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Low Level Amplifiers

Contents

GaAsFET Preamplifier for 70 cm

By Chip Angle, N6CA

(From *The ARRL Handbook*)

The preamplifier described here and shown in Figs 1 through 3 offers good noise performance and gain, and is suitable for terrestrial, EME and satellite applications at 432 and 435 MHz. Gain is approximately 15 dB and the noise figure is 0.55 dB, measured on an HP8970A noise-figure meter with the HP346A noise source. This preamplifier is easy to build and offers stable operation with little adjustment.

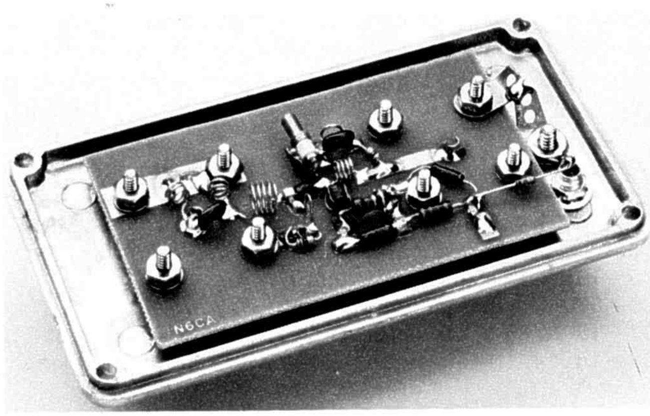

Fig 1—The 70-cm GaAsFET preamplifier is built on a PC board that is mounted to the lid of a diecast box. This version uses a Zener diode instead of the 3-terminal regulator shown in Figs 2 and 3. Connector mounting hardware also holds the board in place. Component layout is shown in Fig 3.

Circuit Details

The schematic diagram of the 70-cm GaAsFET preamplifier is shown in Fig 2. The circuit was originally designed for an NEC NE21889 GaAsFET, but a Mitsubishi MGF1402 or MGF1302 device will work fine. The version shown here uses an MGF1402, but most single-gate GaAsFETs will work.

This preamplifier uses source feedback to bring the input impedance close to 50 ohms. Input and output return loss is typically better than 15 dB. This means that a band-pass filter can be used ahead of the preamplifier without introducing mismatch loss or instability.

The design uses plenty of decoupling capacitors and RF chokes. Good-quality bypass capacitors are a must for stable operation, so use chip capacitors where specified. D1 and D2 are included for reverse and overvoltage protection. Regulator U1 allows virtually any voltage greater than 9-V dc to be used.

Construction

The preamplifier is built on a G-10 glass-epoxy printed-circuit board using surface-mounting techniques. Layout is shown in Fig 3; Fig 4 is a full-scale template. All components mount to the circuit traces. The other side of the board is unetched copper except around the connector center pins, and acts as a ground plane. All grounded pads on the etched side are connected to the ground plane with eyelets or pieces of tinned wire that pass through holes in the board and are soldered to both sides.

The board is mounted to the lid of a die-cast box (Hammond 1590B or Bud CU-124) and is designed to accommodate type-N connectors. Aluminum spacers for the connectors must be fabricated, as shown in Fig 3. These spacers mount between the box lid and the ground plane of the PC board. Q1 has two source leads. Only one is used on this board, and the extra lead may be clipped off. The ferrite bead on the drain lead mounts in a small hole cut in the board. The drain lead passes through this bead and is soldered to a pad.

GaAsFETs are static-sensitive, so handle them accordingly. It's best to assemble the rest of the circuit and install Q1 last. Use a grounded iron if possible, and solder the leads quickly.

Adjustment

The preamplifier shown in Fig 1 was assembled in the ARRL lab and tested before any adjustments were made. For starters, C2 was set at midrange. As assembled, the preamp measured 13 dB gain with a 0.57-dB noise figure—perfectly acceptable performance for a device such as this. After adjusting C2 and bending L3 and L5, the gain increased to 15.25 dB with a 0.54-dB noise figure. This is acceptable for all but perhaps the most demanding EME applications. No amount of spreading or compressing the coils could make the gain fall

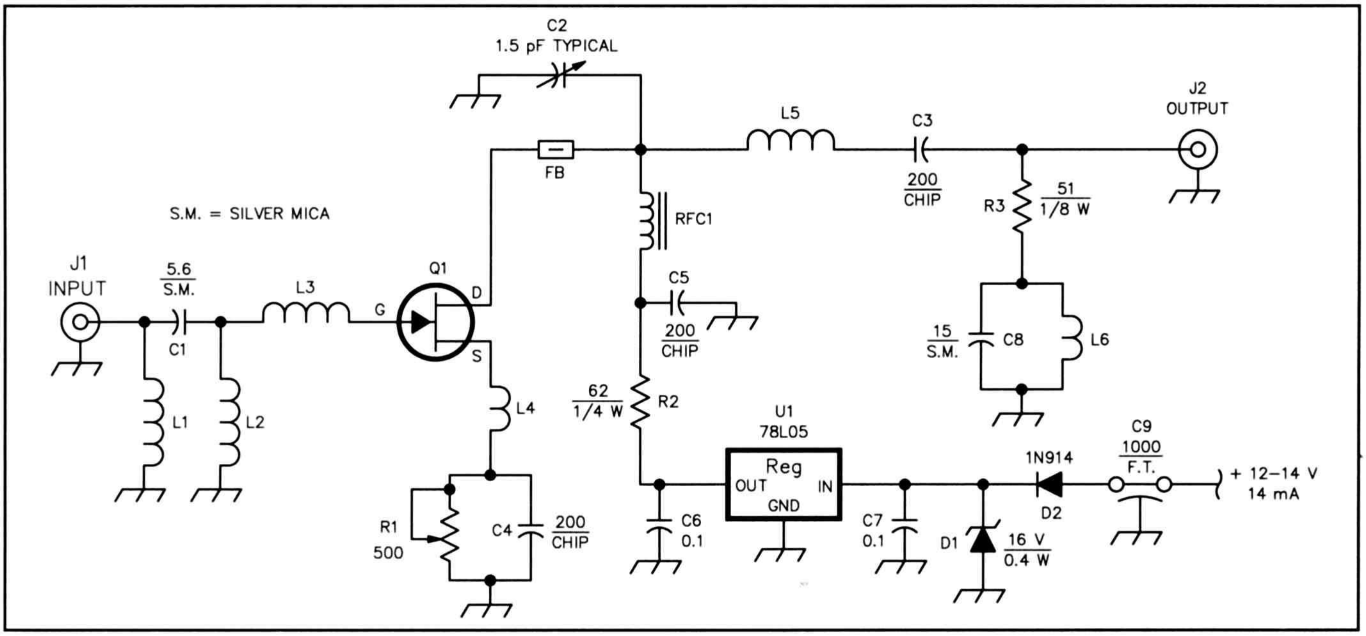

Fig 2—Schematic diagram of the 70-cm GaAsFET preamplifier. Resistors are carbon-composition types. Resistor values are given in ohms; capacitor values are given in pF.

C1—5.6-pF silver-mica capacitor or same as C2.
C2—0.6- to 6-pF ceramic piston trimmer capacitor (Johanson 5700 series or equiv).
C3, C4, C5,—200-pF ceramic chip capacitor.
C6, C7—0.1-μF disc ceramic capacitor, 50 V or greater.
C8—15-pF silver-mica capacitor.
C9—500- to 1000-pF feedthrough capacitor.
D1—16- to 30-V, 500-mW Zener diode (1N966B or equiv).
D2—1N914, 1N4148 or any diode with ratings of at least 25 PIV at 50 mA or greater.
FB—FB-43-101 or FB-64-101 ferrite bead.
J1, J2—Female chassis-mount Type-N connectors, PTFE dielectric (UG-58 or equiv).
L1, L2—3 t no. 24 tinned wire, 0.110-inch ID, spaced 1 wire diam.
L3—5 t no. 24 tinned wire, 3/16-inch ID, spaced 1 wire diam. or closer. Slightly larger diameter (0.010 inch) may be required with some FETs.
L4—1 t no. 24 tinned wire, 1/8-inch ID.
L5—4 t no. 24 tinned wire, 1/8-inch ID, spaced 1 wire dia.
L6—1 t no. 24 tinned wire, 1/8-inch ID.
Q1—Mitsubishi MGF1302 (see text).
R1—200- or 500-Ω Cermet potentiometer set to midrange initially.
R2—62-Ω, 1/4-W resistor.
R3—51-Ω, 1/8-W carbon-composition resistor, 5% tolerance.
RFC1—5t no. 26 enam. wire on a ferrite bead.
U1—5-V, 100-mA 3-terminal regulator (LM78L05 or equiv TO-92 package).

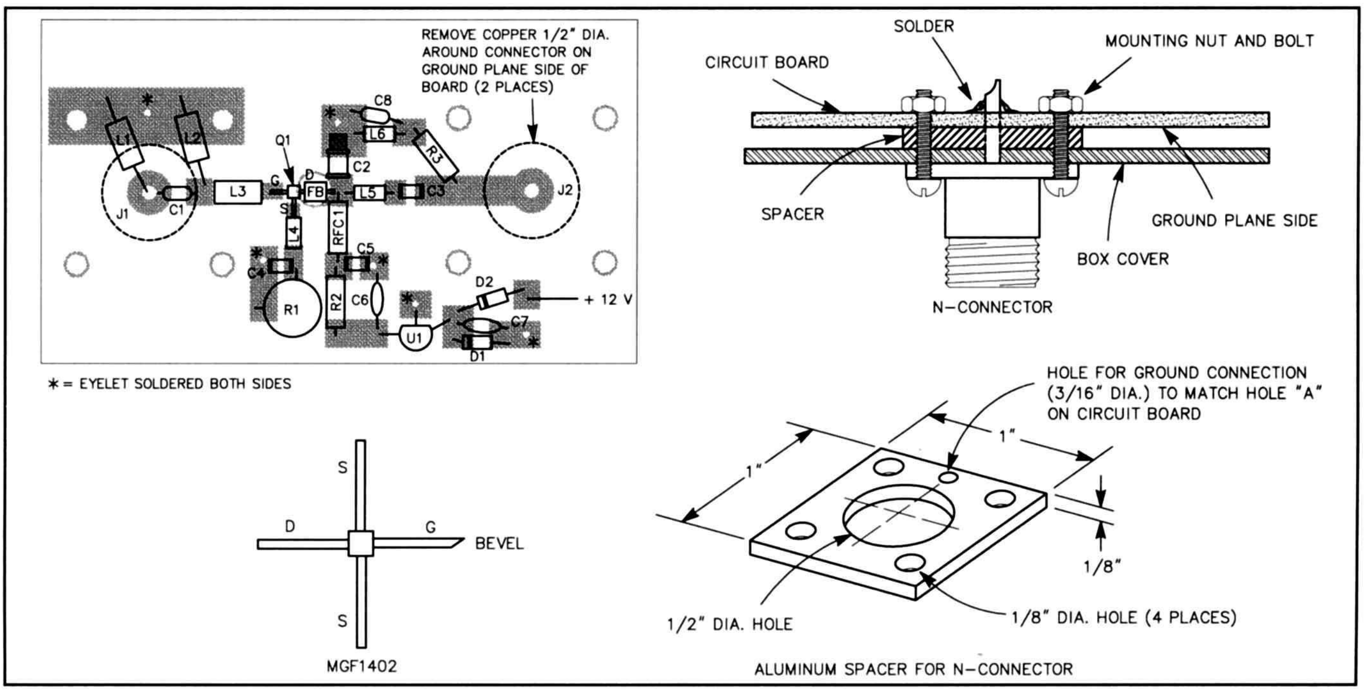

Fig 3—Parts-placement diagram for the 70-cm preamplifier.

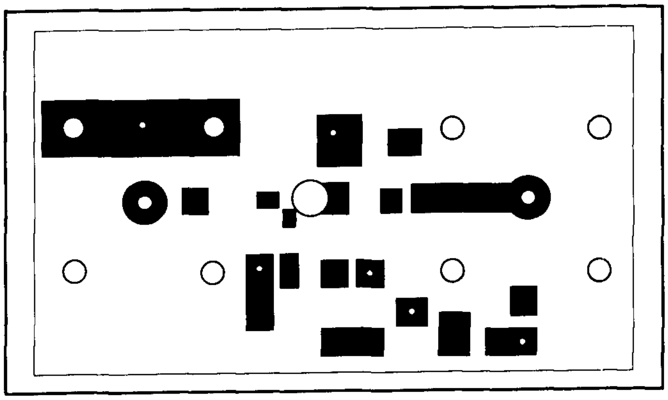
Fig 4—A full-size etching pattern for the preamplifier.

below 12 dB or the noise figure rise above 0.65 dB. At no time did the preamp display signs of instability. In short, this is a reproducible project. You can assemble it without test equipment and be reasonably sure of the performance.

A Half-Watt 903-MHz Amplifier

By Zack Lau, KH6CP

(From May 1988 *QEX*)

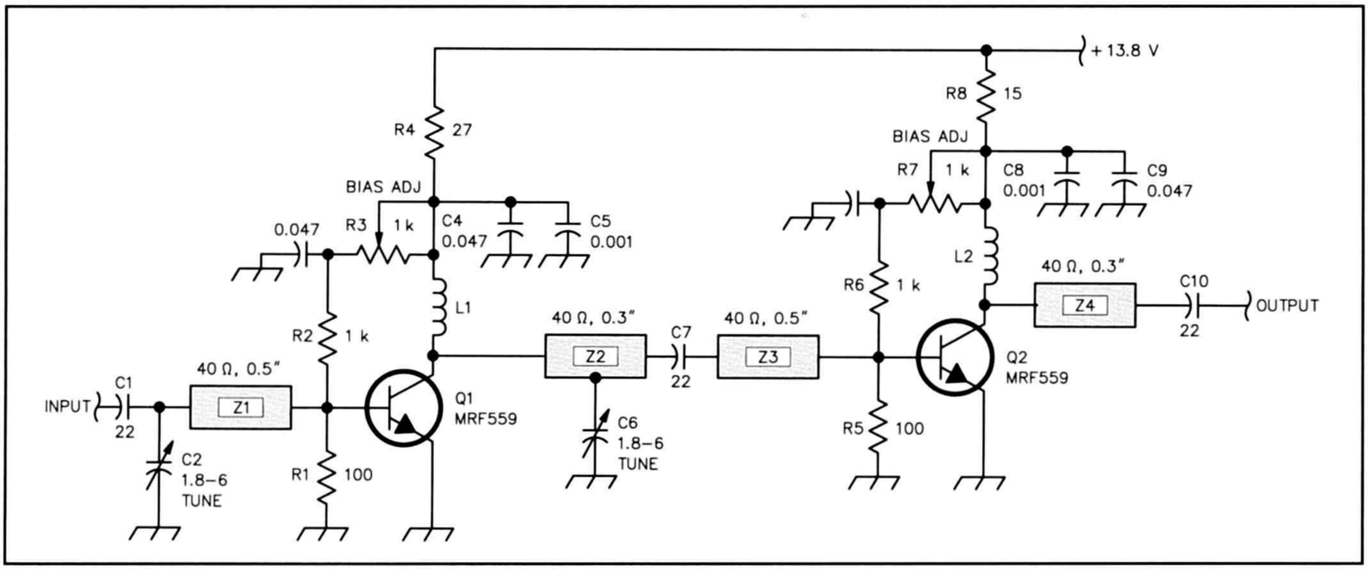

Fig 1—Schematic of an inexpensive 0.5-W 903-MHz amplifier. Resistors are ¼ W. Capacitors are NP0 chip capacitors unless noted, although more expensive porcelain capacitors may work better.

