Simple Low-Noise Microwave Preamplifiers

These preamplifiers cover the 2.3- to 10-GHz ham bands. They offer good performance, yet require no RF alignment!

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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.

This article describes the design and construction of low-noise amplifiers (LNAs) for 2.3, 3.4, 5.7 and 10 GHz. If the 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!

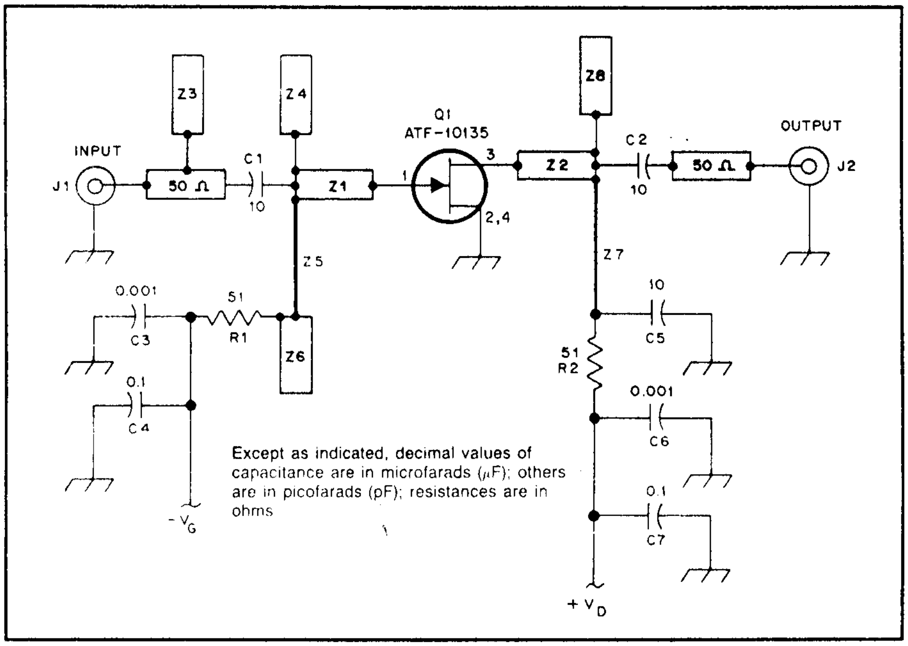


Fig 1—Schematic of the 2.3-GHz preamplifier. Z1 through Z8 are microstriplines etched on the PC board. Shaded rectangles marked "50 Ω" are 50-Ω transmission lines etched on the PC board. All resistors and capacitors are chip types. C1, C2 and C5 can be 0.05- or 0.1-in. square. C4 and C7 enhance "low-frequency"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

