low-cost 1296-MHz preamplifier

Low-noise, high performance 1296-MHz stripline preamplifier uses new Motorola MRF-901 microwave transistor

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A welcome side effect of the FCC's recent allocation of frequencies near 960-MHz to the Land Mobile Radio Service is the introduction by semiconductor manufacturers of low-cost, high quality active devices for the low end of the microwave spectrum. This technological revolution has proved to be a boon to amateur activity in the 1296-MHz band by bringing state-of-the-art components within the price range of microwave experimenters for the first time. This article presents construction details and performance data on a pair of preamplifiers for 1296 MHz which use the low-noise (under 2 dB), low-cost (under $10.00) Motorola MRF901 microwave transistor. Future developments will undoubtedly bring us a multitude of transistors offering superior performance and/or lower cost.

Numerous previous articles[1-5] have covered the design and construction of high quality preamplifiers for the 1296-MHz amateur band. These amplifiers used outstanding transistors from a number of different manufacturers. Designed primarily for military and aerospace applications, this generation of microwave transistors is characterized by high reliability over a wide temperature range, hermetic construction featuring a ceramic case with gold-plated leads, and (without exception) a cost far beyond the financial resources of the average experimenter.

The new transistors developed for the 960-MHz Land Mobile Band, with plastic cases and tinned-copper leads, are admittedly less rugged than their military predecessors; storage temperature is not above 150°C, breakdown voltages are lower and derating curves are steeper. These devices are, after all, intended for commercial service. Their reliability is, however, wholly adequate for an extended life in intermittent amateur service, and their electrical performance at 1296 MHz compares favorably with that of earlier devices costing an order of magnitude more.

design trends

Early solid-state uhf preamplifiers designed for amateur use achieved input and output impedance matching through the use of pi networks composed of piston trimmer capacitors and slab inductors. This approach, typified by the designs of Katz[1] and Vilardi,[2,3] assured a proper impedance match regardless of the transistor characteristics because of the pi network's unique ability to "match anything to anything." Unfortunately, the pi network's very versatility made it difficult for the amateur who lacked the proper test equipment to know exactly when his amplifiers were tuned for optimum performance. Additionally, extensive tweaking of the input and output circuits made it possible to inadvertently adjust the amplifier into a condition of instability, with the resulting oscillations ultimately destroying the fragile transistor.

The microstripline designs of Donecker[4] and others changed all that. All matching transformers and reactances were etched onto a printed-circuit board, with no tuning adjustments whatever, so there was no need to optimize an amplifier on expensive test equipment. This approach made it practically impossible to destroy a transistor by inadvertently mismatching it. On the other hand, the lack of tuning adjustments made it impossible to compensate for minute differences between components or printed-circuit boards. And, since a board was computer designed to the parameters of a particular transistor, the experimenter had little opportunity to modify the design so he could use a different, more readily available device. In fact, some attempts to substitute transistors on the same circuit board led to a net degradation of the system noise figure to that of a simple diode mixer.

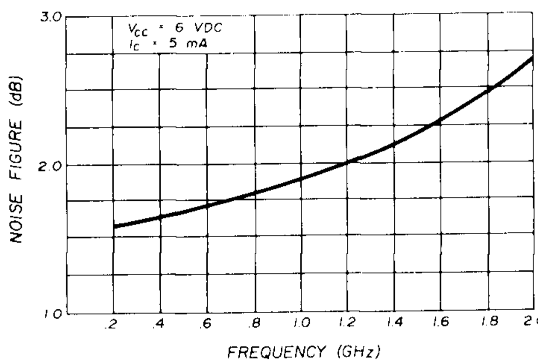


fig. 1. Noise figure vs operating frequency for the Motorola MRF-901 transistor.

