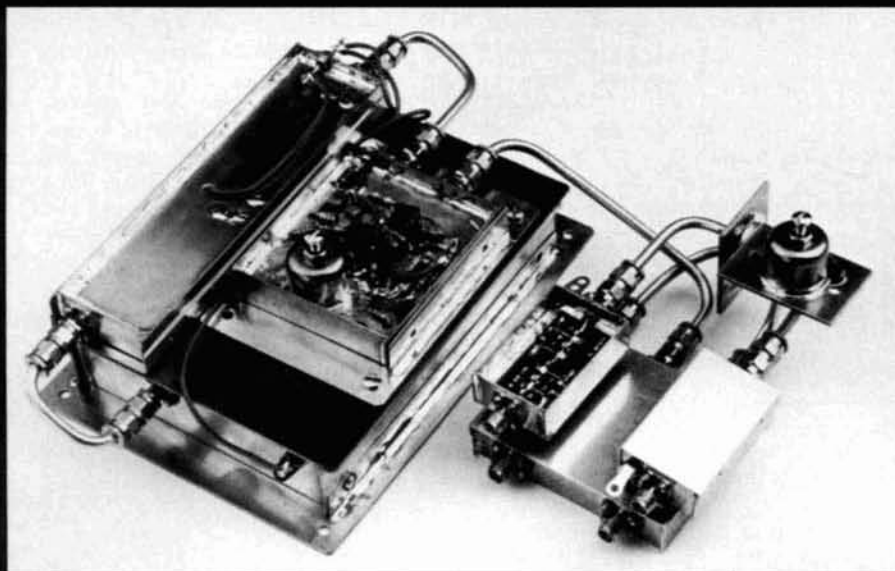# Home-Brewing a 10-GHz SSB/CW Transverter

Part 1—Narrowband 10-GHz operation—without exotic or surplus parts—has finally arrived for the microwave builder!

By Zack Lau, KH6CP
ARRL Laboratory Engineer

L ooking for some challenging micro-wave equipment to build? How about a complete 10-GHz transverter with stability good enough for weak-signal CW work? You don't have to find any exotic pieces to build this project—all of the parts are fairly common. In fact, everything has been available for years.

Despite the transverter's compact package, however, it consists of several modules that you must build. And although the VHF/UHF circuitry follows the no-tune concept developed by Jim Davey, WA8NLC; Rick Campbell, KK7B; and others, the X-band (10-GHz) parts need to be tuned up—preferably with a spectrum analyzer that works through 10.4 GHz.[1] To give you an idea what it takes to build this transverter, see the sidebar, "Should I Attempt This?"

Design Philosophy

Unlike the no-tune transverters,[2] I decided to develop the transverter as a set of building blocks with stainless-steel or gold-plated SMA connectors. Although this construction method is more expensive and time-consuming than a more integrated approach, it offers several advantages. Most importantly, it allows you to check small portions of the transverter for proper performance. If something doesn't work, trouble-shooting is fairly straightforward. And, if you just can't get one of the modules to work, you can simply build another one. Another advantage of this construction method is the shielding that results from packaging circuits in separate boxes. This helps greatly to keep

[1]Notes appear on page 28.

the transverter spectrally clean, with a minimum of spurious outputs and responses. Finally, the transverter is easily updated or expanded to take advantage of improving technology. Making its receiver section state-of-the-art is simply a matter of adding the 1-dB noise figure preamplifier described in December 1992 QEX.[3]

A Brief Overview

Fig 1 and Table 1 show the transverter's configuration and measured performance. A local oscillator (LO) feeds a power splitter that drives a pair of mixers. One mixer is used on transmit and the other on receive. The transmit mixer is followed by a filter and amplifiers. A filter following the final stage is optional. Low-noise amplifiers and an image-stripping filter precede the receive mixer. Without adequate image rejection, the receiver sensitivity can degrade by as much as 3 dB.

Table 1
10-GHz Transverter Performance*

Transmit Converter

144-MHz Drive (dBm)	10-GHz Output[†] (dBm)
−10.0	3.8
−3.0	8.5
0.0	10.3
1.0	10.8
3.0	11.6
5.0	12.2
10.0	12.8

Power Output versus Supply Voltage[†]

(Drive signal: −0.8 dBm at 144.06 MHz)

Supply (V)	Output Power (dBm)
10.34	8.5
10.51	10.0
10.75	10.0
12.34	10.0
14.02	10.0

Receive Converter

IF (MHz)	Gain (dB)	Noise Figure (dB)
144	8.82	2.73
146	8.79	2.70
148	8.79	2.71

Noise Figure and Insertion Gain versus Supply Voltage

(IF = 144 MHz)

Supply (V)	Gain (dB)	Noise Figure (dB)
10.3	6.59	3.03
10.7	8.81	2.92
10.9	8.64	2.89
11.3	8.59	2.79
12.4	8.68	2.75
13.4	8.70	2.74
13.5	8.73	2.76
14.9	8.75	2.74

*The data in this table comes from the most recently completed prototype, which consists of the modules described in Part 1 and Part 2 of this article.
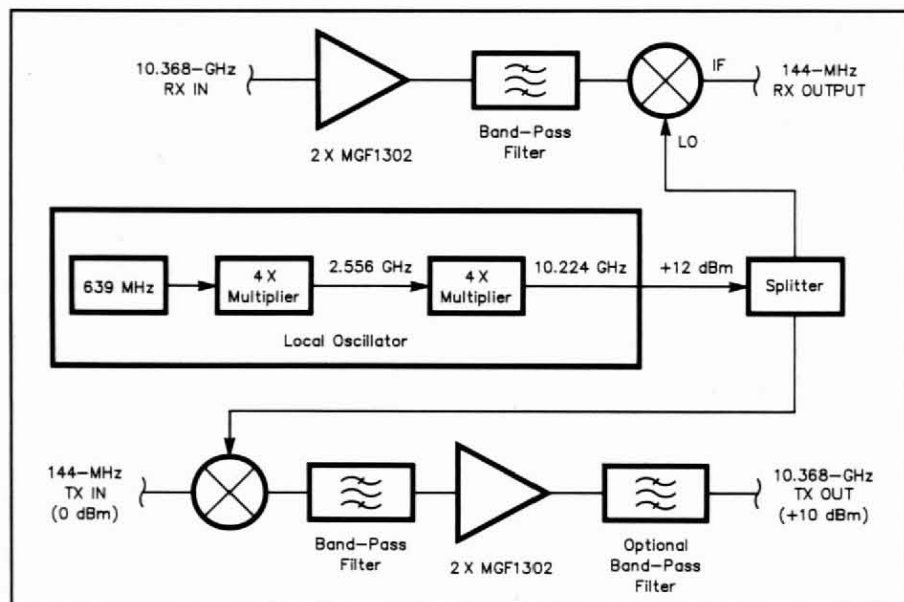[†]Power output was measured with an uncalibrated HP 435B/8481A.

Fig 1—Block diagram of the 10-GHz transverter.

The Local Oscillator

The most critical part of microwave narrowband work, the LO, starts off with the circuitry developed by WA8NLC and KK7B. The 106.5-MHz oscillator (Fig 2A) is multiplied by six (Fig 2B) to produce a 10-dBm (10-mW) signal at 639 MHz. This signal is then multiplied by four and amplified to 7 dBm at 2.556 GHz (Fig 3).

This is essentially the same scheme used in KK7B's 2.16-GHz LO in July 1989 QST,[4] except that I modified the filters for 639 and 2556 MHz. I also added a 0.47-μF capacitor to provide a low-impedance input for the 78L05 regulator (it can oscillate if not properly bypassed). These circuits are built on fiberglass-epoxy G10 or FR4 PC-board material; the remaining circuits are built on 5880 RT/duroid.

Choosing the Circuit-Board Material

This part was actually pretty easy: I looked around for something with low enough loss to work well, but that's also readily available to amateurs. The only stock item that meets this description is 0.015-inch-thick (15-mil) 5880 RT/duroid sold by Microwave Components of Michigan (see the sidebar, "Where to Get the Pieces"). I believe that Microwave Components of Michigan began stocking this board material in response to demand generated by the Tuesday Night Transverter published in the Proceedings of Microwave Update '88.[5] The thicker 30-mil 5880 RT/duroid is definitely unacceptable, as its radiation loss is rather high.

