# CHAPTER 2
# SINGLE-SIDEBAND EXCITERS

## 1. SINGLE-SIDEBAND EXCITER CONSIDERATIONS

The single-sideband exciter must translate the incoming audio frequency signal to a band of frequencies in the r-f range. A single-sideband exciter is, in fact, a complete transmitter in itself. It must generate a radio-frequency sideband from an audio input signal, translate this r-f sideband to the final output frequency, and provide sufficient amplification to drive the r-f power amplifier. A functional diagram of a typical single-sideband exciter is shown in figure 2-1.

To generate the r-f sideband of frequencies, the single-sideband exciter uses low-level modulation and obtains the desired output level through the use of linear amplifiers. Low-level modulation is used since the carrier and unwanted sideband must be suppressed. The best suppression is obtained at a fixed low frequency since the problems involved in building a high-level balanced modulator, capable of working over a wide frequency range, appears to be insurmountable.

The most desirable performance characteristics of a single-sideband exciter would be the ability to generate the desired sideband, completely suppress the undesired sideband, and suppress the carrier. Practical design permits suppressing the undesired sideband and carrier frequencies by more than 40 db.

Careful consideration must be given to the amount of frequency spectrum space occupied by the generated signal. The band of side frequencies is normally held to 4 kc in single-sideband exciters for communication purposes.

The two basic systems for generating single-sideband signals are the filter system, shown in figure 2-2A, and the phase shift system, shown in figure 2-2B.

### a. FILTER SYSTEM

The filter system uses a band-pass filter having sufficient selectivity to pass one sideband and reject the other. Filters having such characteristics are normally constructed for relatively low frequencies, below 500 kc, but recent developments in crystal filter research has produced workable filters at 5 megacycles The carrier generator output is combined with the audio output of a speech amplifier in a balanced modulator. The upper and lower sidebands appear in the output, but the carrier is suppressed. One of the sidebands is passed by the filter and the other rejected, so that a single-sideband signal is applied to the mixer. The signal is mixed with the output of a high-frequency r-f oscillator to produce the desired output frequency. The problem of undesired mixer products arising in the frequency conversions of single-sideband signals becomes important. Either balanced modulators or sufficient selectivity must be used to attenuate these frequencies in the output and minimize the possibility of unwanted radiations.

### b. PHASE SHIFT SYSTEM

The principle involved in the generation of a single-sideband signal by the phase shift method,

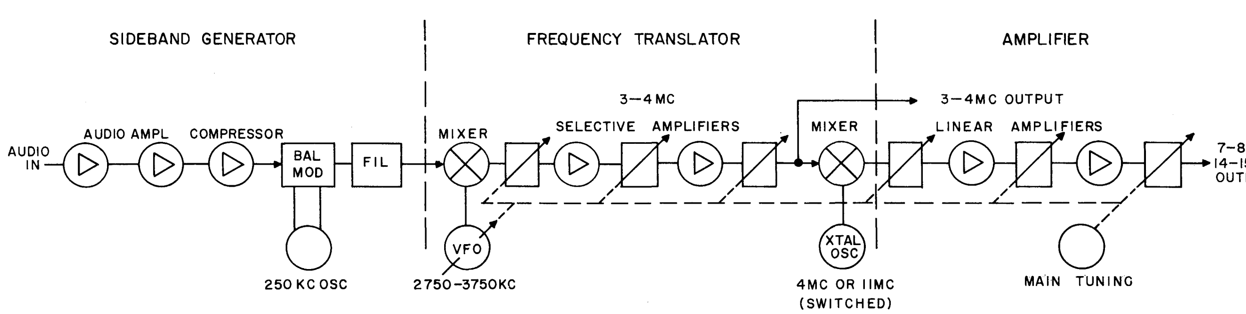



Figure 2-1. Typical Single-Sideband Exciter, Functional Diagram

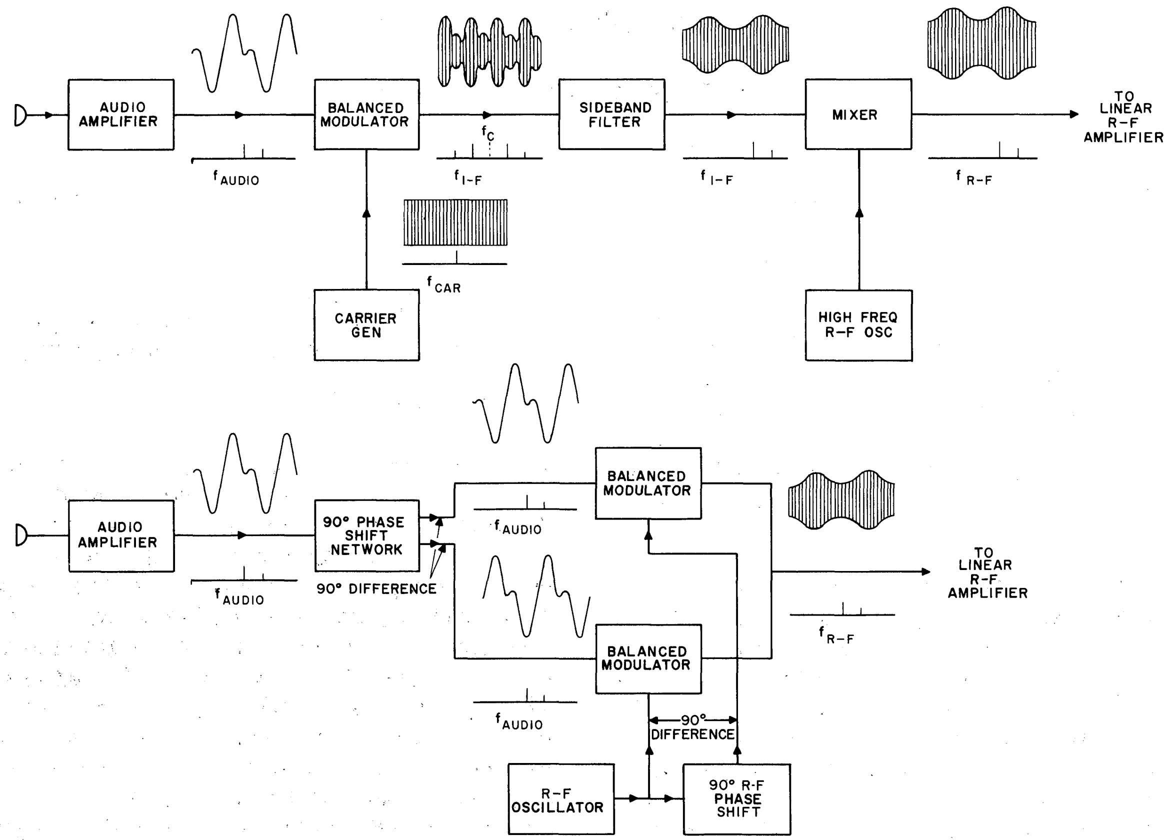



Figure 2-2. Basic Single-Sideband Generator, Block Diagram

shown in figure 2-2B, is centered about two separate simultaneous modulation processes and the combination of the modulation products. The audio signal is split into two components that are identical except for a phase difference of 90 degrees. The output of the r-f oscillator (which may be at the operating frequency if desired) is also split into two separate components having a 90-degree phase difference. One r-f and one audio component are combined in each of two separate balanced modulators. The carrier is suppressed in the modulators, and the relative phases of the sidebands are such that one sideband is balanced out while the other sideband is accentuated in the combined output. If the output from the balanced modulator is of sufficient amplitude, such a single-sideband exciter can work directly into the antenna, or the power level can be increased in a following linear amplifier.

## 2. THE SINGLE-SIDEBAND GENERATOR

The sideband generator processes the input audio signal, generates the r-f sideband in a modulator, selects the desired sideband while suppressing the unwanted sideband, and suppresses the carrier. The circuits which perform these functions are shown in the single-sideband generator portion of figure 2-1. The audio input wave must be amplified, amplitude limited, and shaped before being applied to the modulator circuits. Sideband generation is accomplished by using this audio input signal to vary the amplitude of a carrier wave in a modulator. The desired sideband is selected from the modulator output using frequency discrimination or phase discrimination. The carrier wave is suppressed by using balanced modulators or rejection filters.

### a. INPUT SIGNAL PROCESSING

Processing of the audio input signal is an important part of single-sideband generating. If the input signal is a tone, or group of tones, of constant amplitude, such as the signal from a data gathering device, only a limited degree of processing will be required. However, if the input audio signal is a voice signal, rather elaborate input processing circuits must be designed to obtain optimum results.