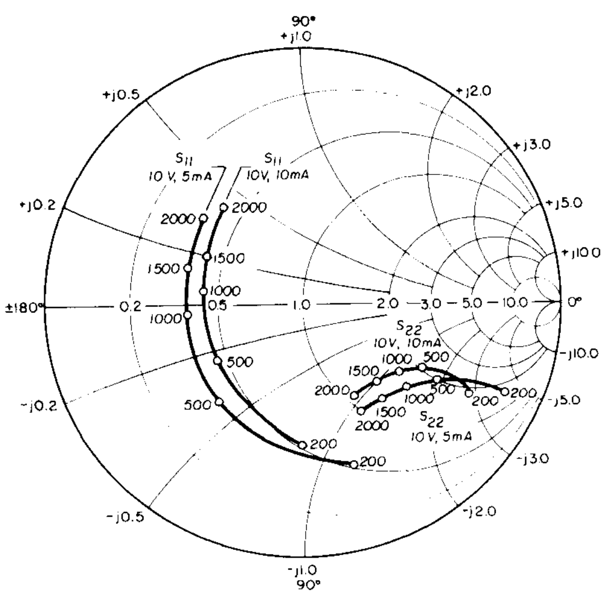
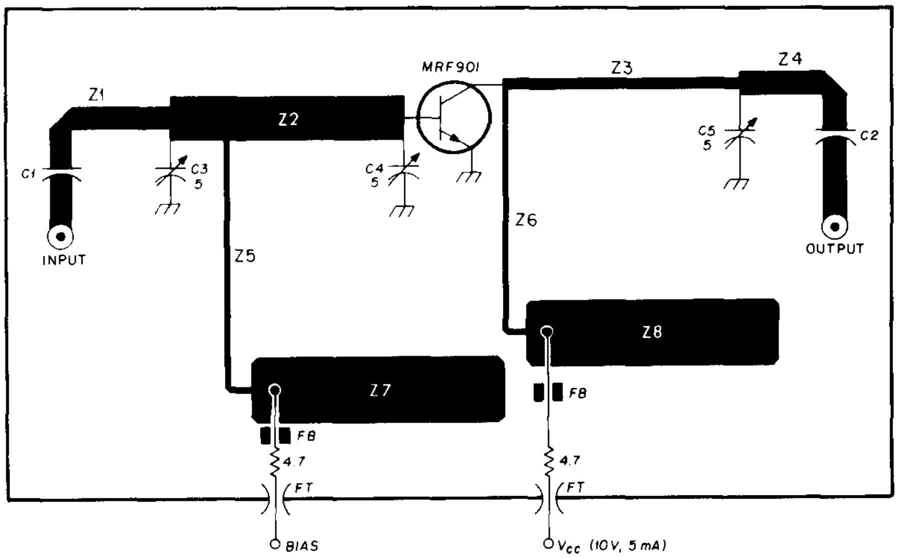


fig. 2. Input reflection coefficient, S_{11} and output reflection coefficient, S22, vs frequency for the Motorola MRF-901.

I attempted to rectify these limitations in my preamplifier designs by incorporating "tweaking" capacitors into a printed microstripline design.[5] By allowing one input and one output adjustment per stage, an amplifier is easily optimized, while lessening both the test equipment requirements and the likelihood of circuit instability. The same design approach is used in the preamplifiers presented here.

There is, however, one situation where the pi network matching technique still excels. For optimum system performance, it is necessary to match the input to the *first* preamplifier stage for optimum noise figure, *not* optimum gain. Optimum noise figure is achieved by deliberately and precisely mismatching the applicable input. Most rf transistor manufacturers publish curves or tables of complex impedances for proper input and output power match. Unfortunately, proper *mismatch* information for optimizing noise figure is seldom provided. Thus, it may be desirable to use a wide-range pi network at the input of the first preamplifier stage so that the source reflection coefficient at figure optimized amplifiers around this transistor, and performance has consistently measured 2.8 dB (with the preamplifier looking into a high-quality double-balanced mixer). The 0.7 dB discrepancy is due, of course, to the familiar second-stage noise contribution,