If availability wasn't an issue, I might have chosen a board thickness that helps to optimize stability via source inductance.[6] Another criteria for choosing board thickness is the interface with the transistors and connectors. Often, it is desirable to minimize the discontinuity between these interfaces by selecting trace widths comparable to the connector diameters and transistor-lead widths. The 15-mil board works pretty well in this area—the 46-mil trace widths fairly closely match the widths of the specified 50-mil chip capacitors.

Crystal Frequency

When choosing an LO crystal, the most important consideration is the crystal's calibration. The tolerance of the International Crystal Manufacturing high-accuracy crystal (#473590) I recommend is 10 parts per million. This means that the crystal can be as much as 1.06 kHz off the marked frequency without deviating from the specified accuracy. Because the LO is multiplied by 96, the transverter's conversion frequency could be as far as 102 kHz from the expected frequency, even without taking temperature variations into account. Although the oscillator circuit allows some adjustment to compensate for frequency error, attempting to shift the frequency seems to degrade stability.

To make sure that the conversion frequency falls inside the 2-meter band, I specify a 106.499-MHz crystal. Selecting a 106.500-MHz crystal might prove to be unwise if it was cut 10 ppm high—the usual calling frequency of 10.368100 GHz would be just below the 2-meter IF radio's 144.0-MHz band edge—a problem with some radios. You may want to choose another frequency, perhaps even lower, to move the IF to 145 or 146 MHz. If you do this, you'd be wise to investigate possible sources of interference. Keep in mind that hilltops are often pretty bad in terms of interference problems.

The stage following the 639-MHz to 2.556-GHz multiplier is a GaAsFET multiplier, filter and amplifier (Figs 4 and 5) that takes the 2.556-GHz input and provides at least 12 dBm at 10.224 GHz to the LO splitter/mixer board (to be described in Part 2).

Bias Supplies

I know it's not the cheapest way to go, but I decided to build a negative bias supply into each module that requires one (all the stages that use MGF1302s). This reduces the chance
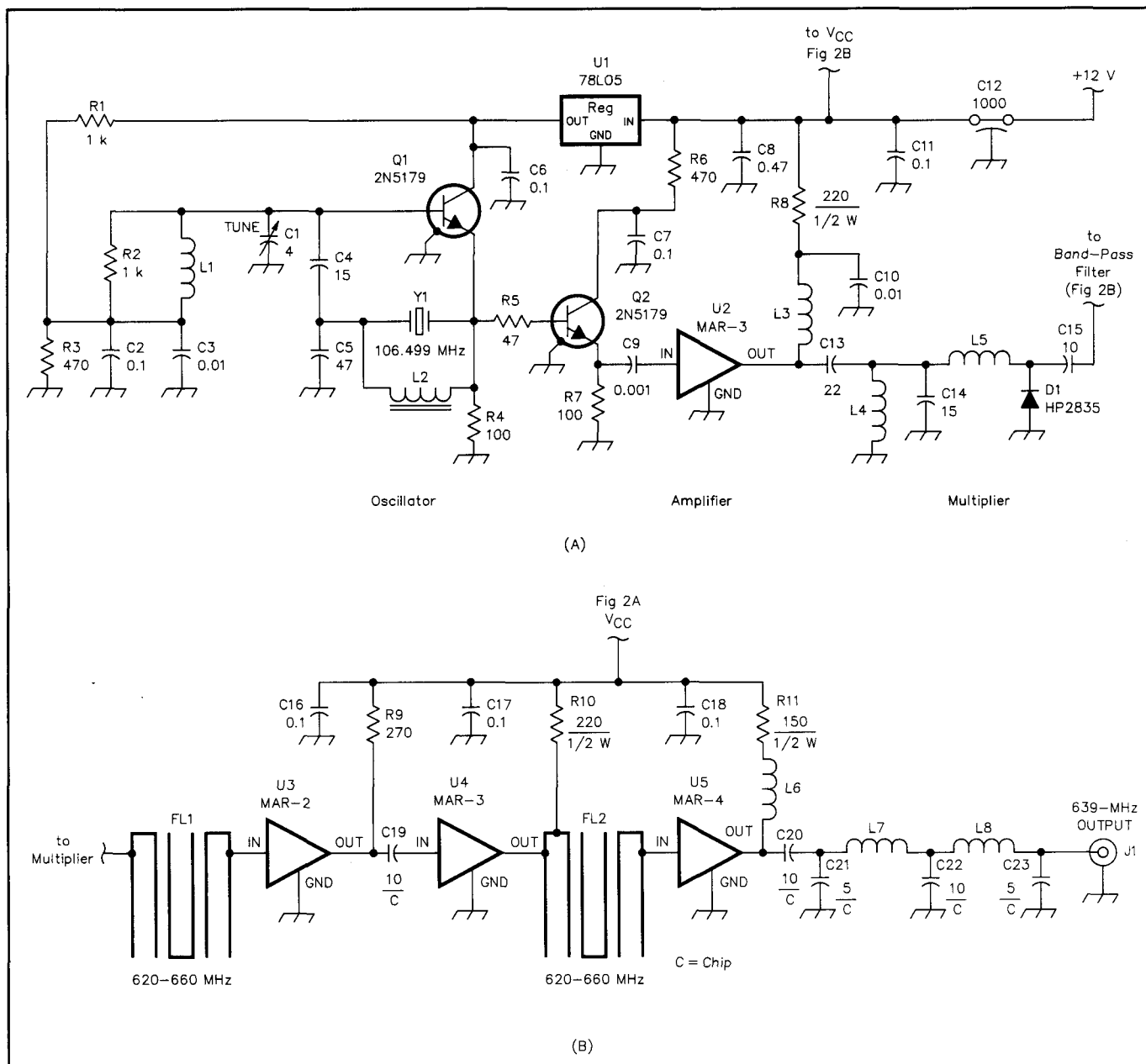
Fig 2A

(A) Oscillator — Amplifier — Multiplier

(B)

Fig 2—Schematic of the crystal oscillator and times-6 multiplier. Resistors are ¼-W carbon-film or carbon-composition types unless otherwise indicated.

C1—Air-dielectric trimmer capacitor that can be set to approximately 4 pF. Low temperature coefficient is more important than exact value, as L1 can be adjusted to compensate.

C8—Minimum value required to stabilize U1 is 0.33 µF. An electrolytic capacitor can be substituted if proper polarity is observed.

C12—1000-pF feedthrough capacitor. Exact value not critical (100 pF to 0.1 µF should work well).

D1—Schottky diode. Hewlett-Packard 5082-2835, -2811 and -2800 work well.

FL1, FL2—Band-pass filters printed on PC board.

J1—SMA female chassis-mount connector.

L1, L3, L4, L6—8 turns #28 enameled wire, 0.1-inch ID, closewound.

L2—12 turns #30 enameled wire on T-30-6 toroid core.

L5—5 turns #28 enameled wire, 0.1-inch ID, closewound.

L7, L8—2 turns #28 enameled wire, 0.062 inch ID, turns spaced one wire diameter.

Q1, Q2—2N5179 or BFR91.

U1—78L05 5-V, 100-mA, three-terminal regulator.

U2, U4—MAR-3 or MSA-0385 MMIC.

U3—MAR-2 or MSA-0285 MMIC.

U5—MAR-4 or MSA-0485 MMIC.

Y1—106.499 MHz, fifth-overtone, series-resonant crystal (International Crystal Manufacturing #473590).

of misconnecting the positive and negative supplies. I also opted for active bias supplies, as shown in Fig 5. This figure shows the two equations for calculating components for different bias conditions. For instance, to bias an FET at 3 volts and 30 mA, you first calculate the effect of any resistors used for stability. Often, a 51-Ω resistor is used to stabilize the circuit; if present, it increases the circuit bias voltage to 4.53 volts. One set of standard values that comes close to the bias conditions given above, and accounts for the 51-Ω resistors, is: $R_{dn} = 16 \ \Omega$, $R_{an} = 3.6 \ k\Omega$, and $R_{bn} = 1.1 \ k\Omega$.

