PLUG-IN 11-GHz LNA MODULE WITH GROUND PLANE TUNER

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ABSTRACT

A tunable single-stage MESFET LNA plug-in module with a 2-dB noise figure and 10-dB gain becomes the front-end stage of mass produced low noise down-converters for the 10.7- to 11.7-GHz Digital Communication Systems. The LNA modules are tuned in a test receiver and then randomly inserted into down-converters to speed up production testing. Space feedback is used to enhance the LNA noise figure and gain.

INTRODUCTION

The microstrip RF circuit board in a low-noise microwave communications down-converter contains a low-noise amplifier (LNA) directly connected to a circulator and a single-sideband mixer. An occasional loss of noise figure or gain is not easily traced to the faulty RF circuit since each circuit needs to be tested separately. The plug-in LNA module solves this problem since it is tuned and tested in a test receiver. This eliminates LNA uncertainties and allows the circulator and single-sideband mixer to be fully tested by easily replacing the LNA module with a circuit board that has a 50-ohm transmission line and a bias blocking capacitor. If damage to the LNA is suspected, it may be reinserted into the test receiver for performance evaluation.

DESIGN OF LNA MODULE

The MESFET used in the modules was originally an NEC NE67383, which may now be directly replaced by the NE04583. The substrate is the 3M217 1-oz clad material with a 0.015-inch thick teflon fiberglass dielectric. The transistors required quarter-wave transformer matching circuits near 12 GHz to be located at the package interface and even into the package area. To locate the matching quarter-wave transformer away from the package, an 0.080-inch wide open stub was placed adjacent to the gate and drain leads. The length of the stub was chosen to provide the correct susceptance that would combine with the conductance of a quarter-wave transformer to form the optimum source and load impedances for the FET.

Although a number of FET tuning techniques have been described in the literature (1,2,3,4), none could be located that was small enough to be contained on the LNA circuit board size of 0.82 by 0.88 inch. The ground plane tuner was chosen because of its compact size and the use of tuning screws that remain fixed after they are adjusted.

A sketch of the tunable plug-in LNA modules appears in Figure 1. The wider conductor pattern next to the FET package consists of the quarter-wave transformer width plus the open circuited stub on one side. The width of the quarter-wave transformer is increased over the region where the ground plane is removed to be the equivalent impedance of the section of the transformer with a ground plane when the tuning screws are partially advanced into the tuner housing toward the substrate. Advancing the tuning screws toward the substrate reduces the ground plane height of the transformer to lower its impedance. The sloping sides of the transformer with the ground plane recessed resulted from conductor pattern optimization changes to 50-ohm lines with the maximum ground plane height where they were joined to normal 50-ohm line width to smooth the reflection pattern provided by a time domain reflectometer (TDR). The transformer sides are constructed by 60-degree lines that begin 0.030 inch outside the ground plane opening and terminate at the lines outlining the transformer width.

Table 1 gives the typical optimum source and load reflection coefficients for the FET that may be compared to the values for different tuning screw penetrations. The tuning action of the gate and drain tuners may be understood by an inspection of the reflection coefficient data in tables 2 through 5. All data has been corrected to move the reference to the edge of the open circuited stub where the gate and drain FET leads are attached. Data in Tables 2 and 4 was taken by inserting each tuning screw by the same amount. Since the screw opposite the open stub behaves differently from the other screw, data is given in Tables 3 and 5 to show only one screw varied while the other was fixed at four turns. Note that the gate reflection coefficients change very little with frequency in the normal tuning range of 3 to 4 turns. Both tuners shift rapidly in magnitude and angle and have a loop in the swept polar response when the screws almost touch the substrate dielectric, but this is beyond the required tuning range.

The optimum reflection coefficient data in Table 1 is given as an approximate reference only since it was derived from California Eastern Laboratory data and limited laboratory measurements and does not include the gate and drain lead lengths to the matching networks. Although this data does not show the source reflection coefficient

