uhf local-oscillator chain for the purist

Design and construction of an LO system that offers excellent spectral purity, stability, and calibration tolerance with output between 380 and 540 MHz

For many experimenters a major stumbling block toward building a high-performance uhf or microwave station seems to be the local-oscillator chain. This is especially true in EME applications, where any degree of success demands spectral purity affording at least 60 dB spurious rejection, calibration tolerance to within a few hundred Hz, and frequency stability of a few tens of Hz over the temperature extremes encountered in the station. These stringent requirements, along with the extensive test-equipment required to verify them, seem to put the whole business of LO design and construction into the category of "more art than science."

background

Certainly the most artistic uhf LO developed in recent years is the circuit by Joe Reisert, W1JR, originally published in his now-defunct *W6FZJ 432 MHz EME Newsletter*. The circuit has since been presented in *ham radio*[1] and duplicated by hundreds of uhf enthusiasts with a high degree of success. I used Joe's circuit in my original 1296-MHz transceive converter[2] and was entirely pleased with the results. The design offers exceptional spectral purity (**fig. 1**), good thermal stability, and adequate calibration tolerance (all as functions of the crystal used, of course).

Joe's circuit was designed to be built in three-dimensional space above an unetched PC board, which was used merely as a ground plane. I developed printed-circuit artwork for this LO some time ago to improve its repeatability by ensuring proper component layout. During the PC-artwork development, it seemed reasonable to replace a number of discrete components with their microstripline equivalents, thus reducing component count and cost. This task completed, I trimmed from the circuit every nonessential component in further attempts at cost reduction. When I realized that my circuit bore little resemblence to Joe's original design I threw caution to the wind, abandoned his original framework altogether, and ended up with a completely new uhf LO.

spectral purity

The result is shown schematically in **fig. 2**. I call it "Mr. Clean" in recognition of the excellent spectral purity achieved (see **figs. 3** and **4**). The circuit can be

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built for a 5-mW output at any desired frequency between 380 and 540 MHz, thus serving well as an LO for 432-MHz converters, 1296- or 2304-MHz converters (if followed by an appropriate ×3 or ×4 multiplier), or a weak-signal source. The circuit offers spurious rejection of more than 40 dB, a calibration tolerance of ±10 ppm, and temperature stability on the order of ±0.3 ppm/°C over the range of −10 to +60C. To date I've built more than 50 copies of this circuit, all with equal performance. The design has also been successfully duplicated with little difficulty by W6OAL, KØJHI, and WA6TLX.

The importance of spectral purity in a uhf LO cannot be overstressed, especially when the output frequency is multiplied into the microwave region. **Fig. 5** is an example of the LO output of a popular European 1296-MHz receiving converter. Compare this figure with the LO of my 1296-MHz system (**fig. 6**).

