compact and clean
L-band local oscillators

A clean, L-band local-oscillator system featuring spurious rejection greater than 30 dB with simple test equipment

The recent popularization of microstripline construction for Amateur uhf equipment[1] has made it relatively simple for countless experimenters to build state-of-the-art multipliers, amplifiers, mixers, filters, and the like directly from magazine construction articles. A major exception, unfortunately, has been in the area of microwave local oscillator chains. Most will agree that the LO is the weak link in just about every microwave transmitter, receiver, or converter. Local oscillators generally require extensive tweaking on costly spectrum analyzers, even then often falling short of the required calibration tolerance, stability, and spectral purity. And, since a spurious or drifting LO can negate all the benefits of the very finest low-noise front end or ultra-linear power amplifier, it is evident that the LO requires a great deal of attention. I've been making an effort in recent months to take some of the mystique out of local oscillator design and construction. In this article I shall present the results of that effort — a high-stability, crystal-controlled LO for 1.1 through 1.6 GHz that is only 6.4 × 10 cm (2.5 × 4 inches) and employs microstripline construction (with absolutely *no* coils to wind). It can be built for about $70 in parts, and can be completely aligned with only a VOM and a diode detector.

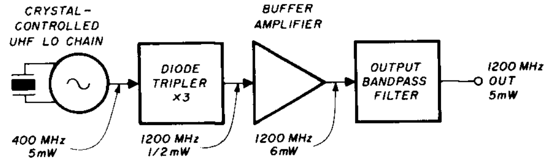


fig. 1. Block diagram of a module LO system for L band. Each block represents a physically separate stage, individually boxed and interconnected by short lengths of coaxial cable.

The basic approach that numerous experimenters (myself included) have used for L-band local-oscillator chains over the past several years is blocked out in **fig. 1**. I implemented this system modularly, with each of the blocks representing a separate, shielded box, the various modules being interconnected via coaxial cable. The basic 400-MHz oscillator is a version of my recently published uhf LO chain,[2] driving a diode tripler built on a microstrip bandpass filter board.[3] In order to make up the power lost in the passive multiplier, a buffer amplifier is employed.[4] The final microstrip filter keeps all spurious frequency components down better than 40 dB with respect to the desired output.

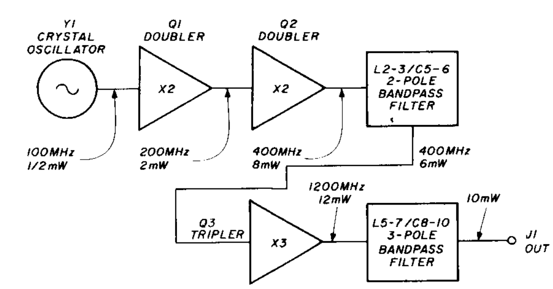
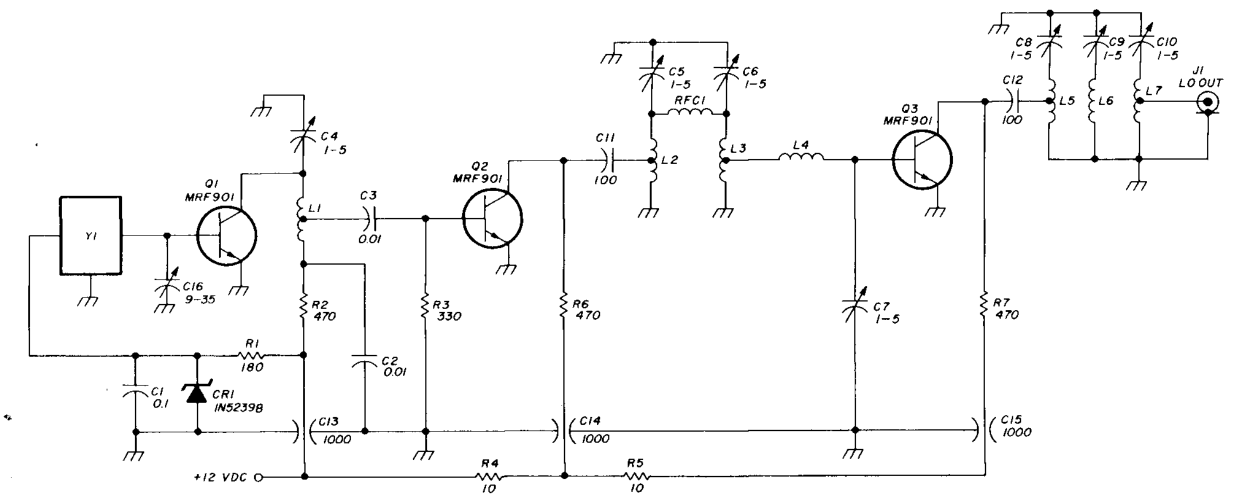


fig. 2. Block diagram of the microstrip local oscillator.

