CHAPTER 3
SINGLE-SIDEBAND RECEIVERS

1. SINGLE-SIDEBAND RECEIVER CONSIDERATIONS

The operation of a single-sideband receiver is, in a limited sense, the reverse of the process carried out in a single-sideband exciter. The received single-sideband radio-frequency signal is amplified, translated to a low i-f frequency, and converted into a useful audio-frequency signal. The reception of a high-frequency single-sideband signal is essentially the same as receiving a high-frequency AM. signal. Receivers are invariably of the superheterodyne type to provide high sensitivity and selectivity. The absence of a carrier in the received SSB signal accounts for the principal difference between single-sideband and AM. receivers. In order to recover the intelligence from the single-sideband signal, it is necessary first to restore the carrier. This local carrier must have the same relationship with the sideband components as the initial carrier used in the exciter modulator. To achieve this, it is a stringent requirement of single-sideband receivers that the oscillator which produces the reinserted carrier have extremely good frequency accuracy and stability. The total frequency error of the system must be less than 100 cycles per second, or the intelligibility of the received signal will be degraded.

The single-sideband receiver must be able to select a desired signal from among the many signals which populate the high-frequency band. Good selectivity becomes an essential requirement when signals of considerable variance in amplitude are spaced close together in the frequency spectrum. The sensitivity of the receiver must be sufficient to recover signals which are of very low amplitude, almost lost in the noise which is constantly present in the antenna. These requirements determine the design of the front end, or r-f section, of the receiver.

Double conversion superheterodyne circuits are used in present day receivers. The principal advantages of such circuits are the extra image rejection obtained and the decided improvement in frequency stability. This can be achieved by using a crystal oscillator in the high-frequency conversion and injecting the tunable oscillator at a lower frequency conversion where its error has less effect.

In a conventional receiver, the audio intelligence is recovered from the radio-frequency signal by means of an envelope detector. This detector may be a simple diode rectifier. This same diode detector, provided with a local carrier, can also be used to recover the audio signal from a single-sideband suppressed carrier signal; however, the amplitude of the local carrier must be quite high in order that the intermodulation distortion be kept low. Better performance, particularly with respect to distortion, may be obtained by using product demodulators to recover the audio signal.

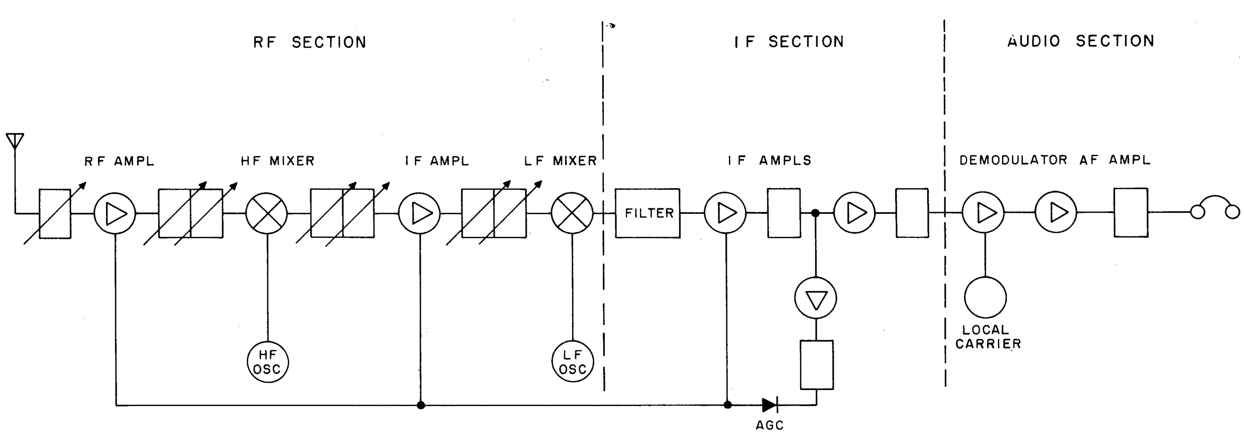

Figure 3-1. Typical Single-Sideband Receiver, Functional Diagram

The characteristics of the automatic gain control system of a single-sideband receiver must be somewhat different from those of a receiver designed for conventional AM. signals. The conventional avc system provides the automatic gain control by rectifying the carrier signal, since this carrier is relatively constant and does not vary in amplitude rapidly. This avc system can have a relatively long time constant. In a receiver for single-sideband suppressed carrier signals, the agc rectifier must be of a quick acting type because the signal amplitude is changing very rapidly and frequently disappears altogether.

