Elementary Mode S

Satellite fun on 2.4 GHz–the easy way!

by Ed Krome KA9LNV

The launch of the Microsats has provided some really interesting opportunities for experimentation in both operating modes and frequencies. The digital modes include PSK (Phased Shift Keying) from 1200 baud (PacSAT and LuSAT) to 9600 baud (UoSAT 14), 1200 baud packet AFSK (Audio Frequency Shift Keying) (DOVE), digitized pictures (WeberSAT), and a digi-talker (DOVE).

If this isn't enough to make any experimenter think he's in heaven, there are also three different frequency schemes in use. The most common frequency combination is Mode J, with a 2 meter (145 MHz) uplink (Earth to satellite) and a 70cm (435 MHz) downlink (satellite to Earth). The active digital repeater/mailbox satellites, PacSAT, LuSAT and UoSAT, use this scheme. DOVE's main transmissions are on the 2 meter band, as this satellite was designed for easy reception in classrooms using a minimal ground station.

Two of the satellites (PacSAT and DOVE) also incorporate a third downlink frequency as a beacon: Mode S, which operates in the 13cm band. Way up there. Yeah, 2400 MHz. What, you don't have any 13cm equipment? That's not hard to believe, since that is the lowest band for which there is not a single piece of integrated commercial equipment available. No plug-in modules for the Yaesu FT-736, either. But the band is there, part of our amateur allocation, and alive and well. OSCAR-13 has a full transponder for Mode S, allowing QSOs with a 70cm uplink. And various areas of the country have terrestrial activity in a different segment (2304 MHz) of the band. There is even EME (Earth-Moon-Earth) activity up there.

While this is more of a "how to" than a pure construction article describing 13cm receiving equipment, I have included "benefit of experience" construction techniques on some commercially available kits. And, for the more adventurous types, I have included construction information for a 13cm antenna.

Mode S and How to Get There

Becoming active on the downlink end of Mode S has the same requirements as any other band: an antenna to catch the signal and a receiver to hear it. On the higher VHF and UHF bands, the receiver part of this recipe is usually handled with a two-part approach. A converter changes the VHF or UHF signals

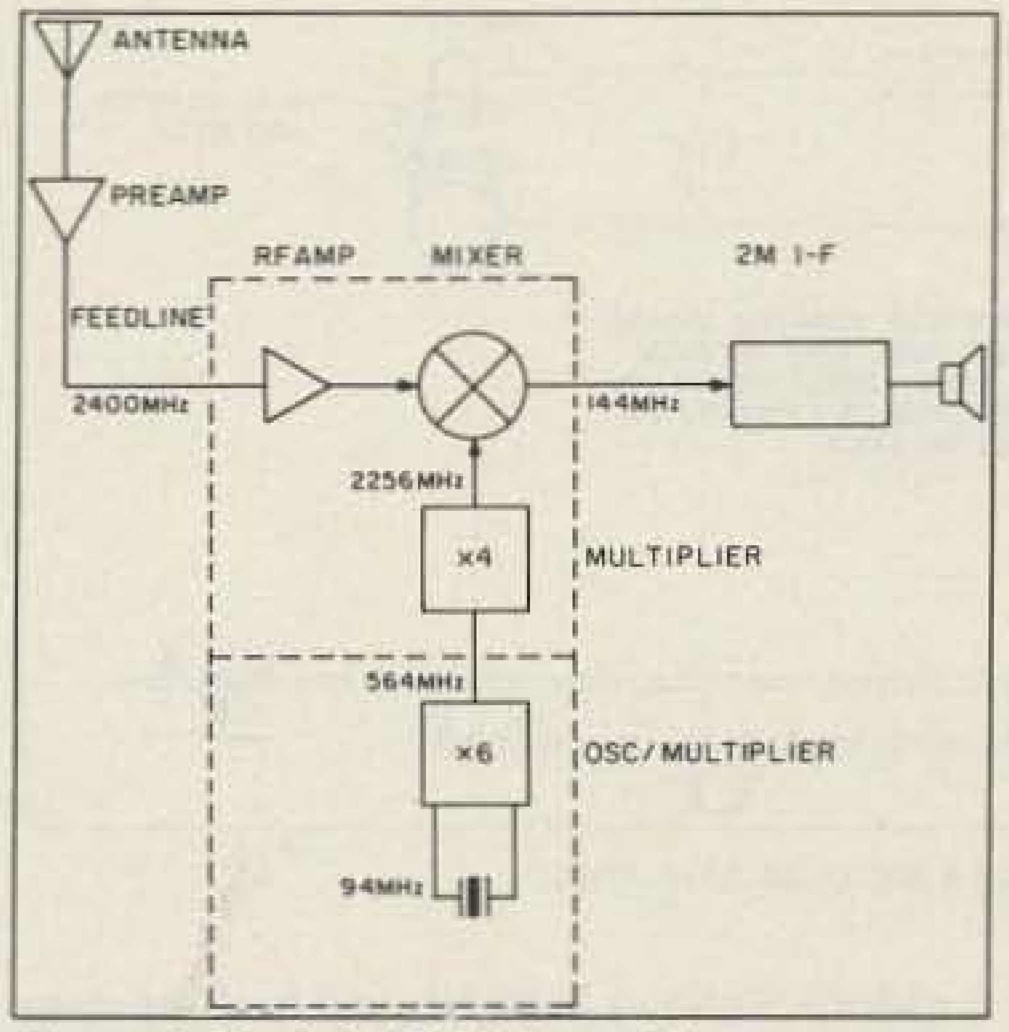

Figure 1. Basic 2400 MHz receiving converter.