The modular LO chain has some major drawbacks. It is physically large, since each stage must occupy its own separate enclosure to achieve acceptable spurious rejection. The cost of jumper cables, coax connectors, and die-cast aluminum boxes can be

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



designation	description
C01-03	miniature ceramic disc capacitor, 0.01 μF
C04-10	ceramic piston trimmer capacitor, Triko 202-08M, 1-5 pF
C11-12	chip capacitor, ATC type 100B, 100 pF
C13-15	ceramic feedthrough capacitor, Erie 2404-000-X5UO-102P, 1000 pF
C16	ceramic trimmer capacitor, 9-35 pF
D01	zener, 9.1 V $\pm$ 5%, 400 mW. 1N52393
J01	SMA receptacle, E. F. Johnson 142-0298-001
L01-07	microstrip inductor (PC artwork LO-1200-601)
Q01-03	uhf silicon bipolar transistor, Motorola MRF-901
R01	carbon composition resistor, 180 ohm 10% 1/4 watt
R02, 06, 07	carbon composition resistor, 470 ohm 10% 1/4 watt
R03	carbon composition resistor, 330 ohm 10% 1/4 watt
R04-05	carbon composition resistor, 10 ohm 10% 1/4 watt
RFC01	0.33 μH molded choke, Nytronics mini-ductor
Y01	crystal oscillator assembly, International Crystal OE-5, 90 to 130 MHz (output frequency $\div$ 12)

fig. 3. Schematic diagram of the L-band local oscillator. C1, C2, and C3 are miniature ceramic disc capacitors. C4 through C10 are Triko 202-08M, 1-5 pF ceramic piston trimmers. ATC type 100B chip capacitors are used for C11 and C12. All resistors are ¼ watt, 10 per cent tolerance. The rf choke is a Nytronics Mini-ductor. The crystal oscillator assembly should be in the frequency range of 90 to 130 MHz, depending upon the desired output frequency (LO output frequency divided by 12).

prohibitive. Plus, the use of a passive multiplier followed by a buffer amplifier is a crude and inefficient way to generate the required 5 to 10 mW of LO output.

I toyed with the idea of integrating the LO chain onto a single board, but became convinced that first it would be necessary to develop a reliable active multiplier circuit to take the place of the diode tripler and buffer amplifier modules. For a time I considered the push-pull tripler approach which Wade had used in his 1296-MHz LO,[5] but in studying the spectrum analyzer photos from his article, I noticed a few potential difficulties. Wade's output filter had the advantage of requiring no tuning whatever, but it afforded only about 20 dB of spurious rejection. His active multiplier, though far easier to tune than my diode triplers, appeared to offer about the same degree of conversion loss. Since I was seeking multiplier gain of not less than unity, I decided to try a single-ended active tripler followed by a tunable, 3-pole microstrip filter to keep the spurs down.

What finally produced acceptable results was an active parametric multiplier, a circuit technique I had employed in an earlier 1296-MHz converter.[6] The secret is to place a series tank circuit, which resonates at the desired output frequency, in the base lead of a standard class-C common-emitter multiplier. This throws the base into a negative-resistance region at the stage's *output* frequency, enhancing the gain of the desired frequency multiple relative to that of the other multiples. The result is an improvement in the multiplier's spurious rejection without resorting to harmonic-cancelling circuits like push-pull and push-push.