C2, C6—1.8-6 pF trimmer capacitors. Mouser 24AA70.
C3, C4, C9—Tiny ceramic capacitors or chip capacitors.
L1—7 t no. 22 tinned copper wire, space wound; no. 32 drill bit used as temporary form.
L2—5 t no. 22 tinned copper wire, space wound; no. 33 drill bit used as temporary form.
Q1, Q2—MRF559.

The two-transistor amplifier shown in Fig 1 is an inexpensive way to amplify the 10 mW of RF output available from a monolithic microwave integrated circuit (MMIC) to 0.5 W on the 903-MHz band. Q1 and Q2, MRF559s, are inexpensive plastic-cased devices. When driven with an Avantek MSA-0404 MMIC (around 10 mW saturated output), the saturated CW output is 0.5 W as measured with an HP435/8482A power meter and a Bird 10-dB attenuator. A two-tone IMD test indicates that the MMIC saturates before this amplifier does, since the higher order IMD products are down 47 dB. See Fig 2.

The amplifier is built on a 1/16-in., double-sided glass-epoxy PC board (Fig 3). All components mount on the etched side. The other side is left unetched to act as a ground plane. The 40-Ω striplines (Z1-Z4) are made using 0.15-in.-wide traces.

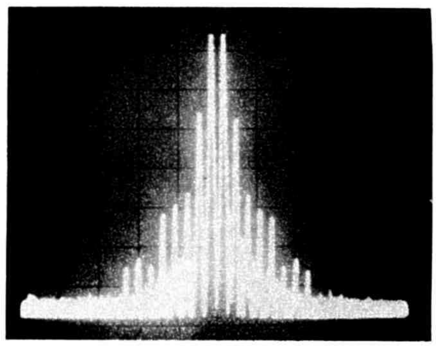

Fig 2—Spectral display of the 0.5-W 903-MHz amplifier during two-tone intermodulation distortion (IMD) testing. Third-order products are approximately 26 dB below PEP output, and fifth-order products are approximately 47 dB down. Vertical divisions are each 10 dB; horizontal divisions are each 10 kHz. The amplifier was being operated at 560-mW PEP output on 903.1 MHz.

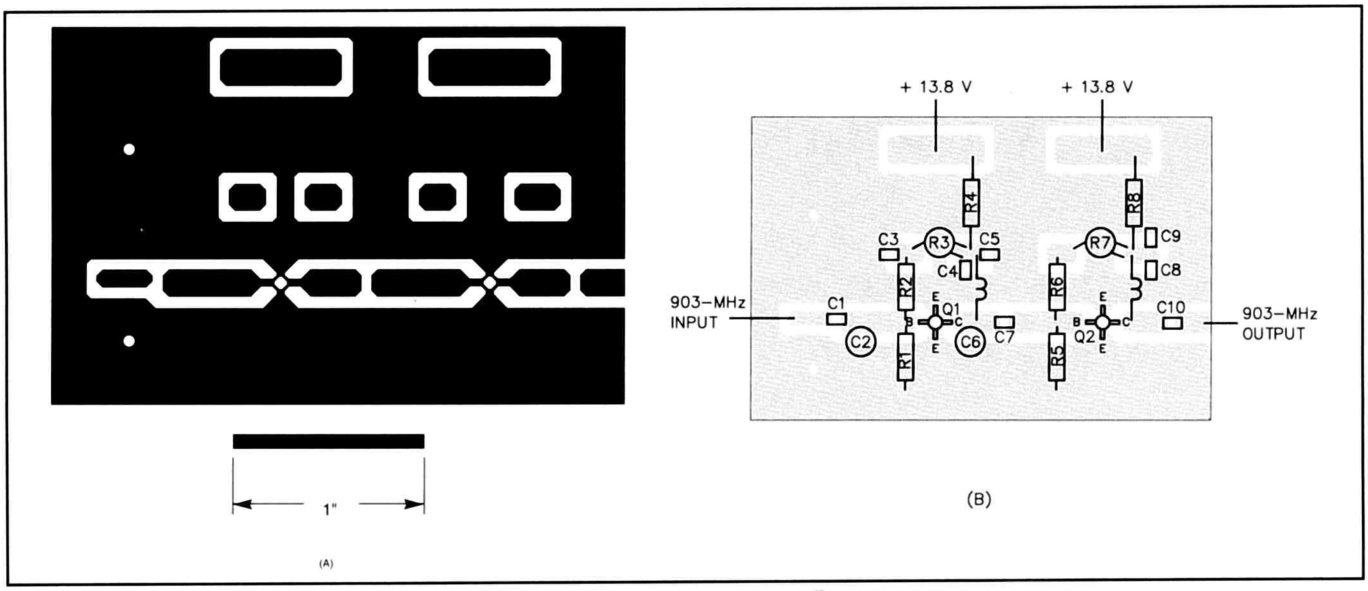

Fig 3—Circuit-board etching pattern (A) and part-placement diagram (B) for the 0.5-W 903-MHz amplifier. The etching pattern is shown full size from the etched side of the board. Black areas represent unetched copper foil. Board material is ¹⁄₁₆-in. G-10, double sided. The other side of the board is unetched to form a ground plane. The shaded area in B represents the copper pattern. All components are mounted on the etched side of the board.

Use good VHF/UHF construction techniques and keep the leads short when mounting components. Drill oversize holes for Q1 and Q2 so the leads lie flush against the board traces. Use copper foil wrapped through the transistor mounting holes to connect the top and bottom ground planes at the emitters of Q1 and Q2. Wrap the board edges with copper foil to connect the top and bottom ground planes.

Use R3 and R7 to adjust bias currents to 22 mA for Q1 and 87 mA for Q2. Note: These are the *total* currents as indicated by the voltage drops across R4 and R8. The bias currents do drift slowly without RF drive, but this is not a problem as long as the supply voltage is switched off during receive. The prototype works fine without a bypass capacitor at the junction of R6 and R7.

Tune-up is simple. Apply drive and adjust C2 and C6 for maximum output. Attempts at matching the output with a tunable network failed to improve gain or output power. Better results may be obtainable by using Teflon board and porcelain chip capacitors.

HEMT LNA for 1296 MHz

By Tommy Henderson, WD5AGO

(From *Proceedings of Microwave Update '91*)

Introduction

EME (Moon Bounce) is a very demanding mode of operation. A tenth of a decibel (dB) gained on receive noise figure (NF) can offer a 0.5- to 1.0-dB system improvement. Most GaAsFET preamps have a difficult time achieving below 0.5 dB NF (35 Kelvin) at room temperature on 1.3 GHz. Cooling the preamp[1] is one way of achieving lower noise figures; but cooling is somewhat difficult to do. Another possibility is to design a preamplifier around super low noise devices called HEMTs (High Electron Mobility Transistors). Data sheets specify HEMTs to have noise figures between 0.2 to 0.35 dB and gain of 17 to 20 dB, at a frequency of 2 GHz. The problem with most HEMTs is maintaining stability at low frequencies, because they are designed to be operated above 4 GHz.

Circuit

The original work to evaluate the HEMTs at 1296 MHz took place on a test fixture, where parts could be installed and removed easily without the use of solder. The first item of concern was to monitor the noise figure while checking for instability (the latter turns out hard to evaluate without the use of computer modeling). Grounding the source leads and not using source bypass capacitors aided in both categories. Negative bias must now be used on the gate and should be turned on before or at the same time as V_{DD}. A battery is the simplest way to apply gate bias; you can also use a power supply.[2,3] Another benefit of grounded source is that the operating perimeters for lowest noise figure are easily found for several different devices through the negative bias adjustment.

HEMTs that were tested included the MGF4303, FHC30LG, NE32184, NE20283, and ATF35176. All devices showed noise figures less than 0.5 dB and gains from 18 to 22 dB! The Avantek ATF35176 is one of the newest line of P-HEMTs and is available from Penstock Inc. Noise figures of 0.39 to 0.55 dB were achieved, while gains ranged from 12 to 18 dB. Best results were obtained with the ATF35176. Because NF results seem to be different from meter to meter, an ATF10135 preamp was used as a standard. Also, the ATF10135 GaAsFET was placed in the test fixture for further comparison.

Stability has been a problem with the HEMTs, and I tried several different methods of taming them. Place conductive foam near the circuit, keep the source inductance less than 0.07 inches, and don't use ferrite beads on the drain lead. Good component layout also helps.

After the original circuit was built and used, an opportunity to have the circuit modeled using the Touchstone computer software design program shed light on the potential instability problems. To correct the low-frequency instability, I removed the input choke to ground; for high frequency instability, a series resistor with a controlled amount of inductance was added. Retuning the circuit yielded a preamp with a stability factor K above one from 100 to 20,000 MHz. The gain dropped 3 dB and noise figure increased only 0.04 dB. It is difficult to obtain the figures given on computer modeling, due to inaccurate S parameter data below 2 GHz, and stray reactances that may enter the real circuit.

Construction Notes

I didn't make a circuit board. Instead, all connections other than grounds were made point to point in air, to reduce losses. You can make a box from unused double-sided circuit board. Solder the source leads of Q1 directly to the box. Alternately, solder the source leads to a $1/2$- × 1-in.-piece of thin brass, and bolt the brass to the box. This method helps prevent overheating the HEMT.

Adjustment

Adjust V_g and V_d for lowest noise figure. Typical values are:

V_g: – 0.40
V_d: 2.5
NF: 0.4 dB
Gain: 17 dB
S11: 9 dB

Conclusion

The circuit in Fig 1 has been tested on HP 8970s with noise figures from 0.32 to 0.45 dB. A two-stage version (the same preamp cascaded and tuned) measured 0.29 dB on NRAO

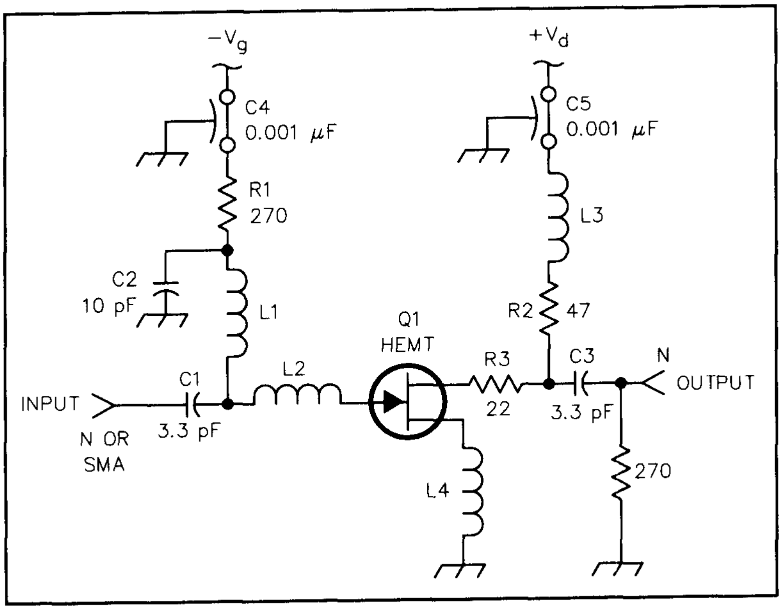

Fig 1—Schematic of the 1296-MHz HEMT preamplifier. Resistors are ¼-W carbon film or composition. Capacitors are 100-mil ATC chips.

C1, C2—3.3 pF, 100-mil ATC chip caps.

L1—4 t no. 30, 0.1-in. ID, 0.25-in. long.

L2—4 t no. 30, 0.06-in. ID, 0.25-in. long. Compress or expand turns for minimum NF.

L3—1 t, 0.07-in. ID (lead of R2, 0.1-in. long on V_d side).

L4—0.06-in. long source leads, 0.05-in. above ground plane.

R3—22 Ω, carbon comp. Make leads 0.1-in. long, and connect 0.2-in. away from Q1.

(National Radio Astronomy Observatory) lab equipment without cooling; the gain was 32 dB. The preamp performs well from 1100 to 1500 MHz with minor adjustment of L1. For over three years, HEMTs uncooled and cooled have been in service in my 1296-MHz EME system with good success. They are worth a look at, if you want to get below the 0.5-dB NF barrier.

Notes

[1]Henderson, T., "Electronically Cooled 1.3 GHz LNA," *Proceedings of the 24th Central States VHF Society Conference* (Newington: ARRL, 1990), pp 1-8.

[2]Ward, A., "Simple Low Noise Microwave Preamplifiers," *Proceedings of Microwave Update '88* (Newington: ARRL, 1988), p 65; also *QST*, May 1989, pp 31-36, 75 (reprinted in this chapter).

Table 1

Device	*Bias*	*NF*	*Gain*	*S11*
ATF10135	1.7 V_ds 15 mA	0.55 dB	12 dB	6 dB
ATF10135	2 V_d −0.2 V 20 mA	0.51 dB	13 dB	9 dB
ATF35076	2V_d −0.4 V 18 mA	0.39 dB	18 dB	7 dB

A 2304-MHz Preamp Using the MGF1302/1402

By Jim Davey, WA8NLC
(From *Proceedings of Microwave Update '89*)

Here's a simple preamp for 2304-MHz that is designed around the Mitsubishi MGF1402/1302 GaAsFET. It has been built by several amateurs with good results. If the directions are followed closely, the noise figure will be well under 1 dB. If a noise-figure meter is available, the gate circuit can be optimized for a noise figure of about 0.7 dB. The circuit (Fig 1) is patterned after a 1296 preamp published by W6PO several years ago in the EIMAC *EME Notes*.

The preamp is built on 0.031-in. Teflon board with a dielectric constant of 2.5 (Fig 2). I have not tried it myself, but Duroid 5880 will probably work OK. The board is mounted in a small open top box made of ½-in. wide brass strip stock available at hobby stores. Clearance holes are drilled in the ends for SMA-connector center pins. The connectors can be bolted or soldered to the brass wall. I prefer this type of mounting method to right-angle mounting through the board for both mechanical and electrical reasons.

The GaAsFET is supported by a 50-mil size porcelain chip capacitor under each source lead. A small hole just large enough to pass the chip capacitor is drilled at each location and the capacitor inserted so the metallized end is flush with the ground plane on the back of the board. A quick pass with a hot soldering iron and solder will tack the capacitor to ground. If the 50-mil size capacitors are used, the other end will protrude slightly on the circuit side. Center the transistor between the two exposed ends of the capacitors and solder. Leave some lead on one side to attach the bias resistor.

The preamp is adjusted by spreading or compressing the turns on the gate coil and adjusting the length of the stub on the gate for lowest noise figure.

Parts can be purchased from Microwave Components of Michigan, PO Box 1697, Taylor, MI 48180.