Single-sideband receivers have three main sections: a radio-frequency section, an intermediate-frequency section, and an audio-frequency section. These sections of a typical single-sideband receiver are shown in figure 3-1. The principal requirement of the r-f section is to select the desired signal in the antenna and translate this signal to a lower r-f frequency (intermediate frequency) with a minimum of distortion and generation of spurious signals. The intermediate-frequency section provides selectivity and amplification. The audio section recovers the audio-frequency intelligence and provides the necessary audio-frequency amplification.

2. R-F SECTION

The r-f section consists of an r-f amplifier and one or more mixers which translate the signal to the intermediate frequency. The use of an r-f amplifier as the first stage of a receiver provides increased sensitivity and reduction in spurious responses. Increased sensitivity results from the lower inherent noise of amplifiers compared with mixers. Spurious signals are reduced because increased r-f filtering can be used without degrading the signal-to-noise ratio. The amplification provided by the r-f amplifier offsets the losses inherent in the passive filter circuits.

The sensitivity of a receiver is usually defined as the minimum signal with which a 10 db signal-plus-noise-to-noise ratio may be obtained. This definition has a practical basis because it recognizes the fact that ultimately the noise level is the limiting factor in readability, and that a signal 10 db stronger than the noise level is acceptacle for voice communication. Maximum receiver sensitivity is not determined by the gain of the receiver but by the magnitude of the receiver noise. The three sources of noise which contribute to the noise level of a receiver are the antenna to which the receiver is connected, the input resistance of the receiver, and the grid circuit of the first tube used in the receiver. If the gain of the first amplifier is low, it is possible that the noise of the second tube in the receiver can also have some effect on the receiver over-all noise level.

a. NOISE SOURCES

A noise voltage will be present across the terminals of any conductor due to the random motion of electrons. This random electron motion is known as thermal agitation noise and is proportional to resistance of the conductor and its absolute temperature. All noise currents and voltages are random fluctuations and occupy an infinite frequency band. The actual magnitude of noise voltage which affects a device is proportional to the bandwidth of the device. The noise voltage can be calculated with the following equation.

$$E_n = \sqrt{4\ KTBR}$$

where E_n = rms noise voltage
K = Boltzmann's Constant, $1.38\ (10)^{-23}$
T = absolute temperature
B = bandwidth in cps
R = resistance in ohms

If the antenna to which the receiver is connected could be placed in a large shielded enclosure, there would exist at the terminals of this antenna a noise voltage equal to the thermal agitation noise of a resistor which is equal to the radiation resistance of the antenna. Even if a receiver could be built with no internal sources of noise, noise would still be introduced into the receiver from the antenna, and weak signals would have to compete with this noise.

Additional noise signals originating in atmospheric disturbances, the sun and other stellar sources, and in electrical machinery increase the noise threshold below which even a perfect receiver could not detect signals. In the h-f band from 2-30 mc, this threshold is usually much higher than that set by receiver internal noise sources. However, the external noise threshold is subject to many variations, and it is possible that under certain favorable combinations of conditions, the receiver noise could be a factor at frequencies in the upper half of the band. For this reason, the noise generated in the receiver circuits is an important consideration.

The internal noise generated in a receiver is conveniently described by a number called the noise figure. The noise figure is expressed as the ratio in decibels between the noise level of the receiver to the noise level of a so-called perfect receiver, in which all the noise is assumed to be generated in the antenna by thermal agitation. A perfect receiver in which the input circuit is designed to match the antenna resistance has a noise figure of 3 db.

The sources of noise in a receiver are the input circuit resistance, the first tube grid circuit, and the second tube grid circuit if the first tube gain is low.

These noise sources are shown in schematic form in figure 3-2. For convenience, the tube noise is usually expressed as being equivalent to the noise generated in a resistance of the proper value, referred to as the equivalent noise resistance of the tube. A tube having a low value of equivalent noise resistance is a low noise tube. Equivalent noise resistances of a number of tubes are listed in table 3-1. From the figures shown, it can be seen that triodes have lower noise than pentodes, and amplifiers have lower noise than mixers. Tube noise, although important, is not a decisive factor in tube selection. Pentode tubes offer advantages over triodes as amplifiers, since they have very low grid-to-plate capacitance and give large gain without neutralization. Pentagrid mixers require less oscillator power, have excellent isolation between signal and oscillator circuits, and give high conversion gain.

