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Microwave Building Blocks: The Doubly-Balanced Mixer

WB6IGP adds another piece to his puzzle.

This article describes a high-performance doubly-balanced microwave mixer that you can construct. This can be used in a downconverter giving good isolation between all ports—unlike the relatively poor performance of the singly-balanced mixers. The operating frequency range of this mixer can be any frequency up from 500 MHz, depending on the size and scaling of the device.

I wanted to build a system for single sideband on 1296 MHz but didn't want the unit to be purchased or locked into a design in which the components could not be used in another project. I wanted the components to be universally adaptable, and that required a building-block concept with all units connected with coax. In this way, as I worked toward my goal, each unit of the project would be constructed and tested by itself and could be used in another project if I desired.

The use of doubly-balanced mixers is not new and there are many available. The most common of them are the little eight-pin packs available from several manufacturers such as Anzac (MD-108), Mini Circuit Lab's (SRA-1), and Relcom (M6F). I have been able to obtain and use all of these units and find them excellent in their application. The devices exhibit very good isolation between all ports, keep spurious responses to a minimum, and, having a slightly higher conversion loss than singly-balanced mixers, require an amplifier following the mixer. This is a very small price to pay for the performance they give. See Fig. 1 for details.

One deficiency is the lack of units that give the same performance in the higher frequency range above 500 MHz. The lack of availability of this type of reasonably-priced mixer was the prime reason for starting this project. First, I built several types of mixers (singly balanced) to be able to gain some insight into what was needed. The first design that I tried was a Rat Race mixer, which looks like a stop sign. I tried everything to make that design work but had little luck. I then tried the Rat Race mixer that resembles a rectangle that is similar to the stop-sign mixer tried previously. This rectangular Rat Race mixer worked as advertised. This was the mixer that was used in the 1296-MHz stripline transceiver in the 1985 *Handbook*. See Fig. 2.

No project is a loss, and the stop-sign Rat Race mixer taught me several things about striplines, the method of running them, and the discontinuities you can have if you run the lines at a sharp angle. I found out that by mitering (slicing off) the sharp edge at the right angle junction, you improve the impedance transformation around the bend. If you leave the junction with a sharp edge, you will see a sharp spike in the standing

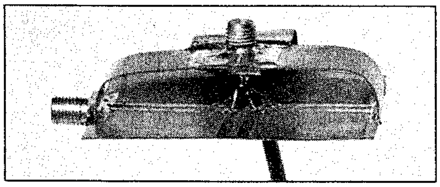

Photo A. Mixer front view showing diode placement and common ground strap.

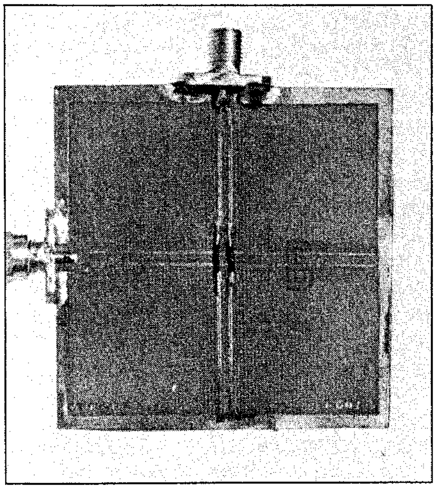

Photo B. Mixer rear view showing jumpers with insulation required for tuned lines.

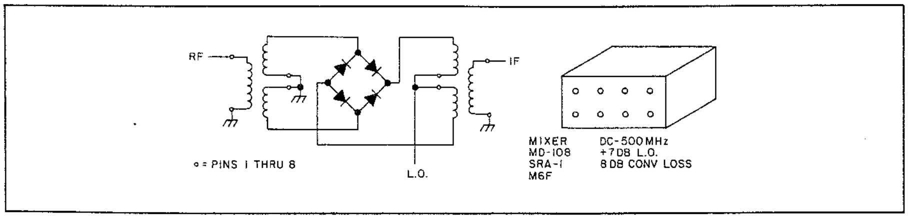

Fig. 1. Common doubly-balanced mixer design for Dc–500 MHz.

