# MMICs Mimic Mixer

By H. Paul Shuch, N6TX
14908 Sandy Lane
San Jose, CA 95124

Diode balanced mixers, long the favored circuit for heterodyne downconversion in RF receivers, suffer from two drawbacks: conversion loss, and the need for relatively high local-oscillator (LO) injection levels. The active balanced mixer circuit presented here uses two inexpensive monolithic microwave integrated circuits (MMICs) to afford significant conversion gain, and low noise figure, and requires extremely low LO drive levels.

### The Mixer As A Nonlinear Element

The typical passive balanced mixer consists of three segments, as shown in Fig 1. The coupler is used to apply components of the RF input and LO signals to the nonlinear element, in a desired amplitude and phase relationship. It may consist of transmission-line delay networks, resistive or reactive power dividers, balun transformers, coaxial or waveguide directional couplers, hybrid couplers, or some combination of these. The coupler may be implemented with lumped constants, coaxially, with toroidal transformers, in stripline, or in microstripline form.

It is in the nonlinear network, typically comprised of Schottky barrier diodes, that sums and differences of the LO- and RF-input signals are generated. Diodes also generate harmonics, which in turn are responsible for the intermodulation products that often plague frequency conversion. Because diodes are passive, rather than active devices, their use also results in a signal amplitude loss in the conversion process. This familiar conversion loss also degrades system noise performance.

Because conversion only occurs when the diodes are forward biased to the knee of their response curve (remember, mixing is a nonlinear function, and thus requires a nonlinear response), a substantial amount of LO injection is necessary. This can be augmented by a dc bias for those mixers operating in "starved LO" mode, but doing so reduces the mixer's spurious-free dynamic range.

The IF matching network often provides two functions: It is responsible for transforming the diode network's output to the desired system impedance, as well as filtering from the IF the unwanted products of the input-signal and LO frequencies that have been passed along in the conversion process.

### Consider Active Mixing

An active balanced mixer can borrow the basic topology of the familiar passive mixer, by substituting one or more RF active devices for the diode array. Nonlinear gain stages will affect not only the RF input signal (substituting conversion gain for the passive-mixer loss), but the LO signal as well, significantly reducing LO injection requirements. An additional advantage is that the noise performance of the active devices used can essentially establish system noise figure, often negating the need for preamplifiers ahead of the mixer.

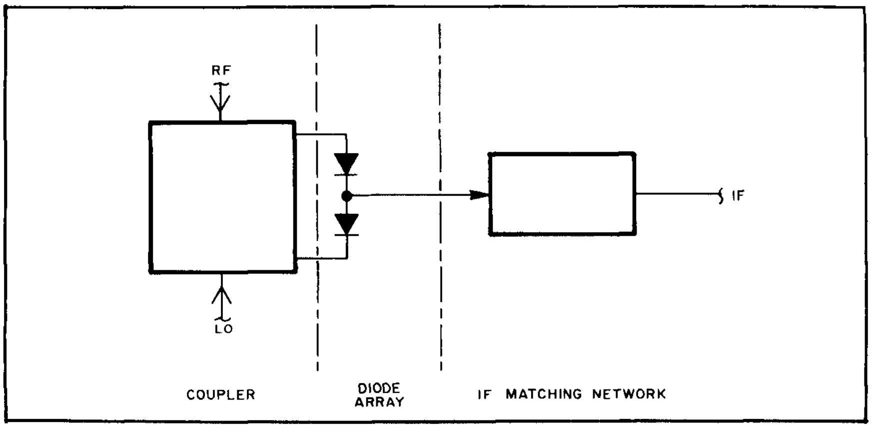

**Fig 1—Block diagram of a passive balanced mixer.**

One problem is that the nonlinear network must remain just that—nonlinear—for frequency conversion to occur. Past attempts to employ class-A preamp stages in balanced mixers[1] have met with only limited success, because excellent linearity (generally a requirement for preamplifiers) severely limits conversion efficiency.

MMIC gain stages are now available at low cost, and their application requires a minimum of external components. However, they are generally biased in class A. In fact, high linearity is one of their major selling points. In order to employ MMIC amplifiers for frequency conversion, it is necessary to bias them closer to cutoff.

