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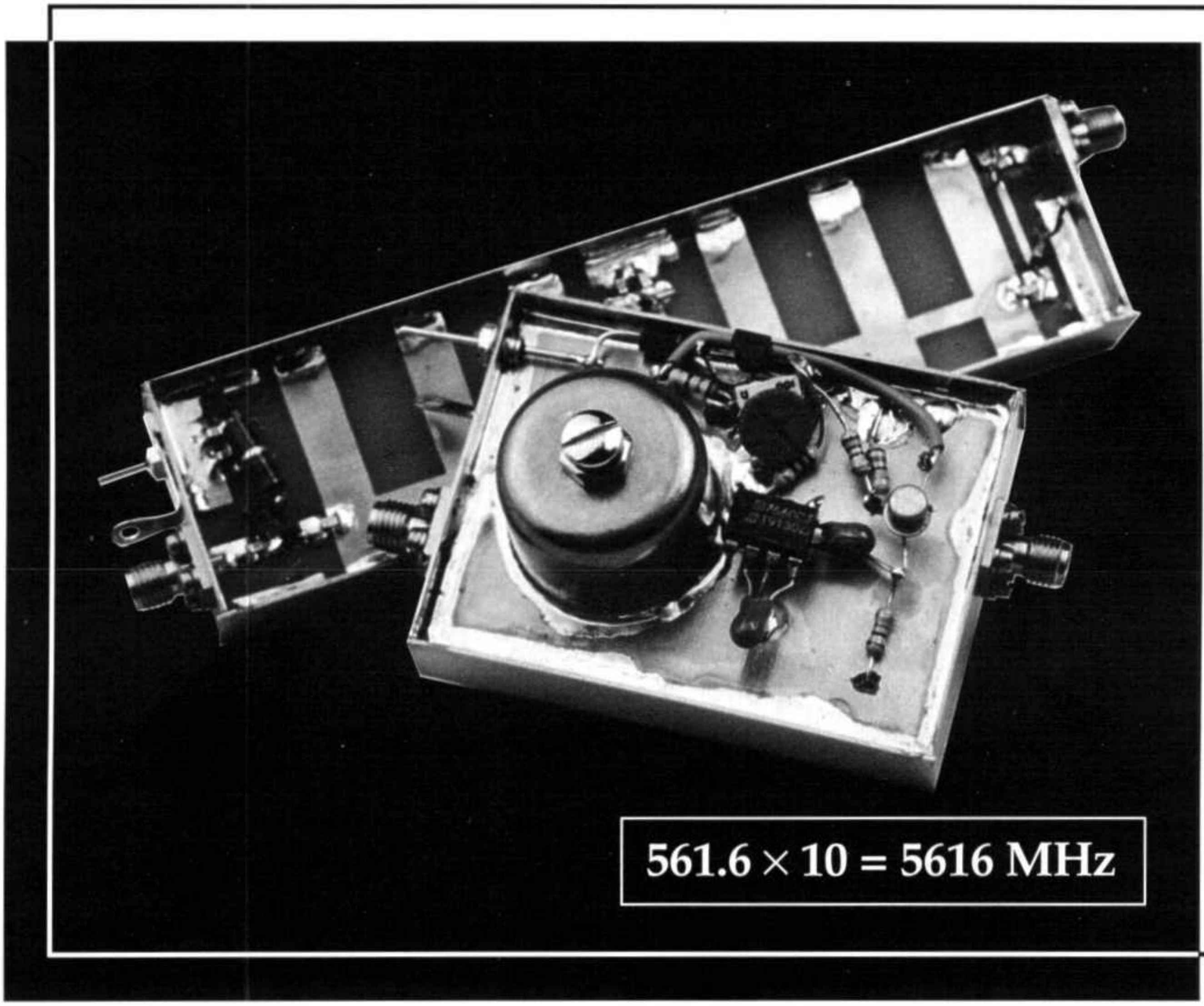
ARRL Experimenter's Exchange

May 1993



561.6 × 10 = 5616 MHz

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About the Cover:

No tune (well, *almost* no tune) microwave technology from Zack Lau, KH6CP: multipliers for a 5616-MHz LO.

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2) document advanced technical work in the Amateur Radio field

3) support efforts to advance the state of the Amateur Radio art

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Both theoretical and practical technical articles are welcomed. Manuscripts should be typed and doubled spaced. Please use the standard ARRL abbreviations found in recent editions of *The ARRL Handbook*. Photos should be glossy, black and white positive prints of good definition and contrast, and should be the same size or larger than the size that is to appear in *QEX*.

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Empirically Speaking...

The Iron Is Hot

If you've been reading *QEX* for the last year or so, you will have noticed that we're starting to run more material about UHF/microwave homebrewing. Although this is partly because of a conscious effort to get more RF homebrew material in *QEX*, it also is indicative of a trend toward the higher frequencies. This trend can best be summed up using the current buzzword: no tune.

For years, any work on the higher frequencies was limited to those hams who had access to test equipment useable at those frequencies. And since such equipment tends to be expensive, only those who worked in laboratories so equipped—or the exceptionally well heeled—could play the game. That's changing now due to the efforts of a few dedicated experimenters such as Rick Campbell, KK7B, and our own Zack Lau, KH6CP.

Until the development of this new trend, most UHF/microwave homebrew equipment was used by the weak-signal crowd. Lacking sufficient challenges at the lower frequencies, they pushed ever higher to find new obstacles to overcome. With the advent of no-tune technology, the opportunity now exists for other users to exploit these bands. Two potential uses of no-tune technology come to mind immediately: satellites and packet. No-tune transverters represent the least expensive way of getting a satellite station up for those hams who already have the IF equipment (SSB transceiver). For those who don't, see "Single-Conversion Microwave SSB/CW Transceivers," by Rick Campbell, in the May 1993 *QST*. For packet, an existing 56-kbaud modem design (D. Heatherington, WA4DSY, "A 56 Kilobaud RF Modem," *ARRL 6th Computer Networking Conference,* 1987) generates and accepts 28-MHz signals at transverter power levels.

There are other applications for microwave point-to-point links, including control links for repeaters and remote bases. The point is that it has never been simpler to put a signal on the amateur UHF and microwave bands. Consider using these bands for your next project!

This Month in *QEX*

Slow-scan TV is growing in popularity, largely due to the advent of low-cost, computer-based SSTV systems. Gene Harlan, WB9MMM, shows us some techniques for making a *really* low-cost SSTV system using a SoundBlaster board in "Slow Scan TV With the SoundBlaster."

One of the oft-overlooked parts of building a project—particularly one you designed yourself—is testing. Power-supplies are particularly important in this regard, since failure in the power supply may cause nasty voltages to get to the device being powered—you can lose it all in a flash (literally!) Bert Kolts, WA0WZI shows how to ensure that won't happen in, "Smoke Testing for Beginners—An Introduction to Power Supply Testing."

If you've never connected a transverter to a driving source, you may be tempted to think it's a plug-and-play operation. But improper drive can cause splatter and other unwanted effects, so it's best to set up the system so that proper drive levels are certain. David Laag, WA6OWD shows us how in, "Optimizing Drive Levels In Microwave Transmitting Converters."

Robert Dubke, K0SIR, has been through the mill on connecting up a 9600-baud modem. In "All G3RUH Modems Are Not the Same," he describes a needed modification to some modems to keep the modulation from affecting the radio's local oscillator during receive.

Finally, *QEX* columnist Zack Lau, KH6CP, presents a system for generating a 5616-MHz LO in this month's "RF" column. *—KE3Z, email: jbloom@arrl.org (Internet)*

Slow Scan TV with the Sound Blaster

By Gene Harlan, WB9MMM
5931 Alma Dr
Rockford, IL 61108

Buying special boards and equipment is not the only way to do slow scan TV. Now you can copy SSTV using an IBM PC compatible and a Sound Blaster card!

The frugal nature of most hams, including me, leads us to look for better and less expensive ways to do things. I have had an interest in slow scan TV (SSTV) for many years, but I never wanted to spend the money to buy new equipment. It hasn't been cheap to get into SSTV, at least not until the last couple of years. Several low-cost units have come to the market recently, and interest has soared because of them. This is evident in the number of articles explaining SSTV such as those in the January and February 1993 issues of *QST*[1,2].

I started in slow scan about 1977 by starting to build my own display. I had picked up a P7 picture tube at a hamfest, built the surrounding electronics, and had it partly working when a Robot Model 70 monitor & Model 80 camera became available at a price I couldn't pass up. So much for building my own equipment! I'll never forget the excitement of my first SSTV contact with XE1JOF in Mexico City. While all I sent him was a picture of myself sitting in front of my equipment, he sent me a travelogue of the area around Mexico City. At that time the only mode that was used to any extent was 8-second black and white. To send color you needed to send 3 separate frames of 8 seconds, one each of red, blue, & green. It's bad enough to sit still for 8 seconds, much less sitting still for 24 seconds!

As I said before, hams are always looking for better or different ways of doing things. My wife, Shari, bought me a Creative Labs Sound Blaster card for a Christmas present two years ago.[3] (How she thought of it I'll never know. . .) Well, you can't have a programmable board that you cannot program, so I purchased the developers' kit as well (I mean, she did). Now I could have some fun!

What is the Sound Blaster?