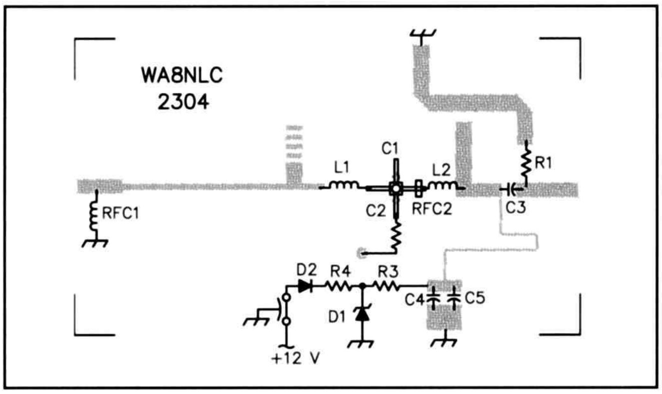

Fig 1—Schematic diagram of the 2304-MHz preamp.
C1-C4—Porcelain chip cap, 10-pF (0.050-in. preferred).
C5—470-pF chip cap.
D1—Zener diode, 4.7-V, 400-mW.
D2—1N914 or equiv.
L1—2 t no. 28 enam, spaced 3 wire diam, 0.055-in. ID.
L2—1.5 t no. 28 enam, spaced 1 wire diam, 0.055-in. ID.
R1—50-Ω, ⅛-W carbon composition or chip resistor.
R2—68-82 Ω, select for I_d = 10 mA.
R3—100 Ω typ., select for V_{ds} = 3.0 V after I_d is set.
R4—270 Ω, ¼ W carbon composition or film.
RFC1—4 t no. 28 enam, closewound, 0.055-in. ID.
RFC2—T12-6 core over drain lead of transistor.

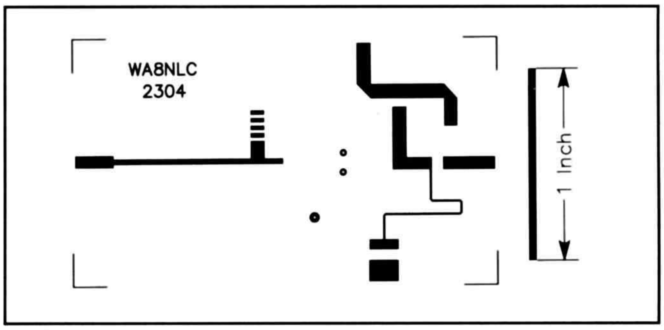

Fig 2—Circuit-board artwork for the preamplifier.

Simple Low-Noise Microwave Preamplifiers for 2.3 Through 10 GHz

By Al Ward, WB5LUA

(From May 1989 *QST*)

One of the hurdles to overcome in building a microwave station is construction of a good low-noise preamplifier. Techniques using lumped constants (capacitors and inductors) that work well at lower frequencies are often difficult to realize above 2304 MHz. Once a design is worked out and the preamplifier built, the unit must then be tuned for minimum noise figure (NF) before any sort of reasonable performance can be expected. Preamplifier tune-up itself presents a hurdle because many hams don't have access to NF test equipment that is accurate in the microwave region.

If these low-noise amplifiers (LNAs) are duplicated exactly from the information presented, no RF adjustments are required. Just bias their active devices properly, and the units are ready to go—with NFs under 1 dB at frequencies up to 5.7 GHz and around 1.5 dB at 10.368 GHz.

The 10-GHz amplifier is designed around the Hewlett-Packard ATF-13136 GaAsFET, and the lower-frequency units are designed around the Hewlett-Packard ATF-10136. Both devices have a nominal gate length of 0.3 micron. The ATF-10136 has a total gate periphery of 500 microns. The ATF-13136 has a gate periphery of 250 microns, making it more appropriate for higher-frequency operation. Best of all, these transistors are not high-priced exotics. Both the ATF-10136 and the ATF-13136 are the short lead versions of the ATF-10135 and ATF-13135 respectively. The long lead versions (35 package) are being phased out of production in favor

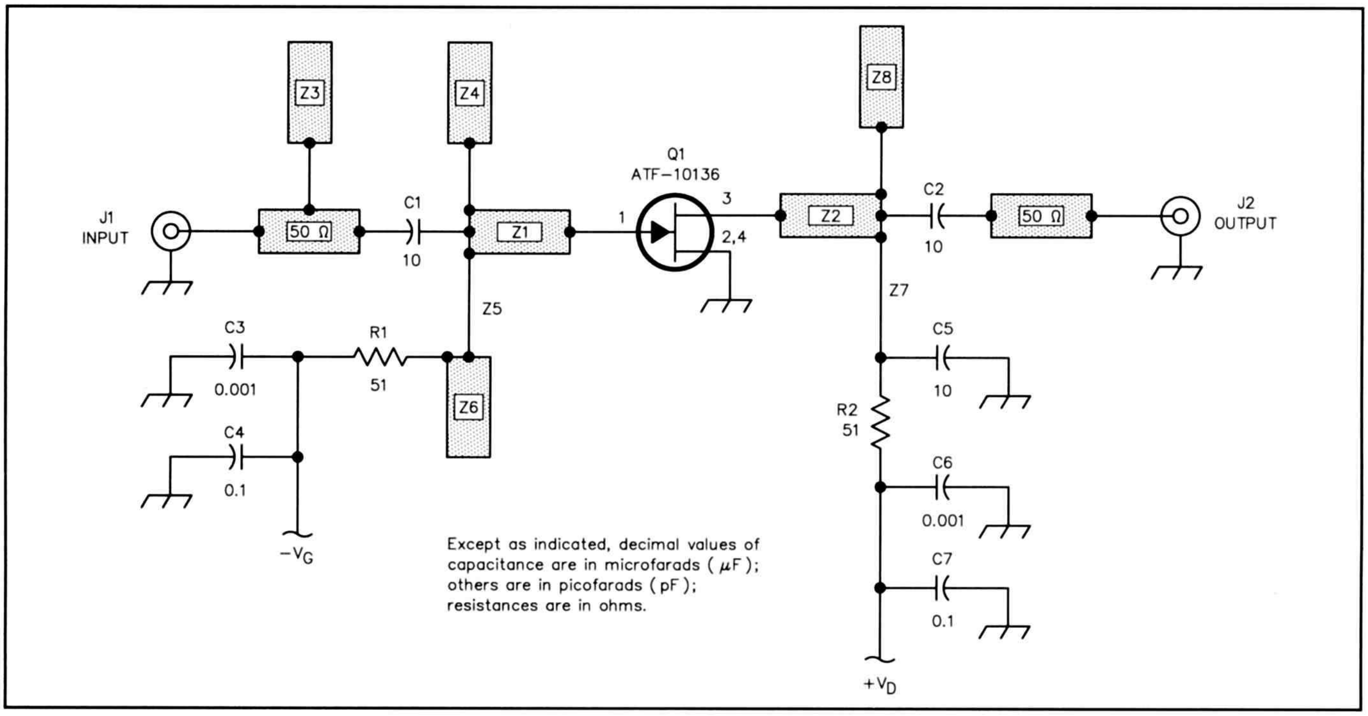

Fig 1—Schematic of the 2.3-GHz preamplifier. Z1 through Z8 are microstriplines etched on the PC board. Shaded rectangles marked "50 Ω" are 50-Ω transmission lines etched on the PC board. All resistors and capacitors are chip types. C1, C2 and C5 can be 0.05- or 0.1-in. square. C4 and C7 enhance "low-frequency" bypassing. J1 and J2 are SMA female connectors; see text.

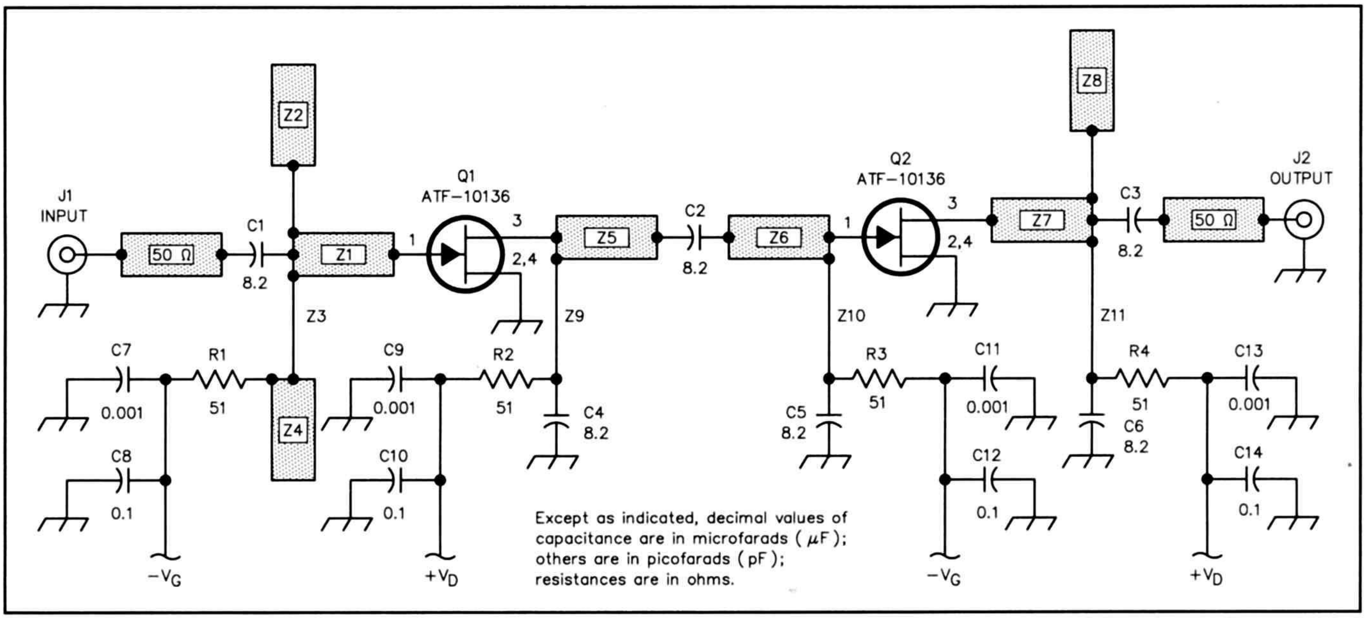

Fig 2—Schematic of the 3.4-GHz preamplifier. Z1 through Z11 are microstriplines etched on the PC board. Shaded rectangles marked "50-Ω" are 50-Ω transmission lines etched on the PC board. All resistors and capacitors are chip types. C1-C6 are 0.05-in. square. C8, C10, C12 and C14 enhance "low-frequency" bypassing. J1 and J2 are SMA female connectors; see text.

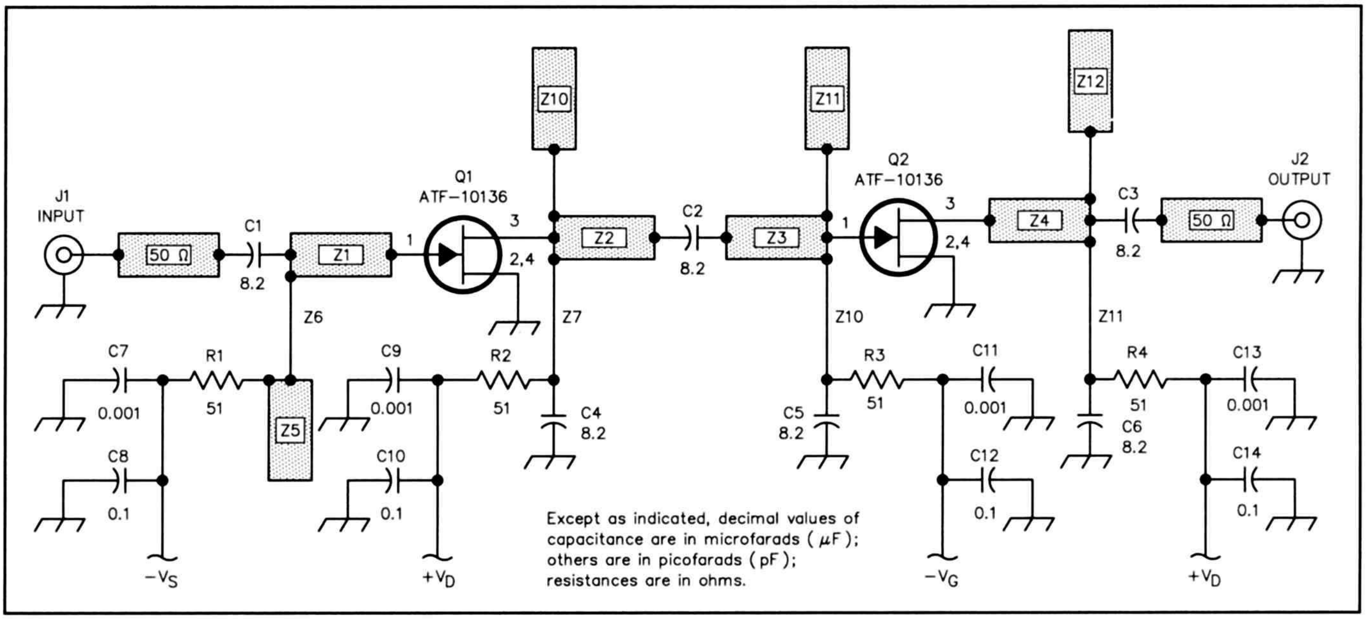

Fig 3—Schematic of the 5.7-GHz preamplifier. Z1 through Z12 are microstriplines etched on the PC board. Shaded rectangles marked "50-Ω" are 50-Ω transmission lines etched on the PC board. All resistors and capacitors are chip types. C1-C6 are 0.05-in. square. C8, C10, C12 and C14 enhance "low-frequency" bypassing. J1 and J2 are SMA female connectors; see text.

of the short lead versions. The short lead versions are required for most commerical "pick and place" high volume assembly lines.

Circuit Description

Schematics for the preamplifiers are shown in Figs 1-5. Fig 1 shows a single-stage 2.3-GHz design. Figs 2 and 3 show 2-stage preamplifiers for 3.4 and 5.7 GHz. Figs 4 and 5 show single- and two-stage 10-GHz LNAs.

The same basic circuit configuration is used for each preamplifier. All impedance matching is accomplished with microstriplines. None of the amplifiers contains adjustable RF components. Fixed-value capacitors and resistors are also used in the gate- and drain-bias decoupling circuitry.

I did the initial design for these preamplifiers with the aid of a Smith Chart and optimized them through computer simulation. LNA design is made considerably easier by computer-aided design software. I was fortunate to have access to Touchstone, an RF design program made by EESOF.

One of the most important parameters that the computer

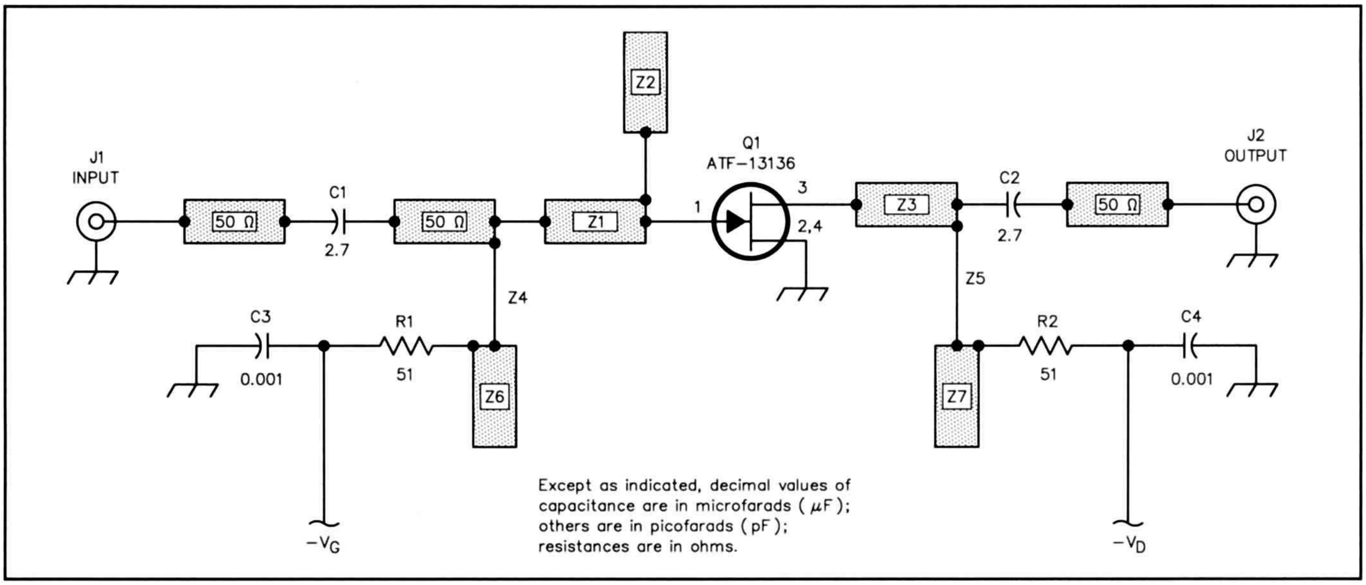

Fig 4—Schematic of the single-stage 10-GHz preamplifier. Z1 through Z7 are microstriplines etched on the PC board. Shaded rectangles marked "50-Ω" are 50-Ω transmission lines etched on the PC board. All resistors and capacitors are chip types. C1 and C2 are 0.05-in. square (ATC Type A capacitors are preferred). J1 and J2 are SMA female connectors; see text.