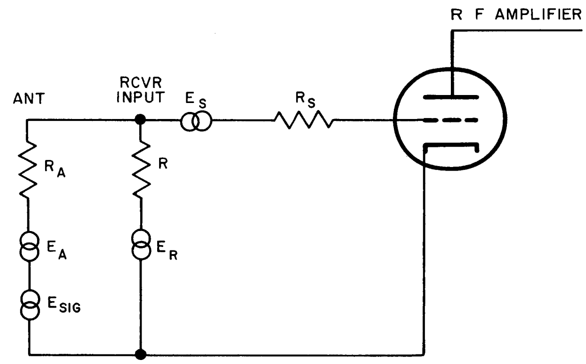

Figure 3-2. Noise Sources in R-F Section of Single-Sideband Receiver

TABLE 3-1. EQUIVALENT TUBE NOISE RESISTANCE

Type	Application	gm or gc	Calculated Req
2C51	Triode Amplifier	5500	455
6AC7		11200	220
6AH6		11000	230
6AN4		10000	250
6BK75		6100	410
6BQ7A		6400	390
6BZ7		6800	370
6J4		11000	230
6J6		5300	470
6T4		7000	360
6U8		8500	295
12AT7		6600	380
12AU7		2200	1140
12AX7		1600	1560
12BH7		3100	810
5687		10000	250
5842		24000	105
6386		4000	625
6AG5	Pentode Amplifier	5000	1650
6AH6		9000	720
6AK5		5100	1880
6AK6		2300	8800
6AU6		5200	2660
6BA6		4400	3520
6BC5		5700	1350
6BD6		2350	13800
6BH6		4600	2360
6BJ6		3800	3860
6BZ6		6100	1460
6CB6		6200	1440
6U8		5200	2280

TABLE 3-1. EQUIVALENT TUBE NOISE RESISTANCE (Cont)

Type	Application	gm or gc	Calculated Req
2C51	Triode Mixer	1375	2900
6AN4		2500	1600
6J4		2750	1450
6J6		1575	2540
6T4		1750	2290
12AT7		1650	2430
12AU7		550	7280
12BH7		775	5170
5687		2500	1600
6386		1000	4000
6AG5	Pentode Mixer	1250	6600
6AK5		1280	7520
6BA6		1100	14080
6BC5		1425	5400
6BZ6		1525	5840
6U8		1300	9120
6X8		2100	7780
6BA7	Pentagrid Converter	950	61700
6BE6		475	174000
6SA7		450	240000
6SB7Y		950	61700