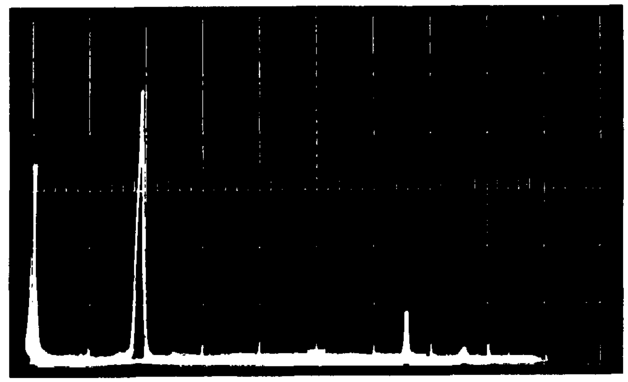


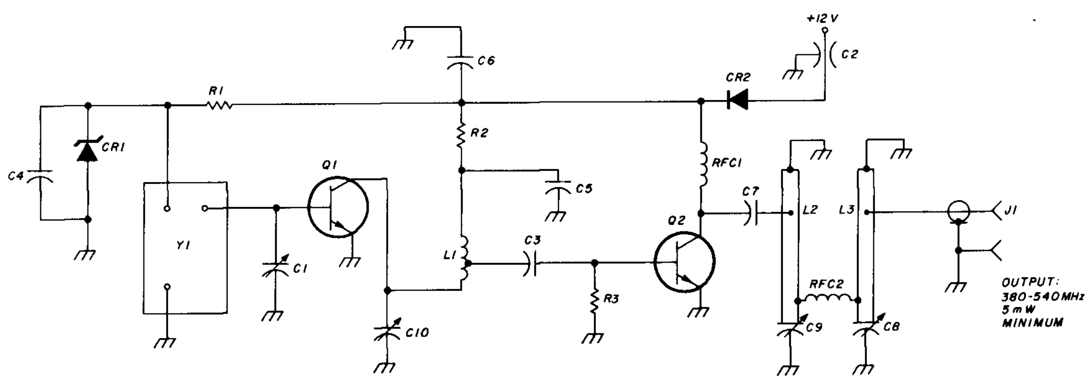
fig. 1. Dc-to-2 GHz spectral display of the Reisert local oscillator (reference 1) shows its excellent spurious-response rejection. Vertical scale is 10 dB/division; horizontal scale is 200 MHz/division; resolution is 1 MHz.

oscillator circuit

The primary requirements for a usable local oscillator, as mentioned previously, are stability and spectral purity. Frequency stability is generally achieved by using an oscillator circuit that draws minimum current through the crystal (thus minimizing crystal heating). This in turn dictates operating the basic oscillator at an *extremely low output power level* and making up the necessary gain in the following buffer or multiplier stages.

I learned from Joe Reisert some time ago that it's important to let the crystal oscillate at its natural resonant frequency. That is, when plugging a crystal into the oscillator circuit *for which it was cut*, you'll achieve the greatest stability by letting the crystal oscillate wherever it wants to. Any attempt to VXO or "rubber" the crystal's oscillation frequency to achieve a desired dial calibration will result in a net degradation of local-oscillator stability. This is especially true when the crystal frequency will subsequently be multiplied to the ultimate output frequency.

Since frequency pulling of the oscillator is to be avoided in the interest of stability, great precision is required in the crystal frequency calibration, with reespect to the particular oscillator circuit used, if the i-f calibration is to bear any relationship to the operating frequency. Crystal manufacturers can generally optimize custom-ground crystals for operation



C1	8-24 pF ceramic trimmer	L1	4t 1-mm (no. 18 AWG) tinned, 17.8 mm (0.7 inch.) diameter × 5 mm (0.2 inch) long. Tap 1t up from C5 end
C2	1000-pF feedthrough	L2, 3	Microstripline inductors (see PC artwork)
C3-C6	0.01-μF miniature ceramic discap	Q1, 2	2N5179
C7	33-pF chip cap (ATC 100B or equivalent)	R1, 2	180 ohms 5% ¼w carbon composition
C8-C10	1-9 pF piston trimmer (Triko 203-09M or equivalent)	R3	330 ohms 5% ¼w carbon composition
CR1	9.1-V zener (1N757A or equivalent)	Y1	International Crystal OE-5 oscillator module. Frequency between 95-135 MHz ($f_{out}/4$)
CR2	1N3600 (or equivalent general-purpose silicon diode)	RFC1,2	0.33 μH miniature molded choke
J1	Output receptacle (E. F. Johnson 142-0298-001 or equivalent)		

fig. 2. Schematic of the Microcomm Model LO-70 uhf local-oscillator chain, which evolved from the design by Joe Reisert, W1JR.

in a particular circuit, provided the schematic is supplied. Unfortunately, when ordering high-precision crystals from two different reputable manufacturers for use in Reisert's oscillator circuit, I found calibration errors on the order of 10 kHz at 432 MHz — certainly beyond my expectations for a $30 crystal! And since you can be certain the crystal manufacturer certainly didn't build up Reisert's circuit and check the crystal for proper operation in it, perhaps it's better to use an oscillator circuit with which the crystal manufacturer has some experience.