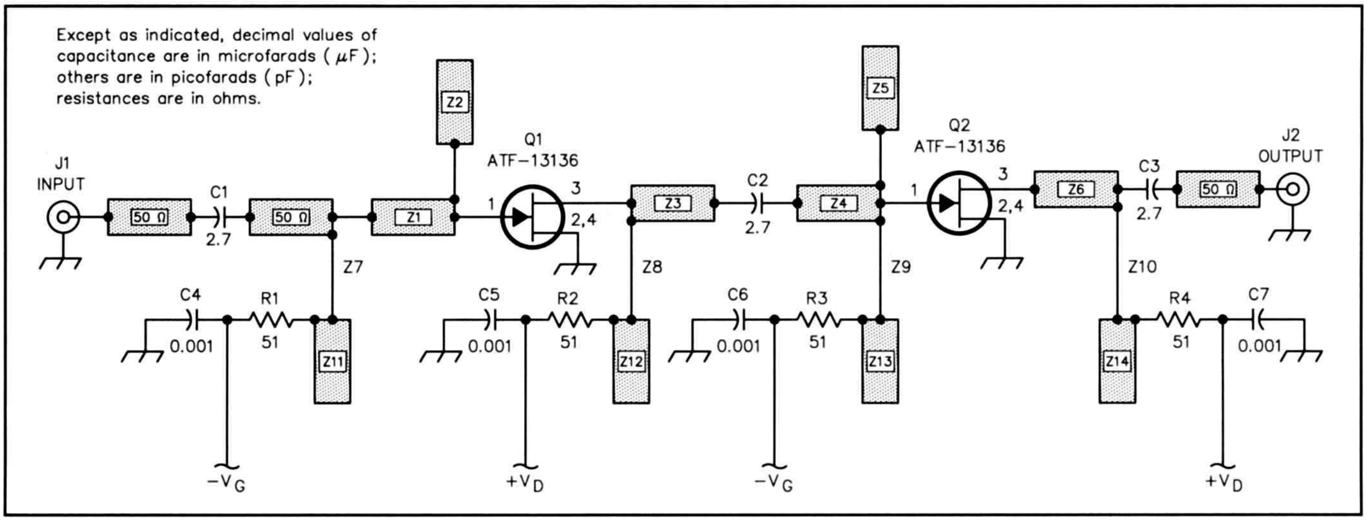

Fig 5—Schematic of the two-stage 10-GHz preamplifier. Z1 through Z14 are microstriplines etched on the PC board. Shaded rectangles marked "50-Ω" are 50-Ω transmission lines etched on the PC board. All resistors and capacitors are chip types. C1-C3 are 0.05-in. square (ATC Type A capacitors are preferred). J1 and J2 are SMA female connectors; see text.

can analyze is stability. Proper choice of components in the bias decoupling networks and the use of source inductance in the form of source-lead length helps to maintain stability. The results are improved input and output SWR, while maintaining low noise figure and moderate gain. In the case of the 3.4, 5.7 and 10-GHz amplifiers, the effect of the "through-the-board" mounting of the source leads is taken into account in the design so that no plated-through holes are necessary to achieve good performance.

Bias Networks

To minimize circuit losses, ground the GaAsFET source leads directly to the ground plane. To operate these devices with their source leads at dc ground, you must bias each device's gate negatively relative to its source. This can be done in a number of ways, so I left bias circuitry off the PC boards.

Three basic bias circuits are shown in Fig 6. Two are passive. The third—and most desirable—is an active bias network that uses a PNP transistor to set the GaAsFET drain voltage and current.

The simplest bias network, shown in Fig 6A, uses a 3.3-V Zener diode to set the drain voltage. A 1.5-V AA cell is used for the bias supply. Bias, applied through R1, sets the gate voltage, which in turn determines the drain current. Generally, the AA cell is connected so that there is always a negative voltage applied to the gate. The preamplifier is then turned on by connecting V_D to a positive voltage source. Because there is a 51-Ω resistor in series with the drain, there is some interaction between drain voltage and drain current: Greater drain

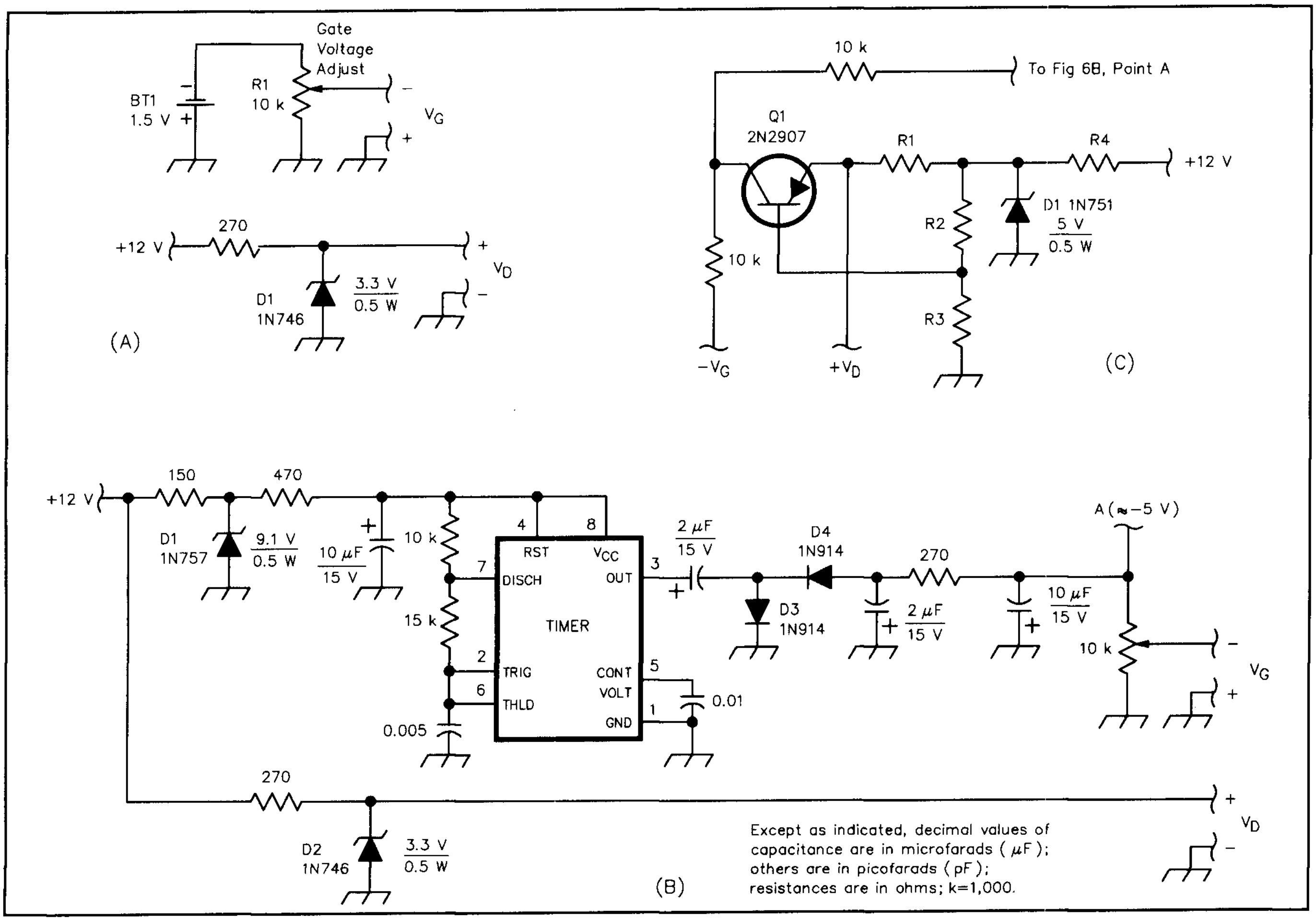

Fig 6—Bias circuits for the preamplifiers. See text for discussion. The passive circuit at A uses a 1.5-V cell for the gate supply and a Zener diode to stabilize the drain supply. The circuit at B, another passive arrangement, uses a 555 timer IC to generate negative gate bias, and a Zener diode to stabilize the drain supply. C shows an active bias circuit. The values of R1, R2 and R3 can be varied for different FET operating conditions; see text and Table 1. The value of R4 should be chosen so that 10-15 mA of Zener current flows when the FET (or FETs, for a two-stage design) is powered at rated bias.

current produces a lower drain voltage. The gate voltage required to properly bias the device varies from unit to unit because of slight variations in pinch-off voltage. (Pinch-off voltage is the gate voltage required to turn the FET off.) A disadvantage of this simple bias circuit is that it lacks compensation for bias changes over temperature variations. Although not optimum, this technique has been used at WB5LUA and WA5VJB with good results. A high-grade, long-life alkaline AA-size cell should last several months before its voltage drops low enough to cause the FET to draw excessive drain current.

An adaptation of the simple passive bias configuration is shown in Fig 6B. Drain voltage is again provided by a 3.3-V Zener diode, but this circuit replaces the AA cell with a positive-to-negative voltage inverter. Several manufacturers make suitable inverter ICs. A less-expensive approach is to use a common 555 timer in the simple inverter circuit shown. With simple battery bias, the negative supply is continuously applied to the FET gate. With the inverter of Fig 6B, gate and drain supplies are simultaneously applied to the FET. This approach has been used by manufacturers of satellite TV receiving equipment for years. Although there can be problems if the drain voltage is applied before the negative gate voltage, the 51-Ω resistor in series with the drain safely limits the maximum drain current—even if the application of gate voltage to the FET is delayed.

An improvement on both passive circuits is the active bias circuit shown in Fig 6C. The negative gate supply uses the inverter of Fig 6B, but the drain supply employs an inexpensive PNP transistor in a circuit that effectively sets both the drain voltage and drain current regardless of device variations. It also offers a more constant bias over temperature than the passive designs. Drain voltage is set by R2 and R3, a voltage divider at the base of Q1. The voltage is then raised by the emitter/base junction voltage of Q1. Drain current is set by R1. The gate voltage required to sustain the drain voltage and current is set automatically by the voltage divider set up by the emitter/collector junction of Q1 and the negative voltage source. About −1 V is supplied to the FET gate.

Table 1 gives resistor values for various bias conditions. I suggest building a separate bias network for each FET stage to properly set each device's bias point. I have, however, used a single active bias supply to power a two-stage amplifier with good success. If the devices are fairly well dc matched (drain

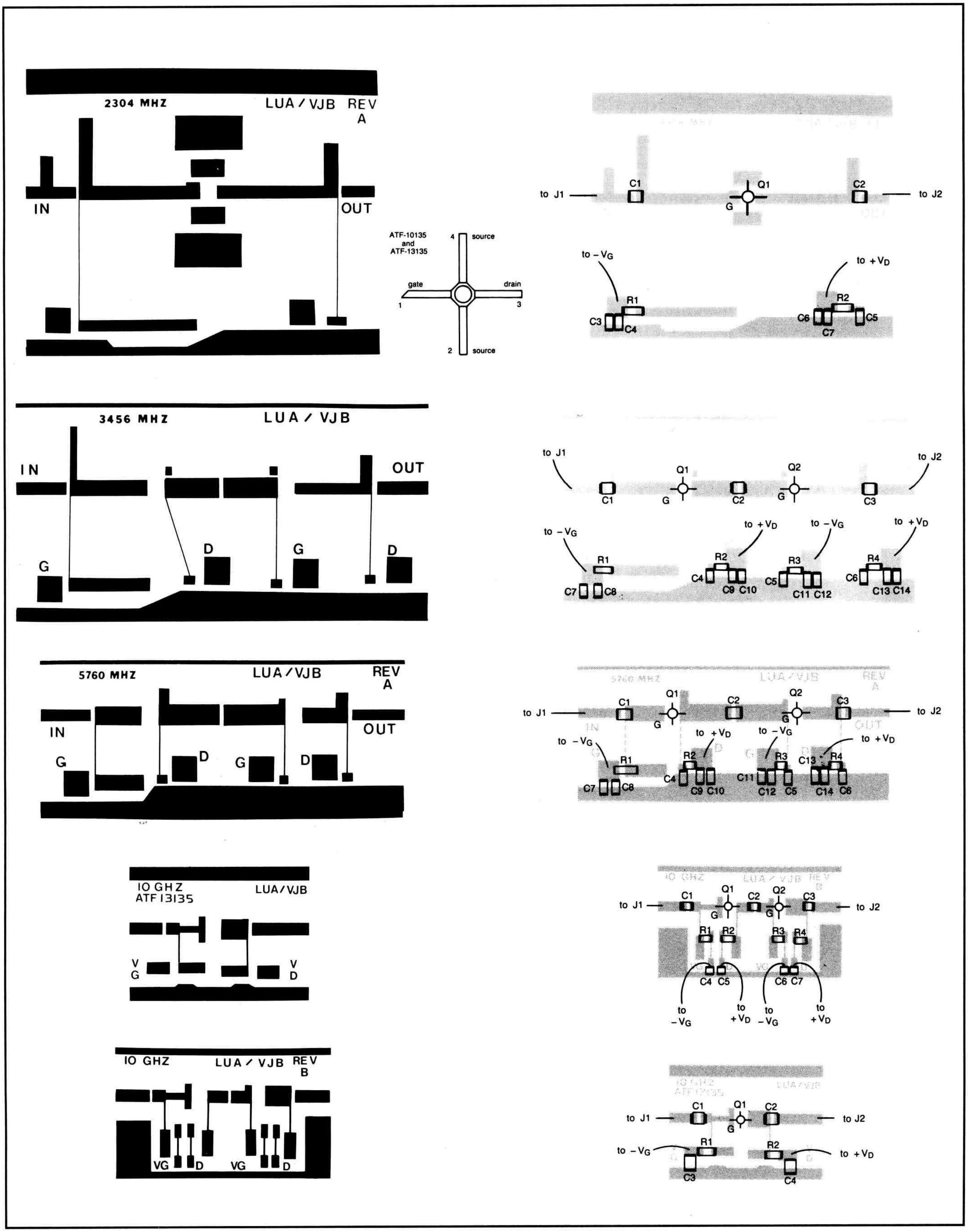

Fig 7—Circuit-etching patterns and parts-placement guides for the preamplifiers. The etching patterns are shown at full size. PC board material is double-sided, 0.031-in-thick Rogers Duroid 5880 or Taconic TLY-5 (dielectric constant, 2.2). Black areas represent unetched copper foil. The back side of the board is left unetched to act as a ground plane. The parts-placement guides are not shown at their actual size. All components mount on the etched side of the board.

current vs gate voltage), this technique will be okay. It will not, however, keep the device drain currents equal if they are not dc matched.