The Sound Blaster is a card that plugs into a slot in an IBM PC compatible computer and provides sound input and output capabilities. It is used with computer games, multimedia applications, or just plain anything that uses sound. There are currently three versions being sold: the standard Sound Blaster V2.0, the Sound Blaster Pro, and the new 16-bit version for even fancier applications. I'm using the Sound Blaster Pro. It accepts sound input via a microphone or LINE IN jack and produces stereo sound output. It even has its own built-in 4-watt amplifier. Another connector provides an input for a joystick or MIDI (musical instrument digital interface) device (see Fig 1). The Sound Blaster comes with a collection of programs such as *VEDIT2* (records voice and sounds, allows editing, echo effects and more), *TALKING PARROT* (great for the kids as it will mimic what you say in a higher pitch and sometimes tells you that you have "bad breath"!), and other programs that play music or other sounds. A fun and enjoyable device all by itself!

After getting the Sound Blaster, I started thinking of programs I wanted to write. It didn't take longer than the next time I heard SSTV on 14.230 MHz that I realized I had a project. Thoughts of connecting the audio out of my receiver to the microphone input of the Sound Blaster and connecting the sound output of the Sound Blaster to the microphone input of my transceiver raced through my head. Let the programming begin!

It was very slow going at first as the initial software from the development kit was for Microsoft C and I was

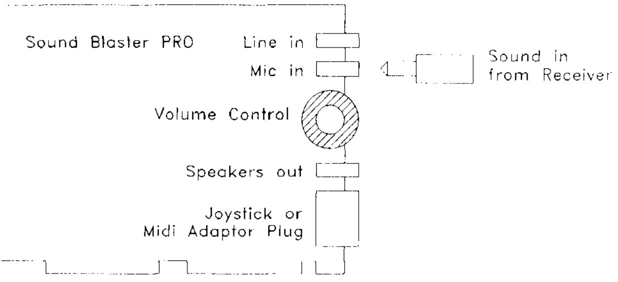

Fig 1—Diagram of the Sound Blaster's connections.

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[1] Notes appear on page 6

using Borland Turbo C. After about 9 months, I received an update disk that covered my needs. What I didn't know is that I *still* had a long road ahead. First I had to figure out the .VOC file format used to store sound, and I had to understand how to convert all those numbers in the file to frequencies. I decided the easiest way to begin would be by recording SSTV audio to a disk file then, when the sound stopped, read the file and display it on the screen.

Examining the .VOC File Format

The sound disk file has an extension of .VOC—in my case TEMP.VOC—which consists of a header and data.

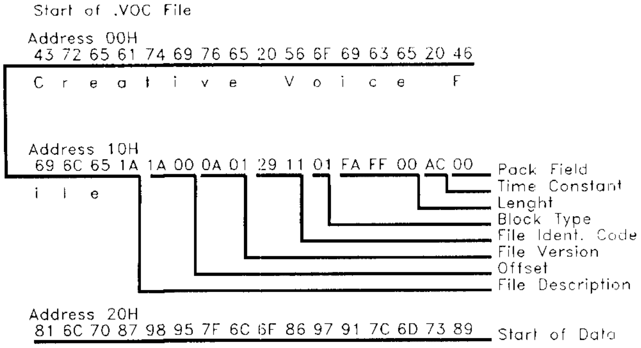

Fig 2—An example .VOC data file containing the data graphed in Fig 3. The format of the .VOC file is given below. Numbers of more than one byte are stored least-byte first, as is standard for Intel processors.

Bytes 00-13H	**File description ("Creative Voice File"+1AH).**
Bytes 14-15H	**Offset in the file of the first data block (normally 001AH).**
Bytes 16-17H	**File version (major, minor); currently 1.10**
Bytes 18-19H	**File identification. This is the complement of the version number added to 1234H; currently this results in 1129H.**

Each data block has a format as follows:

Byte 00H	**Data block type:** **00H = Terminator (EOF)** **01H = Sound data** **(Other types are not used by this program.)**
Bytes 01-03H	**Data block size in bytes (not used for terminator blocks).**

Type 1 data blocks include the following:

Byte 04H	**Sample rate constant = 256- (10^6/rate).**
Byte 05H	**Packing type; only type 0 (8-bit data) is used by this program.**
Bytes 06-?	**Sampled data bytes.**

The data portion consists of bytes of information with values from 0 to 255 decimal (00H to FFH hexadecimal). Fig 2 shows a set of numbers that make up one cycle of a given frequency. (Hexadecimal numbers are used for this example.) The numbers represent the input voltage, with the center point (zero volts) represented as the number 80H. The most positive amplitude possible is FFH and the most negative is 00H. The data in the example begins at location 20H in the file. The data, starting with 81H, 6CH, 70H, 87H, etc, are plotted in the graph of Fig 3 as *samples* of the input waveform.

The time between sample points is determined by the sample frequency. After trying sample rates from 8 kHz up to 22 kHz, a rate of 12 kHz was chosen. With this frequency, each sample has a time of $\frac{1}{12}$ kHz = 83.333 μs.

Calculating Frequency

Now we can begin calculating the input frequency. If we know the time of one cycle (the period), we can convert to frequency by taking the reciprocal of that number (1/period). Each input cycle extends over a number of samples. The tricky part is not in adding up the number of samples in the period, but in figuring the amount of time to allocate when the zero crossing occurs between samples. This effect is shown in Fig 3 at A and B. For my program, I assumed that the waveform was a straight line between points. Linear interpolation is then used to estimate the time of the zero crossing.

The calculations for the transition from sample 3 (70H) to sample 4 (87H) in Fig 3 are:

70H = 112 decimal,
87H = 135 decimal,
80H = 128 decimal
135 – 112 = 23 (this is the total swing from negative to positive)
135 – 128 = 7 (the amount on the positive side only)
Period = $\frac{1}{12000}$ = 83.333 μs
Time per 1-bit change in amplitude: 83.333 μs/23 = 3.623 μs
The time from the zero crossing until sample 4 is therefore: 3.623 μs × 7 = 25.62 μs to the period.

In the example of Fig 3, the cycle of the waveform consists of 5 sample periods of 83.333 μs each plus the time from the positive going zero crossing (A) which we calculated as 25.62 μs plus the time at the end of the waveform (B) which, using the same technique as above, is 61.591 μs. Adding these together gives a total period for that cycle of 503.876 μs which is 1984 Hz ($1/(503.876 \times 10^{-6})$). I found that I had to use a full cycle of audio to make the calculations rather than a half cycle because there could be a dc offset on the input which would make the positive side of the signal appear to be a very high frequency and the negative side a very low frequency, or vice versa.

One of the many good points of the Sound Blaster card is that it has its own clock so the sample rate does not depend on the host computer. An 8-kHz sample rate did not provide a satisfactory image, whereas 12 kHz did. Going to 22 kHz did not give much improvement so 12 kHz was chosen. This allows the use of the lower priced Sound Blaster with its maximum sampling rate of 12 kHz.

The SSTV Software

The choice of video mode was based on the fact that I haven't seen anyone else using the 640 × 480, 256-color VGA mode as yet. When I get to displaying color, I think it will look great. This mode is harder to work with, though, because when you use a 256-color video mode with more resolution than 320 × 200, there is no standard among manufacturers of video cards. It is necessary to detect which video card you are using, and then set up the proper mode. I purchased drivers from Peter Jones to overcome this problem.[4] Peter's documentation is well done and I used his fax machine a couple of times to get help! He was very prompt and helpful.

There are two versions of the software currently available. One is a shareware version which gives a taste of what SSTV is all about.[5] The only mode is the 8-second black and white mode. The second version includes Robot 8-, 12-, 24-, and 36-second black and white, and Robot 36- and 72-second color modes (displayed in black and white), as well as Scotty 1 and Scotty 2 (also displayed in black and white).[6,7] I plan a third version which will include color and add transmit capability to each of the previous versions. Hopefully it will be available by the end of 1993, depending on the work load at my "real" job.

During the development of the program, I needed a method for varying the sync, black, and contrast frequencies. These adjustable parameters have been left in the program for experimentation.

The sync frequency of SSTV is 1200 Hz, but I found that the program works well using anything below 1350 Hz. Alt-F1 and Alt-F2 make this adjustment. The black frequency for SSTV is 1500 Hz. If you change this frequency by use of Alt-F3 and Alt-F4, you will shift the whole video range up or down. In other words, the range is defined to be from 1500 Hz (black) to 2300 Hz (white). Changing black to 1400 Hz changes the range to 1400-2200 Hz. The range (1500-2300 Hz) is 800 Hz. The program divides this range into 64 levels of gray scale, resulting in 12.5 Hz per step of gray scale. By adjusting the number of hertz per step with Alt-F5 and Alt-F6, you can experiment with the contrast to see the difference it makes.

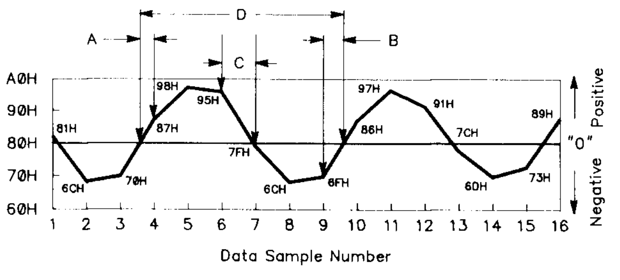

Fig 3—A graph of the example data. A sample occurs at each division of the horizontal axis. The vertical axis is the amplitude, from 00H to FFH, where 80H represents zero. The part of the graph labeled A is the time from the positive-going zero crossing to the next sample. This period is calculated by the program (see text). Likewise, B is the period from a sample to the negative-going zero crossing. C is the period between samples, and D is the period of the input cycle.

