RF mixers

Joe Carr explains the importance of choosing the right rf mixer in all applications up to microwave.

My last two articles have developed the basic theory behind RF mixers, and introduced a simple mixer circuits. This month I take a look at higher performance mixer circuitry.

A mosfet double-balanced active mixer[1] is shown in **Fig. 1**. The dual-gate mixer is ideal for this type of application, but the fets need careful selection.

Instead of the *3N211* mosfets shown, *40673*s could be used. These have the advantage of being relatively insensitive to casual electrostatic damage during handling, and are low cost. In addition, in a circuit such as this, the *40673* can provide between 15 and 20dB of conversion gain.

However, this gain is not without cost. The devices are relatively easily overdriven in the presence of large RF input signals. When this occurs the advantages of the device evaporate in increased intermodulation products and degraded noise performance.

The same circuit using *3N211* devices, or equivalent, will produce less conversion gain, of about –5 dB, but better overall performance. With local-oscillator injection of 8V peak-to-peak, and a 10dBm RF input signal, this circuit will exhibit a respectable third-order intercept point of +17dBm.

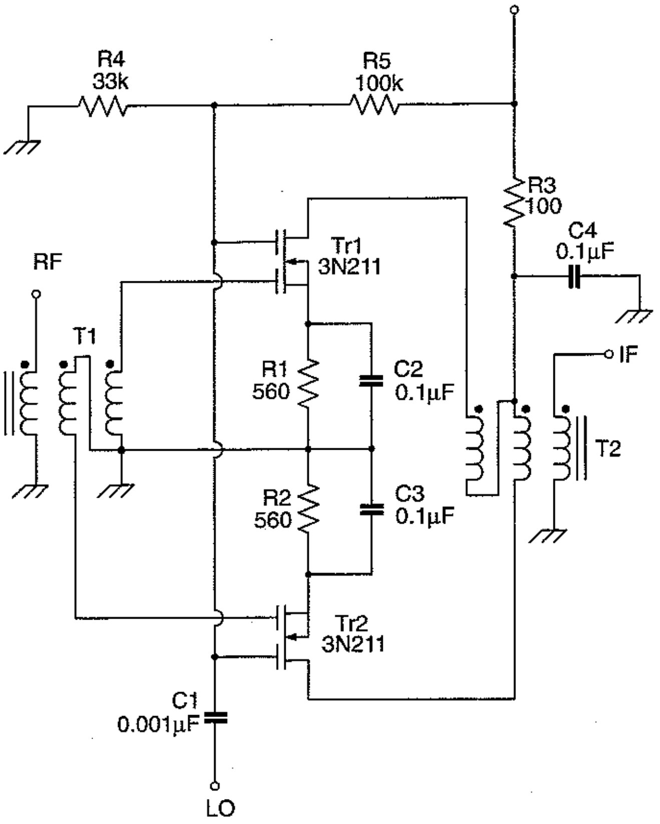

Fig. 1. The dual-gate mixer is useful, but the fets need to be chosen carefully for best performance.

Bipolar alternative useful to 500MHz

An active double-balanced mixer based on n-p-n bipolar transistors[2] is shown in **Fig. 2**. This circuit is usable to frequencies around 500MHz.

Normally, the use of non-IC transistors in a circuit such as this normally requires matching of the transistors for best performance. That need is overcome by using a bit of degenerative feedback for $Tr_{1,2}$ in the form of unbypassed emitter resistors $R_{3,4}$.

The base circuits are driven with the LO signal from a balun transformer, T_1 in a manner similar to the earlier junction-fet circuit. The output transformer, however, is rather interesting.

It consists of four windings, correctly phased, with the IF being taken from the junction of two of the windings. The RF signal is applied to the remaining two windings of the transformer.

This mixer exhibits a third-order intercept of +33dBm, with a conversion loss of 6dB, and only 15 to 17dBm of LO drive power.

Benefits of quad mos and junction fets

Although using bipolar transistors can result in an active double-balanced mixer with a high third-order intercept point, or TOIP, there is a trend towards using junction and mos fets.

Typical designs use four active devices. This approach is made easier by the fact that many IC makers are producing RF mos and junction fet products that include four matched devices in the same package.

Figure 3 shows a mixer circuit based on the use of four junction-fet devices ($Tr_{1\text{-}4}$). These transistors are arranged such that the source terminals of $Tr_{1\text{-}2}$ are tied together, as are the source terminals of $Tr_{3,4}$.