The active bias arrangement can also be used with a battery instead of the voltage inverter. Since the active bias network automatically adjusts gate voltage for a required bias condition, the circuit will adjust the gate voltage as it drops with battery age. The gate requires about –1 V, so the battery can age significantly before the FET bias condition is altered significantly. If this technique is used, it is best to start out with a 5- to 6-volt battery source. The active bias network will compensate for a battery voltage deteriorating to 1-1.5 V. Active bias networks are discussed in greater detail in Hewlett-Packard application note ANA002.

Construction

Construction of all amplifiers is similar. Part-placement guides and etching patterns are shown in Fig 7. All amplifiers are etched on 0.031-in.-thick Duroid 5880 or Taconic TLY-5 PC-board material with a dielectric constant of 2.2. The etched PC board can be installed in a housing such as a die-cast aluminum box. Another method, one that I prefer, is to solder thin (0.02-in.-thick) brass side walls to the PC board to form a shielded enclosure. The brass walls also connect the top and bottom ground planes, which is essential for low-loss "low-frequency" bypassing. Power connections for V_G and V_D can be made via 0.001-µF feedthrough capacitors soldered to the brass walls. See Figs 8 and 9.

SMA-type end-launch connectors are used for J1 and J2 to provide a transition from coaxial cable to the microstripline. Two- or four-hole gold-plated connectors are easily soldered to the PC board or brass side walls, depending on your assembly technique. End-launch connectors are preferred to the right-angle type because of the impedance discontinuity associated with the right-angle transition. Additional amplifier tuning may be required if right-angle connectors are used.

The type and size of the chip capacitors used in these amplifiers becomes increasingly important as frequency increases. For the blocking capacitors, I strongly recommend using good-quality RF-type ceramic chip capacitors, such as those made by ATC. The values specified are common and should not be hard to find. The physical size of the capacitors is especially critical at 10 GHz, where the 0.05-in.-square type *must* be used. Anything larger produces a sizable mismatch on the microstripline.

The value of the "low-frequency" bypass capacitors is less critical. Anything in the 820- to 1500-pF range will work fine. The value of the "high-frequency" bypass capacitors is somewhat more critical, though. Stay within 10% of the values indicated. Again, use good-quality capacitors for "high-frequency" bypassing.

To obtain a low noise figure, the preamp's FET source leads must be properly grounded. In the case of the 3456-MHz and higher-frequency preamplifiers, bend the FET source leads down right at the case and insert them through slots in the PC board. See Fig 10A. This technique works fine for the long leaded devices. For the short leaded devices, I would suggest using 0.050 inch to 0.070 inch wide copper wire straps to bring the bottom ground plane to the top of the printed circuit board where the device can be soldered directly to the "C wire" strap. The "C wire" strap should be positioned close enough to the edge of the package such that the device source lead length is minimal, i.e. less than 0.010 inches of source lead for the 3456 MHz through 10368 MHz preamplifiers. See Fig 10B.

Table 1
Active Bias Circuit Values for Various Drain Currents

V_{DD} (V)	V_{DS} (V)	I_D (mA)	R1 (Ω)	R2 (kΩ)	R3 (kΩ)
3.5	2.5	20	75	2.2	2.8
3.25	2.5	15	117	2.2	2.3
4.0	3.0	20	50	2.2	4.3

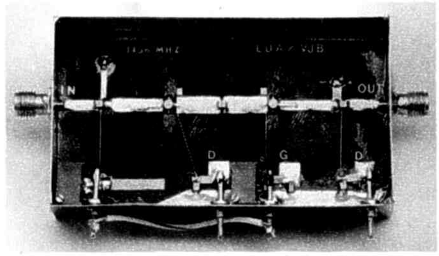

Fig 8—This prototype two-stage 3.4-GHz preamplifier was built by the author. The enclosure is made from sheet brass soldered to the PC board (see text).

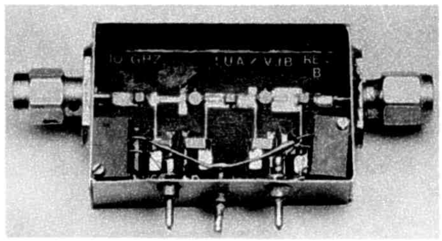

Fig 9—A completed two-stage 10-GHz preamplifier.

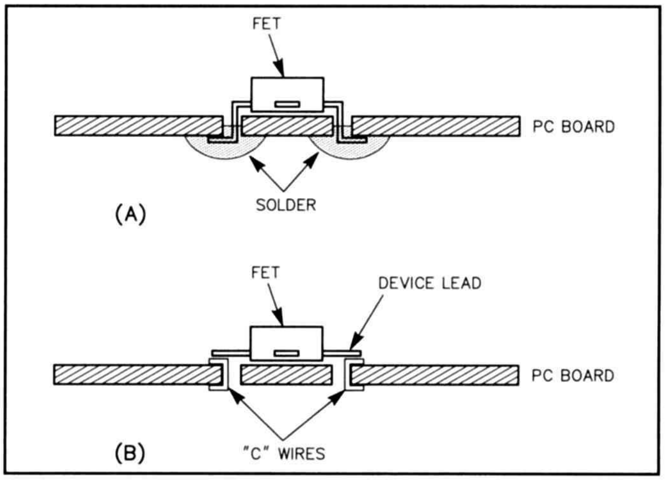

Fig 10—The ATF-10135 and -13135 FET source leads are bent, inserted through slots cut in the PC board, and soldered to the ground plane. The ATF-10136 and -13136 leads are not long enough to pass through the board, so you must add "C wires." See Fig 10B.

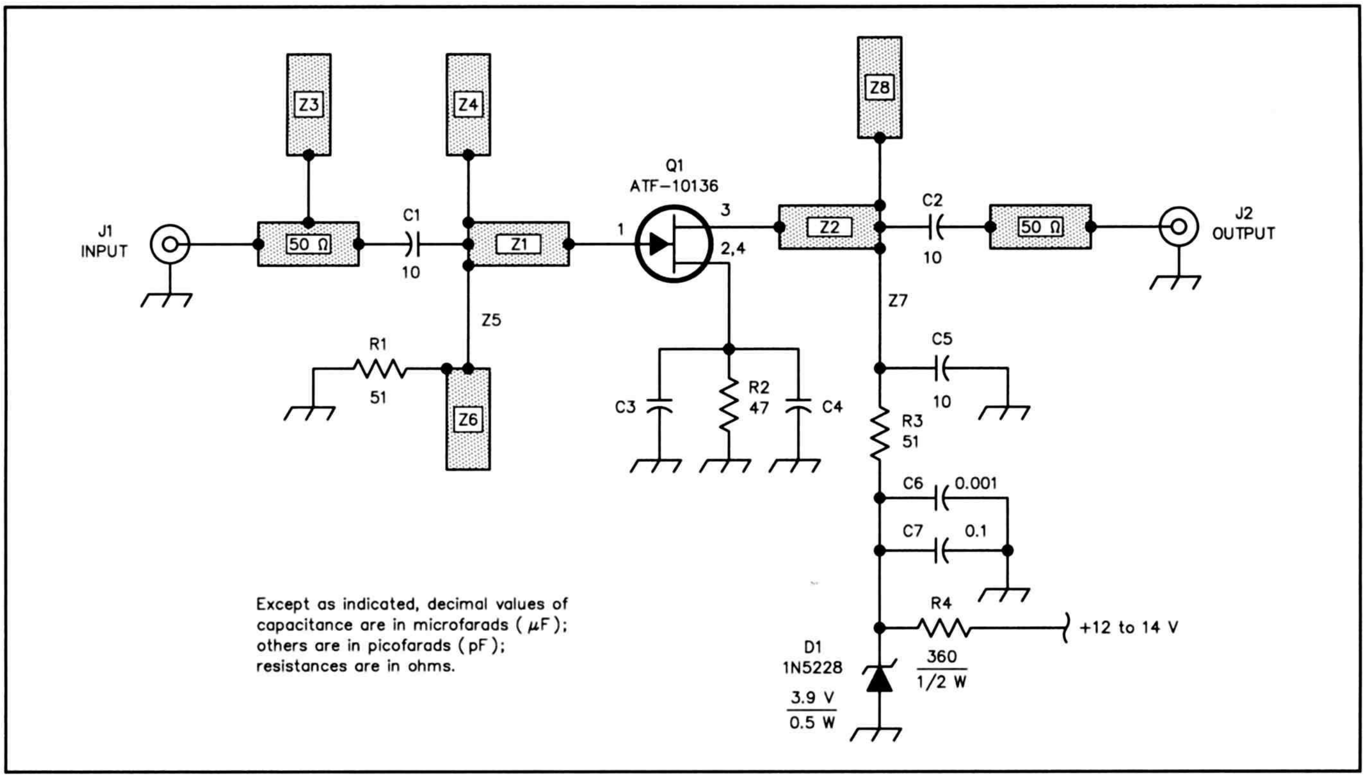

Fig 11—Schematic diagram of the self-biased version of the 2.3-GHz preamplifier. Z1 through Z8 are microstriplines etched on the PC board. Shaded rectangles marked "50-Ω" are 50-Ω transmission lines etched on the PC board. All capacitors are chip types.

C1, C2, C5—0.05- or 0.1-in. square chip capacitor.
C3, C4—470- or 1000-pF leadless, round, disc-ceramic capacitor (see text).
J1, J2—SMA female connectors (see text).
R1, R3—51-Ω chip resistor preferred; ¼-W carbon-film resistor with short leads should be okay.
R2—47-Ω ¼-W carbon-film resistor.

The slots can be made with a sharp hobby knife or something similar. Be sure to clean up the area where the leads will pass through the slots by removing any extra dielectric material or copper. The source leads should be passed through the board, again bent at right angles and laid neatly along the bottom foil. Solder them to the bottom ground plane and try to force the solder to cover the length of the slot if possible.

Device installation is different with the 2304-MHz preamplifier because additional source-lead inductance is required. This inductance is addedby making each FET source lead 0.07 inch long in the case of the ATF-10135, rather than grounding them with the minimum possible lead length. Ground pads have been established on the artwork, and these pads must be properly connected to the bottom ground plane. Cut slots near the edge of the two pads closest to Q1. Insert a 0.1-in.-wide copper strap through the slots and solder top and bottom. Each source lead is then 0.07 in. long when Q1 is centered on the PC board. For the short leaded ATF-10136, I would suggest adding an additional length of 0.020 inch wide copper foil to lengthen each source lead as required. The leads from an "old" transistor will work fine.

Components for these preamplifiers, including chip capacitors, leadless capacitors, chip resistors and SMA connectors are available from Microwave Components of Michigan and Down East Microwave. Etched PC boards are available from Down East Microwave.

Table 2

Actual Preamplifier Performance Versus Computer Simulation and Projected Worst-Case Performance

Device	*Freq (GHz)*	*Bias per device*	*Gain (dB) Type*	*Gain (dB) Worst Case*	*Gain (dB) Simul*	*Noise Figure (dB) Typ*	*Noise Figure (dB) Worst Case*	*Noise Figure (dB) Simul*
ATF-10136*	2.3	2 V @ 20 mA	13.5	12.0	13.9	0.5-0.6	0.8	0.60
ATF-10136**	2.3	2 V @ 20 mA	13.0	12.0	13.0	0.65	0.9	0.70
ATF-10136	3.4	2 V @ 20 mA	23.0	22.0	24.1	0.8-0.9	1.0	0.58
ATF-10136	5.7	2.5 V @ 15 mA	18.0	17.0	20.6	0.9-1.0	1.2	0.85
ATF-13136*	10.4	3 V @ 20 mA	8.5	7.5	10.6	1.25-1.5	1.7	1.25
ATF-13136	10.4	3 V @ 20 mA	18.0	15.0	21.9	1.5-1.7	2.0	1.35

*Single-stage amplifier
**Self-biased, single-stage amplifier

Results

If the preamplifiers are built according to the information given in this article, RF adjustments should not be required. A slight adjustment can be made to the bias point if desired, but performance should be very close to that shown in Table 2 with the bias conditions shown. Based on test results obtained from preamplifiers built by a number of hams using available components, the average builder should be able to meet the worst-case gain and NF specifications shown in Table 2. If slightly different dielectric material or construction techniques are used, the amplifier can be tuned by moving small capacitive tabs along the microstripline while monitoring NF and gain. A properly modified toothpick makes a handy low-loss tool for moving tabs around on the circuitry. Cut the end of a toothpick on a diagonal. Wet the end of the toothpick and use it to move small metal tabs around on the etch.

Applications

The 2304-MHz preamplifier provides acceptable receive performance in the 2401-MHz OSCAR band with no modification. The NF at 2401 MHz should be only 0.1 or 0.2 dB greater than that obtainable at 2304 MHz, and LNA gain at both frequencies should agree to within a dB. Using a pair of these preamplifiers at the feed of my 2401-MHz satellite system, I see about 5 dB of sun noise and 10 to 15 dB of signal-to-noise ratio from the Mode S transponder aboard OSCAR 13. My antenna is a 4-foot diameter UHF TV dish with ¼-inch mesh.

A similar two-stage 2304-MHz preamplifier is in use at the feed of my 24-foot home-brew stressed parabolic reflector. The measured NF of this preamp is 0.65 dB. With this system, I have worked W3IWI/8, SK6WM, OE9XXI and W4HHK on 2304-MHz EME.

Variations

In the original design, source leads were grounded directly to obtain the lowest possible noise figure. This necessitates the use of a dual-polarity supply as discussed earlier. The typical approach at VHF is to self-bias the FET by using a resistor connected in series between the source and ground. A capacitor is used to bypass the resistor at RF. As the frequency of operation increases, it becomes increasingly difficult to obtain high-quality, low-impedance bypassing. Although the self-biasing technique is simpler to build and uses a single power supply, some RF performance is sacrificed.

I evaluated self-biased versions with the help of the computer, and several prototypes were built and tested. The artwork was modified to include 0.075-in.-square pads to mount the FET source leads. Chip capacitors were then bridged between these pads and a ground pad. The ground pad was then connected to the back ground plane by using 0.1-in.-wide ribbons through the board. This technique was tried on all preamplifiers except the 10-GHz models. With this configuration, the preamp NF at 2304 and 3456 MHz was 0.2 to 0.25 dB greater than that of the grounded-source design. The gain of the 2304-MHz model decreased approximately 2 dB, while gain of the 3456-MHz model was reduced by slightly more than 3 dB. At 5760 MHz, performance deteriorated even further: NF increased by 0.8 dB, and gain decreased by 6 dB.

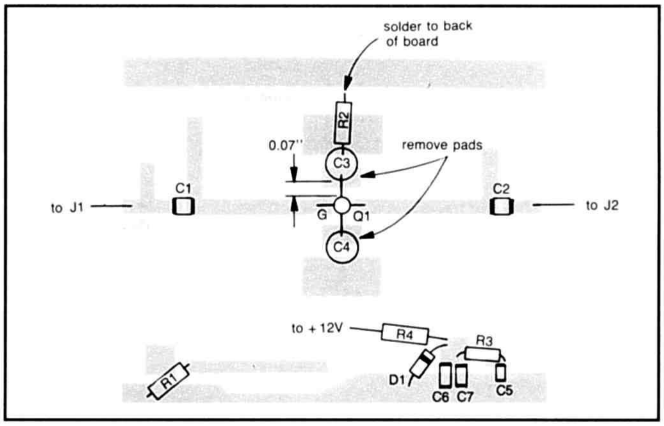

Fig 12—Part-placement guide for the self-biased 2.3-GHz preamplifier. The etching pattern is the same as shown in Fig 7, except two pads are removed and Z3 must be lengthened. See text.