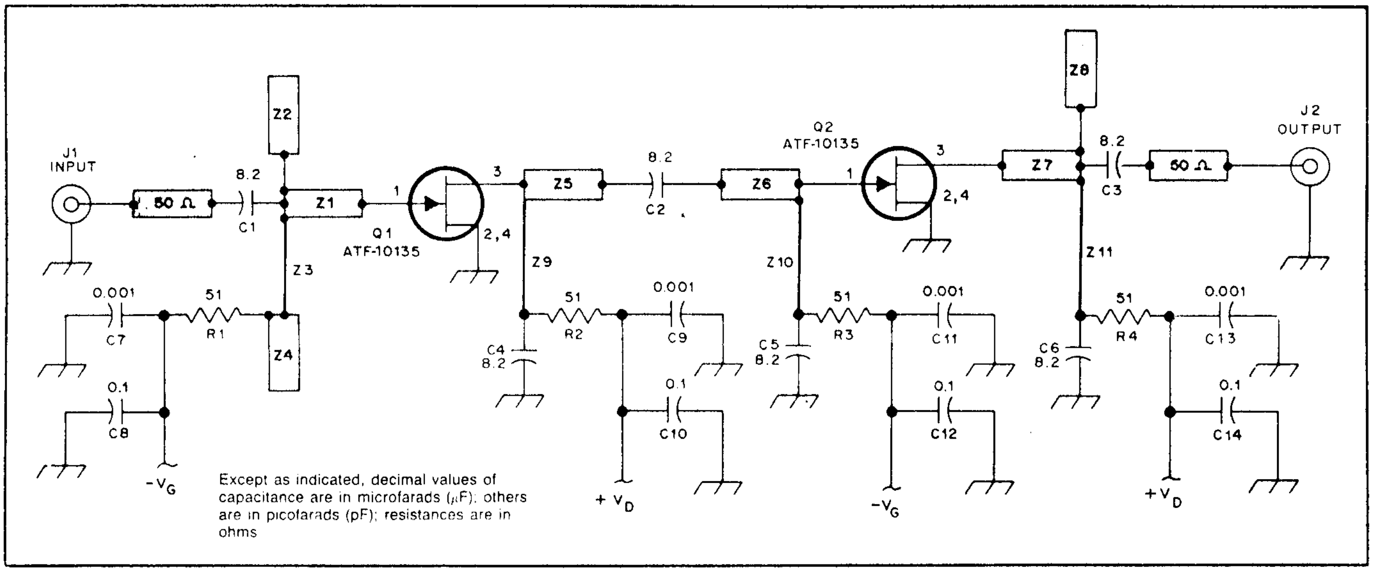
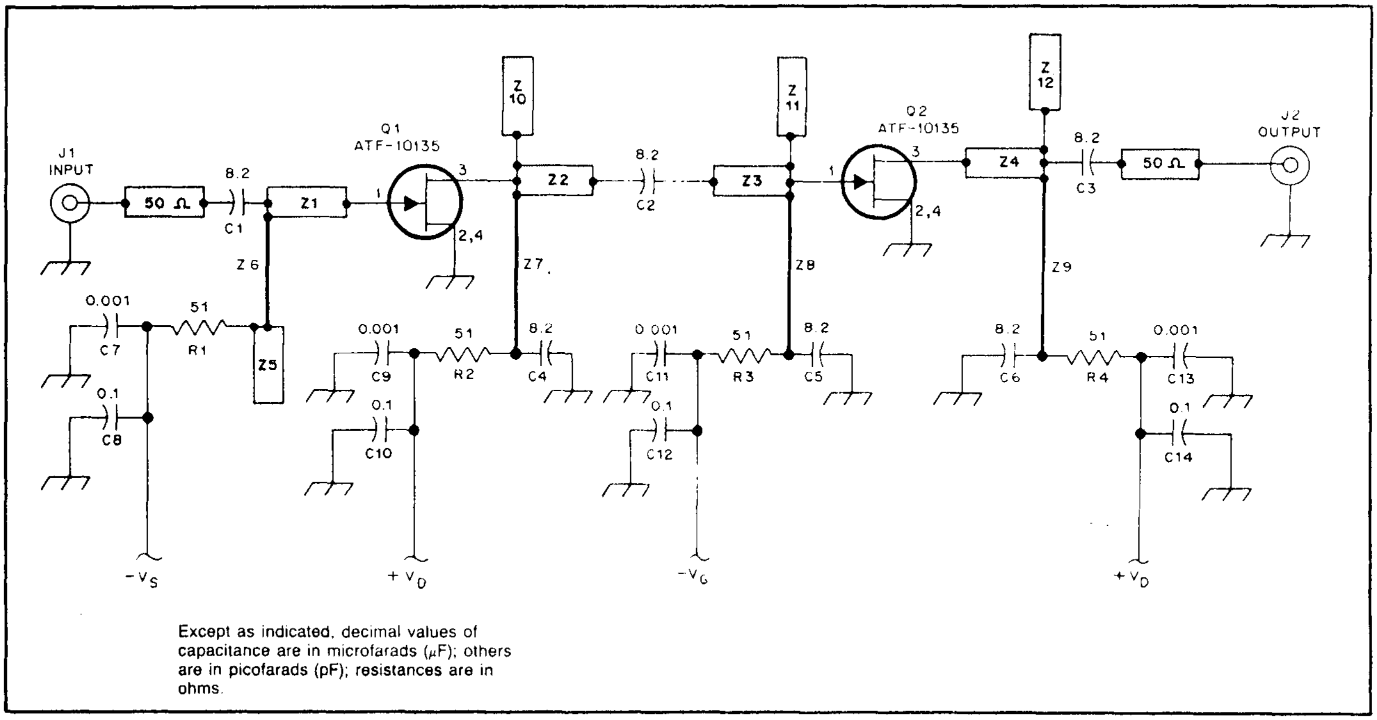
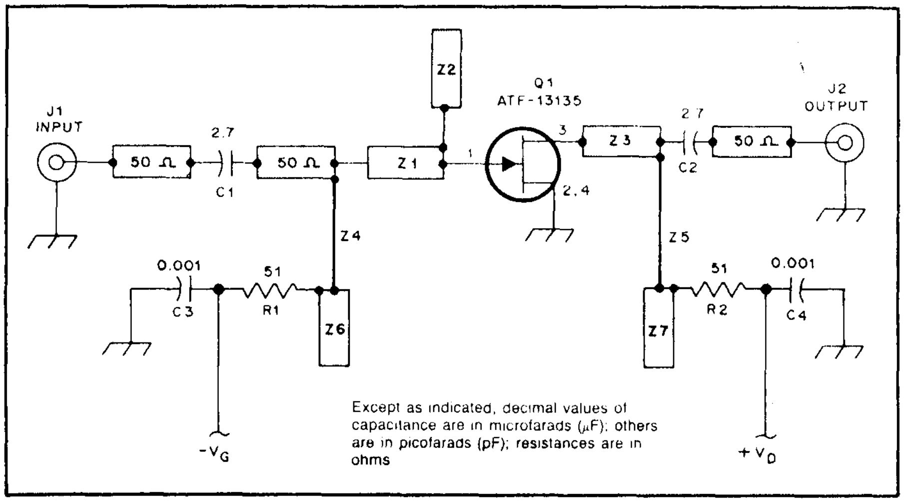