I decided to use an oscillator circuit of the crystal manufacturer's choosing. In so doing I found that

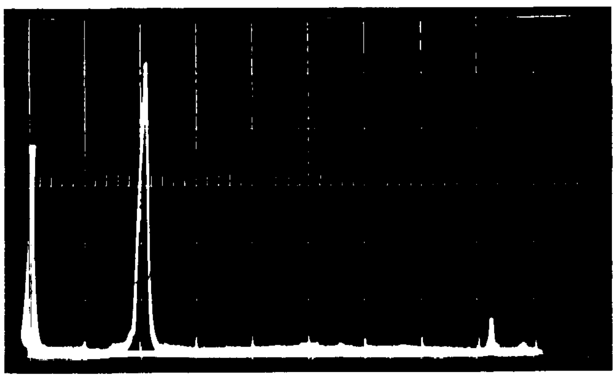


fig. 3. Spectral response of the local oscillator presented in this article compares favorably with the Reisert circuit. The analyzer settings are as in fig. 1.

crystals from widely separated production runs all fell well within the manufacturer's calibration tolerance limits of ±0.001 per cent, as well as the claimed thermal stability specifications of ±0.002 per cent from −10 to +60°C. The crystal *and* oscillator circuit (on a PC board, inside a can for shielding) are available as a preassembled module from International Crystal Manufacturing Company as their Model OE-5. Specifications and the oscillator schematic are shown in **fig. 7**. This assembly costs around $20 in single quantities, supplied at your selected operating frequency in the 100-MHz range. Since it's no more expensive than a crystal of equivalent specifications ordered separately, why bother to build your own oscillator circuit?*

Output power from the OE-5 oscillator module is low, on the order of 1/2 mW, which certainly holds down crystal heating. Spectral purity is enhanced by starting with the highest crystal frequency practical (in this case, around 100 MHz), and performing low-order integer multiplication in active stages whose bias current is optimized to the favored conduction

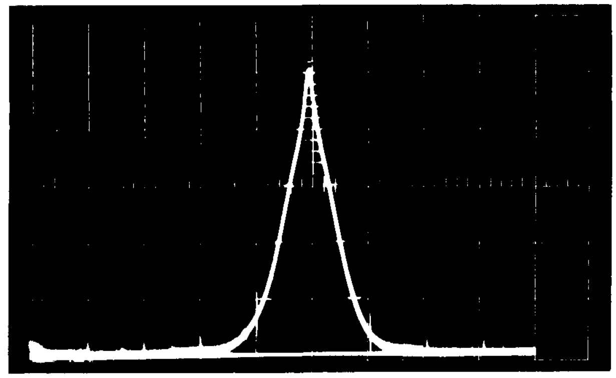


fig. 4. Spectral display of the Microcomm LO-70 LO-chain (operating frequency ±100 MHz) shows the absence of close-in spurious components. Vertical scale is 10 dB/division; horizontal scale is 20 MHz/division; resolution is 1 MHz.

angle for the multiplication desired. This oscillator, like Reisert's, uses two common-emitter bipolar doublers operating Class C. Each multiplier stage affords about 5 dB gain, so the output power from the LO chain is on the order of 5 mW (7 dBm).

Note that, from the OE-5 circuit schematic in **fig. 7**, the oscillator output is taken from a link in a parallel-resonant circuit. This coupling link provides a dc bias return for the base of first doubler transistor, Q1, as seen in the LO chain schematic, **fig. 2**. Trimmer capacitor C1 is used to resonate the OE-5 module output coupling link, which provides a double-tuned interstage and greatly improved spectral purity. However, as with all double-tuned circuits, these two tanks are somewhat interactive, so during tuneup it may be necessary to readjust the OE-5 trimmer capacitor along with C1.

