WORKING WITH MIXERS

As long as you follow some basic rules, mixer circuits are easy to understand and use.

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Mixer circuits are designed to operate as frequency translators They are nonlinear circuits that produce an output frequency spectrum that includes various products of two input frequencies As shown in Fig. 1, if two input frequencies, F1 and F2, are combined in a nonlinear mixer, then the output spectrum will include the products:

$$F = mF1 \pm nF2 \quad (1)$$

where F represents the output products, F1 and F2 are the two input frequencies, and m and n are integers (0, 1, 2, 3). In any given circuit the mixer products may be out to several higher orders It is commonly, and erroneously, assumed that the output spectrum looks like Fig 2 Assume that the two inputs are F1 and F2. The outputs will include F1, F2, F1+F2 (sum frequency) and F1-F2 (difference frequency) Of these frequencies, we usually only need one.

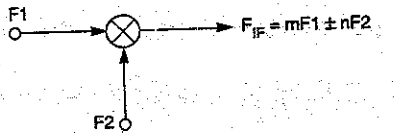


Fig. 1. If two input frequencies, F1 and F2, are combined in a nonlinear mixer, then the output spectrum will include the products F = mF1 ± nF2

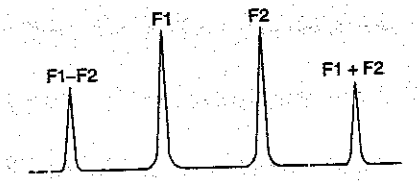


Fig. 2. It is commonly, and erroneously, assumed that the output spectrum of a mixer looks like the graph shown here.

Although there are a number of applications for the mixer, let's take a look at only one. The most common application is the *superheterodyne* receiver design. Nearly all radio and TV receivers sold today are "superhets" In the superhet the incoming RF signal (F_{RF}) is converted to an *intermediate frequency* (IF) by "beating" a local oscillator (LO) signal (F_{LO}) against the RF frequency. That process is called *heterodyning*, from which the name superheterodyne was derived.

Figure 3 shows the block diagram of a typical superhet receiver The radio signal at F_{RF} is picked up by antenna, and then (sometimes) amplified in an RF amplifier circuit This signal is mixed with F_{LO} in the mixer to produce two output signals, in addition to F1 and F2: F1+F2 (sum) and F1-F2 (difference) These frequencies correspond to the results of Eq (1) when m = n = 1.

The IF amplifier is used to process the output signal of the mixer. Either the sum or the difference signal can be used for the IF, as they are mirror images of each other. In AM and FM broadcast band (BCB) receivers, the difference frequency is typically used. In the United States and Canada, manufacturers usually use 455 kHz as the AM BCB IF, and 10 7 MHz as the FM BCB IF. In car radios, 262 5 kHz is used as the AM BCB IF. European and Japanese radios have sometimes used other frequencies for the IF, but they are close to these values In recent years, we have seen high frequency (HF) shortwave receiver designs that use two conversion steps. The first IF is around 50 MHz, but this frequency is later down converted to a second IF such as 9 MHz, 8 83 MHz, or 10 7 MHz In Fig. 3 the difference frequency F_{LO}-F_{RF} is shown being selected.

The IF amplifier provides most of the signal gain found in the receiver It also provides most of the selectivity of the receiver The reasons for doing the frequency conversion is that the IF amplifier operates at one frequency only, and that means it is easier to obtain quality selectivity characteristics (the best filters are single-frequency devices) and high gain without either variation in gain with frequency or spurious oscillations

Mixer Problems. One of the most common problems in using a mixer is the image response Figure 4 shows how that works The LO and RF are separated by the amount of the IF. Unfortunately, that means that there are two frequencies separated from the LO by the amount of the IF. In Fig. 4 the RF is located at F_{LO} - F_{IF} Ideally, that is the only frequency that is received. But notice that F_{LO} + F_{IF} (the "image" frequency) is also valid Any signal that appears at the image frequency will also appear to the receiver as a valid IF signal.

