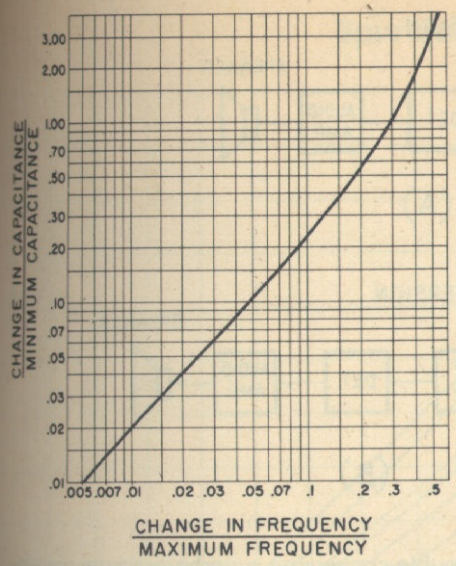

Fig. 8-11 – Minimum circuit capacitance required in the circuit of Fig. 8-10A as a function of the capacitance change and the frequency change. Note that *maximum* frequency and *minimum* capacitance are used.

The method shown at Fig. 8-10B makes use of capacitors in series. The tuning capacitor, C1, may have a maximum capacitance of 100 pF or more. The minimum capacitance is determined principally by the setting of C3, which usually has low capacitance, and the maximum capacitance by the setting of C2, which is in the order of 25 to 50 pF. This method is capable of close adjustment to practically any desired degree of bandspread. Either C2 or C3 must be adjusted for each band or separate preadjusted capacitors must be switched in.

The circuit at Fig. 8-10C also gives complete spread on each band. C1, the bandspread capacitor, may have any convenient value; 50 pF is satisfactory. C2 may be used for continuous frequency coverage ("general coverage") and as a bandsetting capacitor. The effective maximum-minimum capacitance ratio depends on C2 and the point at which C1 is tapped on the coil. The nearer the tap to the bottom of the coil, the greater the bandspread, and vice versa. For a given coil and tap, the bandspread will be greater if C2 is set at higher capacitance. C2 may be connected permanently across the individual inductor and preset, if desired. This requires a separate capacitor for each band, but eliminates the necessity for resetting C2 each time.

Ganged Tuning

The tuning capacitors of the several rf circuits may be coupled together mechanically and operated by a single control. However, this operating convenience involves more complicated construction, both electrically and mechanically. It becomes necessary to make the various circuits **track** – that is, tune to the same frequency for a given setting of the tuning control.

True tracking can be obtained only when the inductance, tuning capacitors, and circuit inductances and minimum and maximum capacitances are identical in all "ganged" stages. A small **trimmer** or **padding** capacitor may be connected across the coil, so that various minimum capacitances can be compensated. The use of the trimmer necessarily increases the minimum circuit capacitance but is a necessity for satisfactory tracking. Midget capacitors having maximum capacitances of 15 to 30 pF are commonly used.

The same methods are applied to bandspread circuits that must be tracked. The inductance can be trimmed by using a coil form with an adjustable brass (or copper) core. This core material will reduce the inductance of the coil, raising the resonant frequency of the circuit. Powdered-iron or ferrite core material can also be used, but will lower the resonant frequency of the tuned circuit because it increases the inductance of the coil. Ferrite and powdered-iron cores will raise the *Q* of the coil provided the core material is suitable for the frequency being used. Core material is now available for frequencies well into the vhf region.

The Superheterodyne

In a superheterodyne receiver, the frequency of the incoming signal is heterodyned to a new radio frequency, the **intermediate frequency** (abbreviated "i-f"), then amplified, and finally detected. The frequency is changed by modulating the output of a tunable oscillator (the high-frequency, or local oscillator) by the incoming signal in a mixer or **converter** stage to produce a side frequency equal to the intermediate frequency. The other side frequency is rejected by selective circuits. The audio-frequency signal is obtained at the detector. Code signals are made audible by heterodyne reception at the detector stage; this oscillator is called the "beat-frequency oscillator" or BFO. Block diagrams of typical single- and double-conversion receivers are shown in Fig. 8-12.