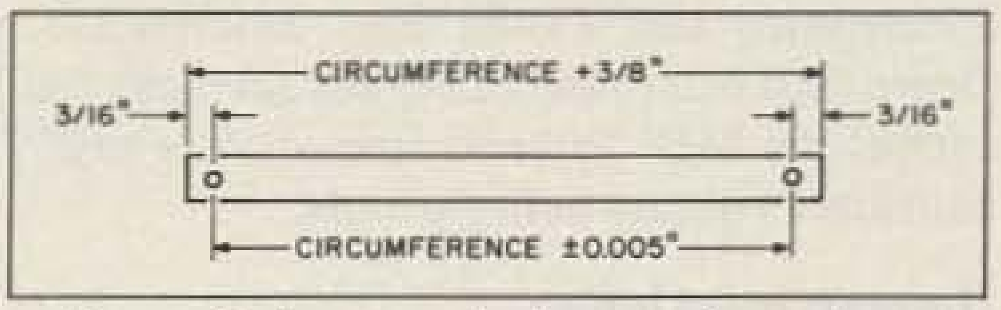

Figure 2. Loop yagi element dimensions.

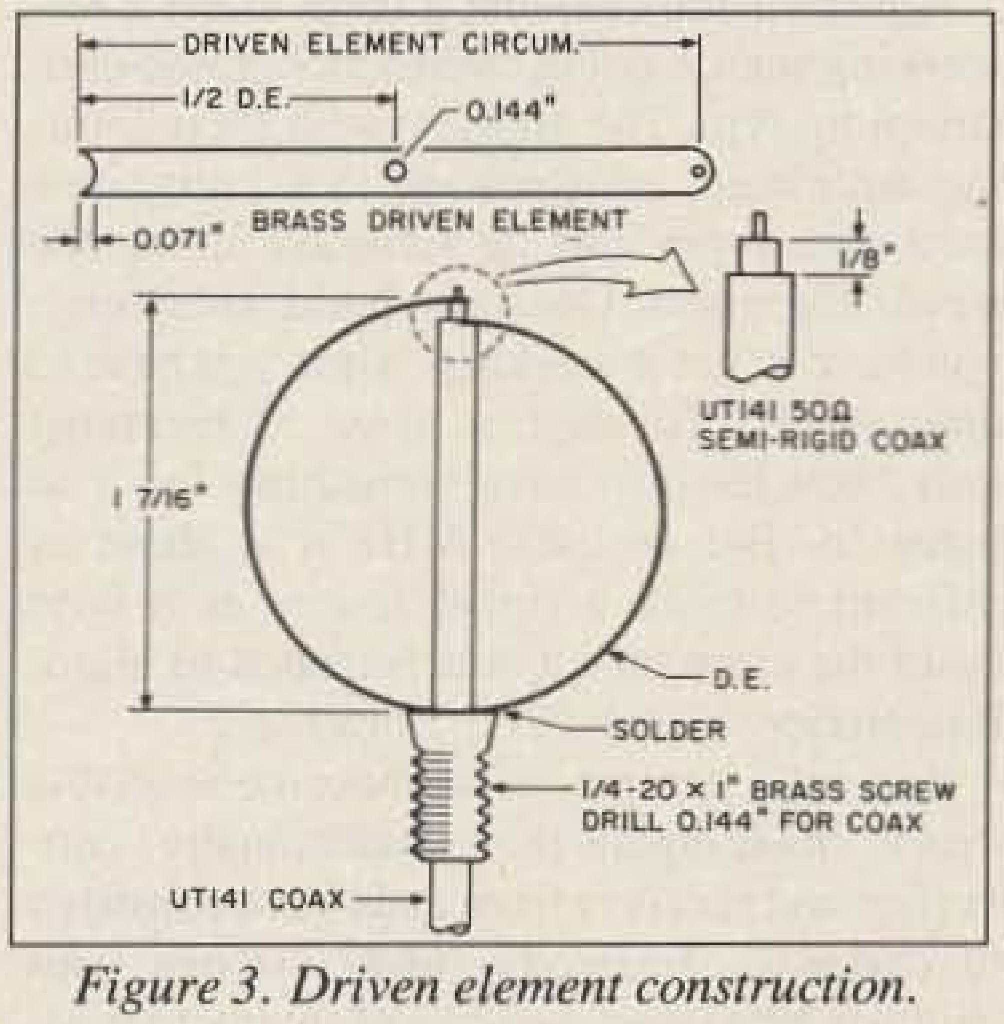

Figure 3. Driven element construction.

to something more manageable, which is then fed to an HF or VHF receiver. In this manner, one good HF or VHF receiver (or transceiver) can be used for many bands by merely adding the appropriate converter. In my own station, my integrated receivers and transmitters are all HF stuff, good only to 30 MHz. And they contain lots of vacuum tubes, too. Converters do everything beyond that, and sometimes converters get plugged into converters. This works fine.

Coming up with a receiving converter for 13cm presents some interesting problems. A basic 13cm converter, like any other superheterodyne device, consists of three parts: an RF amplifier chain, a local oscillator, and a mixer. Because antennas and converters are usually separated by some distance and coupled by some sort of (lossy) feedline, standard practice is to divide the RF amplifier section of the converter into two separate parts: the converter proper, and a second part of the RF amplifier chain, called a preamplifier, mounted as close as possible to the antenna. (See Figure 1.) While preamps can't compensate for an inadequate antenna, they can do wonders for high loss feedlines. And they get better as the frequencies get higher. A very low noise preamplifier mounted close to the antenna will amplify the desired signal as well as the background noise. At frequencies above 432 MHz, background noise from the sun, sky, etc. is quite low, so you amplify a lot of signal and not much noise. The cable connecting the preamp to the rest of the converter merely attenuates the desired signal, but it attenuates any accompanying noise with it as well.