A computer simulation predicted similar results. In addition, the computer simulation indicated an oscillation in the 7- to 8-GHz range for all models. Apparently, the inductance associated with the addition of the chip capacitors, associated mounting pads, and ribbon ground returns is great enough to cause instability at higher frequencies.

In looking for a way to avoid this oscillation, I tried using leadless round disc capacitors to bypass the source leads. I soldered the FET leads directly to the capacitors and soldered the capacitors to the bottom side of the PC board. This technique was tried on the 2304-MHz preamplifier; see Fig 12.

The bypassed-source 2304-MHz preamplifier uses the same artwork shown in Fig 7 for the grounded-source version. You'll need to make one change to the artwork, though. The input stub (Z3 of Fig 11) must be made slightly longer (increase its length from 0.22 to 0.38 in.) to help tune out the effect of the source bypass capacitors. Z3 can be extended by soldering a piece of copper foil to the end of the etched line. To mount C3 and C4, the source bypass capacitors, drill holes the diameter of the capacitors through the PC board as shown. See Fig 13, a photograph of the finished unit. Be sure to place the holes so that the FET source leads are 0.070 in. long when Q1 is centered between Z1 and Z2. Solder a brass or copper sheet across the holes on the ground-plane side, and solder one side of C3 and C4 to the sheet. Then solder the Q1 source leads to the tops of C3 and C4.

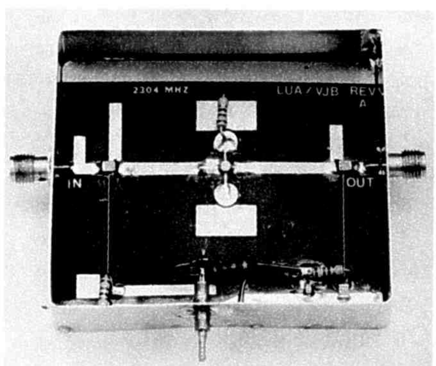

Fig 13—The prototype self-biased 2.3-GHz preamplifier. The large rectangular pads near C3 and C4 are not needed and were dropped from the final artwork.

According to the computer simulation, this technique yields unconditional stability in the 7- to 8-GHz range. The overall stability of a preamp built in this way is comparable to the grounded-source design. The *measured* performance of this configuration is good too. Compared to the grounded-source model, the gain of the bypassed-source LNA is within 1 dB, and the NF is within 0.1 dB, of that obtained with the grounded-source configuration—and no stability problems are evident. This technique is suggested for the 2304-MHz model only.

Although the preamplifier circuits are designed for minimum noise figure, the ATF-10136 and the ATF-13136 devices are capable of producing moderate power at microwave frequencies. When biased at 4 V and 70 mA, the ATF-10136 is capable of producing 20 dBm (100 mW)—operating at its 1-dB gain-compression point—at 4 GHz. Slightly less power can be expected at 5.7 GHz. At 12 GHz, the ATF-13136 is capable of producing 17 dBm at its 1-dBm gain-compression point when biased at 4 V and 40 mA.

Summary

Any one of these amplifiers can be constructed easily in an evening. They offer low noise figure, acceptable gain, good input and output SWR, and good stability. Several dozen of them are already in use nationwide with good results. Copies of the 10.368-GHz preamplifiers, for instance, were used by WA5VJB and WA7CJO to make the first-ever 10-GHz EME QSO!

Microwave LNA Update

By Al Ward, WB5LUA

(From *Proceedings of Microwave Update '89*)

Hewlett-Packard has a series of low-noise plastic FETs that use the same die as the ATF-13136, a 250-micron Ku-band low-noise FET. Although the S parameters and noise parameters are somewhat different from the ATF-10135 device, I decided to try the ATF-13484 in the 2.3-GHz LNA described in *QST* for May 1989.[1] With a slight amount of rebiasing and a slight extension of the first input stub, I was able to achieve a 0.85-dB noise figure with an associated gain of 15.6 dB at 2.4 GHz. The device should provide nice performance in A0-13 Mode-S operation. A schematic is shown in Fig 1.

Shortly after I published the *QST* article, my company made the decision to supply only the short-leaded ATF-10136 and ATF-13136. The use of automated assembly lines with pick-and-place machines created the need to buy the devices with precut leads, ie, 0.040 in. vs 0.177 in.

Unfortunately, in amateur applications where plated through holes are a luxury item, the shorter lead parts can not be mounted as easily. The original article suggested the use of "C wires" as one means of grounding the source leads on the short-leaded devices. I decided to try using small rivets as an alternative. With the help of Downeast Microwave, I built up two more 10-GHz LNAs using very small tin plated brass rivets (0.050-in. diameter). The center-to-center spacing of the rivets was 0.160 in. I had to be careful that the rivets did not touch the adjacent matching networks. The ATF-13136 device (with 0.040-in. leads) was then centered between the rivets and the input and output matching networks. Noise fig-

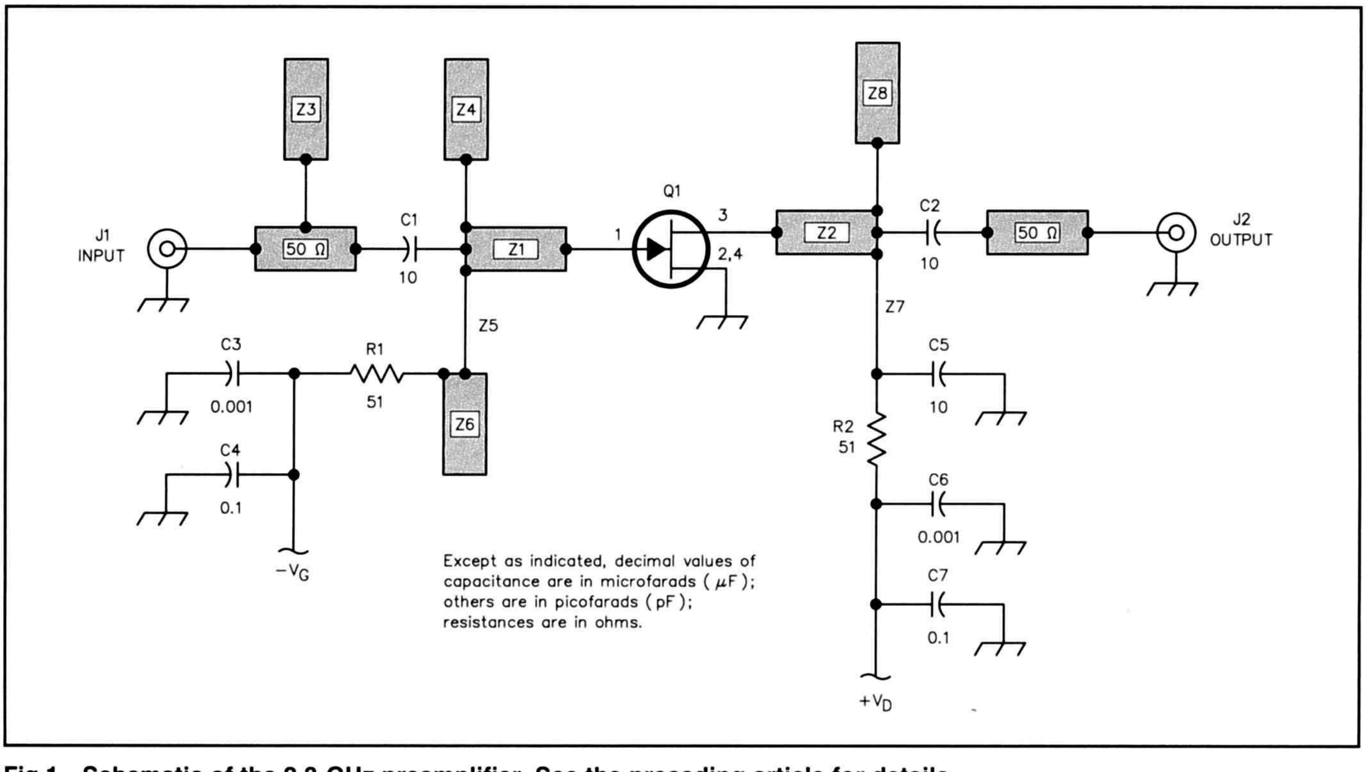

Fig 1—Schematic of the 2.3-GHz preamplifier. See the preceding article for details.

ure and gain performance of both the single and dual stage LNAs was comparable to the typical values shown in the original article.

On the prototype boards, I installed the rivets from the front, and used a small hammer to flatten them out on the back. I then soldered them to the ground plane. As it turned out, the flattened area appeared smaller in diameter than the face of the rivet, so it might have been better to install the rivets from the back. Whatever technique you use, just make sure that they don't touch the etched circuits. Rivets of all sizes are available from International Eyelets, Inc, at 1-800-333-9353.

Note

[1]A. Ward, "Simple Low-Noise Microwave Preamplifiers for 2.3 Through 10 GHz," May 1989 *QST*, pp 31-36, 75 (reprinted in this chapter).

GaAsFET and HEMT Amplifiers for 24 GHz

By Tom Hill, WA3RMX

(From *Proceedings of Microwave Update '91*)

Introduction

Amateur projects using GaAsFETs at 24 GHz are fairly rare.[1,2] There is a fundamental device-technology reason for this. The available (within reasonable cost) packages that the manufacturers put their FET die into, are just not suitable much beyond 18 GHz. There are resonances in the package itself, and worse, even with automated wire-bonding equipment the parts still have so much variation between individual units that they cannot publish specifications at these frequencies. In professional designs, this is overcome by using the naked FET die and ceramic hybrid technology with gold wire-bonding. This technology is still out of reach even for the "above average" microwave experimenter.

This paper describes the steps I went through to build several amplifiers using packaged FETs that are not specified above 18 GHz. While this procedure can be used as a guideline for your efforts, it is not an exact plan for construction.

Project Plan

Active Devices

The goal is to find parts that are as low cost (we *are* on an amateur budget) as possible while having some chance of performance at 24 GHz. I used NE04583, NE32083, and ATF35176. The first is a 0.3-micron surplus MESFET, while the other two are low-cost HEMT parts. All of these are packaged parts with die that have basic performance well above 18 GHz. There are several other parts available today that look quite promising, but I have not yet tried them.

Materials

The first and most far-reaching decision to make, is how to implement the interstage tuning networks, and what board material to use. The problem is that with the impedances unknown in advance, the form of the network is also mostly unknown. Each interstage network will be custom built as the amplifier is tuned up. Moreover, since the individual FETs are so different, an etched board with a copy of the first network discovered to work will likely fail miserably when the next FET is installed. Each amplifier will likely require a large amount of retuning to get the best results. The easiest topology to allow this much tweaking without too much damage is a straight 50-ohm line with a length sufficient to allow both shunt inductive straps and shunt capacitive copper tape "snowflakes" to be moved back and forth along the line until improvement is obtained. If 10-mil thick Duroid material is used, this provides for a 50-Ω line width that is almost the same width as the FET gate and drain leads. This is quite convenient for construction. The Duroid also has fairly low loss at these frequencies. Fortunately we do not need a broadband amplifier in this application, so we can simply tune for maximum at 24.192 GHz, which is relatively easy with this topology.

Bias

The second problem is the bias injection scheme. First I wanted a technique that allows the source of the FET to be directly connected to the ground plane. I also wanted a feed-back bias that will keep current constant as temperature changes. The so-called "PNP Wrap-Around" bias circuit satisfied all these needs. See Fig 1 for the schematic of the 3-stage NE045 amplifier. Fig 2 is the schematic of the 2-stage ATF351 amp.

Next I wanted a scheme that didn't need really good inductors and bypass capacitors that work well at 24 GHz. The solution that I chose is to segment the top-side ground plane into islands that have the gate and source bias on them. These fairly large areas of ground plane are quite effective for bypassing at frequencies above a few GHz. For the lower frequencies, the gaps between these ground planes are bridged with many chip capacitors. I alternate between several values of capacitor to try to avoid a resonance at some particular VHF.

Power Supply

The power supply includes the standard automatic switch that allows the drain voltage to be applied only if the gate bias is present. This keeps the drain current from becoming excessive during turn-on and turn-off transients.

I chose +7 and –5 volts, as these voltages were already required by the 6-GHz IF amplifier in my system. You may change the basic supply voltages if necessary, as long as the actual FET bias conditions are provided for.

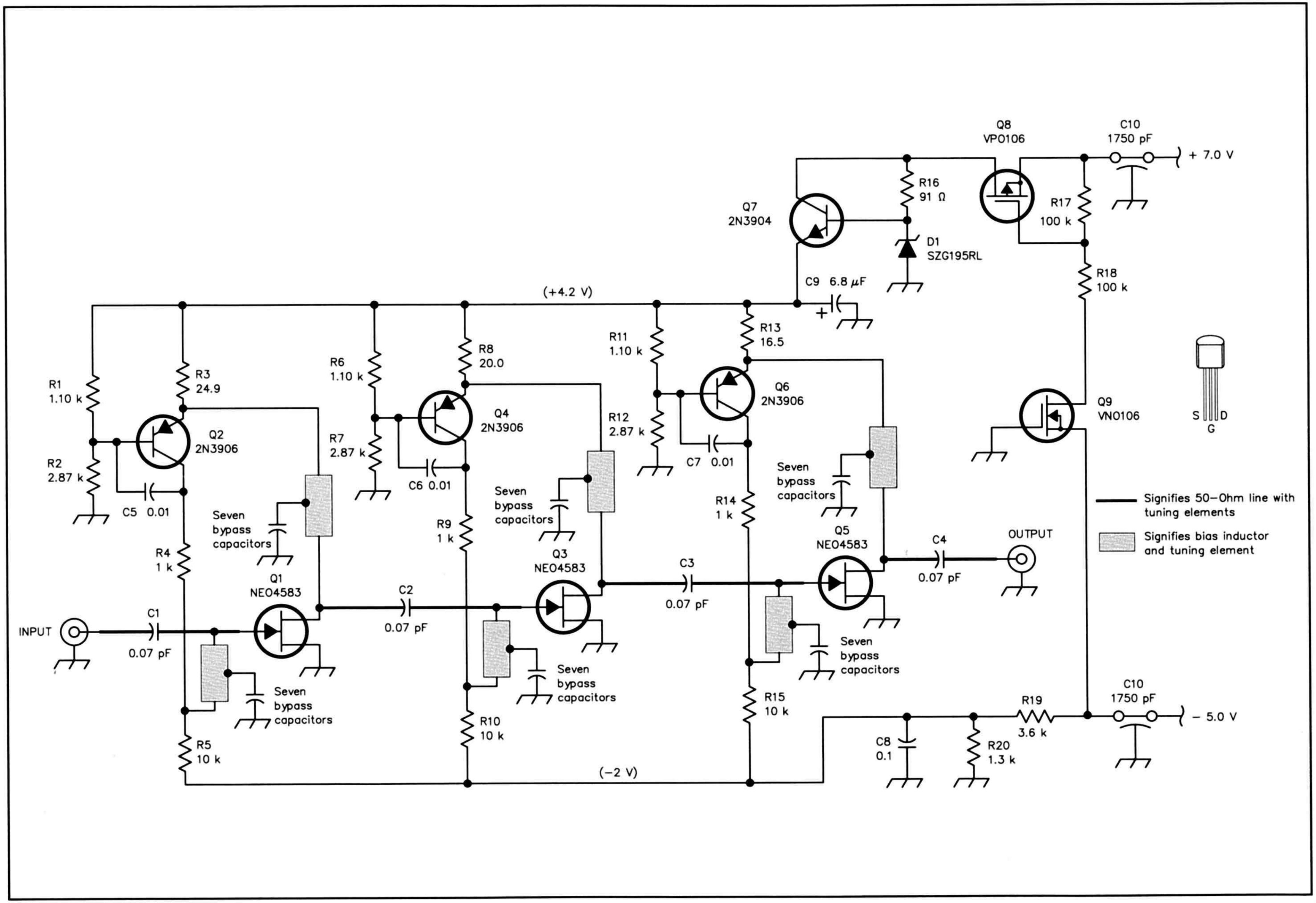

Fig 1—Schematic diagram of the second NE045 amplifier. Resistors are ¼-W carbon-film.