Fig 2—Schematic of the 3.4-GHz preamplifier. Z1 through Z11 are microstriplines etched on the PC board. Shaded rectangles marked "50 Ω" are 50-Ω transmission lines etched on the PC board. All resistors and capacitors are chip types. C1-C6 are 0.05-in. square. C8, C10, C12 and C14 enhance "low-frequency"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



Except as indicated, decimal values of capacitance are in microfarads (µF); others are in picofarads (pF); resistances are in ohms.

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.



Except as indicated, decimal values of capacitance are in microfarads (µF); others are in picofarads (pF); resistances are in ohms

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.

The 10-GHz amplifier is designed around the Avantek ATF-13135 GaAsFET, and the lower-frequency units are designed around the Avantek ATF-10135. Both devices have a nominal gate length of 0.3 micron. The ATF-10135 has a total gate periphery of 500 microns. The ATF-13135 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: The ATF-10135 sells for about $12.00, and the ATF-13135 is about $29.00 in small quantities.

Circuit Description

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

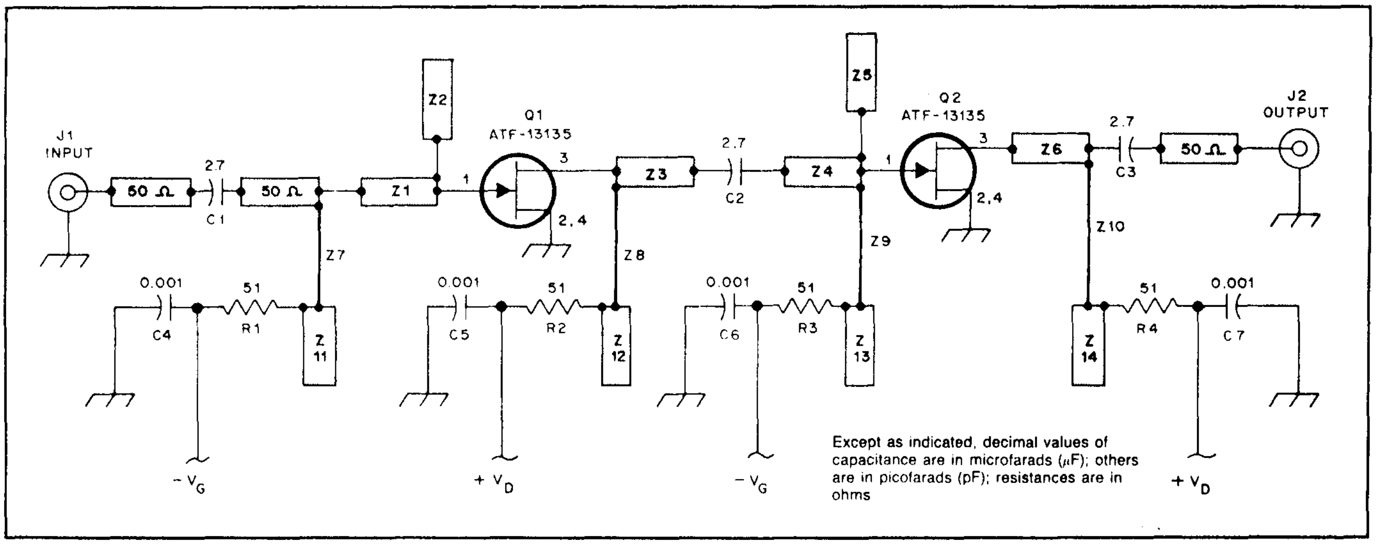
The same basic circuit configuration is used for each preamplifier. All impedance matching is accomplished with microstriplines. None of the amplifiers contain adjustable RF components. Fixed-value capacitors are used for input, output and interstage coupling. Fixed-value capacitors and resistors are 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 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. An in-depth design analysis of these preamplifiers will be covered in a future *QEX* article.