Saving To .VOC & .PCX Formats

The received image is saved to the TEMP.VOC file. Most of the time, due to the size of this file (about 100k of data for every 8 seconds), you would not want to save the data in the .VOC format. (TEMP.VOC can be renamed if desired to save it for later playback in that format by pressing F7 from the main menu, and then F4. The program will ask for a name at that point.) Most of the time you will want to save the pictures in .PCX format. This is done by pressing F7 from the main menu, and then F1. The .PCX picture format will save the picture in a much smaller file than the .VOC format does. The pictures can be recalled later in this program or in many of the paintbrush or picture viewing programs that are available. Also, when future versions of the program allow you to send pictures, you will be able to load pictures created in the same paintbrush programs or by using one of the video capture boards on the market.

Conclusion

It has been very rewarding doing this project. I have had phone calls and letters from people who are enjoying using it. I didn't expect many people to actually send money for shareware, but they *really do!* I have even received a registration from the Canary Islands. This is my first attempt at shareware, so the results are exciting! I have many other ideas for the Sound Blaster and plan to pursue them as time permits. Some of these include weather satellite pictures, RTTY, and many of the other communication means we use with ham radio.

Thanks to Thomas P. Myers, N9LHK, for his proofreading efforts.

About the Author

Gene Harlan received his license in 1973 after many years of interest and not doing anything about it. Only after meeting Ray, W9VTL, did he get inspired and do something about it. Getting the Amateur Radio license also started a chain reaction with his wife Shari, now WB9SFT (ARRL Section Manager for Illinois), and son Shawn, KA9BXA, also getting licensed. Gene's amateur activities created enough interest in electronics for him to enroll in Rock Valley College where he received his Associate in Electronics degree. He is now Manager of

Technical Support Services at Arachnid, Inc in Rockford, IL. Gene is a past president of the Rockford Amateur Radio Association and the Experimental Amateur Radio Society.

Notes

[1] J. Langner, "Slow Scan TV—It Isn't Expensive Anymore," *QST*, Jan 1993, pp 20-30. R. Booth, "The Beat of a Different Drum: The Cop MacDonald Story," *QST*, Jan 1993, p 31.

[2] R. E. Taggart, "A New Standard for Amateur Radio Analog Facsimile," *QST* Feb 1993, pp 31-36.

[3] Creative Labs, Inc, 2050 Duane Ave, Santa Clara, CA 95054. USA Technical Support Line 408 982-9226.

[4] VGA BGI drivers for Borland *Turbo C* available from Jones Computer Supplies, RR#3, Perth, Ontario, Canada, tel 613 267- 6704.

[5] The program *SSTV for the Sound Blaster* (8-second black and white version) is available on Compuserve and other bulletin boards as shareware. On Compuserve it is located in HAMNET, Library 6 (SLOWSC.ZIP). It is also available from the author (see below) for $20 (Illinois residents add 6.25% sales tax).

[6] The program *SSTV II for the Sound Blaster* (receives Robot 8-, 12-, 24-, 36-second black and white and Robot 36- and 72-second color [displayed in black and white] and Scotty 1, Scotty 2 [displayed in black and white]) is available from the author for $39.95 (Illinois residents add 6.25% sales tax). Shipping charges on foreign orders $15, USA free. Specify 5¼" or 3½" disk. Order from Gene Harlan, WB9MMM, 5931 Alma Dr, Rockford, IL 61108, tel 815 398-2683.

[7] Requirements include an IBM PC AT or compatible with a VGA monitor capable of 640 × 480, 256 colors, minimum of 640K memory, hard drive with at least one Mbyte free, and using PC/MS DOS V3.3 or higher. A numeric coprocessor will speed up the display but is not necessary. □□

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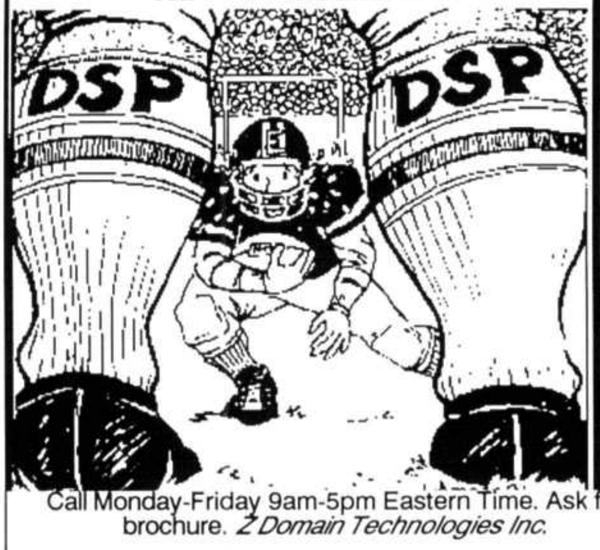

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Smoke Testing for Beginners—An Introduction to Power Supply Testing

By Bertram S. Kolts, WA0WZI
PO Box 122
Masonville, CO 80541

It's Field Day and you've just heard an XYZ call CQ. Wow, your new homebrew rig sure is working great! All those hours spent in the basement last winter, slaving over a hot soldering iron, really seem worth it now, but just as you are signing your call, your buddy throws the transfer switch to the standby generator. The light flickers momentarily and... Oh, no! The rig's gone silent! I've lost the XYZ! What happened? The rig's been working fine all day.

After a few unprintable words the problem is found to be nothing more than a blown fuse. Fortunately, you've got some spares in the tool box and the rig is back on the air in a few minutes, but the XYZ is nowhere to be heard.

You were lucky only the fuse blew. What would have happened if the series pass element in your regulator had shorted out? Could your rig withstand the overvoltage, or would your pride and joy be reduced to a pile of "used-to-be" semiconductors?

If this sounds a bit like I am picking on power supplies, I am. They are often a beginner's first homebrew project because they are quick and easy to build. However, they are deceptively simple, even for many experienced builders.

If you are like most homebrewers, when you finished building the power supply you measured the output voltage, perhaps even with a load, and called it good. But without further testing and evaluation there is no way to be certain how it will operate under other environmental conditions, or to know how safe it *really* is.

The most important reason to test the power supply thoroughly is safety. There is the danger of electrical shock or perhaps even a fire (ever see capacitors or ICs explode?), depending on the failure mode. Reliable operation under many different operating conditions, such as temperature or line voltage variations (remember the generators that were switched?) are also important, not just for Field Day or emergency operations, but for pride and confidence in the equipment you worked so hard to build.

Safety Considerations

Line voltage can kill! With this warning in mind, we can proceed to the first tests of our new power supply, the primary wiring of the transformer. In the commercial world, electronics manufacturers test their power-supply primary wiring with an instrument called a Hi-potter. This instrument applies 1500 V between the line and ground and between the neutral and ground and measures the resulting leakage currents. While this is a quick and easy way to be sure that the wiring and leakage currents are as they should be, the Hi-potter is not a piece of equipment that most of us are likely to have sitting around in the junk box! Fortunately, there are some things that can be done to ensure that the primary wiring of the supply is safely configured.

Take a minute and visually inspect the primary wiring to be certain the line cord and plug are wired correctly. Are the line and neutral connected to the right pins? Make sure that the third prong (the ground) of the plug is connected to the chassis. When in doubt, refer to the ARRL *Handbook* or *QST*. They contain lots of useful information about proper ac line wiring.

While you are still looking inside the chassis, inspect any components, such as capacitors, that you might have placed across the line. It is quite possible for them to see voltage transients that exceed 1000 V, so be sure these parts are rated for at *least* 1500 V.

Don't forget to check the line switch, too. Be sure that it is rated for at least twice the amount of current you expect it to carry and that it has the required voltage rating. Did you remember to build in a pilot lamp to know when the supply was really on?

There is just one more test to perform before we can apply power to that new project. With the supply unplugged and the line switch ON, measure the resistance from line to ground and from neutral to ground. Both of these readings should be at least 2 MΩ.

All of these tests help to assure us that the transformer is not shorted to ground and that there are no excessive leakage currents caused by faulty components.

Remember, *never* apply line voltage to any new power supply without doing these simple checks first! They could save your life and keep your project from self destructing.

Margin Testing

The goal of margin testing is to ensure that the power supply will continue to provide its rated output voltage and current over a range of varying environmental conditions. These might be changes in power line voltage, such as brownout conditions, or momentary interruptions, like our generators being switched, or even changes in temperature. If the power line voltage drops 2 volts, we don't want our output voltage to drop too! A robust power-supply design will make the power supply immune to many of these changes and make it a more reliable tool. If you do not test your supply, however, you will never know if it will perform when you need it to or how it will perform under adverse conditions.

The first thing to consider is the ability of the power supply to provide the necessary power. We should check the output voltage at both maximum and minimum load current. A simple load can be made from discrete resistors, but be sure that they can handle the power! If they get too hot try cooling them with a fan. I have built small loads of a dozen or more resistors mounted in a long box with a fan at one end for cooling. Crude, but effective.

Immunity to line voltage variations is another test we should perform. While the power-line voltages supplied by your utility company, or your generator, are nominally around 120 volts, they can vary a lot. Sometimes this variation can be as much as 10 or 20 volts—or more. The output of the supply should stay constant over a range of input voltages. A reasonable range of operation would be +10% to –15%, or 132 volts to 102 volts. The lower end of the range is larger than the upper end because brownout conditions are much more likely to occur than overvoltage conditions.

If you should have a supply that operates on 220 V, the same tests apply. Just use set nominal line to 220 V, high-line to 242 V, and low-line to 187 V.

The easiest way to check the line voltage range is to use a variable autotransformer that allows the output voltage to be adjusted. Of course, to be sure that our test is done under the worst conditions, the output of the power supply should be loaded to its maximum rated current.

If you can't find an autotransformer to beg or borrow, don't panic. Just do the tests at nominal line voltage instead. While this will not be as good a test as stressing the input voltage over its entire range, any testing that you can do is better than none.