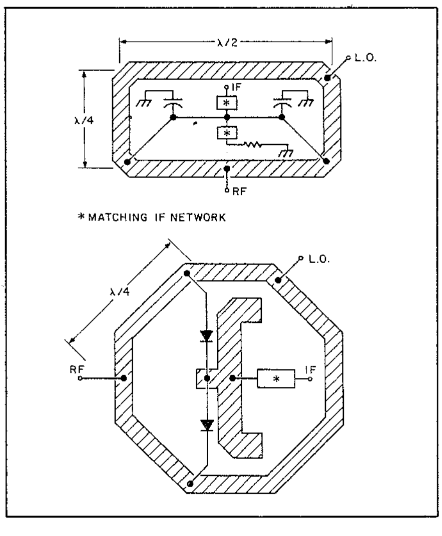

Fig. 2. Rat Race mixers 1.3 GHz (not to scale).

wave at the junction (a rather large discontinuity). There is a ratio to determine how much you should slice off, but, not being a purist, I elected to remove about 25% of the junction and it seems to work out OK. An alternative method is to use rounded bends with a radius of three to four times the stripline width. See Fig. 3 for details on the junction mitering.

PC Board Materials

There is a field full of printed circuit board materials to choose from, including paper, epoxy, fiberglass, Teflon™, and ceramics. Each has a different dissipation factor and dielectric constant depending on the material used as the host for the copper substrate. Paper is not a good choice, since it acts as a wick which absorbs moisture from the surroundings, which eventually ruins the dielectric. Epoxy and fiberglass are good board materials, and the G-10 variety glass epoxy can be used up to the 1-2-GHz microwave bands with reasonable results. Almost all printed circuit boards used today use a good quality glass-epoxy. It has a dielectric constant of about 5.5.

The next upgrade in printed circuit board material is Teflon or Duroid. Both types of board have a dielectric constant of about 2.2 to 2.5 and are excellent selections for use at microwave frequencies. They offer excellent dimensional stability in high-temperature and high-humidity environments without affecting the board. They are also very resistant to solvents and chemicals.

By the way, if a board states it has 1/2 oz. of copper, it means that the PC board has a .0007-inch-thick layer of copper on one side (1 oz. of copper equals approximately .0015-inch-thick copper; 2 oz. equals approximately .0020-inch-thick copper). Also, the copper is not applied to the Teflon with adhesives or glue, but is pressed on with heat and considerable force; it does not come off once pressed!

With all this now in firm grasp, I proceeded to construct the 3-dB hybrid mixer. This unit looks somewhat like a figure "H" lying on its side with a large square hole in its center. This mixer was the first successful hybrid type that I constructed (see Fig. 4).

This mixer consists of three sections: the input coupler, the diode array, and the i-f matching network. I have used this mixer in a lot of designs, the most recent being the 1296-MHz ATV receiver (October, 1985, *73 Magazine*). I also used the same mixer design in a receiver for 2300 MHz and 4200 MHz. I never had a failure with this design and am very impressed with it.

To sum up the performance of the singly-balanced mixer, it is easy to construct and a proven performer. The design uses few components and requires a lower-level local-oscillator power injection. However, the one drawback is that the isolation between ports is poor. Local-oscillator energy can be reflected into the rf port and all sorts of things can happen, such as spurious responses.

