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## ABOUT THE COVER

Reception of VISSR signals—the highest-resolution weather-satellite images presently available—requires stable, high-gain, low-noise preamplifiers. Until recently, such preamps were available only commercially, at high cost. Now you can build your own VISSR low noise amplifier. See the article beginning on page 3.
A Low-Noise Preamp For Weather Satellite VISSR Reception

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Geostationary weather satellites, from which radio amateurs have long delighted in recovering earth images, actually provide two distinct products. WEFAX, or weather facsimile, is the more familiar of the two, and consists of preprocessed and enhanced frames, taken at visible or infrared wavelengths, relayed via a frequency modulated microwave carrier, in slow-scan format (four lines per second). Because of its relatively narrow bandwidth (30 kHz per channel) and respectable output power (on the order of five watts), the WEFAX signal is commonly received with little effort using relatively simple equipment. But the data is secondhand. WEFAX images are analog retransmissions of raw satellite data that has been downlinked to a central data-collection facility for processing, then returned to the satellite for distribution. In WEFAX mode, the satellite is thus serving as a repeater.

In its other operating mode, the familiar WEFAX satellite provides a wide-band digital signal variously called VISSR (for Visible and Infrared Spin-Scan Radiometer, the image sensor on the satellites), VAS (for VISSR Atmospheric Sounder), or HRPT (for High-Resolution Picture Transmission, which highlights the signal’s advantage over WEFAX). Throughout this article, I shall use the term VISSR.

The ultimate microwave challenge is reception and display of raw satellite data prior to processing. This has—until recently—been an elusive goal, because in the digital mode, the satellite is transmitting at greater than 2 Mbits per second. Hence, a wide receiver bandwidth (on the order of 8 MHz) is required. Thus, though the VISSR transmitter power is on a par with that of the WEFAX transmission, the modulation sidebands are spread over a frequency spectrum about 300 times as wide. The resulting low spectral density makes it necessary to employ some rather sophisticated receiving equipment: government stations employ 60-foot dishes, parametric amplifiers and large mainframe computers for image processing.

Nevertheless, a few enterprising radio amateurs have succeeded in building homemade VISSR receiving stations, defying the odds as did those first few homebuilders who recovered TV pictures from domestic communications satellites a decade earlier. In truth, to date they have been successful in recovering only “stretched” VISSR data, which is the more narrowband of the two available digital weather-satellite services. For this, the Government uses only a 24-foot dish! For stretched VISSR and TVRO reception alike, success depends upon the development of low-noise, high-gain, stable receive preamplifiers, which is the subject of this article. The techniques presented here can, of course, be applied equally well to other services and other frequencies.

Performance Requirements

Actually, the satellite TV analogy is apt in that the spectral densities of the two transmissions are roughly equivalent. So, the antenna and preamp requirements for VISSR and TVRO reception should be about the same. The frequencies differ, of course, with TVRO operating near 4 GHz, and VISSR around 1.7 GHz. For a given parabolic-antenna diameter, gain varies inversely with the square of wavelength. Therefore, you can expect a given TVRO dish to produce about 7 dB less gain in VISSR service. But, it’s a lucky coincidence that free-space path loss varies directly with frequency, at precisely the same rate. Which means, for a given antenna, the two effects exactly cancel! In other words, if receiver noise figure is equivalent between the two services, a TVRO dish will perform just as well for VISSR as it did for satellite TV.

What does that leave us with for required preamp performance? Successful TVRO installations typically require a low-noise amplifier (LNA) with noise temperature on the order of 100 Kelvins (a 1.3-dB noise figure), and enough gain to overcome feed-line losses and mixer noise (typically 40 dB). These figures give us our design objectives for the VISSR LNA: 100-Kelvin noise temperature, with about 40 dB of gain, should suffice. Such a preamp will not only do a credible job receiving stretched VISSR on a 12-foot-diameter TVRO dish, but provides spectacular standard WEFAX reception using a dish made from a 2-foot-diameter snow sled!

LNA Topology

The active device of choice to establish the required low-noise performance is obviously the gallium-arsenide fieldeffect transistor, or GaAsFET. But, stability considerations dictate limiting preamplifier gain to about 15 dB per stage, suggesting that this would have to be a three-stage preamplifier. Unfortunately, my success rate in producing stable and reliable three-stage GaAsFET preamps leaves much to be desired! The problem is that cascaded GaAsFETs are hard to match, squirmily to tune, exhibit poor input SWR when tuned for minimum noise figure, are high-Q and narrow-band devices by nature, and love to oscillate! I’m sure I’m not the only one who’s had those experiences.

Bipolar monolithic microwave integrated circuits (MMICs), on the other hand, are the most docile of devices. They have moderately low noise figures and acceptably high gain, are wideband by design, have 50-ohm inputs and outputs, are unconditionally stable for any combination of source and load impedances, and cost less than the discrete components needed to duplicate their function. I have used them successfully as the input stage of WEFAX receivers; unfortunately, they’re about 2 dB too noisy for VISSR front ends.