### Coupler Selection Considerations

A previous study[2] evaluated the suitability of several hybrid coupler topologies for use in passive balanced mixers. Four different couplers, each realizable in microstripline form, were considered (see Fig 2 and Table 1). In attempting to trade off four mutually exclusive parameters (SWR, amplitude imbalance, isolation, and insertion loss), the 1.5-wavelength hybrid ring coupler, or *rat-race*, was determined to be the most suitable alternative for passive mixer use. Because the same considerations of match, balance, isolation and loss apply equally to active-mixer design, I see no compelling argument against employing the same coupler topology in active balanced mixers.

### Biasing The MMICs

Fig 3 shows a simplified equivalent circuit of the bias scheme typically used with MMICs. This is a version of modified collector feedback, which results in a relatively constant collector potential, somewhat independent of the applied potential or the value of the collector bias resistor, $R_c$. The combination of the dc source ($V_{cc}$) and the collector resistor ($R_c$) can

[1] Notes appear on page 6.

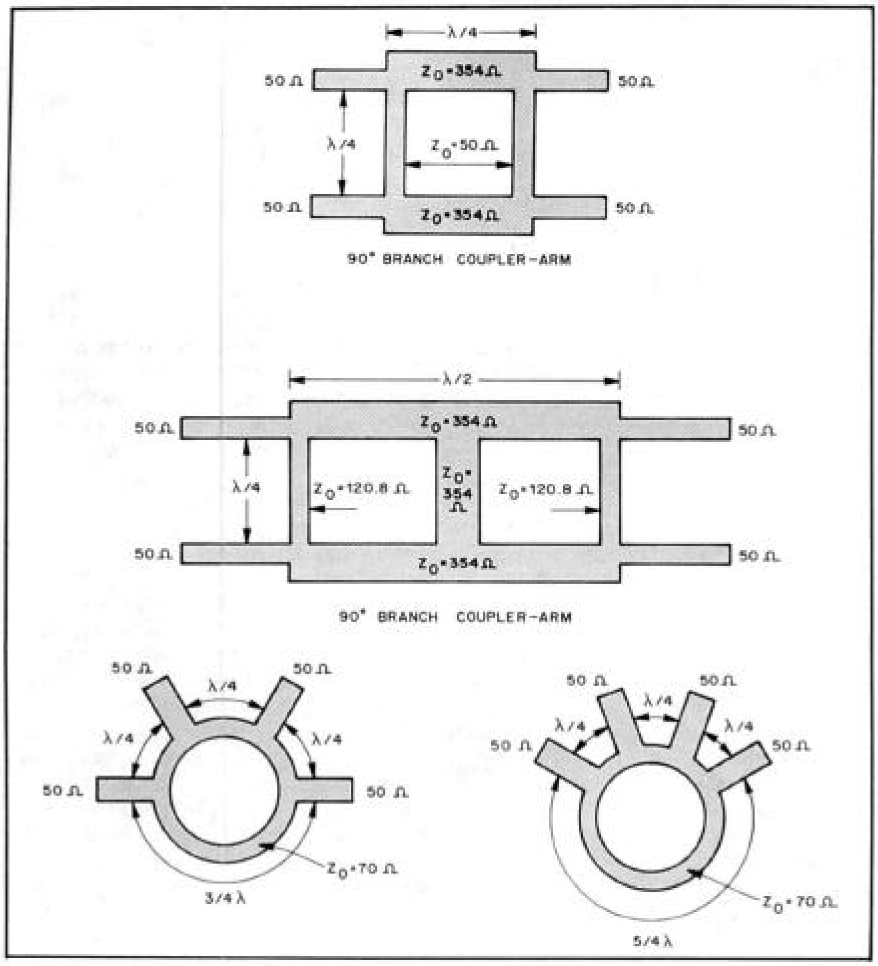

**Fig 2—Four microwave hybrid couplers. See Table 1 for a performance comparison.**

**Table 1**

**Hybrid mixer performance comparison for a 20% bandwidth**

| *Hybrid Type* | *SWR* | *Amplitude Imbalance (dB)* | *Isolation (dB)* | *Relative Insertion Loss* |
|---|---|---|---|---|
| Two arm, 90° branch | 1.45 | 0.7 | 14 | 1.0 |
| Three arm, 90° branch | 1.12 | 0.5 | 25.3 | 1.7 |
| 3/2 λ, 180° ring | 1.14 | 0.4 | 23.0 | 1.5 |
| Extended, 180° ring | 1.40 | 0.9 | 23.0 | 2.0 |

