

**PRACTICAL
RF DESIGN MANUAL**

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that reason. A doubly balanced active or passive mixer is the usual choice of the designer in the interest of minimum spurious responses and good dynamic range. Information on mixer design and performance is given in Chapter 6.

Output from the mixer at $f_1 + f_2$ or $f_2 - f_1$ is routed through a broadband transformer to a set of switchable *LC* bandpass filters. They will remove most of the unwanted mixer output frequencies and contribute to purity of the waveform developed by the overall heterodyne generator.

Q_2 is shown as a Pierce oscillator for use with fundamental crystals below approximately 20 MHz. For higher orders of IF output from the mixer, we could make Q_2 an overtone type of oscillator to permit using much higher Q_2 injection frequencies at the mixer, Q_3 . For example, suppose we were interested in extracting a tunable IF of 48 to 50 MHz from Q_3 . Assume that Q_2 is an overtone oscillator that permits the crystal to oscillate on its third overtone. If we design the VFO to cover a 2-MHz range, we will be able to provide an IF of 48 to 50 MHz by selecting the correct crystal frequency at Y_1 . We will use the sum frequency of the two signal sources, so we will design the VFO to tune from 5 to 7 MHz. Therefore, Y_1 will have to provide output from Q_2 on 43 MHz. Thus, $5 + 43 = 48$ MHz, and $7 + 43 = 50$ MHz.

We can take a different approach in our design to cover the same IF range. Four third-overtone crystals could be employed at Q_2 to yield four 500-kHz switchable IF tuning ranges. If we adopted this technique, it would be necessary for the VFO to tune only 500 kHz rather than 2 MHz. It would also provide much greater bandwidth on an analog frequency-readout dial. This technique is the preferred one for many commercial receivers and transmitters operating in the high-frequency spectrum.

Mechanical switching (*SLA*, *SLB* and *SLC*) can be replaced by diode switching to simplify the mechanical layout of the equipment. A phase-locked loop (PLL) would be a good substitute for the VFO shown in Fig. 5.7, as it would offer improved frequency stability. We can see from the foregoing that the circuit shown is indeed basic and quite flexible with regard to design philosophy. It was used merely to demonstrate the principles of heterodyne frequency generation.

MIXERS, BALANCED MODULATORS AND DETECTORS

There is little difference between the functions of mixers, balanced modulators, and detectors in standard communications circuits. All three operate on the principle of combining two frequencies to produce a third one. The design goals are, therefore, quite similar. We are interested in having any of the three circuits perform with high dynamic range, minimum distortion, and good suppression or isolation between the various ports of the circuit device.

We have a number of choices open to us when choosing a particular mixer, modulator, or detector, and the best circuit for the application will be founded on cost effectiveness, performance standards, and available circuit space in the composite product. In all examples we can expect optimum performance from balanced circuits as opposed to single-ended circuits. We need to make a choice between passive and active versions of the three types of circuits, since passive devices yield a conversion loss, and active circuits usually ensure a conversion gain. It should be said, however, that an active mixer, modulator, or detector can exhibit unity gain, or even a conversion loss. This will depend upon how the device is used in the circuit, as we will learn later in the chapter. Figure 6.1 provides a relative comparison between the three circuits we shall examine in this discussion.

6.1. MIXERS

The most common use of mixers is found in receivers and heterodyne frequency generators in transmitters. We have our choice between

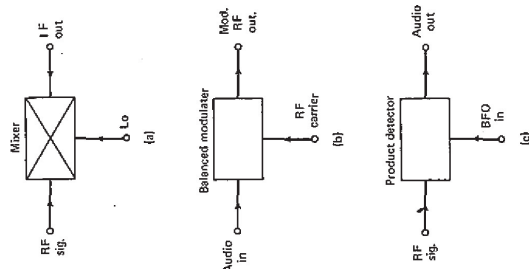


Figure 6.1 Comparison of a mixer, balanced modulator, and product detector.

passive (no operating voltage required) and active (operating voltage needed) devices. Furthermore, we can elect to use the most fundamental form of mixer, the single-ended variety, if high performance is not mandatory, and when equipment cost must be held within specified constraints. The simplest passive mixer is one that contains a single diode. Circuits of this type are sometimes used in UHF and microwave receivers, but are not attractive in circuits that operate below approximately 450 MHz. In the lower VHF region and at high and medium frequencies, it is more desirable to use two diodes in a singly balanced configuration or four diodes in a doubly balanced mixer (DBM). In all instances there will be a conversion loss that is usually of the order of -5 to -8 dB. Additionally, diode passive mixers require substantially greater local-oscillator (LO) power levels to provide the required amount of LO injection to the mixer, as referenced to an active mixer.