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



Except as indicated, decimal values of capacitance are in microfarads (μF); others are in picofarads (pF); resistances are in ohms

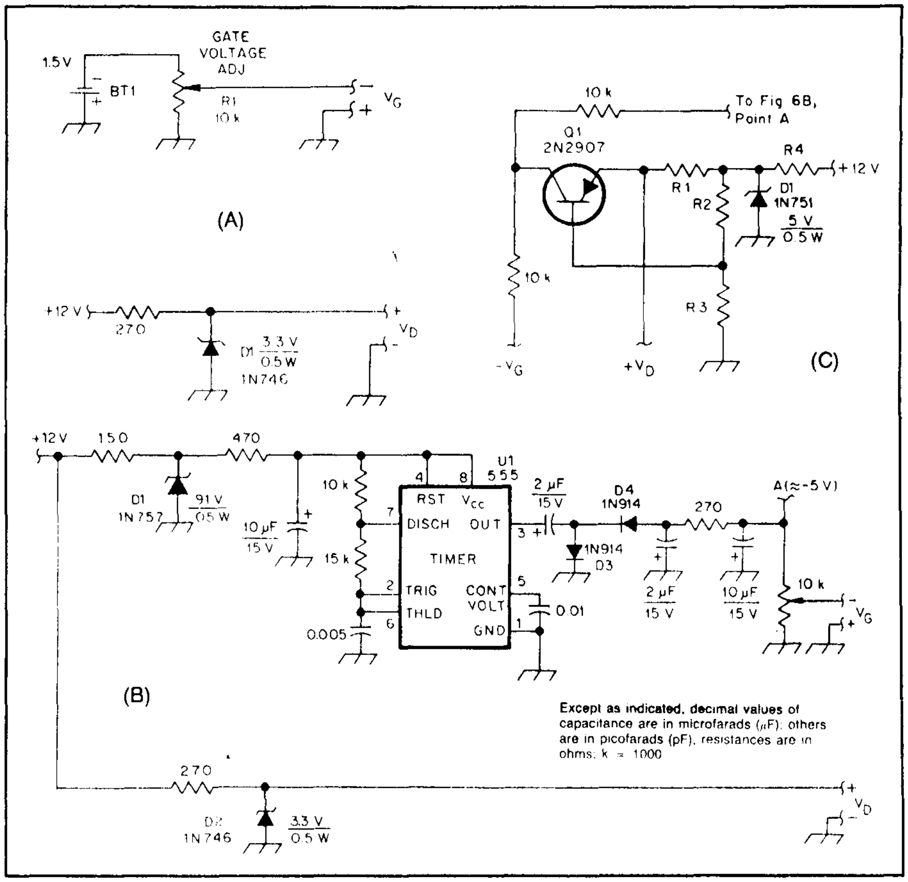
Fig 5—Schematic of the two-stage 10-GHz preamplifier. Z1 through Z14 are microstriplines etched on the PC board. Shaded rectangles marked "50 Ω" are 50-Ω transmission lines etched on the PC board. All resistors and capacitors are chip types. C1-C3 are 0.05-in. square (ATC Type A capacitors are preferred).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

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-ohm resistor in series with the drain, there is some interaction between drain voltage and drain current: Greater drain 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-ohm resistor



Except as indicated, decimal values of capacitance are in microfarads (μF); others are in picofarads (pF); resistances are in ohms; k = 1000

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.