Within limits, the all-important signal-to-noise ratio is mostly preserved, even from a long run of pretty lousy cable. If you mounted that same very low-noise preamp after a run of cable, the preamp would be amplifying a signal attenuated by the loss of the cable. The signal-to-noise ratio would be lower, and once signal is lost, it's gone forever. It doesn't matter how much gain you add, you just amplify noise. And any cable becomes lossier as the frequency goes up. For example, a 100-foot run of Belden 9913 may have only 1.6 dB loss at 144 MHz, but it has over 10 dB loss at 2400 MHz. Extremely good coax can minimize this, but have you priced ⅞" Andrews Heliax hardline and connectors

Sources of Supply

Down East Microwave (Bill Olson W3HQT)
Box 2310, RR1
Troy ME 04987
(207) 948-3741

SSB Electronic USA (K3MKZ)
124 Cherrywood Drive
Mountaintop PA 18707
(717) 868-5643

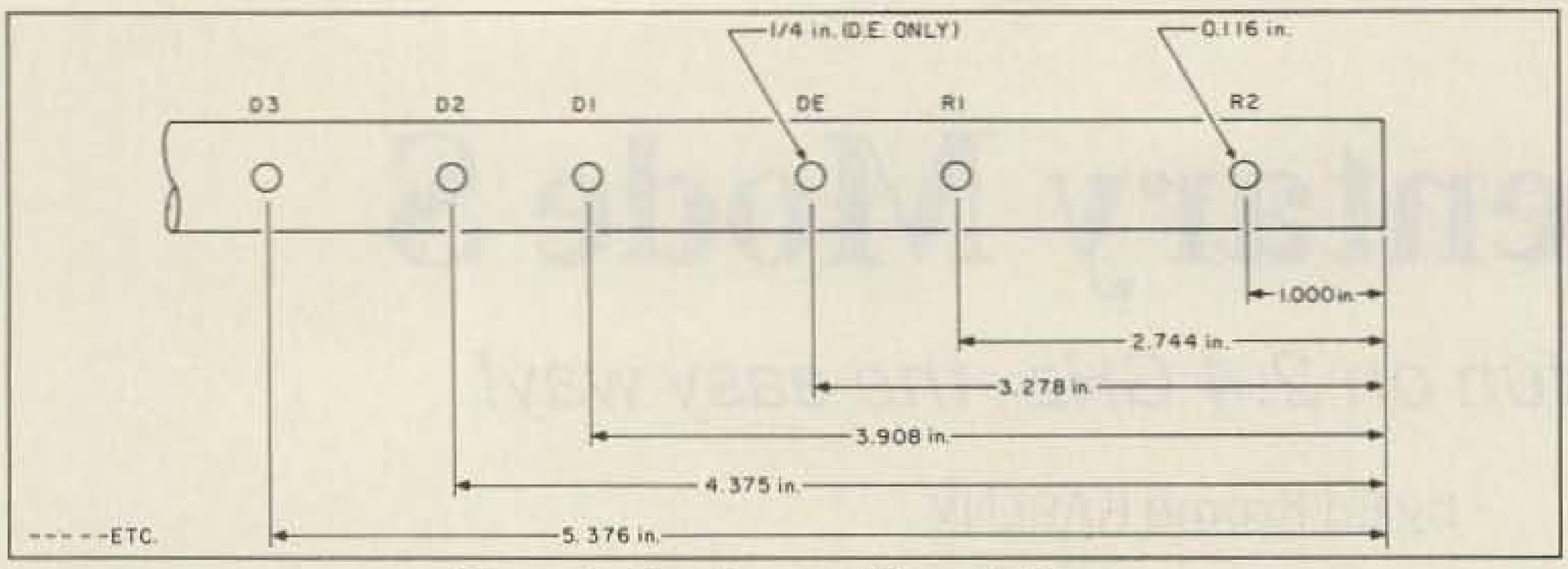

Figure 4. 13cm loop yagi boom drilling.

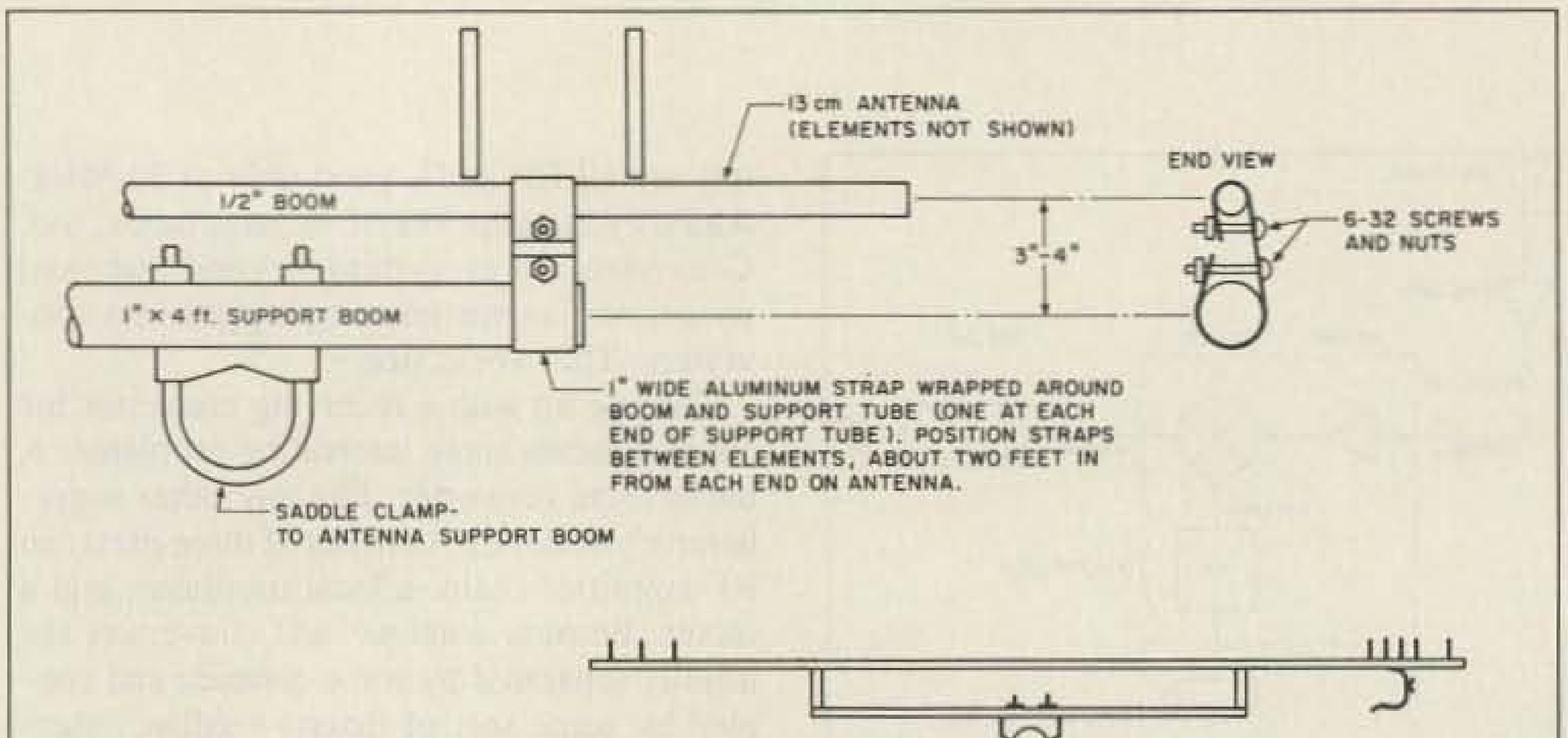

Figure 5. 13cm antenna and support assembly.

lately? Preamps are much cheaper.