With the active multiplier and an output filter tacked onto the end of one of my 400-MHz LO chains, I found I was getting as much output, with as clean a signal as my modular LO had yielded. Plus, it took up only half the space, and without the various coaxial jumpers between stages. **Fig. 2** shows the block diagram of the new LO, and the complete schematic is shown in **fig. 3**.

circuit description

Refer to **fig. 3** and the accompanying parts list. The stages to the left of Q3 are essentially the same

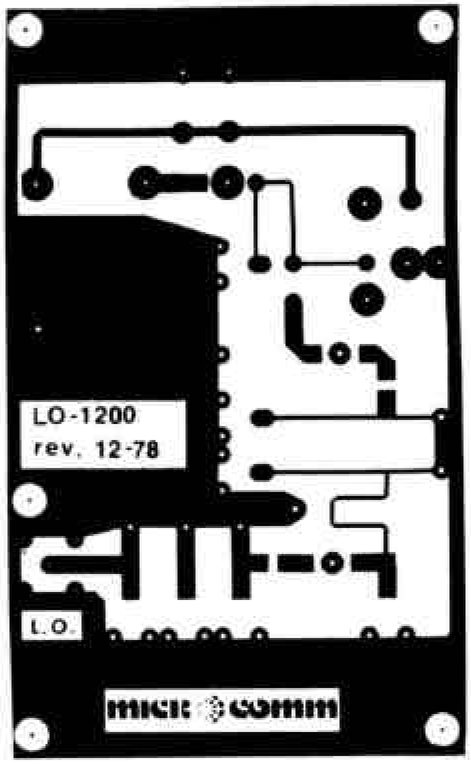


fig. 4. Full-size artwork for the printed circuit board. The reverse side remains unetched, acting as a groundplane.

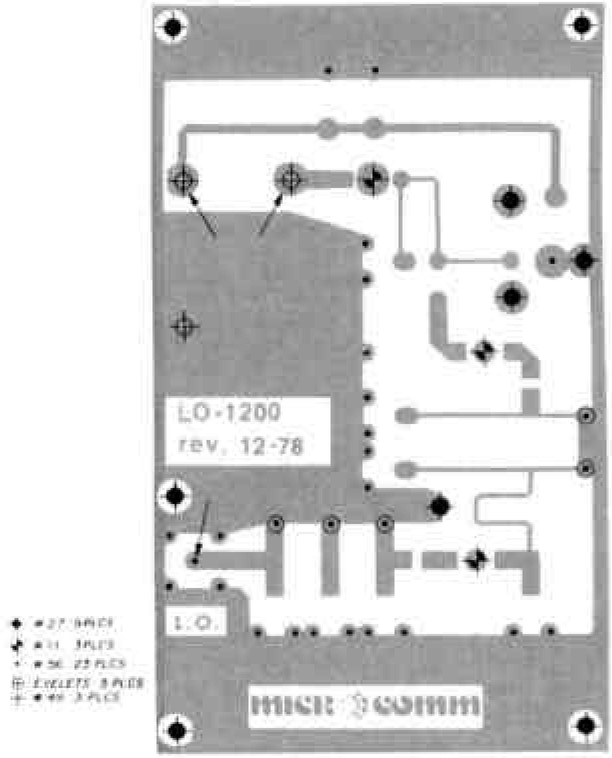


fig. 5. Drilling diagram for the etched side of the circuit board. In addition to the etched side, the three locations marked with arrows are also countersunk on the groundplane side.

as those used in my uhf LO, except for a few component substitutions. Oscillator module Y1 is a high-stability, crystal overtone oscillator producing −3 dBm (1/2 mW) of output near 100 MHz. This assembly requires a regulated +9 volt supply, which is furnished by zener diode CR1. The output port of Y1 exhibits dc continuity to ground, this continuity being essential in providing a bias return for the following stage.

At the input to Q1, common-emitter class-C double stage, C16 is used to resonate Y1's output inductive link, creating a double-tuned, interstage transformer between the oscillator stage and the first multiplier. The output circuit for Q1 consists of microstripline inductor L1 resonated by C4 at 200 MHz.

Collector current for Q1 is limited to 10 mA at R2. This resistor, along with C2 and C13, provide power supply decoupling for the first multiplier stage.

Q2 serves as a second class-C common-emitter doubler. Its input is fed via C3, which is tapped down on L1 for impedance matching. R3 provides base bias return. The collector is shunt-fed by R6, with a collector current of approximately 15 mA. The output circuit for Q2 consists of two microstripline inductors (L2, L3) resonated at 400 MHz by two piston trimmers (C5 and C6). Inductive coupling between filtering poles, provided by RFC1, suppresses higher-order harmonics at the output of the second doubler. The conversion gain of each doubler — exclusive of any filter losses — is on the order of +6 dB.