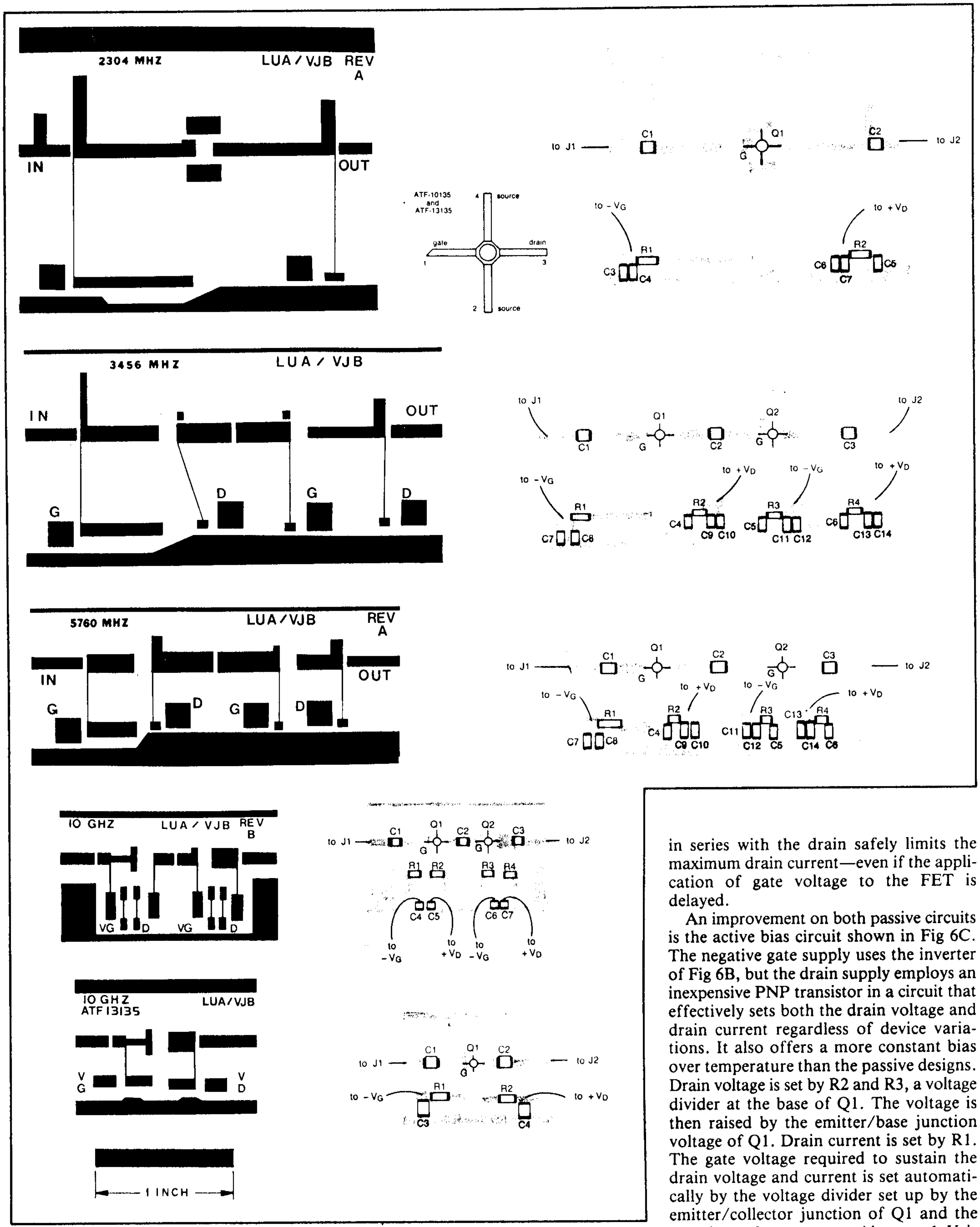


Fig 7—Circuit-etching patterns and parts-placement guides for the preamplifiers. The etching patterns are shown at full size. PC board material is double-sided, 0.031-in-thick Rogers Duroid 5880 or Taconic TLY-5 (dielectric constant, 2.2). Black areas represent unetched copper foil. The back side of 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.

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 active bias network for each FET stage to properly set each device's bias

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

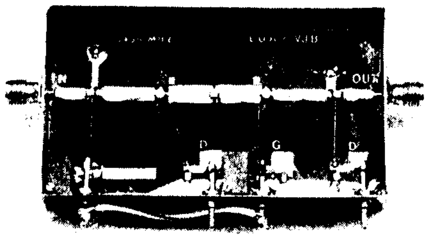


Fig 8—This prototype two-stage 3.4-GHz preamplifier was built by the author. The enclosure is made from sheet brass soldered to the PC board (see text). The trimmer potentiometers are for adjustment of the gate supply for each stage.