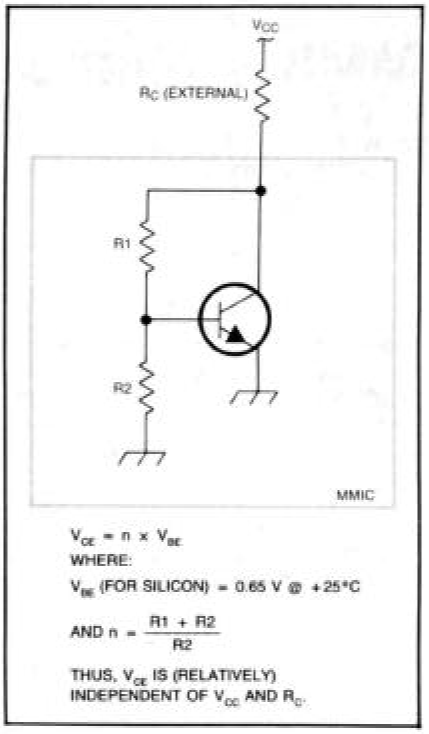

**Fig 3—An example of MMIC biasing.**

thus be thought of as a constant-current source, allowing easy control of the device's quiescent collector current.

I determined empirically that conversion efficiency is maximized at a quiescent current roughly half that recommended for linear amplification. For a single MMIC amplifier, then, mixing can be accomplished by roughly doubling the manufacturer's recommended bias-resistor value. As an added bonus, decreasing device current appears to somewhat lower the MMIC's internal noise figure.

For balanced mixer service, it's desirable to employ two identical MMIC amplifiers, which can be operated in dc parallel. Because their collectors are tied together to extract the IF component anyway, it's reasonable to drive both collectors with the bias resistance recommended for a single stage of amplification. This results in each MMIC being biased at half its accustomed current, which places it in class AB, facilitating frequency conversion.

## Assembling A Prototype Active Balanced Mixer

Some years ago, I developed a passive, diode balanced mixer for down-converting 1.7-GHz weather-satellite images to VHF.[3] The mixer used a ring hybrid coupler as described earlier, and because several etched circuit boards were left over from the project, I decided to assemble an MMIC active mixer on the same substrate. The schematic diagram of the mixer circuit is presented in Fig 4, and a photo of the mixer appears in Fig 5.

Hybrid coupler HY1 affords two paths between the RF input-signal (J1) and LO (J2) ports, which are 180° out of phase with each other. This affords the isolation between the RF input-signal and LO ports, which is characteristic of balanced mixers. Because the collectors of MMICs U1 and U2 are connected in parallel, their outputs are in phase. Hybrid HY1 applies the LO components from J2 to the inputs of the two MMICs 180° out of phase. Thus, though the MMICs amplify the LO signal (allowing low injection levels), the LO components at their outputs cancel, affording isolation between the LO and IF ports.

Because this design is a singly balanced mixer, there is no inherent isolation between the RF input-signal and IF ports. Note that hybrid HY1 applies the RF input-signal from J1 to the two MMIC inputs in phase. Thus, both MMICs amplify the RF input signal, and an appreciable input-signal component exists at the outputs of the MMICs. To diminish the input-signal component present at the IF port, the IF impedance matching network (C3, C4, L1, C5) is employed as a low-pass filter.