circuit description of the LO chain

The 200-MHz signal from Q1 is applied through

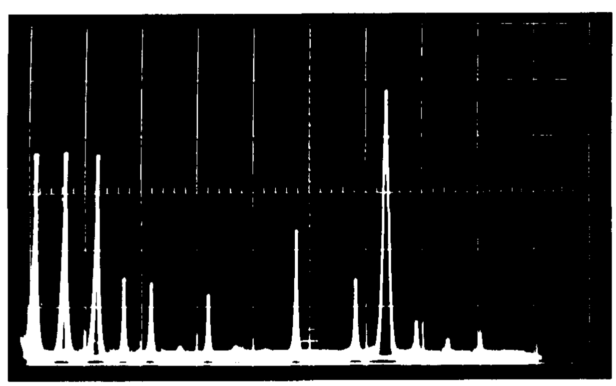


fig. 5. The importance of spectral purity in a uhf local oscillator chain is compounded when the output frequency is multiplied into the microwave region. This is the output of the local oscillator used in a popular European 1296-MHz receive converter. The effect of inadequate filtering at all stages is evident.

*Lead time for this oscillator module runs typically six to eight weeks, so order well in advance.

tuned circuit L1, C10, to the base of the second doubler, Q2. Nothing exotic here, but Q2's collector feeds a rather unusual output-filtering arrangement, which is largely responsible for the spectral purity of this LO. Basically, microstripline inductors L2 and L3, with trimmer capacitors C8 and C9, form two parallel-resonant circuits. RFC2 inductively top-couples them for a standard two-pole bandpass.

There are really more filtering elements here than meet the eye. For example, Q2's collector feed choke, RFC1, and coupling capacitor, C7, form a single L-section high-pass filter, which keeps any 200-MHz component from Q2's base from entering the output filter. Additionally, C8, C9, and RFC2 form a pi network lowpass filter which supresses harmonics from Q2. Thus the entire output circuitry consists of one lowpass filter, one high-pass filter, and two bandpass sections — all ensuring that Mr. Clean lives up to its name.

construction

All components including the OE-5 oscillator module mount on a 63.5 × 76 mm (2.5 × 3 inch) PC board. PC-board artwork is provided in **fig. 8**. Microstripline dimensions are a function of the material used, so be certain to etch this board on 1.6 mm (0.0625 inch) thick fiberglass-epoxy PC laminate, double-clad with 1-ounce copper (0.035 mm or 0.0014 inch thick). One side of the board should remain unetched to serve as a ground plane.

Drill the board as in **fig. 9**. Note that to avoid short circuiting the OE-5 power and output pins as well as the rf output at J1, it's necessary to remove ground plane metal from around the three holes marked countersink in **fig. 9**. A 3.25-mm, (0.125-inch) twist drill does an adequate job. Be careful not to drill too far through the board!

Note that in **fig. 2** the ends of the output filter

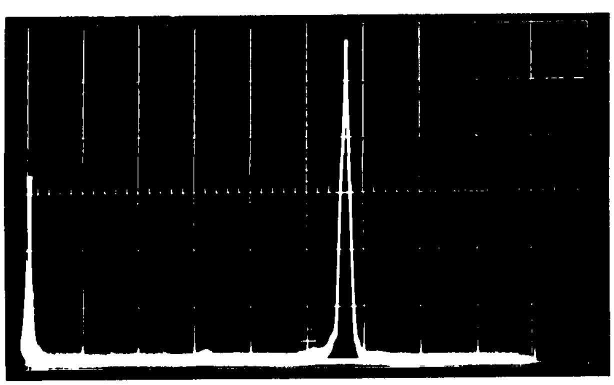


fig. 6. The output spectrum of the author's 1296-MHz system contrasts sharply with that of fig. 5. This clean display results from driving the uhf LO described in this article into a well-filtered multiplier circuit. Spurious rejection over the dc-to-2 GHz region approaches 60 dB.