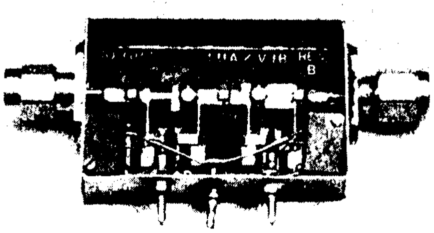


Fig 9—A completed two-stage 10-GHz preamplifier.

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 current v 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 Avantek application note AN-A002.[1]

Construction

Construction of all amplifiers is similar. Etching patterns and parts-placement guides are shown in Fig 7. All amplifiers are etched on 0.031-inch-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-inch-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 low-loss 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-inch-square type *must* be used. Anything larger produces a sizable mismatch on the microstripline.

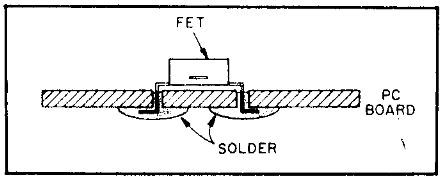


Fig 10—The FET source leads are bent, inserted through slots cut in the PC board, and soldered to the ground plane. See text.

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 10. 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 added by making each FET

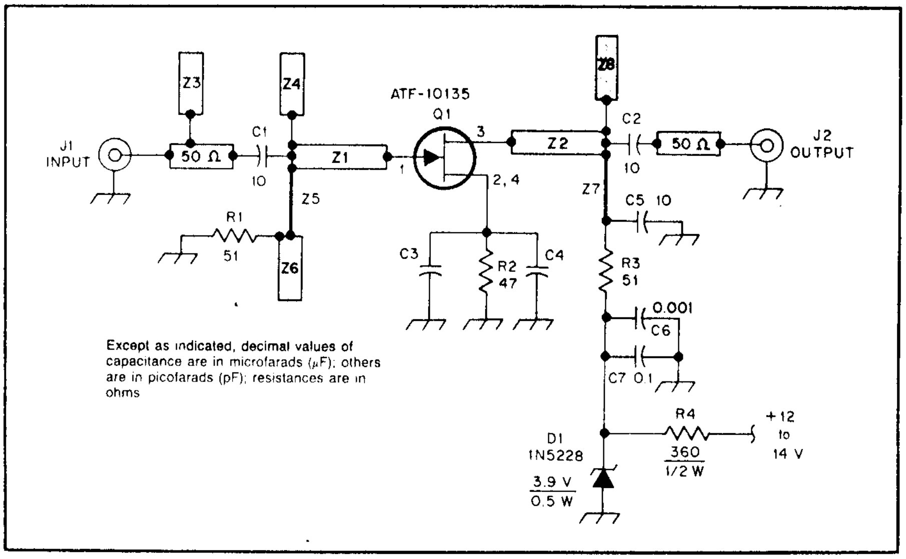


Fig 11—Schematic diagram of the self-biased version of the 2.3-GHz preamplifier. Z1 through Z8 are microstriplines etched on the PC board. Shaded rectangles marked "50 Ω" are 50-Ω transmission lines etched on the PC board. All capacitors are chip types.

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.

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[1] Notes appear on page 75.

Table 2

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

Device	*Freq (GHz)*	*Bias per device*	*Gain (dB)*			*Noise Figure (dB)*		
			Typ	*Worst Case*	*Simul*	*Typ*	*Worst Case*	*Simul*
ATF-10135*	2.3	2 V @ 20 mA	13.5	12.0	13.9	0.5-0.6	0.8	0.60
ATF-10135**	2.3	2 V @ 20 mA	13.0	12.0	13.0	0.65	0.9	0.70
ATF-10135	3.4	2 V @ 20 mA	23.0	22.0	24.1	0.8-0.9	1.0	0.58
ATF-10135	5.7	2.5 V @ 15 mA	18.0	17.0	20.6	0.9-1.0	1.2	0.85
ATF-13135*	10.4	3 V @ 20 mA	8.5	7.5	10.6	1.25-1.5	1.7	1.25
ATF-13135	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