I used Intersil ICL7660s to generate the negative bias supplies because they require few external parts. A cheaper alternative is to use NE555 timer chips as oscillators driving rectifiers.[7] I published such a circuit, with a PC-board pattern, in March 1991 *QEX*.[8]

Filter Construction

The transverter's band-pass filters are made from half-inch copper pipe caps, as shown in Figs 6 and 7. These were developed by Roman Wesolowski, DJ6EP; and Kent Britain, WA5VJB.[9] They're affordable, too:
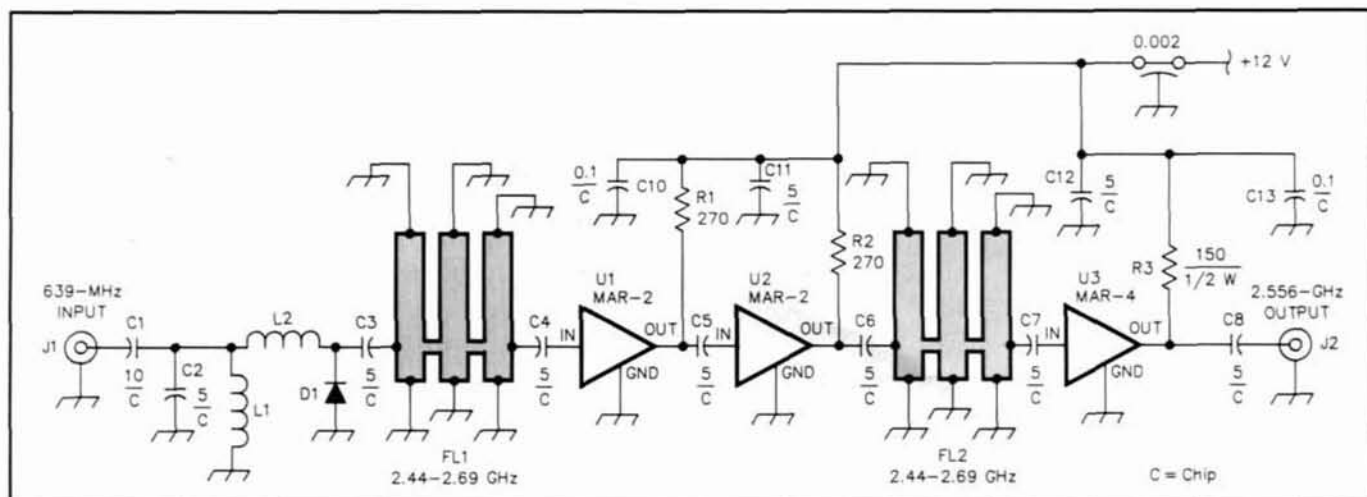
Fig 3—Schematic of the 639-MHz to 2.556-GHz multiplier. Resistors are ¼-watt carbon-film or carbon-composition types unless otherwise indicated.

D1—Schottky diode. Hewlett-
Packard 5082-2835 or equivalent.
J1, J2—SMA female chassis-mount
connector.

FL1, FL2—Printed band-pass filters.
L1—3 turns #28 enameled wire, 0.062 inch
ID, turns spaced one wire diameter.

L2—Printed inductor.
U1, U2—MAR-2 or MSA-0285 MMIC.
U3—MAR-4 or MSA-0485 MMIC.

You can buy half-inch plumbing caps at home-supply stores for as little as 12 cents each. (Designed to cap pipes that are 0.5 inch ID, these caps actually measure 0.62 inch ID and about 9/16 inch long.) I drill and tap the caps (at top center) with #4-40 threads and use nickel-plated brass screws; unplated brass screws should work as well. Kent Britain has forced steel screws through the caps to thread them. Don't use these screws for tuning, though, as steel is unacceptably lossy. I often polish my plumbing caps so that they look nice and solder easily.

A pipe-cap filter ahead of the mixer is adequate in terms of system noise figure, giving an image rejection around 24 dB with a 144-MHz IF. For critical applications, a waveguide filter, such as the one published by Glenn Elmore, N6GN, in July 1987 QEX,[10] is recommended. With such a filter, 50 dB of image rejection is easily obtained with a 144-MHz IF. However, for lightweight portable transceivers, plumbing-cap filters seem to be the best compromise. For a clean transmitted signal, you should use one at the final transmit amplifier's output as well.

The filters are built on unetched, double-sided, 1/16-inch G10 or FR4 PC-board material. I recommend that you use 0.141-inch semirigid coaxial cable (UT-141) to make the probes. A probe length of about 75 mils is optimum. If you cut them too short—say, 50 mils—the insertion loss climbs from an acceptable 1 to 2 dB to as much as 5 or 8 dB. If the probes are cut too long—say, 100 mils—the image rejection drops to a measly 10 to 14 dB, though the insertion loss also drops (to 0.5 dB). The probes are spaced 5/16 inch center to center and the pipe cap is soldered to the ground plane so that the probes are centered within it.

How do you determine the best probe lengths and spacing for pipe cap filters? I developed the filters in this transverter using

a spectrum analyzer and trial and error. The signal source was an X-band mixer and the 10.224-GHz local oscillator. I could have done a lot better with a network analyzer or a scalar sweep setup, but I used what was available to me.

Filter construction can be fairly critical for optimum performance. In particular, the probes must be accurately cut to length. I estimate my error margin in measuring and cutting probe lengths to be about 10 mils. The ends of the probes are filed flat, not chamfered or rounded. Filter loss seems to be a few tenths of a decibel lower with the dielectric left on the probes, although it is easier to trim the probes exactly with the dielectric removed.

You may be tempted to use 0.085-inch

semirigid cable because it's easier to handle than UT-141. A similar filter I made using this material gives 24 dB of image rejection, but has 3.4 dB of loss. The probe length for this cable is 70 mils. A filter using 100-mil probes of 0.085-inch semirigid cable has only 2 dB of loss, but the image rejection drops to a barely acceptable 17 dB. UT-141 is better for this application.

I recommend that you assemble the cable and solder it to the ground plane *before* measuring and cutting the probe length. Otherwise, the length may change as you work on the cable. With these filters, a potential problem is caused by the center conductor moving around slightly, particularly when the cable is straight and the center conductor forms the center contact at the

Fig 4—Schematic of the 2.556- to 10.224-GHz multiplier. Resistors and capacitors are chip components. L1-L6 are source-lead inductances. L_{S1}-L_{S16} are stray inductances. Z1-Z45 are etched on the circuit board.

FL1—Pipe-cap filter. See Fig 6.
  Countersink the ground-plane side of the
  circuit board hole (by hand) to keep the

$\frac{1}{8}$-inch UT-141 probe center conductors
from shorting to it.

Q1-Q3—Mitsubishi MGF1302 GaAsFET.
  Substitution not recommended.

connector end. Bending the cable helps to prevent this problem, but the best solution is to use connectors that captivate the center conductor, keeping it from being pushed inward.

Enclosures

As shown in the title photo, I use 0.025-inch-thick, half-inch-wide brass sheet stock to make the enclosure walls. Instead of

soldering SMA connectors to the walls, I attach them with #2-56 screws; either method is acceptable. The 25-mil brass stock is ideal for tapping small screw holes. Other commonly available thicknesses can also be used, although 20-mil stock is a bit flimsy and 32-mil stock is more difficult to solder.

Duplicating the Circuit Boards

Using PC-board layout software, I've de-

veloped artwork for each of the transverter's circuit boards. To make it as easy as possible for *QST* readers to build this transverter, ARRL HQ is making the circuit-board artwork available in three forms: as PostScript files downloadable from the ARRL HQ telephone BBS; as negative film for those with access to photographic methods of circuit-board production; and as laser-printed positive images that can be transferred directly to

+10–15 V dc

C16
0.002

D1
1N4001

C10 0.47

U1
78L05
Reg
IN   OUT
GND

C11
0.47

R7
47

10 μF
16 V T

C12
0.01

U2
ICL7660
8 V+   VOUT 5
2 CAP+
4 CAP−
GND
3

C13
10 μF
16 V T

(A)

Except as indicated, decimal values of
capacitance are in microfarads (μF);
others are in picofarads (pF);
resistances are in ohms; k=1,000, M=1,000,000.
T = tantalum electrolytic

R8
200

FET
BIAS

C14
0.01

R9
16

to
V_{d1}

Q4
2N3906

R13
10 k

R12
10 k

R10
1.1 k

to
V_{g1}

R11
3.6 k

C15
0.01

to
V_{d2}

Q5
2N3906

R14
16

R18
10 k

R17
10 k

R15
1.1 k

to
V_{g2}

R16
3.6 k

to
V_{d3}

Q6
2N3906

R19
16

R23
10 k

R22
10 k

R20
1.1 k

to
V_{g3}

R21
3.6 k

+5 V

to
V_{dn}

R_{dn}

Q_N
2N3906

R_{nn}
10 k
−5 V

R_{gn}
10 k

R_{bn}

V_b

to
V_{gn}

R_{an}

$$R_{dn} = \frac{5 - V_{dn}}{I_{dn}}$$

(B)

