelch and Audio Circuits

As we listen to the sound portion of television broadcast we do not hear any noise or hiss from the speaker when the audio modulation is temporarily removed.

The reason for this is that the carrier is still present to keep the receiver quiet. In fact the carrier is always present, from the beginning of the first program until the final program at night.

This is not the case in two-way communication systems. As soon as each transmission is completed, the carrier and modulation is discontinued at the transmitter. Without some means of silencing the receiver during periods of no transmissions, the long periods of noise becomes bothersome. This receiver silencing is accomplished by means of the squelch circuits, which prevents noise voltages from reaching the speaker whenever the transmitter carrier is off.

The incoming signal, whether modulated or unmodulated controls the squelch operation. When the carrier is received the squelch "opens" and the receiver operates normally. In the absence of the carrier the squelch "closes" preventing noise voltage from passing through the audio stages. The squelching (which actually silences the receiver) must not be confused with a similar expression, "receiver quieting", which is the noise reduction at the limiters in the presence of a signal.

Squelch Requirements

Here are the requirements of the squelch circuit.

1. The squelch must silence the receiver during periods of no signal.

2. The squelch must not interfere with receiver operation for weak signals.

3. The squelch must not operate (open) on strong noise pulses or other interference at the receiver.

4. Fading signals must not cause fluttering - opening and closing of the squelch with signal.

5. Squelch action must be independent of changes of power supply voltages. It should not be necessary to readjust the squelch control for small normal changes of primary power supply.

6. The squelch must open completely for weak signals at the receiver frequency.

Noise Compensated Squelch

The complete squelch circuits shown in figure 16 illustrates all components for noise compensated squelch control.

In figure 16 the DC amplifier becomes the squelch control stage for the first audio amplifier. This DC amplifier either conducts, biasing the audio amplifier to cutoff, or becoming nonconductive so the audio stage operates normally. Therefore, the squelch operation is realized through the bias of the DC amplifier.

The variable squelch bias voltage that controls the audio amplifier is developed across Resistor 3. (R3) shown in figure 16. When the DC control tube conducts, the voltage at the audio grid becomes less positive, (more negative to cathode) and the audio stage cannot operate.

When the DC control tube stops conducting, the voltage of R3 increases and causes the audio grid to become unbiased. The cathode circuit of the audio amplifier makes use of a voltage divider to establish a DC voltage at the cathode. This cathode voltage, however, is fixed rather than variable. The "squelch control" adjustment is incorporated in the noise amplifier rather than the cathode of the audio stage.

In order to control the squelch operation, the bias at the DC control tube must be either highly negative (in order that the tube dosnot conduct) or it must be near zero bias so it will conduct and overbias the audio stage, cutting it off.

The bias of the DC amplifier depends upon two separate voltages: (1) A negative voltage available from the grid of the limiter stage, this voltage is present at all times and (2) A positive voltage from the noise section of the squelch circuit. This positive voltage is variable.

Without an incoming signal the noise is high and a strong positive voltage (from the noise section) is applied to the grid of the DC amplifier. With a signal, however, the noise input to the noise section is greatly reduced and the positive voltage to the DC amplifier grid is also lowered. As we shall soon see, this variable voltage from the noise amplifier section determines whether the squelch will be open or closed.

We are now ready to analyze the squelch operation as controlled by the two DC voltages at the DC amplifier (squelch tube) grid. When a signal is received, little or no noise is applied to the noise circuit (figure 16) from the discriminator, and the o output from the noise section may be considered as zero. The only voltage at the grid is the strong negative voltage from the grid of the limiter. This bias (about -17 volts) is enough to prevent the DC amplifier (squelch) tube from operating. As a result the audio stage is biased normally and the signal reaches the speaker.

As long as the carrier is coming into the receiver the noise applied to the noise section is very low (due to the action of the limiters) and the receiver squelch remains open. As soon as the carrier is removed, the squelch closes. With no carrier to provide noise reduction to the limiters, the discriminator output is mostly a strong noise voltage which, in turn, reaches the noise section of the squelch. As a result, a high positive voltage appears at the output, and this positive voltage is applied to the DC amplifier grid circuit, (squelch circuit). This positive voltage counter-acts the negative voltage from the limiter grid, with the result that the voltage at the DC amplifier grid is about zero volts. Without bias at the grid, plate current is established in the DC amplifier and the receiver is squelched. Noise coming from the discriminator cannot get through the audio amplifier.

From this discussion we see that the noise section (figure 16) must in some way, supply a positive DC voltage to the grid of the control tube when there is no signal. Also, this voltage must be removed when a signal comes in. Keeping this in mind let us see how the noise section of the squelch circuits operate.

In Figure 16 the voltage acros C1 is present as long as no signal is being received, but it is removed whenever a signal is present.

The discriminator output is applied to the grid of the noise amplifier as well as the audio grid. With no signal coming into the receiver the discriminator output consists of noise voltage only, having a wide range of frequencies. When a signal is received, the discriminator output contains very little noise and consists mainly of voice frequencies in the 300-3000 cycle range. The coupling capacitors tothe noise amplifier stage are chosen so that the lower audio frequencies are attenuated. (The higher noise frequencies are allowed to pass.)

Thus when noise is present (no signal applied) the input to the noise rectifier is high and its DC voltage is also high. With a signal, the noise output from the discriminator decreases, and the noise input to the noise rectifier drops to a low value. The noise rectifier is now near zero volts.

The noise rectifier operates the same as the power line rectifier in a small table model radio. The rectifier is connected so its output voltage is positive, and the two filter capacitors, C1 and C2 maintain the output voltage at a steady DC level. This DC voltage to the controltube (squelch tube) tends to make the grid positive to ground. Actually this positive voltage opposes the negative voltage from the limiter grid and the net voltage at the DC amplifier grid is near zero-volts.

The variable resistor in the cathode of the noise amplifier becomes the squelch control. The cathode bias on the noise amplifier determines the gain of the stage and thus determines the amount of voltage applied to the noise rectifier. In this manner the squelch control determines the amunt of rectified DC output voltage applied to the DC amplifier, and controls the bias and conduction of that tube.

As soon as the carrier is received the noise output from the discriminator decreases, due to limiter action, and the input to the noise amplifier consists mainly of voice frequencies. Because of the "low frequency" discimination of the coupling capacitors, the input to the noise rectifier is small and the positive rectified output voltage decreases. In the absence of any high positive voltage from the noise amplifier the grid of the "squelch" DC amplifier tube becomes very negative and the tube cannot conduct. The squelch is now open. Because of this action at the grid of "control" tube (DC amplifier) the squelch will open on very weak signals.

The positive opening of the squelch for weak signals is further insured by using a common cathode resistor for the DC control amplifier tube and the audio amplifier. When the audio tube conducts, the current through this resistor increases increasing the bias across the common bias resistor. (The audio stage is so designed that its plate current is much greater than the DC amplifier tube.) With this increased bias voltage applied to the DC control tube grid, cutoff will be assured.

Supply voltage change causes corresponding changes in the gain or amplification of the various stages of the receiver.

If the voltage should increase, the noise reaching the limiter stage also increases to produce a greater negative grid voltage. This negative voltage tends to make the grid of the DC amplifier (control tube) more negative. At the same time, however, the noise at the noise amplifier and rectifier also increases and produces a higher positive output from the noise rectifier.

These two DC voltages, the negative from the limiter and positive from the noise rectifier, counteract each other and the grid voltage at the DC amplifier (cr control tube) remains constant. Therefore, the squelch operation is immune to supply voltage variations.

Increases in noise voltage entering the receiver balance out at the DC amplifier grid in much the same manner. The higher noise level at the limiter grid may increase the grid bias, but the DC output from the noise rectifier also increases and the voltage at the DC control tube grid remains constant.

Clamping

Basically clamping is a condition where the squelch of the receiver opens normally with the application of the carrier, but as the operator at the transmitter talks into the micrphone the squelch circuit in the receiver closes and the message is not heard. The squelch circuit may remain in the "clamp" condition for a long as the incoming carrier is modulated. Clamping may be the result of any of three different factors taking place within the receiver. We shall discuss each of these conditions separately.

1. An incoming unmodulated carrier may be at threshold level of the receiver so that the squelch is open, but due to the limited quieting produced at the limiters, some noise remains. As soon as the carrier is modulated, the carrier level is automatically reduced. (In modulating the transmitter, energy is taken from the carrier and placed in sidebands.)

As a result of the lower signal level at the limiters, there is less quieting and the noise increases at the noise amplifier and noise rectifier. The positive output from the noise rectifier increases and the receiver goes into clamp, the squelch closes.

2. The second possibility of clamping in the receiver results from the modulation of the transmitter by high frequency voice signals ("such as sss") which have a strong high frequency component. This looks like noise to the receiver circuits and produces an increased output from the noise rectifier. As a result the receiver clamps.