Incidentally, in the intended application of this prototype mixer, the design IF is 137.5 MHz. The MMICs are designed for a nominal output impedance of 50 ohms each, thus their paralleled outputs represent roughly a 25-ohm source to the IF port. C3, C4, L1 and C5 were optimized to step this value back up to a 50-ohm match at the desired IF. Fig 6 shows the results of optimizing the IF match over the band of 100 to 175 MHz. The optimization was performed using SuperStar (S-parameter Two-port Analysis Routine), Randall Rhea's microwave circuit analysis package for the IBM® PC and compatible computers.[4]

### Prototype Mixer Test Results

The prototype MMIC active balanced mixer was tested as a downconverter, under the conditions summarized in Table 2. The IF spectrum is shown in Fig 7, with vertical sensitivity of 10 dB per division, with 0 dBm at the top of the screen, and a horizontal sweep of dc to 2 GHz. Swept conversion gain is shown in Fig 8.

The prototype exhibits 18 dB of conversion gain at 1.7 GHz, with a 3-dB band-

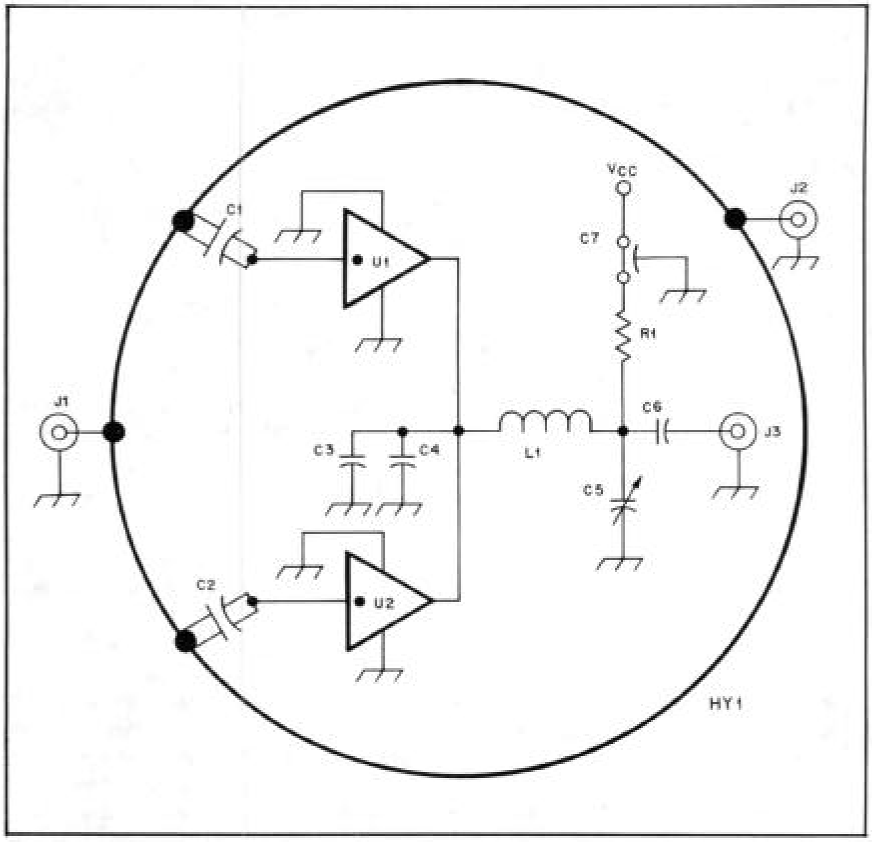

**Fig 4—Schematic diagram of a prototype MMIC active balanced mixer.**

**HY1—540° ring hybrid; 70-Ω microstripline ring 1½ λ at operating frequency (see text).**
**J1, J2—SMA receptacle.**
**J3—BNC receptacle.**
**L1—0.01 μH.**
**C1,C2—50-pF chip capacitor.**
**C3—Etched bypass capacitor, 30 Ω, open stub, ¼ λ at LO frequency.**
**C5—5- to 40-pF ceramic trimmer (15 pF nominal).**
**C6—100-pF silver mica.**
**C7—1000-pF feedthrough.**