The source-pair terminals receive the RF input signal from transformer T_2. The gates of these transistors are con-

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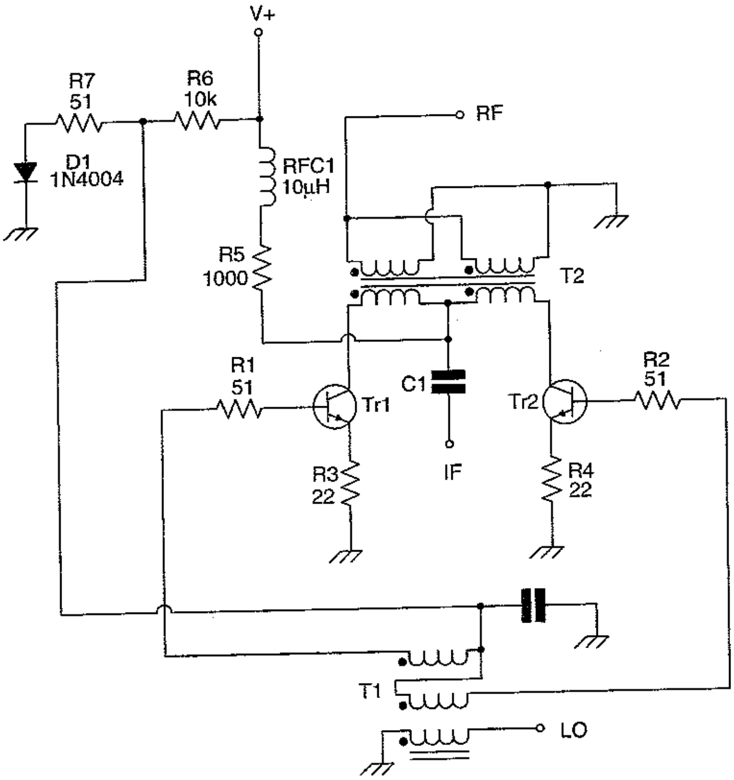


Fig. 2. Bipolar mixers such as this are useful to 500MHz. Normally, discrete transistors in a circuit like this would need matching for best performance. Adding a little degenerative feedback gets round this problem.

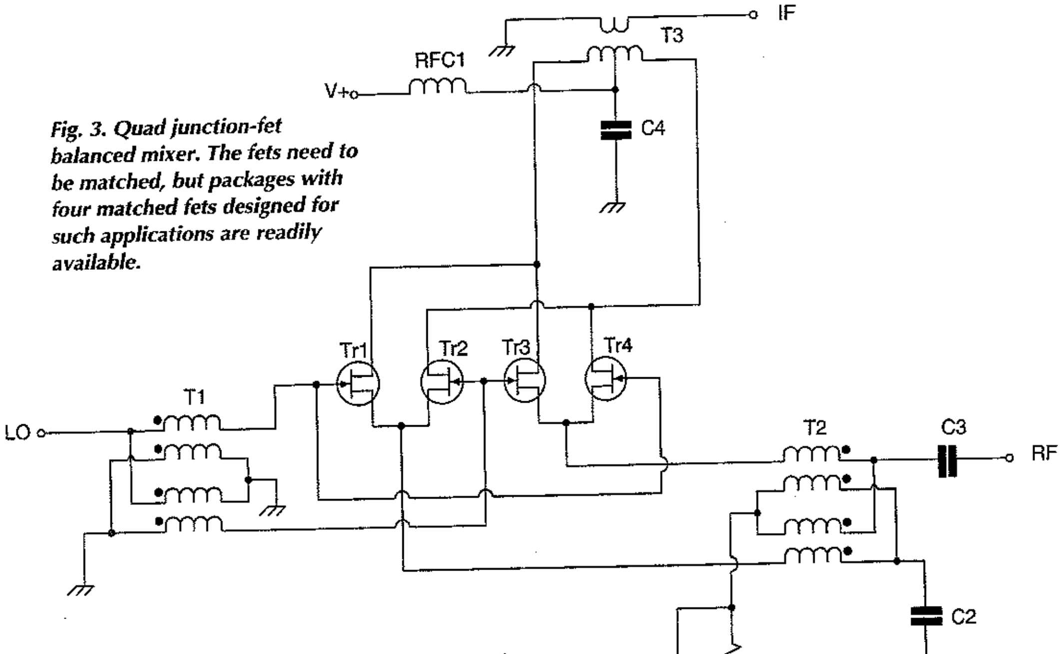


Fig. 3. Quad junction-fet balanced mixer. The fets need to be matched, but packages with four matched fets designed for such applications are readily available.

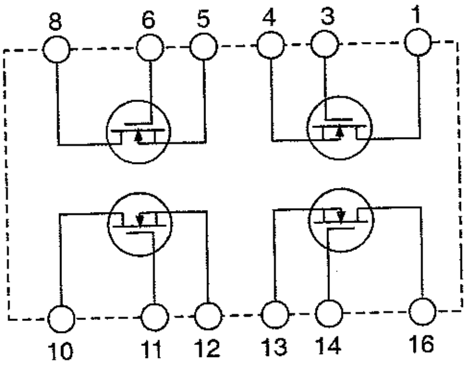


Fig. 4. Siliconix quad MOSFET device contains four fets that can be used independently. When connected as a ring, they form a mixer.

nected such that $Tr_{1,4}$ and $Tr_{2,3}$ are paired.

The local oscillator signal is applied differentially to these gates through transformer T_1. Drains of $Tr_{1,3}$ and $Tr_{2,4}$ are tied to the IF output transformer T_3.