Fuse Selection

Remember the problem we had at Field Day when the fuse blew while the generators were being switched? The next test is designed to help find such problems *before* Field Day. Set up your power supply with the output at maximum load current and, if possible, set the input line voltage to 132 volts. Then cycle the power on and off as fast as possible. Do this at least 50 to 100 times. This will create random switching transients that will stress the input current levels at turn-on.

The fuse should *not* blow at any time during this test. If it does blow then the fuse size or type needs to be changed. A higher current fuse could be used to fix the problem, but a larger fuse might not blow when we want it to. Usually, a slow-blow fuse will be the simplest and safest way to solve transient current problems.

Abuse Testing

Once the operating margins of the power supply have been determined, we can proceed to the fun part of the testing—abuse testing. With abuse testing, we intentionally introduce faults into the circuit to ensure that should similar failures occur during normal operation, no damage will be done to the power supply or to any equipment connected to the output.

Don't panic! If the power supply is properly designed, you will not damage it during these tests. At most, a fuse or two might be blown. If you should happen to damage a component, it is better to find the flaw now and not later when a failure might damage the equipment connected to the output.

One of the most likely errors when using a power supply is to short the outputs to ground, so this is a good place to start our abuse tests. With the supply turned on, short each of the outputs to ground one at a time. You should be able to leave the output shorted indefinitely without damaging anything. The regulators might get hot, or a fuse might blow, but nothing else should happen.

On one occasion, I was performing this test on a supply that was rated at over 20 amps. After being shorted for several minutes the fuse had still not blown and the regulator was far too hot to touch. Finally, the circuit decided that it had been tortured enough. The regulator got so hot that it melted the solder on the pins and fell out of the board!

If the supply has multiple outputs, short each of the outputs to the others while measuring the resulting output voltage from the shorted pair. Again, it is acceptable for a regulator to get hot, or a fuse blow, but nothing else should happen. Also, the output voltage from the shorted pair should not change polarity or exceed the lower voltage of the two outputs.

For example, if a +5-V and a –15-V supply are shorted, the only acceptable result is 0 volts. If the shorted outputs went to +5 volts or –15 volts, then the devices connected to these supplies might be destroyed by reverse polarity or overvoltage. Likewise, if a +15-V and a +5-V supply are shorted, the output should go to somewhere between 0 volts and +5 volts to avoid overvoltage damage to parts connected to the +5-V supply.

This is a very easy test to fail, as most power supply designs overlook the possibility of outputs shorted together. The easiest remedy is to provide a crowbar circuit that will blow the fuse or clamp the output if overvoltage or a reverse polarity occurs. The *Handbook* has several examples of crowbar circuits that you can include in your design.

The most common failure mode for a power supply is probably a shorted regulator or rectifier. If this happens, there is a good chance that the output will be overvoltaged. Once again, a crowbar is the best protection for the output load.

To ensure that these failure modes will not cause a problem in *your* supply, short out each of the regulators and rectifiers while monitoring the outputs. The fuse might blow, but the output voltage should not exceed the specified voltage and no other components should fail.

If your supply uses remote sensing, be sure to include this in your tests as well. The output voltage should be monitored with the remote sense leads disconnected from the load and with the remote sense leads shorted (still disconnected from the load). The output voltage should not exceed its specified limits. That is, it should not rise more than a few percent above nominal.

Power supplies that are designed to be operated from a dc source, such as a battery, should be subjected to the same tests as those intended for ac line operation. In addition, the supply should be protected from damage if the dc source is connected backwards. This can *really* be a smoke test if the supply isn't properly protected.

These tests cover many of the more likely electrical abuses that your supply might encounter, but there are mechanical abuse tests to consider as well. How sturdy is your construction? Can you throw your pet project into the trunk of your car and drive the ten miles up that washboard road to the Field Day site and still find everything intact and operational? Take a look at all of the large and heavy components like transformers and filter capacitors. Are they well secured to the chassis?

Table 1.

POWER SUPPLY TEST CHECK LIST

1 Visual inspection of primary wiring. Third prong securely connected to the chassis (measure with ohmmeter).
2 Voltage rating of any components across the line is greater than or equal to 1500 V.
3 Line switch is properly rated for voltage and current.
4 Resistance from line to ground and neutral to ground is greater than 2 MΩ.
5 Output voltage okay under maximum and minimum load currents.
6 Output voltage okay under maximum load at high and low line voltages.
7 Cycle power switch 50-100 times at maximum load current and high line voltage.
8 Short the outputs to ground and to each other. No over voltage or reverse polarity observed.
9 Short out the regulators and rectifiers. No overvoltage or reverse polarity observed.
10 Shorted and open remote sense leads. No overvoltage seen.
11 Reverse input polarity if supply is run from a dc source. No smoke or reversed output voltage.
12 Drop test the cabinet on all four edges.
13 Check the temperature rise with fan disconnected and maximum load current.
14 Check component temperatures with two-second rule.
15 No cabinet holes of more than ¼ inch, and no holes in the cabinet's top.

Set the supply on a hard, flat surface and then lift one side, so the cabinet or chassis is at about a 30-degree angle. Drop it! Nothing should break. Repeat the drop test for the other 3 sides.

Parts that come loose or are bent during such testing need to be mounted more securely. If you feel really adventurous, this can be done with all 6 sides of the cabinet, but for homebrew equipment this much "crunch proofing" probably isn't necessary.

Heat dissipation is another area of concern. Large power supplies, like those used for linear amps, might use a fan for cooling the high power components. But what happens if the fan should fail, or if the air filter becomes blocked? If you are using a fan in your project, be sure to run an over-temperature test. Disconnect the fan and load the supply to its maximum current. This is a great smoke test! Watch carefully (smell too!) for any parts that start to overheat. My rule of thumb is that if you can't hold your finger on a part for more that two seconds, it's *too* hot and you should consider adding a temperature sensor to your circuit to shut down the supply if it overheats.

While we're on the subject of temperature rises, be sure to check the hottest components in the circuit while at maximum load. Remember that the temperatures outside in summer can easily be 30 degrees F greater than in your basement. I use the same two-second rule here. Hot components will fail much more quickly than cool ones. High temperatures are a component's greatest enemy.

If you have put ventilation holes in your cabinet, be sure that they are no larger than ¼ inch to prevent foreign objects, such as fingers, from being stuck into them. Have you ever heard of the notorious coffee/Coke law? It states that if you put holes in the top of your cabinet, sooner or later someone will spill coffee or Coke into them—and it will probably be you! *Don't put holes in the top of your cabinet!*

Conclusion

These are by no means all the tests that you could run on a power supply, but given the limited resources of the average homebuilder, they should be enough to ensure that your equipment is safe and will operate properly when you need it most. You can use the check list in Table 1 as an aid in testing so you don't forget anything.

Do not forget to wear your safety glasses. Occasionally these tests can become real smoke tests—with a BANG! Capacitors, resistors, transistors, and other parts can explode under the right conditions. Components can be replaced; your eyes cannot.

All of this testing and evaluation may seem like a lot of effort, but there is no other way to achieve reliability and safety. Once you go through this process of testing though, you will probably find that it's a lot of fun. It's especially nice to know that on Field Day your project really will work under all of those conditions and not fail because of a poor design. □□

Optimizing Drive Levels in Microwave Transmitting Converters

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This article describes the various common circuits used to bridge the gap between the IF/driver rig and the transmitter portion of a transmitting converter (transverter). It is applicable to all transverters using narrowband modes (CW, SSB, etc) whether operating on VHF, UHF or SHF frequencies. Its main purpose is to present a simple but highly accurate way of setting the proper drive level so as to prevent problems associated with both overdriven and underdriven transverter stages. Additionally, this method allows for easy measurement of peak power output from a transverter.

The recent advances in technology available to radio amateurs combined with an abundance of surplus materials has helped to fuel increased interest in weak-signal communications. These changes have allowed access to UHF and SHF operation by amateurs who did not possess elaborate microwave fabrication and test facilities. A number of kits are now available to help populate all amateur microwave bands up to and including the 10-GHz band.

This article presents a test procedure which will help amateurs who are using transverters for narrowband (SSB or CW) weak-signal communication. The procedure outlined here is designed to use a minimum of expensive test equipment while producing accurate results. The need for a spectrum analyzer is avoided if you are using a well designed kit or homebrewed system. As is the case with all amateur equipment, you are encouraged to use a spectrum analyzer if you are uncertain if your rig meets FCC Part 97 requirements. The bottom line is that your system will possess excellent transmitted audio and make your rig more easily copied at distant locations and weak signal levels.

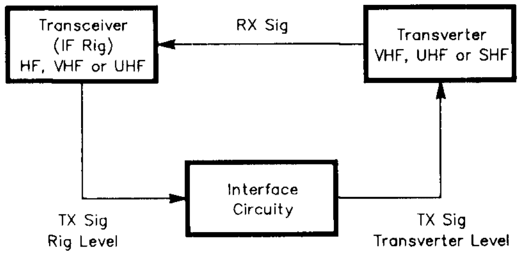

Fig 1

The make-up of a typical complete microwave station is shown in Fig 1. The IF portion of the system consists of a HF, VHF or UHF amateur transceiver. The choice of rig to use for the IF depends upon the IF frequency needed for a particular transverter design (28, 144 or 432 MHz, etc). An interface circuit is necessary for each type of transceiver to allow for the correct and safe operating transmit power level to be applied to the transverter.

The basic type of IF rig does not allow for any external connections to the transceiver other than the antenna connector. Such rigs are quite cost effective and small in size but do not contain "high performance" features found in higher priced rigs. These rigs may offer some challenge to the design of interface circuitry as there is usually no available adjustment of the transmitter power requiring an interface attenuator circuit capable of handling full transmitter power. Obviously, excess power dissipated in the attenuator circuitry is power wasted by the rig. It is advisable to remove the PA circuitry from these rigs and just use the transmitter exciter portion to drive your transverter.