Current technology in low-noise, high performance preamps uses GaAsFET (Gallium Arsenide Field Effect Transistors) devices. SSB Electronic and Down East Microwave manufacture good preamps. Later on in this article I'll detail a home-constructed device that offers good performance at a reasonable cost.

Since we have been working from the back end forward, the last part of the Mode S equation is the antenna.

Among EME types, the parabolic dish is the only way to go. The rest of us have really only two readily reproducible designs to work with, the loop yagi and the helix.

The Yagi-Uda (usually called simply "yagi") type of antenna, with many near half-wavelength parasitic elements, is the most common design at VHF and lower frequencies. Element lengths get unmanageably critical at 23cm and above, so yagis have mostly been replaced by the loop yagi. Loop yagis were originally developed by Mike Walters G3JVL and replace the yagi's straight elements with near full-wave loops made from strips of aluminum. Construction tolerances are still tight, but manageable. One of the best parts of a loop yagi is the driven element feed system. No balun is required, just a solder-it-together brass loop element on a piece of feedline. And it is at DC ground, which provides static electricity protection for your equipment. You can buy loop yagis in kits or ready-made (from Down East Microwave), or you can "roll your own."

Available Hardware

A review of available receiving equipment for Mode S shows both kits and built-up converters and preamps available from SSB Electronics and Down East Microwave. Down East Microwave also has antennas and carries the SHF Systems line of "no-tune" converter kits and built-up units.

Homestyle—Almost

Now let's look at what it takes to get a real working station going on Mode S, home-construction style. The problem with 13cm limiting equipment construction to a (very) few hard-core types can be summed up in one word: alignment. Once you build something, you have to get it working. Then you have to optimize it. To align a piece of receiving gear, you have to have something for it to listen to. But on 2400 MHz it is about as difficult to build a signal source as it is to build the converter it was intended to align. Remember "Catch 22"? Tricky, eh?

Recently, equipment has become available that is changing all that. Traditionally, converters and receiver front ends have consisted of myriads of sharply tuned circuits with trimmer capacitors and lots of interactive adjustments. Designs of this type are hard enough to get working at HF frequencies, and they get progressively worse as you go higher. The best alignment (and troubleshooting) device, the spectrum analyzer, is not a household appliance. In their quest for compact, reproducible UHF ham gear, several amateurs, among them Richard Campbell KK7B and Jim Davey WA8NLC, have developed a series of "no-tune" transverters. Honest. Only one possible adjustment in an entire transverter and that is in the local oscillator. That doesn't sound too bad, does it?

These no-tune transverters are based on two developments. One, the MMIC, is recent. The second, bandpass filtering using broadband printed hairpin filters, has been around awhile. MMIC's or Monolithic Microwave Integrated Circuits are truly incredible devices. Tiny and inexpensive, they are broadband gain blocks with fixed input and output characteristics. They don't oscillate or require any critical external components. They are typically 50 ohms in and out with low VSWR. With these devices, gain is so easy to get that it is no longer necessary to worry about whether or not you get gain from more ticklish circuits, such as frequency multipliers, or to worry about filter loss. Not enough signal at some stage? Add another MMIC. No problem.

With gain no longer a problem, the designers could do things like develop passive, no-tune diode frequency multipliers. Drive a diode into generating harmonics and select the one you want with filters. Anyone who has ever built VHF gear knows that the worst part of the whole mess is getting active frequency multipliers to work right. Ugh.

Easy, broadband gain also worked well

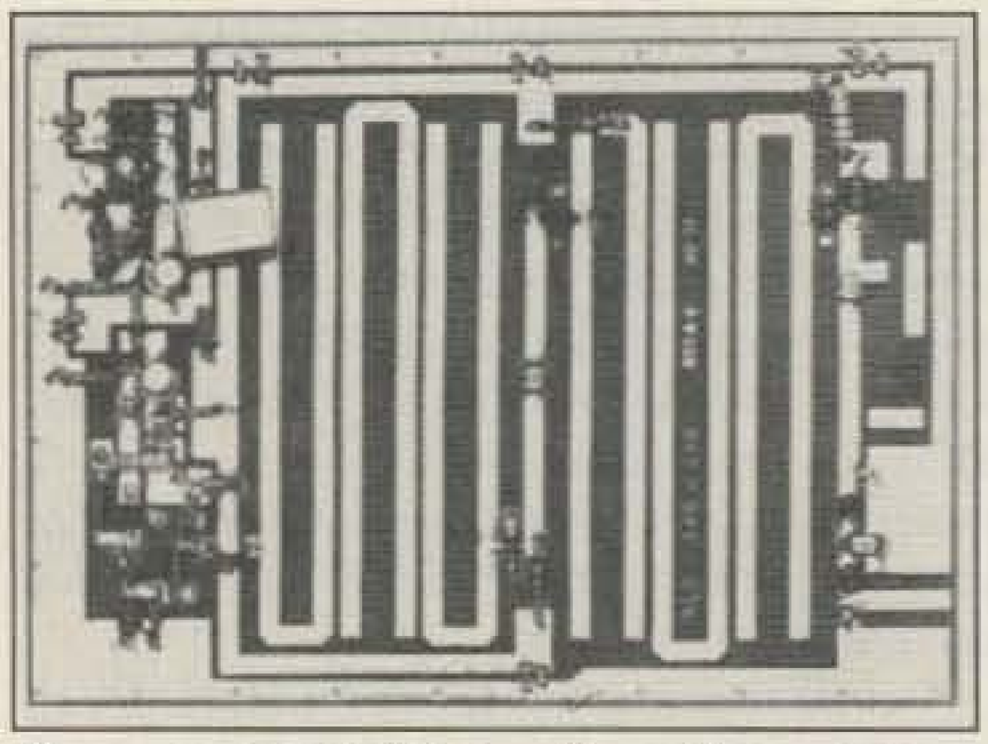

Photo A. 564 MHz local oscillator (Down East Microwave SHF-LO).