A likely compromise, it would seem, is to cascade a single GaAsFET stage (to establish the required noise figure) with a couple of MMIC stages (to establish system gain). The result looks like the circuit shown in Fig 1, with the gain and noise data representative of the prototype I ultimately built. The overall performance of the cascade preamplifier, as calculated by Teledyne’s computer program, RF Toolbox, is shown in Table 1.

Designing the GaAsFET First Stage

I selected the Avantek ATF-10235 low-noise gallium-arsenide FET for the input stage, for a number of reasons. At 2 GHz (the lowest frequency at which the data sheet fully characterizes the device, but
crude, the output circuit is even more so. Scattering parameters indicate the output impedance of the FET is also near 200 ohms; shunting the output with a 68-ohm resistor (which happens to double as the drain bias resistor) just happens to bring the output impedance rather near 50 ohms. This resistive swapping of the output also serves to stabilize an otherwise unstable active device. There is, of course, a gain penalty in resistive swapping, but this FET has more gain than we need in the input stage, anyway.

The input FET is a common-source stage, hence, the two source leads need to be at RF ground. To enable source self-biasing, they will be run to ground through bypass capacitors. To keep Q high and losses to a minimum, resonant (quarter-wave) capacitive stubs are used, as seen in the photographs and PC artwork. The resistors from these stubs to ground fix the FET’s quiescent current by biasing the gate halfway to pinch-off.

Computer analysis of the proposed input stage was performed using Randall Rhea’s program, SuperStar.\textsuperscript{11} Table 2 is the circuit file; expected performance is shown in Table 3. Note that gain peaks near 15 dB at 1680 MHz, that input SWR is nearly perfect, output SWR is a rather poor 3:1, and the device is only marginally stable, as indicated by the Rollot Stability Factor (K) hovering around 1. The relatively high output SWR is the result of totally ignoring the drain-circuit reactance when “matching” the output, and gain drops a few tenths of a decibel.

Swept response is shown graphically in Fig. 3. Input (Fig 4) and output (Fig 5) stability circles confirm what K told us in the data table: The stage is only conditionally stable, with the instability regions just grazing the outer edge of the Smith Charts in both cases.

Selecting the MMIC Output Stages

The two MMIC stages following the GaAsFET must do far more than simply add gain to the preamp. They must, for example, terminate the first stage as to render it unconditionally stable regardless of input match. In addition, the noise contribution of these stages must be negligible. As a rule of thumb, the first stage of a cascade establishes overall noise performance only if its gain exceeds the noise figure of the following stages by about 10 dB.\textsuperscript{12} Because the GaAsFET stage is giving us a gain of 15 dB, this means the noise figure of the stages that follow must be under 5 dB. The selected MMICs more than meet this requirement.

The use of MMICs as gain blocks is well covered in the Mini-Circuits MAR guide,\textsuperscript{13}, and this design is based on considerations outlined therein. Because the selected MMIC has input impedances rather close to 50 ohms at the frequency of interest, no attempt is
made to provide further matching. The observed gain correlates well with the device data sheets.

**Optimizing the Cascade**

The true power of computer-aided design rests in the ability to do repetitive "what if" analyses. By adding the two MMICs (and their shunt collector bias resistors) to the SuperStar data file, it's possible to discern the effect of the latter stages on the input FET, and optimize as required. The expanded circuit file, seen here as Table 4, shows the length of the input microstrip line, and the value of the drain bias resistor, preceded by a question mark [?]. This indicates that these values are available for manipulation when "tuning" the circuit in computer analysis, and in fact the final values (selected for optimized performance of the overall amplifier) are slightly different from those shown in Table 2.

The performance achieved after computer optimization is shown in Table 5, and graphically in Fig 6. Note that at the operating frequency, the overall amplifier has a gain of 40 dB, the input and output SWR is under 2:1, reverse isolation is on...
the order of 56 dB, and the circuit is now unconditionally stable (the Rollot Stability Factor, K, is well over unity). The input (Fig 7) and output (Fig 8) instability regions now fall far off the edges of the Smith Chart, confirming that this amplifier will be stable for any combination of real source and load terminations.

Construction, Tune-Up and Test

The circuit schematic is shown in Fig 9 along with the parts list. Assembly details parallel my previous microstrip preamplifiers.14,15 If the design approximations described earlier seem crude, the construction techniques I employed are even more so. This amplifier was built on a substrate of 1/8-inch fiberglass-epoxy PC-board stock, double clad, with one ounce of copper per square foot per side. PC-board artwork is shown in Fig 10, but I fabricated the prototype with what AMSAT stalwart Gordon Hardman calls an Approx Knife—there’s nothing exact about it! Actually, four straight cuts (two in parallel, spaced 0.1 inch apart for the microstrip; two in an X to form the bypass capacitors) plus a bit of “peel,” do an amazing job of defining this amplifier! A view of each side of the assembled amplifier is shown in Fig 11. A parts-placement diagram is shown in Fig 12.