As a numerical example, assume that an intermediate frequency of 455 kHz is chosen and that the incoming signal is at 7000 kHz. Then the high-frequency oscillator frequency may be set to 7455 kHz in order that one side frequency (7455 minus 7000) will be at 455 kHz. The high-frequency oscillator could also be set to 6545 kHz and give the same difference frequency. To produce an audible code signal at the detector of, say, 1000 Hz, the heterodyning oscillator would be set to either 454 or 456 kHz.

The frequency-conversion process permits rf amplification at a relatively low frequency, the i-f. High selectivity and gain can be obtained at this frequency, and this selectivity and gain are constant. The separate oscillators can be designed for good stability and, since they are working at frequencies considerably removed from the signal frequencies, they are not normally "pulled" by the incoming signal.

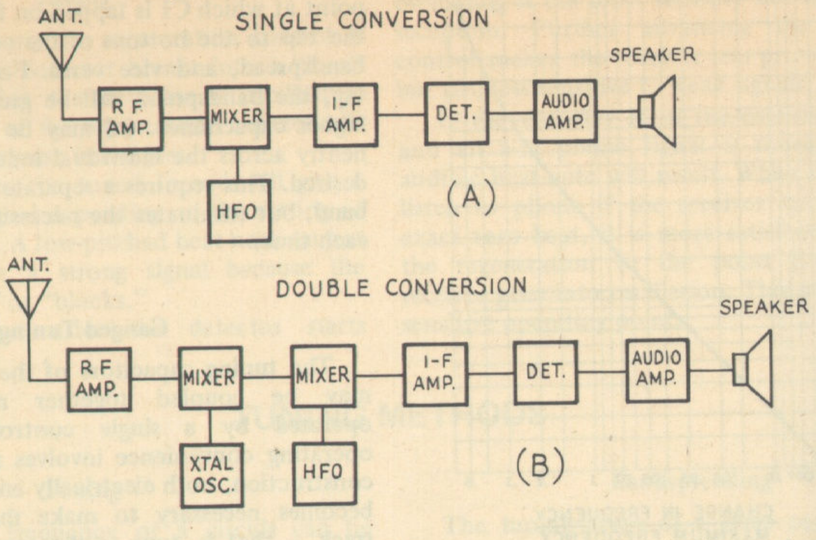

Fig. 8-12 — Block diagrams of a (A) single- and (B) double-conversion superheterodyne receiver.

Images

Each hf oscillator frequency will cause i-f response at two signal frequencies, one higher and one lower than the oscillator frequency. If the oscillator is set to 7455 kHz to tune to a 7000-kHz signal, for example, the receiver can respond also to a signal on 7910 kHz, which likewise gives a 455-kHz beat. The undesired signal is called the **image**. It can cause unnecessary interference if it isn't eliminated.

The radio-frequency circuits of the receiver (those used before the signal is heterodyned to the i-f) normally are tuned to the desired signal, so that the selectivity of the circuits reduces or eliminates the response to the image signal. The ratio of the receiver voltage output from the desired signal to that from the image is called the **signal-to-image ratio**, or **image ratio**.

The image ratio depends upon the selectivity of the rf tuned circuits preceding the mixer tube. Also, the higher the intermediate frequency, the higher the image ratio, since raising the i-f increases the frequency separation between the signal and the image and places the latter further away from the resonance peak of the signal-frequency input circuits.

The Double-Conversion Superheterodyne

At high and very-high frequencies it is difficult to secure an adequate image ratio when the intermediate frequency is of the order of 455 kHz. To reduce image response the signal frequently is converted first to a rather high (1500, 5000, or even 10,000 kHz) intermediate frequency, and then – sometimes after further amplification – converted to a lower i-f where higher adjacent-channel selectivity can be obtained. Such a receiver is called a **double-conversion superheterodyne** (Fig. 8-12B).