As mentioned previously, tripler Q3 operates as a parametric multiplier. The input is applied via a low-pass filter consisting of microstripline inductor L4 and piston trimmer C7. The series inductance of C7 is such that it self-resonates at the desired output frequency, maximizing gain at that particular frequency by driving the base impedance of Q3 negative. For this reason, use only the specified capacitor at C7. Shunt collector feed for the active tripler is via R7, with dc decoupling provided by R5 and C15. Collector current for Q3 is on the order of 15 mA, and the stage operates at approximately 3-dB gain.

The output of Q3 is capacitively coupled via C12 into a 3-pole output filter consisting of microstripline

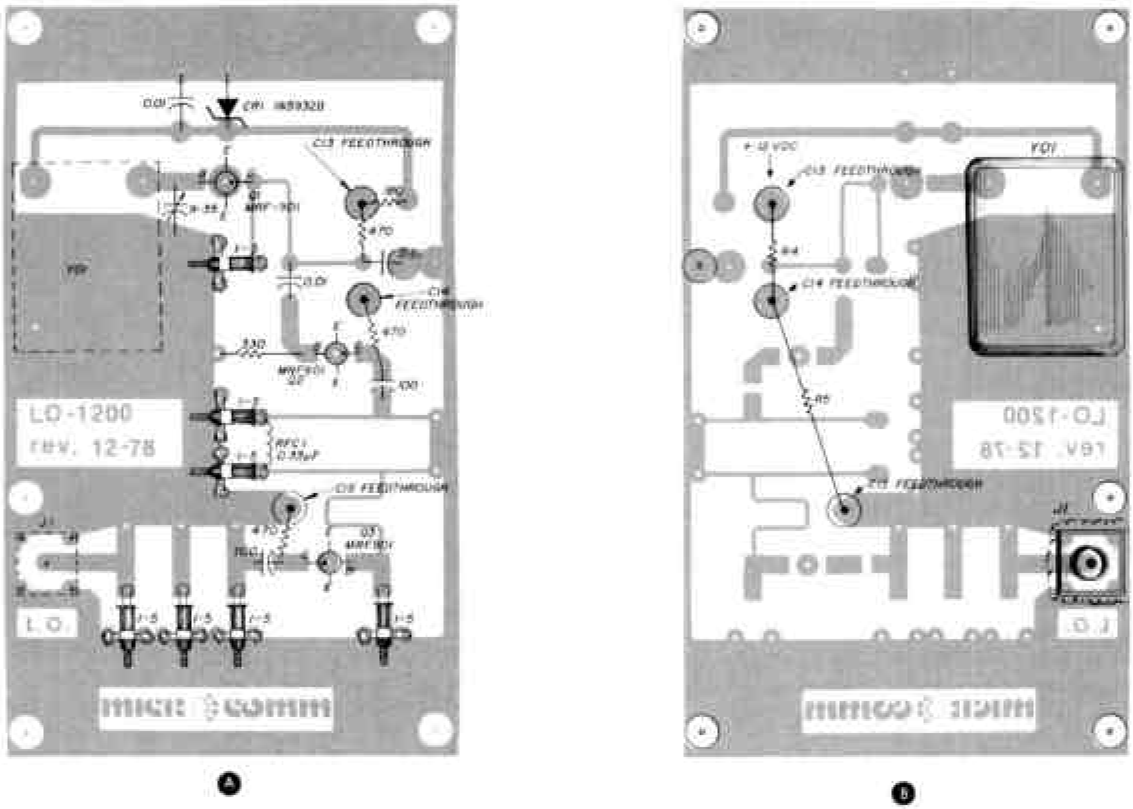


fig. 6. Component placement diagrams for the microstripline and groundplane sides.

inductors L5, L6, and L7, resonated at 1.2 GHz by piston trimmers. Coupling between filter poles is a result of the proximity of the piston trimmer stators; hence, spacing between filter poles is critical.