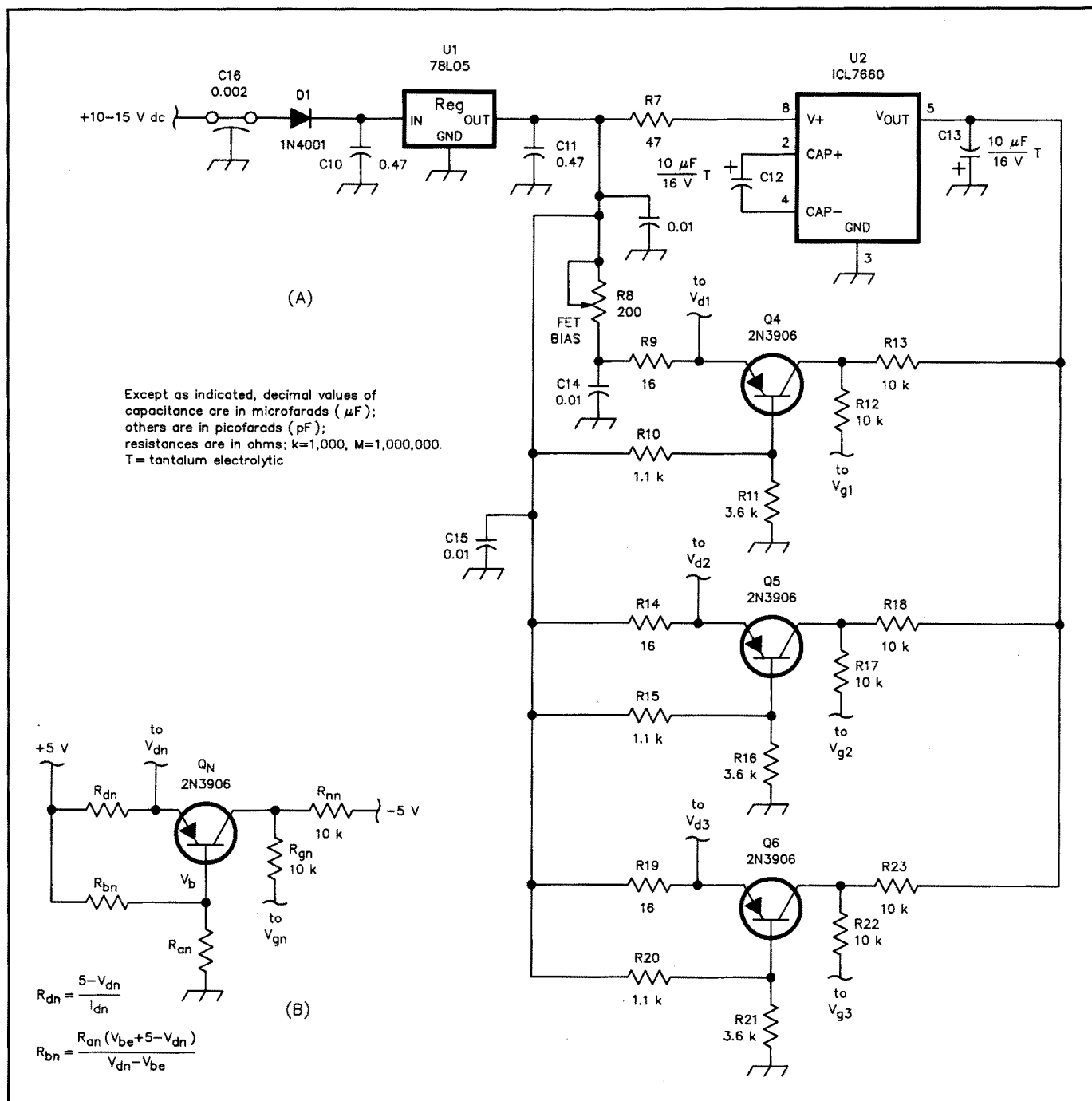$$R_{bn} = \frac{R_{an}(V_{be} + 5 - V_{dn})}{V_{dn} - V_{be}}$$

Fig 5—At A, schematic of the multiplier bias supply. At B, generalized FET bias circuit and equations.

C12, C13—Tantalum electrolytics preferred, but aluminum electrolytics should work.
C16—Feedthrough capacitor. Value not critical.

D1—Reverse-polarity protection diode.
Q4-Q6—General-purpose PNP transistor; 2N3906 and MPS2907 suitable. Plastic-cased devices are easiest to use.

R8—200 Ω used in the prototypes. 100 or even 50 Ω may be suitable.
U1—78L05 5-V regulator.
U2—ICL7660 negative-voltage generator.

the PC-board material.[11]

Several methods are available for transferring toner from the laser engine to the circuit board. Plain paper is my favorite.[12] Start with a clean circuit board (roughed with 400-grit sandpaper) and a laser-printed reversed positive image of the board on plain paper. Then use an ordinary household iron at its linen setting to iron the image onto the board. Buffer the iron from the sheet of paper with the pattern on it with a second, clean sheet of paper. Run the iron over the board in

a pattern that uniformly heats the material for 30 seconds or so for the 15-mil Teflon boards and at least a minute for the G10/FR4 boards. The iron's heat liquefies the plasticized toner and fuses it to the circuit board.

After ironing, place the board and paper (now fused to the board) into plain water for a few minutes, then remove it from the water and carefully rub away as much of the paper as you can. If the transfer process leaves incomplete traces, clean the board again with sandpaper and start over with a new copy of

the artwork. You can correct minor imperfections with an etch-resist pen and carefully cut pieces of Scotch tape. Cover the bottom (ground-plane) side of each board with Scotch tape, then etch the boards. Peel off the tape and remove the toner with plain steel wool.

Oscillator Construction

I didn't develop circuit-board artwork for the 106.5-MHz local oscillator. If you want stability adequate for a 10-GHz SSB/CW system, a quartz-crystal-controlled system is

marginal—you really can't throw away any stability to make construction easier. Remember: *The LO is multiplied by 96 before being mixed with the 144-MHz IF*
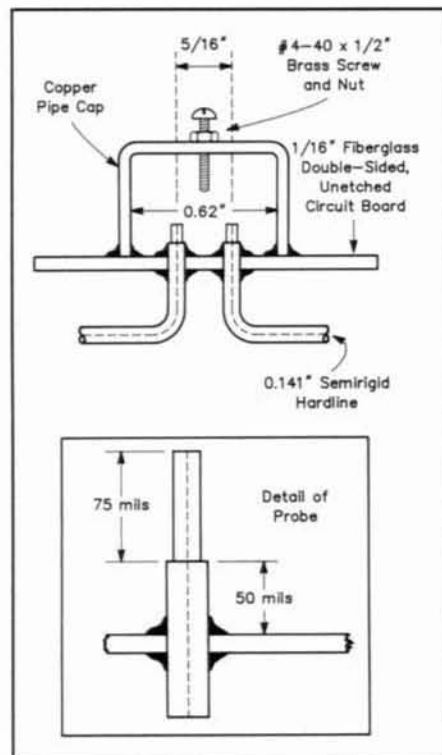

Fig 6—Simple and effective 10-GHz filters can be made using copper pipe caps and probes made from 0.141-inch semirigid coax. The total probe length above the ground plane is 125 mils (⅛ inch). Solder the pipe cap to the ground plane so that the probes are centered within it. A #4-40 × ½-inch brass (or nickel-plated brass) screw with a lock nut tunes the filter.

signal! You could use a double-sided circuit-board layout, except that stability is ten times worse than that of a ground-plane version. So, I opted for the ground-plane version (Fig 8A). I also used a high-stability, air-dielectric trimmer at C1, as some ceramic trimmers have a high temperature coefficient. The trimmer value isn't critical, as L1 can be adjusted to compensate.

I recommend that you build and align the oscillator as follows. Build the oscillator with a 47-Ω, ¼-watt resistor in place of the inductor/crystal combination (L2 and Y1). When you power up the circuit, tune C1 so that the oscillator operates at 106.5 MHz. After replacing the 47-Ω resistor with the crystal and its resonating inductor, verify that the oscillator starts reliably as power is applied. A minor adjustment of C1 may be necessary for reliable starting. I don't recommend trying to adjust C1 for a given oscillation frequency.