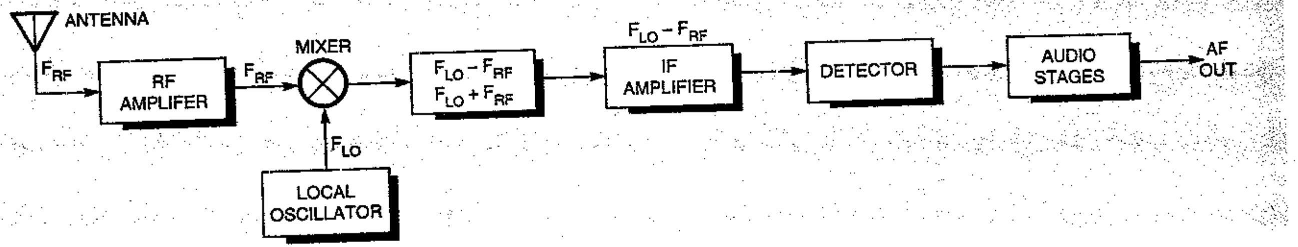


Fig. 3. A block diagram of a typical superheterodyne receiver. Though the difference-signal output of the mixer is used here, either the sum or difference signal output could be used

The problem doesn't end there, unfortunately. The receiver has a certain bandwidth (BW). No signal has zero bandwidth, so a receiver designer will match the bandwidth with the modulation being received.

Typically, an AM BCB signal likes to see 10 kHz, an AM shortwave signal 6 kHz, an SSB signal 2.7 kHz, a land-mobile FM signal 5 kHz, and an FM BCB signal 200 kHz. Any signal that falls within the bandwidth will appear in the IF amplifier as a valid signal. Thus, all of the signals at F_{RF} - (BW/2), *i.e.* around the RF signal in Fig. 4, and F_{RF} + (BW/2), *i.e.* the image, will appear in the IF amplifier.

Notice in Fig. 4 that the baseline is not a nice clean line as it was in our ideal case of Fig. 2. Rather, there is a lot of noise in the system. The noise might be noise from the environment (both natural and man made), or it might be noise generated by the circuits inside the receiver. Even a simple resistor with no current flowing in it will produce a noise signal due to thermal agitation of the electrons inside the resistor material. Thus, in addition to any radio signals that might be present in the vicinity of the RF and image frequencies, any noise present will also appear in the IF amplifier.

It gets better: The local oscillator signal might be somewhat imperfect. Indeed, it will be imperfect . . . there's no "somewhat" about it. Three problems exist: LO harmonics, LO noise, and *discretes*.

Figure 5 shows the situation with respect to harmonics. All signals other than a perfect sinewave produce harmonics, *i.e.* signals of integer multiples of the basic signal. Thus, a 1000-kHz signal will have harmonics of 2000 kHz, 3000 kHz, 4000 kHz, and so forth, unless they are truly pure sinewaves (not likely).

In the example of Fig. 5 the LO signal (F_{LO}) has harmonics of $2F_{LO}$ and $3F_{LO}$. Any signals or noise that falls within the bandwidth (or passband) also appears around those harmonics plus or minus the IF: $2F_{LO} \pm (F_{IF} \pm (BW/2))$.

Figure 6 shows another problem with the LO signal: noise. The LO signal is ideally a spike with only amplitude and no width. That doesn't occur in practice. The real LO signal will have several different forms of noise around it. There will be signal components caused by thermal noise in the oscillator circuit. There will also be single-sideband phase noise present. These are difficult to filter out unless the LO is a single-frequency circuit, and its output signal can be passed through a very narrow (high Q) bandpass filter.

Discretes are modulation of the LO signal (either AM or FM) caused by other frequencies in the circuit. Of course, it's possible for oscillators and other signals within the circuit to modulate the LO, but the principal source of discretes is improperly filtered DC power-supply voltages. The AC power-line frequency in North America is 60 Hz (in some other parts of the world 50 Hz is used). When full-wave rectified, this produces a 120-Hz (twice the line frequency) ripple-frequency signal on the DC output of the power supply. If the ripple signal is allowed to remain on the DC power line, then it will modulate the LO signal and possibly cause problems.