Objectively, we want the mixer to withstand strong applied RF signals without creating excessive distortion products. It should also be able to accommodate strong signals without producing cross-modula-

tion effects and gain compression. Gain compression is the point at which a 1-dB reduction in mixer output occurs when the RF input signal level is increased until that value of compression takes place. Another important consideration is the mixer noise figure (NF). This is especially important above, say, 15 MHz, where the atmospheric noise is often lower in amplitude than is the receiver front-end noise. Mixers are much noisier in mixer service than they are as RF amplifiers when the same device is used in each application. When the mixer noise becomes too great for the operating frequency, we can reduce the effective receiver NF by using a low-noise RF amplifier ahead of the mixer. Its gain must exceed that of the mixer if an improvement is to be realized. Also, the local oscillator and its associated amplifiers must be as spectrally pure as possible in terms of noise before the LO energy is injected into the mixer. Excessive noise output from the LO system will effectively increase the mixer noise figure. Eliminating this noise is an important design problem if we are to strive for high receiver performance. The penalty for using a preamplifier is observed in reduced mixer dynamic range, owing to the increased RF signal level that is applied to the mixer input port. It can be seen from this discussion that all manner of design trade-offs accompany the implementation of a mixer.

Still another important mixer parameter is the intermodulation distortion (IMD) products generated within the device. The IMD should be as low as possible to ensure high dynamic range. IMD is manifested as additional unwanted receiver responses to one or more strong signals in the receiver passband. The effect is one of having a single incoming signal appear in several places as the receiver is tuned away from the signal that is causing the IMD responses. The IMD products are numerically related to the interfering signal and another strong signal nearby in the receiver passband. The IMD characteristics of a given mixer can be determined in laboratory tests by applying two RF signals at the mixer input (two-tone test) and observing the third-order distortion products at the mixer output. A block diagram of a suitable setup for mixer evaluation is shown in Fig. 6.2. A spectrum analyzer, two signal sources, a LO source, step attenuators, a combiner, and post-mixer amplifier and lattice filter are required. The post-mixer amplifier must be as good as or better than the mixer under test (MUT) in terms of IMD. A CATV bipolar transistor (2N5109) meets the requirement easily when operated in a linear broadband configuration.

Port-to-port signal isolation is a vital mixer consideration. That is, we do not want the LO energy to appear at the RF or IF ports of a mixer in sufficient magnitude to create additional frequencies through unwanted mixing action. Doubly balanced mixers offer the best solution to port isolation. Singly balanced mixers are the second choice, and single-ended mixers are the worst we might select for resolving the problem.

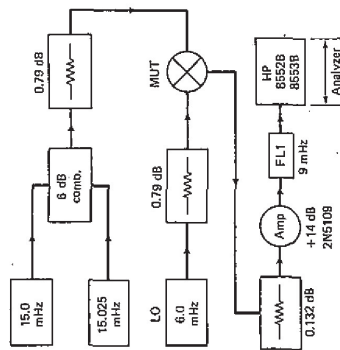


Figure 6.2 Block diagram showing the test setup for measuring mixer dynamic range.

Maximum mixer conversion gain will occur only when the input and output of the mixer are well matched to the characteristic impedances of the source and load. Intentional mismatch is often applied to reduce the conversion gain and to enhance the IMD characteristics by operating the output of an active mixer at low impedance levels. This technique reduces the ac voltage swing and helps to keep the collector or drain of a mixer transistor within a more linear operating range.

6.1.1 Single-Ended Mixers

The practicality of active single-ended mixers is realized in the design of inexpensive receivers, such as the pocket-sized AM band transistor radio. A bipolar-transistor mixer is capable of delivering conversion gains as great as 30 dB under well-matched conditions and careful biasing. Unfortunately, the dynamic range of such a mixer is very poor, which helps to explain the unsatisfactory strong-signal performance of most imported "pocket radios." But this type of mixer contributes to a reduction in receiver stages with respect to overall receiver gain. RF amplifiers are seldom used in receivers of this general variety.