The amount of amplification required depends upon the output capability of the source of the audio signal and the input signal requirements of the modulator. Modulators require an audio signal in the range of .1 to 1 volt at impedances of 200 ohms for diode modulators or several hundred-thousand ohms for vacuum tube modulators. The output of a microphone may be from 100 to 1000 times less than the .1 to 1 volt range. Telephone line levels will also be considerably less than the required level. To obtain efficient utilization of the transmitter power amplifier, the applied driving signal should be as close to maximum without exceeding the overload level. To avoid driving the power amplifier into overload, it is necessary to adjust gain to the point where maximum output is obtained with the maximum input signal.

When the input signal is made up of extreme variations, such as a peak level to average level of 4:1, the average transmitted power level will only be 1/4 the maximum output the transmitter is capable of furnishing. This analogy is illustrated in figure 2-3. An effort must be made to compress the dynamic range of the human voice to make it more compatible with the electrical characteristics of a communications system. The two methods most commonly used to reduce these amplitude variations are compression and clipping circuits.

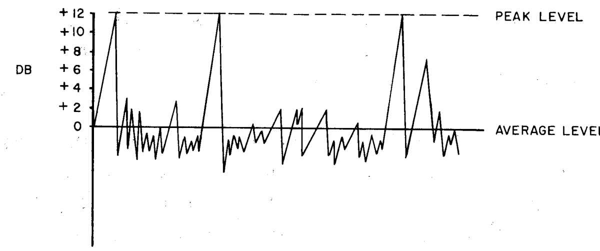



Figure 2-3. Peak-to-Average Level Variations of Speech

(1) COMPRESSOR CIRCUIT

A compressor is an automatic variable gain amplifier whose output bears some consistent relation to its input; for example, a one db rise in output for a two db rise in input. This circuit has very low steady state distortion. Common compressors use some type of feedback loop that samples the output of the amplifier and regulates the gain of the stage The time constants of this type circuit are necessarily slow to prevent oscillation, motorboating, and distortion. The attack time, the time necessary to reach steady state condition after a sudden rise in input level, will be several milliseconds. The release time, the

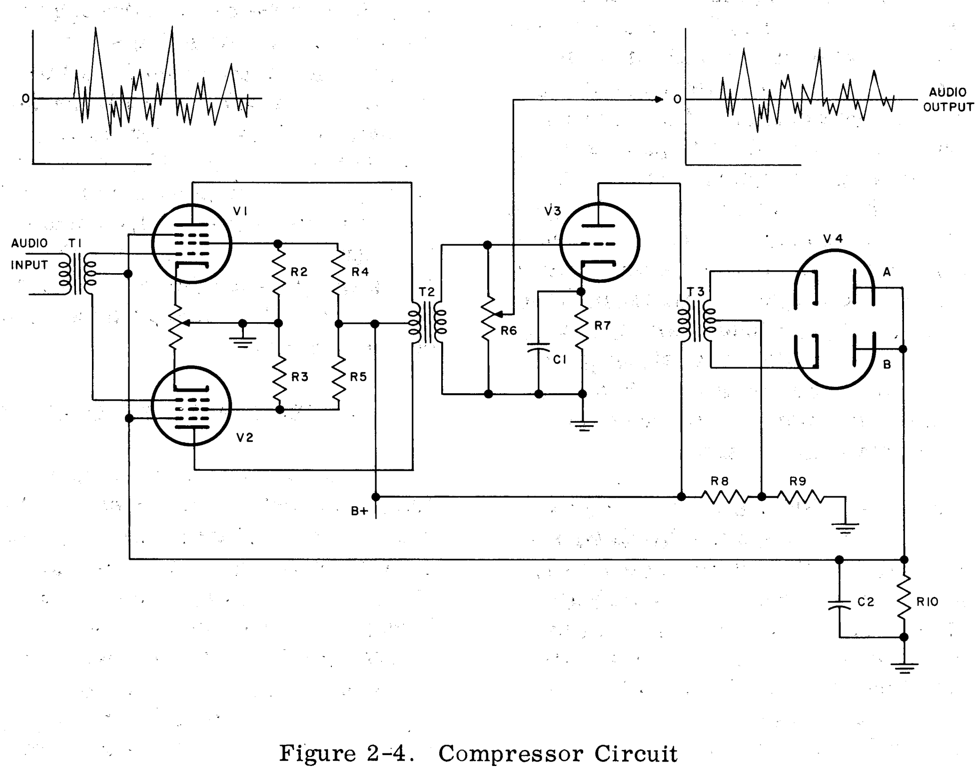



Figure 2-4. Compressor Circuit

time necessary to reach a steady state condition after a sudden drop in input level, will be several seconds. Compression of about 10 db is usually considered as an acceptable maximum value.

Operation of the compressor circuit, illustrated in figure 2-4, is such that the d-c bias voltage applied to the control and suppressor grids of the push-pull stage is in direct proportion to the amplitude of the signal passing through the circuit. If a large amplitude signal is impressed on the control grids of V1 and V2, such as a large amplitude low frequency, the signal is amplified and appears across transformer T3. As the audio signal swings positive at the top of the secondary of the transformer, tube V4B conducts, since the bottom of the secondary is negative with respect to ground, and the resultant current flow creates a bias voltage drop across resistor R10. The negative voltage on the control and suppressor grids of V1 and V2 reduces the gain of the tubes to limit the excursion of the audio signal. Conversely, as the audio signal swings negative at the top of the secondary of transformer T3, tube V4A conducts. Since the plates of the rectifiers are in parallel, the bias voltage is produced on both positive and negative going portions of the audio signal.

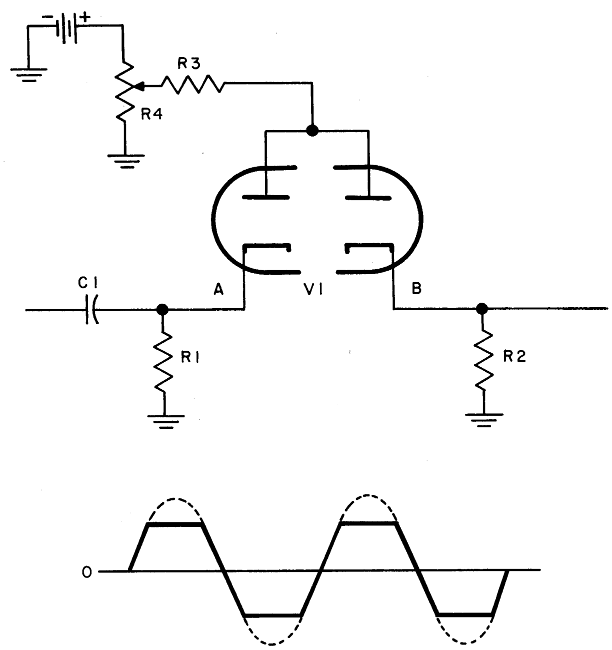



Figure 2-5. Clipper Circuit

(2) CLIPPER CIRCUIT

The clipper circuit, illustrated in figure 2-5, prevents the amplitude of a signal from exceeding a preset level. Its time constants are practically instantaneous, and it functions on each cycle of a wave. Distortion is very high, which results in loss of individuality in speaking and broadening of the spectrum occupied by the speech. Low-pass filters are usually used in conjunction with clippers to limit the spectrum and reduce distortion. The advantages of clipping is simplicity of circuit design and its ability to prevent overmodulation. The ability to prevent overmodulation results from its extremely fast attack on a wave after it exceeds the threshold. A well-designed clipper has no overshoot and an extremely fast release. A weak signal following one cycle after a wave that is heavily clipped will not be limited. This means that a weak consonant that follows a loud vowel in human speech will be given full amplification, although the preceding vowel was severely clipped. This amplifying of weak sounds in relation to soft sounds is referred to as consonant amplification.

The clipper circuit, illustrated in figure 2-5, serves as an instantaneous voltage amplitude limiter at a predetermined point on the positive and negative going portions of the audio signal. As the cathode of V1A swings positive, the tube will conduct until the potential on the cathode reaches the potential of the plate. The current flow through resistor R3 causes a voltage drop across R3 which is alternately reenforcing and bucking the plate voltage in exact response to the applied audio signal. This action causes the current through V1B to vary as the plate voltage varies and the signal in the output, across resistor R2, will be the same as the signal at the input, across resistor R1. When tube V1A is cut off, due to the cathode becoming more positive than the plate, there is no change of the plate voltage applied to V1B, and the current through the tube is held at a constant point. When the signal starts negative, the current variations through V1B will follow the current variations through V1A until the current through V1A becomes sufficiently great to cause the negative voltage drop across resistor R3 to equal the applied d-c plate potential. At this point the plate of V1B is no longer positive with respect to the cathode, and V1B ceases to conduct. The net result of this action is the clipping (or limiting) of the positive and negative peaks of an audio signal at a value predetermined by the setting of potentiometer R4.