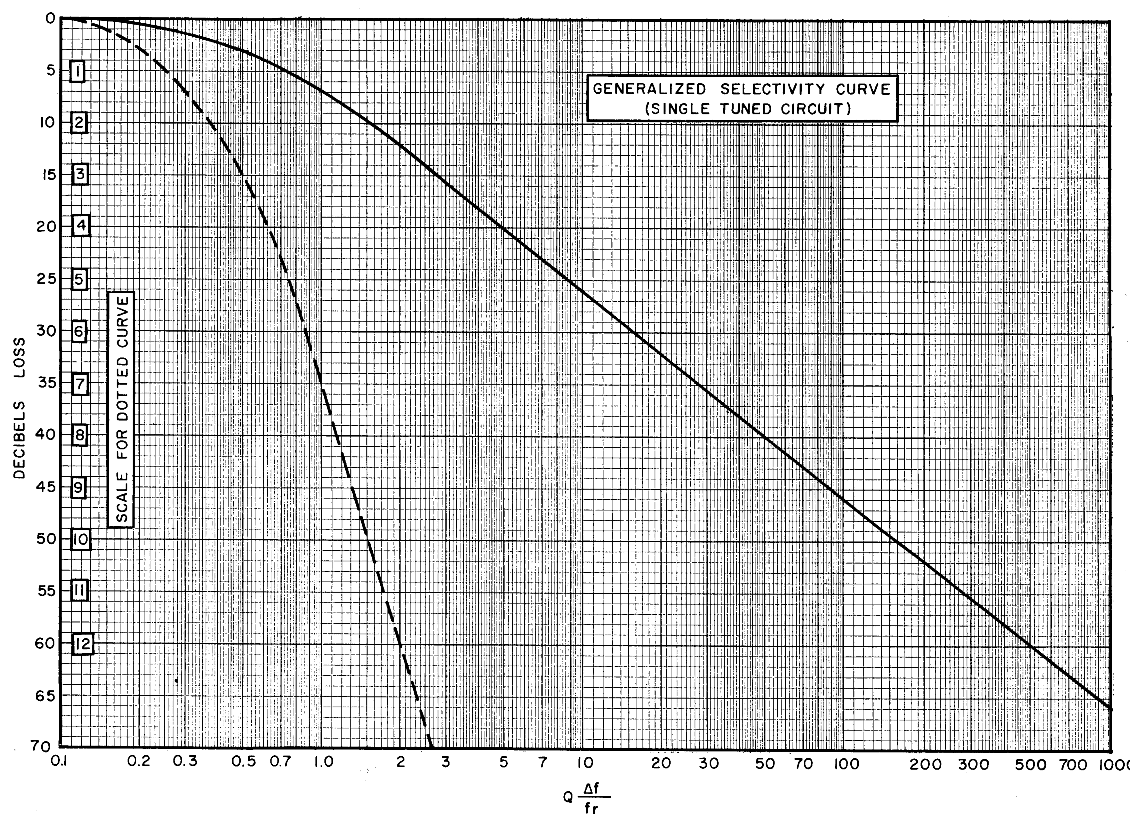

Figure 3-3. Generalized Selectivity Curve

b. R-F SELECTIVITY

For minimum spurious responses, it would be best to provide all the selectivity ahead of the amplifiers in the receiver. This is impractical for several reasons. First, the h-f band spans a range of frequencies in which filters having the required selectivity would be large and difficult to tune. Furthermore, they would have such high insertion loss that the noise figure would be seriously degraded. In some applications where the noise figure can be sacrificed and preselection is a necessity, r-f filters are used. Usually a single-tuned circuit is used between the antenna and the r-f amplifier grid. The selectivity required to suppress adequately the various spurious signals is provided by a tuned filter between the r-f amplifier and the mixer. The tuned filter may consist of several parallel-tuned LC circuits interconnected by mutual inductance or capacitance. The number of tuned elements required depends on the Q factor, frequency, and attenuation required. A universal selectivity curve relating these factors is a convenient tool and is shown in figure 3-3.

c. MIXERS

The r-f signal is translated in frequency from the operating frequency to the intermediate frequency by means of modulation in circuits commonly called mixers. This process has been previously described in detail in chapter 2. The problems encountered in using mixers in receivers is slightly different from those encountered in exciters. Referring to figure 3-4, it can be seen that to translate a desired signal of 1500 kc to an intermediate frequency of 500 kc, a local oscillator having a frequency of 2000 kc can be used. Going further into the example, it can be seen that there are several other signals that can enter the i-f amplifier through the mixer. Some of these signals are listed in figure 3-4. The response at 2500 kc is called the image response and is usually the most troublesome. The higher order responses are attenuated in the mixer tube. Careful selection of a tube and the operating point is necessary to obtain the maximum possible suppression of these responses.

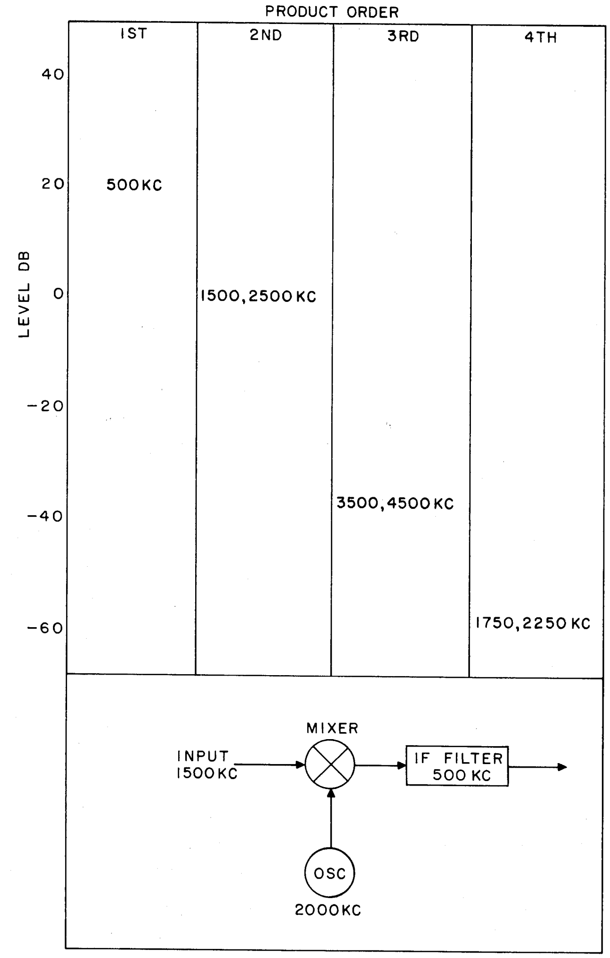

Figure 3-4. Typical Receiver Mixer Spurious Response

Careful selection of frequencies used in the i-f amplifier is necessary to avoid spurious responses. These responses occur whenever the spurious response frequency coincides with the desired frequency. This type of response is referred to as a crossover, tweet, or birdie, and is illustrated in figure 3-5. A signal of 1001 kc when mixed with an oscillator signal of 1500 kc yields a desired signal of 499 kc. Due to the nonlinearity of the mixer, another product is generated which has frequency equal to the difference between the second harmonic of the signal and the oscillator frequencies. Both these signals are passed by the i-f filter because they are only 3 kc apart. These signals will be demoduled by the audio section to yield an audio output (or tweet) of 3 kc in addition to the usual desired output. Spurious responses are minimized if the intermediate frequency is kept as low as possible consistent with good image rejection.