Figure 6.3 contains the circuit of a typical single-ended bipolar mixer. Approximate values are listed for the components and operating voltages for best performance. A mixer is necessarily a nonlinear device and would operate, ideally, with a square-law response. Therefore, the

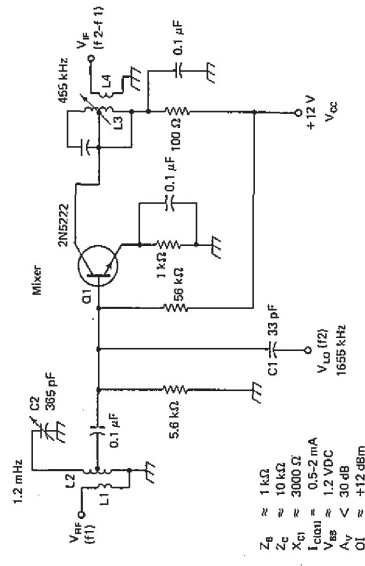


Figure 6.3 Practical circuit for a bipolar-transistor mixer.

forward bias on Q1 of Fig. 6.3 is held to a low value. The V_{BE} used will aid conversion gain and enhance the weak-signal response of the mixer. The base of Q1 is tapped toward the grounded end of L2 to effect an impedance match between the mixer input and the antenna. Typically, the input impedance of this kind of mixer is 1000 Ω .

The collector could be connected directly to the top end of L3, since the characteristic impedance of the collector will be on the order of 10,000 Ω with the biasing specified in Fig. 6.3. By tapping the collector down on the tuned circuit we can control the conversion gain (reduce it) to a desired value. Also, as the collector is tapped down on the tuned circuit, we are minimizing the loading effects on the tuned circuit, thereby elevating the Q. This provides increased selectivity at the mixer output. This mixer requires very low injection power from the LO. Since we are applying 0.5 V rms of LO signal across the base-emitter port, the power requirements will be minimal. C1 should have fairly high reactance at the signal frequency to prevent undue loading of the input tuned circuit by the LO circuitry. Light coupling via C1 will also help reduce oscillator pulling when C2 is adjusted.

Mixer distortion (IMD) can be defined either in terms of the IMD products being a specified number of decibels below the desired output signal level (IF) or by means of the third-order output intercept number. The intercept point is an imaginary point established when a 10-dB increase in the two input test tones causes the desired mixer output

products to increase by 10 dB, but the third-order IMD products increase by 80 dB. In other words, if we had a mixer that was without a gain-compression trait, we could find a point at which the level of the desired output product would be equivalent to that of the third-order IMD product. We would define this as the third-order intercept point, the position on a set of curves where the desired output-product curve intersected with the curve of the third-order product. This is shown in Fig. 6.4. The curves in this hypothetical example converge at the +20

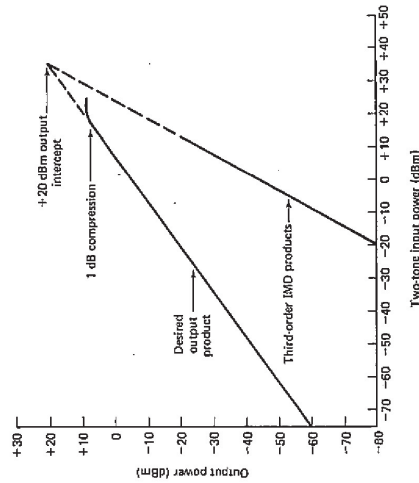


Figure 6.4 Curves that show the third-order output intercept point of a mixer.

dBm output intercept point. It becomes apparent that the greater the output intercept number, the higher is the dynamic range of the mixer. In the case of the circuit of Fig. 6.3 the output intercept is quite low, +12 dBm. Strong mixers yield numbers as great as +45 dBm. A typical number for a medium-quality receiver would be on the order of +25 dBm.

In terms of mixer performance our concern is for the third-order input intercept characteristic, even though it is related directly to the output intercept number. The input intercept can be obtained by subtracting the conversion gain of the mixer from the output. Hence, if the conversion gain were 10 dB and the output intercept were +35 dBm,

the input intercept would be +25 dBm. It can be seen from this that it is important to minimize the mixer conversion gain in the interest of elevating the input-intercept characteristic. Frequently, this is done in an active mixer by using broadband techniques and introducing intentional mismatches at the input and output ports. Irrespective of the mixer input intercept, the final determination of receiver performance is based on the receiver input intercept number. This dictates that care must be given to the design of the input circuitry, inclusive of the RF amplifier that precedes the mixer, in the event that such a stage is used.