Other Spurious Responses

In addition to images, other signals to which the receiver is not tuned may be heard. Harmonics of the high-frequency oscillator may beat with signals far removed from the desired frequency to produce output at the intermediate frequency; such spurious responses can be reduced by adequate selectivity *before* the mixer stage, and by using sufficient shielding to prevent signal pickup by any means other than the antenna. When a strong signal is received, the harmonics generated by rectification in the detector may, by stray coupling, be introduced into the rf or mixer circuit and converted to the intermediate frequency, to go through the receiver in the same way as an ordinary signal. These "birdies" appear as a heterodyne beat on the desired signal, and are principally bothersome when the frequency of the incoming signal is not greatly different from the intermediate frequency. The cure is proper circuit isolation and shielding.

Harmonics of the beat oscillator also may be converted in similar fashion and amplified through the receiver; these responses can be reduced by shielding the beat oscillator and by careful mechanical design.

MIXER PRODUCTS

Additional spurious products are generated during the mixing process, and these products are the most troublesome of all, as it is difficult indeed to eliminate them unless the frequencies chosen for the mixing scheme are changed. The tables and chart given in Fig. 8-13 will aid in the choice of spurious-free frequency combinations, and they can be used to determine how receiver "birdies" are being generated. Only mixer products that fall close to the desired frequency are considered, as they are the ones that normally cause trouble. The horizontal axis of the chart is marked off in steps from 3 to 20, and the vertical axes from 0 to 14. These numbers can be taken to mean either kilohertz or megahertz, depending on the frequency range used. Both axes must use the same reference; one cannot be in kHz and the other in MHz.