(3) FREQUENCY RESPONSE SHAPING

The energy contained in a voice signal is confined principally to frequencies below 1000 cycles per second. Most of this energy is used to produce the vowel sounds which contribute little to intelligibility. The energy used to produce the consonant sounds is largely high frequency in content and is very important in intelligibility. An improvement in intelligibility will result if the frequency response of the audio input signal circuits is modified to amplify the high frequencies more than the low frequencies.

**b. MODULATORS FOR SINGLE SIDEBAND**

The r-f sideband is obtained by combining the audio signal obtained from the processing circuits and an r-f carrier wave in an amplitude modulator. There are many types of modulators, but they can be grouped into two main functional divisions: (1) those in which the modulation is dependent on the polarity of the modulating signal, and (2) those where the modulation is dependent on the instantaneous waveform of the modulating signal. For practical reasons, it is more convenient to group modulator circuits in the following three categories, based on the circuit components: (1) rectifier modulators (2) multielectrode vacuum tube modulators, and (3) nonlinear reactance modulators. Each group has its advantages and disadvantages, and these control the extent of their use. Because one of the characteristics of a modulator is frequency changing or frequency translating, this type of modulator is used in the frequency changing portion of a single-sideband exciter.

(1) RECTIFIER MODULATORS

Rectifier modulators have several advantages which make them particularly useful for single-sideband generation. Their great advantage is high stability in comparison with vacuum tube modulators. They require no heating elements, and therefore no power is required and no heat has to be dissipated. They can be made quite compact, have long life, and require little maintenance. Rectifier modulators may be one of three general types, ring, series, or shunt. These type names refer to the manner in which the diodes are connected in the circuit. In all circuits, the rectifiers are made to work like switches by using a large r-f switching signal which greatly exceeds the audio signal level. These modulators are almost invariably connected as balanced modulators so that, as nearly as possible, there is no output of the r-f switching voltage in the modulator output terminals

The basic circuits of the ring, shunt, and series modulators are shown in figures 2-6A, 2-7A, and 2-8A. It must be assumed that the rectifiers are capable of switching at zero voltage from an infinite back resistance to a zero forward resistance and back again. The basic signal circuits may then be represented by the equivalents shown in figures 2-6B, 2-7B, and 2-8B. These equivalent signal circuits are shown for any half-cycle of the carrier voltage, with switches shown in place of the rectifiers. Practical rectifiers are not ideal, but will have a finite forward and backward resistance. If it is assumed that the carrier frequency is several times that of the input signal, the resulting output waveforms are as shown in figures 2-6C, 2-7C, and 2-8C.

The output of these modulators consists of a series of pulses whose polarity and repetition frequency are determined by the switching or carrier voltage, and whose amplitude is controlled by the input audio signal. A spectrum analysis of these output signals reveals the presence of an upper sideband and a lower sideband displaced about the switching or carrier frequency. A similar set of sidebands is placed about the second harmonic of the carrier frequency and some other undesired products higher in frequency.

The ring modulator has the highest efficiency, being capable of twice as much output voltage as the shunt or series modulator. Where carrier balance is important, a split ring modulator may be used in which it is possible to balance independently the two sets of diodes. The shunt modulator has the unique ability of being able to handle input and output terminations of the unbalanced, one-side-grounded type.

Rectifier balanced modulators are capable of a high performance; however, if they are to retain this performance for long periods of time, they must be carefully made of good quality, accurately matched components. Initial carrier balance exceeding 40 db may be readily obtained, but it is difficult to retain this degree of carrier suppression if the environmental conditions are severe. The level of third order intermodulation products can be held to 50 db below the desired sideband output signal.

(2) MULTIELECTRODE VACUUM TUBE MODULATORS

Multielectrode vacuum tube modulators are flexible and used in a wide variety of applications in addition to generating sidebands. They are capable of giving conversion gain rather than loss as the case in rectifier modulators. However, they are quite unstable as to gain and impedance which makes them undesirable in balanced modulators. Since they employ vacuum tubes they require power, dissipate heat, and have relatively short life compared with rectifier modulators. Vacuum tube modulators, employing modulating functions dependent on the instantaneous amplitude of the modulating signals, are basically one of two types: a product modulator, or a square law modulator.

In a product modulator the output signal is proportional to the two input signals. In single-sideband application the input signals would be the carrier signal and the modulating signal. An example of such a product modulator is a double grid vacuum tube. The carrier voltage is applied to one grid, and the modulating signal applied to the other. Modulation takes place due to the combined action of the grids on the plate current. It is important to realize that nonlinearity is not necessary, and modulation will take place even if each grid has a linear mutual characteristic.