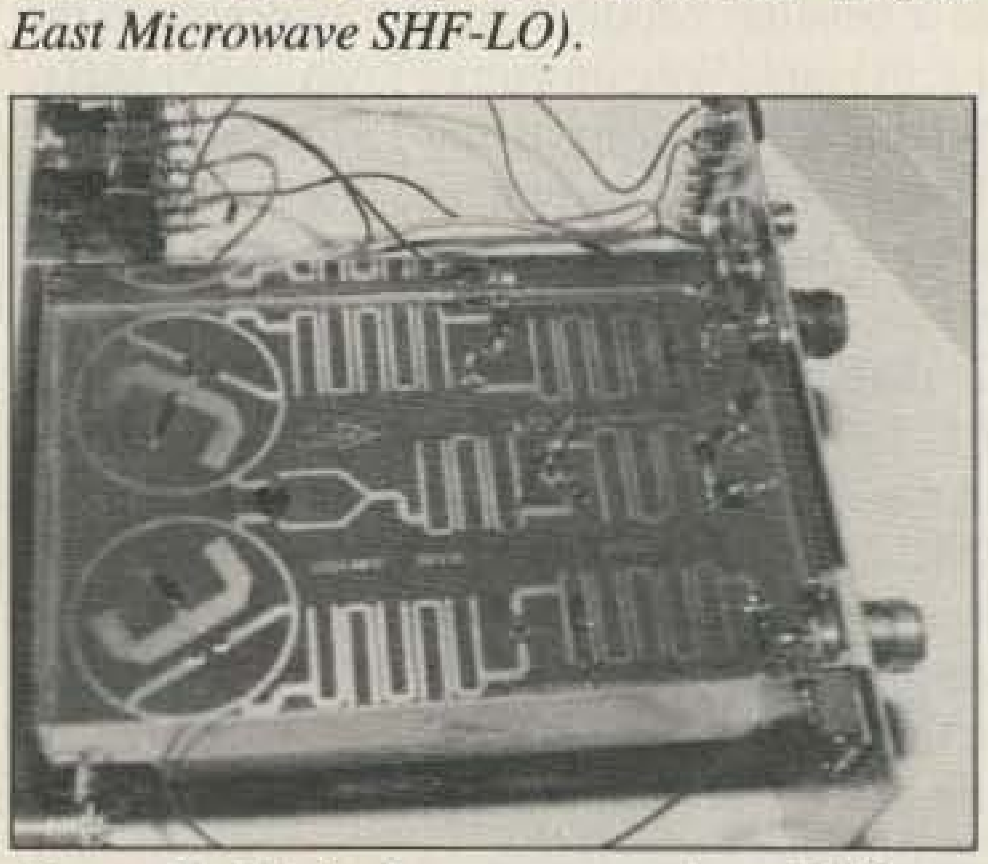

Photo B. Mode S transverter board (Down East Microwave SHF-2301).

Photo C. 13cm "no-tune" preamp (WB5LUA design—available from Down East Microwave).

with the design of printed hairpin bandpass filters. Filters were designed with manufacturing tolerances taken into consideration to provide broad, flat passbands and steep slopes. Manufacturing irregularities which were once fatal now have little effect. These filters also have no tuning required, or even possible.

The entire no-tune transverter is available in two forms as kits from Down East Microwave. One version is a dedicated S-band receive converter (the SHF-2401K). The second is a transverter, which has the same receiver and also a 10 mW transmit section (SHF-2304). If you are going to build something like this anyway, get the transverter and help get more amateur activity on 13cm. Even barefoot, 10mW is adequate for local contacts. You can always add transmit power later. Remember, as amateur radio operators, we either use those frequencies or we may lose them. The commercial guys are always hungry for spectrum, and ours looks tasty. Both units use a 2 meter IF (Intermediate Frequency). *[Ed. Note: See the February 91 issue of 73 for a review of these kits.]*

Construction Hints

As the photos show, construction of these devices is straightforward. Build the local oscillator first. You must follow the recommended layout and use good construction techniques. Keep the leads short and solder the joints well. Be sure to ground the one pad that is noted as requiring through-the-board grounding. Also, pay attention to the orientation of the transistors and MMICs. The Avantek MSA-04 series has the dot on the output, while the MCL MAR series has the dot on the input. The total tune-up requirements are to tweak a 10 pF trimmer for maximum LO output. Photo A shows a complete and functioning local oscillator.

A common complaint deals with the difficulty of installing chip capacitors. To do this right, you need a small (15 watt) soldering iron with a small tip, tweezers, a toothpick, and a magnifying glass. The last item is a suggestion that I learned through experience. Since I passed a certain magic age, I find I can't see far away with my glasses off, and I can't see close up with them on. So I bought a set of Sears headband-mounted binocular magnifiers. These are only 2½ power, but they're perfect for getting parts in the right place.

To mount the chip caps (now that you can see them), first lightly tin one circuit board pad. Don't tin both or the chip may not sit flat on the board. Then place the chip cap where you want it with the tweezers. Hold it in place with the toothpick and remove the tweezers. Touch the iron to the pre-tinned circuit board trace. Flow the solder onto the end of the cap. Then solder the other end of the cap. Resolder the first end if needed to insure a good connection.