C1,C2	Dc block. 50-150 pF chip capacitor (ATC 100B or equivalent)
C3,C4 C5	1-5 pF piston trimmer (Johannson JMC4642 or Triko 201-01M)
FB	Ferrite bead, slipped over resistor lead
FT	470-1000 pF feedthrough capacitor
Z1, Z4	50 ohm microstripline, 0.1" (2.5mm) wide, any convenient length
Z2	32.4 ohm, quarter-wavelength, microstripline, 0.20" (5mm) wide, 1.15" (29mm) long
Z3	74.8 ohm, quarter-wavelength microstripline, 0.045" (1mm) wide, 1.24" (31.5mm) long
Z5, Z6	Rf choke. 100 ohm, quarter-wavelength microstripline, 0.02" (0.5mm) wide, 1.25" (32mm) long
Z7, Z8	Rf short, 25 ohm, quarter-wavelength open-circuited microstripline, 0.30" (7.5mm) wide, 1.14" (29mm) long

fig. 3. Schematic of the 1296-MHz preamplifier. Capacitor C3 is used only with the noise-matched stage (see text). Quiescent collector current is 5 mA for the noise-matched stage, 10-mA for the power-gain stage. Full-sized printed-circuit layout is shown in fig. 5.

which noise figure is minimum can be empirically achieved.

transistor characteristics

Fig. 1 shows the manufacturer's claimed noise figure as a function of operating frequency for the MRF-901 transistor. At 1296 MHz the device is capable of delivering a noise figure below 2.1 dB. I have built several noise-

which was summarized quite well in the appendices to Reisert's recent article on 432 MHz preamplifiers.[6] Working through the textbook formula, it is found that the noise-figure optimized MRF-901 stage's intrinsic noise figure is on the order of 2.3 dB. Thus, the losses and mismatch errors inherent in this design still yield performance within 0.2 dB of optimum.

The specification sheets for the MRF-901 list input and output reflection coefficients (S_{11} and S_{22}) in polar form, tabulated for numerous combinations of frequency, power supply voltage and quiescent collector current. The two static conditions of greatest interest to the amateur are 10 volts at 5 mA (for a noise-matched first amplifier stage), and 10 volts at 10 mA (for a gain-optimized second preamplifier stage), as discussed in a previous article.[5] Reflection coefficients corresponding to these bias conditions were plotted on a Smith chart, then connected with a smooth curve as shown in **fig. 2**. The design parameters for the 1296 MHz preamplifiers were determined from interpolation of this Smith chart data.

design procedure

Two preamplifier stages are discussed here, one optimized for noise figure, the other for power gain. The gain-matched second stage was designed along lines analogous to that described in my previous articles. No noise-matched reflection coefficients were available from Motorola for the MRF-901, so a pi network was included in the input to the noise-figure matched stage, as discussed previously.

Fig. 3 is a functional schematic of the 1296-MHz preamplifier stages (the only differences between the stages optimized for noise figure and gain are the quiescent collector current [5 and 10 mA, respectively], and the use of an additional input matching capacitor, C3, in the noise-matched stage).

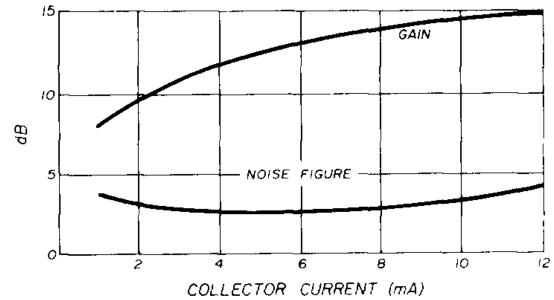


fig. 4. Typical power gain and noise figure of the 1296-MHz preamplifier as a function of collector current.