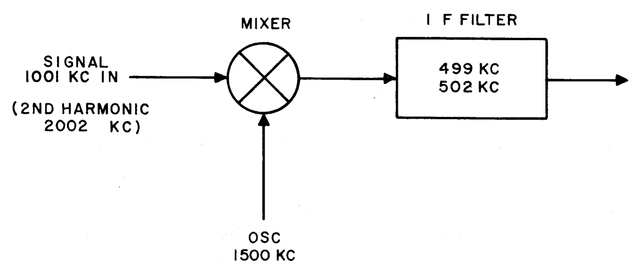

Figure 3-5. Receiver Mixer Crossover Response

As the range over which the receiver must operate is increased, it becomes increasingly difficult to find frequency schemes which are reasonably free of spurious responses. In order to keep these responses attenuated when covering the h-f band (2-30 mc), it is necessary to resort to double conversion or the use of two intermediate-frequency sections. Single conversion is then used on the low frequencies, and the second conversion is brought into use at high frequencies.

The use of double conversion makes possible an improvement of frequency stability through the use of a crystal-controlled high-frequency oscillator. Tuning is accomplished by providing a variable first intermediate frequency ganged to the tunable low-frequency oscillator. As shown in table 2-3, the frequency stability of crystal oscillators are many times better than that obtainable from tunable oscillators. Furthermore, the tuning rate remains the same on the high-frequency bands as it is on the low-frequency bands. On the low-frequency band, the r-f amplifier feeds directly into the tunable i-f circuit, retaining the favorable ratio of signal to i-f frequencies.

For the best sensitivity, it is desirable to have as much gain as possible ahead of the mixers. This would insure that the signal level would be strong enough to override completely the noise from the mixer. From the standpoint of strong signals, it is desirable to have low amplification until the selectivity of the receiver is effective. This would keep the level of strong adjacent channel signals from becoming high enough to overload the initial stages of the receiver. These requirements for no amplification ahead of the selective filter for strong signal reception, and high gain in the r-f amplifier for weak signal reception, conflict, and a compromise is necessary.

When a receiver is tuned to a weak signal and a strong signal is present outside the passband of the i-f selective filter, a type of interference known as cross modulation can exist. The selectivity of the r-f section circuits is not so good as the i-f selective filter, and there is a region near the operating frequency in which strong signals are accepted by the r-f section. Due to the sharp selectivity of the i-f circuits, these signals are not passed by the i-f amplifier and, therefore, do not produce automatic gain control voltage. As a result, these large interfering adjacent channel signals are amplified along with the weak desired signal by the r-f amplifier. When these interfering signal voltages are large enough to drive the amplifier and mixer tubes into nonlinear operation, they cause modulation of the desired signal. To minimize the generation of cross-modulation interference, it is necessary to very carefully select the tubes used in the r-f section. The application of automatic gain control bias is helpful since as the desired signal level increases, the gain of the r-f amplifier can be decreased, reducing the amplification of the interfering signals as well as the desired signal. It is necessary that the tube used in the r-f amplifier retain its linearity with the application of variable bias. It is interesting to note that cross modulation is not as troublesome in single-sideband reception. As an example, if both the undesired adjacent channel signal and the desired signal are conventional AM. signals with full carrier, the modulation of the undesired signal is readily transferred to the desired signal through the process of cross modulation. Effectively the modulation on the undesired signal is modulated onto the carrier of the desired signal. This undesired modulation is passed through the receiver as readily as the desired modulation, and considerable interference results. In the case of single-sideband suppressed carrier reception, there is no carrier present to be modulated, and therefore, the modulation is applied to each of the sideband signal components. As the single-sideband signal consists of a number of relatively weak components, this undesired modulation is spread. Furthermore, when the single-sideband signal is demodulated, the interfering signal is merely recovered as noise and is not as troublesome.

3. I-F SECTION

The intermediate-frequency section contains the frequency selective filter elements and the principal amplifier stages.

a. SELECTIVITY

Consideration must be given to the bandwidth of the receiver as well as the transmitter if the advantages offered by single-sideband communications are to be realized. Optimum receiver selectivity occurs when the noise bandwidth (6 db point) is wide enough to pass the required intelligence, and the skirt bandwidth (60 db point) is narrow enough to reject an unwanted signal in the adjacent communication channel. Extremely steep skirts on the selectivity curves are required to obtain this optimum passband. Ideally, the ratio of the 60 db to 6 db bandwidths should be 1. See curve 3 in figure 3-6. This figure shows the selectivity obtainable from a Collins Mechanical Filter and also from three pairs of double-tune, slightly overcoupled i-f transformers (coil Q's of 150). These curves are superimposed for comparison and show how nearly the mechanical filter selectivity curve approaches the ideal selectivity curve.