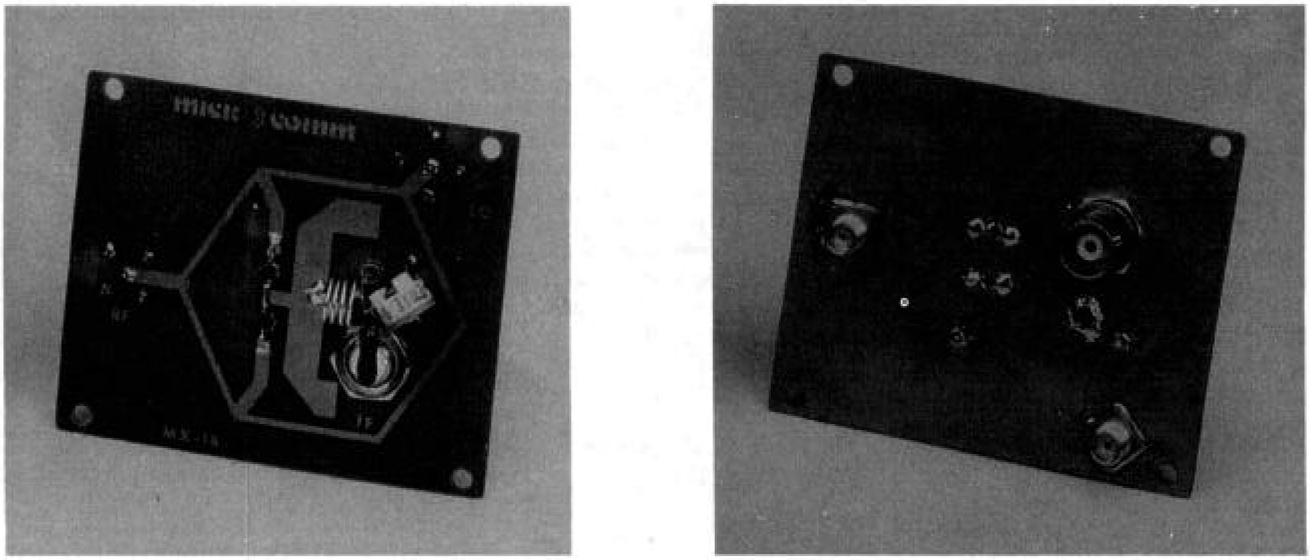

**Fig 5—The prototype active balanced mixer is built on a substrate originally designed for use with a passive mixer. The MMICs are placed in the holes normally occupied by the hot-carrier diodes. A bias network has been added to the IF filter section.**

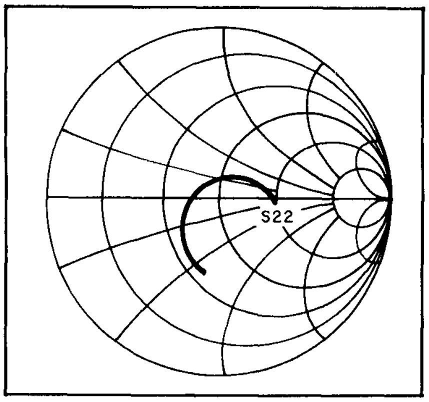

Fig 6—SuperStar plot of the mixer's IF port match, swept from 100 to 175 MHz.

**Table 2**
**Prototype Active Balanced Mixer Test Conditions and Results**

$V_{CC}$ = +12 V; $I_C$ = 30 mA

| Port | *Frequency (MHz)* | *Amplitude (dBm)* | *Gain (dB)* |
|---|---|---|---|
| LO | 1533 | −15 | N/A |
| RF | 1691 | −40 | N/A |
| IF | 138 | −22 | +18 |
| | 1533 | −36 | −21 |
| | 1691 | −45 | −5 |

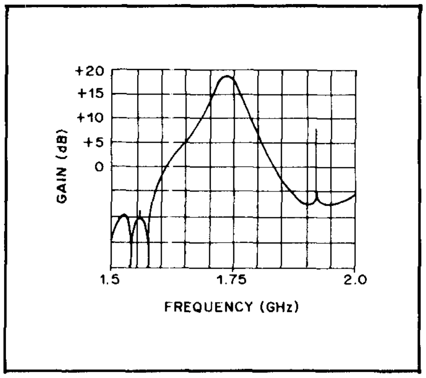

Fig 8—Swept conversion gain of the prototype MMIC active balanced mixer.