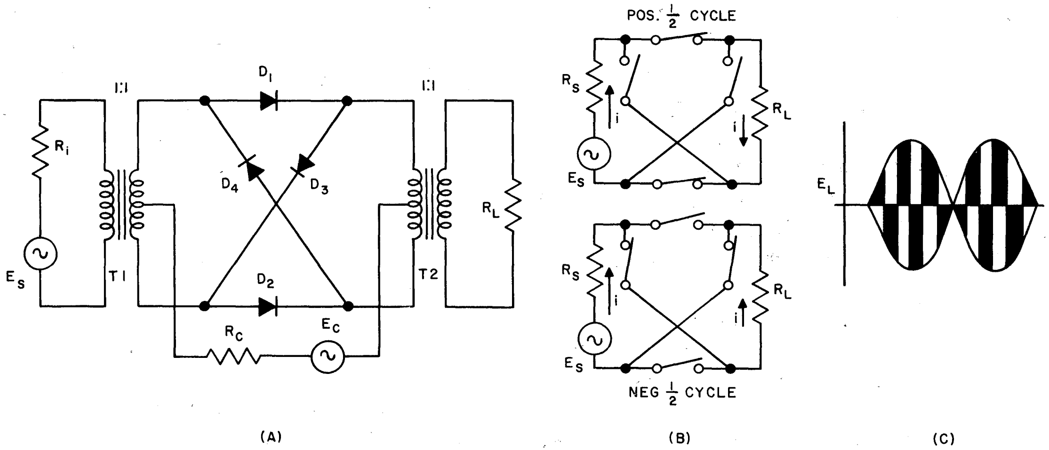



Figure 2-6. Basic Ring Modulator Circuits

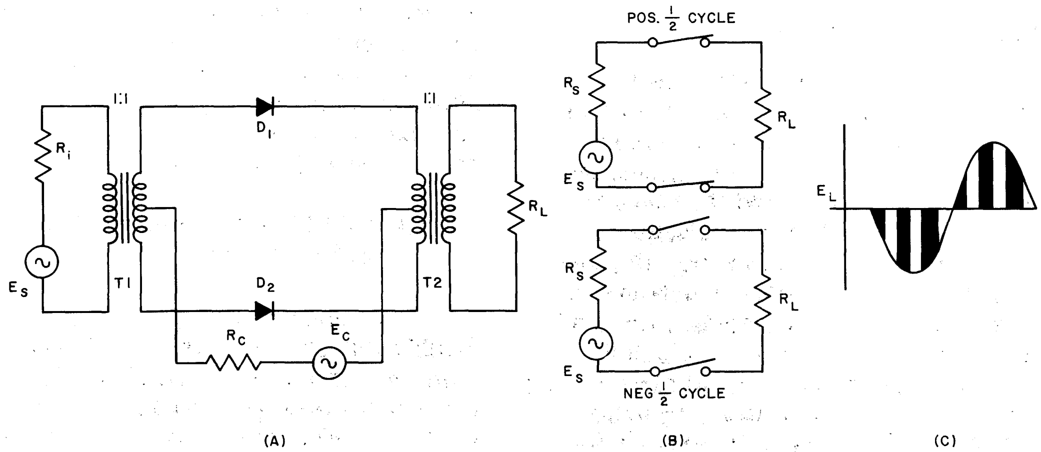



Figure 2-7. Basic Shunt Modulator Circuits

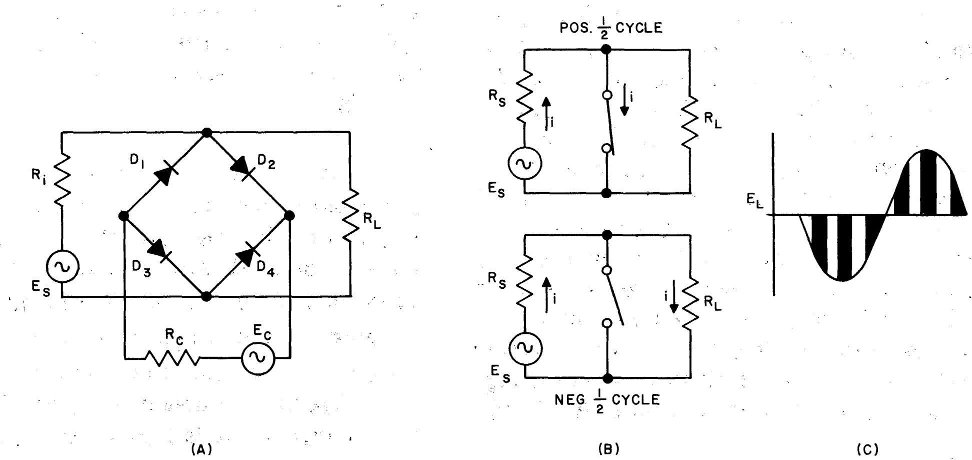



Figure 2-8. Basic Series Modulator Circuits

In contrast to the product modulator is a square law modulator in which modulation takes place directly because of a nonlinearity. An example of a square law modulator is a triode vacuum tube in which the shape of the plate current versus grid voltage curve has at least second order curvature or square law. This characteristic is possessed by all vacuum tubes and is the cause of distortion in amplifiers. If the curvature is purely square law, it can be shown that the output signal will contain only the desired sum or difference frequency and no other products except the second harmonics of the input signals. Product modulators and square law modulators are particularly useful in frequency changers because they generate a minimum of unwanted products.

Vacuum tube modulators in which the modulating function is dependent on the polarity of the modulating signal are large signal devices that have high efficiency but also generate considerable amounts of spurious signals. An example of such a modulator is a plate modulated triode operated class C. The modulating signal is used to vary the plate voltage applied to the class C amplifier. The resulting output is a series of pulses recurring at the carrier frequency rate and with amplitude proportional to the modulating signal. The tuned output circuit is necessary to suppress the harmonics of the signal. The double grid vacuum tube can also be used as a switching type modulator by increasing the amplitude of the signal applied to one of the grids. This signal can be large enough to drive the plate current of the tube to cutoff in one direction and saturation in the other, resulting in an output signal somewhat similar in waveform to that of a rectifier modulator.

Modulators using nonlinear reactances, instead of rectifiers or vacuum tubes, have not seen much use in high-frequency equipments due to the lack of materials usable at high frequencies. With suitable components such as titanate capacitors and ferrite-core inductors now available, it is probable that such modulators will be used more frequently in the future.

### c. SUPPRESSING THE CARRIER

The carrier frequency can be suppressed or nearly eliminated by the use of a balanced modulator. The basic principle in any balanced modulator is to introduce the carrier in such a way that current at the carrier frequency in the output circuit cancels out.

(1) VACUUM TUBE BALANCED MODULATORS

The requirements stated above are satisfied by introducing the audio in push-pull and the r-f drive in parallel, and connecting the output of the tubes in push-pull, as shown in figure 2-9A. Balanced modulators can also be connected with the r-f drive and audio inputs in push-pull and the output in parallel (figure 2-9B) with equal effectiveness. The choice of a balanced modulator circuit is generally determined by constructional considerations and the method of modulation preferred by the builder. Screen-grid modulation is shown in the examples in figure 2-9, but control grid or plate modulation could be used with the same result. In balanced modulator vacuum tube circuits, there will be no output with no audio signal because the circuits are balanced. The signal from one tube is balanced or canceled in the output circuit by the signal from the other tube. The circuits are thus balanced for any value of parallel audio signal. When push-pull audio is applied, the modulating voltages are of opposite polarity, and one tube will conduct more than the other. Since any modulation process is the same as mixing, sum and difference frequencies (sidebands) will be generated. The modulator is not balanced for the sidebands, and they will appear in the output. The amount of carrier suppression obtained is dependent upon the matching of the two tubes and their associated circuits. Normally, two tubes of the same characteristics can be adjusted to give at least 30 db of carrier suppression without further filtering. Balance is difficult to maintain since tube characteristics change with age and supply voltage variations. Since in suppressed carrier single-sideband transmission it is desirable to suppress the carrier at least 40 db, the selective filter following the balanced modulator is used for further carrier suppression.

(2) DIODE BALANCED MODULATORS

The operation of diode balanced modulators was discussed in paragraph 2.b. (1) and figures 2-6, 2-7, and 2-8. The equivalent circuits illustrated in figures 2-6B, 2-7B, and 2-8B do not present the carrier balancing action of the modulators. This action may be analyzed from the basic circuits shown in figures 2-6A, 2-7A, and 2-8A. Using the ring modulator as an example, the carrier currents may be as shown in figures 2-10A and 2-10B. Assume that the carrier generator voltage is such that D1 and D2 conduct. The current flow will be through $R_c$, T1, D1 and D2, T2, and back to the generator. The current through the two windings of the output transformer T2 are out of phase and will cancel. On the next carrier half-cycle, D3 and D4 conduct, and the phases of all currents are changed by 180 degrees. The output currents are again out of phase. Therefore, no carrier voltage appears across the output load, $R_L$. Carrier currents may be similarly traced in the shunt and series circuits to show the balancing action of the carrier currents.

### d. SIDEBAND SELECTION

It is a property of all modulators that the output consists of a pair of sidebands symmetrically disposed on either side of the carrier frequency. Since the objective is to transmit only a single sideband, a