The remedy is to control the modulating signal at the transmitter by some type of deviation control circuit which limits automatically the undesirable deviations and high frequency components and thereby eliminates this type of clamping.

3. The third possibility of clamping comes about when the incoming signal is overdeviated - again a factor to be controlled

at the transmitter. At the receiver, the sideband energy of the overdeviated signal falls outside the acceptance of the audio filter, and less energy reaches the limiters. With less energy applied, the limiters allow more noise into the noise section of the squelch circuit and the receiver clamps.

Anti-Clamp Circuit

The anti-clamp circuit of figure 16 has been developed, patented and used by Motorola in their communications receivers.

The coupling circuits from the discriminator to the noise amplifier allows the upper voice signals as well as noise to reach the grid of the noise amplifier. Only the RF and the RC circuits are in this path.

Noise alone, applied from the discriminator to the noise amplifier provides some clipping of the noise voltage peaks in the plate circuit of the noise amplifier. This results in a near maximum output voltage from the stage to the noise rectifier. When a modulated signal is received, voice signals reaching the noise amplifier drive the stage into full limiting.

Two factors are responsible for this limiting action. First, the high frequency voice signals have a high amplitude and swing the noise amplifier to saturation and cutoff. That is on positive peaks the voice signals drive the stage to saturation and the negative peaks drive the grid far beyond cutoff. Second, the high frequency voice frequencies are lower than the noise frequencies - one cycle of voice energy lasts longer than one cycle of noise. The noise amplifier is held longer at cutoff and saturation. The time periods when noise can get through the stage are very short.

In review, a weak carrier just opens the squelch - we understand when this weak transmitter carrier is modulated, some of the center frequency carrier power is diverted to the plus and minus 15 KC modulation. This causes a slight reduction of center frequency power from the transmitter and would allow the squelch to close during modulation. As this condition could only exist during modulation, some of the upper modulation frequencies are used to keep the noise amplifier output from increasing. When modulation is removed, center frequency continues to keep the squelch open. Only when the carrier is removed will the squelch close.

NOTE: While the coupling capacitors associated with the noise amplifier play an important role in passing certain frequencies, this is accomplished only in conjunction with its associated resistors. This should be kept in mind by the service-man making any parts substitutions. The value of these resistors as well as the coupling capacitors are critical and must not be changed. In other words, the rc ratio must remain unchanged.

Squelch Threshold and Squelch Setting

If the squelch does not open on weak signals the receiver is effectively dead, even though the desired signal is available at the first audio stage from the discriminator. For example, if the squelch does not open for signals weaker than one microvolt, these signals do not get through to the speaker. Thus, it can be seen that the opening of the squelch determines to a considerable degree the sensitivity of the receiver.

A well designed squelch circuit will open for signals well below the 20 db quieting sensitivity rating of the signal circuits, and the squelch does not interfere with the operation of the receiver. Because the weakest signal producing any degree of intelligence is that which causes about 3 or 4 db of quieting. The squalch must be completely open for this signal level coming into the receiver.

The opening of the squelch on the weak signals is affected by the setting of the squelch control. This control must be adjusted so that, without a signal coming in, the receiver is just quieted or squelched. If the control is advanced still further the signal required to reduce the conduction of this tube must be stronger, and weak signals may not be heard.

Summary of Squelch Operation

Squelch is realized through the control of the first audio amplifier DC grid bias. With the squelch closed, noise coming into the antenna or generated within the receiver cannot reach the speaker. As soon as a signal comes in, the squelch opens and allows normal reception.

When the control tube is conductive, the audio stage is disabled. In order to open the squelch, the positive voltage due to noise is reduced and only negative bias from the limiter grid is present at the grid of the control stage. This high negative voltage, (not being balanced out by positive voltage from the DC rectifier) will stop this control tube from conducting, which in turn allows the audio stage to operate normally.

The noise compensated squelch offers the advantage of (1) making the circuit immune to noise pulses, (2) making the action more positive for small input signals, (3) providing for a quick opening response, and (4) making the squelch circuit independant of the supply variations. Also by applying higher frequency voice signals from the discriminator to the noise amplifier, the squelch cannot clamp (close) on weak signal inputs.

The Audio Amplifiers

The audio signal reaching the first audio amplifier is usually less than one volt, and another audio stage is therefore required to operate the speaker.

A typical circuit is shown in figure 16. Capacitor C-3 and resister R-4 from the deemphasis network, and the corrected audio voltage is available across C-3. The volume contrd parallel to C-3 determines the amount of audio voltage applied to the grid of the first audio amplifier. The bypass capacitor between the plate load and the decoupling resistor prevents any noise present in the B plus supply line from entering the audio section at this point.

The second audio stage - the power amplifier provides the power needed to properly operate the speaker. The bypass capacitor from plate to ground reduces the amplitude of the higher audio frequencies above 3000 cycles. The circuit is quite straight forward except for its bias arrangement.

A fixed bias for the power amplifier is obtained from the grid circuit of the second limiter. With no signal present the noise alone in the limiter provides an appreciable amount of grid leak bias - very little increase in bias is seen in this stage even when a signal is received. (The limiter is already at saturation from the noise.) Therefore, the second limiter bias remains relatively constant at all times and provides a convenient source of fixed bias for the audio output stage.

The volume is controlled (figure 16) by varying the bias of the first audio amplifier stage. As the volume is reduced to a lower setting, the bias on the stage is increased and the signal operates on a lower portion of the characteristic curve. This means less amplification and a lower audio output.

As this type volume control is adjusted to a low level the audio stage operates on a lower portion of the characteristic curve and due to the nonlinearity of the curve at the lower portion strong audio inputs may be distorted. To minimize this distortion, the circuit is arranged in figure 16 sothat the limiter utput voltage is also reduced when the volume controlis adjusted to a lower level. This is accomplished by lowering the limiter plate and screen voltages. This in turn lowers the plate saturation level and produces a lower limiter output voltage, resulting in a smaller audio voltage from the discriminator. This lower audio signal does not operate over as wide a portion of the characteristic curve and the distortion is reduced.

Another circuit necessarily affected by the volume control is the noise amplifier stage. The object here is to compensate for the noise level available from the noise amplifier when the receiver is in squelch. When the volume control is set for a low level of audio output, under no signal conditions the noise frm the limiter would also be reduced. If this condition went uncorrected, setting the volume control would also require resetting the squelch control.

In reducing the cathode bias on the noise amplifier in proportion to low volume control settings, the gain of the noise amplifier stage is increased so that the same amount of noise reaches the noise rectifier regardless of volume control setting.

NOTE: In figure 16 it will be observed that there is an audio volume control at the discriminator output. This control is a maximum level control and in mobile units is on the receiver chassis. This control being set for the highest maximum desired by the radio technician. In the mobile, the volume control on the remote control head, controls the volume from zero to the maximum allowed by the chassis mounted, discriminator output control. The control head, volume control affects the voltages of three stages. (1) the bias of the first audio amplifier, (2) the plate and screen voltages of the second limiter and (3) the cathode bias of the noise amplifier.

Important words used in this Chapter

Clamping: A form of undesirable squelch action which prevents the message from reaching the speaker. Although the squelch opens for the incoming unmodulated carrier, it closes again as soon as the carrier is modulated. This occurs (1) when the unmodulated carrier is weak and barely opens the squelch, or (2) when the transmitter is overdeviated to the extent that much of the sideband energy is beyond the bendpass of the receiver tuned circuits. In either case clamping is the result of the reduced signal amplitude reaching the limiters when the carrier is modulated.

Closed Squelch: The condition in which the squelch has operated to silence the receiver. Noise voltage cannot get through to the speaker.

Noise Compensated Squelch: A circuit which utilizes the noise voltages (normally present in the receiver without a signal) to initiate and control the squelch operation.

Open Squelch: The condition in which the squelch is inoperative, with the result the receiver may work normally. This condition is evident when a carrier is being received.

Squelch: A circuit which disables the audio section in the absence of a carrier. As a result, the noise which is normally heard without a signal being received cannot reach the speaker.

Squelch Threshold: The minimum setting of the squelch control which will permit the squelch to close. A weak signal at the receiver input will open the squelch.

Maximum squelch or full on squelch: The condition caused by adjusting the squelch control fully clockwise, producing an extremely high bias on the audio stage. A weak signal may not open the squelch there is a loss of receiver sensitivity.

CHAPTER NINE

Before starting our discussion about receiver trouble testing, we must be sure previous tests have been made which definitely establish the receiver as the offending unit. That is, we must be sure the power supply and the antenna system are normal.

The specific procedure for trouble testing the receiver will vary for each service problem; we may use one technique for the receiver in the vehicle and another for the receiver at the base station. The mobile receiver is the more common of the two so we shall start our discussion with this unit.