The middle price/quality range of transceivers contain more of the interface circuitry necessary to easily connect them to your transverter. It still may be necessary to modify these radios to bypass high-power output stages in dedicated service. If you want to keep your transceiver stock, an acceptable interface method may be available, as top-of-the-line equipment usually comes

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[1] For more information about the San Bernardino Microwave Society, please contact the author at the above address.

from the factory set up for direct connection to a transverter, and little or no modification is necessary. For any of the rigs mentioned here, consult the service manual to see what connections are available for you to use.

Most modern HF rigs have an external ALC input for use with a linear amplifier. The ALC input accepts a dc feedback voltage used to control the maximum transmitter output power and prevent overdrive of a linear amplifier. Some VHF and UHF rigs have ALC inputs but most do not or have it available only for certain modes. The manufacturers of VHF/UHF power amplifiers have taken this into account and incorporate an input power leveling circuit to allow use with a large range of input drive levels. Such circuits would complicate transverter design and in most cases are not really necessary.

It must be noted here that just turning the transmitter microphone level control down in SSB mode does not prevent the rig from putting out full power. Driving the microphone input harder by speaking louder will produce more output power even at lower microphone level settings. The internal ALC is used to limit the amount of drive to the power stages and prevent them from being driven into distortion. In the CW mode, the drive adjustment for a required level of power can be very touchy and the output power for all modes may drift with changes in chassis temperature.

When available, the use of the rig's external ALC input to limit the transmitter power is essential for proper maintenance of transverter drive level. It is the only safe method for preventing overdrive of the transverter and the resulting distortion, excessive bandwidth, spurs, harmonics or, in severe cases, mixer or power-stage burnout. When using the ALC to control high power transmitters it is important to check the transmitter for full-output power spikes at the leading edge of voice syllables or CW dots and dashes. These spikes usually result from too slow of an attack time in the ALC circuitry and may be curable by removing some of the filtering of the ALC voltage within the rig. Be sure to check for this problem if you use a high power transmitter with lots of ALC shutdown, like a 100-watt rig shut down to 5 watts.

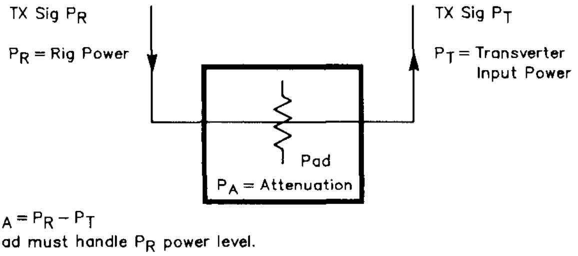


Fig 2

At this point you should determine the type of interface needed by your transverter or which type best suits your situation. Fig 2 shows the interface used when no ALC input is available. A fixed attenuator controls the amount of drive available to the transverter. If you must attenuate a transmitter with a power output of more than 1 watt, make certain that the attenuator used can handle the highest power the transmitter will make. This will prevent the attenuator from failing and allowing a high power level to reach the transverter with almost certain disastrous results.

Fig 3 describes the circuit used when an ALC input is available. The input attenuator is used to roughly match the transmitter power level to the requirements of the transverter. As in the paragraph above, if you are using a high-power transmitter attenuated down substantially, carefully observe the described precautions. In this case, the preferred point to acquire the ALC voltage is at point A. This protects the transverter in situations where it has failed and the rig's transmitter compensates by applying more power.

If you are lucky, your rig has a transverter output which has power levels which closely approximate the transverter input requirements. Many rigs like this have a circuit which shuts down the high power PA and bypasses it when using the transverter output. This prevents high power consumption during transmit, making these rigs more desirable for field use. These rigs may in fact need an amplifier stage between them and the transverter depending on the transverter's drive requirements. If the power levels used cannot damage the transverter by overdriving it, the ALC may be sampled at point B. This is the

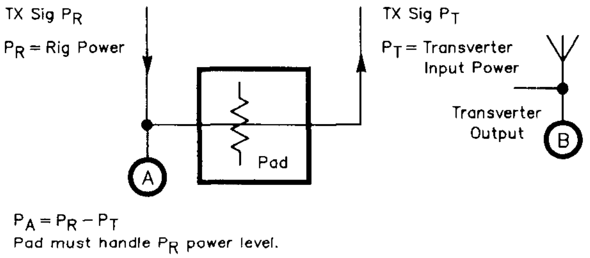


Fig 3

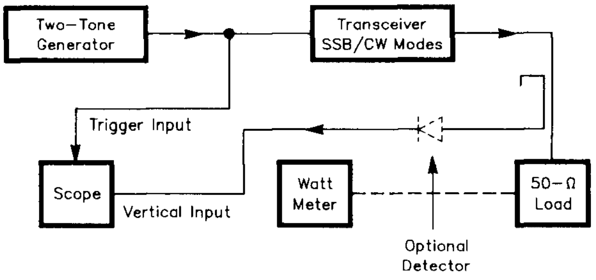


Fig 4

ideal situation as the ALC can then compensate for changes in amplifier gain within the transverter and always give the transverter correct drive levels.

Fig 4 shows the test set up used, and Table 1 lists the equipment required, to determine rig output power or to set a particular transverter drive level. The first step is to look at the linearity of your rig in the SSB mode. Connect your rig into a dummy load and connect an oscilloscope across the load using an isolation tee or high impedance probe with the correct power and frequency ratings. Connect the microphone that came with the rig and using a normal radio voice adjust the microphone level control until the recommended ALC meter deflection is achieved. If your rig does not have an ALC meter or microphone level control, move on to the next step.

Connect the two-tone generator (see note in Table 1) to the rig and set tones A and B so that they are at the same level. Then adjust the two-tone level so that the ALC meter is deflected to the correct operating point. Observe the output on the scope and make certain that the sinusoidal shape of the wave has been preserved. If you are using an oscilloscope that does not have enough vertical bandwidth to look directly at the waveform, it will be necessary to use an RF detector ahead of the oscilloscope. When using an RF detector remember that you are looking at only half of the envelope (positive or negative) of the waveform. If your rig does not have an ALC meter, adjust the two-tone generator to the maximum level which prevents distortion of the sinusoidal waveform observed on the oscilloscope. Record the peak voltage observed on the scope, as this represents the peak linear output from your rig. Do not readjust the microphone level or two-tone generator after this test has been made.

Place your rig into the CW mode and adjust the CW level to match the peak voltage recorded previously. By connecting your rig to an average reading wattmeter you may now read on the wattmeter the peak power your rig will make with a linear output.

If you are using the ALC to substantially reduce the power output from your rig, you may use the ALC voltage to set the amount of power that you need to drive your transverter. Place your ALC tap across the termination and adjust the ALC feedback voltage with a potentiometer or fixed resistor divider to give you the correct amount of power across the load.

At this point you should know the amount of power your rig makes and how much attenuation (or amplification) you need to match your transverter drive requirements. Connect your equipment as shown in Fig 5, go back to the SSB mode and observe the waveform at the

TABLE 1

50 Ohm Termination: At least capable of handling your rig at full output power.

Isolation Tee: Made from a type N tee and barrel adapter. (Remove the pin from the tee portion of the tee adapter and adjust coupling for about –20 dB.)

Detector for <30 MHz: Tapped off a 50-Ω line consists of a 10-kΩ resistor in series with a 1N4148 diode, fed through a 500-pF feedthrough capacitor. (Diode polarity matches ALC requirements for rig used.)

Detector for >10 MHz: Hewlett Packard crystal or Schottky detector model 423A, B or equivalent. Just about any Type N detector mount will work correctly with the proper diode installed. This detector is good through 10 GHz.

Wattmeter: A through-line or termination wattmeter for the frequency range of the IF rig used.

Power Meter: Hewlett Packard 431 or 432 series with appropriate thermistor mounts or equivalent.

Directional Coupler: For the frequency range of the output of the transverter. Appropriate coupling level to get about +10 dBm at the detector for full power out. Consult specifications for the detector used.

Termination: For power output level and frequency range of the transverter.

Oscilloscope: Use what you have. You don't need anything special.

Two-Tone Generator: Use two audio oscillators or build one (see note). Some rigs have one built in.

Assorted Pads: Good for the frequency range that you need. 3-, 6-, 10- and 20-dB are suggested as a starting point.

Note: *Complete information for two-tone testing is available in the* ARRL Handbook. *Tone frequencies and a test generator are shown on pages 25-21 and 25-22 of the* 1993 Handbook. *The procedure, including waveform photographs and how to interpret them is covered on pages 18-14 through 18-17 of the same* Handbook. *Numerous other articles in amateur periodicals and handbooks exist.*

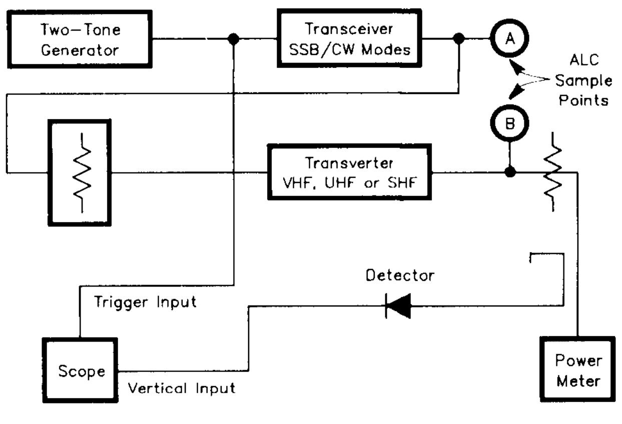


Fig 5

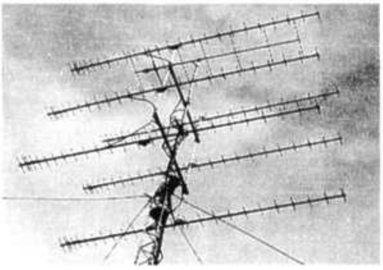
output of the transverter. By adjusting the ALC feedback voltage or the amount of fixed attenuation between the rig and the transverter, apply the highest amount of drive which still preserves the sinusoidal shape of the output waveform as observed on the oscilloscope. Record the peak level as observed on the oscilloscope as this represents the peak output power of the transverter.