Tune-up? There is none! Just drop the parts (carefully) into the PC board, solder sparingly using a minimum amount of heat, test for proper dc bias with both ports terminated in 50-ohm loads, and you’re done. Don’t forget to observe proper antistatic precautions when working with this, or any, GaAs device.

The noise figure of the completed amplifier measures about 1 dB; nonideal components and substrate losses account for the excess noise. I say “about” because, at these low noise levels, measurement errors are on a par with the measured value itself. Fig 13 shows the swept forward gain of this preamplifier, as measured on a microwave network analyzer. Compare it to the predicted gain in Fig 6. Amazed? So was I!

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**Notes**


3. For the GOES series of satellites operated by the US, this facility is located at Wallops Island, VA.


9. RF Toolbox, a collection of useful programs for MS-DOS® computers, is available gratis to microwave and RF professionals. Address your letterhead request to: Teledyne Microelectronics, 12964 Panama Street, Los Angeles, CA 90066.


11. SuperStar Version 3.2 is available for $95 from Circuit Busters, 1750 Mountain Glen, Stone Mountain, GA 30087. This highly sophisticated microwave circuit analysis and optimization program (the name derives from “S-parameter Two-port Analysis Routine”) is somewhat slow when compared to its industry-standard counterparts, Super-Compact and Touchstone. On an 8-MHz 80286-based PC outfitted with an 80386 numeric co-processor, the program took several minutes to optimize this preamplifier. For occasional use (only as directed), I feel this is a small price to pay for a program selling for twenty times less than the competition. Please remember: No computer program is a substitute for sound engineering judgment.

12. See note 8.


C1, C2—Etched bypass capacitors (see PC artwork).
C3-C5—1000-pF feedthrough (Erie 2404-9-X6U/O).
C6-C10—100-pF 10%-tolerance, ceramic chip (ATC 100B).
J1, J2—SMA connectors (Johnson 142-0296-001).
L1—Etched, tapped inductor (see PC artwork).
Q1—ATF-1023S, Avantek GaAsFET.
U1—78L05 5-V regulator.
U2, U3—MAR-6 Mini-Circuits MMIC.
R1, R2—27 Ω.
R3—100 Ω.
R4, R5—510 Ω.
Misc: Die-cast, enameled enclosure (Pomona 2901).

Fig 9—Schematic diagram of the 1691-MHz VISSR LNA. All resistors are 1/4-W, 5% carbon units.

Fig 10—PC-board etching pattern for the low-noise amplifier PC-board. This pattern is etched onto one side of a 1/16-inch-thick, double-sided, fiberglass-epoxy board. The non-component side remains fully clad, and serves as a ground plane.

Fig 11—Views of both sides of the VISSR LNA PC board.
Fig 12—Parts-placement diagram for the VISSR LNA.

Table 1
Cascade Noise Figure and Gain
The following input data are expressed in decibels:

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<th>Component</th>
<th>Noise Figure (dB)</th>
<th>Gain (dB)</th>
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<td>Stage 3</td>
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<td>Stage 4</td>
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<td>Stage 6</td>
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</table>

As a result of the above:

Composite noise figure = +0.71 dB or
Total system gain = +40.00 dB or

1.18 as a ratio.
10000.00 as a ratio.

Noise Figure Measurement
Given information:
NF (dB) 0.71

Calculated Result:
T (eff) = 51.50573 K

Fig 13—The swept forward gain of this preamplifier, as measured on a microwave network analyzer.

Table 2
Circuit-Parameter input to SuperStar
CIRCUIT VISSRFET_LNA
SST AA DG 50 20 1691
TRL BB DG 50 741 1691
TWO CC SP 50 'CIRCUITS/STAR/DATA/AT10235.220
RES DD PA 768
CAX AA DD
OUTPUT
GPH AA S21 50 5 15
GPH AA S12 50 -30 -10
SMH AA S11 50
SMH AA S22 50
FREQ
SWP 1400 2000 31
### Table 3
Run of VISSRFET.LNA Under SuperStar

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<tr>
<th>Freq (MHz)</th>
<th>Input SWR</th>
<th>S21&lt; ANG</th>
<th>S12 Output K</th>
<th>Freq (MHz)</th>
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### Table 4
Expanded Circuit-Parameter Input To SuperStar

CIRCUIT VISSRCAS.LNA
SST AA DG 50 20
TRL BB DG 50 738

NANO 50 1525.7220
RES DD PA 775
NANO 50 1525.36316
RES FF PA 520
NANO 50 1525.36316
RES HH PA 520
NANO 50 1525.36316
RES AA S11 50
NANO 50 1525.36316
RES AA S22 50
NANO 50 1525.36316
RES FREQ

### Table 5
Run of VISSRCAS.LNA Under SuperStar

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