The Mobile Receiver

The trouble isolation chart in figure 17 will serve as a useful step by step guide in trouble shooting the receiver. It lists a number of possible troubles and suggests corrective procedures. In this chapter we assume the only test instrument available is the Motorola test set. We are also assuming that there is also no carrier frequency signal available for testing the receiver.

Audio Test

The first step when isolating trouble in a receiver is to turn the volume control full on and open the squelch fully counter-clockwise. A loud noise should be heard in the speaker. If there is no sound, the fault is likely to be in the audio or squelch sections of the receiver. We continue with procedure (2) which is to the left in figure 17.

Here we use the Motorola test set plugged into the receiver and adjusted to measure the receiver output (Position 8 with tester P8501 or position 11 on tester TU 546.) We make two tests. First, if the speaker circuit of the receiver is defective, we will now hear noise in the test set speaker. Second, the test meter measures the receiver output voltage. Lets first assume that the test set shows a reading and a loud sound is heard in the test set speaker. We may immediately assume that the speaker or its circuit in the receiver is defective. If the receiver is mounted in the trunk, the speaker is a separate unit which interconnects to the receiver through the control head. It is likely that the wiring is defective.. In some models the speaker wires plug into the control head, and one of these connections may be bad. If the trouble cannot be found through visual inspection it may be necessary to use an ohmmeter or a substitute speaker.

If there is neither noise from the speaker nor a reading on the meter, the speaker circuit is probably good. We now proceed to 3, figure 17. Remove the noise rectifier tube in the squelch section and listen for noise from the speaker. Removing the noise rectifier disables the squelch section of the receiver and helps to further pinpoint the problem to either the audio circuit or the squelch circuit. If the squelch circuit is defective (if the coupling capacitor between the noise amplifier and the noise rectifier is leaky), there will be a constant positive voltage present at the DC control tube grid and the squelch will remain closed. If the squelch is to open, the negative voltage from the second limiter must be available and the positive voltage from the noise section must be removed.

If there is still sound after the noise rectifier tube is removed, try new tubes in the squelch section, procedure 4. If there is no change in the operation, the fault is in the squelch circuits and the receiver must be brought to the service bench for more detailed checks.

If there is no sound however, with the noise rectifier tube removed, proceed to procedure 5 and replace, one at a time, the audio discriminator and second limiter tubes.

If any of these tubes correct the trouble, a high noise level will be heard and the receiver may be checked for normal operation. If however, these tube replacements do not produce any change, the receiver must be further tested on the service bench.

RF IF Tests

When the service man hears noise in the speaker after procedure 1, he immediately proceeds to 6 on figure 17. Here he takes readings in positions 1,2,4,5 and 6 on the test set.

If the reading at position 2 is low, (position 1 is normally low without a signal applied) the trouble is either in the

RF or IF stages. This includes both oscillators and mixers. It is not possible to isolate the trouble further within this large section of the receiver by making additional tests with the test set, so the best solution is to follow procedure 7, figure 17. Replace tubes one by one, noting the change in the noise and in the meter readings, position 2 in particular.

It is sometimes possible, by noting the changes in the noise level, to isolate the trouble within the entire front end of the receiver. If upon removing the high frequency oscillator or mixer tube, the noise does not decrease, the trouble is likely to be in that stage or the stage following. If the noise changes, the receiver is operating to some extent from this point to the speaker but some stages may be weak.

If tube substitution restores the meter reading at position 2 to near normal (and other positions as well) we may be reasonably sure that the trouble has been found and corrected. It is necessary, however, to completely check the receiver operation. This necessitates a complete check on alignment, particularly with a signal from the base station.

If the readings taken at meter position 1 and 2 are normal, we next check the reading at position 6. Although this reading indicates oscillator activity, the test set does not actually measure the injection voltage from the oscillator plate circuit to the mixer. Besides, even if the reading at position 6 is normal we cannot be sure that the injection signal to the mixer is at the correct frequency - the oscillator may be off frequency and require alignment.

If the reading at position 6 is too low, the next procedure, 8, is to try a new oscillator tube. If the new tube does not restore operation, a crystal known to be good should be tried. If the readings are still too low it will probably be necessary to remove the receiver from the vehicle for bench service. If the reading at position 6 returns to normal, the fault is corrected.

When analyzing the reading at meter positions 4 and 5 (the primary and secondary of the discriminator) we have to take into account the readings at position 1 and 2. If the reading at position 5 is low, we must first make sure that the readings in position 1 and 2 are near normal. If they are not the trouble is in the circuits preceeding the limiters rather than in the limiter or discriminator circuits. Therefore, we are concerned with low reading at position 5 only when position 1 and 2 are near normal. If position 5 is still low, we should try new tubes in the limiter and discriminator stages (procedure 9 in figure 17). If the readings remain low, either the receiver requires alignment or there is some other trouble for which it may be necessary to remove the receiver for bench service.

The reading at position 4 should normally be close to zero. When only noise is present the idling of position 4 should be within two scale divisions of zero on the test meter. If the reading at position 4 is not zero (with no channel signal applied), it is possible that the low or high frequency IF section requires retuning. Also a strong signal on some nearby channel may produce "noise", causing the discriminator noise idle to swing off zero.

When the reading at position 1, 2, 4, and 5 are normal the trouble may be due either to off channel operation of the receiver or low sensitivity in the receiver front end. For off channel operation we may follow the suggestion under Figure 17 reading at position 6 block. For low sensitivity follow the suggestions of procedure 7.

Using a signal for Isolation of Trouble

When a signal on channel frequency is available, it is often easy to determine the trouble more quickly and with greater reliability.

In general, we should start our trouble shooting (checking) in the same manner as recommended in the chart of figure 17. Unless there is some noise in the speaker there is no need for the channel signal. We already know that the trouble is likely to be in the audio or squelch circuit. Also the reading in position 6 should be normal, for without the high frequency oscillator working properly there would be no hetrodyning action and therefore no IF to measure or to cause noise quieting.

Assuming then, we have established the presence of noise in the speaker and that we have obtained a normal reading at test set position 6, we may now check any change in the readings at position 1, 2, 4 and 5, with the signal applied. It is also important to note any change of noise heard in the speaker when the signal is applied.

Unless the readings in positions 1 and 2 show a reasonable increase (with signal) and the noise decreases relative to the applied signal strength the trouble is in the RF or IF sections. Figure 18 is the trouble isolation chart that we can use when a channel signal is available.

Position 4 may show no change, read zero on signal, or swing away from zero, if there is no change in the reading and there is very little noise quieting, the trouble is in the limiter or discriminator stage, try replacing tubes. If this does not correct the trouble, the receiver probably requires further servicing with additional test equipment. If the reading swings away from zero when the signal is applied, the high frequency oscillator is off frequency and may be readjusted so reading is zero. (Be sure first, that the discriminator reads zero with a 455 KC signal.) If the reading shows zero with the signal applied, the oscillator frequency is correct. The trouble, if any, is either in the RF or the IF stages. See the suggestions of procedure 7 figure 17.

Alignment

While general alignment procedures can only be given for specific receivers, we shall, in this chapter, use the motorola receiver.

The following equipment will be required to align the receiver:

(1) A Motorola test set including a 455 KC crystal

(2) A known source of signal at the channel frequency

(3) A frequency meter of acceptable accuracy and stability. (This frequency meter to verify the correct signal generator frequency.)

The first step is to align the circuits tuned to the last IF frequency, 455 KC. This requires the test set and a 455 KC crystal. The 455 KC signal is applied to the grid of the first stage of the second IF amplifiers. A shorting wire is connected across the secondary terminals of the discriminator transformer with the test set supplying the 455 KC signal, the "primary" of the discriminator transformer is adjusted to maximum at meterposition 5. (This adjustment is made from the bottom of the chassis.) After completing this adjustment the lock nut is secured and the secondary shorting wire is removed. Once this adjustment has been made it is not likely that a readjustment will be required for some time.

The next step is to tune the discriminator secondary transformer. (Be sure the shorting wire has been removed.) Switch the test set to position 4 and with a signal, adjust the discriminator to a zero setting. The secondary is adjusted from the top of the discriminator transformer assembly.

The remaining 455 KC adjustments are in the second IF plate circuits. (Position two). The signal is loosely coupled to the input of the filter which is just ahead of the second IF stages. The applied signal is kept low so the peaking adjustments are linear. If the applied signal is too strong the circuits will be saturated, in which case the test set meter, during adjustment, will show little or no increase.