Set your rig to the CW mode and readjust the CW level to match the currently recorded peak voltage on the oscilloscope. You may now read the peak output power for your transverter on the power meter.

If you encounter difficulty in finding the point where the sinusoid shape of the output waveform is distorted or are unsure of the drive level requirements for your transverter, the following procedure is suggested. Move the detector from the output of the transverter to the output of its mixer stage. In a well designed system the input to the mixer should not exceed about 10 dB less than its LO drive level. Using the above procedure, make sure that when two-tone SSB is applied to the mixer its output is not distorted. Then do the same for each subsequent gain stage until all stages are checked for linear operation.

This procedure works with all linear amplifiers and transverters. The test equipment required to perform these tests is listed below and is not very expensive. Almost all items are available from surplus stores or swap meets. If you are unsure what you are buying, take a friend who is familiar the equipment.

Remember, it is always a pleasure to work stations with great sounding signals! □□



All G3RUH Modems Are Not the Same

By Robert E. Dubke, KØSIR
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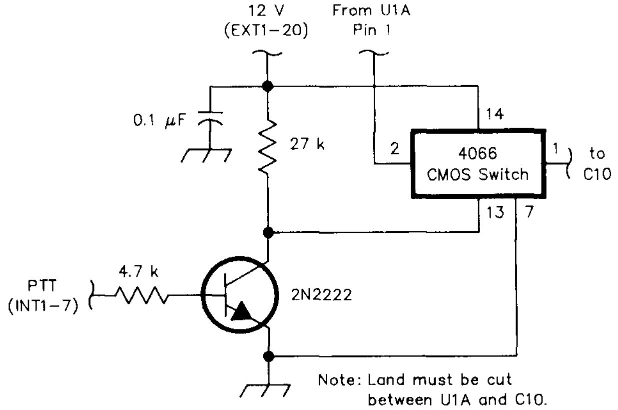
In building a high speed backbone for packet, one of the nodes was to use a Kantronics Data Engine with a DE19K2/9K6 19200/9600-baud (G3RUH compatible) modem and an ICOM 38A, a 222-MHz band transceiver. This seemed like an easy thing to implement because the 38A had already been wrung-out using a MFJ compatible G3RUH modem. Wrong! Upon investigation it was found that the 38A's VCO, used for both transmit and receive modes, was being continuously modulated by the Kantronics G3RUH modem in receive mode. This rendered the receiver useless. Of three brands reviewed (Kantronics, Pac-Comm and MFJ), only the MFJ had the switch circuitry necessary to prevent this receive-mode condition.

The ICOM 28A/H and 38A/H models have a common design in this area and contain an audio switch for the mike. Unfortunately, it is located before a low-pass audio filter that must be circumvented for 9600-baud use. The modem's transmit audio had to be inserted at the junction of R45 (15 kΩ) and R15 (2.7 kΩ), which was *after* the switch and filter. The receive audio was picked off at pin 9 of IC1 (MC3357P).

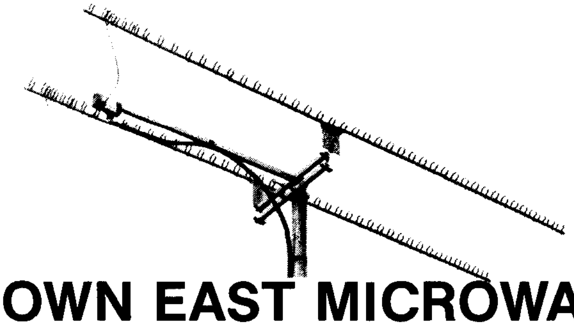
The solution selected was to add a simple audio switch to the Kantronics DE19K2/9K6 modem that consists primarily of a CMOS switch. See Fig 1. The labels on the connections are Kantronics designations. The circuit-board trace creating the audio path between U1A and C10 must be cut. In the new circuit, the 4066 CMOS switch adds a switch in this audio path. The 2N2222 transistor provides signal-level conversion for the PTT, which enables and disables the CMOS switch. The CMOS switch, a 14-pin DIP IC, may be mounted in "dead-bug" fashion or by straddling a piece of foam insulation material. The 2N2222 was soldered directly to the PC board components. There is very little room for a separate board for mounting components.

This modification should work for the Kantronics DE9600 (G3RUH-compatible) modem and the Pac-Comm NB96 series of G3RUH modems as well. Now if only the ice will stay off the 222-MHz beams, the backbone will be perking along FB.



Note: Land must be cut between U1A and C10.

Fig 1



RF

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A 5616-MHz Local Oscillator

This project uses circuitry described in Rick Campbell's July 1989 *QST* article, "A Clean, Low-Cost Microwave Oscillator." Rick's article describes a system comprising a 540-580 MHz oscillator with a 4X multiplier that can be used for 2.3-GHz work. I've replaced his multiplier with a 5X multiplier and a simple GaAs FET doubler and amplifier to produce the 5616-MHz output I wanted. The first prototype of the 2.8-to-5.6 GHz doubler was actually designed many years ago, though it wasn't reliable enough to work in, say, the cold and windy weather one finds on Mount Washington. This revised version delivers +15 dBm, which is enough for driving a pair of mixers. Alternately, you can obtain +7 to +9 dBm for driving a single mixer from just the doubler stage, without the MGF 1302 amplifier, by merely shortening the board.

Computer simulations of the circuit were not performed since I don't have accurate nonlinear models for the MGF 1302 transistor or a linear model for the bandpass filter. Surprisingly little seems to have been written about designing probe- or loop-coupled filters, except for cut-and-try. I guess solutions to distributed electromagnetic problems are too difficult unless there is a lot of symmetry involved.

The 561.6-MHz Local Oscillator

561.6 MHz falls very close to the center frequency of Rick's 540-to-580 MHz local oscillator, so I didn't see any need to modify his filters. However, due to the difficulties experienced in cold weather, I decided to add a

Table 1—RF input/output measurements for the 5X multiplier.

P_{in} *to MAV-11 (dBm)*	P_{out} *of MAV-11 (dBm)*	P_{out} *of multiplier (dBm)*
0.0*	11.0	—
3.0	14.0	6.1
4.0	14.9	6.6
5.0	15.8	7.0
6.0	16.7	7.2
7.0	17.4	7.2
8.0*	18.0	—
10.0	18.9	6.5
12.0	19.2	6.8

* The MAV-11 has 11 dB of gain at 0 dBm in, with 1-dB compression occurring at 8.0 dBm in.

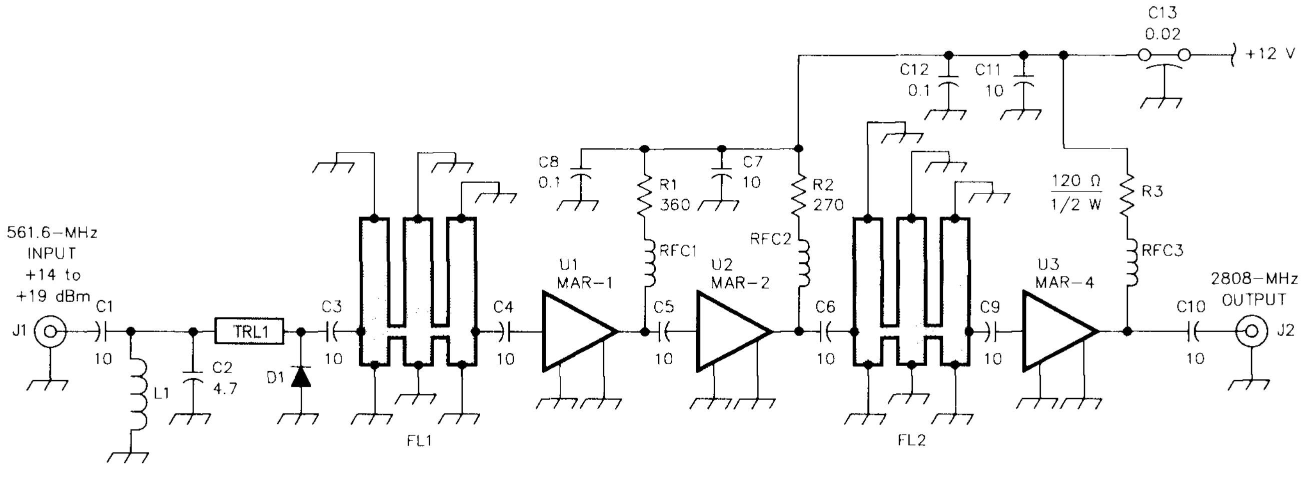

Fig 1—Schematic of the 5X multiplier board.

C1-C12—chip capacitors.
R1,R2—¼-watt metal-film or carbon-composition resistors.
D1—HP5082-2835 or similar Schottky diode.
FL1,FL2,TRL1—etched circuit-board elements.
J1,J2—SMA female jacks.
L1—3t no. 28 enam, 0.063-inch ID, spaced 1 wire diameter.
RFC1-RFC3—4t no. 28 enam, close wound, 0.1-inch ID.
U1—MAR-1 or MSA-0185 MMIC.
U2—MAR-2 or MSA-0285 MMIC.
U3—MAR-4 or MSA-0485 MMIC.