There are several quad FET ICs on the market that have found favour as mixers in radio receivers. Siliconix's *SD5000* quad DMOS fet is shown in **Fig. 4**.

This device contains four fets that can be used independently. When connected as a ring, they form a mixer.

Calogic carries the theme a little further in its *SD8901* DMOS quad fet mixer IC, **Fig. 5**. The fets, $Tr_{1\text{-}4}$, are connected in a ring such that opposite gates are connected together to form two LO ports, LO_1 and LO_2.

The RF signals are applied differentially across drain-source nodes $Tr_{1,2}$ and $Tr_{3,4}$. Similarly, the IF output is taken from the opposite pair of nodes: $Tr_{1,4}$ and $Tr_{2,3}$. The *SD8901* comes in an eight-pin metal can package.

The circuit for using the *SD8901*, **Fig. 6**, is representative of this class of mixers. The RF and IF output terminals are through transformers T_1 and T_2, respectively.

The local-oscillator signal is applied directly to the LO_1 and LO_2 ports, but requires a divide-by-two circuit comprising a J-K flip-flop.

Note that this divider makes the LO signal a square wave rather than a sine wave. An implication of this circuit is that the LO injection frequency must be twice the expected LO frequency.

Gilbert-cell mixers

The Gilbert transconductance cell, **Fig. 7**, is the basis for a number of IC mixer – for example the *NE602* shown in **Fig. 8**, and analog multiplier devices like the *LM1496*.

The Gilbert mixer consists of two cross-connected n-p-n pairs fed from a common current source. The RF signal is differentially applied to the transistors that control the apportioning of the current source between the two differential pairs. The local oscillator signal drives the base connections of the differential pairs.

Integrated Gilbert-cell devices such as the Philips/Signetics *NE602* in Fig. 8 are used extensively in low-cost radio receivers. The Gilbert cell is capable of operating to 500MHz. An on-board oscillator can be used to 200MHz.

One problem seen on such devices is that they often trade off dynamic range for higher sensitivity.

Passive double-balanced mixers

The diode double-balanced mixer, **Fig 9**, is one of the more popular double-balanced mixer approaches. It has th obvious advantage over active mixer of not requiring a DC power source.

The circuit uses a diode ring, $D_{1\text{-}4}$, t perform the switching action. In Fig. 9 only one diode per arm is shown, bu some commercial double-balance mixers use two or more diodes pe arm.

This configuration is capable of 30 t

60dB of port-to-port isolation, and is not difficult to apply.

With proper design, it is easy to build passive diode double-balanced mixers with frequency responses from 1 to 500MHz.

Commercial models that work into the microwave region are not hard to find. Intermediate-frequency outputs of typical diode double-balanced mixers can be DC to about 500MHz.

The diodes used in the ring can be ordinary silicon small-signal diodes such as *1N914* or *1N4148*, but these are not as good as hot-carrier Schottky diodes like the *1N5820, 1N5821* and *1N5822*.

Whichever diodes you choose though, they should be matched for use in the circuit. Diode differences can degrade a mixer's performance.

The usual approach is to match the diode forward voltage drop at some specified standard current, such as 5 to 10mA, depending on the normal forward current rating of the diode. It is also important to match the junction capacitance of the diodes.

The mixer in Fig. 9 uses two balun transformers, T_1 and T_2, to couple to the diode ring. The double-balanced nature of this circuit depends on these transformers, and as a result the LO and RF components are suppressed in the IF output.

Diode double-balanced mixers are characterised according to their drive level requirement, which is a function of the number of diodes in each arm of the ring. Typical values of drive required for proper mixing action are 0dBm, +3dBm, +7dBm, +10dBm, +13dBm, +17dBm, +23dBm and +27dBm.

Figure 10 shows the internals of a commercially available passive double-balanced mixer made by Mini-Circuits (PO Box 166, Brooklyn, NY, 11235, USA:Phone 714-934-4500; Web site http://www.minicircuits.com). These type no. *SBLx* and *SRAx* devices are available in a number of different characteristics, **Table 1**.

The standard package for *SRA/SBL* devices is shown in **Fig. 11**. Non-insulated pins are grounded to the case. Pin-outs for common SRA/SBL devices are shown in **Table 2**.

The regular SRA/SBL devices use a local-oscillator drive level of +7dBm, and can accommodate RF input levels up to +1dBm. The devices will work at lower drive levels, but performance deteriorates rapidly, so it is not recommended.

Note that the IF output port is split into pins 3 and 4. Some models tie the ports together, but for others an external connection must be provided for the device to work.

The nice thing about this type of commercially available mixer is that the system impedances are already set to 50Ω. Otherwise, impedance matching would be necessary for them to be used in typical RF circuits.

Note, however, that if a circuit or system impedance is other than 50Ω, then a mismatch loss will be seen unless steps are taken to effect an impedance match.

The problem becomes considerably greater when a mismatch occurs at the IF port of the mixer. The mixer works properly only when it is connected to a matched resistive load. Reactive loads, and mismatched resistive loads deteriorate performance.