Construction of the converter board itself is probably even easier than building the LO (Local Oscillator). The hard part, at least on the early boards, is that you must use thin brass foil to connect the MMIC ground leads and several pads to the ground plane side of the circuit board. I found that the best way to ground the MMICs is to cut pieces of brass foil about ¼" long and as wide as the MMIC ground pads, then make a 90 degree bend back about 3/32" from one end. Slip the long end through the board hole from the circuit side (use the magnifiers to make absolutely sure that there are no shorts to the input or output pads), then hold it in place by putting an awl into the hole. This will form the brass to the hole at the top, allowing you to insert the MMIC down into the hole in the board, where it belongs.

While holding the foil in the hole with the

2304/2401 MHz Loop Yagi

Element	Spacing (Original 2304 MHz) (inches)	(cm)	Circumference (Original 2304 MHz) (inches)	Circumference (Scaled to 2350 MHz) (inches)
R2	1.000	2.54	5.480	5.373
R1	2.744	6.97	5.480	5.373
DE	3.278	8.33	5.125	5.025
D1	3.908	9.93	4.676	4.584
D2	4.375	11.11	4.676	4.584
D3	5.376	13.66	4.676	4.584
D4	6.378	16.20	4.676	4.584
D5	7.081	17.99	4.676	4.584
D6	8.380	21.29	4.676	4.584
D7	10.383	26.37	4.676	4.584
D8	12.385	31.46	4.676	4.584
D9	14.388	36.55	4.676	4.584
D10	16.390	41.63	4.676	4.584
D11	18.393	46.72	4.676	4.584
D12	20.395	51.80	4.534	4.445
D13	22.398	56.89	4.534	4.445
D14	24.400	61.98	4.534	4.445
D15	26.403	67.06	4.534	4.445
D16	28.405	72.15	4.534	4.445
D17	30.408	77.24	4.534	4.445
D18	32.410	82.32	4.392	4.306
D19	34.413	87.41	4.392	4.306
D20	36.415	92.49	4.392	4.306
D21	38.418	97.58	4.392	4.306
D22	40.420	102.67	4.392	4.306
D23	42.423	107.75	4.392	4.306
D24	44.425	112.84	4.335	4.250
D25	46.428	117.93	4.335	4.250
D26	48.430	123.01	4.335	4.250
D27	50.433	128.10	4.335	4.250
D28	52.435	133.18	4.335	4.250
D29	54.438	138.27	4.335	4.250
D30	56.440	143.36	4.335	4.250
D31	58.443	148.45	4.335	4.250
D32	60.445	153.53	4.335	4.250
D33	62.448	158.62	4.335	4.250
D34	64.450	163.70	4.335	4.250
D35	66.453	168.79	4.335	4.250
D36	68.455	173.88	4.279	4.195
D37	70.458	178.96	4.279	4.195
D38	72.460	184.05	4.279	4.195
D39	74.463	189.14	4.279	4.195
D40	76.465	194.22	4.279	4.195
D41	78.468	199.31	4.279	4.195
D42	80.470	204.39	4.279	4.195
D43	82.473	209.48	4.229	4.146
D44	84.475	214.57	4.229	4.146
D45	86.478	219.65	4.229	4.146
D46	88.480	224.74	4.229	4.146
D47	90.483	229.83	4.229	4.146
D48	92.485	234.91	4.229	4.146
D49	94.488	240.00	4.229	4.146

Boom: 8' length of ½" diameter aluminum tubing (do not use anodized tubing).
Elements: All elements are made from aluminum strips 0.25" wide by 0.032" thick.
Circumference: Distance between centers of 0.116 holes drilled in each element. Tolerance ±0.005". Each element is to be made approximately ⅜" longer than the specified circumference dimension to allow approximately 3/16" overlap between the ends of the element.

Table 1. Scaled from W1JR 13cm 52-element design.