The final +10 dBm (10-mW) LO output is available on connector J1. This level is suitable for driving most transmit and receive diode balanced mixers.

construction

Assembling the LO is relatively simple, since all circuitry is mounted on a single printed circuit board and the bulk of the critical components are implemented as etched microstriplines. The circuit should be etched on fiberglass-epoxy circuit laminate 1.5 mm (0.063 inch) thick, clad on both sides with 1 ounce per square foot copper. One side of the board is etched in accordance with the artwork supplied in **fig. 4**, the other side remaining fully clad and serving as a groundplane. It is essential that the pattern of the printed circuit artwork be followed exactly (photo etching is recommended), since the dimensions of the microstriplines are critical and the placement of the circuits on the board determines the degree of spectral purity achieved. In fact, the layout of the board was changed several times during the development phases in order to optimize performance and ease of tuning.

After the board is etched, it should be drilled as in **fig. 5**. Be sure to remove a small portion of groundplane metallization from around the holes that will accommodate the center pin J1 and the output and power pins of oscillator Y1. Neglecting this crucial step will result in these pins being shorted to ground, which will obviously have a detrimental effect upon circuit performance! Note that five of the microstripline inductors (L2, 3, 5, 6, and 7) must be grounded through the board. This is best accomplished, as outlined in reference 3, with eyelets 0.5-mm in diameter set with a punch and soldered on both sides of the board.

When mounting components on the printed circuit board, you will find it helpful to refer to the photographs, the schematic diagram in **fig. 3**, the layout drawings shown in **fig. 6**, and perhaps to reference

2. I personally find it easiest to install J1 first, soldering the five pins to their respective pads on the microstripline side of the printed circuit board and then running a smooth bead of solder around the body of the connector, securing it electrically and mechanically to the groundplane side. Next, I install feedthrough capacitors C13, 14, and 15. Here I prepare a small solder preform (1 turn of multi-core solder wrapped around the body of the capacitor just under the flange), position the capacitor in its mounting hole, and apply heat to the flange from above. The solder preform will flow, filling the space between the flange and the groundplane. This technique prevents excess solder from accumulating on the groundplane side of the printed circuit board.

Installing the resistors and capacitors according to the layout diagram is relatively easy. Do *not* install power decoupling resistors R4 and R5 at this time; they will be added during the tune-up sequence. When installing the three transistors, note that the raised dot on the plastic package indicates the collector lead. The base lead emerges from the opposite side of the transistor package, with the two emitter leads appearing at right angles to the collector and base. Bend the two emitter leads of each transistor down sharply before installing the transistors in their holes. That way the emitter leads can protrude through to the groundplane side, where they will be bent over and soldered directly to ground.

When installing oscillator stage Y1, care should be taken to prevent traces on the oscillator's printed circuit board from shorting to the groundplane of the LO main circuit board. I recommend installing a thin insulating washer between the oscillator can and the groundplane.

The only additional advice I might offer in microstripline projects is that it is not unusual for component leads to be laid on and soldered directly to printed circuit board traces or pads, rather than running the component leads through holes in the board. For this reason, it is generally helpful to preform and pretrim the component leads prior to installation.

tune up and test

I cannot overemphasize the importance of employing a systematic, orderly approach in tuning up local-oscillator chains. Tuning for maximum smoke (a favorite Amateur pastime) is a surefire way to make one or more of the multiplier stages oscillate (see **fig. 7**). Further, since the LO chain was designed to provide maximum user flexibility, it may be built for a fairly wide range of frequencies and applications. As a consequence, each of the resonant circuits has a relatively wide tuning range, and it is entirely possible to tune up any one of the multiplier stages on the *wrong* multiple, if maximum apparent output power is the only criterion.

In fact, whether a microwave spectrum analyzer is available or not, it's a good idea to pre-align the various piston trimmers to the appropriate part of the spectrum. This is easier than it may sound. If the intended output frequency is below about 1.3 GHz, adjust all seven of the piston trimmer capacitors to *maximum* capacitance (screws all the way *in*). If the intended output frequency is above about 1.4 GHz, adjust all piston trimmers for *minimum* capacitance (screws almost all the way *out*). And, if the oscillator is intended to operate between about 1.3 and 1.4 GHz, pre-adjust all piston trimmers at about mid-range. Now, as you proceed with the alignment procedure, it should not be necessary to adjust any of these capacitors by more than a couple of turns. Keep this in mind, because if you find yourself adjusting the trimmers more than just a little, you're probably enhancing the *wrong* frequency component.