Figure 12 shows a circuit using a passive diode double-balanced mixer. The diplexer is a critical component to this type of circuit.

Proper loading

The diplexer is a passive RF circuit that provides frequency selectivity at the

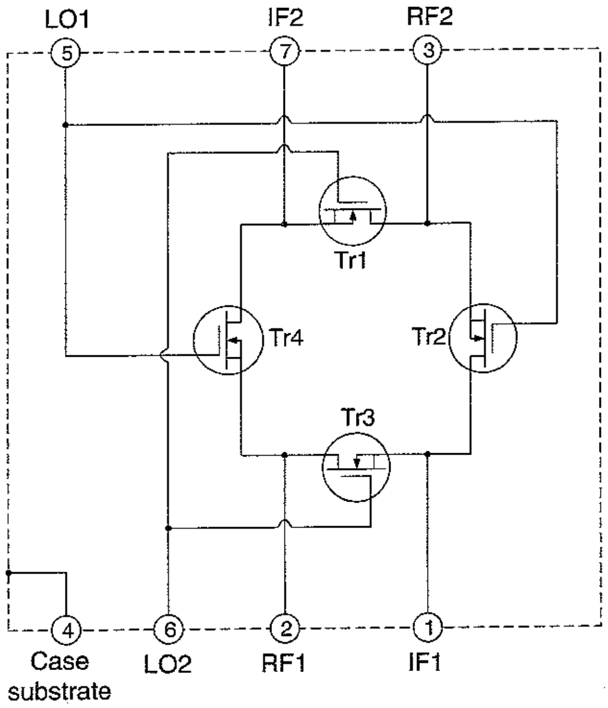
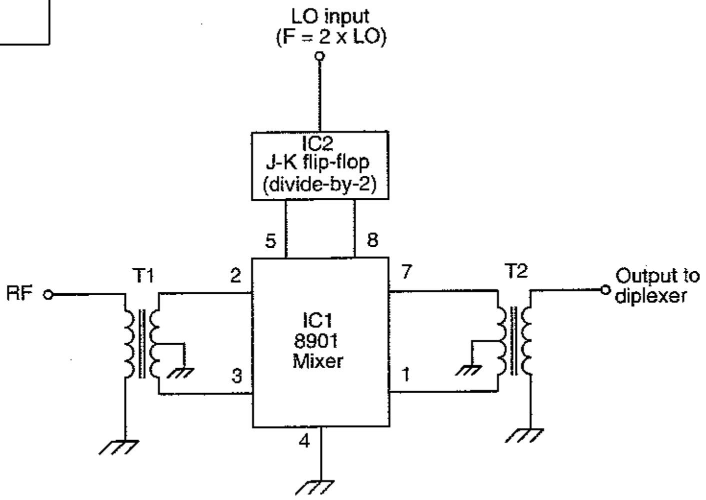


Fig. 5. In Calogic's SD8901 mixer, fets Tr_{1-4} are connected in a ring such that opposite gates are connected together to form two LO ports, LO_1 and LO_2. RF signals are applied differentially.

Fig. 6. Typical mixer application circuit using the SD8901. The local-oscillator signal is applied directly to the LO_1 and LO_2 ports on pins 5 and 6, but a divide-by-two circuit is needed so the LO signal is a square-wave – not a sine wave.



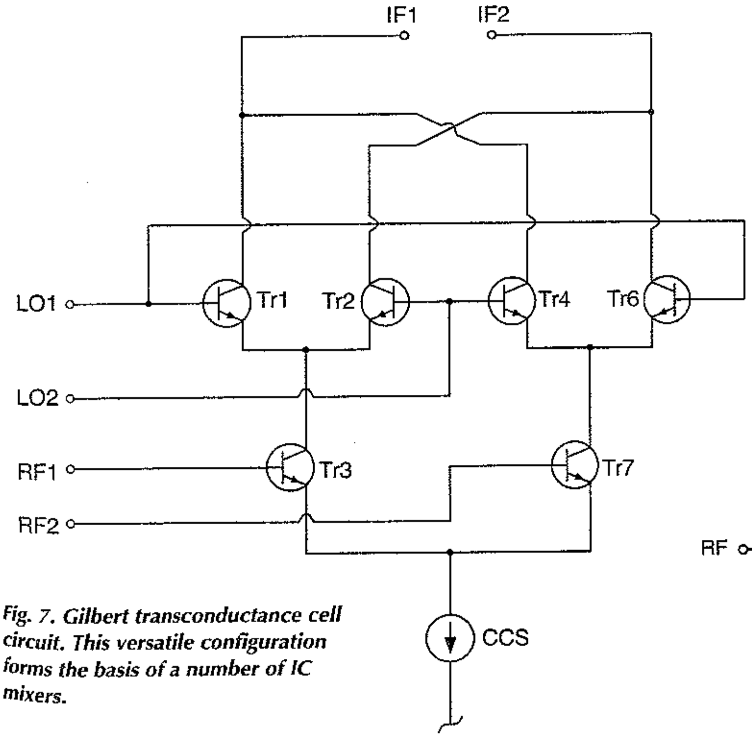


Fig. 7. Gilbert transconductance cell circuit. This versatile configuration forms the basis of a number of IC mixers.