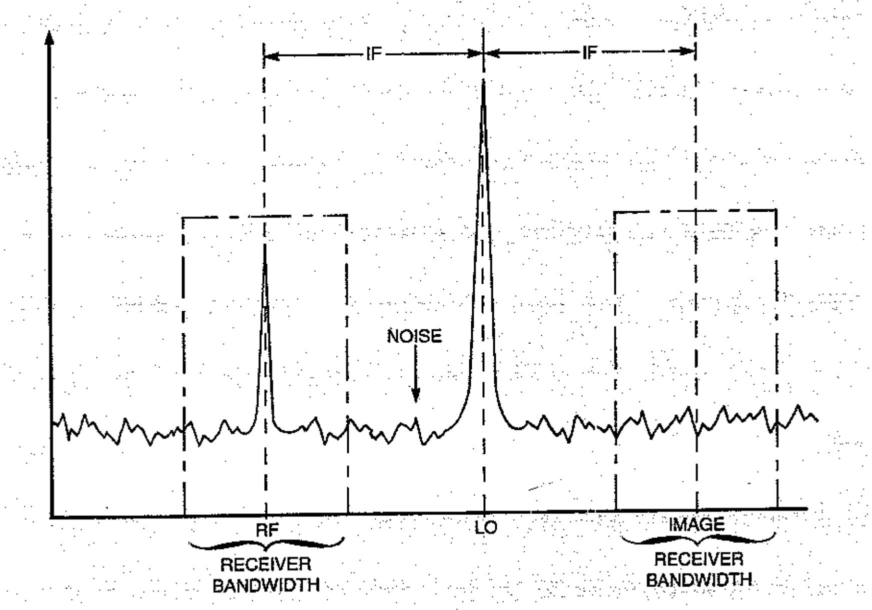


Fig. 4. While the RF signal located at F_{LO} - F_{IF} is the desired one, an image signal located at F_{LO} + F_{IF} is also valid.

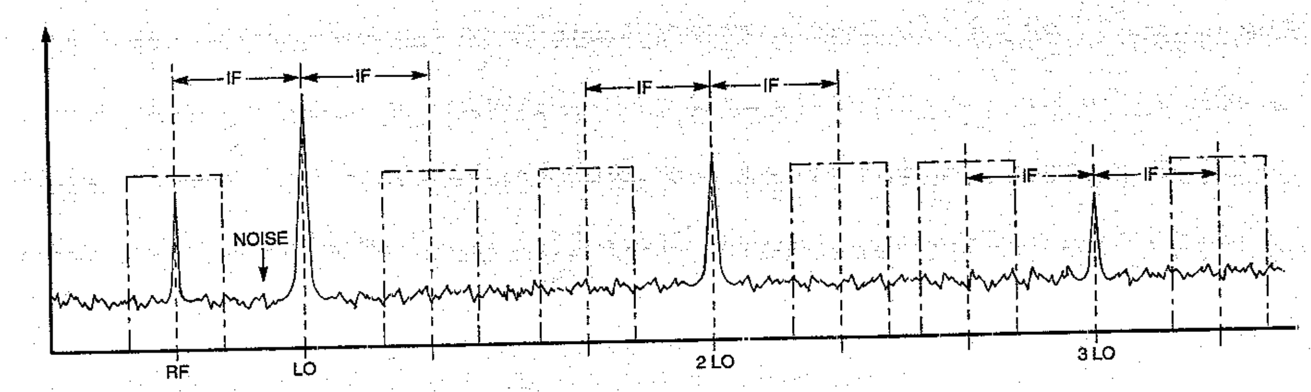


Fig. 5. Any noise that falls within the receiver's passband also appears around any internally generated harmonics.

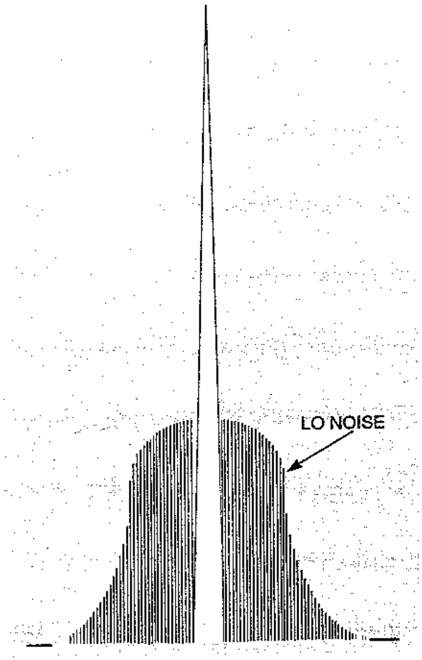


Fig. 6 While the LO signal is ideally a spike with only amplitude and no width. a real LO signal will have several different forms of noise around it

Power supply discretes fall so close to the LO signal that they cannot usually be filtered out of the LO signal They must be filtered out before they arrive at the LO. To cure this problem with the LO (as well as others) it is customary in high-quality receivers to provide adequate decoupling and filtering of the DC power lines and to provide the LO circuit with a voltage regulator of its own. The voltage regulator must be separate from any others used for the rest of the receiver.