The 639-MHz to 2.556-GHz multiplier (Fig 9) has no tuning adjustments. You simply verify that its power output is between 5 and 10 dBm.

Amplifier Design

I chose to use MGF1302 GaAsFETs for all the 10-GHz circuits. These seem to be the most readily available, low-cost parts that work well at this frequency. The transverter uses seven of them, and they cost less than $7 each from several sources—see the sidebar, "Where to Get the Pieces." Ideally, a transverter like this would use 10-GHz MMICs for gain blocks, but these weren't available during project development. Not only were the available packaged GaAs MMICs too pricey (around $40 each), but they weren't designed to work at 10 GHz. The second choice was the Avantek ATF13735, but commercial purchasers have
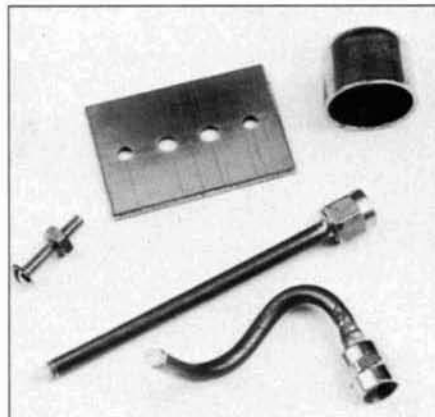

Fig 7—The pieces that make up a 10-GHz band-pass filter, before assembly. *(photos by Kirk Kleinschmidt, NT0Z)*

made the standard part the short-leaded ATF13736, which is more difficult to use than the long-leaded version. I prefer to use devices with long leads since they're easier to install in circuits that use lead inductance as a circuit component.

Multiplier and Amplifier Construction

In each of the transverter's building blocks, I build the RF circuitry on one side of the ground plane and the biasing circuitry on the other. After etching the boards, I drill and countersink holes for the power leads. Also countersink the ground-plane foil around the multiplier board's filter-cable holes so that the UT-141 center conductor doesn't short to the ground plane. Countersink the holes *by hand* with a relatively large drill (³⁄₁₆ to ¼ inch). It's important to do this manually—you'll be surprised how easy it is to drill through such thin, soft material! Cut slots for the FET source leads as discussed in the next section. Then add the brass walls
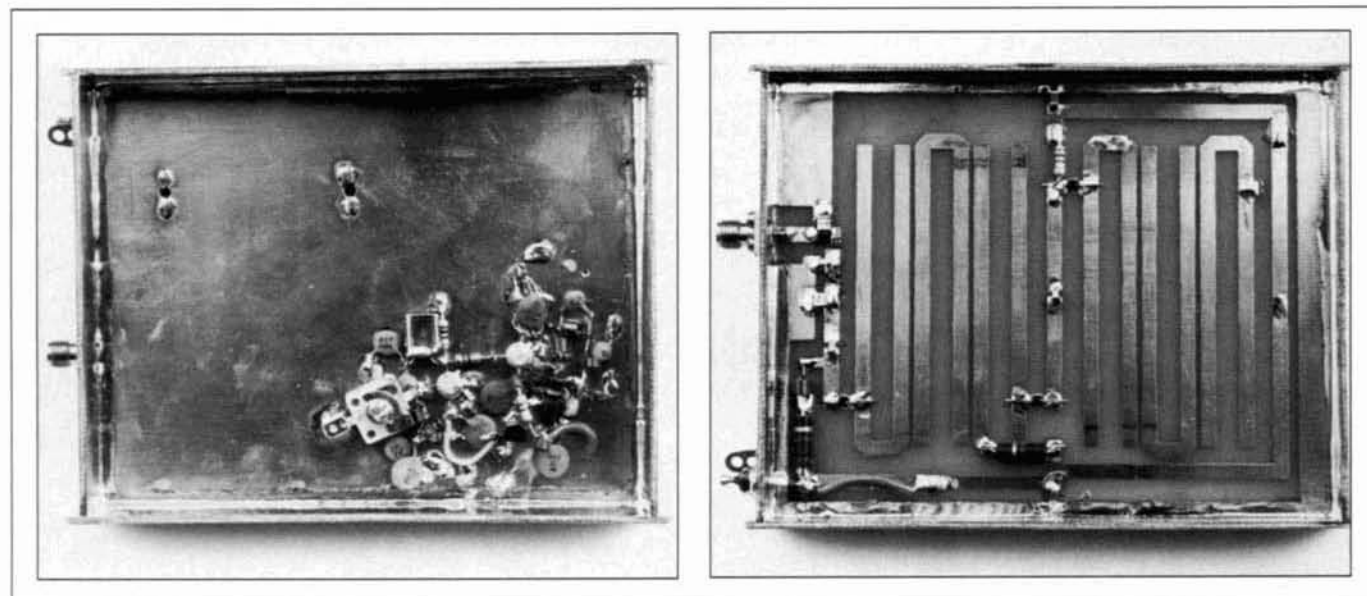
Fig 8—At left, a photo of the 106.5-MHz oscillator circuit, built ground-plane style on the back of the 639-MHz multiplier board. Oscillators built this way exhibit stability an order of magnitude better than etched PC-board versions. This is especially important for minimizing drift at the 96th harmonic of the oscillator frequency—10.224 GHz. At right, a top-side view of the 3¾- × 4¾-inch assembly shows the 639-MHz etched band-pass filters.
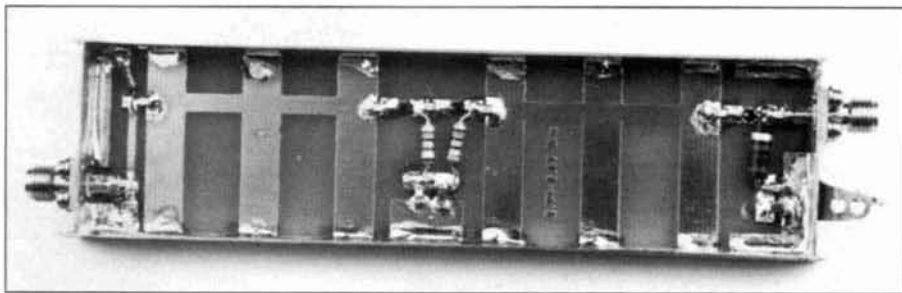
Fig 9—The 1 ¼- × 5-inch 639-MHz to 2.556-GHz multiplier board uses MMICs to provide a 5-mW filtered intermediate LO signal that drives the 10.224-GHz multiplier.

and install the connectors. Build the biasing circuitry after the transistors are installed.

Circuit performance may be improved slightly, as discussed in the next section, though the design is relatively broadband and should operate adequately despite minor construction variations. Computer simulations predict gain flatness within a decibel across the 10-GHz band.

I glue RF-absorptive rubber or foam to the insides of the enclosure lids. This reduces the chance of waveguide effects disrupting circuit operation.[13]

GaAsFET Installation Tips

Beware of soldering irons with significant ac leakage. People blow up lots of devices because their soldering iron tips aren't at ground potential. Measure your soldering iron's tip-to-ground potential if you have any doubts.

The circuits in this transverter use the GaAsFET source-lead inductance as a circuit component. Use the photos as guides when installing them. Bend the source leads down at the ceramic device body, then insert them into holes carefully cut in the circuit boards using a #1 X-ACTO blade or similar weapon, as is done in *The ARRL Handbook*'s GaAsFET preamplifiers.[14] Be sure to cut the holes so that the device is centered on the board traces. Once the device is installed, bend the source leads up flush with the bottom of the board and solder them to it.

Of course, take the usual precautions when handling GaAsFETs, which are static-sensitive. Chapter 24 of *The ARRL Handbook* discusses these practices.

Adjusting the 2.556- to 10.224-GHz Multiplier

First, adjust the filter-tuning screw for maximum output. Next, set the bias trimmer for maximum power output. You may then want to tune the amplifiers. Do this using a tuning tool made out of a ⅟₁₆-inch-square piece of thin copper sheet or foil stuck into the end of a piece of Teflon tubing. Slide the tool along the input and output lines, looking for hot spots—places where the presence of the foil makes the power output increase. After finding them, turn off the power. Next, solder a piece of foil at each hot spot and adjust its position with high-quality tweezers.