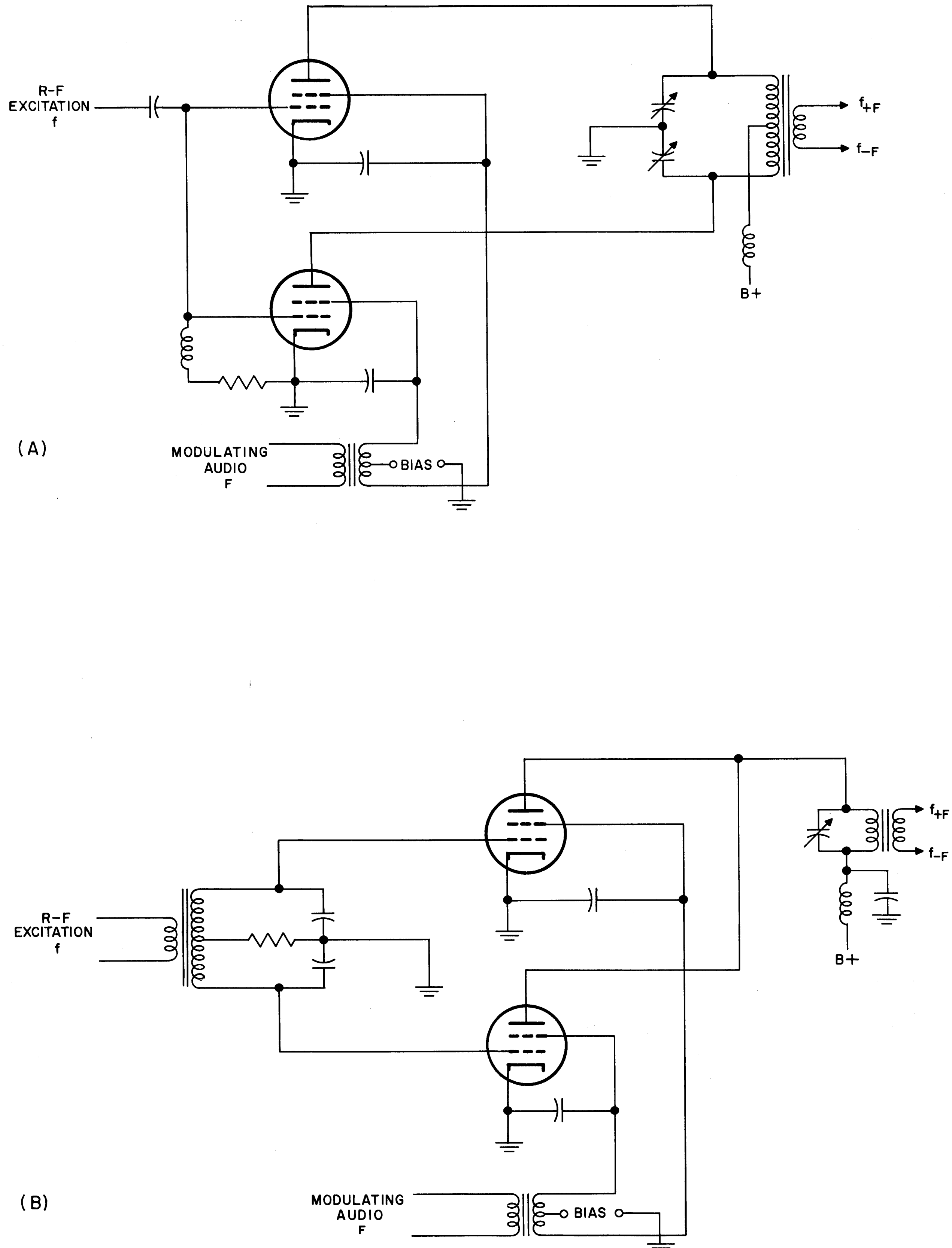



Figure 2-9. Vacuum Tube Balanced Modulators

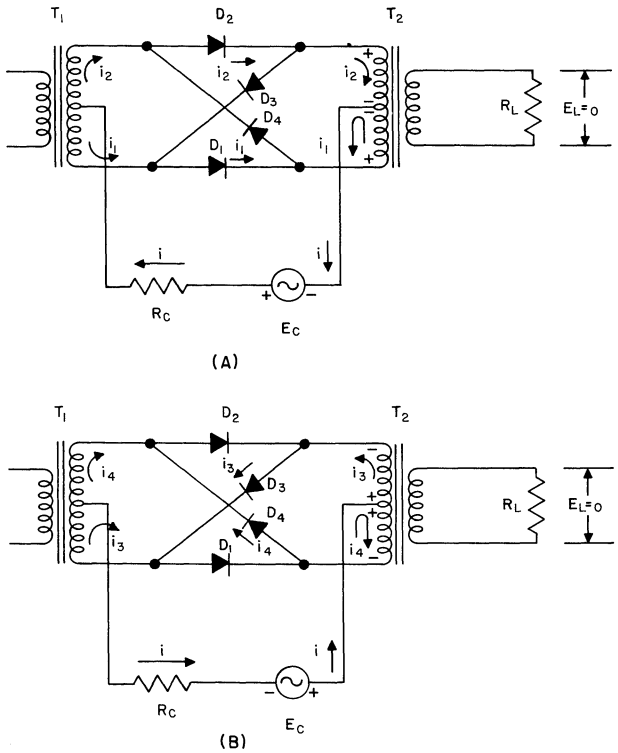



Figure 2-10. Ring Modulator Carrier Current Paths

means must be found to select the desired sideband and suppress the undesired sideband. This may be accomplished through the use of one of two techniques: the technique of frequency discrimination (filtering) or the technique of phase discrimination (phase shift).

(1) FILTER SYSTEM OF SIDEBAND SELECTION

The frequency discrimination method uses a frequency selective filter to select the desired sideband. This is possible because the modulating wave is usually confined to a restricted band of frequencies, and this frequency band is separated from the carrier by an appreciable amount. The rapid increase of attenuation required of a sideband selecting filter in order that it may adequately suppress the unwanted sideband is a decisive factor in filter design. Components having a high rate of change of impedance with frequency, or high Q, must be used. The requirement is a certain amount of attenuation in a given number of cycles. For a given frequency of filter operation and a certain degree of sideband suppression, the quality or Q factor of the components making up the sideband filter is determined. This means that for low-frequency sideband selection a lower Q element may be used, conversely for high-frequency sideband selection high Q elements are required. Inductors and capacitors have low Q factors and can be successfully used for sideband filters only at relatively low frequencies, up to about 50 kilocycles per second. Small metal plates and quartz crystal plates on the other hand have extremely high Q factors and can be used to build sideband filters capable of operating at higher frequencies. Mechanical filters or metal plate filters have been built to operate up to 600 kilocycles, and crystal filters have been made to work at frequencies as high as 5 megacycles.

Removing the unwanted sideband through the use of a selective filter has the advantage of simplicity and good stability. The suppression unwanted sideband is determined by the attenuation of the sideband selecting filter. The stability of sideband suppression is determined by the stability of the elements used in constructing the sideband filter. This stability can be quite high because it is possible to use materials that have very low temperature coefficient of expansion.

(2) PHASE SHIFT METHOD OF SIDEBAND SELECTION

In the phase shift method, two balanced modulators are used, and the exciting signals to these modulators are arranged to have phase relationships such that when the outputs of these two modulators are combined, the desired sideband components are reinforced and the unwanted components are canceled out. Into modulator number 1 the modulating signal and the carrier signal are fed directly. Into modulator number 2 these signals are fed after first being passed through networks which shift the relative phase of these signals 90°. In other words, the modulating signal fed into modulator number 2 is shifted 90° with respect to the phase of the audio signal fed into modulator number 1. Similarly the phase of the carrier voltage fed into modulator number 2 is shifted 90° relative to the phase of the carrier voltage fed to modulator number 1. If these phase relationships are maintained over the desired modulating signal frequency range, the action is to suppress completely one set of sidebands and to reinforce the opposite set in the output of the combining circuit. If balanced modulators are used, the carrier signal will not appear in the output. Practically speaking, it is very difficult to design a phase shifting network that will perform according to the above restriction for the modulating signal phase shift network. However, if a separate phase shifting network is inserted in each modulating signal input circuit, it is possible to maintain a phase difference of 90° between the two network outputs over the required signal frequency range. The action of this circuit with these networks is identical with that in which a 90° phase shift is used in one branch alone.

The phase shift method of single-sideband generation does not require a rapid change of discrimination in a narrow frequency interval; therefore, it can be used to generate a single-sideband signal which can have extremely low-frequency components.

Since no selective filter is required, it is possible to generate the single sideband at the operating frequency with no frequency conversion being required. The degree of suppression of the undesired sideband is dependent on the accuracy with which the undesired sideband components are canceled. To obtain complete cancellation, it is necessary to maintain accurately the phase shifts and amplitudes of the signals applied to the combining network. These requirements place a very stiff specification on the phase shift and amplitude control properties of the circuit. The circuit is also somewhat more complex since two modulators are required.

## 3. TRANSLATION TO THE OPERATING FREQUENCY

The single-sideband signal is translated to the operating frequency by the use of one or more frequency changers. These frequency changers perform their function through the modulation process which is identical with that used to generate the sideband signal. The sideband signal is used to modulate a high-frequency carrier whose frequency is such that the upper or lower sideband is on the desired operating frequency. As a result of this modulation process, the sideband signal will be shifted to a new frequency that is either the sum of the carrier and sideband frequencies or the difference between the carrier and sideband frequencies. It is important to realize that if the lower sideband of the translation modulation process is selected, an inversion of the sideband signal occurs. That is to say, an upper sideband signal will be converted into a lower sideband signal. Another important consideration is the frequency accuracy and stability of the carrier used in the modulation process since any error in the carrier frequency is passed on to sideband signal in exact proportion. The translation system consists of two major components: the modulator (commonly called a mixer) and the carrier (commonly called oscillator signal).

All modulators previously described can be used for frequency changing. Vacuum tube modulators are used almost exclusively in this service, because these circuits have considerable gain and generate a minimum of spurious products. It is these spurious products which exert the most influence on the design of the frequency translation system.

### a. SPURIOUS MIXER PRODUCTS

In order to show how undesired frequencies may be generated in a mixer stage, consider the case where signal and oscillator voltages are applied to the same grid of a mixer tube. In order that the desired sum or difference frequency be generated, it is necessary that the plate current versus grid voltage characteristic have some nonlinearity or curvature. The components of the plate current will be the d-c, signal, oscillator, signal second harmonic, oscillator second harmonic, and the sum and differences of the signal and oscillator. It is necessary to eliminate all the products except the desired sum or difference product by filtering. To obtain the desired sum or difference product, we would desire a tube in which the characteristic curve had only second order curvature. Unfortunately, all practical tubes have characteristic curves having higher order curvature. This higher order curvature contributes additional unwanted frequency components into the output current. Sometimes the frequency of these unwanted components is far removed from the desired output frequency, and they are easily filtered out, but often these frequencies are very nearly equal in frequency to the desired signal frequency, and they will fall within the passband of the filter used in the mixer output circuit. The amplitude or strength of these undesired mixer products varies from tube type to tube type and tube to tube and with a given tube will change when the operating point is varied. Consequently, it is not surprising that tube designers have not been particularly successful in designing tubes having the desired second order curvature to the exclusion of any higher order curvature. The circuit designer, therefore, must select his mixer tubes by means of a series of experiments in which the amplitudes of these undesired mixer products are measured. The result of such an experimental determination of mixer product amplitudes is shown in table 2-1.