Noise produced by the oscillator itself can be minimized by using a low-noise transistor or IC device, and by proper mounting of the components. A major contributor to phase noise, for example, is movement of the components. Remarkably small amounts of motion on frequency-determining components, or other components that affect frequency indirectly, can cause FM, PM, or phase noises.

Note that the spectrums shown in Figs 4 and 5 assume that there are only two frequencies present (F1 and F2, or F_{RF} and F_{LO}) That rarely occurs in real situations. In the radio receiver, for example, there are a lot of signals arriving at the antenna simultaneously. They can cause problems even if they are not situated at the RF and image frequencies (or at their phantoms around the harmonics of the LO) If a group or spectrum of signals appears at the RF input port, then all of them will be converted by the LO In addition, they will beat against each other and produce new signals that also heterodyne against the local-oscilator signal This is called intermodulation distortion (IMD)

All in all, with these problems and others, what arrives at the output of the mixer is a real mess for the IF amplifier to handle Fortunately, there are some things that we can do about it

Practical Mixer Circuits. The passive Schottky diode double-balanced mixer (DBM) circuit is probably one of the best solutions to the problems normally encountered with mixer circuits, especially if the desired effect is to keep signals not needed out of the IF amplifier A non-balanced mixer (which is what is in most AM and FM BCB radios) passes the two input frequencies and all of their products to the IF output (as in Fig 2) A single-balanced mixer will suppress either F_{LO} or F_{RF}, but not both. A double-balanced mixer, on the other hand, suppresses both F_{LO} and F_{RF} in the IF output, so the output only contains the sum and difference products A well-designed DBM will also suppress the even harmonics of the LO and RF input signals

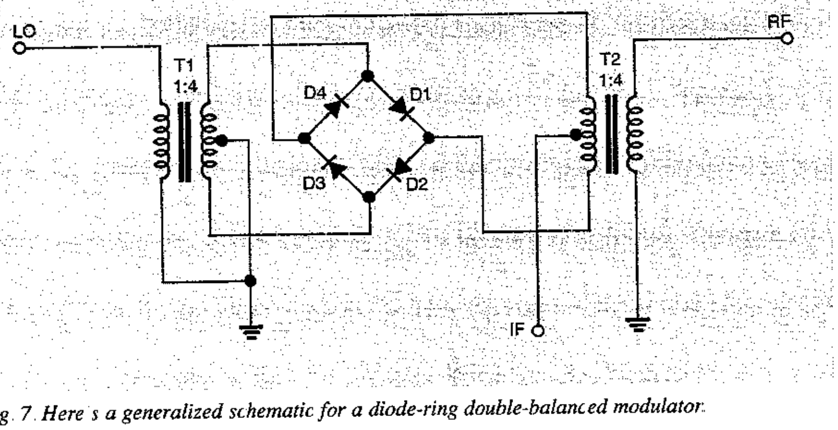


Fig. 7. Here's a generalized schematic for a diode-ring double-balanced modulator.

The DBM circuit in Fig 7 consists of a diode ring (D1-D4) of Schottky devices, and two 1:4 BALUN transformers in which the 4R winding is center-tapped. The LO and RF signals are applied to the ends of the ring, and the IF is taken from the center-tap of T2, the RF input transformer. The degree of suppression of F_{RF} and F_{LO} is determined by the degree of balance The balance is controlled by the construction of transformers T1 and T2, and by the matching of diodes D1 through D4 Isolation between F_{LO} and F_{RF} is improved by the diode switching action of D1-D4. The switching action acts to prevent transformers T1 and T2 from interacting with each other.