Coming in Part 2

When you finish building the blocks described this month, you'll have a clean 10.224-GHz local oscillator. Next month, I'll describe the mixer/splitter board and the preamplifier/power amplifier circuit, and some 10-GHz antenna ideas.

Notes

[1] It *may* be possible to tune up the system using a Gunnplexer unit with an S meter, but I haven't attempted it and can't guarantee that it will work. A Gunnplexer should be able to pick up a properly functioning LO even with lots of attenuation between them.

[2] *QST* has published a series of no-tune transverters developed by KK7B and WA8NLC, including versions for 903, 2304, 3456 and 5760 MHz. The most recent of these is J. Davey, "A No-Tune Transverter for the 2304-MHz Band," *QST*, Dec 1992, pp 33-39. See the notes at the end of D. Mascaro, "A High-Performance UHF and Microwave System Primer," *QST*, May 1991, pp 30-33, for details on the others.

[3] Z. Lau, "The Quest for 1 dB NF on 10 GHz," RF, *QEX*, Dec 1992, pp 16-17.

[4] R. Campbell, "A Clean, Low-Cost Microwave Local Oscillator," *QST*, Jul 1989, pp 15-21.

[5] K. Bailey, R. Larkin and G. Oliver, "TNT for 10 GHz," *Proceedings of Microwave Update '88* (Newington: ARRL, 1988), pp 80-95. This book (and other conference proceedings referenced here) is available from the ARRL Publication Sales Department for $12 plus shipping and handling.

[6] Amplifier stability is affected by the inductance of the FET source leads.

[7] I've also used little surplus boards with surface-mount NE555s, although some of these are poorly constructed and had to be resoldered for reliable operation.

[8] Z. Lau, "Power Supply for GaAsFET Amplifier," *QEX*, Mar 1991, pp 10-11.

[9] K. Britain, "Cheap Microwave Filters," *Proceedings of Microwave Update '88*, pp 158-162.

[10] G. Elmore, "A Simple and Effective Filter for the 10-GHz Band," *QEX*, Jul 1987, pp 3-5, 15.

[11] The ARRL BBS can be reached at 203-666-0578 (1200/2400, N, 8, 1); one 250-kbyte file, KH6CP10G.ZIP, contains all the PC-board artwork. Send paper and film artwork requests to the Technical Department Secretary, ARRL, 225 Main St, Newington, CT 06111. Request the MAY 1993 *QST* KH6CP 10-GHz TEMPLATE and be sure to indicate whether you need paper or film artwork. The template package also includes part-placement diagrams for the transverter's circuit boards.

[12] This method will be more fully described by John Grebenkemper, KI6WX, in an upcoming *QST* article.

[13] K. Britain, "Works Great! Until You put it in the Box?," *Proceedings of the 25th Conference of the Central States VHF Society* (Newington: ARRL, 1991), pp 33-34. See Note 5 for ordering information.

[14] L. Wolfgang, ed, *The ARRL Handbook for Radio Amateurs*, 1993 ed (Newington: ARRL, 1992), pp 32-22 through 32-38.
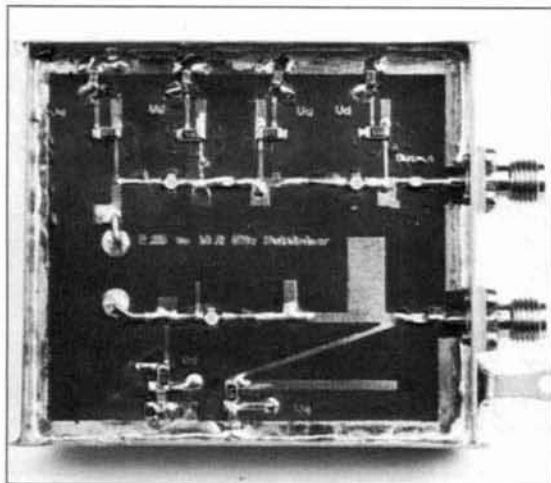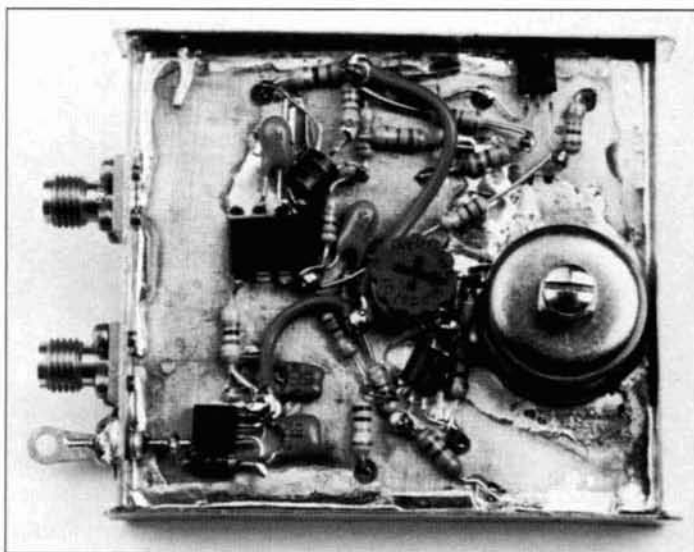
Fig 10—At left, the business end of the 2⅛- × 2⅜-inch 2.556- to 10.224-GHz multiplier module. At its far left, the UT-141 probes couple to the pipe-cap filter shown at right. The FET biasing circuits are also shown at right.

Home-Brewing a 10-GHz SSB/CW Transverter

Part 2—Designed to work with last month's 10.224-GHz local oscillator, this month's mixer, power amplifier and preamplifier round out your narrowband 10-GHz transverter.

By Zack Lau, KH6CP
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In Part 1,[15] I described a 10.224-GHz local oscillator (LO) designed to drive a dual-mixer board like those used in the no-tune transverters. If you've completed the modules described last month, you should have a working 10.224-GHz LO. The mixer board described this month contains a two-way etched power splitter that delivers equal LO signals to the transmit and receive mixers, which are also etched on the same PC board. On transmit, one of the mixers combines a 144-MHz IF signal with the LO to generate a 10.368-GHz signal; on receive, the other mixer combines the incoming 10.368-GHz signal with the LO to produce a 144-MHz IF output. An external pipe-cap filter (described last month) in each 10-GHz mixer line eliminates the image, passing only the desired signal. Two-stage GaAsFET amplifiers of the same RF design, but using different bias settings, serve as a 10-GHz preamplifier and power amplifier.

Part 1 also shows the transverter block diagram, and covers construction techniques and etching-pattern availability for the transverter's circuit boards, component sources, and performance data for the finished transverter. I suggest that you review that before going ahead with construction of this month's modules.

Mixer Construction and Tweaking

If you're building transverters from surplus hardware, the most difficult module to obtain is not the LO, but the mixer. Builders have gotten widely varying results, even when copying the same design. For most people, 10 GHz is just too high a frequency to accurately build a no-tune mixer that works well. The difficulty is that a full-wavelength microstrip transmission line is only 0.6 inch long at 10 GHz. So, a typical rat-race mixer (which requires signals to be 180° out of phase for proper cancellation) really needs to built with tolerances under 0.005 inch (5 mils).

This problem has several solutions. One is to simply accept the inferior performance. Usually, the conversion loss isn't too bad if you copy a known-good layout, but the LO rejection relative to the PEP output signal can be as little as 10 dB. For receive purposes, LO

rejection really doesn't make much difference.

A better solution is to tune the mixer. Once you've etched and assembled the mixer board, terminate all ports in 50-Ω loads or sources. You don't want to look at the mixer though an image-reject filter, unless it is properly tuned. Otherwise, the mixer and filter tuning will interact, making it difficult to adjust the mixer for proper operation. I normally connect the mixer to the LO, attach a 0- to -10-dBm, 50-Ω 144-MHz source at the IF port, and a spectrum analyzer at the RF port.

I usually adjust the LO rejection first. This is done by placing a small piece of copper foil at point A or B indicated in Fig 11—at either side of the junction between the 70-Ω ring and the LO-input line. This shortens the transmission line slightly on one side. Usually, the LO suppression improves with the copper at one point and worsens with it at the other point. True, the copper foil mismatches the amplitude slightly, but this is better than having an improper phase shift. Usually, LO rejection is 17 or 18 dB below the saturated output (this equates to the specification-sheet figure of 27 or 28 dB of LO-to-RF port isolation). Keep in mind that even a lid covered with absorptive rubber or foam affects the tuning slightly. You don't want to tune the mixer to perfection only to have to retune it after installing a cover.