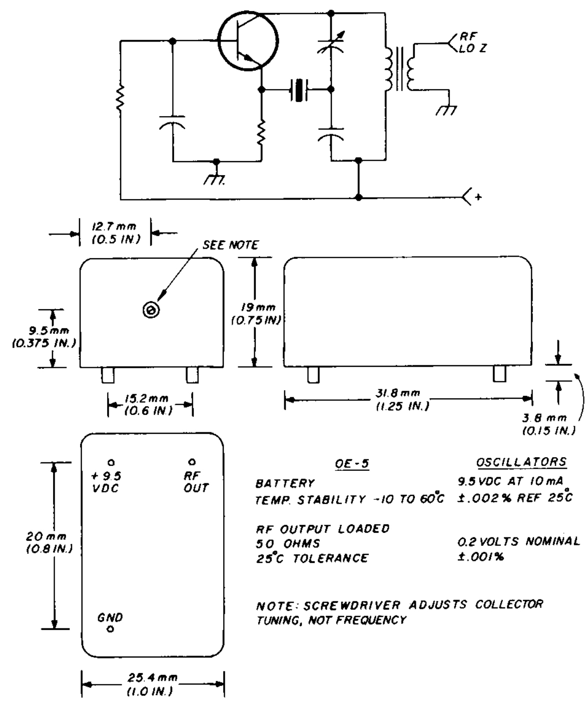


fig. 7. Schematic, dimensions, and specifications on the International Crystal OE-5 oscillator module.

microstripline inductors (L2 and L3) are grounded through the board. This can be accomplished by installing small 1-mm (0.04-inch) OD eyelets through the board at two locations indicated in **fig. 9**. These eyelets can be set then soldered to *both* sides of the board to ensure a reliable ground. For those who prefer not to prepare their own board, an etched, drilled, and plated board, with eyelets in place, is available from the author.*

Component layout on the printed circuit board is shown in **fig. 10**. I recommend mounting all components *except* the OE-5 oscillator module; save that for last. Note that R3, C8, C9, C10, and the emitter and case leads of Q1 all ground to a large ground plane area on the stripline side of the board as well as the unetched ground plane side. Be sure to solder these components at *both* sides.

When mounting the OE-5 module to the ground plane side of the main board, there's a slight chance that circuit traces on the OE-5 board might short circuit to the ground plane. Make a thin spacer from sheet acetate or Teflon the size of the OE-5 board, with holes drilled for the three pins. When installing

*An etched, drilled, and plated board for this local oscillator, complete with grounding eyelets for L2 and L3, is available for $6.50 postpaid in the U.S. and Canada ($7.00 elsewhere) from Microcomm, 14908 Sandy Lane, San Jose, California 95124. A completely assembled LO chain, adjusted to your selected operating frequency between 380-540 MHz, is also available at nominal cost. Send a stamped, self-addressed envelope to Microcomm for details. Amateurs indicate callsign on correspondence.

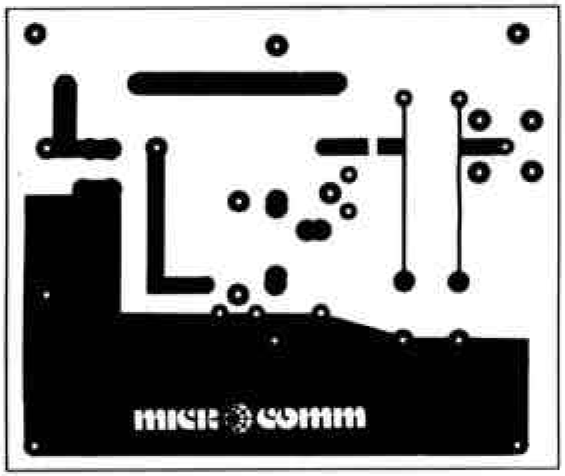


fig. 8. Full-size PC-board layout for the uhf local oscillator. Substrate material should be 1.6 mm (0.0625 inch) thick fiberglass-epoxy PC board, double-clad with 1 ounce copper (microstripline side shown).

the OE-5, grasp the three pins firmly with needle-nose pliers. Gently *ease* each pin, one at a time, into the main board. Do not use force.

tune up

There are at least three different techniques for tuning this local oscillator chain. I hope you can keep them straight, because in this section I'll tell you a) how *not* to tune an LO, b) how I tune my LOs, and c) how to tune yours.