Spurious Response Chart

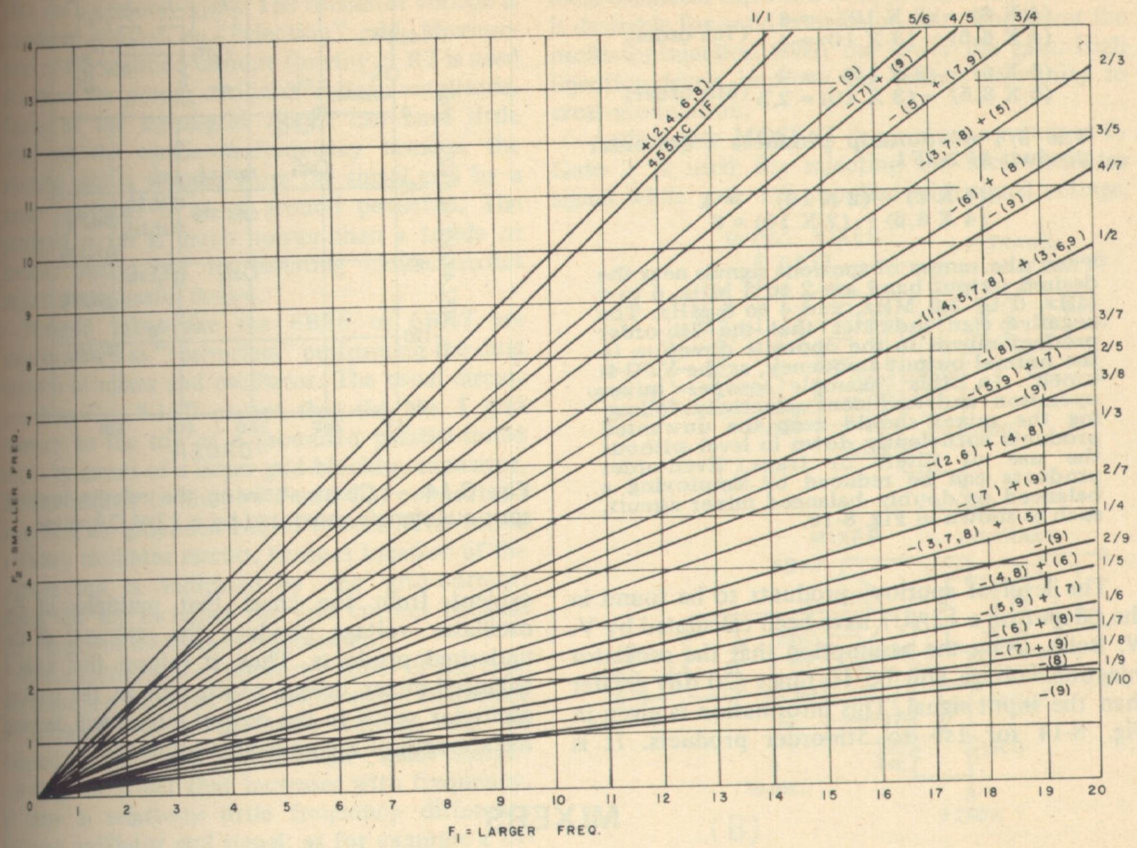

TABLE 1

F2 ~ F1

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	

TABLE 2

F2 ~ F1

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

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Fig. 8-13 — Chart to aid in the calculation of spurious frequencies generated during the mixing process.

To demonstrate the use of the chart, suppose an amateur wanted to mix a 6- to 6.5-MHz VFO output with a 10-MHz ssb signal to obtain output in the 80-meter band (the same problem as with a receiver that tunes 3.5 to 4 MHz, using a 6- to 6.5-MHz VFO to heterodyne to a 10-MHz i-f). Thus, F1 is 10 MHz and F2 is 6 to 6.5 MHz. Examination of the chart shows the intersection of these frequencies to be near the lines marked 2/3 and 3/5. In the case of the transmitter, difference (subtractive) mixing is to be used. The order of the products that will be close to the desired mixer output frequency is given on each line in parentheses. A plus sign in front of the parentheses indicates the product order in a sum (additive) mix, and a minus sign the order of a difference mix. For this example, the chart indicates the 3rd-, 7th-, and 8th-order products in a 2/3 relationship are going to be near the 80-meter band, plus the 6th-order product of the 3/5 relationship.

The exact frequencies of these products can be found with the help of the two small tables in Fig. 8-13. The product orders from 1 to 9 are given for all the product lines on the chart. The first digit of each group in a box is the harmonic of the lower frequency, F2, and the second digit is the harmonic of the larger frequency, F1. The dot indicates sum mixing and no dot indicates products in a difference mix. In the example, the chart shows that the 2/3 relationship will yield a 3rd-order product 2F2-F1, a 7th-order product 4F2-3F1, and an 8th-order product 5F2-3F1.

(Continued on next page)

(2 X 6) — 10 = 2
(2 X 6.5) — 10 = 3 (3rd order)

(4 X 6) — (3 X 10) =-6
(4 X 6.5) — (3 X 10) =-4 (7th order)

(5 X 6) — (3 X 10) = 0
(5 X 6.5) — (3 X 10) = 2.5 (8th order)

The 3/4 relationship produces a 6th-order product 4F2-2F1.

(4 X 6) — (2 X 10) = 4
(4 X 6.5) — (2 X 10) = 6

Thus, the ranges of spurious signals near the desired output band are 2 to 3 MHz, 6 to 4 MHz, 0 to 2.5 MHz, and 4 to 6 MHz. The negative sign indicates that the 7th-order product moves in the opposite direction to the normal output frequency, as the VFO is tuned. In this example proper mixer operation and sufficient selectivity following the mixer should keep the unwanted products sufficiently down in level without the use of filters or traps. Even-order products can be reduced by employing a balanced or doubly balanced mixer circuit, such as shown in Fig. 8-16.

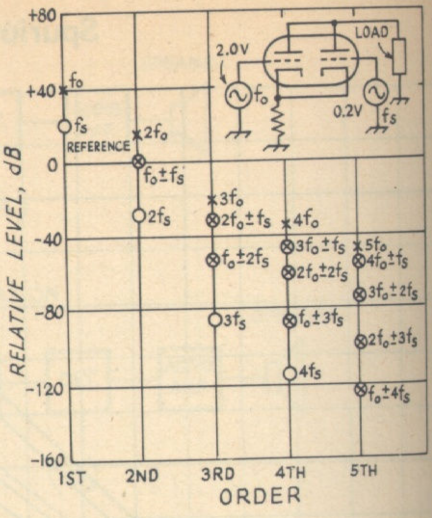

Fig. 8-14 — Chart showing the relative levels of spurious signals generated by a 12AU7A mixer.