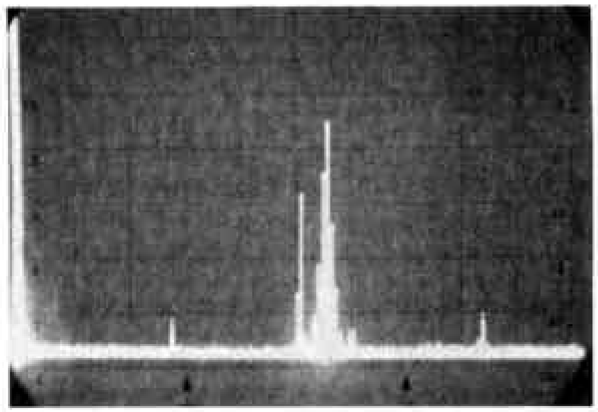


fig. 7. Aligning microwave LO chains for maximum output power often results in a spurious output spectrum. In this case, the LO was tuned for maximum output. The numerous spurs near the desired output are not harmonically related to the crystal frequency. This suggests that they are the result of one of the active stages going into self-oscillation. The horizontal scale is 0 to 2 GHz, with a vertical calibration of 10 dB/cm.

The approach I recommend for tuning this L-band LO requires no test equipment other than a VOM and a diode detector (or some other means of monitoring relative rf power). It is based upon the principle that, as a class-C multiplier stage is tuned, the signal level applied to the next stage (hence the next stage's collector current) will vary. By knowing what kind of variations to expect and by monitoring stage current closely, it is possible to tune the LO chain to produce an output spectrum such as that shown in **fig. 8**. But it is necessary to monitor the various stage currents separately, to be sure you're observing proper multiplier action and not oscillation.

With the piston trimmers pre-adjusted as outlined, the next task in aligning the L-band LO is to get the oscillator stage oscillating. On the side of the crystal oscillator can is a small access hole, behind which is found the ceramic trimmer capacitor which resonates the oscillator's collector tank circuit. This trimmer is pre-adjusted at the factory to ensure that the oscillator will start each time power is applied; it should not be adjusted at this time. Rather, it should be possible to optimize drive to the first multiplier stage merely by adjusting C16, which, you'll recall, resonates the oscillator stage's output coupling link.

Apply a well-regulated voltage between +12 and +13 volts to feedthrough capacitor C13. This powers both the oscillator stage and the first doubler. Monitor the current drawn by these two stages as C16 is adjusted through its range. Since the sum of the current drawn by the oscillator stage and its zener regulator will remain constant at between 16 and 22 mA (depending upon the power supply potential), any variation in current as C16 is adjusted represents the collector current of Q1. There is a point in C16's tuning range where the current at C13 will rise smoothly to about 10 mA above its minimum value (that is, 26 to 32 mA, total), and this is the point to adjust C16. Now, momentarily remove V_{cc} from C13. If the current returns to the previous value, all is well. If on the other hand Q1 appears not to be drawing any current (that is, total current at C13 decreases to between 16 and 22 mA), then the oscillator stage is not starting smoothly and it will be necessary to re-adjust Y1's trimmer. Do so *carefully*; it should be necessary to rotate the trimmer only about ten degrees one way or the other, and the current should rise again, indicating oscillation. Now, repeak C16 for the proper rise in current, and again remove and re-apply power. The adjustments of C16 and the oscillator's trimmer capacitor are somewhat interactive, so repeat the above procedure until the oscillator starts reliably each time power is applied.

Once the adjustment of C16 and the oscillator trimmer is completed, do not under any circumstances change their settings while aligning the balance of the local-oscillator chain. I usually paint a dot of nail polish on C16 to lock it down and tape over the access hole in the side of Y1, lest I be tempted to backtrack and screw things up completely! Remember, the objective is to perform a reasonably clean LO alignment without the use of any costly test equipment, so don't jump sequence.

The easiest way to resonate the collector tank of the first multiplier stage is to monitor the current drawn by second doubler, Q2. Apply operating potential to feedthrough capacitors C13 and C14, and this time monitor the current drawn at C14. This current should peak smoothly at 10 to 12 mA while adjusting C4 no more than two or three turns from its preset position.