The system noise figures of several gain-matched 1296-MHz preamplifiers I've built with MRF-901 transistors all measured between 3.2 and 3.5 dB, while yielding 12 to 14 dB of power gain. Thus, for all but the most critical applications, the use of a noise-figure matched first preamplifier stage may not be necessary (see **fig. 4**).

construction

Fig. 5 is a full-sized printed-circuit layout for either preamplifier stage. The only visible difference between the gain-

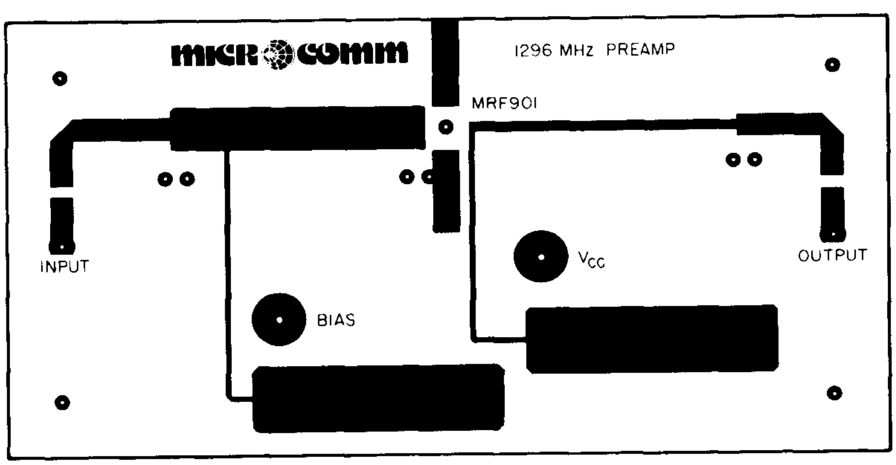


fig. 5. Full-sized printed-circuit board for the 1296-MHz preamplifiers using MRF-901 transistors. Component layout is shown in fig. 3.

matched and noise-matched stages is the incorporation of a variable capacitor, C3, in the noise-matched stage. Note, however, that the quiescent collector current differs between the two stages. More on this later.

The amplifiers are built on 1/16 inch (1.5mm) G-10 fiberglass-epoxy circuit board, double-clad with 1 ounce copper.

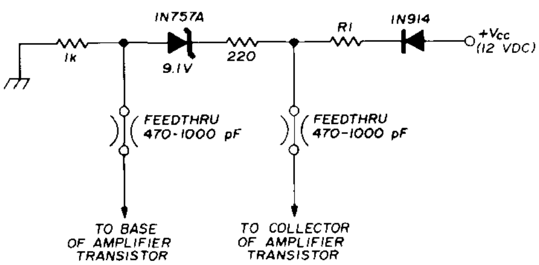


fig. 6. Zener bias circuit, developed by W1JAA, for use with transistor preamplifier stages. For 10 mA collector current, R1 = 120 ohms; for 5 mA collector current, R1 = 240 ohms.

I still receive occasional letters from readers who question my repeated use of glass-epoxy material at 1296 MHz. I will concede that the 0.2 dB excess noise figure above optimum which I have mentioned previously *may* be due to losses in the substrate. However, I feel that 0.2 dB is a small price to pay for the convenience and ready availability of this low-cost printed-circuit material.

Construction of these amplifiers is substantially the same as that of my previously published circuits. If you are unfamiliar with the fabrication of microstripline amplifiers, you are urged to refer to reference 5 for specific construction hints, as well as suggestions for tuneup and operation. That material is not repeated here.

bias circuit

The zener bias circuit introduced by Reisert[6] is not only simpler but also electrically superior to the active bias scheme I used in some of my earlier designs. Reisert's circuit is presented in **fig. 6** along with component values for the two required bias conditions. I refer the interested reader to his very fine article for a complete description of the operation of this bias circuit.

One appealing feature of this biasing scheme is that the power supply voltage can be varied upward or downward, as required, to optimize the stage for gain or noise figure. In this manner the performance of the preamplifier can be readily tailored to the requirements of the system in which it is installed.

conclusion

As the commercial microwave communications industry expands, sophisticated amplifiers have come within the reach of the average amateur experimenter. For those who prefer not to build their own equipment, low-cost 1296-MHz preamplifier modules are now available. A commercial version of the gain-matched stage, featuring a guaranteed maximum noise figure of 3.2 dB is currently available for under $40 from Microcomm.*

*For full specifications send a self-addressed, stamped envelope to Microcomm, 14908 Sandy Lane, San Jose, California 95124.

references

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