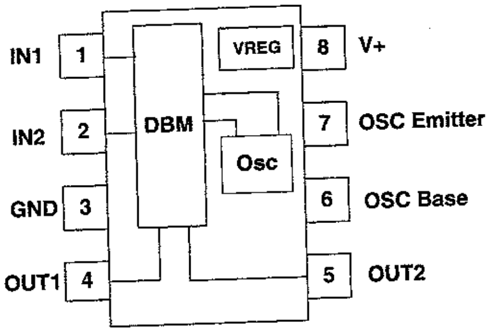


Fig. 8. One IC based on the Gilbert-cell principle is the NE602.

Table 1. Key performance figures for Mini-Circuits SBLx and SRAx passive double-balanced mixers, Fig. 11.

Type No	LO range (MHz)	IF range (MHz)	Mid-band loss (dB)
SRA-1	0.5-500	DC-500	5.5-7.0
SRA-1TX	0.5-500	DC-500	5.5-7.0
SRA-1W	1-750	DC-750	5.5-7.5
SRA-1-1	0.1-500	DC-500	5.5-7.5
SRA-2	1-1000	DC-500	5.5-7.5
SBL-1	1-500	DC-500	5.5-7.0
SBL-1X	10-1000	5-500	5.5-7.5
SBL-1Z	10-1000	DC-500	5.5-7.5
SBL-1-1	0.1-400	DC-400	5.5-7.0
SBL-3	0.025-200	DC-200	5.5-7.5

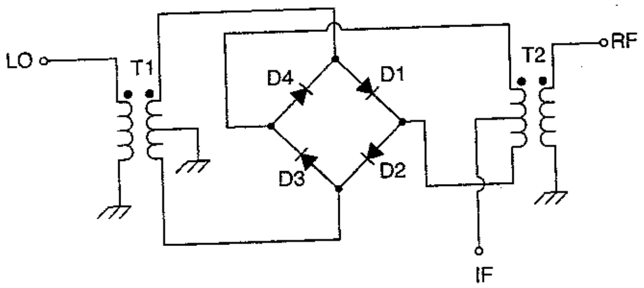


Fig. 9. Involving diodes instead of active switches, the passive double-balanced mixer has the benefit of not needing a DC power source.

Table 2. Pin designations of SBLx and SRAx passive double-balanced mixers.

Type No	LO	RF	IF	GND	Case
SRA-1	8	1	3,4	2,5,6,7	2
SRA-1TX	8	1	3,4	2,5,6,7	2
SRA-1W	8	1	3,4	2,5,6,7	2,5,6,7
SRA-1-1	8	1	3,4	2,5,6,7	2
SRA-2	8	3,4	1	2,5,6,7	2,5,6,7
SBL-1	8	1	3,4	2,5,6,7	2
SBL-1X	8	1	3,4	2,5,6,7	2
SBL-1Z	8	1	3,4	2,5,6,7	XX
SBL-1-1	8	1	3,4	2,5,6,7	XX
SBL-3	8	1	3,4	2,5,6,7	XX

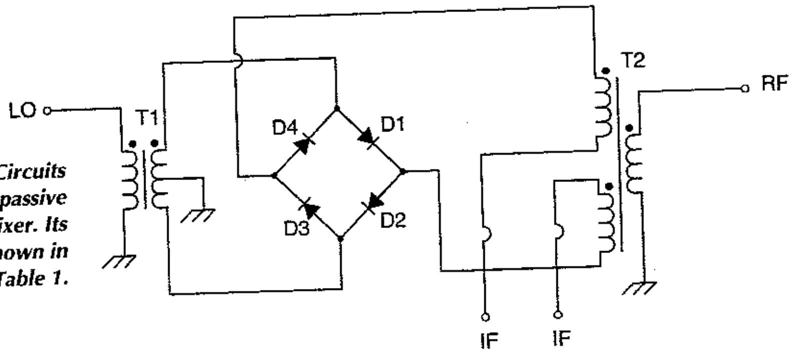


Fig. 10. Mini-Circuits SRA/SBL passive double-balanced mixer. Its characteristics are shown in Table 1.

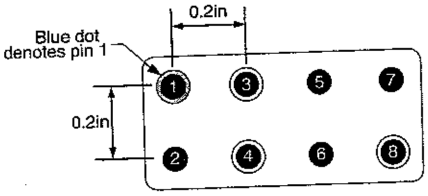


Fig. 11. Package details of the double-balanced mixer in Fig. 10.