It can be seen that there are several undesired products that are greater in amplitude than the desired signal and a considerable number that are weaker than the desired signal. Furthermore, it can be seen that as the order of the mixer product involved increases, its amplitude decreases. The presence of undesired mixer products in the output of the frequency translation system may be minimized through intelligent selection of the signal and oscillator frequencies. The problem of frequency selection is relatively simple where the operating frequencies are fixed. Where the operating frequency must be varied, the problem becomes more complex; and if continuous operation over wide frequency ranges is required, the problem is exceedingly complicated. In an attempt to simplify the problem, circuit designers have resorted to charts in which the frequency of the spurious mixer products is plotted with respect to the signal and oscillator frequencies. Such a chart is shown in table 2-2.

The following example illustrates the spurious product problem. In this example, it is desired to produce a single-sideband transmitter capable of operating on the amateur 20, 40, and 80 meter bands. These bands are 3.5 to 4.0 megacycles, 7.0 to 7.3 megacycles, 14.0 to 14.35 megacycles. Assume that the single-sideband signal has been generated at 250 kilocycles carrier frequency. The lowest frequency band 3.5 to 4.0 megacycles can be covered by mixing

TABLE 2-1. CALCULATED FREQUENCY PRODUCTS CONTAINED IN THE PLATE CURRENT OF A 12AU7 TRIODE MIXER

CALCULATED FREQUENCY PRODUCTS CONTAINED IN THE PLATE CURRENT OF A 12AU7 TRIODE MIXER

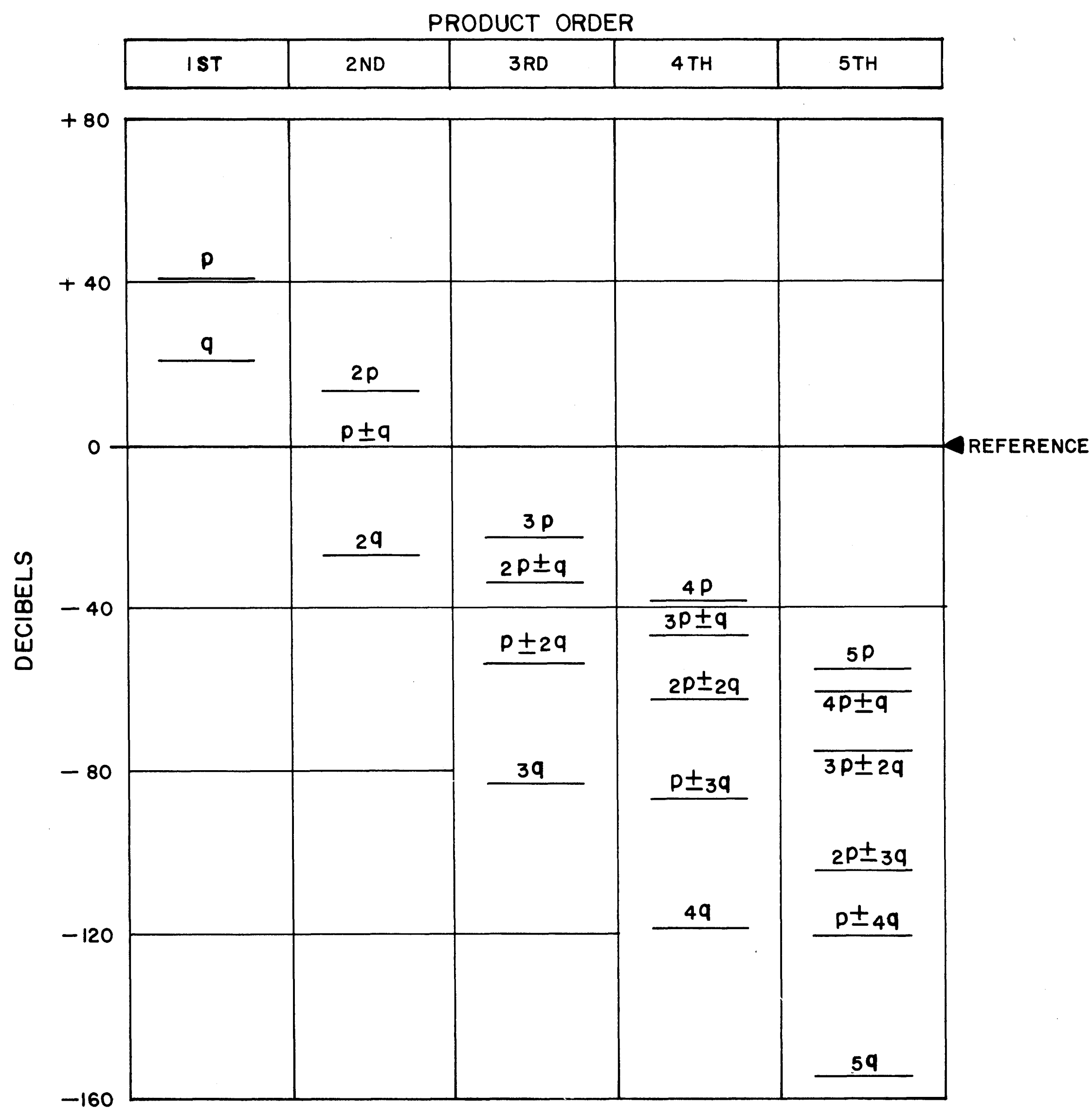
$e_{osc} = P\cos pt = 2V\,rms$ $e_{sig} = Q\cos qt = .2V\,rms$

$E_b = 250V$ $E_k = 10V$ $E_{bb} = 415V$ $R_L = 10K$

TABLE DERIVED FROM POWER SERIES EXPANSION

WHERE $e_{in} = P\cos pt + Q\cos qt$

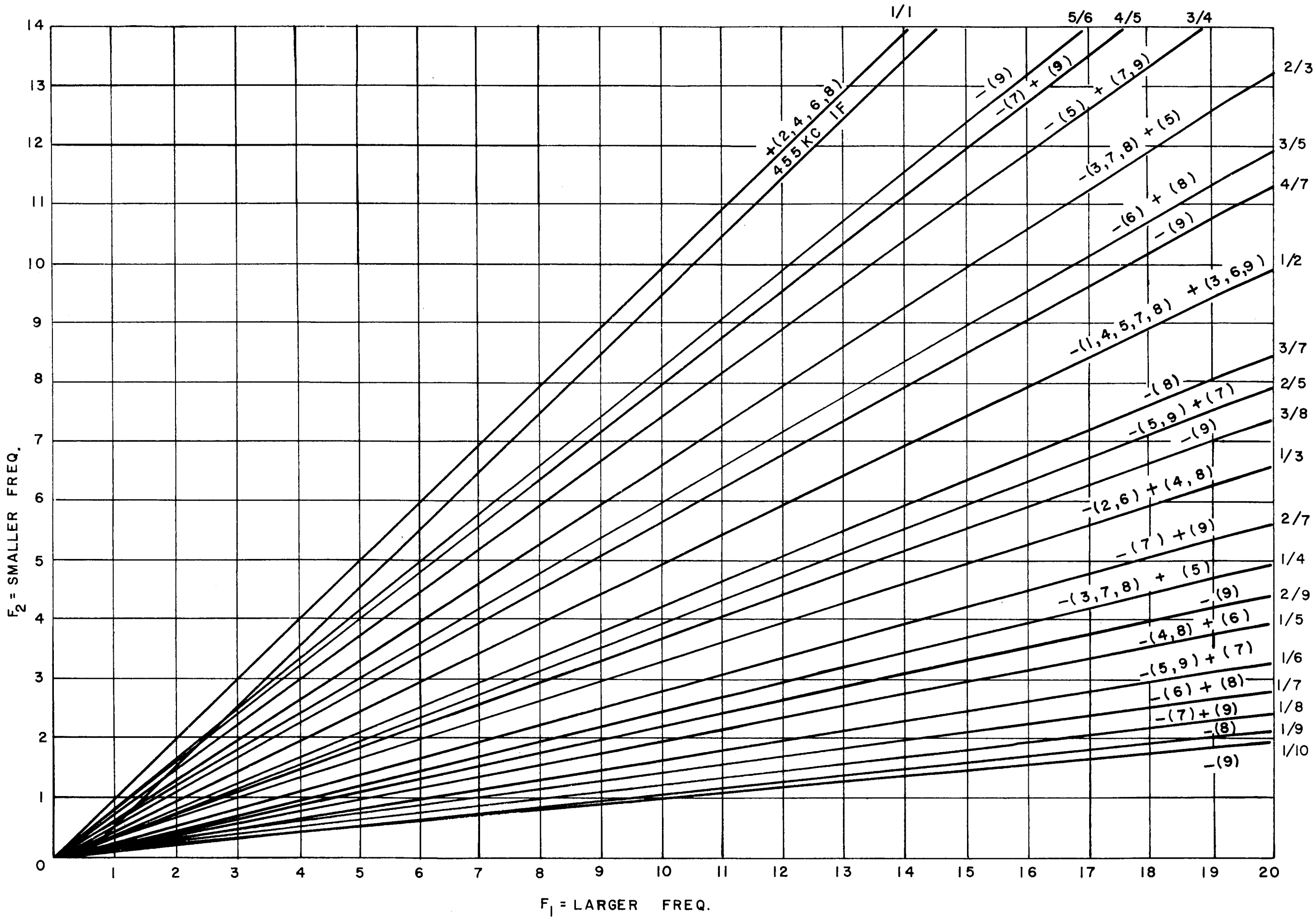
ZERO DB REFERENCE IS MAGNITUDE OF $(p \pm q)$