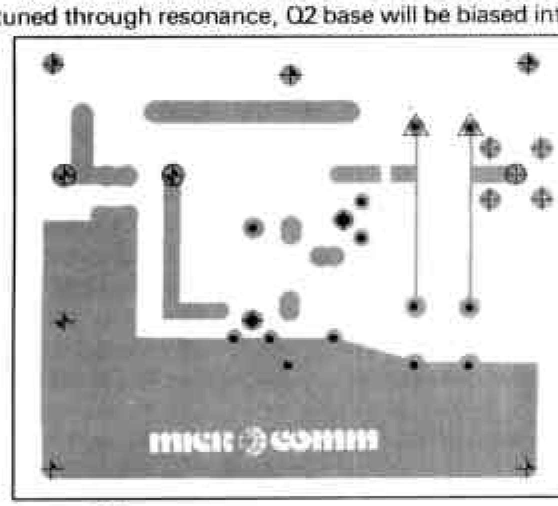
Avoid like the plague the "maximum smoke" technique. It's *not* possible to successfully tune this circuit, Reisert's circuit, or anyone else's LO circuit, for maximum indicated output power alone. **Fig. 11** illustrates quite graphically that if you tune for maximum power it's likely to be distributed over a maximum number of frequencies. I can't overemphasize the importance of tuning up uhf LO chains using proper test equipment together with a systematic procedure for minimizing spurious spectral responses. I'm a firm believer in the use of spectral analysis and wouldn't dream of tuning up one of my own LO chains without the use of a microwave spectrum analyzer. Take another look at **fig. 3** and compare it with **fig. 11**. You can see the dramatic effect of tuning each stage of the LO chain for maximum spectral purity rather than maximum output. And the test equipment needn't put you into hock forever. Even a simple homebrew spectrum analyzer[3] will allow you to achieve spectacular purity.

But you probably don't have a spectrum analyzer and cringe at the thought of having to build one before you can tune the LO you've just finished constructing, right? There's another way; I call it the "poor man's spectrum analyzer." You'll need a vhf cavity wavemeter (a grid-dip oscillator in the wavemeter mode will do), some sort of a relative power-indicating device (the one I told you not to use in method a above), and a bandpass filter tuned to the approximate LO output frequency. (There are some constraints surrounding the selection of the proper filter, which I'll cover later.) You'll also need some sort of resistive attenuator or pad, 3 to 10 dB, with a 50-ohm impedance and a volt-ohmmeter.

Preliminary steps. First connect the pad to the LO output connector, the power meter to the other end of the pad, and a +12 Vdc supply to feedthrough capacitor C2. **Caution:** Do *not* exceed 12 volts, as this is the V_{ceo} (maximum collector-to-emitter potential) of the 2N5179s used as the multiplier transistors! In fact, series diode CR2 does provide some protection, and I have not had any transistor failures operating at 13.5 volts from a fully charged car battery — but why take chances?

With power applied, tune C1 and the OE-5's trimmer cap until the OE-5 oscillates, as indicated by an abrupt increase in supply current. With the OE-5 oscillating, set up the grid dipper in the wavemeter mode, tune it to the crystal frequency, and sniff around the microstripline going to the base of Q1 for some rf. Once you've found it, disconnect V_{cc}, then reconnect it. Did the oscillator start? If not, try retuning the OE-5 trimmer and C1 slightly until the oscillator starts reliably each time.

Now tune the first multiplier. As L1 and C10 are tuned through resonance, Q2 base will be biased into



Key
- install eyelet here (see text)
- no. 60, 1 mm (0.04 inch) (11 places)
- no. 56, 1.2 mm (0.046 inch) (5 places)
- no. 49, 1.85 mm (0.073 inch) (3 places)
- no. 27, 3.7 mm (0.144 inch) (5 places)
- no. 12, 4.8 mm (0.189 inch) (2 places)
- countersink ground plane side here (see text)

fig. 9. Drilling template for local oscillator PC board (viewed from microstripline side).