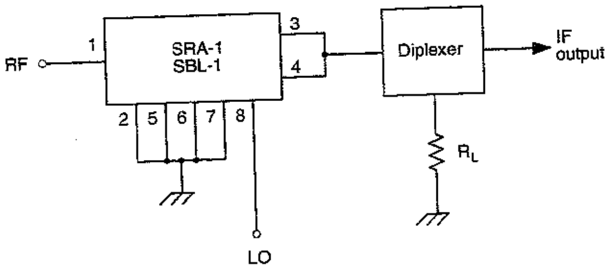


Fig. 12. Terminating a passive double-balanced mixer with a diplexer.

output, while looking like a constant resistive impedance at its input terminal.

Figure 13 shows a generalisation of the diplexer. It consists of a high-pass filter and a low-pass filter that share a common input line, and are balanced to present a constant input impedance.

With appropriate design, the diplexer will not exhibit any reactance reflected back to the input terminal – eliminating the reflections and voltage/standing-wave ratio problem. Yet, at the same time it separates the high and low frequency components into two separate signal channels.

The idea is to forward the desired frequency to the output and absorb the unwanted frequency in a dummy load. **Figure 14** shows the two cases. In each case, a mixer nonlinearly combines two frequencies, F_1 and F_2, to produce an output spectrum of mF_1 $\pm nF_2$, where m and n are integers representing the fundamental and harmonics of the two frequencies.

In some cases, you will only be inter ested in the difference frequency, so you will want to use the low-pass output of the diplexer, Fig. **14a**). Th high-pass output is terminated in matched load so that signal transmitte through the high-pass filter is full absorbed in the load.

The exact opposite situation is show in Fig. **14b**). Here we are interested i the sum frequency, so the high-pas output port of the diplexer is used, ar low-pass output port is terminated in resistive load. In this case, the sign passed through the low-pass filter se tion will be absorbed by the load.

Bandpass diplexers

Figures 15 and **16** show two differe bandpass diplexer circuits common used at the outputs of mixers. The circuits use a bandpass filter approac rather than two separate filters.

Figure 15 represents a π-netwo approach, while the version in Fig. is an L-network. In both cases,

$$Q = \frac{f_o}{BW_{3dB}}$$

and,

$$\omega = 2\pi f_o$$

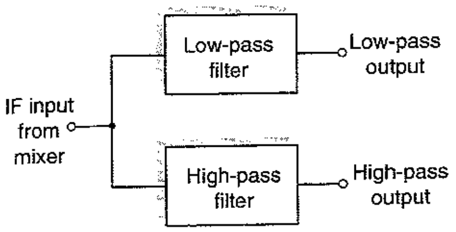


Fig. 13. A passive diplexer following the mixer provides selectivity while looking like a constant resistive impedance at its input terminals.

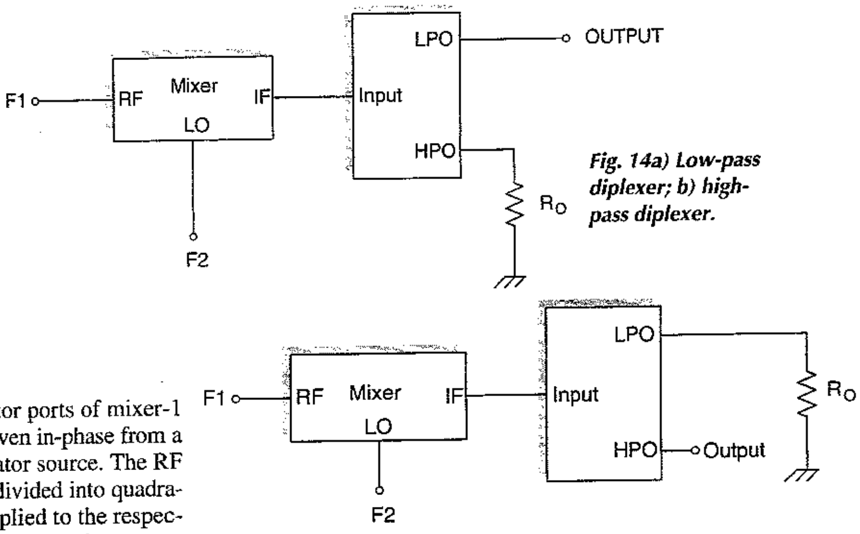


Fig. 14a) Low-pass diplexer; b) high-pass diplexer.

where f_0 is the centre frequency of the passband in hertz, BW_{3dB} is the desired bandwidth in hertz and Q is the relative bandwidth.

For the circuit of Fig. 15,

$$L_2 = \frac{R_o Q}{\omega}$$

$$L_1 = \frac{R_o}{\omega Q}$$

$$C_2 = \frac{1}{R_o Q \omega}$$

$$C_1 = \frac{Q}{\omega R_o}$$

And for the circuit of Fig. 16,

$$L_2 = \frac{R_o Q}{\omega}$$

$$L_1 = \frac{R_o}{\omega Q}$$

$$C_1 = \frac{1}{L_1 \omega^2}$$

$$C_2 = \frac{1}{L_2 \omega^2}$$

A dual double-balanced mixer

The normal passive diode mixer provides relatively high third-order intercept and –1dB compression points. It also provides a high degree of port-to-port isolation. Because of the switching action of the diodes in the ring, they are shut off at the instances where they would feed through the other ports.