COEFFICIENTS OF POWER SERIES FROM REPORT BY DR. V.W. BOLIE DUAL TRIODE MIXERS 7/23/53

$a_1 = 3.47 \times 10^{-4}$, $a_2 = 1.47 \times 10^{-5}$, $a_3 = 2.2 \times 10^{-7}$, $a_4 = 3.7 \times 10^{-8}$, $a_5 = 5.7 \times 10^{-9}$

TABLE 2-2. SPURIOUS RESPONSE CHART




$F_2 \sim F_1$

| ORDER | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1/1 | | •20 •02 | | •13 •31 | | •24 •42 | | •35 •53 | |
| 1/2 | 10 | | •12 •30 | 31 | 32 | •33 •51 | 52 | 53 | •54 •72 |
| 1/3 | | 20 | | •22 •40 | | 42 51 | | •53 •71 | |
| 1/4 | | | 30 | | •32 •50 | | 52 | 71 | |
| 1/5 | | | | 40 | | •42 •60 | | 62 | |
| 1/6 | | | | | 50 | | •52 •70 | | 72 |
| 1/7 | | | | | | 60 | | •62 •80 | |
| 1/8 | | | | | | | 70 | | •72 •90 |
| 1/9 | | | | | | | | 80 | |
| 1/10 | | | | | | | | | 90 |
| 2/3 | | | 21 | | •23 •41 | | 43 | 53 | |

$F_2 \sim F_1$

| ORDER | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 2/5 | | | | 41 | | | •43 •61 | | 63 |
| 2/7 | | | | | | | 61 | | •63 •81 |
| 2/9 | | | | | | | | | 81 |
| 3/4 | | | | | 32 | | •34 •52 | | 54 |
| 3/5 | | | | | | 42 | | •44 •62 | |
| 3/7 | | | | | | | | 62 | |
| 3/8 | | | | | | | | | 72 |
| 4/5 | | | | | | | 43 | | •45 •63 |
| 4/7 | | | | | | | | | 63 |
| 5/6 | | | | | | | | | 54 |

• INDICATES SUM MIXING
OTHER — DIFF MIXING

this single-sideband signal with the output of a variable frequency oscillator tunable from 3.25 megacycles to 3.75 megacycles. Due to the large difference between the signal and oscillator frequencies, there are no difficulties with undesired mixer products. However, the oscillator signal is only 250 kilocycles removed from the output frequency and must be filtered by means of a band-pass filter or else balanced out through the use of a balanced modulator. As it is quite difficult to build a modulator which can retain balance over a wide frequency range, it is necessary to resort to a combination of both methods to obtain suppression of this spurious frequency of at least 60 db. As the operating frequency increases, it becomes difficult to suppress this product, and some other method must be found. This is because the selectivity required in the tuned circuits is so high as to be impracticable. A solution to the problem is to use a second conversion following the first. In this mixer, the 3.5 to 4.0 megacycle output of the first conversion is mixed with the output of a crystal oscillator at 3.3 megacycles. This crystal frequency is chosen rather than 3.5 megacycles because with a 7.0 megacycle output frequency, there is a crossover of the second harmonic of the 3.5 megacycle signal with the desired output. A closer look at the frequencies involved, however, reveal that even with this crystal frequency, the second harmonic of the crystal at 6.6 megacycle is only 400 kilocycles removed from the low-frequency desired output, and the 7.4 megacycle second harmonic of the input signal is only 400 kilocycles on the other side of the desired output frequency. Selectivity of a very high order would be required to reduce these spurious signals satisfactorily. Some relief can be obtained by extending the range of the variable frequency oscillator used in the first mixer so that the output frequency from the first conversion runs from 3.0 to 4.0 megacycles. Now, a crystal oscillator

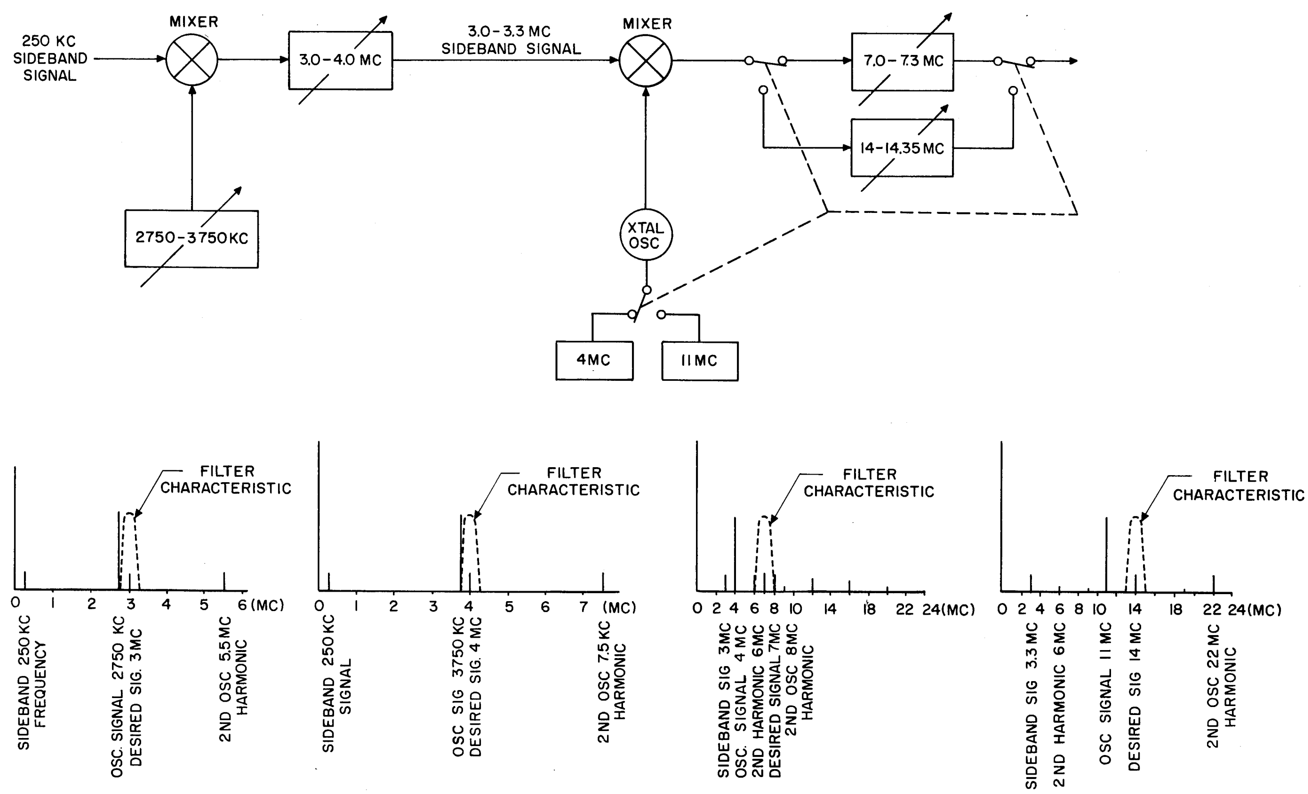



Figure 2-11. Selectivity Considerations in Frequency Translators

frequency at the second mixer of 4 megacycles can be used. With this frequency the range of the first converter system of 3.0 to 3.3 megacycles can be used to cover the 7.0 to 7.3 megacycle band. With this frequency scheme, the second harmonic of the crystal oscillator is at least 700 kilocycles removed from the desired operating range, and the second harmonic of the signal frequency ranges from 100 to 700 kilocycles below the desired output frequency range. These can be filtered adequately with relatively simple filters. According to the spurious frequency chart, a seventh order crossover occurs at the low end of the band when the third harmonic of 3 megacycles mixes with the fourth harmonic of 4 megacycles to yield a frequency equal to the output frequency. However, the level of a seventh order spurious signal is sufficiently low that it may be neglected, providing sufficient attention is paid to the selection of the mixer tube and its operating point. In considering frequencies to be used to cover the 14 to 14.35 megacycle band, one notes that if the difference product is selected, a clear region exists in the spurious chart between the 1/5 line and the 1/6 line. However, if such a scheme were adopted, the dial scale for this band would be reversed with respect to the two lower frequency bands, a distinctly unattractive feature. Fortunately, it is possible to use the sum product if a crystal frequency of 11 megacycles is used. The ninth order crossover occurring near the low end of the range is of no consequence since it is of negligible amplitude.