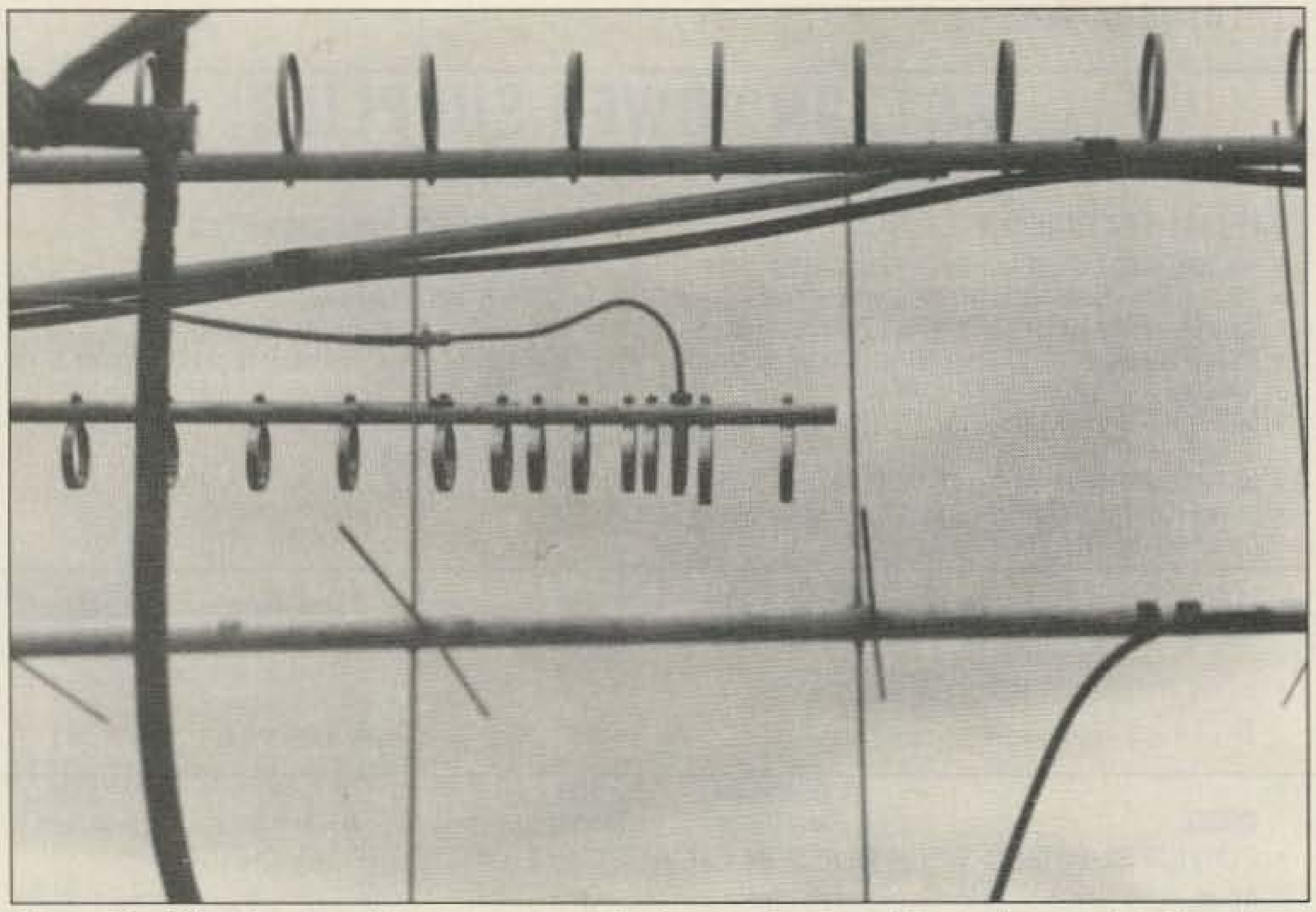

Photo D. 13cm loop yagi, mounted upside down, showing driven element detail and two reflectors. A 23cm loop yagi is on top, with a 2m cross yagi behind it. The T-shaped structure on the left is the power divider with hardline phasing lines for two 19 element yagis on 70cm.

awl, use your fingernail to spread the foil away from the hole and lock it into place on both sides of the board. A little experimenting will make it easy. Before you solder, inspect it carefully for shorts. Solder the top side lightly so the MMIC will sit flat on the board. Sometimes it is helpful to solder the pad, then clean it off with a piece of Solder-Wick™ desoldering braid. The resulting pad will now be well-tinned and easy to solder quickly.

Several pads on the converter board must be connected to the foil side of the board. One way to do this is to make slots in the board by carefully rocking an X-acto® knife blade through the board. The Teflon™ board material cuts easily. Then thread a strip of the brass foil through the slot, bend it flat on both surfaces, and solder it in place.

A suggested construction technique is to solder the MMIC bias resistors to the centers of the hairpin filter elements where possible. This improves stability. Photo B shows the routing on a complete transverter board.

Mounting the HP-2822 diode packs can be interesting. They are as small as chip capacitors, have three leads, and are surface mount devices. The same technique that works on the chip caps works here also. Tin one pad, position the diode pack with tweezers and a toothpick, then tack one lead. Then solder everything.

The initial results using this converter absolutely amazed me—it worked the first time I fired it up. I heard the S-band beacon on DOVE the first time I tried. Not bad.

A suggestion on improving the versatility of the converter: Wire it to work both commonly-used segments of the band. Remember about "use it or lose it"? The satellite subband is at 2400 MHz. Use of a 94.00 MHz crystal in the LO puts the Microsat S-band beacons (2401.221 for DOVE) at an IF of 145.221. A 90.00 MHz crystal will put the 2304 weak signal frequency at 144 MHz. Wire a small DPDT relay to the board to switch between the two crystals. Keep the leads short.

Preamp Construction

The next segment of the Mode S rig is the preamp. Fortunately, Al Ward WB5LUA has developed a series of no-tune preamps for the UHF bands, all the way to 10 GHz. These were detailed in *QST*, May 1989. Construction is easy, but for best results you must follow Ward's instructions. The 13cm version uses an ATF 10135 GaAsFET, and offers a less than 1 dB noise figure. While all the preamps were shown with grounded sources (which require separate gate bias supplies), the 13cm unit was also shown in a self-biased version. This means that there is no negative gate bias supply to fuss with, but you must ensure that the source leads are properly RF grounded.

Proper RF grounding of the two source leads is done by connecting them to very low inductance disk capacitors. The RF energy thinks the capacitors don't exist and that the source leads are really grounded, but there is no DC ground. So, self-biasing is accomplished by standing the sources above DC ground with a resistor.

Never content to leave well enough alone, I built two preamps and used slightly different construction techniques on each. On one unit, I drilled holes to fit the disk capacitors through the circuit board as instructed in the article, then grounded the capacitors underneath.

On the second I used a different technique. First, use the X-acto knife to make slots in the circuit board at the inside edges of the small rectangular pads on either side of the GaAsFET. Then thread ¼" wide strips of very thin brass foil through the slots. Flatten the foil to the board and solder it to both sides. Tin one side of a disk capacitor. Then position one disk capacitor properly (with the tinned side down), and heat the brass strip from the underside with a 40 watt iron. When the heat transfers through the foil, it will melt the solder and stick the capacitor in place. It is very easy to break a disk cap by excess pressure, so be careful. After mounting the disk caps, check them with an ohmmeter to insure against shorts to ground.

The circuit board is very flexible and bends easily, so make it more rigid before mounting the rather delicate chip devices. One way to do this is to bend or piece a ¾" wide by 0.016" thick hobby brass strip all the way around the circuit board. Leave ⅛" overlapping the bottom side of the board. Mount the connectors and feed-through on the strip. Then solder connectors and strip to the circuit board. Solder the board ground plane to the strip all around. Mount the chip components, zener diode and GaAsFET last. Doing the heavy soldering between the walls and board first not only physically protects the components from fractures induced by bent boards, it also keeps you from frying the chip components.

Kits are available from Down East Microwave. I built two of these, one with right-angle-mount N-connectors and one with end-launch SMA connectors, just like Ward suggested. Both work, but the SMA version (which has the brass foil source grounding straps) works better. This unit is shown in Photo C.

The Antenna

Last but not least is the loop yagi. The design I used was based on that presented by Joe Reisert W1JR at the first annual 1296/2304 Conference (19–22 September, 1985, in Estes Park, Colorado). His design was for 2304 MHz. Since I wanted to use the antenna on both 2304 and 2401, I did the unpardonable and scaled W1JR's element lengths to 2350 MHz. I did not change the element spacing. This antenna has 52 elements and fits on an 8′ section of ½" diameter aluminum tubing.