But where an even higher degree of performance is needed, designers sometimes opt for the dual double-balanced mixer as shown in **Fig. 17**. The –1dB compression point is usually ≤4dB.

Image-reject mixers

In cases where very good image rejection performance is needed in a receiver, a circuit such as **Fig. 18** can be used. This circuit uses a pair of passive double-balanced mixers, a 0° power splitter and two 90° power splitters to form an image reject mixer.

The local oscillator ports of mixer-1 and mixer-2 are driven in-phase from a master local-oscillator source. The RF input, however, is divided into quadrature signals and applied to the respective RF inputs of the two mixers.

The IF outputs of the mixers are then recombined in another quadrature splitter, to form separate USB and LSB IF outputs.

VHF/UHF microwave mixers

When the frequencies used for LO, RF and IF begin to reach into the VHF and above region, the design approaches change a bit.

Figure 19 shows a simple single diode unbalanced mixer. Variants of this circuit have been used in UHF television and other types of receivers. The circuit is enclosed in a shielded space in which a strip inductor L_1 and variable capacitor C_1 form a resonant circuit.

The LO and RF signals are applied to the mixer through coupling loops to L_1. A UHF signal diode is connected to L_1 at a point that matches its impedance.

External to the mixer chamber, an IF filter is used to select the mixer prod-

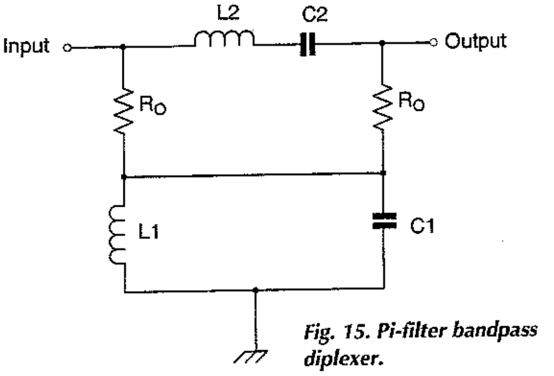


Fig. 15. Pi-filter bandpass diplexer.

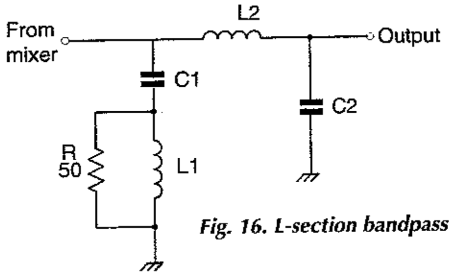


Fig. 16. L-section bandpass diplexer.

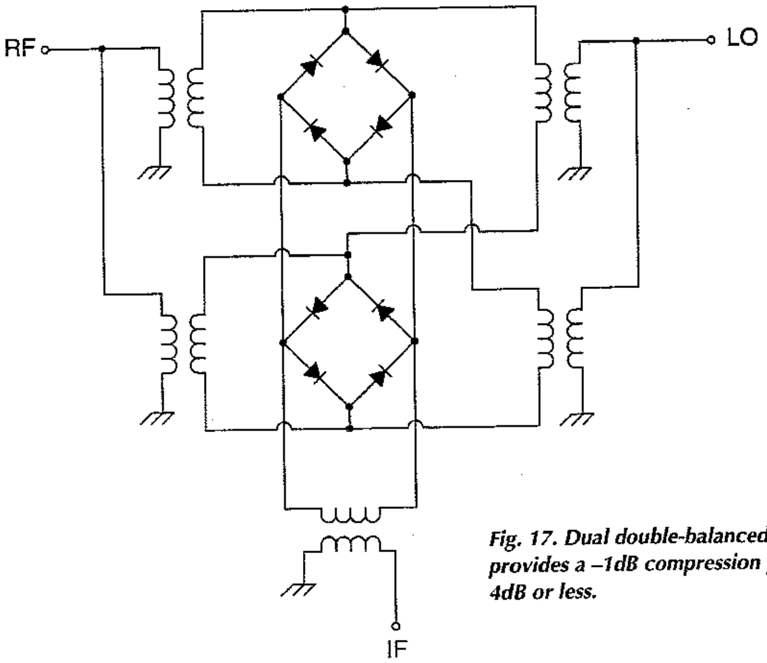


Fig. 17. Dual double-balanced mixer provides a –1dB compression point of 4dB or less.

uct desired for the IF section of the particular receiver.

A single-balanced mixer is shown in **Fig. 20**. This mixer circuit uses two diodes, D_1 and D_2, connected together, and also to the ends of a half-wavelength 100Ω transmission line. The LO signal is applied to D_2 and one end of the transmission line. IF and RF filters are used to couple to the RF and IF ports.

These mixers suffer from RF and LO components appearing in the output. **Figure 21** shows an improved version that will solve the problem. It is used in the UHF and microwave regions.

The LO and RF input signals are applied to two separate ports of a quadrature hybrid coupler. The input and output filtering are made using printed-circuit-board transmission lines.