I find that the obtainable LO rejection depends on how well I made the board. Mixer rings that look almost perfect often allow 5 or 10 dB better rejection; ones that look as if they were drawn quickly with a crayon may be almost impossible to tune (though they often work just fine for receive).

Finally, tune the mixer's RF port for maximum output into a 50-Ω load (as described in Part 1 under "Adjusting the 2.556- to 10.224-GHz Multiplier"). I've been unable to etch mixers consistently, so all of my mixers are a little different.

Three short wires, 0.21 inch of #28 enameled wire, serve as 10-GHz RF chokes and 144-MHz shunts at the mixer board's RF and LO inputs (Fig 11).[16] This improves the isolation between the mixer's IF ports. Without them, there is little to stop a 2-meter signal from crossing the power divider. Adding these wires increases the isolation between the IF ports from an almost negligible 4 dB to a decent 40 dB.

It shouldn't be necessary to tune the load termination, though you may want to. As you might guess from the layout, I tacked on the radial stub to ground the 51-Ω chip resistor. Purists may want to use a 68-Ω resistor and tune out the reactance to get a really good 50-Ω load at 10 GHz (as is done in the TNT[17]).
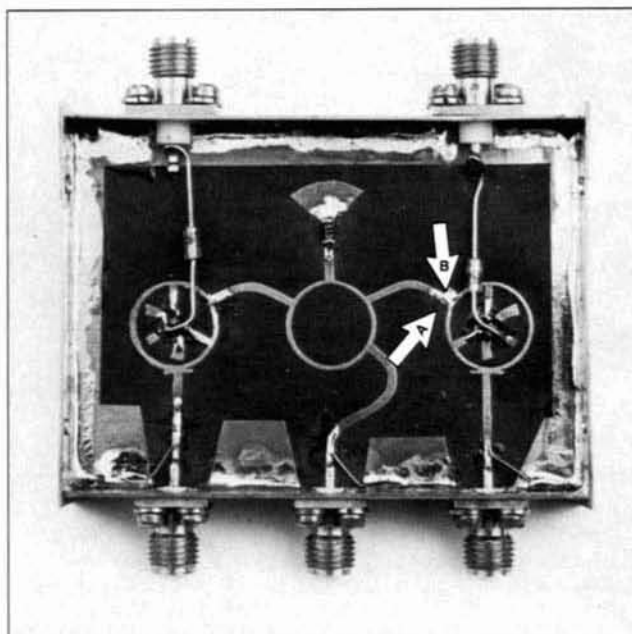

Fig 11—The splitter/mixer board. The IF ports (at top) are connected to the mixers via 0.01-μF encapsulated chip capacitors. Ceramic capacitors can be used instead. The mixers use Hewlett-Packard HSMS 8202 Ku-band diode pairs. The HP HSMS 2822 2-GHz diode pair can be substituted, but this device has more conversion loss at 10 GHz than the HSMS 8202. Mixer tuning for best LO rejection is done by adding a small piece of foil at point A or point B. *(photos by Kirk Kleinschmidt, NTØZ)*

[15]Notes appear on page 31.

If you have them, you can also use 50-Ω microstrip terminations for this; I've gotten them from surplus isolators.

Power Amplifier and Preamplifier

The same RF design is used for the transmit and receive amplifiers (see Figs 12 and 13). Tripling the bias current from the 10 mA used in the receive-side amplifier to 30 mA in the transmit amplifier increases the circuit's 1-dB compression point from 5.7 to 10.8 dBm. Gain increases from 18 to 19 dB and the noise figure rises by about 1 dB. Computer-modeling results indicate that the Rollett stability factor, K, drops a little, but since it's still above 3 (a K greater than one denotes a stable design), this shouldn't be a problem—even if the amplifier is terminated at the input and output with a high mismatch (such as sharp filters).

It may be possible to get a bit more output by increasing V_{ds} to slightly more than the 3 volts I used, but this would require redesigning the bias circuit (Fig 5). Like many transistor amplifiers, this amplifier's saturated

output, typically 14 dBm, is more than twice the recommended output for linear operation.

System Integration

To complete the transverter, build two band-pass filters as shown in Part 1. You can tune them with the aid of the diode detector described in the sidebar, but a few minutes with a spectrum analyzer makes the process easier.[18] Then, following the block diagram of Fig 1, assemble the transverter's blocks. Connect a suitable IF radio, check to make sure the transmit converter and receive converter operate, and you're on the air!

Antenna Thoughts

Most people looking for a high-gain antenna end up with some sort of parabolic reflector. If you put a low-gain horn antenna in the right spot in front of a reflector that is anything close to a parabola, it will probably outperform anything of similar dimensions on this band. People have used everything from metal snow sleds to trash-can covers, in addition to

more obvious choices such as light collectors and surplus military/commercial gear. Commercial sources for new dishes exist, but even small dishes are expensive when purchased new. Look for a surplus reflector.

Perhaps the simplest antenna I've seen is a quarter-wave monopole—with a piece of sheet metal as the ground plane! The most complicated is undoubtedly a loop Yagi—it works, but it is more of a curiosity than a practical way of getting 18 to 20 dBi of gain. A horn is much easier to make. *The ARRL Antenna Book, The ARRL UHF/Microwave Experimenter's Manual*, the RSGB *Microwave Handbook, Volume 3* and various VHF/UHF/microwave conference proceedings contain duplicable designs. Chapter 18 of the RSGB *Microwave Handbook, Volume 3*, contains all the information you need to get started.

I have yet to adjust one of my 10-GHz antennas with an SWR meter, yet I've made lots of 10-GHz contacts of more than 200 km. Usually, if I do any tweaking at all, such as adjusting the location of a dish feed, it
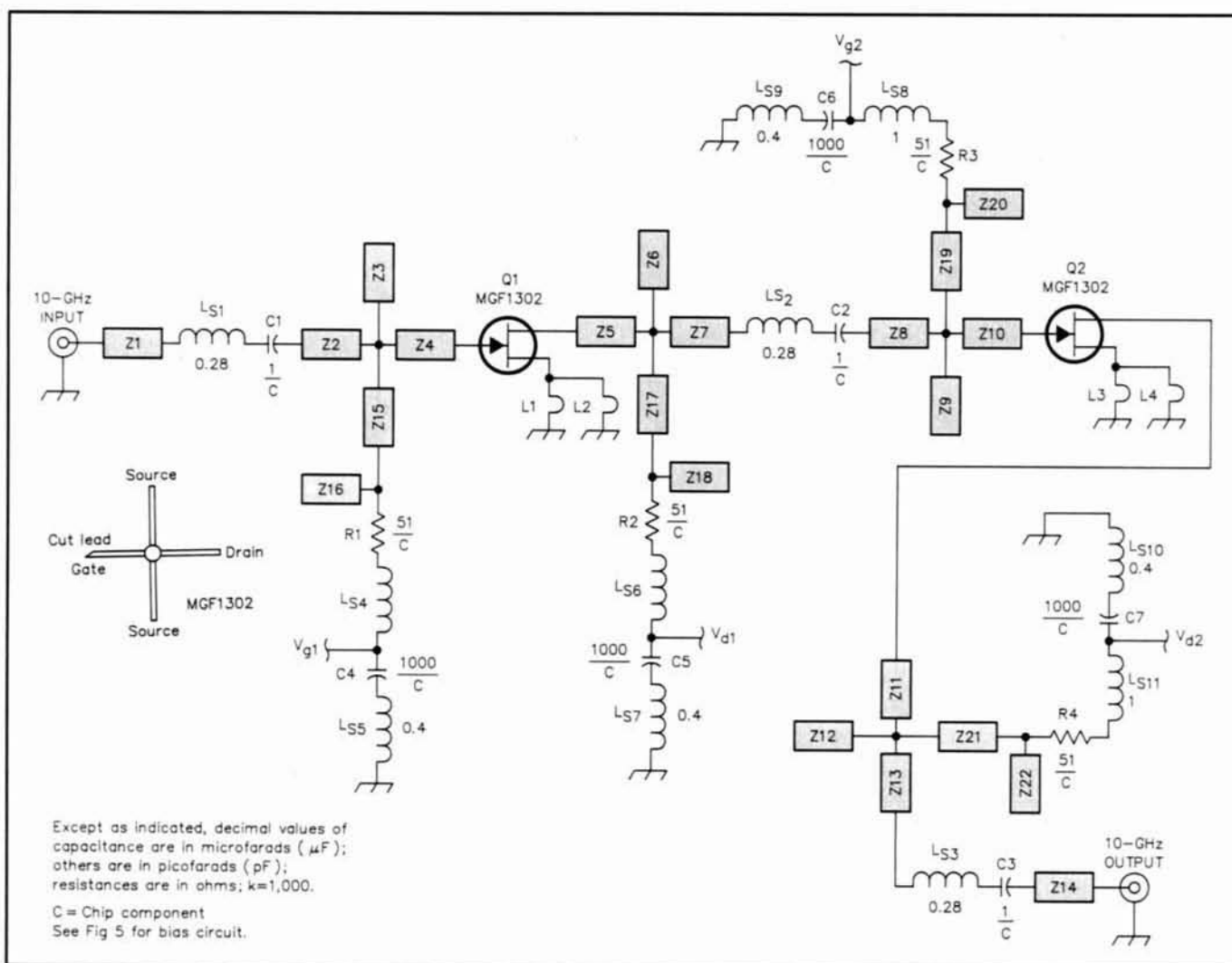