One line of popular commercial DBMs is manufactured by Mini-Circuits (P.O Box 350166, Brooklyn, NY 11235-0003; Web: www.minicircuits com) The basic internal circuit is shown at the top of Fig. 8. and the pin-outs are shown at the bottom. Pin 1 is identified by the blue dot around the terminal. There are several models popular with amateur builders, and these are summarized in Table 1 These mixers are designed for a +7 dBm LO signal level and RF signal levels up to +1 dBm

Figure 9 shows a basic circuit in block-diagram form for using the Mini-Circuits' mixers In this case the SBL-1 is selected, but the same pinouts are found on others The RF input signal is applied to Pin 1

Note the presence of some RF input filtering. It is there to improve the IMD performance. Depending on the application, specifically the RF frequencies involved, the filter might be a low-pass filter, high-pass filter, or bandpass filter If the range of RF input frequencies is limited, then opt for the bandpass filter so that undesired signals above and below the band of interest are attenuated Otherwise, determine where the interfering signals are

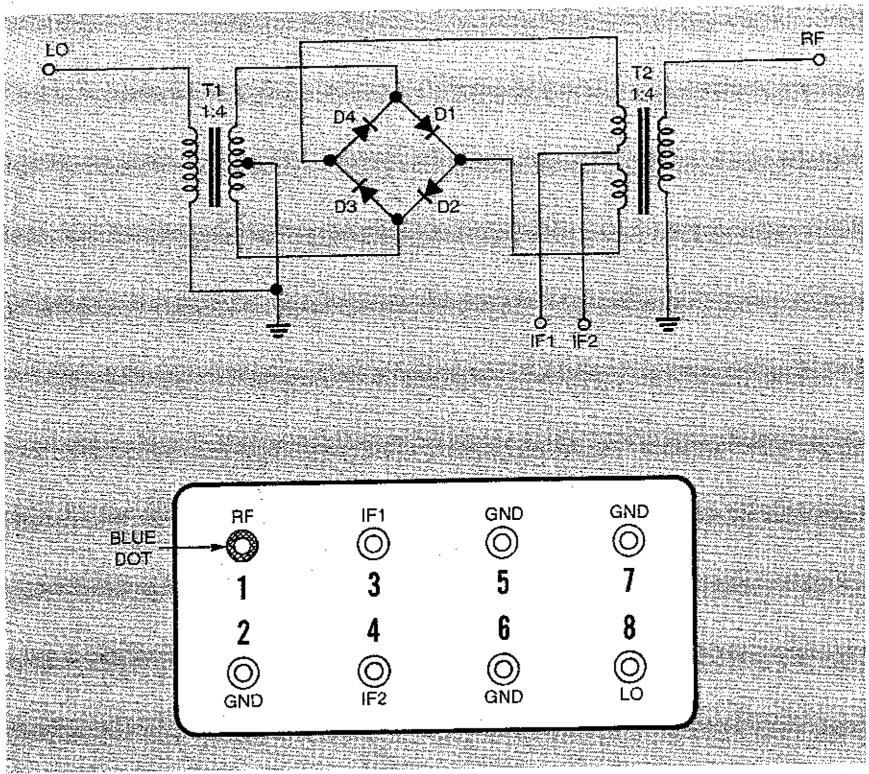


Fig 8. One popular line of DBMs is made by Mini-Circuits. Here is the basic circuit and pinouts for the members of the series. More details can be found in Table 1.

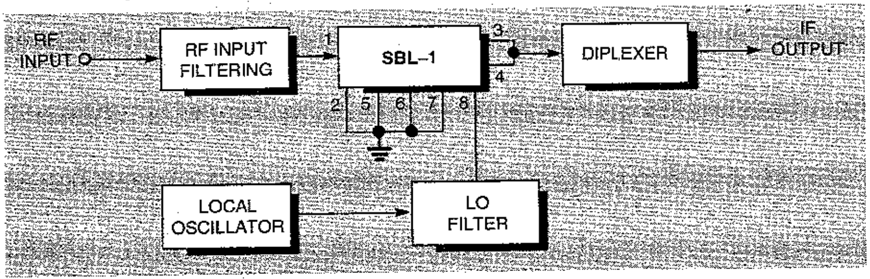


Fig. 9. This block diagram shows how the Mini-Circuits' DBM is typically used.