Adjusting the interstage circuitry between the second doubler and the parametric tripler is perhaps the trickiest part of aligning this LO because there are three separate trimmer capacitors and the adjustments are all interactive. Note that at this point the only clue you have to proper alignment is the collector current drawn by Q3, so watch it closely. Apply operating potential to all three feedthrough capacitors (C13, 14, and 15), this time monitoring current at C15. First, adjust C7, slightly, just to the point that a few milliamperes of current flow through C15. Now, carefully adjust both C5 and C6 to maximize this current. As before, a peak should occur before the trimmers have been adjusted very far from their preset positions. Once a peak has been found with C5 and C6 both set at approximately the same point, re-adjust C7 slightly. At this point, C4 (the collector tank of the first multiplier) may be adjusted ever so slightly to maximize current at C15. Now, back to C5 and C6 again, then C7 if necessary, and so on until the current at C15 settles in at about 15 mA. Note that when you're done, both C5 and C6 should have their tuning screws protruding by about the same amount.

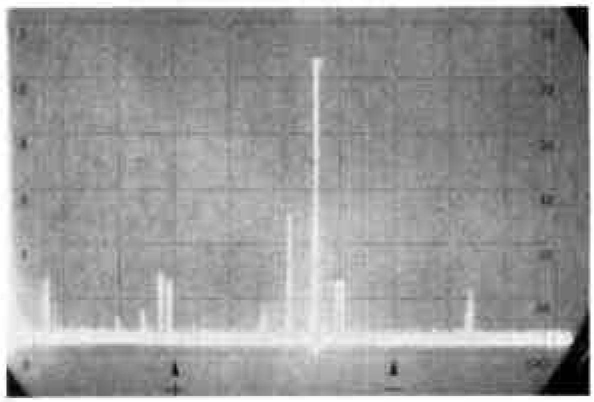


fig. 8. This photograph shows the output spectrum of the L-band LO system after being aligned as described in the article. Spurious rejection of close to 30 dB was achieved with the simple test equipment called for in the article.

All that remains is to align the output bandpass filter. An rf-diode detector can be connected to the output connector, the dc from the diode assembly being fed to a sensitive microammeter as an indication of relative rf output. Any other method of measuring relative rf power (bolometer bridge, calorimeter, or similar) may also be employed. The object is

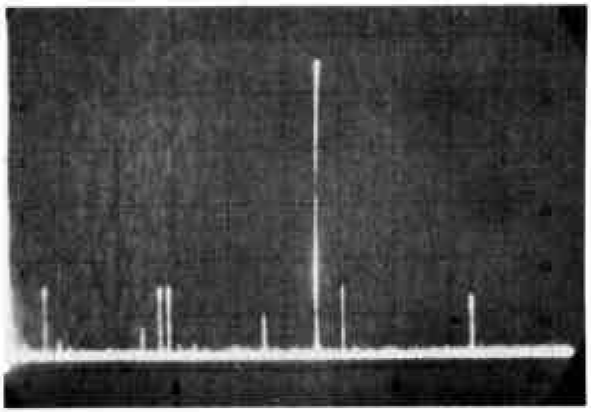


fig. 9. Example of the output spectrum after aligning the local-oscillator chain with a microwave spectrum analyzer. In this case, all spurs are down greater than 40 dB.

to adjust C8, C9, and C10 simultaneously for maximum indicated output (the three trimmer capacitors should all track relatively closely). Keep monitoring the current at C15. If it jumps abruptly, the tripler stage is self-oscillating. It can be tamed down by slightly adjusting C7 until current at C15 returns to its proper value.

With C8, C9, and C10 all peaked at approximately the same setting (not too far, you hope, from the preset position) and output power maximized, one last adjustment to C7 is in order. Adjust this capacitor for the maximum output level obtainable *without causing an increase in the current at C15.* At this point, you may be tempted to go back and repeak all the other trimmer capacitors in the circuit; resist that temptation. You can only disrupt what would in all likelihood be a very clean output spectrum, such as that shown in **fig. 8.**

Of course, if you are fortunate enough to have access to a microwave spectrum analyzer, adjusting the trimmer capacitors ever so slightly can indeed clean up the output spectrum still further (see **fig. 9**). But this should be attempted only after the current-sensitive tuning method has been completed and decoupling resistors R4 and R5 installed.