conduction and supply current will increase by 5-10 mA (Q2's collector current). Try it. The only problem is that tank L1/C10 may resonate at more frequencies than the desired $F_{xtal} \times 2$. So tune the dipmeter (still in wavemeter mode) to the second harmonic of the crystal frequency, couple it *loosely* to L1, and tune for an indication of rf. Once you've found it, repeak C1 and C10 for the combined occurrence of *maximum* rf and *maximum* supply current; then check to make sure the oscillator still starts up each time power is applied. If not, retweak the oscillator trimmer *slightly* until it does. At this point you should start to see some indication of rf at output connector J1. Remember that your relative-power indicator can't distinguish between frequencies, but just for starters, tune C8 and C9 for maximum output. At this point the output spectrum (if you could see it) would probably appear as in **fig. 11**, but don't worry about it.

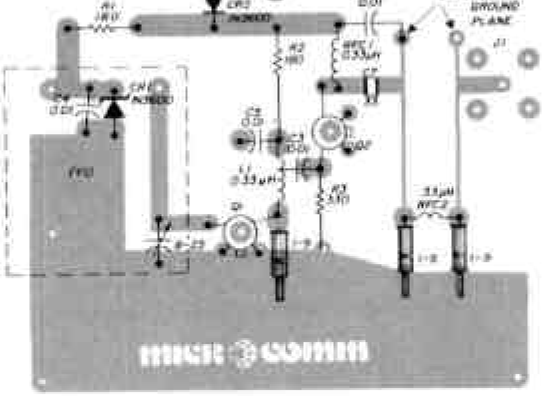


fig. 10. Parts layout, Microcomm model LO-70 uhf local oscillator (microstripline side).

Final adjustments. Now that you've completed the preliminary tune up you're ready to clean up your act. Insert the bandpass filter (tuned to the desired output frequency) between the pad and the power indicator, and *carefully* retweak all trimmers for maximum output power. The adjustments will interact, so go back and do it again. Check to make sure the oscillator still starts each time you apply power. When you're finished remove the filter and pad, and measure output power at J1. It should be on the order of 5-10 mW, and the spectrum should appear as in **fig. 3**.

But don't count on it. The first time I tried this procedure, I ended up with almost as much output at 1200 MHz as I had on 400 MHz. This didn't make much sense to me, as I was using a high-Q, quarter-wavelength, trough-line filter in aligning the LO, and I knew it had sharp skirts! Just for good measure I swept the filter, and the problem became immediately evident (see **fig. 12**). A quarter-wave transmission line, shorted at one end, makes a dandy resonator. Unfortunately, so does a three-quarter-wavelength transmission line. The filter I chose exhibited a passband at the third harmonic of the LO frequency, and by tuning for maximum signal through the filter, I was actually optimizing the spurious output! I mention this because quite a few bandpass filters exhibit multiple resonances. The halfwave slab resonator described in the ARRL *VHF Manual and Handbook* does, so it would not yield a spurious-free output if used as a tune-up aid

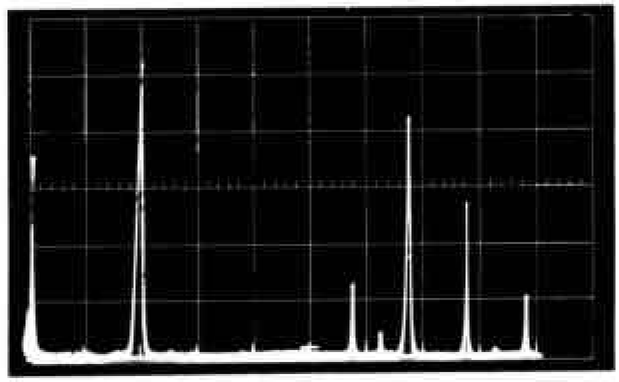


fig. 11. This spectral display, with measurement conditions as in figs. 1 and 3, illustrates the importance of tuning the local-oscillator chain using a spectrum analyzer. This is what results if the LO is tuned for maximum output as indicated on a power meter. Note that the worst spurious component is down by only 10 dB.