TABLE 1—MINICIRCUITS MIXERS

Model No.	LO/RF	IF	RF Pin	LO Pin	IF Pin	Ground Pins	Case
SRA-1	0.5-500	DC-500	1	8	3,4*	2,5,6,7	2
SRA-1-1	0.1-500	DC-500	1	8	3,4*	2,5,6,7	2
SRA-2	1-1000	0.5-500	3,4*	8	1	2,5,6,7	2,5,6,7
SBL-1	1-500	DC-500	1	8	3,4*	2,5,6,7	None
SBL-1-1	0.1-400	DC-400	1	8	3,4*	2,5,6,7	None

* Pins must be connected together

with respect to the desired signal and select a type of filter and cut-off frequency that either gets rid of the most signals or the most dominant signal. Whichever filter is selected, however, it must be designed to terminate in a 50-ohm resistive impedance.

If a very pure frequency conversion is necessary (as in a high-quality receiver or converter), then place a filter in the line between the LO output and the mixer's LO input. As with the RF filter discussed above, select the filter that eliminates the greatest amount of undesired energy. For the most part this means a low-pass filter with a cut-off frequency above the highest LO frequency and the lowest harmonic. Sub-harmonics are also an issue, but are usually less of a problem. If they are, then either use a bandpass filter centered on the LO range, or cascade a low-pass and high-pass filter.

The local oscillator must be able to produce an output level that will produce a power level of +7 dBm at the LO input (pin 8). The LO output power must be sufficient to overcome the losses of the filters and any other components in the signal path, yet still produce +7 dBm at the LO input of the mixer. For example, if the filter has a 2 dB insertion loss, then the LO must produce +9 dBm output power into a 50-ohm load.

Some designers place a 1- to 3-dB fixed broadband attenuator in each of the signal lines of the mixer. The idea is to damp impedance excursions and to allow the mixer to see a constant 50-ohm source or load impedance at each pin. If you use well-designed filters for the inputs and terminate the IF output properly, then the attenuator should not be necessary. If you prefer to use attenuators, however, the Mini-Circuits' catalog (see their Web site) has examples.

The best way to terminate the IF output of the mixer is to use a diplexer circuit. A diplexer is a circuit that produces a constant impedance over a broad range of frequencies, and will pass a desired frequency and (here is the important part) absorb undesired frequencies. One way to build a diplexer is to connect both high-pass and low-pass filters at the IF output of the mixer. Depending on whether you want the sum or difference frequencies, connect the output of one filter to the load being served (*e.g.* a following amplifier) and the other to a resistive dummy load that is matched to the system impedance.

Diplexer Design. Figure 10 shows a practical bandpass diplexer design intended for use with mixers. The values of the R_O resistors is the system design impedance (50 ohms in most cases). The values of L1, L2, C1, and C2 are determined by the center frequency (f_o) of the desired pass band. The Q of the filter is f_o divided by the necessary bandwidth (BW). The values of these components for

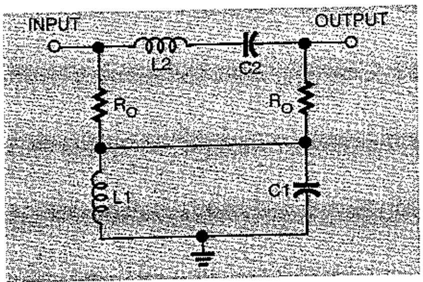


Fig. 10. Here's a practical bandpass diplexer design intended for use with mixers. Values are calculated using the equations in the text

any given frequency can be calculated from the equations below:

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

and

$$\omega = 2\pi f_o$$

The component values are:

$$L2 = \frac{R_o Q}{\omega}$$

$$L1 = \frac{R_o}{\omega Q}$$

$$C1 = \frac{1}{L1\omega^2}$$

$$C2 = \frac{1}{L1\omega^2}$$

Mixer Selection. Several different specifications may be applied to a mixer when making a selection. First you want to select the frequency range Don't select a mixer that barely covers the frequency you are interested in. For example, if you want to handle an RF input signal of 1.2 MHz, don't select a 1- to 400-MHz device Select a device with a 0.5- or 0.1-MHz lower end Keep in mind the RF, LO, and IF frequencies when selecting the mixer for an application Here are some other specification to keep in mind:

Isolation. The LO-RF, LO-IF and RF-IF isolation tells you something about how much signal will feed through the pathway specified. For example, the LO-RF isolation tells you the amount the LO signal is attenuated when it reaches the RF port Numbers such as 30 to 60 dB are common

Dynamic Range This specification tells you the power range in which the mixer works properly. It is a good idea to obtain the highest dynamic range possible.