A JFET is capable of better performance in a single-ended mixer, compared to a bipolar transistor. Figure 6.5 illustrates how we might

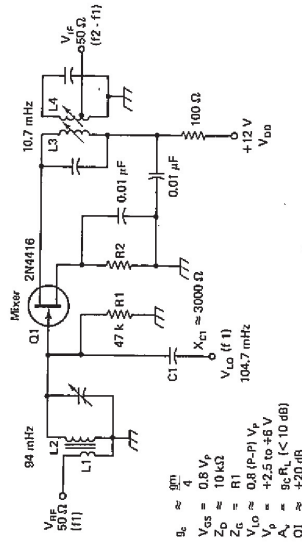


Figure 6.5 Practical JFET single-ended mixer.

use a 2N4416 or similar FET as a mixer. Conversion transconductance (g_c) will be approximately 0.25 the g_m of the same device in amplifier service. Hence, if the FET was rated at 5000 μ S as an amplifier, the conversion transconductance would be roughly equal to 5000/4, or 1250 μ S. Once we know this number we can approximate the conversion gain by

$$A_V = g_c R_L$$

where A_V is the voltage gain in decibels, g_c is the conversion transconductance in siemens, and R_L is the drain load in ohms. Therefore, if we had a 1250 μ S (0.0125 S) g_c and an effective mixer drain load of 1000 Ω , the gain would be

$$A_V = 0.0125 \times 1000 = 12.5 \text{ dB}$$

We will impair mixer performance, however, if we attempt to elevate the conversion gain by increasing the drain load impedance. In the

circuit of Fig. 6.5 we would be prudent to tap the FET drain toward the V_{DD} end of L_3 to force the drain down to a lower impedance than it sees in the circuit, as shown. Typically, the drain impedance will be approximately 10 k Ω with a circuit such as that of Fig. 6.5. This technique will reduce the peak drain-voltage swing, thereby reducing the change in junction capacitance. The latter, which introduces a *varactor effect*, results in the generation of harmonic currents.

Source resistor R_2 is selected to yield a gate-source dc potential that is 0.8 the pinchoff voltage (V_p) of the FET. In practice, this will be a somewhat arbitrary number, as the manufacturers' data sheets are not specific. V_p is not listed in most of the literature, but we can use the more common parameter, $V_{GS(off)}$, which is of equal magnitude to V_p , but of opposite polarity. For a 2N4416 the spread is listed as -2.5 to -6 V, equating to a V_p of +2.5 to +6 V. Arbitrarily, we can assume a midrange value for V_p , accepting in our design example a voltage of 4.25. Therefore, R_2 will be chosen to yield a V_{GS} of 0.8×4.25 , or 3.4 V. Because the listed $V_{GS(off)}$ values are rather nebulous, we will fare much better in the final analysis by making empirical adjustments to the V_{GS} while the mixer is in operation. A compromise between IMD and conversion gain must be made when establishing the operating conditions. Ideally, the g_m should be held below 10 dB in the interest of good mixer performance.

Under the foregoing guidelines the LO injection should be approximately 0.8 p-p the V_p value. An output intercept of +20 dBm is typical for the mixer of Fig. 6.5, although a theoretical value of +30 dBm exists for FETs such as the U310 in a fully optimized circuit. Since gate injection of the LO is suggested in our circuit example, C1 should follow the rule set forth for the circuit in Fig. 6.3. Source injection can be used in this style of circuit, but substantially more LO power will be required and mixer instability may result.

Dual-gate MOSFETs provide comparable performance to JFETs in mixer circuits. They offer the advantage of having a pair of gates rather than a single gate, thus making it easy to introduce the LO and RF signals at separate ports. Normally, the LO energy is applied to gate 2 and the RF input signal is routed to gate 1, as demonstrated in Fig. 6.6. This type of FET is rather fragile in terms of excessive gate voltage, compared to a JFET, but the isolation between the two gates is advantageous toward minimizing LO pulling effects and interaction between the LO output circuitry and the RF signal input circuit. Some manufacturers rate the gate-to-gate isolation as high as 50 dB, but in a practical circuit that magnitude of signal separation would be difficult to achieve. A 25- to 30-dB isolation value is more common, owing to stray coupling external to the MOSFET.

Gate 2 can be biased separately by means of a resistive voltage divider connected to the V_{DD} line. Comparable performance can be ob-

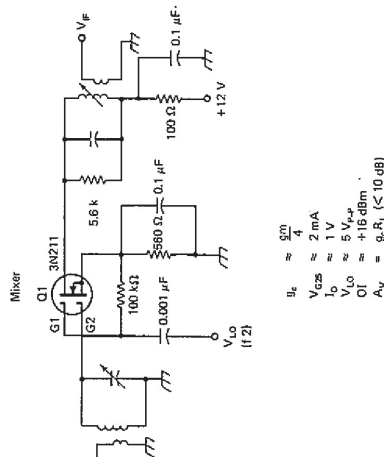


Figure 6.6 Improved single-ended mixer performance can be realized by using a dual-gate MOSFET, which permits two-port injection.