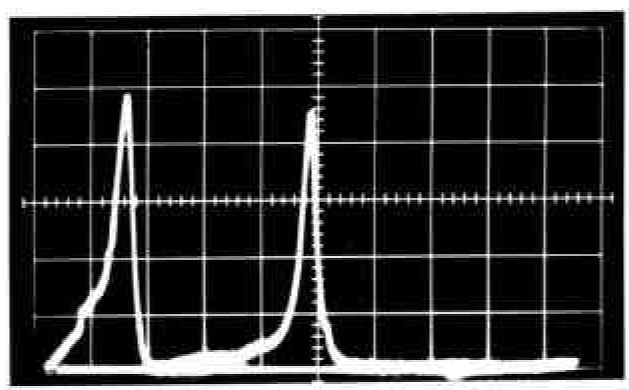


fig. 12. Swept-frequency response of the quarter-wave, trough-line resonator first used as a tune-up aid for this LO, as described in the text. Vertical scale is 5 dB/cm, with the second major division from the top of the screen representing 0 dB insertion loss. Horizontal scale is 250 MHz/cm, yielding a dc-2.5 GHz display. Note that, while the insertion loss at 400 MHz (the desired frequency) is less than 1 dB, the insertion loss at the third harmonic (1200 MHz) is on the order of only 3 dB.

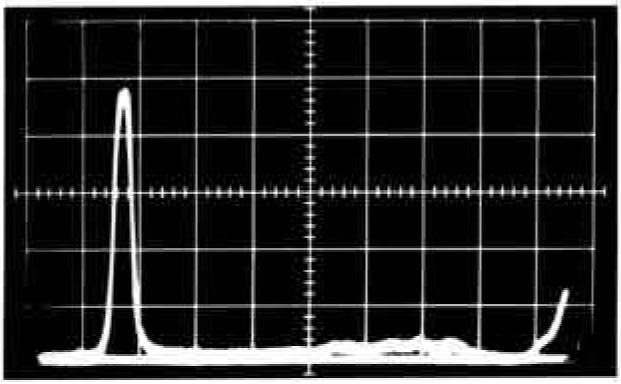


fig. 13. Swept-frequency response of the Microcomm model PB-70 filter ultimately used as a tuning aid for aligning this LO, as described in the text. Vertical and horizontal scales are as in fig. 12. Note absence of spurious responses out to 2.5 GHz, as well as the passband insertion loss of less than 1 dB.

for this LO. Best bet is to use either an interdigital filter or helical resonator, or a multipole design whose interstage coupling is designed to supress higher-order modes. The Microcomm model BP-70 is one such filter (see **fig. 13**), as is the Spectrum International model PSf432. Also useful are the surplus military filters of the F-197/U variety, which have recently surfaced at numerous ham auctions and flea markets around the country.

Given a single-response bandpass filter tuned to the approximate operating frequency of the LO, it's possible to tune this oscillator circuit to a degree of spectral purity rivaling that achieved on a laboratory microwave spectrum analyzer.

conclusion

I've presented a uhf local-oscillator chain that offers stability, calibration tolerance, and spectral purity on a par with Joe Reisert's very fine circuit, but with fewer components and easy assembly on a PC board. I am currently using this LO in my 432-MHz receive converter, driving multipliers in my 1296- and 2304-MHz converters, in my 1296-MHz hand-held transceiver, and in an S-band satellite ground station design I am producing commercially. I find the circuit easy to assemble and extremely reliable. I hope other uhf and microwave experimenters find it useful.

references

1. Joe Reisert, W1JAA, "What's Wrong with Amateur vhf/uhf Receivers — and What You Can Do to Improve Them," *ham radio*, March 1976, page 45.
2. H. Paul Shuch, WA6UAM, "Easy-to-Build ssb Transceiver for 1296 MHz," *ham radio*, September 1974, page 8.
3. H. Paul Shuch, WA6UAM, "Low-Cost Microwave Spectrum Analyzer," *ham radio*, August 1977, page 54.

ham radio