**b. OSCILLATOR REQUIREMENTS**

It must be realized that the frequency stability of the output signal is dependent on the frequency stability of the carrier frequency and the oscillator outputs used in the frequency changers. The total frequency error is the sum of the error in all three of these oscillators. This oscillator frequency error has two aspects. First, there is the accuracy of the calibration of the frequency involved. The second aspect of the frequency error is that of stability or a drift. If the equipment is to be operated and continuously monitored by skilled operators, it is possible to get by with rather large errors in both calibration and drift. In come cases, it is possible to use equipment in which the calibration error is relatively large, but the frequency drift is quite small. In this case, it may be possible to carry out effective communication with such an equipment, providing an operator is available to make the initial tuning adjustment. In some cases where it is desired to operate the equipment on many channels by remote control and with relatively unskilled operators, it is necessary to provide equipment with a high degree of performance both with respect to calibration and drift. Authorities tend to disagree as to the allowable frequency error which can be tolerated in a single-sideband communication system used for voice communication. As the error increases, the naturalness of the reproduced speech suffers first. If the error is such as to place the reinserted carrier on the high side of the original carrier frequency, the voice becomes lower pitched. If the error is such as to place the reinserted carrier on the low frequency side, the voice becomes higher pitched. As the error is increased, a point is reached where intelligibility is degraded. The frequency error at which this occurs is approximately 100 cycles per second. When the single-sideband transmitter is used to transmit narrow-band telegraph or teletype signals, it is sometimes necessary to maintain accuracy considerably higher than that required for voice transmission.

The stability that can be obtained from oscillators is an important factor in the design of a frequency translation system. Typical oscillator frequency errors are shown in tabular form in tables 2-3 and 2-4. In table 2-3, the frequency error is the long-term frequency error. Calibration, drift, and aging all contribute to the long-term frequency error. The errors listed in table 2-3 are typical for a term of several months. The short-term frequency errors are shown in table 2-4. The short-term frequency

TABLE 2-3. TYPICAL OSCILLATOR LONG-TERM FREQUENCY ERROR

| OSCILLATOR TYPE | ERROR % | ERROR CPS | | |
|---|---|---|---|---|
| | | 3 mc | 10 mc | 30 mc |
| Variable Frequency Oscillator | .05 | 1500 | 5000 | 15,000 |
| Crystal Oscillator | .005 | 150 | 500 | 1500 |
| Temperature Controlled Crystal Oscillator | .001 | 30 | 100 | 300 |
| Precision Standard Oscillator | .0001 | 3 | 10 | 30 |

TABLE 2-4. TYPICAL OSCILLATOR SHORT-TERM FREQUENCY ERROR

| OSCILLATOR TYPE | ERROR PPM | ERROR CPS | | |
|---|---|---|---|---|
| | | 3 mc | 10 mc | 30 mc |
| Variable Frequency Oscillator | 20 | 60 | 200 | 600 |
| Crystal Oscillator and Temperature Controlled Crystal Oscillator | 1 | 3 | 10 | 30 |
| Precision Standard Oscillator | .01 | .03 | .1 | .3 |

error is principally that of frequency drift, although in some cases aging is rapid enough to have some effect. From the data shown in these tables, it can be seen that single-sideband equipments using variable frequency oscillators would require manual operation and frequent attention. For an equipment to meet the stability and accuracy requirements for quick frequency selection by remote control by unskilled operators, it is necessary to use the form of oscillator known as a stabilized master oscillator, in which a variable frequency oscillator is stabilized by comparing its frequency with that of a frequency derived from a reference standard oscillator. Oscillators of this type are described in a later chapter.

## 4. AMPLIFICATION

In order that the single-sideband exciter have useful output, it is necessary to provide amplification of the sideband signal. Since the output power will be used to drive the power amplifiers of the system, the power output of the exciter is determined by system considerations. The driving power required is usually quite small since it is customary to use high gain tetrode tubes in most linear amplifiers. As a result, the power output of the single-sideband exciter may be limited to a fraction of a watt. This power level can be readily obtained through the use of receiving type tubes.

Pentode receiving tubes designed for use as r-f or i-f amplifiers in receivers may be used for low-level voltage amplifier stages. Low grid-to-plate capacitance is a necessary requirement for linear r-f amplifiers, since positive feedback through this path increases distortion. High mutual conductance is a useful characteristic because the required gain is then obtained with a minimum of stages. Receiving-type power pentodes may be used to obtain moderate power output, although most types suffer from having relatively large grid-to-plate capacitance. Tubes designed for video power amplifier use are best suited for use in linear r-f power amplifiers.

### a. TUNED CIRCUITS

Tuned circuits used in a single-sideband linear amplifier perform a dual function. A tuned circuit provides a suitable load impedance for the amplifier stage, so that the amplifier may provide sufficient voltage amplification. Secondly, this tuned circuit acts as part of a selective filter which acts to suppress unwanted mixer products generated in the frequency translation system. To obtain sufficient selectivity, it is quite often necessary to use double-tuned and even triple-tuned circuits in order that the required selectivity be obtained.

### b. LINEAR AMPLIFICATION

It is necessary to use linear amplifiers in a single-sideband transmitter in which low level modulation is used. The single-sideband system is an amplitude modulated system and once the modulation is performed, the amplitude relationships of the sideband components must be faithfully maintained. The principal distortion component encountered in tuned linear amplifiers is the third order intermodulation product. This product is so called because its generation depends on the third order curvature of the input-output amplifier characteristic. Unlike audio linear amplifiers which must handle a wide frequency range, tuned radio-frequency linear amplifiers seldom have difficulty with products generated due to second order curvature, such as sums and difference frequencies and harmonics. These frequencies usually fall far outside the tuned passband and are suppressed accordingly. On the other hand, the third order intermodulation products are always close to the desired frequency band, and many of the products actually fall within the desired passband. These intermodulation products are generated whenever there are two tones, or frequencies, within the amplifier passband whose frequencies are sufficiently close together that the second harmonic of one will mix with the other to yield a third frequency within the tuned amplifier passband. The amplitude of these spurious products can be controlled by limiting the input signal amplitude so that operation of the tube is always over a linear part of its input-output characteristic. It is readily possible to obtain sizable voltage and power amplification using receiving type tubes and still limit the amplitude of the third order intermodulation product to a level more than 50 db below the desired.

An important consideration in transmitters using linear power amplifiers is that the amplifier be driven with sufficient signal and yet not be overdriven to cause excessive intermodulation distortion. There are many factors which tend to cause the output of a single-sideband exciter to vary. The gain of the amplifier stages changes from one frequency channel to another due to the impedance of the tuned circuits, used as the load impedances in these stages, varying with frequency. Tube gain characteristics change from tube to tube and from time to time as the tubes age. Changes in temperature and other environmental factors can also cause changes in amplifier gain. An effective way to cope with these variations is to sample the driving voltage of the power output amplifier with a rectifier, and to use the resulting d-c to control the gain of one or more amplifier stages in the exciter. This control voltage may be used to control the gain of amplifier stages using remote cutoff characteristic tubes similar to those used in receiver r-f amplifiers on which automatic gain control is used.

## 5. SUMMARY

The single-sideband exciter consists of three major sections: a single-sideband generator, a frequency translator, and a voltage power amplifier. In the sideband generator the audio input signal is processed by the use of amplification, amplitude limiting, and frequency energy distribution. The processed signal is then converted into an r-f sideband in a modulator. The desired signal or sideband is selected and the unwanted sideband suppressed, using the technique of frequency discrimination or phase discrimination. The desired sideband is then translated to the desired range of operating frequency by means of a frequency translation system. The desired output level is obtained through the use of linear amplifiers.