7808 8-volt regulator to bias the buffer amplifier and MMICs. This addition requires that the MMIC biasing resistors be changed as well. The new values are 110 Ω for R8 and 120 Ω for R9 and R10. U3 and U4 now MAR-2s. (See Fig 2, pp 16-17, July 1989 *QST*). In place of U5 of Rick's design, I used two MMICs: an MAR-3 driving an MAV-11. (Rick's PC board provides pads usable for two MMICs at the output.) The MAR-3 uses a 100-Ω bias resistor, while the MAV-11 requires 62 Ω. 10-turn RF chokes made from #28 wire, 0.12-inch ID, are used to prevent the low-impedance bias resistors on the last two stages from degrading the output power. Even with a 300/56-ohm (series/shunt) resistive pad connected to monitor the output frequency, the output power is +15.7 dBm into a 50-Ω load, though it degrades to +15 dBm at a supply voltage of +9.1 volts.

561.6-to-2808 MHz Multiplier

This multiplier, a scaled version of Rick's 2.3-GHz multiplier, covers 2.7 to 3.0 GHz. (See Fig 1.) Its filtering isn't adequate by itself, having 4th and 6th harmonic spurs down 30 and 15 dB, respectively. But the 2808-to-5616 MHz doubler that follows this multiplier uses a sharp tunable filter, so these spurs aren't too much of a problem. Since this is a 5X multiplier rather than a 4X multiplier, a bit more RF drive is needed than with Rick's original design. As Table 1 shows, +14 dBm to +19 dBm of local oscillator drive is needed. Since this is easily obtained with an MAV-11 or MSA-1104 MMIC at this frequency (as from the 561.6-MHz LO), I don't consider this a problem. Since the spectral purity of the first multiplier isn't that critical, I actually sacrificed a bit of filtering to make it easier to build. One printed-circuit layout consideration

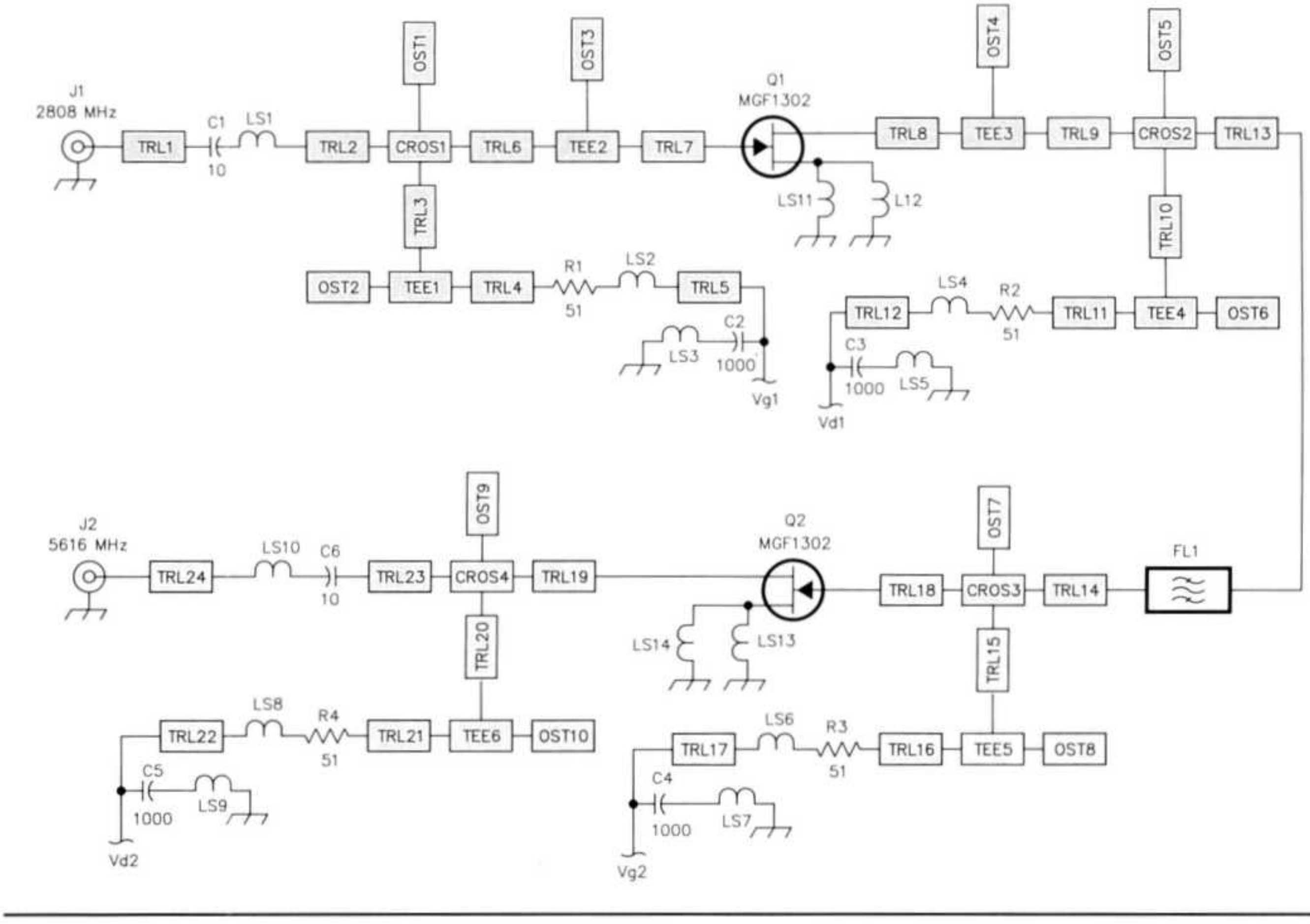

Fig 2—RF schematic of the doubler board.

C1,C6—10-pF chip capacitors for RF use.

C2-C5—1000-pF chip capacitors

FL1—Pipe-cap filter. Use a ¾-inch copper pipe cap. Tap a 6-32 hole in the closed end of the cap and insert a 6-32 brass or nickel-plated brass tuning screw. The probes are ¼-inch lengths of UT-141 center conductor with teflon dielectric, soldered to the circuit board (see text for assembly details).

J1,J2—SMA female jacks.

LS1-LS14—Stray inductances associated with real parts (included for computer modeling purposes).

Q1, Q2—Mitsubishi MGF 1302 GaAs FETs

R1-R4—51-Ω chip resistors.

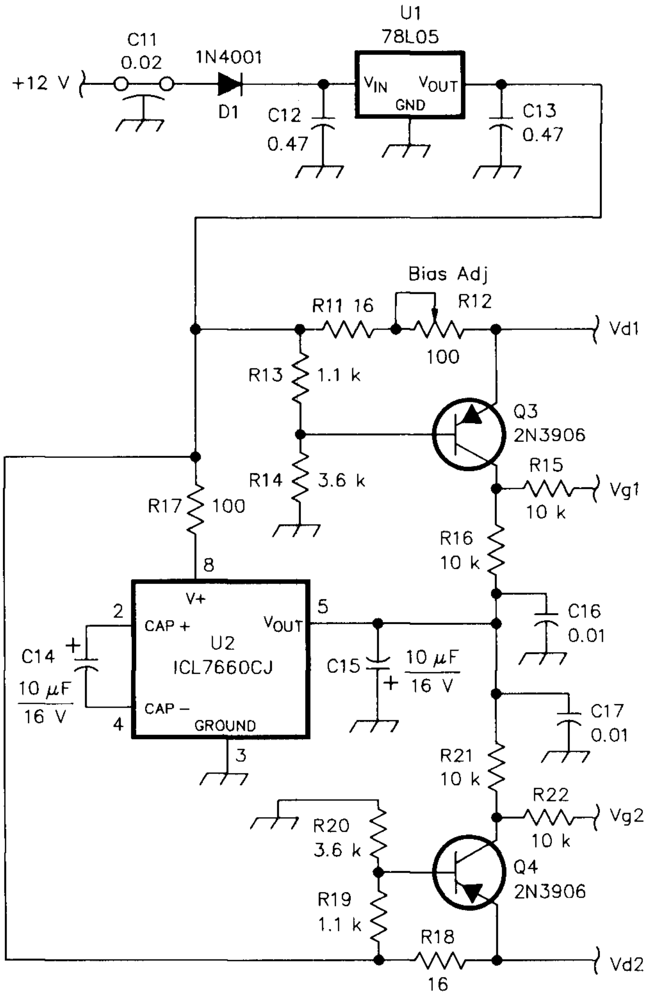

Fig 3—Schematic of the GaAs FET biasing circuit.
C11-Feedthrough capacitor. Value not critical.
Q3, Q4—2N3906, 2N2907 or other general-purpose PNP transistors.
U1—78L05 5-volt voltage regulator IC.
U2—Intersil ICL7660CPA or SI7660CPJ. CMOS voltage converter IC.

is the distance between the input and output connections and the side of the board. The spacing should allow coax jacks to be mounted to the wall of a box that butts up against the edge of the board. I prefer not to have to trim coax jacks!

By the way, if the frequency of this design isn't quite what you wanted, there is a relatively simple way of scaling Rick's 4X multiplier filter up in frequency. Merely make a photocopy and then shorten the lengths of the lines. I've done this by cutting the photocopy apart and reattaching the pieces with tape to shorten the coupling lines. Then mark the cut lines with a pencil and you have your scaled filter. I've actually done a fair amount of "artwork" this way.