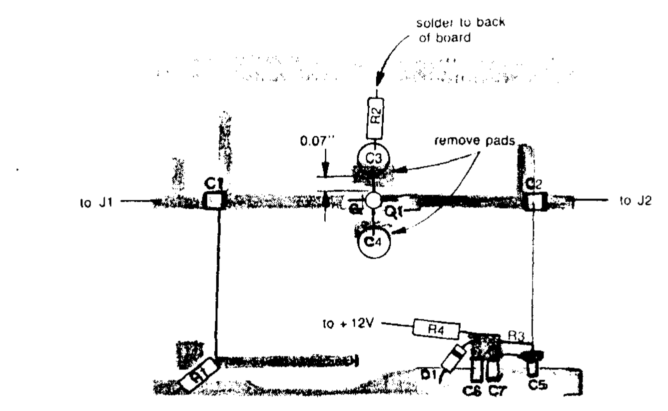

Fig 12—Parts-placement guide for the self-biased 2.3-GHz preamplifier. The etching pattern is the same as shown in Fig 7, except two pads are removed and Z3 must be lengthened. See text.

source lead 0.07 inch long, 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-inch-wide copper strap through the slots and solder top and bottom. Each source lead is then 0.07 inch long when Q1 is centered on the PC board.

Components for these preamplifiers, including chip capacitors, leadless capacitors, chip resistors and SMA connectors are available from Microwave Components of Michigan.[2] Avantek GaAsFETs are available from distributors around the country (see note 1). Etched PC boards are available from Down East Microwave.[3]

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 have been 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 AMSAT-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 moonbounce (earth-moon-earth, 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-inch-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-inch-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.

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 11.

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 inch) 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

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Simple Low-Noise Microwave Preamplifiers

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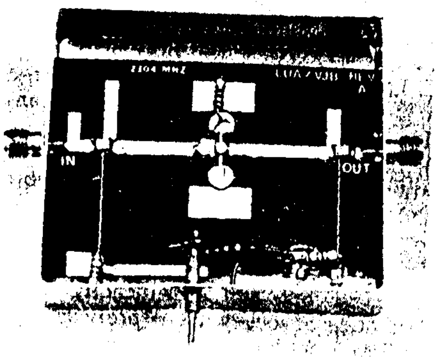

Fig 13—The prototype self-biased 2.3-GHz preamplifier. The large rectangular pads near C3 and C4 are not needed and were dropped from the final artwork.

diameter of the capacitors through the PC board as shown. See Fig 12. Be sure to place the holes so that the FET source leads are 0.070 inch 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 is a photograph of the finished unit.

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-10135 and the ATF-13135 devices are capable of producing moderate power at microwave frequencies. When biased at 4 V and 70 mA, the ATF-10135 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-13135 is capable of producing +17.5 dBm at its 1-dB gain-compression point when biased at 4 V and 40 mA.

Summary

This article has described a series of low-noise amplifiers that require minimal adjustment for optimum performance. Any one of them can be constructed easily in an evening. They offer low noise figure, acceptable gain, good input and output SWR, and good stability.

I would like to thank Kent Britain, WA5VJB, for his valuable help in laying out the artwork for all of these preamplifiers and their subsequent revisions. His help, plus that of many other people, was invaluable in testing out the prototypes. Several dozen of these preamplifiers 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! I also thank George Vendelin, to whom I owe a great deal for his guidance and advice.

Notes

[1] Avantek AN-A002, as well as other Avantek application notes, are available from your local Avantek distributor. If you do not know the location of your local distributor, contact Avantek, 3175 Bowers Ave, Santa Clara, CA 95054-3292, tel 408-727-0700.

[2] Microwave Components of Michigan, PO Box 1697, Taylor, MI 48180, tel 313-753-4581.

[3] Down East Microwave, Box 2310, RR 1, Troy, ME 04987, tel 207-948-3741. *QST* and ARRL in no way warrant this offer.

Al Ward, WB5LUA, earned a BSEE from the University of Illinois in 1973. He worked for Texas Instruments from 1973 until 1987 as a microwave design and systems engineer. In 1987, he joined Avantek as a microwave semiconductor field applications engineer. First licensed as WN9QZE in 1965, Al is well known for his technical and operating achievements on VHF and above. He holds WAS and WAC on 50, 144 and 432 MHz, and WAS on 220 MHz. He has worked 30 states and WAC on 1296 MHz. Al holds a number of VHF/UHF/microwave distance records and has operated EME on all bands from 144 to 2304 MHz. He is presently active on SSB and CW on all bands from 50 MHz through 10 GHz, and can even be found chasing DX on 160 meters.