Selectivity performance has generally been made by comparing the shape factor, which is the ratio of the 60 db to the 6 db bandwidths. This basis of evaluation has developed from the problem of avoiding adjacent channel interference. While it is customary to define receiver performance in terms of shape factor, it is not always adequate. It can be shown that better shape factors are easier to obtain in wide-band systems than in narrow-band systems. The shape

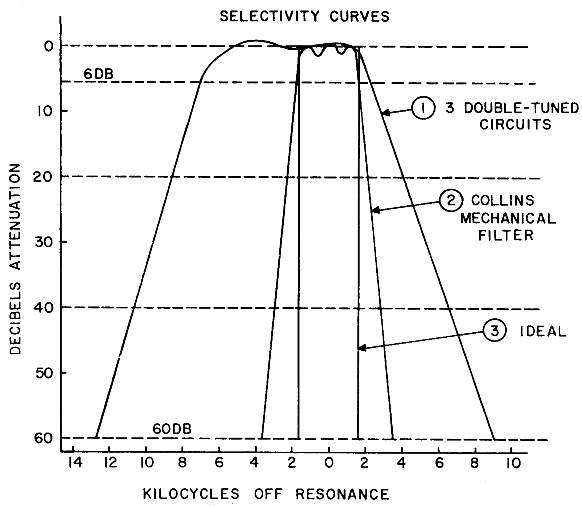

Figure 3-6. Selectivity Comparison

factor is a good comparison if the selectivity curves being compared have the same nose bandwidth. A better method of specifying the performance of a selective system is to define the selectivity in terms of the nose bandwidth and the decibel attenuation per kilocycle on the slopes of the selective curve.

A receiver having an i-f selectivity as in curves 2 or 3 will have a 3 db advantage over a receiver having a selectivity curve as in 1 when receiving an SSB signal whose bandwidth is 3 kc. This is due to both the receiver bandwidth and the input noise power being cut in half. In addition, interference is reduced because the receiver passband is narrow, thus permitting a large percentage of clear signals.

It is desirable to place the selective filter in the circuit ahead of the amplifier stages so that strong adjacent channel signals are attenuated before they can drive amplifier tubes into the overload region. These filters are very similar to the filters used in sideband generators for selecting the desired sideband while rejecting the undesired sideband. Electro-mechanical elements, piezo elements, and inductance capacitance elements can be used in these filters. In one respect, the requirements for these filters are different from those of sideband selecting filters used in the exciter. In order for the receiver to have good rejection to strong adjacent channel signals, it is necessary for the filter used in the receiver to have the ability to reject signals outside the passband to a much higher degree. Attenuation of 60 db or more is necessary for this purpose, and greater rejection is required under some conditions when receiving extremely weak signals. Since single-sideband transmission occupies one-half the bandwidth of a conventional AM. signal, the i-f filter need be only one-half the bandwidth.

b. AMPLIFICATION

The amplifier portion of the intermediate-frequency section consists of the necessary amplifiers to build up the signal to a level suitable for the demodulator. This amplifier consists of cascaded class A linear amplifier stages using remote cutoff pentode tubes. Tuned circuits may be used to provide the load resistance for these stages. The selectivity of these tuned circuits is helpful in improving the over-all receiver selectivity, especially at frequencies which are down on the skirt of the selectivity curve. Some types of filters have spurious responses outside the passband which can be suppressed in this manner.

c. AUTOMATIC GAIN CONTROL

A factor to be carefully considered in single-sideband receiver design is the use of automatic gain control. The basic function of the automatic gain control is to keep the signal output of the amplifier constant and thus hold constant audio output for changing signal levels. This automatic gain control is also applied to amplifiers in the r-f section. However, it is important to delay the application of avc voltage to the r-f amplifier until a suitable signal-to-noise ratio is reached. Conventional AM. systems are generally not usable since they operate on the level of the carrier. This carrier is suppressed in single sideband. Automatic gain control systems must be used which obtain their information directly from the modulation envelope. Refer to figure 3-7. This can be done with conventional diode rectifiers and additional amplification. This may be a d-c amplifier or an a-c amplifier using the i-f frequency. Special care must be taken to isolate the agc system from the reinserted carrier since it is a large signal of the same frequency as the i-f signals. This problem can be avoided by developing the agc voltage from the audio signal. In either case, the time constant of the system is very important. The control must be rapid enough to prevent strong signals from coming through too loud at first and yet be slow enough not to follow the syllabic variation of normal speech. One solution to this time constant problem is to use a fast change, slow discharge type of circuit. Circuits having a charge time of 50 milliseconds and discharge time of 5 seconds have proven successful. Consideration should also be given to dual time constant circuits having a ratio of 100 to 1. Such a circuit allows the rapid signal changes to develop a control voltage across one RC network and the slow signal variation to develop a control voltage across another RC circuit. These two voltages can then be applied in series or to different stages to give the desired control characteristics. Such a dual time constant circuit is similar to a rapid agc system used in conjunction with a manual gain control.