The next step is to tune the first IF. (12 megacycle IF) The 12 mc IF frequency is supplied by the signal generator. First the signal generator is coupled to the grid of the first IF and the 3 tank circuits are tuned to maximum of meter position 2. Next the signal generator is moved to the grid of the first mixer stage and these three tank circuits are also tuned to maximum at meter position 2. To verify that the frequency of the signal is exactly at 12 megacycles the test set can be set on position 4 and the meter will indicate zero if the signal generator is exactly at 12 megacycles. If not, slight adjustment of the "signal generator" will make the proper zero indication. It is good practice to check the signal generator against the zero discriminator reading from time to time as it is possible for a signal generator to drift slightly, especially if it has not been on for a long enough time for it to be at operating temperature. If it is found that the signal generator has drifted it is simple to check the previous adjustments after reseting the signal generator.

This completes the low and high frequency IF alignments of the receiver. All that remains are the oscillator, multiplier and RF circuits.

With no signal applied and the test meter in position 6 the oscillator tank circuit is adjusted for maximum output. First, however, it is important to set the frequency control trimmer, capacitor so that the tuning slot is parallel to the chassis. This places the oscillator close enough to its correct frequency so that the circuits will be adjusted to maximum even if a slight change of frequency becomes necessary.

After adjusting the oscillator for maximum output the signal generator is set to the channel frequency and applied to the antenna input.

With the test meter on position 2 the frequency multiplier is adjusted for maximum output. With the signal generator ~~and~~

and the test meter unchanged, RF and antenna coils are also adjusted for maximum reading at the test set meter.

The receiver is finally adjusted for the exact channel frequency. This can be done by setting the test meter to position 4 and having the base station transmit the channel frequency. The oscillator trimmer is adjusted so the position 4 (discriminator secondary) reads zero. This is called "netting".

If the radio shop is equipped with a good crystal controlled frequency monitor, any signal generator can be varified against this monitor, and as the frequency of the signal generator is varified, it can be used for final adjustment of the receiver.

After the receiver has been "netted" to the base station transmitter it should be checked for "noise balance". Effective noise balance can be realized only after the receiver has been "netted" to the carrier it is to receive. This requires the receiver to be installed in the vehicle. The vehicle motor is left running while a signal at channel frequency is received from the base station. This signal should have no background noise. If there is ignition noise the first stage of the low or second IF may be returned for a reduction of ignition noise. In making this adjustment it is most important to observe the meter reading at position 2, which must not decrease more than one half microamp (half scale division on the meter). If the above procedure is unsatisfactory, the first IF plate tuning coil can be slightly readjusted. It must be considered however, that this procedure may cause detuning of the circuit so it is important to watch the test meter closely while making this adjustment. The first IF drops off either side of resonance quite sharply so extra care must be used if this adjustment is used for "noise balance".

Unless the "noise balance" is made for the exact carrier frequency to be received, it will not be effective when the receiver is put into actual operation. Furthermore, when the correct noise adjustment is realized, the idling of position 4 on the test meter, without a signal should rest within one or two microamps of zero. This means the discriminator balance for noise input should be not more than one or two marks of zero on the test meter position 4 when the signal is removed.

Sensitivity Check

When the receiver has been aligned or any general service has been performed, a sensitivity check should follow, in order to make sure the receiver will work satisfactorily.

A sensitivity check requires a good quality signal generator with a calibrated output indicator. (The quieting sensitivity of a receiver is the amount of RF signal required at the receiver input in order to reduce the receiver noise by 20 db.) The squelch control is turned completely counter clockwise to open the squelch circuit. With the P8501 test meter plugged into the receiver. The signal generator is connected to the receiver antenna connector through a 6 db

50 ohm pad and placed on channel frequency by switching the test meter to position 4. The signal generator frequency is adjusted so that the test meter indicates zero- now the test meter is turned to position 8 and the receiver volumn is advanced to make the noise indicate 10 on the test meter with the signal generator at zero output. The signal generator output is now advanced until the noise output is reduced until the test meter indicates that one tenth of the noise voltage is present in the output. The micro-volt input to the receiver to produce this 10 to 1 reduction of noise in the receiver is the amount of signal indicated at the signal generator, in microvolts, that is necessary to reduce the receiver noise by 20 db. This value should be checked against the receiver specifications. (Some receiver specifications are: One half microvolt input for 20 db quieting.)

Discriminator Response Curve

One of the most important factors in securing clarity of the message reproduced by the speaker is for the discriminator "recovery slope" to be linear over the deviation limits of the system. This subject was discussed in an earlier chapter dealing with discriminator action. The discriminator response curve must be linear over a frequency range greater than the deviation employed by the system and in general this linearity is one and one half or two times that of the deviation. This allows for some shift in the incoming IF signal and also allows for a slightly off tuned discriminator secondary.

The linearity of the audio recovery can be determined with the test set, using crystals 15 kc above and 15 kc below the center frequency of the last IF. (In our past examples we used a second IF center frequency of 455 KC. Under this condition the two crystals would be 440 KC and 470 KC.)

Each kilocycle of deviation in a 15 KC deviation system should produce approximately one volt at the discriminator output, at 15 KC from center frequency the discriminator output should be at least 15 volts. By comparing the output at 15 KC above center frequency and 15 KC below center, the linearity of the discriminator will be known. A 10 percent variation of the output voltages is permissible, but any greater difference represents noticeable distortion. If these two tests are not within 10 percent of being equal, recheck the alignment of the discriminator primary, the secondary and the last IF section. These voltage checks are made at full discriminator output, not at the input to the first audio stage.

Where the DC type volume control is used, the output of the second limiter will be controlled to some extent by the setting of this control. For an accurate check, therefore, the volume control must be set temporarily at maximum.

Oscillation

In a two way communications receiver unwanted oscillation may take place without the operator or serviceman being aware of the fact. Oscillations in an undesired stage or section of a receiver is thus a problem which must be recognized by the serviceman.

Oscillation may have various effects upon the receiver, depending upon the strength of the oscillation and where it is taking place. One of the most common effects is a partial quieting of noise usually heard in the speaker when the receiver is not squelched. The oscillation acts like a signal in the limiters, reducing the noise. Following this noise reduction it can be expected the noise level to be so low the squelch circuit would be unable to squelch the receiver.

It is a characteristic of most unwanted oscillations that they produce higher than normal readings for the limiter grid circuits and the discriminator primary. Moreover, the discriminator secondary may be full scale in either direction rather than near zero, and alignment adjustment may be critical and eratic.

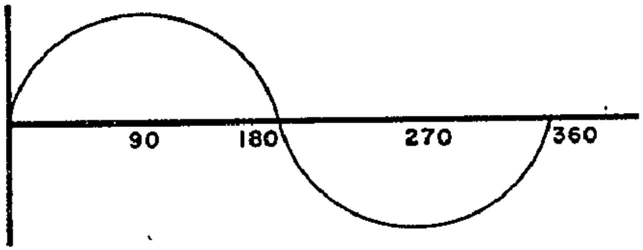
Trouble checking such as "tube pulling" and "grid grounding" usually show which stage is oscillating. Oscillations usually occur in the RF section of the receiver or the last IF section, and pulling the front end (RF) tubes will usually indicate which of these two sections are the offender.

Common cause of oscillation are open bypass capacitors, broken ground leaks, coupling capacitors out of position (away from the chassis instead of close to the chassis) ungrounded shields, and excessive supply voltages. The oscillating section can often be found by bringing the hand close to the suspected section (under the chassis) and noting the change in the meter readings, or in the sound from the speaker.

NOTE:

One type receiver and associated test equipment is mentioned in this and other chapters because any attempt to describe all the different types with their variations would be confusing. However, this one type does illustrate the principals involved and any variation incorporated in other types are fully described in their service manuals.