The level of spurious products to be found in the output of a 12AU7 have been calculated by V. W. Bolie, using the assumption that the oscillator injection voltage will be 10 times (20 dB) greater than the input signal. This information is given in Fig. 8-14 for 1st- to 5th-order products. It is evident from the chart that multiples of the oscillator voltage produce the strongest of the undesired products. Thus, it follows that using a balanced-mixer design which reduces the level of oscillator signal in the output circuit will decrease the strength of the unwanted products.

MIXERS

A circuit tuned to the output frequency is placed in the plate circuit of the mixer, to offer a high impedance load for the output current that is developed. The signal- and oscillator-frequency voltages appearing in the plate circuit are rejected by the selectivity of this circuit. The output tuned circuit should have low impedance for these frequencies, a condition easily met if neither is close to the output frequency.

The **conversion efficiency** of the mixer is the ratio of output voltage from the plate circuit to rf signal voltage applied to the grid. High conversion efficiency is desirable. The device used as a mixer also should be low noise if a good signal-to-noise ratio is wanted, particularly if the mixer is the first active device in the receiver.

A change in oscillator frequency caused by tuning of the mixer grid circuit is called **pulling.** Pulling should be minimized, because the stability of the whole receiver or transmitter depends critically upon the stability of the hf oscillator. Pulling decreases with separation of the signal and hf-oscillator frequencies, being less with higher output frequencies. Another type of pulling is caused by lack of regulation in the power supply. Strong signals cause the voltage to change, which in turn shifts the oscillator frequency.

Circuits

If the mixer and high-frequency oscillator are separate tubes or transistors, the converter portion is called a "mixer." If the two are combined in one tube envelope (as is often done for reasons of economy or efficiency), the stage is called a "converter." In either case the function is the same.

Typical mixer circuits are shown in Figs. 8-15 and 8-16. The variations are chiefly in the way in which the oscillator voltage is introduced. In 8-15A, a pentode functions as a plate detector at the output frequency; the oscillator voltage is capacitance-coupled to the grid of the tube through C2. Inductive coupling may be used instead. The conversion gain and input selectivity generally are good, so long as the sum of the two voltages (signal and oscillator) impressed on the mixer grid does not exceed the grid bias. It is desirable to make the oscillator voltage as high as possible without exceeding this limitation. The oscillator power required is negligible. The circuit is a sensitive one and makes a good mixer, particularly with high-transconductance tubes like the 6CY5, 6EJ7 or 6U8A (pentode section). Triode tubes can be used as mixers in grid-injection circuits, but they are commonly used at 50 MHz and higher, where mixer noise may become a significant factor. The triode mixer has the lowest inherent noise, the pentode is next, and the multigrid converter tubes are the noisiest.

In the circuit of Fig. 8-15A the oscillator voltage could be introduced at the cathode rather than at the control grid. If this were done, C3 would have to be removed, and output from the oscillator would be coupled to the cathode of the mixer through a .001-µF capacitor. C2 would also be discarded. Generally, the same rules apply as when the tube uses grid injection.

It is difficult to avoid "pulling" in a triode or pentode mixer, and a pentagrid mixer tube provides much better isolation. A typical circuit is shown in Fig. 8-15B, and tubes like the 6BA7 or 6BE6 are commonly used. The oscillator voltage is introduced through an "injection" grid. Measurement of the rectified current flowing in R2 is used as a check for proper oscillator-voltage amplitude. Tuning of the signal-grid circuit can have little effect on the oscillator frequency because the injection grid is isolated from the signal grid by a screen grid that is at rf ground potential. The pentagrid mixer is much noisier than a triode or pentode mixer, but its isolating characteristics make it a very useful device.