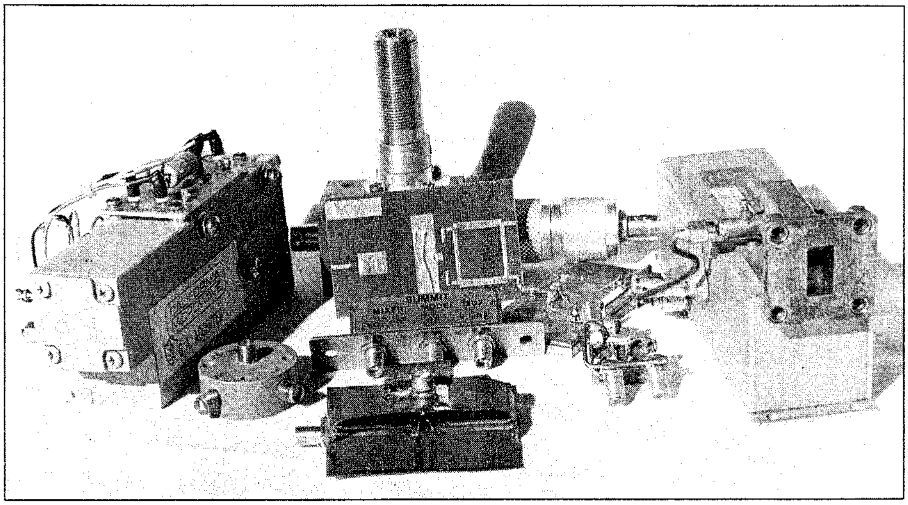

Photo C. A collection of the "building blocks."

Although it created problems of its own, the next mixer I tried proved to be the best overall. The design was first noted in a piece of surplus scrap that was torn apart to see what was going on inside. It was intended for 8-10 GHz, but the principle of its operation remains the same. The unit used two crossed lines looking like a tuning fork with another pair of crossed lines identical to the first. They were constructed on very thin Teflon PC board about .003 inches thick (the thickness of a piece of paper). The orientation of the two crossed lines was at 90 degrees with a 50-Ohm stripline tied to the input of each of the tuning-fork-like striplines. There was a third thin PC board that had four quarter-wave striplines that looked like a four-leaf clover, and at the junction of the quarter-wave stubs were four diodes alternating (anode, cathode, anode, cathode) connected to the stubs.

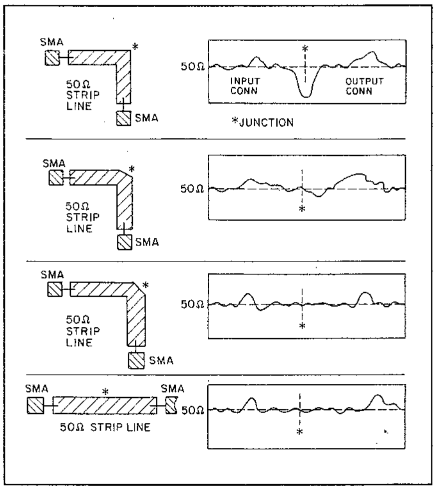

Fig. 3. Stripline junction mitering.

The common point of the four diodes was tied to a stripline for coupling into the device, and Eureka!—a doubly-balanced mixer. One friend's suggestion led to the final design of this mixer: Place it on one single piece of PC board with both striplines (the tuning-fork-looking guys) on one side and the four stubs on the opposite side of the board.

This simplifies the design over the original three-PC-board construction, and makes it easier to reproduce. I located a few pieces of .010" thick Teflon fiberglass material and laid out the mixer design. Even though I use the photographic process to reduce my hand-drawn artwork to proper size, other methods are available. The dimensions for the striplines are: on the diode side, all lines are .100" wide. For the other side (the tuning forks), the line width is .010"-.015" inch; at the point of connection to the coax connector, line width is .025"-.030".

If you use larger values in the etching, you will most likely have some undercutting producing something near the correct dimensions. Not being a purist, I find that you can violate lots of rules, but by not straying off too far, you still can have very good results. I do not have all the instrumentation at my disposal to find out all of my faults; I let performance prove out operation.

One method to make your own PC board is to place masking tape cut to the desired width on the PC board where you want the copper to remain. There is also PC artwork tape that comes in pre-cut widths. This is recommended for lines that are .010" thick. I use the Bishop Graphics PC tape, and it has worked well on these fine lines in early prototypes.