FIGURE 0



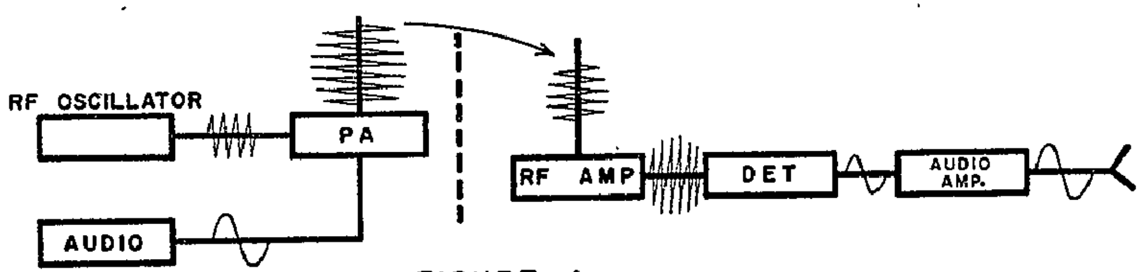
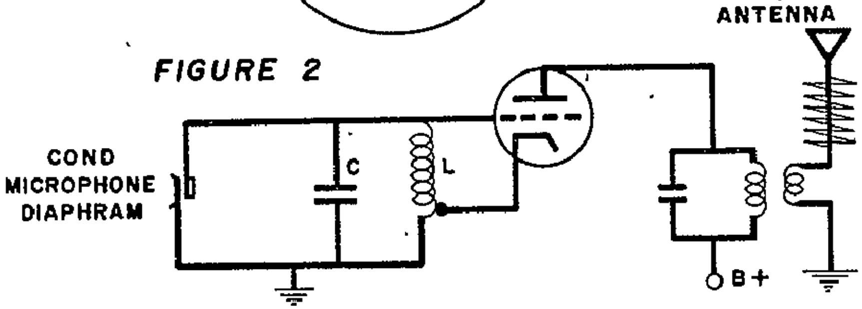


FIGURE 1

FIGURE 2



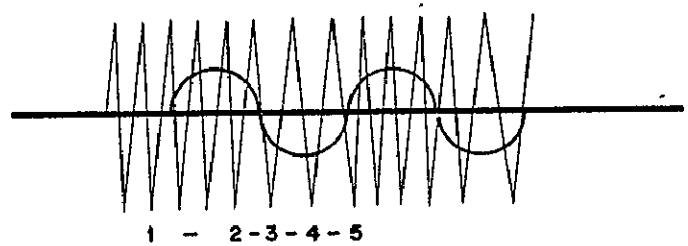


FIGURE 3A

FIGURE 4

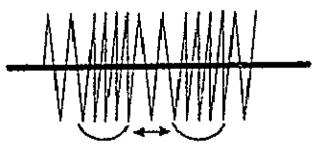
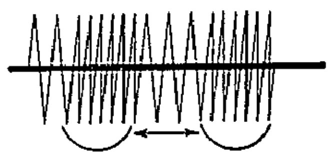
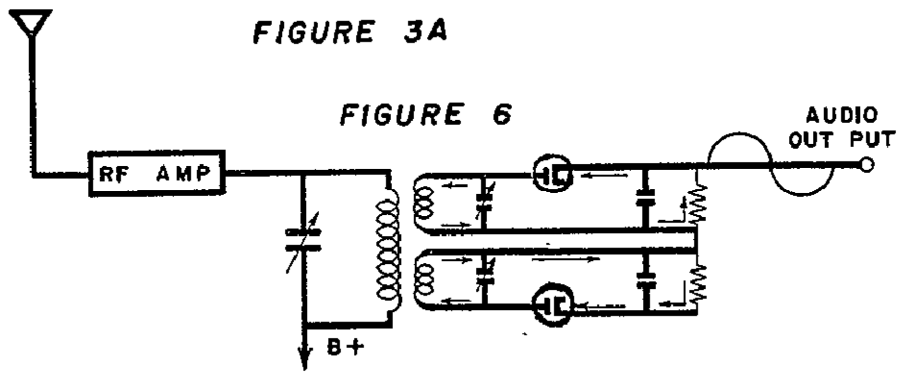
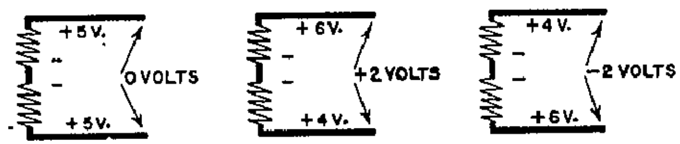