One method of building this antenna is to get a sheet metal shop to shear a bunch of ¼" wide strips about 2′ long from a sheet of 0.032" thick aluminum. Do not use anodized aluminum for the elements or the boom. Element lengths and spacing are itemized in Table 1. Scribe off the required lengths on the strips with a steel scribe point set of dividers. Adjust the dividers with a dial caliper and lay them off. Recneck each dimension. Tolerances are $\pm 0.005''$, so be careful. Remember to leave 3/16" between the center of each hole mark and the end of each strip and ⅜" between adjacent holes on a strip. These will be cut apart later, as it is easier to handle a whole strip. After you scribe a length, mark the element number or group on it with a waterproof marker. Then, with a magnifying glass, center punch each mark accurately. Drill each hole 0.116 (#32 drill) in diameter. Drill them one hole at a time; stacking strips is a sure way to goof. Finally, cut the element strips apart.

Preform each element loop by bending it around a form. A piece of ¾" PVC pipe works fine.

To mark the element locations on the boom, it seems that millimeters are easier to use than inches, so I converted W1JR's dimensions. It's hard to find a tape measure that reads out in decimal inches! Lay a tape along the boom and mark each location. Dimensions are from the end of the boom. This prevents cumulative errors.

Drilling the boom squarely can be challenging. Eyeballing doesn't work. Use a "universal drill guide" with a V-notch designed to drill holes in the center of a pipe.

Before you start drilling, you must devise a method of preventing boom rotation while drilling, thereby keeping all the drilled holes in line. You must also support the boom high enough off the bench so that the drill guide can slide. One way to do this is to first drill a hole through the boom large enough to clear a 1½" long No. 4 or 6 wood screw. Run the screw into the bench only about ¼". The boom will now be free to move up and down as the drill guide is moved, but will be rotationally fixed. Two screws in different locations may be required if your drill guide has a large base and you can't get all the holes without hitting the screw. Slide the drill guide along the bench with the boom in the V-notch and drill each 0.116" hole. Remember to drill the driven element hole ¼" in diameter.

When assembling the elements to the boom, use 4-40 x ¾" stainless screws, nuts and lockwashers. Put the lockwasher between the nut and the boom, not under the element. Coat the ends of each element with a corrosion inhibitor such as No-Al-Ox™. Weather turns aluminum into aluminum oxide, which is a dandy insulator. No-Al-Ox is available from your local electrical supply house and well worth the nominal cost. Assemble the elements with the overlaps all facing the same direction.

For the driven element, drill a 0.144" (#27 drill) hole through a ¼" brass flat head bolt. Also drill the center of the brass strip driven element to 0.144." You must assemble all the parts (element, bolt, nut, boom, etc.) on the UT141 hardline before you solder things together. Use hobby (low-temperature) silver solder and flux for all outdoor connections as it does not deteriorate from weather like regular rosin core solder. A note: Go easy on the heat on the hardline. If you overheat it, it can swell and rupture. Then you start over. I did.

The finished product, or at least the driven element end, is shown in Photo D amidst a variety of other antenna goodies. Once again, complete antennas and antenna kits are available from Down East Microwave.

The 8' long, ½" diameter boom is flimsy and requires mounting support. The strap mounting method shown is easy and works. A single U-bolt through the support boom mounts the whole thing to the antenna cross boom. See Figure 5.

A note on antenna mounting: Many satellite operators use a nonmetallic cross boom between their antennas. This tends to cut down intermod problems on the harmonically related modes, such as Mode J. If you mount this (or any) antenna on an insulated boom and leave the preamp connected, remember where atmospheric static electricity has to go—down the lead in coax into the shack. Keep the coax disconnected from the equipment and thoroughly grounded in the shack when the antenna is not in use. Never use the antenna when thunderstorms are in the area. We are not talking about a direct lightning strike here either; there is little real protection from a situation like that. I strap-ground the 1296 and 2401 antennas right up on the mounting boom.

Results

Now the big question: Does it work? Since I do not have access to test equipment for this frequency, I took the pragmatic approach—I tried it. The first test was with the loop yagi connected to the no-tune downconverter through three feet of RG-142, 12 feet of RG-213 around the rotors, and 65 feet of 9913. And no preamp, as it wasn't built yet. But I heard the DOVE S-band beacon on the first try.

Since the addition of the WB5LUA no-tune preamp, the DOVE beacon is loud enough to hold the PLL (Phased Lock Loop) on my G3RUH PSK modem, and autotune the attached receiver. DOVE's 100 kHz Doppler shift makes this rather touchy sometimes, as a brief fade can cause the signal to run out of the capture range of the modem. Mostly it holds surprisingly well, considering that the rate of change of frequency fairly screams across the band.

This arrangement also works on the big guy, AO-13, Mode S. Downlink signal strength is marginal for SSB, but quite adequate for CW. However, perseverance has yielded a handful of sideband contacts on that mode, which is quite a thrill. Two hints are useful at this point. First, lots of multiplication (X24) between the LO crystal and the injection frequency offers the potential for large frequency conversion errors. It can be very difficult to predict where to initially find S-band signals. My own set-up has over 50 kHz frequency offset, exclusive of Doppler. The solution is to start by trying to find a loud, strong signal like DOVE and tune all over the place until you find it. Then track the signal, recording the apparent frequency and time and compare TCA (Time of Closest Approach, where the Doppler correction should be zero) to the published actual beacon frequency.

Second, the antenna described here is marginal at best for AO-13. The AO-13 13cm beacon is only a watt or so, and at times is 42,000 kilometers away! When you hear a Mode S signal, rock the antenna position to peak it. It is surprising how much difference this can make.

The advent of no-tune preamps and converters has brought Mode S into the realm of the average experimenter. Good construction practices and attention to detail are rewarded by excellent performance on frequencies previously considered almost unattainable. Now, go out and build some gear. See you on Mode S! 73

Contact Ed Krome KA9LNV at 1023 Goldfinch Rd., Columbus IN 47203.