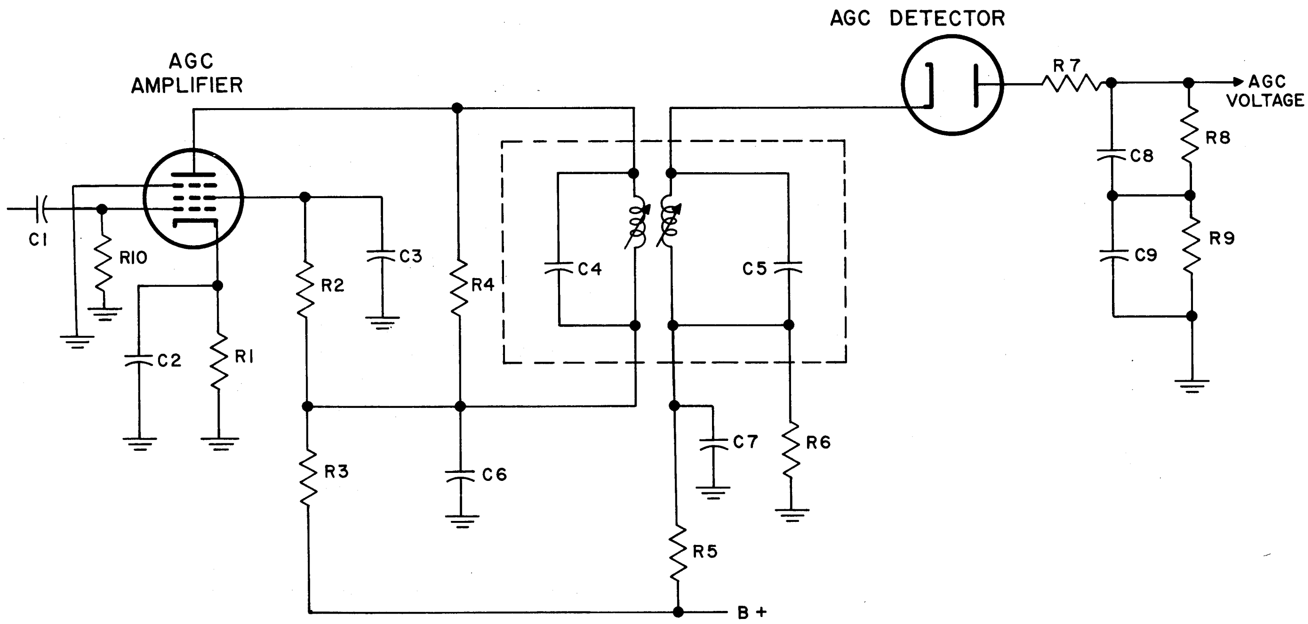

Figure 3-7. AGC Circuit

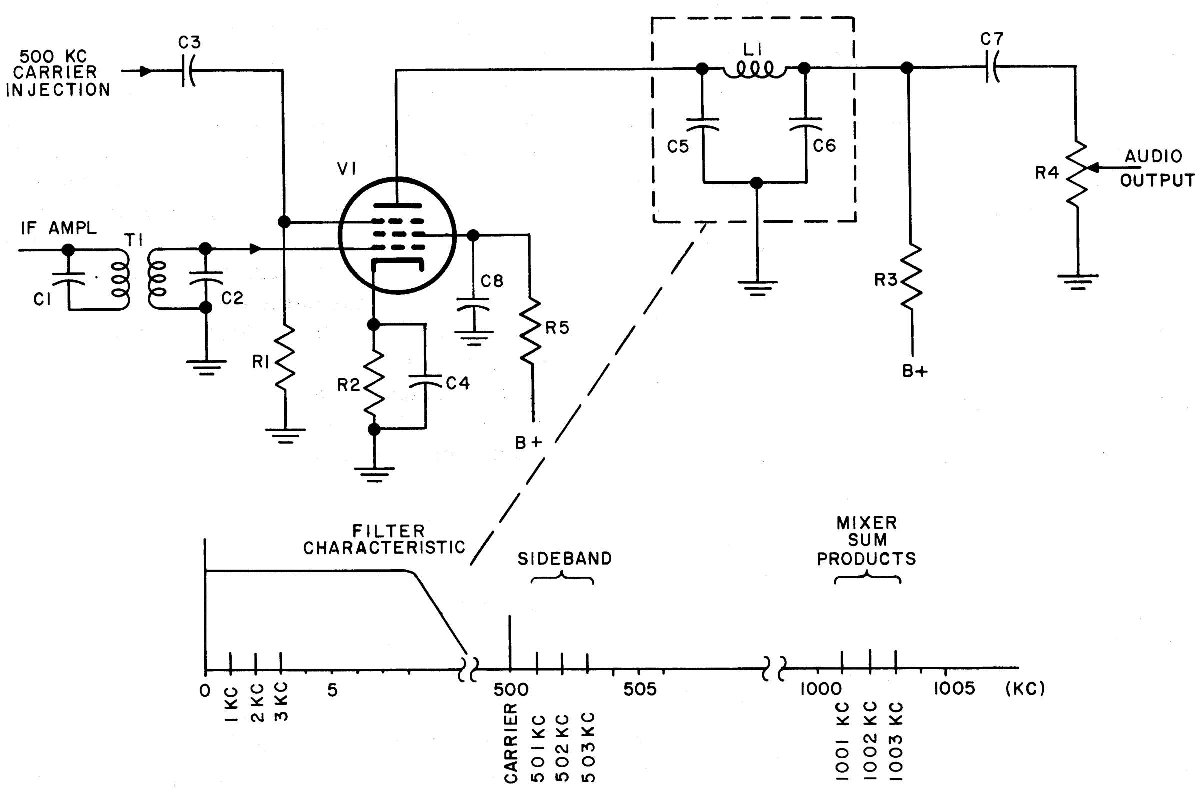

Figure 3-8. Product Demodulator

4. AUDIO SECTION

The information carried by the single-sideband signal is recovered and amplified to a level suitable for the audio output circuits. The circuits used to recover this audio intelligence perform the same function as the modulator in the exciter, and therefore, the same circuits can be used. The single-sideband is first combined with a local carrier. The local carrier must have a proper frequency relationship with the sideband components for faithful reproduction of the original audio signal. In the demodulator, the single-sideband signal is used to modulate the local carrier. The demodulator output consists of an audio signal and several r-f outputs. These signals are easily filtered by passing the output of the modulator through an audio low-pass filter. It is necessary to maintain the proper frequency relationship between the sideband signal and the local carrier. If the received signal is an upper sideband, the carrier frequency is below this sideband; and if the received signal is a lower sideband, the carrier frequency is above the sideband signal. If a receiver must be used to receive either upper or lower sidebands, it is necessary to provide a means of changing the relative position of the carrier with respect to the sideband. One way of accomplishing this is to use two sideband filters in the i-f section and a single carrier at the demodulator. The desired sideband is then selected by switching in the proper filter. A single filter can be used for dual sideband reception by providing a means of shifting the local carrier from one side of the i-f filter passband to the other and then retuning the oscillators in the r-f section.