FIGURE 5







7A 7B 7C

FIGURES

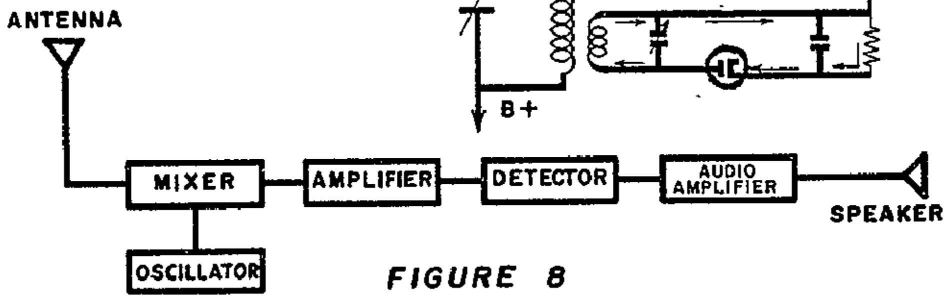


FIGURE 8

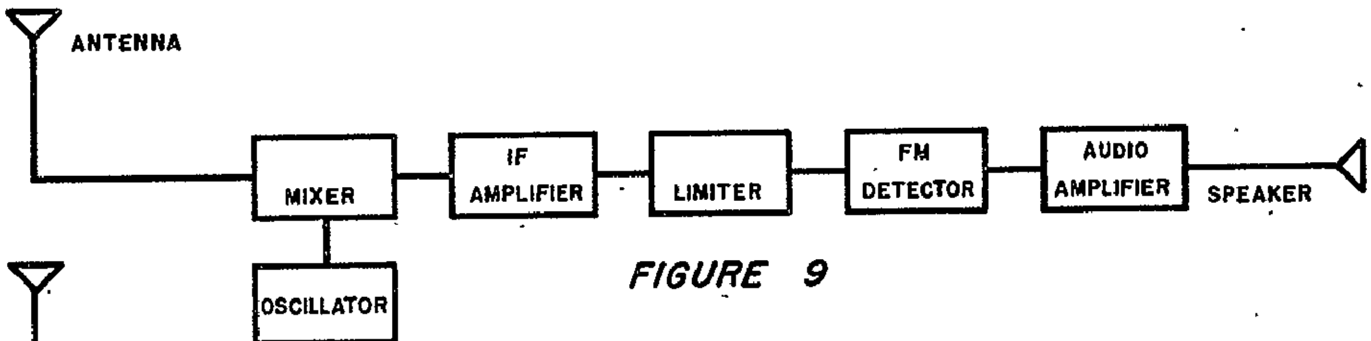


FIGURE 9

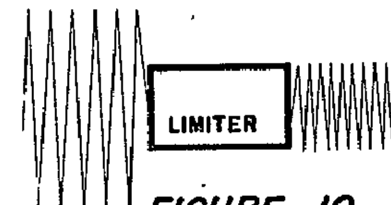


FIGURE 10

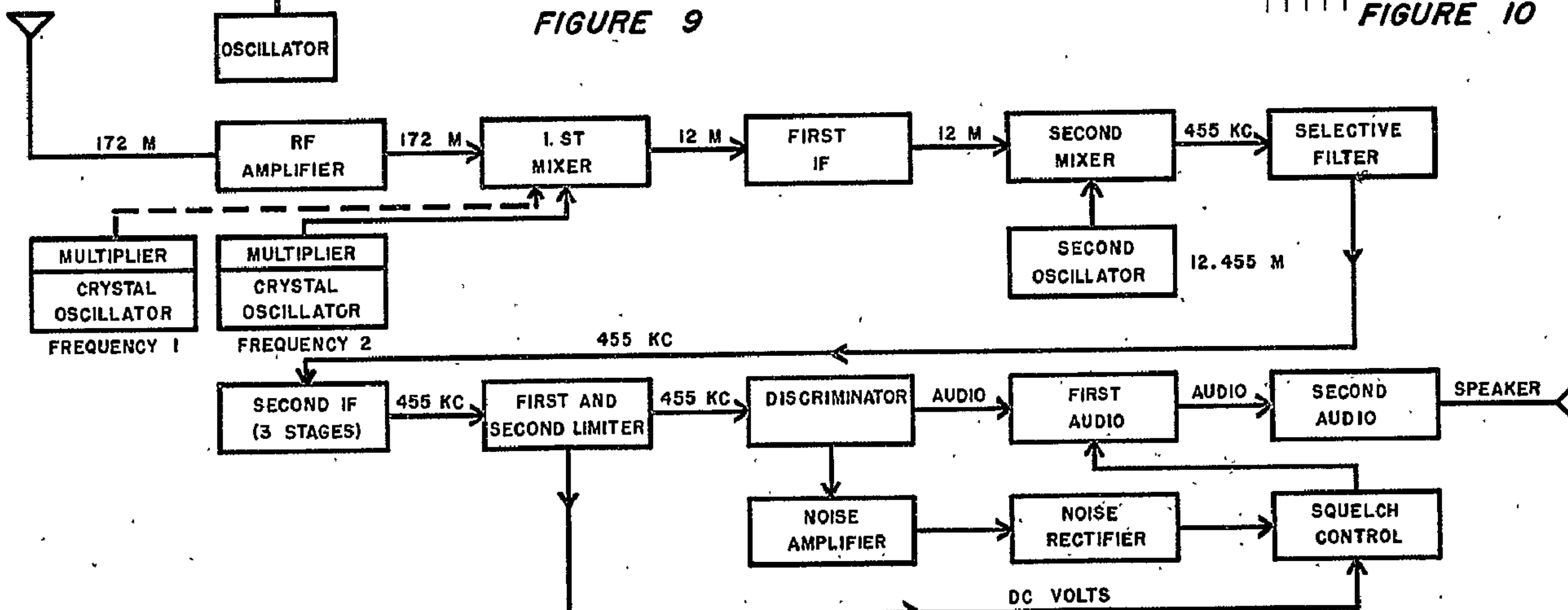


FIGURE 11

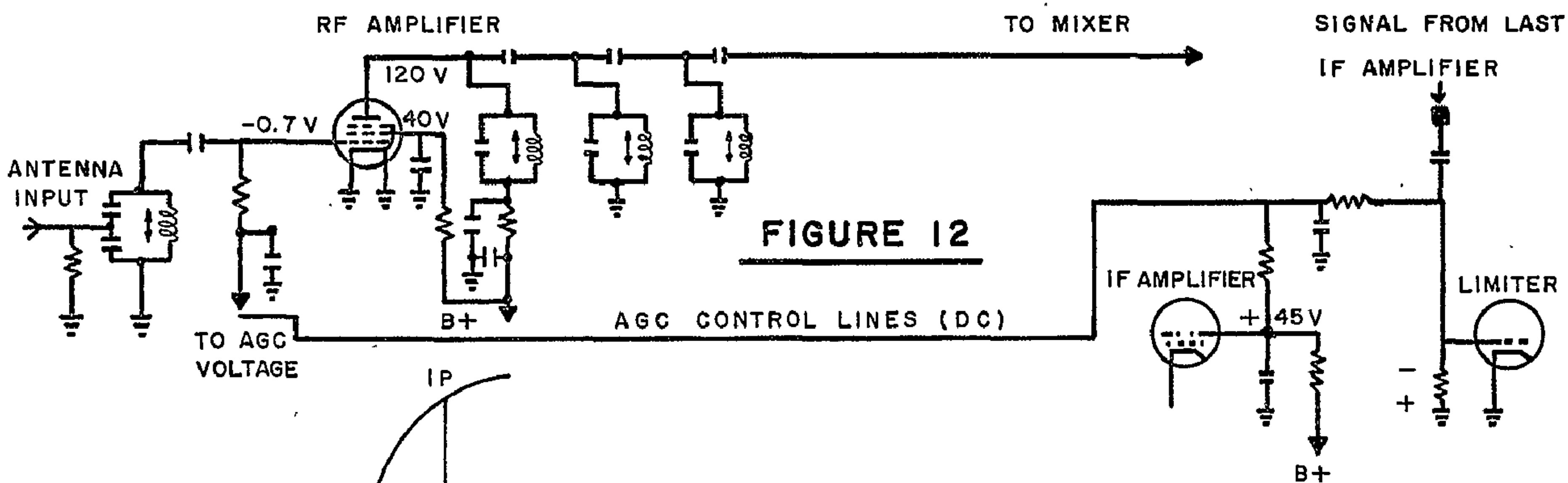


FIGURE 12

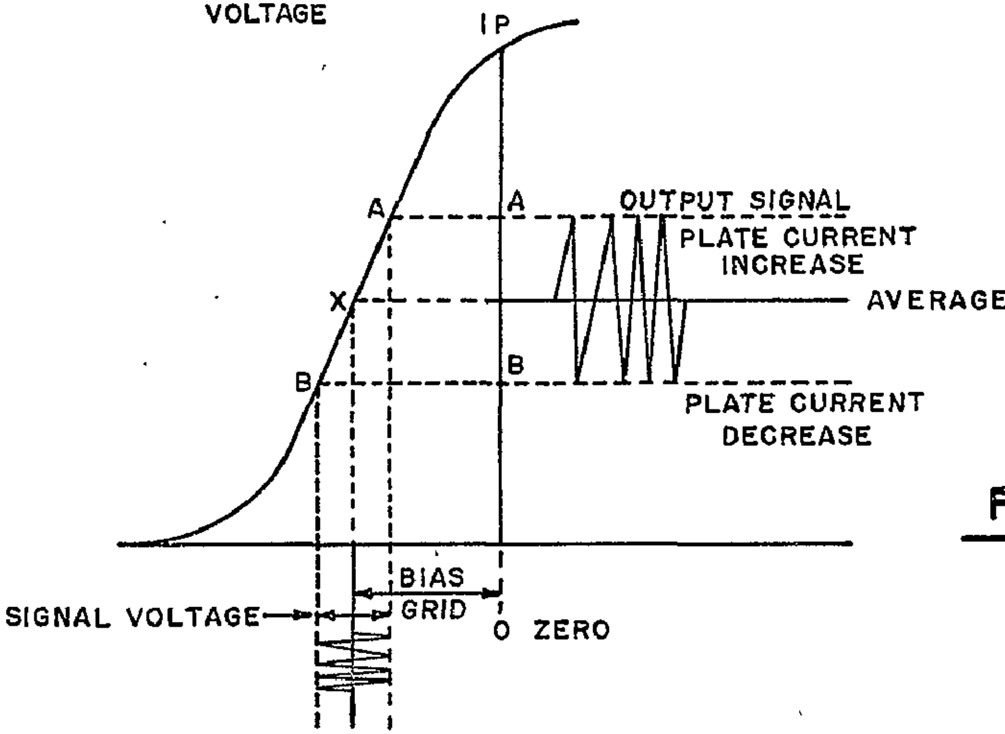
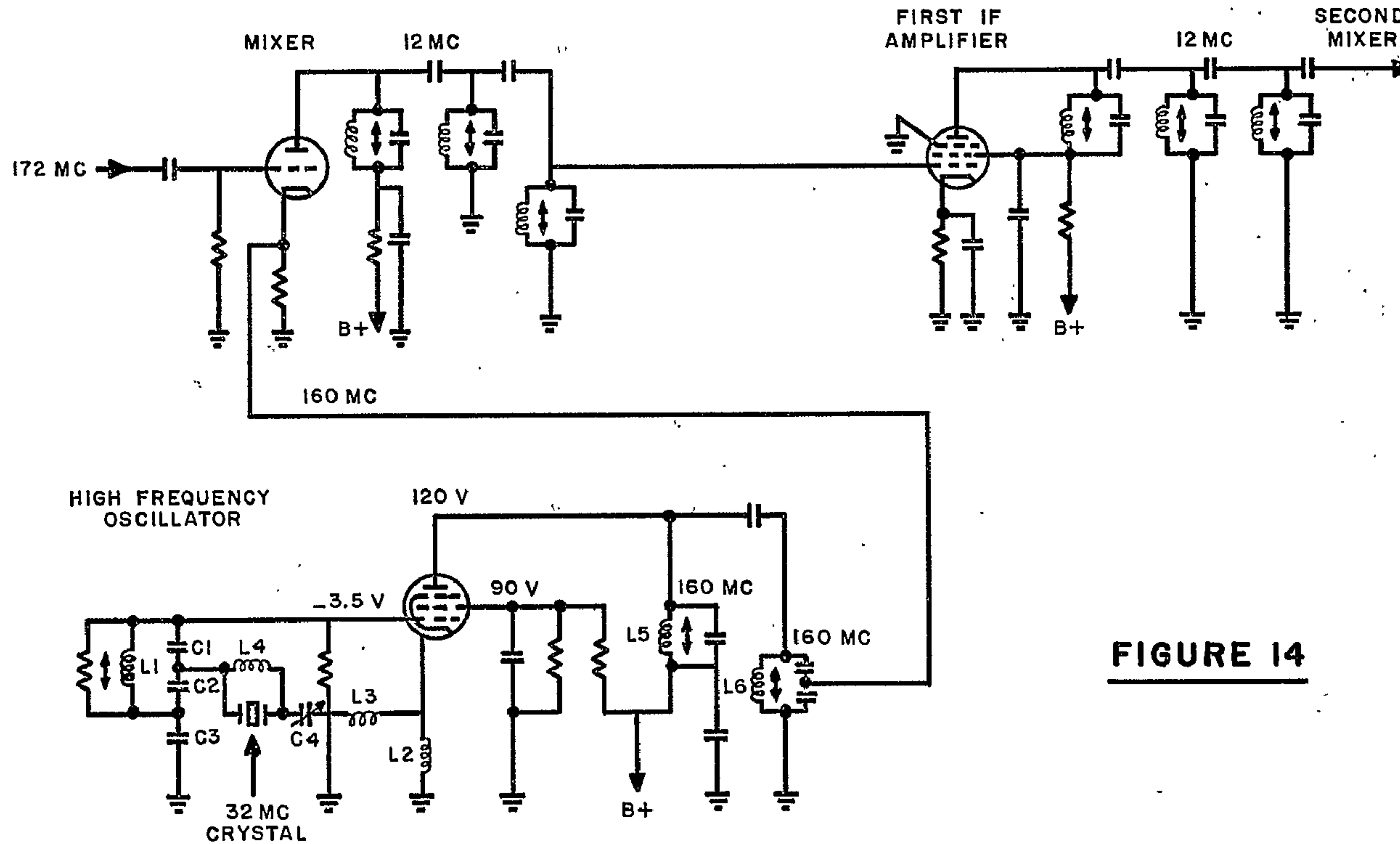