Fig 12—10-GHz low-noise amplifier. Chip components are used unless specified otherwise. L1-L4 are source-lead inductances. L_{S1}-L_{S11} are stray inductances (in nanohenries). Z1-Z22 are etched on the circuit board.

C1-C3—1 pF. Use high-quality, 50-mil ceramic chip capacitors such as ATC 100As.

Q1, Q2—MGF1302. Substitution not recommended. Set bias at 10 mA and V_{ds} = 3.0 V for low-noise receive preamplifier operation. For the transmit

amplifier, set bias at 30 mA and V_{ds} = 3 V. For additional biasing information, see the text and Fig 5.

10-GHz Power Measurement

Measuring RF power at 10 GHz presents a challenge; calibrated measurement devices can be very expensive. Fortunately, measuring *relative* power requires only a diode detector and a sensitive dc voltmeter. The 10-GHz power measurements required to optimize this transverter needn't be absolute; relative power measurement is acceptable. A convenient way to measure power in a 50-Ω system is to couple some RF into a low-offset Schottky diode, such as a Hewlett-Packard 5082-2835 (commonly used as a microwave frequency multiplier), filter its dc output, and measure this voltage with a high-impedance voltmeter. This measurement approach gives useful output down to the milliwatt level. Of course, you can also use a commercial diode detector rated to 10 GHz.

To build a detector, etch or cut a 50-Ω microstripline on a small piece of Rogers 5880 RT/duroid with 1-oz copper cladding (the same material used in the transverter's 10-GHz circuits). See Fig A. A 50-Ω trace is 46 mils wide (0.046 inch) on this material. Terminate the microstrip in SMA connectors and enclose the board with brass strip for rigidity, like the transverter. Mount the diode and other components as shown in Fig A. Fig B shows the equivalent circuit. The length of the diode lead that runs along the 50-Ω stripline affects

Fig A—This 2- × 1¼-inch diode detector gives useful dc output for 10-GHz power measurement down to about 1 mW. It uses a low-offset Schottky diode (such as the HP 5082-2835), with its anode lead soldered to the ground plane. Its cathode lead follows the 50-Ω microstrip trace for about ¼ inch and is spaced about ⅛ inch from the trace (neither dimension is critical; a longer lead and closer spacing increase coupling). A 1- to 10-kΩ resistor, also soldered to the cathode lead, routes rectified energy to a feedthrough capacitor.
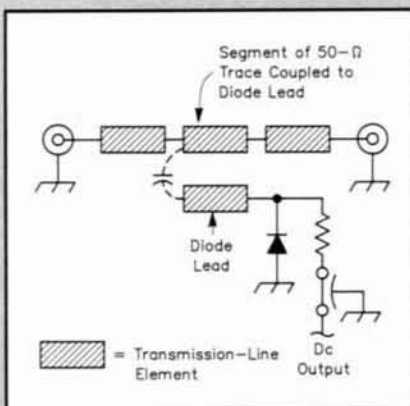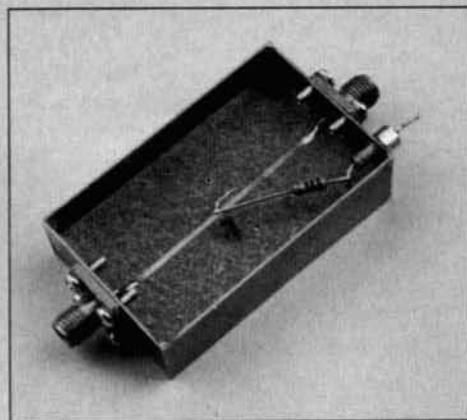

Fig B—Equivalent circuit of the diode detector.

the amount of RF energy coupled into the diode, as does its spacing from the microstrip trace.

This detector can be used for tuning the transverter's multiplier, filters and amplifiers. To use the detector, terminate one end in a 50-Ω load that's good to 10 GHz. (Alternatively, you can substitute a 50-Ω microstrip load for one of the SMA connectors.) Couple RF into the other port via a 3- to 10-dB attenuator, to ensure that the circuit under test is terminated with a stable 50-Ω load. Measure the voltage on the feed-through capacitor using a sensitive voltmeter or oscilloscope.—*Kent Britain, WA5VJB*

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has been for maximum received signal. Similarly, I've adjusted my coax-to-waveguide transitions this way, adjusting tuning screws for minimum loss. Of course, even SWR is no indication of how well an antenna really

works. The *real* test is to compare antennas and see which does best.

Summary

Although it takes some effort to build, the

transverter described in this two-part article provides useful and exciting 10-GHz SSB and CW capability. Perhaps the best part is that you don't have to hunt through flea markets to find a surplus "brick" LO and filters, or deal with any of the other traditional hassles of getting on this fun band! What hilltop will *you* operate from in this year's ARRL 10-GHz Cumulative Contest in August and September?

Notes

[15]Z. Lau, "Home-Brewing a 10-GHz SSB/CW Transverter," *QST*, May 1993, pp 21-28.

[16]Part-placement diagrams with component values and more detail for each of the transverter's modules are part of the template package obtainable from the ARRL Technical Department Secretary. See Note 11 for details.

[17]See Note 5.

[18]When tuning these filters, you can use the finished 10.224-GHz LO and a power meter (see the sidebar) to make sure that the filters aren't tuned to the LO or image frequency. To tune a filter, first connect it to the LO and adjust the tuning screw for maximum output at the LO frequency. Then adjust it for peak response at 10.368 GHz by connecting it to the transmit-amplifier output and backing the tuning screw *farther out of the filter cavity* while looking for maximum filter response. —*Ed.*
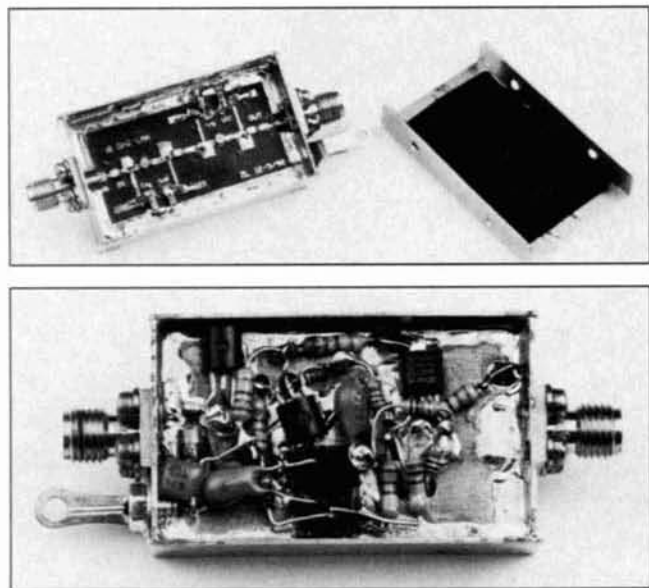

Fig 13—Top and bottom-side views of the completed 10-GHz two-stage amplifier. Microwave-absorptive foam is glued into the lid to suppress waveguide propagation modes inside the amplifier enclosure, which could provide enough feedback from output to input to cause oscillation. The amplifier's bias circuitry, like that of the 10.224-GHz multiplier (Figs 4, 5 and 10) is built on the bottom side of the amplifier board for convenience. External biasing is also acceptable and may be more convenient.