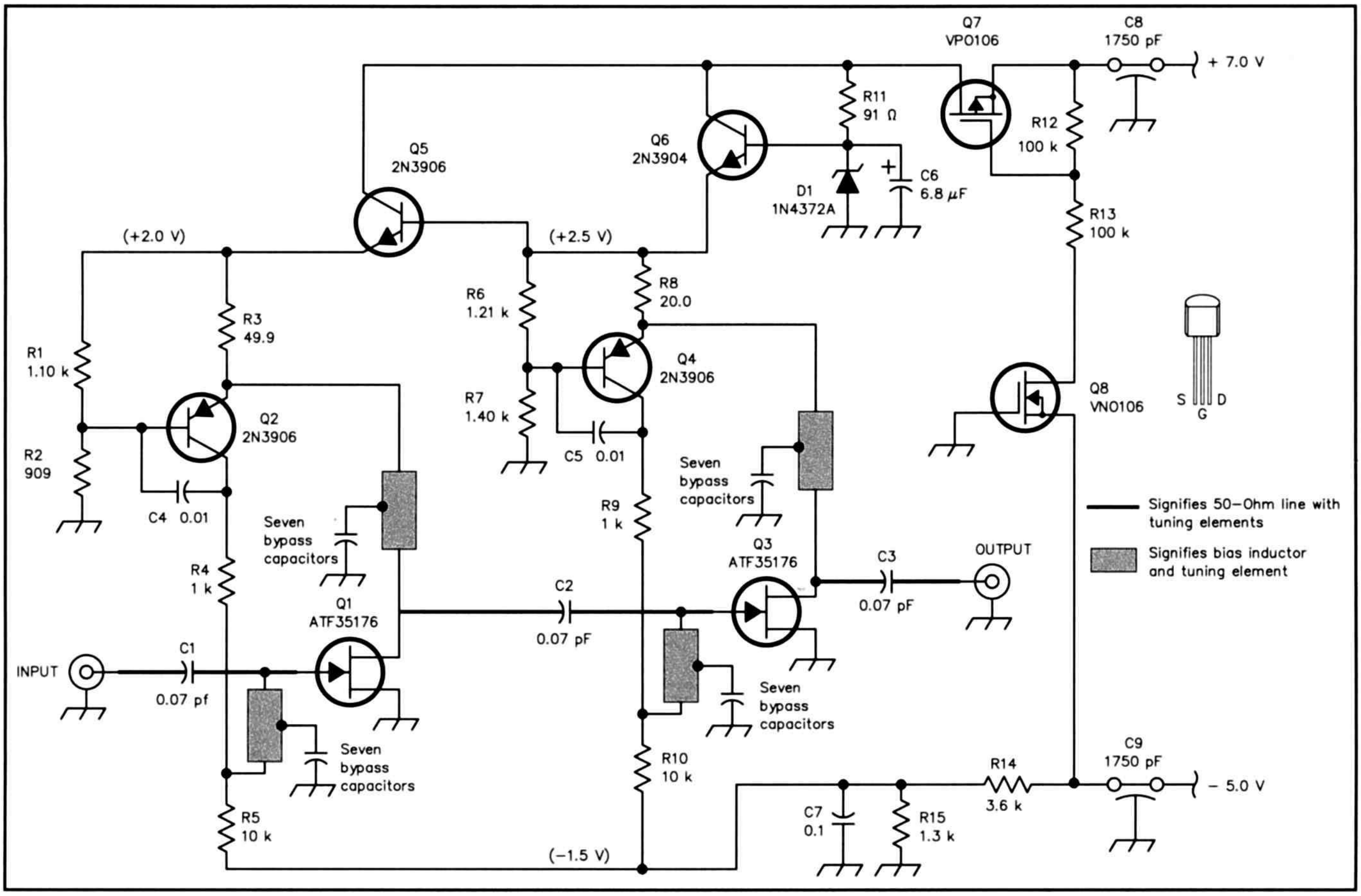

Fig 2—Schematic diagram of the ATF351 amplifier. Resistors are ¼-W carbon-film.

RF Connections

In my transverter[3] I use coax to connect the amplifiers. This adds yet another problem, since the readily available SMA connectors are usually good only up to 12 or 18 GHz. One solution that I have used quite successfully in the past (and what I still used here for the male SMA cables between the amplifiers), is to individually test each connector. I have usually found 20 percent or so of the random connectors obtained surplus will have a severe notch at 22 or 23 GHz with good operation again occurring at 24.2 GHz. For this project I was able to find some surplus female Wiltron "K" connectors. This eliminated one variable from the big list of unknowns, as these connectors are good to 40 GHz, and they mate to standard SMA connectors.

Packaging

For the package I chose a small drawn brass box. I added some microwave absorber material in the top and bottom of the box to eliminate resonances. I don't think that the box is likely very critical to the final outcome of this project.

Construction Procedure

ECB

Since the RF part of the board is really quite simple, I chose to make the boards individually instead of creating filmwork and using photoresist on each board. I simply put plater's tape on the copper where I wanted it to remain. The etchant removes the small areas left. The top-side pattern I used is shown in Fig 3. The bottom ground plane is solid copper.

My calculations determined that a 50-Ω line requires a copper width of approximately 29.7 mils. I rounded this off to 30 mils wide. The gaps in the line that allow for mounting the coupling capacitors are made about 10 mils wide so as to fit as closely as possible the Duroid capacitors' thickness. The packaged FETs have 70 mils between the leads, so that is the width of the space left for them. The line length of 0.3 inches between each adjacent component leaves plenty of room for the tuning elements to be soldered on and moved around.

Capacitors

Very few chip capacitors that can be soldered to circuit boards perform well enough at 24 GHz to serve as coupling caps. I used small pieces of the same Duroid circuit board material as coupling capacitors. A small rectangular piece 0.040×0.030 in. (with copper on both sides) is soldered standing up across each of the small gaps in the transmission line in between each of the FETs as well as at the input and output of the amplifier. These form approximately 0.07-pF capacitors, which have excellent performance that I have tested beyond 30 GHz. While soldering these in place, you should ensure that the solder fillet fully wets the capacitor and the transmission line, so that there are no gaps that can create a notch filter in the middle of your amp.

The bias islands are bypassed with alternating 7 pF and

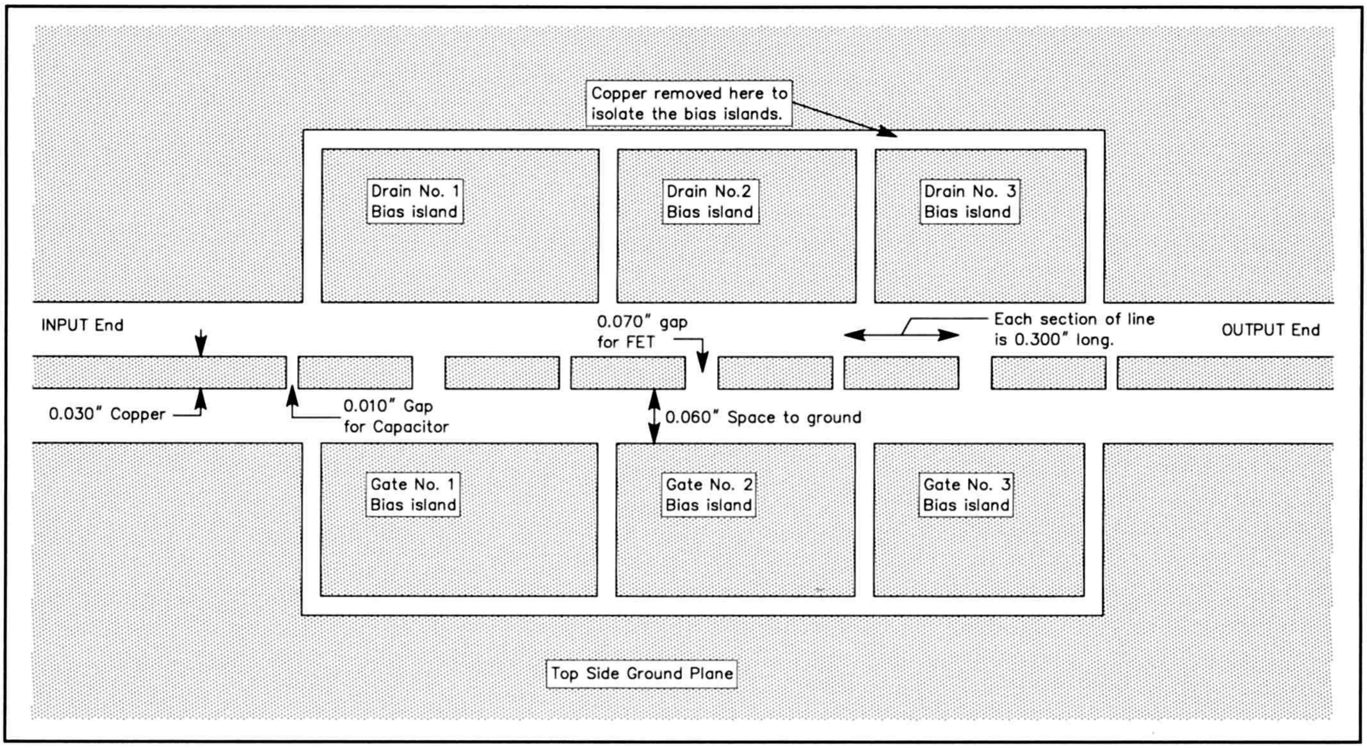

Fig 3—Circuit-board layout for the 3-FET amplifier.

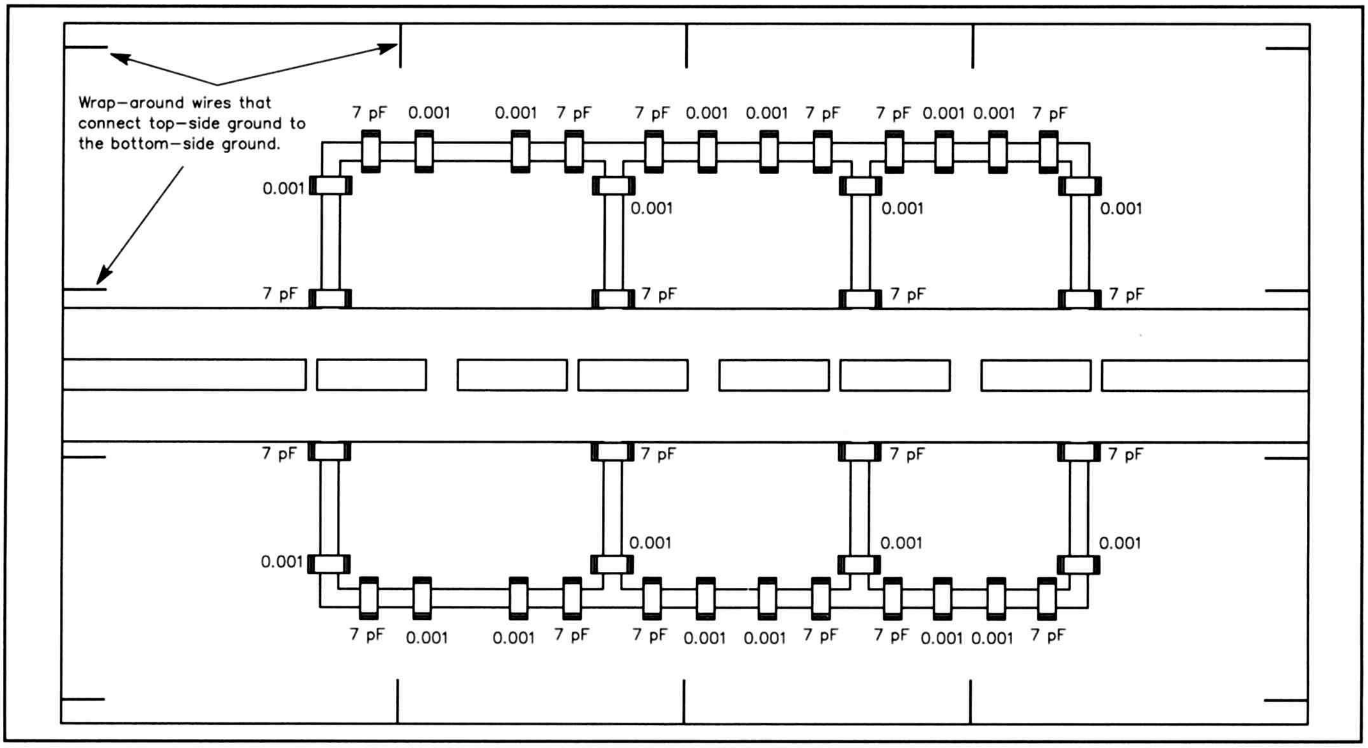

Fig 4—Capacitor locations for the 3-FET amplifier.

1000 pF chip capacitors. For the three-stage amp this is a total of 20 of each value capacitor. See Fig 4 for placement of these.

Grounding

The top-side ground planes must be connected to the bottom-side plane. I put a few straps of small wire around the edges to accomplish this. Particularly important is the edge of the top plane right next to the coax connection (there are four places total like that). These wires are also shown in Fig 4.

FET Testing

I chose to dc test each FET before installation. This is because there is a considerable variation in I_{DSS} between individual FETS of the same type number. I wanted the highest I_{DSS}

parts to be in the output stages. This allows the maximum output power possible. Also this testing allows setting the bias of each stage to be optimized for its particular function. The input stage is biased for low noise, while the output stage is biased for maximum power output. I chose 50% or less of I_{DSS} for the low noise stage, and about 80% of I_{DSS} for the output stage.

This testing also gave me the chance to select the NE045 FETs for the highest I_{DSS} amongst the ones I had available. This will allow for the highest possible output power from the amplifier. See Table 1 for the bias conditions I set for several different amplifiers after I measured the I_{DSS} of the FETs that I planned to use.

FET Installation

After all of the coupling and bypass capacitors have been installed, it is time to mount the FETs. I cannot stress too hard the desirability of good static precautions. I soldered a 2-in, piece of bare wire-wrap wire to ground, and then tacked it to both of the drain bias islands. This grounds them, and will remain in place until the amp is ready to be tested. Another such grounding wire is soldered to the gate bias islands.