FIGURE 13



MIXER
12 MC
FIRST IF
AMPLIFIER
12 MC
SECOND
MIXER
172 MC
B+
B+
160 MC
HIGH FREQUENCY
OSCILLATOR
120 V
-3.5 V
90 V
160 MC
160 MC
L1
C1
C2
L4
L3
C3
C4
L2
L5
L6
32 MC
CRYSTAL
B+

FIGURE 14

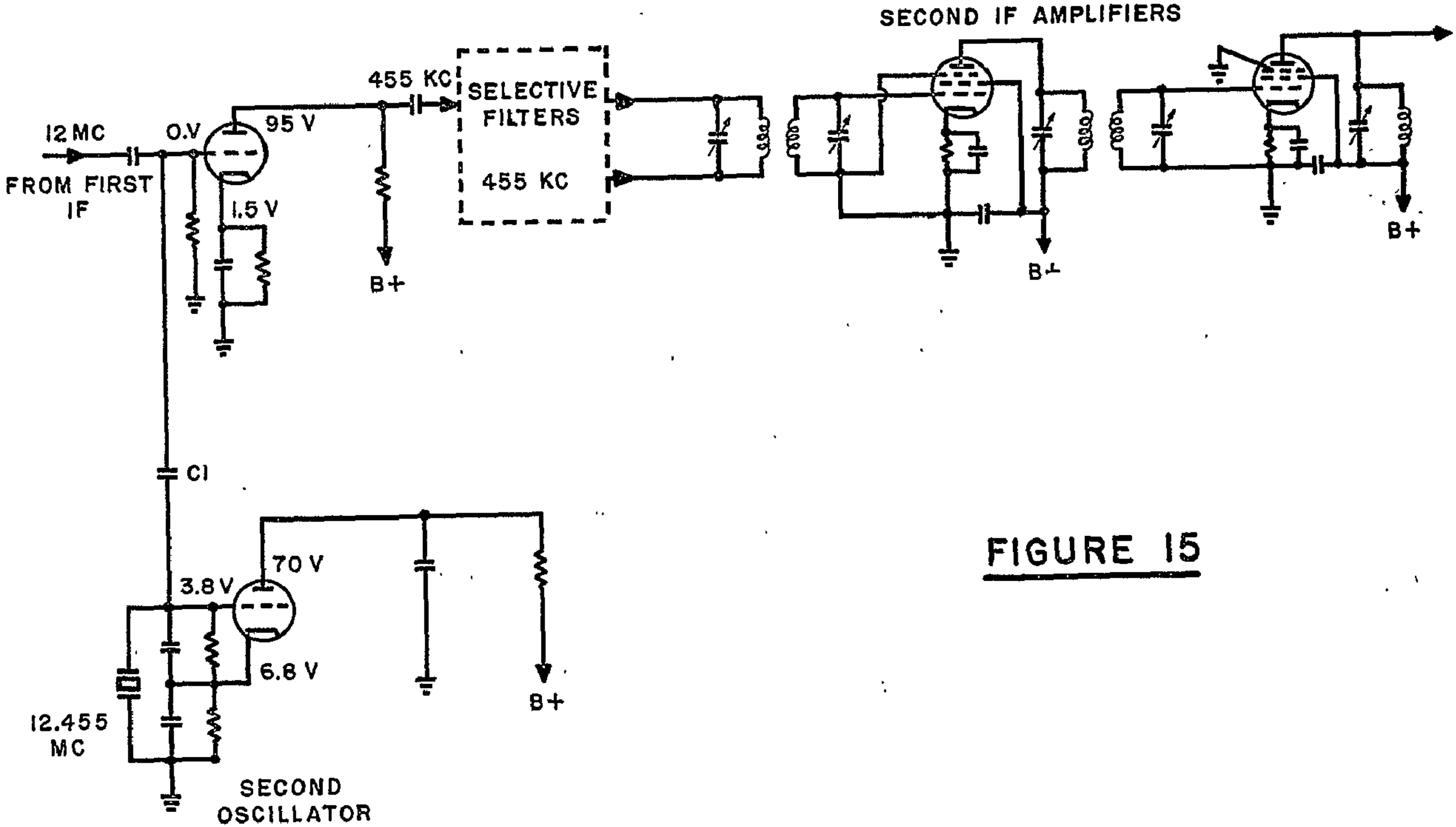

SECOND IF AMPLIFIERS
12 MC
FROM FIRST IF
0.V
95 V
1.5 V
455 KC
SELECTIVE FILTERS
455 KC
B+
B+
B+
C1
70 V
3.8 V
6.8 V
B+
12.455 MC
SECOND OSCILLATOR

FIGURE 15

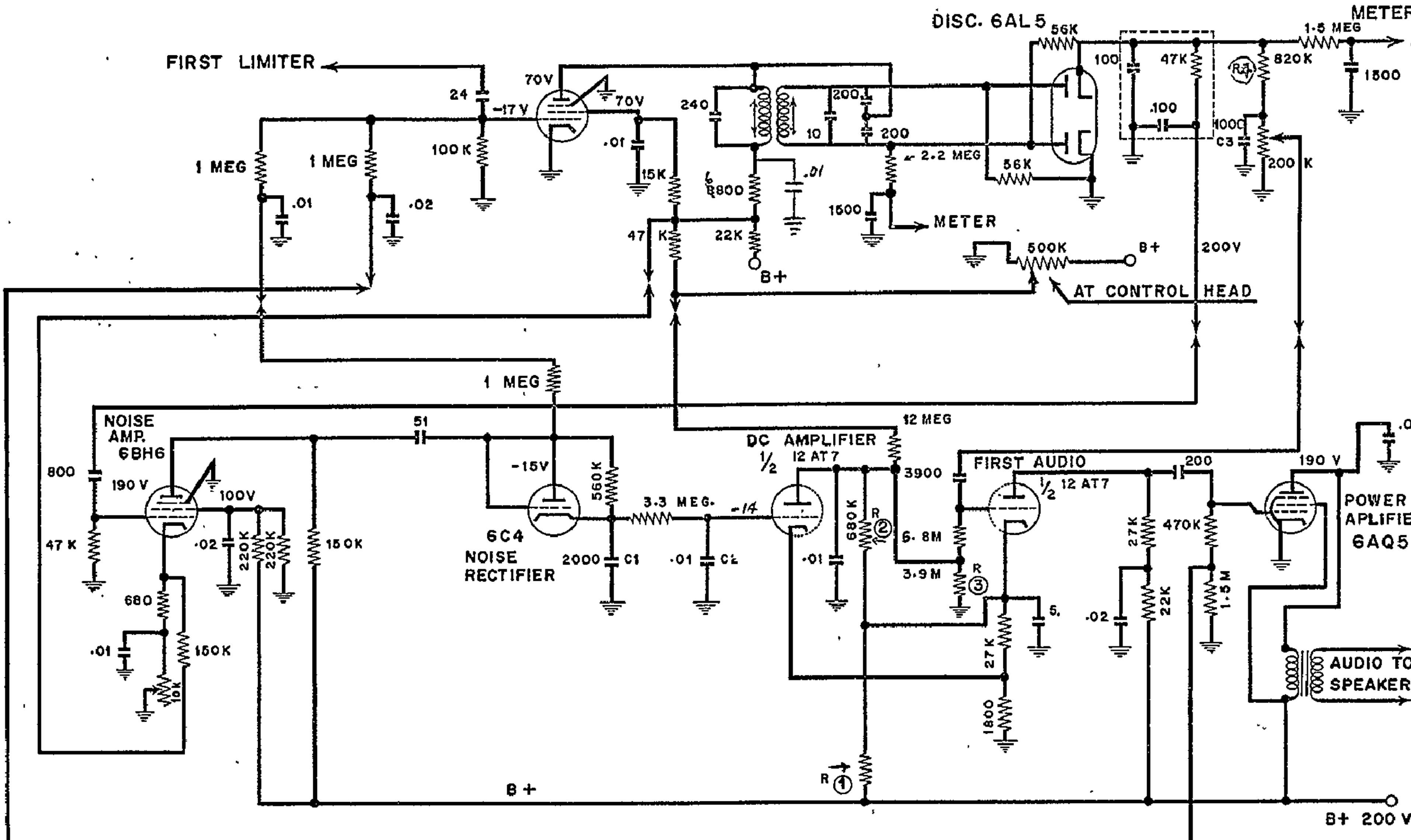

FIRST LIMITER
DISC. 6AL5
METER
1.5 MEG
56K
100
47K
820K
1500
24
70V
-17V
70V
240
200
10
200
.100
1000
C3
200 K
1 MEG
1 MEG
100 K
.01
15K
6800
.01
2.2 MEG
56K
.01
.02
47 K
22K
B+
1500
METER
500K
B+
200V
AT CONTROL HEAD
1 MEG
NOISE AMP. 6BH6
800
190 V
100V
51
-15V
560K
DC AMPLIFIER
1/2 12 AT7
12 MEG
3900
FIRST AUDIO
1/2 12 AT7
200
.02
190 V
POWER APLIFIER 6AQ5
47 K
.02
220K
220K
150K
6C4
NOISE RECTIFIER
2000
C1
3.3 MEG.
-14
.01
C2
.01
680 K
R 2
6.8M
3.9M
R 3
27K
470K
22K
1.5 M
5.
.02
27 K
1800
680
.01
150K
10K
AUDIO TO SPEAKER
R 1
B +
B+ 200 V