tained, however, by strapping gate 2 to the source through a 100-k Ω resistor, as seen in Fig. 6.6. With a 560- Ω source-bias resistor, an effective gate 2 potential of 1 V will result. Under these conditions, a peak-to-peak LO injection of 5 V will enable the mixer to have reasonable conversion gain and acceptable IMD characteristics. Optimum third-order output intercept for a 3N211 was noted during laboratory tests when V_{GS} was set at 4.2 V, and with an 8-V p-p LO injection level. This resulted in a third-order output intercept of +16 dBm. Lowering the drain load impedance of Q1 in Fig. 6.6 would have aided the output intercept number. The 56 k Ω resistor across the output tuned circuit pulls the drain down to an impedance that yields better IMD performance. In a test circuit that contained two 3N211 transistors in a singly balanced mixer, and with broadband coupling transformers at the input and output of the mixer, a third-order output intercept of +20 dBm was observed. The gates and drains were operated at a 200- Ω impedance. Conversion gain was approximately 6 dB when 4.2 V of V_{GS} was applied, and with an 8-V p-p LO injection level. A 560- Ω resistor was used in each source return.

6.1.2 Balanced Mixers

Balanced mixers offer better port-to-port signal isolation than is possible with single-ended mixers. A comparison of the output products

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from single-ended, singly balanced and doubly balanced mixers is presented in Table 6.1. It becomes immediately apparent that the doubly

TABLE 6.1 Comparison of Output Products from Mixers

(N)	Single-Ended Mixer				
	f_o	$2f_o$	$3f_o$	$4f_o$	$5f_o$
f_s	$f_o \pm f_s$	$2f_o \pm f_s$	$3f_o \pm f_s$	$4f_o \pm f_s$	$5f_o \pm f_s$
$2f_s$	$2f_o \pm f_o$	$2f_o \pm 2f_o$	$3f_o \pm 2f_o$	$4f_o \pm 2f_o$	$5f_o \pm 2f_o$
$3f_s$	$3f_o \pm f_o$	$3f_o \pm 2f_o$	$3f_o \pm 3f_o$	$4f_o \pm 3f_o$	$5f_o \pm 3f_o$
$4f_s$	$4f_o \pm f_o$	$4f_o \pm 2f_o$	$4f_o \pm 3f_o$	$4f_o \pm 4f_o$	$5f_o \pm 4f_o$
$5f_s$	$5f_o \pm f_o$	$5f_o \pm 2f_o$	$5f_o \pm 3f_o$	$5f_o \pm 4f_o$	$5f_o \pm 5f_o$
(0.5 N)	Singly Balanced Mixer				
	f_o	$2f_o$	$3f_o$	$4f_o$	$5f_o$
f_s	$f_o \pm f_s$	$2f_o \pm f_s$	$3f_o \pm f_s$	$4f_o \pm f_s$	$5f_o \pm f_s$
$2f_s$	$2f_o \pm f_o$	$2f_o \pm 2f_o$	$3f_o \pm 2f_o$	$4f_o \pm 2f_o$	$5f_o \pm 2f_o$
$3f_s$	$3f_o \pm f_o$	$3f_o \pm 2f_o$	$3f_o \pm 3f_o$	$4f_o \pm 3f_o$	$5f_o \pm 3f_o$
$4f_s$	$4f_o \pm f_o$	$4f_o \pm 2f_o$	$4f_o \pm 3f_o$	$4f_o \pm 4f_o$	$5f_o \pm 4f_o$
$5f_s$	$5f_o \pm f_o$	$5f_o \pm 2f_o$	$5f_o \pm 3f_o$	$5f_o \pm 4f_o$	$5f_o \pm 5f_o$
(0.25 N)	Doubly Balanced Mixer				
	f_o	$2f_o$	$3f_o$	$4f_o$	$5f_o$
f_s	$f_o \pm f_s$	$2f_o \pm f_s$	$3f_o \pm f_s$	$4f_o \pm f_s$	$5f_o \pm f_s$
$2f_s$	$2f_o \pm f_o$	$2f_o \pm 2f_o$	$3f_o \pm 2f_o$	$4f_o \pm 2f_o$	$5f_o \pm 2f_o$
$3f_s$	$3f_o \pm f_o$	$3f_o \pm 2f_o$	$3f_o \pm 3f_o$	$4f_o \pm 3f_o$	$5f_o \pm 3f_o$
$4f_s$	$4f_o \pm f_o$	$4f_o \pm 2f_o$	$4f_o \pm 3f_o$	$4f_o \pm 4f_o$	$5f_o \pm 4f_o$
$5f_s$	$5f_o \pm f_o$	$5f_o \pm 2f_o$	$5f_o \pm 3f_o$	$5f_o \pm 4f_o$	$5f_o \pm 5f_o$

LO = f_s , signal frequency = f_o
 $2f_s \pm f_o$ = third-order product
 $3f_s \pm 3f_o$ = sixth-order product, etc.
 N = number of mixer products

balanced mixer is the stellar performer in terms of isolation and product suppression. It is, thus, the mixer preferred by designers of high-performance equipment.