Penagrid tubes like the 6BE6 or 6BA7 are sometimes used as "converters" performing the dual function of mixer and oscillator. The usual circuit resembles Fig. 8-15B except that the No. 1 grid connects to the top of a grounded parallel-tuned circuit by means of a larger grid-blocking capacitor, and the cathode (without R1 and C3) connects to a tap near the grounded end of the coil. This forms a Hartley oscillator circuit. Correct location of the cathode tap is indicated by the grid current; raising the tap increases the grid current because the strength of oscillation is increased.

The effectiveness of converter tubes of the type just described becomes less as the signal frequency is increased. Some oscillator voltage will be coupled to the signal grid through "space-charge" coupling, an effect that increases with frequency. If there is relatively little frequency difference between oscillator and signal, as for example a 14- or 28-MHz signal and an i-f of 455 kHz, this voltage can become considerable because the selectivity of the signal circuit will be unable to reject it. If the signal grid is not returned directly to ground, but instead is returned through a resistor or part of an agc system, considerable bias can be developed which will cut down the gain. For this reason, and to reduce image response, the i-f following the first converter of a receiver should be not less than 5 or 10 percent of the signal frequency.

Diodes, FETs, ICs, and bipolar transistors can be used as mixers. Examples are given in Figs. 8-15 and 8-16. A single-diode mixer is not shown here since its application is usually limited to circuits operating in the uhf region and higher. A discussion of diode mixers, plus a typical circuit, is given in Chapter 9.

Oscillator injection can be fed to the base or emitter elements of bipolar-transistor mixers, Fig. 8-15C. If emitter injection is used, the usual emitter bypass capacitor must be removed. Because the dynamic characteristics of bipolar transistors prevent them from handling high signal levels, FETs are usually preferred in mixer circuits, although they do not provide the high conversion gain available with bipolar mixers. FETs (Fig. 8-15D and E) have greater immunity to cross-modulation and overload than bipolar transistors, and offer nearly square-law performance. The circuit at D uses a junction FET, N-channel type, with oscillator injection being supplied to the source. The value of the source resistor should be adjusted to provide a bias of approximately 0.8 volts. This value offers a good compromise between conversion gain and good intermodulation-distortion characteristics. At this bias level a local-oscillator injection of approximately 1.5 volts is desirable for good conversion gain. The lower the oscillator-injection level, the lower the gain. High injection levels improve the mixers immunity to cross-modulation.

A dual-gate MOSFET is used as a mixer at E. Gate 2 is used for injecting the local-oscillator signal while gate 1 is supplied with signal voltage.