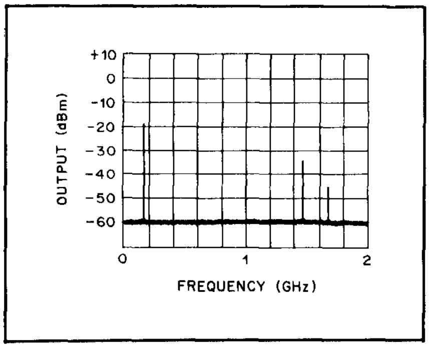

Fig 7—The output spectrum of a prototype active balanced mixer showing suppression of RF input-signal and LO components (see text).

width of more than 50 MHz, when driven with a 1.5 GHz, −15 dBm LO. LO components at the IF are suppressed by 21 dB, though the RF input-signal component at the output, as expected, is only slightly attenuated. A frequency selective IF amplifier stage following this mixer would significantly clean up the output spectrum.

## Other Bands

The hexagonal rat-race configuration seen in the photographs has, over the fifteen years or so I've been building passive balanced mixers, become something of a signature. I like to think the hex shows there's still a bit of sorcery associated with microwave circuit design. I've used this mixer on all six ham bands between 900 MHz and 10.5 GHz, as well as for a number of commercial applications, including WEFAX, MDS, ITFS, TVRO, and various avionics services. The configuration has been widely published,[2,3,5,6] and even more widely imitated.[7] The time has come to share the secret of the hex design.

Think of the rat race coupler as being composed of six microstripline matching transformers, each a quarter wave long at the operating frequency. The trick is to define the operating frequency, as the coupler must pass both the RF input-signal and LO components. For optimum tradeoff between these two frequencies, design the arms to be a quarter wave at the *geometric mean* (square root of the product), rather than the *arithmetic mean* (half the sum) of the two frequencies of interest. Of course, the coupler has a finite bandwidth. For best results, these two frequencies should be within about ten percent of each other.

But how do you control the input-signal-to-LO separation? Simply by judiciously selecting your IF. Because of mixer bandwidth limitations, you would like to use the lowest possible IF. But image rejection demands the greatest possible separation of RF and LO components, hence, the highest possible IF. A paradox? Well, yes, but a good compromise seems to be to always convert down to about a tenth of the input frequency. (If you have to go further, use multiple conversion.) Fortunately, many of our "preferred" amateur conversion schemes are in the right ballpark: 1296 to 144 MHz; 2304 to 220 MHz; 3456 and 5760 to 432 MHz; 10,368 to 1296 MHz. And of course, 1691 (WEFAX) to 137.5 MHz.

As you might imagine, over the years I've taped up quite a few hex couplers for a number of different frequencies. For your convenience, I've included a few PC-board etching patterns in Fig 9. All should be etched on $^{1}/_{16}$-inch-thick, fiberglass-epoxy substrate, double-sided, 1-oz copper PC board and used for the frequencies indicated.

## Summary

The prototype mixer met its original design objectives of conversion gain, low-noise performance, and operation at low LO injection levels. Reducing the quiescent current of the MMICs permits the efficient generation of sum and difference frequencies, which is the overall function of a mixer stage. The observed combination of low LO injection requirements, reasonable conversion gain, and noise figure established by the MMICs should significantly simplify RF-receiver design.

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**Notes**

[1] R. Cooper, "Coleman Terminal Update," *Coop's Satellite Digest*, Oct. '79, p. T6.

[2] H. P. Shuch, "Rat-Race Balanced Mixer for 1296 MHz," *ham radio*, Jul 1977, p 33-39.

[3] H. P. Shuch, "Cost-Effective Modular Downconverter for S-band WEFAX Reception," *IEEE Transactions on Microwave Theory and Techniques*, Dec 1977, p 1127.

[4] SuperStar is available for $595 from Circuit Busters, Inc, 1750 Mountain Glen, Stone Mountain, GA 30087, tel 404-923-9999.

[5] H. P. Shuch, "Microstrip—Magical PC Technique Explained," *73 Magazine*, Oct 1978, pp 80-87.

[6] H. P. Shuch, "A High Performance Conversion Module for the 23-cm Band," *Radio Handbook* (Indianapolis: Howard W. Sams, 1975) 20th Edition, section 20-5.