An example of properly designed JFET singly balanced mixer is seen in Fig. 6.7. It is similar to a circuit suggested by E. Oxner of Siliconix in *Application Note AN72-1*. Dynamic balance is assured through the use of a U430 dual-FET unit. R1 is selected to give a V_{gs} of 0.8 V, the pinch-off voltage, which will be on the order of 2 V, allowing for the published spread of -1 to -4 V, $V_{gs(0)}$. Symmetrical feed is used at the mixer input by means of T1, T2, and T3, providing a 180° phase dif-

Sec. 6.1 Mixers

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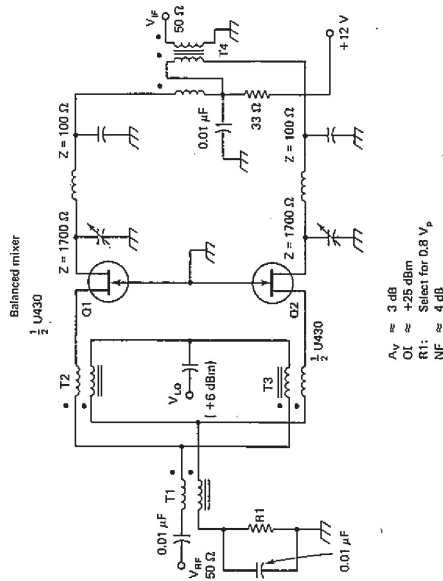


Figure 6.7 Dual FET balanced mixer using a Siliconix U430 device.

differential between the sources of Q1 and Q2. The transformers are all wound on 125 μ i ferrite toroid cores, 0.37-in. diameter. T1, T2, and T3 contain bifilar windings of 15 turns of number 26 enameled wire. T4 is wound on a 0.5-in. diameter ferrite core ($\mu_i = 125$), trifilar fashion, with 15 turns of number 26 enameled wire. These transformer dimensions are suitable for use from 3 to 30 MHz.

Low-pass matching networks are used in the drains of the FETs to lower the drain impedance to 1700 Ω . They are structured to transform the impedance from 1700 ohms to 100 Ω . The 4 : 1 impedance ratio of T4 matches the mixer to a 50- Ω load. Best performance results when V_{LO} is 0.8 p-p $V_{gs(0)}$.

A singly balanced diode mixer is presented in Fig. 6.8. It suffers the same limitations found in singly balanced active mixers, and in addition it yields a conversion loss of approximately 6 to 8 dB. T1 is a trifilar-wound toroidal broadband transformer. T2 is also a broadband transformer, which is used to provide a step-up transformation to the mixer load. The turns ratio is chosen accordingly. Matched silicon switching diodes are satisfactory in this circuit, but hot-carrier diodes will offer improved performance.

A quad of matched silicon or hot-carrier diodes can be used to

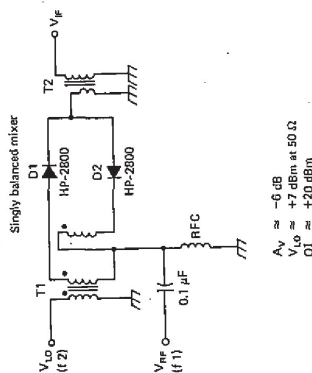


Figure 6.8 Singly balanced two-diode mixer using broadband transformers.

create a doubly balanced diode-ring mixer of the type shown schematically in Fig. 6.9. The circuit, minus T_1 and T_4 , is typical of the manufactured DBM mixer modules found on the industrial market. Well-designed mixers of this kind offer excellent broadband characteristics, with effective bandwidths of more than 100 MHz. A typical DBM might be rated from 500 kHz to 500 MHz. Medium-level DBMs require an LO power of approximately +7 dBm, whereas the high-level DBMs call for LO powers of +15 dBm or greater. Conversion loss is comparable to that of the mixer in Fig. 6.8, being roughly 6 dB.