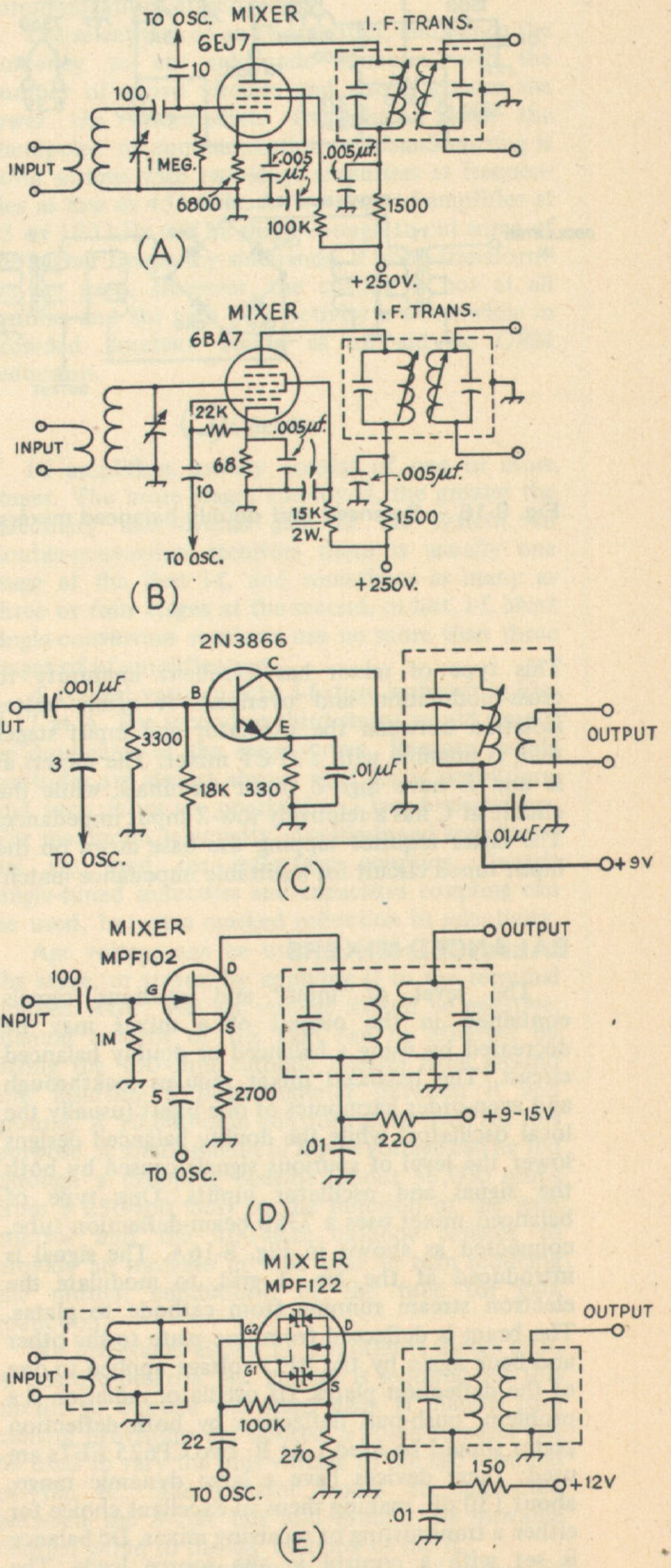

Fig. 8-15 – Typical single-ended mixer circuits.