Lay out the tape and press it onto the copper surface firmly, being careful to cover all ar-

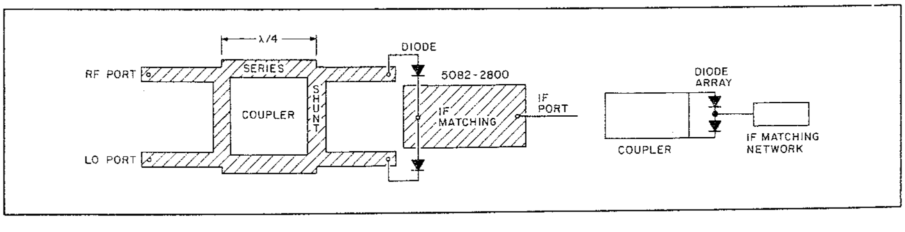

Fig. 4. 3-dB hybrid mixer.

eas you want to protect from the etch. Where you must overlap tape, press lightly with your fingernail on the overlap to reduce any air gap that etch may flow into and undercut the board. Check your tape carefully, as you want none of the tape to fall off in the etch. If it is pressed on firmly but not hard, it will hold. Also, don't press too hard with your fingernail, as this could deform the soft Teflon. I suggest that you use new ferric chloride so that the time in the etch will be at a minimum.

A variation of the above would be to cover the two sides of the board with a short piece of two-inch-wide tape. Lay out the pattern with a pencil and cut the lines with an X-acto™ knife, removing the pieces of tape where you want the copper to be etched away. Do not use hard pressure, or the knife will deform the PC board. See Fig. 5 for details, and Fig. 6 for the artwork for a 1.3-GHz mixer design.

I used several varieties of Hewlett Packard Schottky diodes in the mixers. The 5082-2800 (1N5711) family is available at Radio Shack. The 5082-2835 is a better choice, but could be a problem to find. Some of the mail-order houses have them in stock.

Each diode is mounted to the bottom of the stripline quarter-wave stubs at the junction. The diodes are mounted in an alternating fashion: anode side down, anode side up, anode side down, and finally, anode side up. The opposite sides of the four diodes are tied common, and together they form the i-f output port. It does not matter where you start placing diodes if they are uniform, matched, and alternate around the quarter-wave stubs. I mounted a wide strip of copper from the common foil (both sides' foil tied common) ground edge strip up over the i-f port coaxial connector and on to the opposite side ground foil, to provide a good ground return for the i-f port. Final assembly can be into a small metal box with the i-f port connector fixing the assembly in place. Then the other two connectors can be mounted on sides adjacent to each other at the flange end of the stub lines. Solder the flanges to the ground foil and the center pins to the terminus of the stripline couplers (the tuning-fork-looking guys).

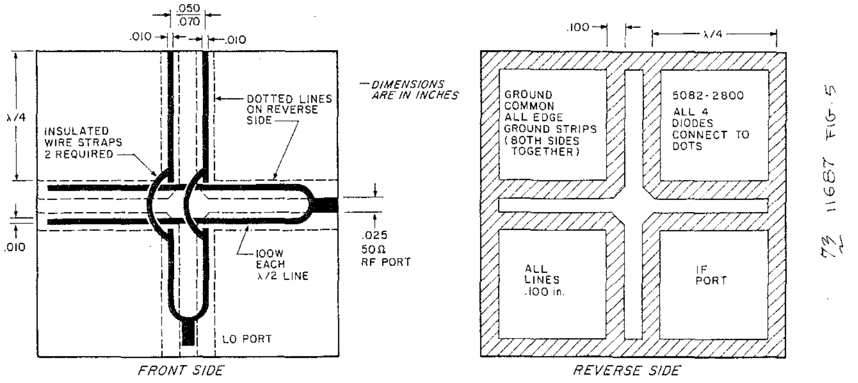

Fig. 5. Doubly-balanced mixer (not to scale).