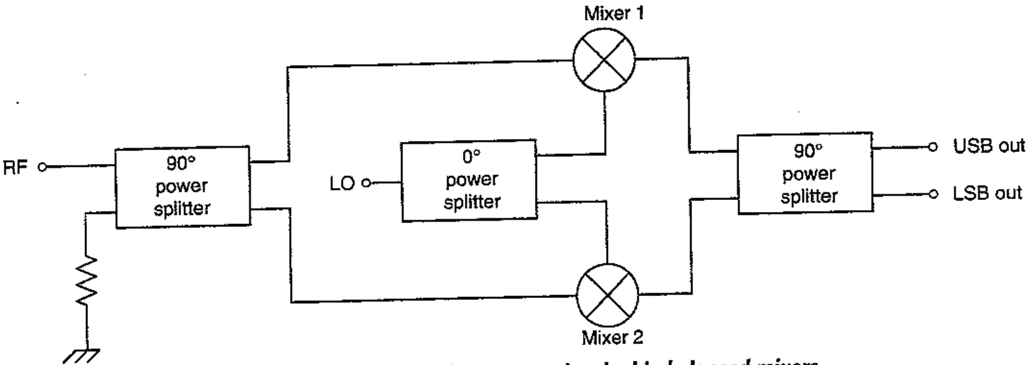


Fig. 18. Image-rejection is improved by using two passive double-balanced mixers together with power splitters.

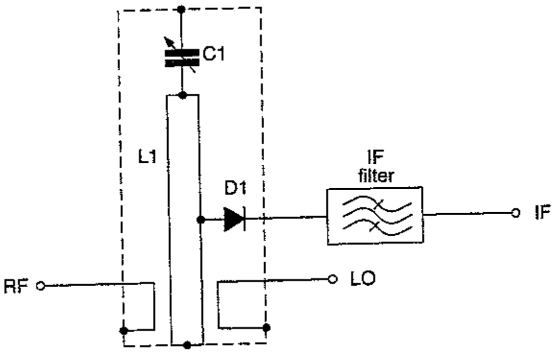


Fig. 19. Simple single-ended diode mixer for VHF/UHF.

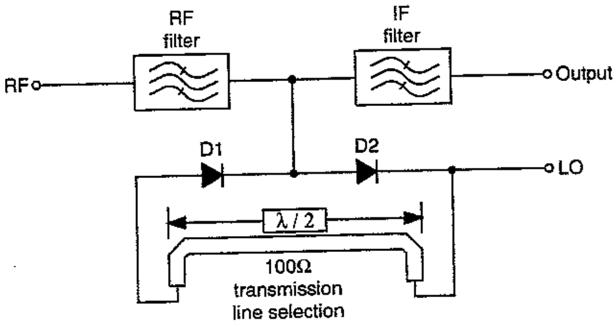


Fig. 20. Such UHF single-balanced mixers suffer from RF and LO components appearing in the output.

Each of the lines is a quarter wavelength, although the actual physical lengths must be shortened by the velocity factor of the printed circuit board being used. A printed circuit RF choke is used to provide a return connection for the diodes.

Note the RF and LO stubs at the output of the mixer, prior to the input of the IF filter. These stubs are used to suppress RL and LO components that pass through the mixer. ■

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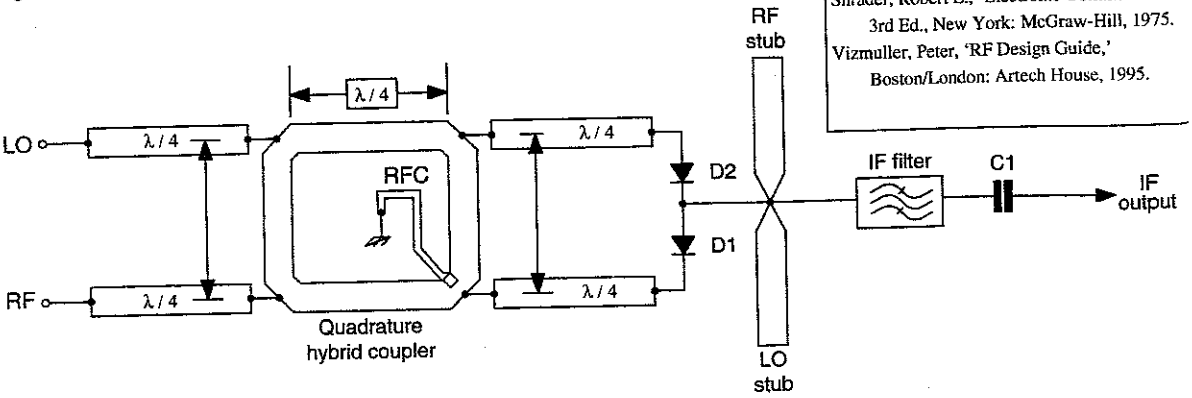

Fig. 21. Microwave mixer is an improvement over the single-balanced mixer of Fig. 20, significantly reducing RF and LO components in the output.

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