Next I used a no. 48 drill (0.076-in.) to put a hole in the center of each area where a FET will be placed. I did this drilling by hand, with a backup piece of wood, to avoid distorting the board. Then I used a small razor-sharp knife to enlarge the sides of the holes where the source leads will be.

The FETS themselves are installed by bending the source leads down and poking them through the hole in the board. These leads are then bent back straight, which will now slightly distort the board. The 10-mil Duroid is soft enough that the FET leads will lift up the board so that the ground plane in fact rises up to go over the top of the source leads. Now the FETs can be soldered in. Be careful not to get solder bridged to the gate or drain leads while soldering the source leads, as they are just barely visible through the hole in the board.

When the gate and drain leads are soldered, extra care must be used to ensure that solder is wicked up between the leads and the ECB runs. If any space is left here at all, a choke will be formed at some frequency that may well be near where you want this amp to work. Even a few mils can be a disaster.

Bias Circuits

I built the bias circuits by simply soldering the components to each other in the air. This particular circuit lends itself well to this method of construction, especially with the bias islands available as mounting pads.

Connectors

After the bias circuits are done, the last parts needed are the connectors. I waited until last to install these as the junction to the ECB is relatively fragile with my style of mounting. I simply butted the 0.047-in. diameter coax from the connectors directly to the edge of the ECB with the center conductor overlapping the copper run. The shield has a large lump of solder bridging to the ground plane. See Fig 5.

Install Board

The board is installed in the box AFTER initial tune-up. This allows the board to be laid on a solid back-up block so that the board is not bent or otherwise distorted while the tune-up is being done.

Table 1
Prototype Bias Settings

	First FET			Second FET			Third FET		
	I_{DSS}	I_D	V_D	I_{DSS}	I_D	V_D	I_{DSS}	I_D	V_D
NE045 #1	22	10	3.5	25	20	3.5	29	20	
NE045 #2	32	20	3.5	34	20	3.5	37	30	3.5
NE32 #1	28	20	2.2	37	25	2.2			
NE320 #2	31	20	2.2	32	25	2.2			
ATF351 #1	17	10	1.5	45	30	2.0			

Tune-Up Procedure

Equipment

I used a Wiltron 360 network analyzer which is really nice and produced the frequency response plots shown here. However, since we really only care about the one frequency, the job can actually be done with the transverter as RF source and a power meter as the indicator. In fact this is how I did the final max-power tune-up. I used an HP 8970A noise-figure meter with my own diode noise head (calibrated to a waveguide noise tube) to test the noise figure. If you are only going for the best you can get, without necessarily knowing just exactly what the number is, you can use a fluorescent light bulb in front of your dish, and a scope on your receiver output for the tuning job.

The worst problem you can really get hung up on is stability. If the amplifier oscillates it can be hard to identify and fix the cause. Certainly, if the power meter reads a bunch out with no input applied, this usually signifies oscillations. Also, an unstable gain or noise figure, particularly when a hand is brought within an inch or so of the board, is another sign of oscillation. When I found these problems, I looked for the part of the RF circuit where I could stop the problems most easily with a light touch of a finger or small piece of microwave absorber material. I then worked on changing the tuning elements in this area until the oscillations went away, before continuing the tune-up procedure.

Adding, Removing, Moving Bias Inductors

Now you may remove those shorting wires and apply dc power. After verifying proper dc operation, and taming any oscillations that might be found, you can start tune-up. With some drive power applied I first found the gain to be about −15 dB or so. That's right! A LOSS of 15 dB.

Don't worry yet; we still have a long road to travel. I first made small (20 mils at a time or less) changes in the positioning of one end at a time of the small wires that connect the bias islands to the gate and drain connections of the FETs. I also sometimes added or removed some of these straps in parallel maybe 100 mils or so away from an existing one. Often these changes might only make 0.1-dB change at a time. I usually got the gain up to maybe +1 to 4 dB with these wires.

Adding Copper "Snowflakes"

I next took a very small sliver of insulator (I used alu-

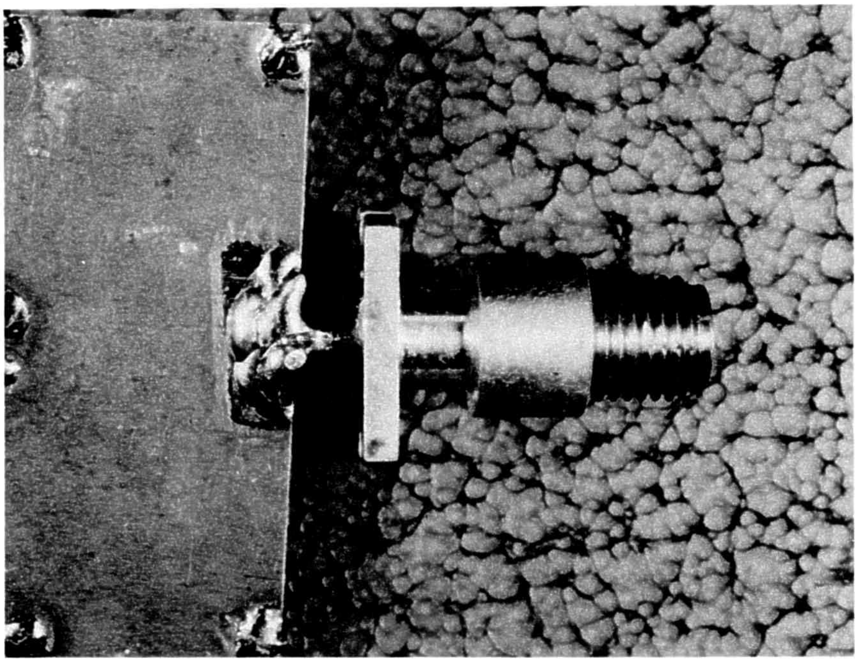

Fig 5—Installation of coax to the board. See text.

mina) with a small piece of metal (about 20 mils square) on the end to find the places on the transmission line where a bit of capacitance will help. I slid the metal end back and forth on the line until an improvement was noted. Then I would solder on a small bit of thin copper tape in that spot. Now recheck for the same result as the wand. Now continue the process. This would result in another 10 dB or so of added gain. Then another round of fun with the small wires will produce some small improvement. It will probably take three or four cycles between the wires and the copper pieces to get the gain optimized. The first time I did this it took 8 hours or so. I also got over 15 dB of gain as a reward!

Maximum Power Output Procedure

Since these FETs are run on really low current and voltage, they really compress at very low power out. To maximize the power out the tuneup must be redone with as much power out as the amp can manage without more than about 3 or 5 dB of compression. Now tune the output matching section to get best power out. This is only needed if you plan to use this particular amp for transmitting.

Low-Noise Procedure

If this amp is to be used as the input of your receiver, a tune-up for lowest noise will be needed. To do this you will put the amp into your test setup for noise, and tune the input network for best noise figure. You may also need to tune some on the first interstate network, but go easy here. The input stage is the major noise source, and the interstate more affects gain. I got about a 2-dB improvement in noise figure by this procedure. Recheck gain and power output when you are done here.

My first amplifier took about 11 hours total of tune-up time to get to final completion. The last one has taken about 4 hours. So it does get easier with a bit of experience.

My Results

I have built 5 units so far. Two with a 3-stage NE045 amp, two with a 2-stage NE320 amp, and one with a 2-stage ATF351 amp. All of these have showed excellent results. The gain of NE045 amp number 2 is just a bit better than the first one, by about 4 dB. The bandwidth is quite narrow, but this has not proven to be a problem. In fact it may well be able to double as the 24-GHz filter as well. All of the amplifiers are reasonably similar in basic performance after the tune-up marathon.

It would be advisable to be aware that there is lots of gain at some lower frequencies in addition to the intended ones.

The NE045 amp was optimized for max power out. One-dB compression occurred with a drive level of –4.5 dBm. I get a good solid 10 mW out of this unit. The others use weaker parts, and consequently get less power out. The ATF35176 produces about 6.5 mW, and the NE320 manages just 1 mW.

Noise

All of the amplifiers have performed surprisingly well even when tuned solely for maximum gain or maximum power out. The NE045 amps have 7- or 8-dB noise figure. The NE320 (still tuned for max gain) has 5.5-dB noise figure. The ATF351 achieved just under 5 dB, so it is the one that I chose to retune for optimum noise figure. With another hour of tuning time, I got it down to 3.5 dB! This is really quite respectable for 24 GHz.

Summary

My transverter now has two of these amplifiers in cascade. The input is a 2-stage NE320 unit. The second unit is a 3-stage NE045 amplifier. The result is an amp with 30-dB gain, 5.5-dB noise figure, and 8-mW output power. I am also putting the ATF351 amp at the dish to get 3.5-dB noise figure at the dish. The ATF35176 amp, combined with a 2.5-W TWT amp makes a really high-performance SSB/CW station.

Notes

[1]M. Kuhne, DB6NT, "GaAsFET Amplifier," *DUBUS*, Jan 1988.

[2]T. Takamizawa, JE1AAH, "HEMT Amplifier," *DUBUS*, Feb 1991.

[3]T. Hill, "SSB/CW Equipment Concepts for 24 and 47 GHz," *Proceedings of Microwave Update '89*, pp 39-62. This amplifier has now been added to that unit.

A 2.5-Watt Linear Amplifier for 2304 MHz

By Dave Mascaro, WA3JUF

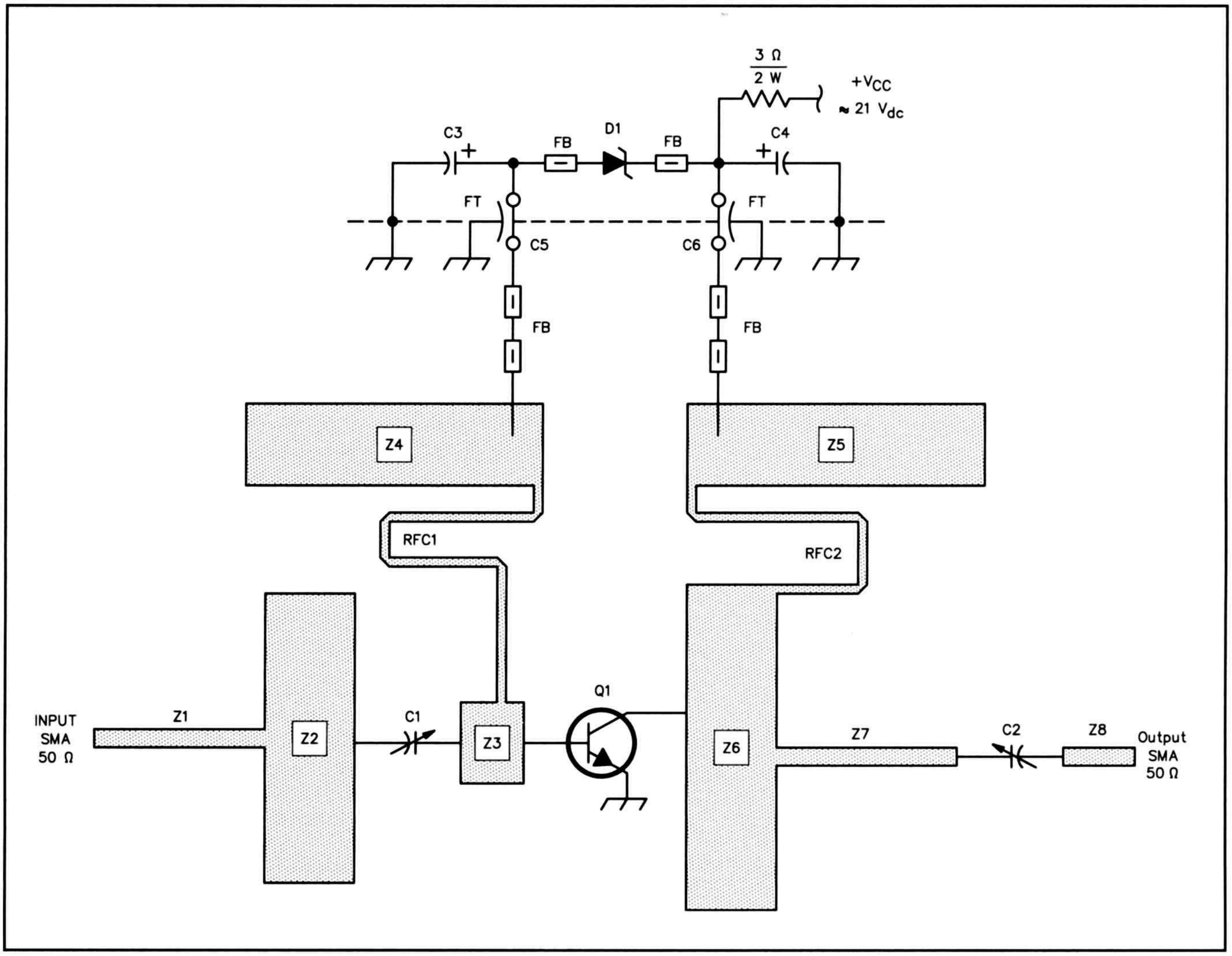

Fig 1—Schematic of the 2.5-W 2304-MHz linear amplifier.

C1, C2—3-pF Johanson Gigi-trim capacitor.
C3—10-µF, 6-V dc electrolytic.
C4—10-µF, 35-V dc electrolytic.
C5, C6—0.001-µF feedthrough capacitor, Spectrum Control SCI 729-303 (series resonant).
D1—20-V, 1-W Zener diode, 1N4747A or equiv.
Q1—Thomson CSF TCC 20 L 25 (SD1855) transistor.
RFC1, RFC2—Microstrip choke, 0.035-in- × 1.10 in.
Z1, Z8—50-Ω microstrip line, 0.080-in. wide.
Z2—0.2 × 0.65-in. microstrip line.
Z3—0.25 × 0.30-in. microstrip line.
Z4, Z5—RF short, 0.275 × 1.0 in.
Z6—0.25- × 0.675-in. microstrip line.
Z7—0.080- × 0.65-in. microstrip line.

This amplifier uses a Thomson TCC 20 L 25 transistor to provide about 2.5 W on the 13-cm band. Drive requirement is about 990 mW. The amplifier operates in Class A. I built the amplifier on 1/32-in. Teflon double-sided PC board. The microstrip circuitry can be etched using Exacto-Edge as I did, or by either negative or positive photo methods.

I milled out a brass carrier and sweat soldered the PC board to the brass. PC-board construction can be used with similar results. You can build a housing from double-sided G-10 PC board, by soldering 4 walls to the microstrip PC board to form a box. Solder the connectors to the ground plane side of the board, with the center pins going through the board and soldered to the 50-Ω input and output lines. Alternately, the connectors could be mounted in the end-launcher method. The connectors are soldered to the side walls of the box, with the center pins soldered to the microstrip input and output lines.

As with all amplifiers, this one needs good RF grounds and power-supply decoupling. You must install ferrite beads where indicated in Fig 1. All excess copper should be etched off the PC board to minimize the effects of RF propagation across the board.

The collector voltage should be about 21-V dc. It is supplied through a 317 three-terminal voltage regulator IC. Adjust the voltage until idling current reaches about 350-400 mA. Idling current value is not critical. You can readjust it for maximum power output after the amplifier is tuned up.

Alignment

Use a razor knife to trim the size of Z6, while simultaneously adjusting C2 for maximum output. Make a straight cut across the foil, but don't remove the excess. If necessary, you can bridge the gap with solder to restore the length. Trim the size of Z2 in the same way, and adjust C1 for best input return loss. If possible, inspect the amplifier with a spectrum analyzer to ensure it is stable.