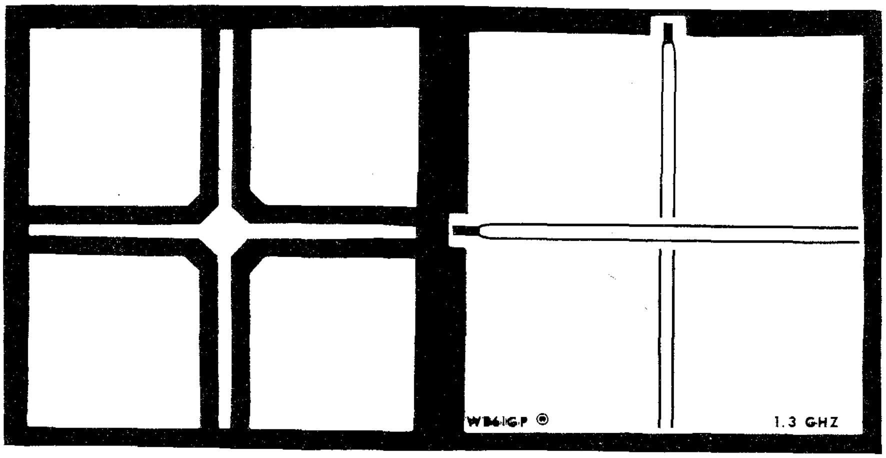

Fig. 6. Artwork, 1.3 GHz mixer. 1:1 scale.

Checkout/Operation

If the diodes are good and there are no solder bridges, the mixer should work without adjustment. Bandwidth for usable performance, according to the textbooks, is plus or minus 500 MHz, or 800 to 1,800 MHz. I tried the mixer out on 450 MHz because I have two calibrated signal generators for this band. I supplied 600 MHz at +8-dB injection into the LO port and connected the i-f port to my two-meter radio. Connecting my test signal generator to the rf port, I set it for 450-MHz input and found that I could reduce the power to the .2-uV level for very near full quieting on the two-meter i-f. Attaching a 450-MHz antenna, I was able to copy many repeaters and even tune up into the commercial band. It performed well.

I tried the mixer out with my trusty old klystron-powered 1.3-GHz signal generator and the results were much the same. Stability was poor, but that was due to the fact that the injection oscillator was free-running and drifting. However, that was the only source at the time that would drive the mixer with the required +8-dB LO injection. The sensitivity was 1 uV, but I believe part of that was in the loss of the coaxial cable used to connect to the input of the mixer. So far this is the most sensitive test that I have performed at this frequency.

I hope that those who undertake this project will find that this mixer is quite a performer and will serve many different uses. I plan to use the mixer in SSB converters for 1296 and 2300 MHz. There have been many articles on rf amplifiers. The device following the mixers will be one of the broadband amplifier modules. I have used the MC-5121 and the MWA-110/120-type monolithic amplifiers and they have worked for me in the past. Just remember to keep the i-f port terminated in 50 Ohms and you will not have any trouble with this or any other mixer.

One point of operation that I did not mention and have not tried is using the mixer in an upconversion mode, using the i-f port as an input, keeping the LO port for injection, and now using the rf port as the output source for driving an amplifier chain to drive a final stage.

This mixer is something UHF experimenters can play with and expand upon. As always, I would be happy to answer any questions concerning this project and other related items. Please enclose an SASE for a prompt reply.

If you are unable to obtain the double-sided Teflon PCB stock, I can provide the .010″-thick double-sided board for $5.50 U.S. postage-paid, or 5 pieces for $20 postage paid, in the U.S. It is available in other sizes up to .062 inches thick. I can also help out with the diodes if you can't obtain them locally; Radio Shack used to have them. ■

References

1. "Stripline 1296 Microwave Receiver," *73*, October, 1985.

2. *The Radio Amateurs Handbook*, 1985.

3. Relcom/Watkins Jennings, 2525 N. 1st Street, San Jose CA.

4. Anzac Electronics, 39 Green Street, Waltham MA 02154.

5. Mini Circuits Lab, 2625 E. 14th Street, Brooklyn NY 11235.

6. Radio Society of Great Britain *VHF/UHF Manual*, Chapter 4.