FIGURE 16

RECEIVER - TROUBLE ISOLATION CHART
NO SIGNAL AVAILABLE
(FIGURE 17)

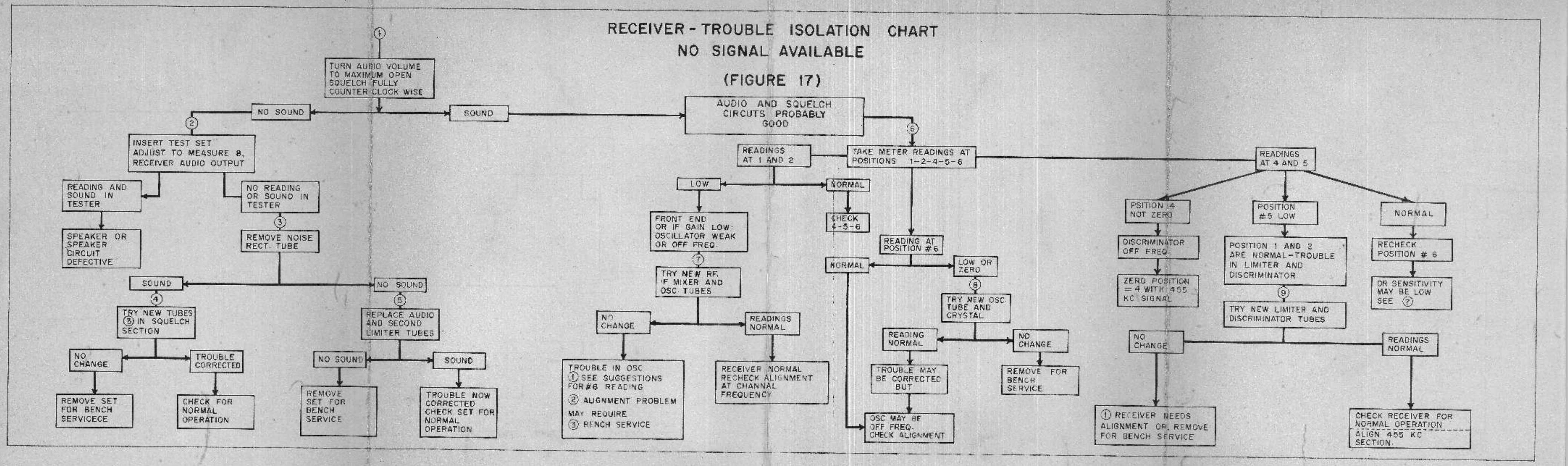
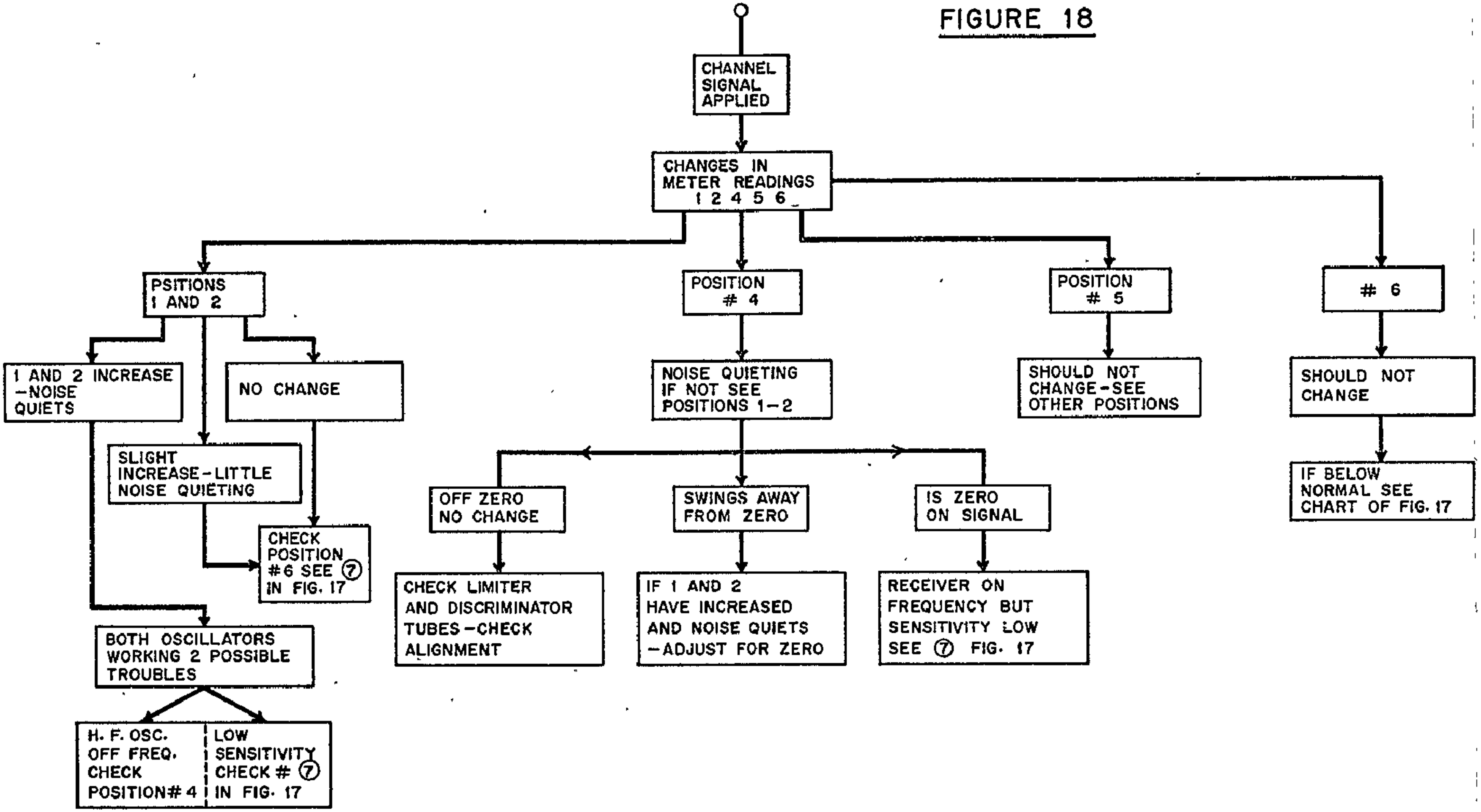


FIGURE 18


CHANNEL SIGNAL APPLIED
CHANGES IN METER READINGS 1 2 4 5 6
PSITIONS 1 AND 2
POSITION # 4
POSITION # 5
6
1 AND 2 INCREASE -NOISE QUIETS
NO CHANGE
SLIGHT INCREASE-LITTLE NOISE QUIETING
CHECK POSITION #6 SEE ⑦ IN FIG. 17
BOTH OSCILLATORS WORKING 2 POSSIBLE TROUBLES
H. F. OSC. OFF FREQ. CHECK POSITION# 4
LOW SENSITIVITY CHECK # ⑦ IN FIG. 17
NOISE QUIETING IF NOT SEE POSITIONS 1-2
OFF ZERO NO CHANGE
SWINGS AWAY FROM ZERO
IS ZERO ON SIGNAL
CHECK LIMITER AND DISCRIMINATOR TUBES-CHECK ALIGNMENT
IF 1 AND 2 HAVE INCREASED AND NOISE QUIETS -ADJUST FOR ZERO
RECEIVER ON FREQUENCY BUT SENSITIVITY LOW SEE ⑦ FIG. 17
SHOULD NOT CHANGE-SEE OTHER POSITIONS
SHOULD NOT CHANGE
IF BELOW NORMAL SEE CHART OF FIG. 17