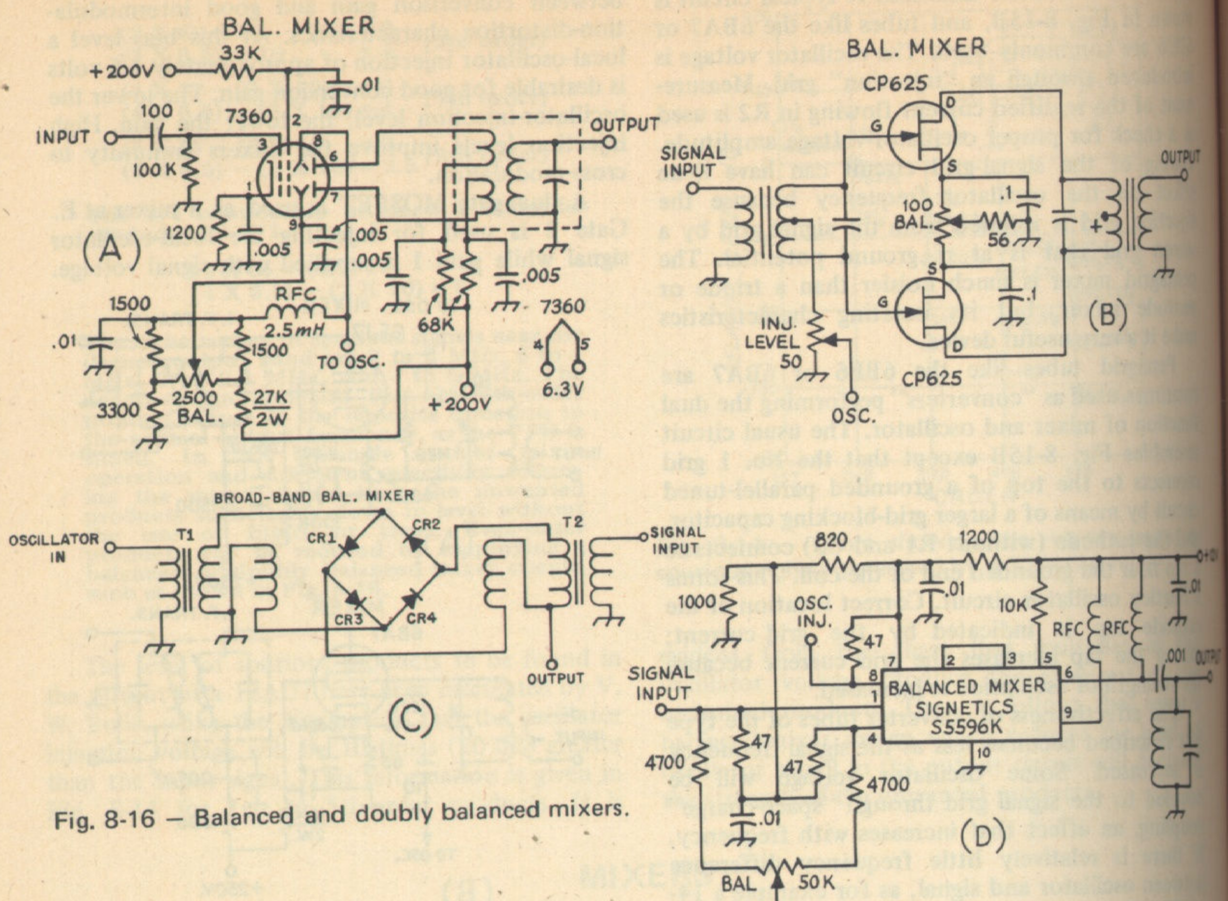

Fig. 8-16 — Balanced and doubly balanced mixers.

This type of mixer has excellent immunity to cross-modulation and overload. It offers better isolation between the oscillator and input stages than is possible with a JFET mixer. The mixers at D and E have high-Z input terminals, while the circuit at C has a relatively low-Z input impedance. The latter requires tapping the base down on the input tuned circuit for a suitable impedance match.

BALANCED MIXERS

The level of input and spurious signals contained in the output of a mixer may be decreased by using a balanced or doubly balanced circuit. The balanced mixer reduces leakthrough and even-order harmonics of one input (usually the local oscillator) while the doubly balanced designs lower the level of spurious signals caused by both the signal and oscillator inputs. One type of balanced mixer uses a 7360 beam-deflection tube, connected as shown in Fig. 8-16A. The signal is introduced at the No. 1 grid, to modulate the electron stream running from cathode to plates. The beam is deflected from one plate to the other and back again by the BFO voltage applied to one of the deflection plates. (If oscillator radiation is a problem, push-pull deflection by both deflection plates should be used.) At B, two CP625 FETs are used; these devices have a large dynamic range, about 130 dB, making them an excellent choice for either a transmitting or receiving mixer. Dc balance is set with a control in the source leads. The oscillator energy is introduced at the center tap of the input transformer.

In the circuit of Fig. 8-16C, hot-carrier diodes are employed as a broad-band balanced mixer. With careful winding of the toroid-core input and output transformers, the inherent balance of the mixer will provide 40- to 50-dB attenuation of the oscillator signal. The transformers, T1 and T2, having trifilar windings – using No. 32 enamel wire, 12 turns on a 1/2-inch core will provide operation on any frequency between 500 kHz and 100 MHz. Using Q3 cores the upper-frequency range can be extended to 300 MHz. CR1 to CR4, inc, comprise a matched quad of Hewlett-Packard HPA 5082-2805 diodes. Conversion loss in the mixer will be 6 to 8 dB.

Special doubly balanced mixer ICs are now available which can simplify circuit construction, as special balanced transformers are not required. Also, the ICs produce high conversion gain. A typical circuit using the Signetics S5596K is shown in Fig. 8-16D. The upper frequency limit of this device is approximately 130 MHz.

THE HIGH-FREQUENCY OSCILLATOR

Stability of the receiver is dependent chiefly upon the stability of the tunable hf oscillator, and particular care should be given this part of the receiver. The frequency of oscillation should be insensitive to mechanical shock and changes in voltage and loading. Thermal effects (slow change in frequency because of tube, transistor, or circuit heating) should be minimized. See Chapter 6 for sample circuits and construction details.