-1 dB Compression Point The input signal level that causes a 1 dB drop in output level, *i.e* a 1 dB increase in conversion loss

Intercept Point The intercept point is the theoretical point on a graph of the output-*vs*-input signal levels that shows where the desired input signal and the n^th^ products become equal in amplitude The third-order products are normally considered the most important, so the third-order intercept point (TOIP) is usually specified. The higher the number the better the device Ω

AIRPORT BUDDY

(continued from page 28)

troubleshooting hints below to locate and correct the fault in the circuit.

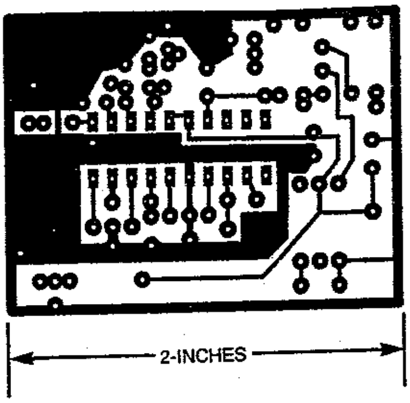
If you notice a large group of stations transmitting voice or music near the maximum CCW setting of the tuning control, those stations are commercial stations that are transmitting at the top of the FM-broadcast band. If you want to eliminate those stations, you can tweak the adjustment range of the receiver by slightly spreading the turns of L1; that will increase the local-oscillator frequency.

Troubleshooting. If the headphones are silent, check the voltage across the battery when the receiver is turned on with a voltmeter The battery voltage should be at least 8 volts—weak batteries will not drive the Airport Buddy. Also measure the current; the normal value is about 10 milliamps. The polarized components (D1, IC1, Q1, and the electrolytic capacitors) should be checked for proper orientation. The voltage at pins 5 and 6 of IC1 should be at least 7 volts. If it isn't, D1 might be installed backwards

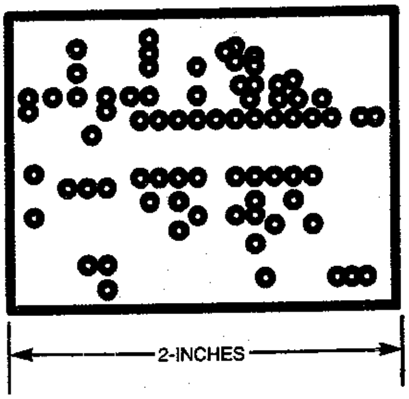
If power to the circuit is normal, check the voltage at pin 7 of IC1 It will normally be about 0.25 volts or less when no signals are being received and increase when an RF carrier is detected

Check the voltage at the source of Q1. If it is about 1 volt, the transistor is drawing current. If not, check its orientation or try a new transistor

If it is suspected that IC1 is not operating, carefully check the components that form the local oscillator: R1. C3–C6, L1, and D2. Check the bias on D2 to be sure that it changes when R6 is turned. Measure the voltage at each pin on IC1 and compare the reading with Table 2. The voltages listed assume that the battery voltage is at least 7 volts. If any pin on IC1 does not seem right, carefully check the wiring for short circuits. If a fault cannot be found, replace IC1



Here's the foil pattern for the Airport Buddy. The circuit is simple enough for a single-sided layout; the other side is a simple solid-copper ground plane



Although this is not a foil pattern for the Airport Buddy's ground plane. it shows the locations of the holes where copper should be cleared away so that the component leads do not short to ground. If you wish, a negative image of this layout could be used as a "foil pattern" that will only etch away a ring around the holes that need to be clear.

Using the Airport Buddy. When receiving signals at the airport, adjust the tuning control over its range very slowly to search out any possible transmissions. Once you have found the active frequency of the control tower, you can then keep the tuning control in that general vicinity to hear the audio communications as each aircraft arrives and takes off Ω