[7] G. Roberts, "Fiddlers Corner Part II," *Journal of the Environmental Satellite Amateur Users' Group*, Vol 5, No. 1, Jan-Mar 1987, p 10.

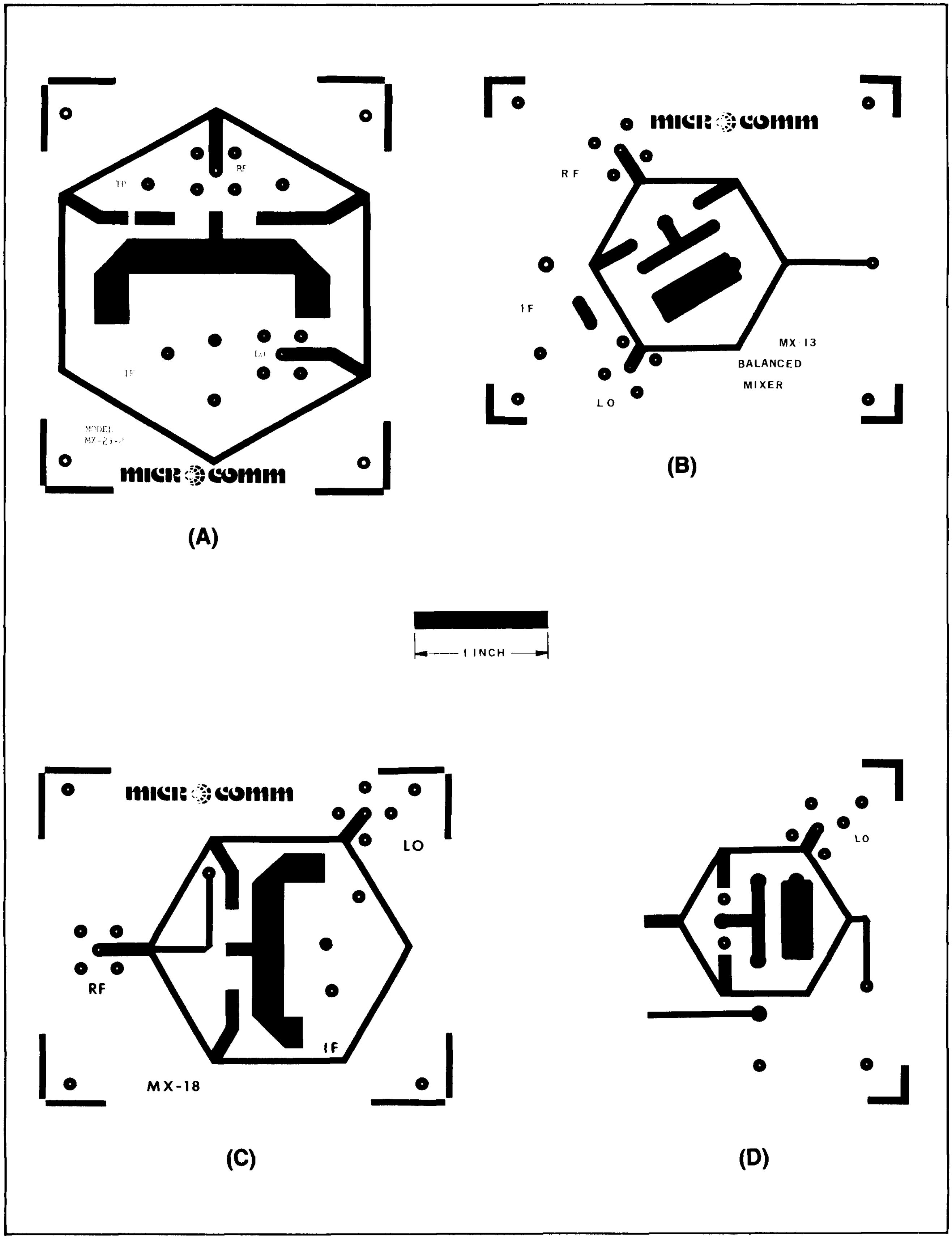

Fig 9—PC-board etching patterns for passive balanced mixers to be used on different frequencies: at A, 1296 MHz; B, 2304 MHz; C, 1691 MHz and D, 2.6 GHz.