a. THE PRODUCT DEMODULATOR

Product demodulator circuits are preferred in single-sideband reception, because they minimize intermodulation distortion products present in the audio output signal and do not require large local carrier voltages. Figure 3-8 shows a typical product demodulator. The sideband signal from the i-f amplifier is applied to the control grid of the dual control pentode tube, V1, through transformer T1. The carrier is applied to the other control grid. The desired audio output signal is recovered across resistance R4 in the demodulator plate circuit. Since the plate current of the demodulator is controlled by both grids acting simultaneously, the plate current will contain frequencies equal to the sum and difference between the sideband and carrier frequency. There will also be components of plate current having a frequency equal to the carrier frequency and the sideband frequency. These components are suppressed by means of a low-pass filter (L1, C5, and C6), and the desired audio signal is passed to the audio amplifier. The frequency spectrum presentation in figure 3-8 shows the principal components which will be present in the demodulator plate current. In this example, it is assumed that the sideband signal consists of three components having frequencies of 501, 502, and 503 kc. The carrier frequency is 500 kc. The plate current components consist of three audio-frequency components of 1, 2, and 3 kc and three r-f components of 1001, 1002, and 1003 kc as well as the carrier and original sideband frequencies. By constructing a low-pass filter in the plate circuit, consisting of L1, C5, and C6, it is possible to filter out all frequencies except the difference frequencies. By this method the audio frequency has been recovered from the i-f sideband signal.