One final thought. Those super-purists fortunate enough to possess a complete laboratory of microwave test equipment will doubtless notice that any tuning adjustment can potentially affect output power, spectrum, *and* frequency. Thus, you may wish to simultaneously monitor all three parameters during alignment. **Fig. 10** is the lab setup I use in aligning these LO chains. The key to the success of this method is the resistive three-way power divider, which applies equal samples of the LO's output signal to the counter, spectrum analyzers, and power meter. The divider is built simply from four 27-ohm, 1/8-watt, carbon-composition resistors, arranged symmetrically in a small shielded box which supports four coaxial connectors.

parts procurement

Readers of my construction articles frequently write asking if I can supply a complete kit of parts for a given project. Unfortunately, I have neither the time nor the inclination to get into that business. But I am not heedless of the plight of the home constructor, and as much as possible like to help identify (or sometimes create) sources for some of the less-common components.

For example, I have in the past endeavored to make etched, drilled, and plated circuit boards available at cost, for the benefit of those experimenters who prefer not to fabricate their own. This project is no exception. I will supply the boards for $10 each, postpaid anywhere in the U.S. or Canada ($11 elsewhere).

In a previous article, I mentioned a source of supply for the Triko trimmer capacitors I employ in this and other modules. Unfortunately, I later discovered that the importer had a $50 minimum order requirement. Thus, I have recently obtained a quantity shipment of the piston trimmer capacitors used in the LO chain, and will gladly supply them to Amateurs in sets of seven pieces (the quantity needed for each LO chain) at $10.50 per set postpaid in the U.S. or Canada, $11.50 elsewhere.

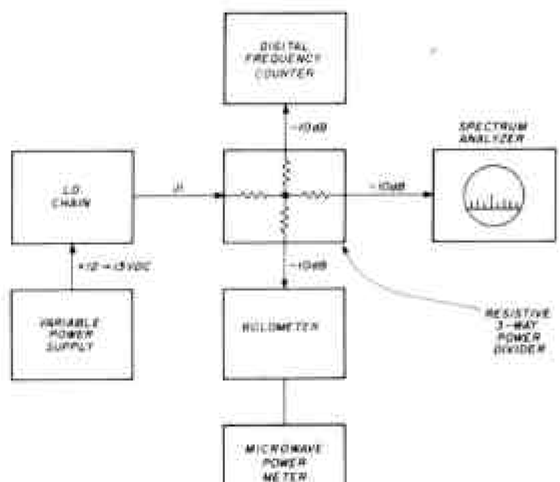


fig. 10. Test configuration for monitoring power, frequency, and output spectrum simultaneously during alignment of the LO chain.

The crystal oscillator assembly designated Y1 is available only from International Crystal Manufacturing Company. I recently spoke to Mr. Royden Freeland, himself a ham and microwave experimenter, and he assures me that this module will be sold to individual experimenters in single quantities. Be sure to allow six to eight weeks for delivery, as the units employ custom-ground crystals.

The MRF-901 transistors used for Q1, Q2, and Q3 are available from Motorola Semiconductor Company. When I first used this particular transistor in a 1296-MHz preamp a few years ago, the price was $9 each. Quantity production and improved yield brought the price down to $4.30 in 1977, and to an unbelievable $1.45 today. At that price, I'd recommend against trying to substitute any other transistor.

The rest of the components used in the LO are, for the most part, garden-variety. Though not necessarily available at your corner Radio Shack, they should nonetheless be obtainable by most experimenters after a bit of scrounging.

Of course, there are always those who need a microwave LO but prefer not to do the scrounging, building, tuning, and testing themselves. To such individuals I am able to offer a completely built, tuned, and tested Model LO-1200 Oscillator Module, packaged in an enameled die-cast aluminum box, operating at your specified frequency between 1150 and 1555 MHz, for $160 postpaid. Foreign orders please add $5 additional postage. This offer is extended to licensed Radio Amateurs only (state your call when ordering), and is restricted to units used for personal, noncommercial applications only. All orders for printed circuit boards, capacitors, or complete LOs must be prepaid in U.S. dollars, and all inquiries must be accompanied by a stamped, self-addressed envelope.

Frankly, I hope nobody takes me up on the above offer. I'd rather design gear than build it for others, and, besides, you're missing out on quite a feeling of accomplishment if you buy your gear ready-made. After all, it is the home constructor to whom this article is dedicated.

Happy building!

references

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ham radio