Transformers T_1 and T_4 of Fig. 6.9 can be added to serve as baluns. This aids the overall balance of the mixer by maintaining sym-

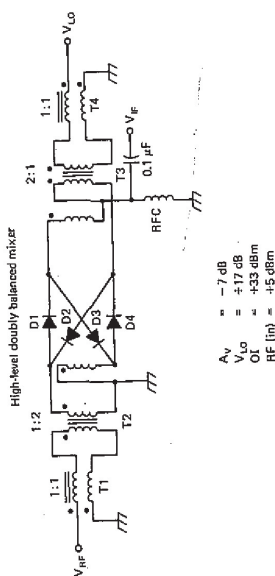


Figure 6.9 High dynamic range and good port-to-port isolation can be had from a doubly balanced diode-ring mixer.

metry at the input and output ports of the circuitry between the input of T_2 and the output of T_3 . T_1 and T_2 are bifilar wound, and trifilar windings are laid on the cores of T_2 and T_3 . Output intercept for this type of mixer (high level) is typically +33 dBm. Best performance results when the mixer is terminated in 50 Ω by means of a diplexer.

An example of a diplexed DBM is seen in Fig. 6.10. A high-pass network consisting of L_1 , C_1 , and C_2 is connected to the IF port of the

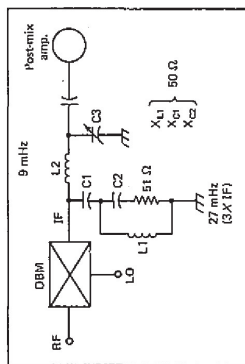


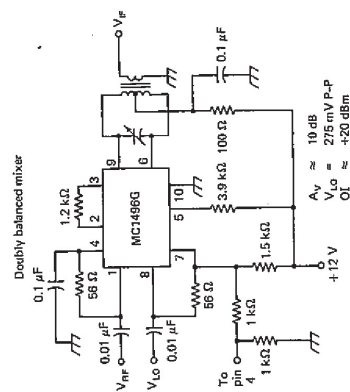
Figure 6.10 A diplexer can be added to a DBM for the purpose of presenting a 50- Ω termination. This improves mixer IMD.

mixer. It is designed for a cutoff frequency of three times the IF. A Q_L of 1 is satisfactory; hence we can use an X_L and X_C of 51 for the resistive termination of 51 Ω . A simple low-pass L network is used between the IF port of the DBM and the post-mixer amplifier to provide an impedance match to 50 Ω . The transformation ratio will be dependent upon the input impedance of the amplifier that succeeds the mixer. Improvements in mixer IMD of 2 to 4 dB have been observed by the addition of the diplexer.

6.1.3 IC Mixers

We could spend countless hours discussing the various types of IC mixers and their respective virtues. Such a treatment is beyond the scope of this text. Therefore, we will examine two of the more common IC mixers for illustrative purposes.

An advantage found in the application of balanced mixers that use ICs is the inherent balance and tracking with temperature that prevails. This is because the bipolar transistors and resistors that are within the IC were all formed at the same time on a common slice of silicon (substrate). This yields transistors with nearly identical dynamic characteristics. Also, when there are temperature excursions of the operating



(a)

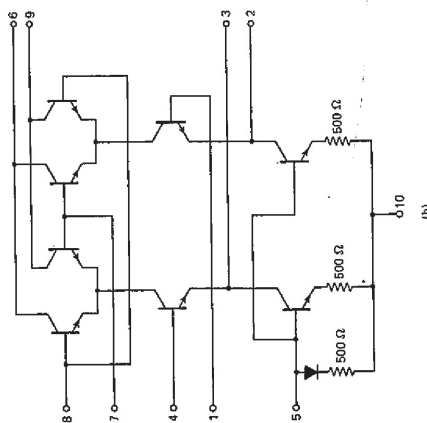


Figure 6.12 (a) Doubly balanced active mixer with a Motorola MC1496G IC; (b) the inner workings of the chip.

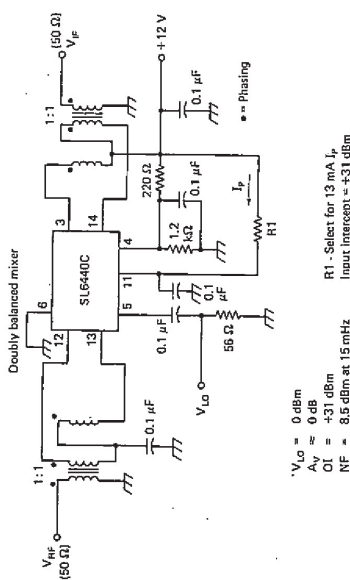


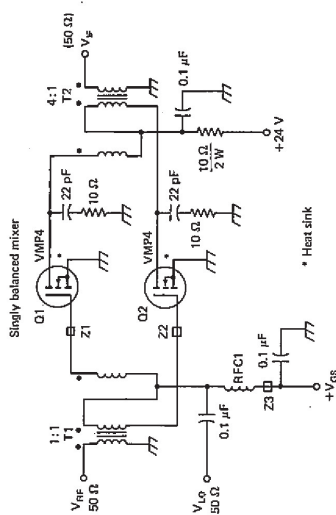
Figure 6.13 A high-level doubly balanced mixer can be obtained by using the Plessey SL6440C IC. Excellent dynamic range is possible with this circuit.

to be 8.5 dB. Plessey rates it at 11 dB at a signal frequency of 100 MHz, the same frequency at which the -1-dB gain was determined.