2808-to-5616-MHz Doubler

The GaAs FET doubler and amplifier each use a Mitsubishi MGF 1302. (See Fig 2.) Substituting another transistor is not recommended, as this frequency is high enough that even differences in package styles become quite noticeable. For instance, an MGF 1402, which is the same semiconductor chip as the '1302 but in a different package, has 8.5 dB of gain without matching in a 50-Ω system, while the MGF 1302 gives 10.1 dB of gain (with both devices operating at 6 GHz with a bias of 3 V at 30 mA).

Often, the stability of a local oscillator amplifier isn't as critical as that of a general-purpose amplifier. Not only is the input well defined, but the huge input signal tends to injection lock the amplifier to the desired frequency, so that even an unstable amplifier might work. But just to be cautious, I lengthened the somewhat lossy 50-Ω input transmission line to improve stability. This has the added benefit that you can merely chop off the amplifier section if you want to drive only a single mixer. (Don't forget to leave enough board for the pipe-cap filter.)

The spectral purity of the output of the LO chain (oscillator, 5X multiplier and doubler) should be adequate for most purposes. The close-in spurs (± 93.6 MHz) are 38 dB down. Harmonic spurs were measured at 2.8 GHz (−42 dB), 8.4 GHz (−47 dB) and 11.2 GHz (−22 dB). An

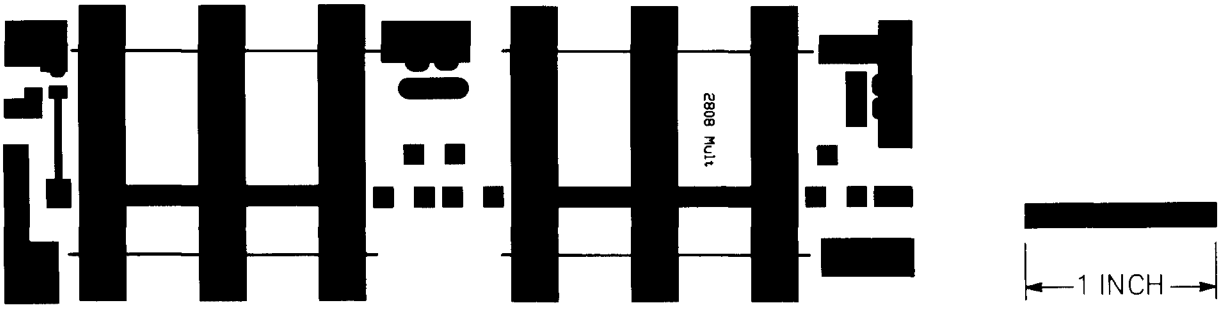

Fig 4A—Etching pattern for the 5X multiplier.

additional pipe-cap filter could be used to get the close-in spurs down another 12 or 15 dB. Slightly better (–43 dB) close-in spur performance was obtained using a 5X multiplier with sharper filtering.

The schematic is a bit cluttered, as I have shown most of the parasitic elements one would include if one were modeling this circuit. As one describes the circuit better to a computer program, the results get closer to reality, so it pays to take these elements into account if you want to computer model the circuits.

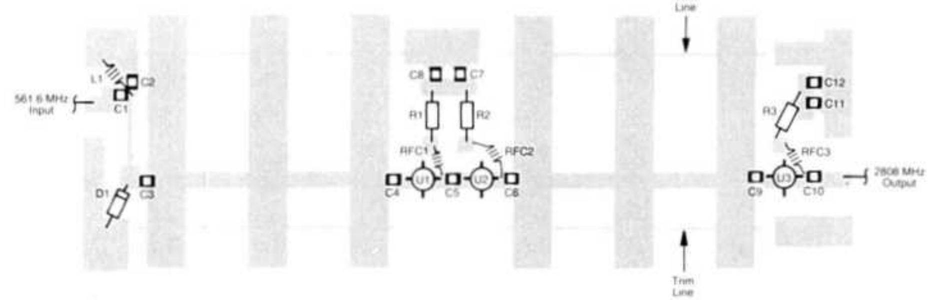

Fig 4B—Parts placement diagram for the 5X multiplier.

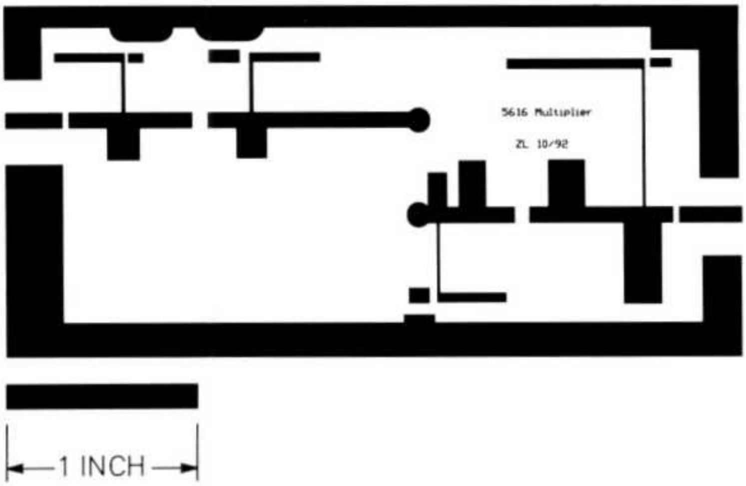

Fig 5A—Etching pattern for the GaAs FET doubler.

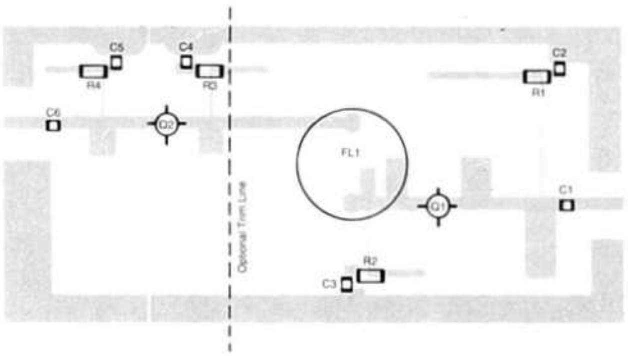

Fig 5B—Parts placement diagram for the GaAs FET doubler.

Construction

The 5X multiplier board should be cut along the indicated lines so that the half-wave resonators are the proper length. It may even be a good idea to use a file to trim the board to the final length unless you have an accurate method of cutting circuit boards to size. I used half-inch brass sheet stock to form walls around the board, which grounds the resonators. SMA connectors are attached to the brass walls with 2-56 screws. This allows me to use stainless-steel connectors rather than costly gold-plated ones. To keep the RF circuitry clean, I prefer to bring the power leads in through the ground plane. A quarter-inch drill is useful for trimming away foil from the ground plane to insulate the power leads. To ground the MMICs, I bend the leads down against the plastic package so that they can be soldered directly to the ground plane.

The 5616-MHz doubler board is also countersunk for dc power connections. The dc circuitry (See Fig 3) is built ground-plane style on the back of the board. The pipe-cap filter is also mounted on the back of the board, with the two filter probes sticking through the board from the circuit side. (Clear the ground-plane foil around the probes with a quarter-inch drill.) The probes are made from the center conductor of UT-141 coax (about the same thickness as #18 wire). I recommend bending these silver-plated wires into "L"s so an eighth-inch or more of the wire is soldered against the pad on the circuit side. This helps to prevent the probes from coming undone during repairs and tuning episodes. The center conductor's Teflon dielectric holds the wire in place during soldering. Solder the pipe cap to the ground plane to enclose the probes. This requires a lot of heat. I use a 100-watt soldering iron designed for stained glass work. The board has half-inch brass sheet walls soldered around it, too. This makes it easy to shield the assembly.

Tuning it Up

Tune the pipe-cap filter first, since you aren't going to see much of anything unless this is tuned. Then adjust the bias of Q1 for maximum output. The optimum setting depends on how much 2.8-GHz drive is provided to the doubler. Finally, you can go back and tweak the filter to get it tuned just right.

Possible Improvements

Those of you not content to just copy something that works well might be interested in these ideas. The major shortcomings of the 5X multiplier are the use of chip capacitors and the difficulty of accurately trimming the board to size. A design that used hairpin filters would be much easier to build, once one developed artwork that worked. It might even be possible to integrate the 5X multiplier, the doubler, and a power splitter on the same board. Let me know if you do! □□

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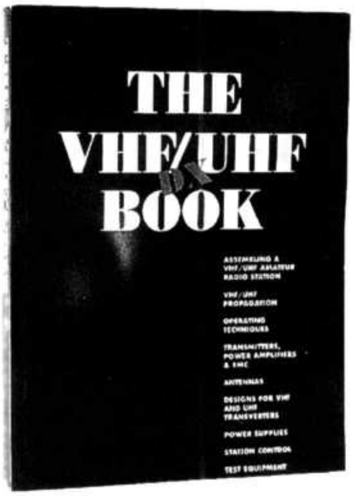

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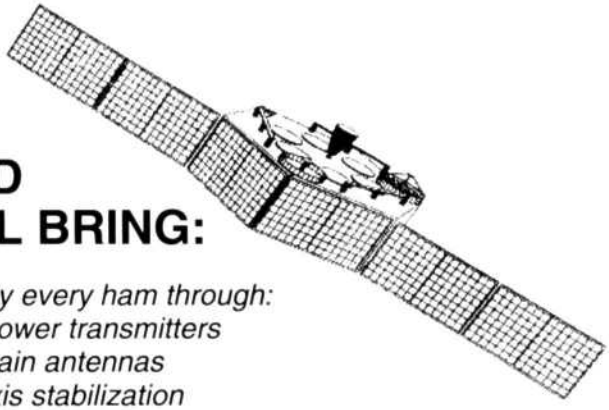

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