In the circuit of Fig. 6.13, R_1 is chosen to permit the desired value of I_p . In the author's tests it was noted that an I_p of 13 mA resulted in optimum mixer performance with an LO level of 0 dBm and an RF signal input of -5 dBm. Under these conditions the LO isolation at the mixer output was 30 dB. The $2f$ LO energy was measured at -75 dB.

If we desire a very strong mixer, we might consider using VMOS power FETs as the active devices. Once again there is the matter of cost-effectiveness to consider, plus the physical bulk of the mixer module. The power FETs are substantially larger than ICs or small-signal devices, and because of the power they dissipate it is necessary to employ heat sinks. Moreover, the power consumption of a VMOS mixer is rather high, placing still another restriction on the design. However, the performance of this variety of mixer offers many advantages, the most significant being high dynamic range if the conversion gain is minimized.

A practical circuit for a high-level, singly balanced VMOS power FET mixer is shown in Fig. 6.14. VHF transistors are used in this laboratory test model, primarily to take advantage of the strip-line packaging format, which lends itself well to heat sinking. Some of the less expensive VMOS units would no doubt yield similar performance, such as the Siliconix VN66AKs, but the TO-5 package would impose restrictions



$I_{cc} = 100 \text{ mA}$
 $V_{LO} = +16 \text{ dBm}$
 $V_{GS} = +2 \text{ V}$
 $A_v = +15 \text{ dB}$
 $Q1 = +43 \text{ dBm}$
 $NF = 5.5 \text{ dB at } 15 \text{ MHz}$

Figure 6.14 Exceptional dynamic range can be obtained when using VMO8 power FETs in a singly or doubly balanced high-level mixer. This circuit yields an output intercept of +43 dBm.

with concern to heat sinking of adequate magnitude. The TO-3 equivalent to the VN66AK would probably be a good low-cost alternative to the VMP4s of Fig. 6.14.

In the test circuit we find broadband balun transformers used at the mixer input and output. This forces a 50-Ω gate-to-gate impedance when the generator impedance is 50 Ω. We should keep in mind that, no matter how spectacular the mixer output intercept number, the input intercept is governed by the conversion gain (or loss) of the mixer. Therefore, the mixer gain should be as low as possible, consistent with the design objectives. It is suggested that the $T1$ matching transformer be configured to provide a 50-Ω input impedance (forced through intentional mismatch). We might even wind the transformer to decrease the effective impedance to some value much lower than 50 Ω. Ideally, the mixer gain should be on the order of unity, thereby yielding an input intercept of +43 dBm. $Z1$ and $Z2$ are necessary in order to damp a VHF parasitic oscillation that became manifest during the tests. $Z3$ aids stability by lowering the Q of R.F.C1.

An output intercept of +38 dBm was obtained with a forward gate voltage of 2, an LO injection power of +16 dBm, and a drain current

(both transistors) of 160 mA. Under these test conditions an RF signal level of -1 dBm was applied. Similar high performance was observed with a gate voltage of +1.5 and a drain current of less than 100 mA, using the same LO and RF signal powers. LO suppression at the mixer output was 36 dB. The one parameter that may cause concern to us is the conversion gain. It can be as great as +20 dB under some operating conditions. This requires an attenuator pad at the mixer output to protect post-mixer circuitry.

6.2. AM DETECTORS

AM detectors are the least complicated of the various demodulators used in communications circuits. Many receivers, for example, rely on

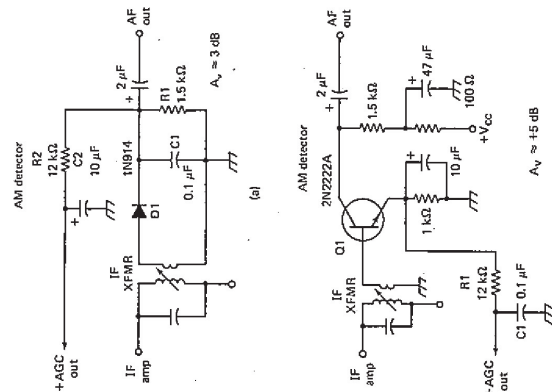


Figure 6.15 (a) One diode is used in this simple AM detector; (b) this circuit utilizes a bipolar transistor as an AM detector to provide a small conversion gain.