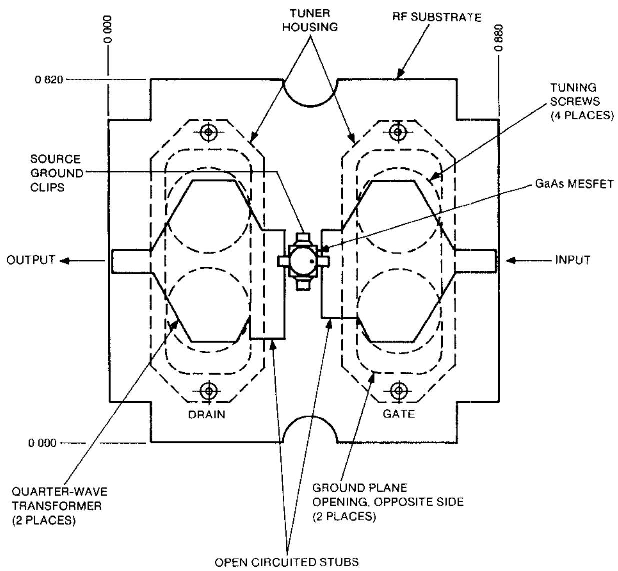

Figure 1. LNA Plug-In Module, Mechanical Sketch.

Table 1. Optimum Source and Load Reflection Coefficients for NE67383

FREQUENCY (GHz)	GAMMA (OPTIMUM)	GAMMA LOAD
10.7	0.51/-172°	0.68/+143°
11.2	0.50/-165°	0.65/+152°
11.7	0.49/-158°	0.62/+158°

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Table 2. Gate Network Return Loss

Screw equally inserted; data referenced to open circuited stub edge; one turn = 0.015 inch of travel (64 threads/inch).

FREQ (GHz)	RETURN LOSS MAGNITUDE/ANGLE VS SCREW TURNS					
	0	1	2	3	4	4.5
10.7	0.68/-161.8	0.67/-162.3	0.64/-163.9	0.59/-168.2	0.52/ 178.1	0.48/159.2
11.2	0.71/-163.1	0.69/-163.4	0.66/-164.6	0.60/-167.9	0.50/ 179.7	0.42/159.7
11.7	0.73/-165.1	0.71/-165.2	0.68/-166.0	0.62/-168.4	0.49/-178.6	0.36/163.3

Table 3. Gate Network Return Loss

A. Open stub screw fixed at 4 turns; other screw varied; data referenced to open-circuited stub edge.

FREQ (GHz)	RETURN LOSS MAGNITUDE/ANGLE VS OTHER SCREW TURNS					
	0	1	2	3	4	4.5
10.7	0.58/-170.8	0.58/-171.5	0.57/-172.8	0.55/-175.7	0.52/ 177.2	0.28/ 105.3
11.2	0.59/-170.6	0.58/-171.2	0.57/-172.4	0.55/-174.9	0.50/ 178.8	0.14/ -16.1
11.7	0.60/-171.0	0.59/-171.5	0.58/-172.4	0.55/-174.4	0.49/-179.3	0.56/-172.2

B. Open stub screw varied; other screw fixed at 4 turns.

FREQ (GHz)	RETURN LOSS MAGNITUDE/ANGLE VS OPEN STUB SCREW TURNS					
	0	1	2	3	4	4.5
10.7	0.56/-169.1	0.56/-170.0	0.55/-171.6	0.53/-175.0	0.51/ 177.2	0.52/148.6
11.2	0.58/-168.1	0.57/-168.8	0.56/-170.2	0.53/-173.3	0.50/ 178.8	0.46/143.6
11.7	0.59/-167.6	0.58/-168.1	0.57/-169.2	0.54/-171.8	0.49/-179.3	0.39/-135.5

Table 4. Drain Network Return Loss

Screw equally inserted; data referenced to open circuited stub edge; one turn = 0.015 inch of travel (64 threads/inch).

FREQ (GHz)	RETURN LOSS MAGNITUDE/ANGLE VS SCREW TURNS					
	0	1	2	3	4	5
10.7	0.80/172.2	0.80/172.1	0.79/171.6	0.77/170.6	0.74/167.5	0.69/158.0
11.2	0.83/166.5	0.82/166.4	0.81/166.1	0.79/165.2	0.76/162.6	0.70/154.1
11.7	0.84/161.8	0.84/161.7	0.83/161.5	0.81/160.8	0.78/158.6	0.72/151.1

Table 5. Drain Network Return Loss

A. Open stub screw fixed at 4 turns; other screw varied; data referenced to open-circuited stub edge.

FREQ (GHz)	RETURN LOSS MAGNITUDE/ANGLE VS OTHER SCREW TURNS					
	0	1	2	3	4	5
10.7	0.75/169.3	0.75/169.2	0.75/168.9	0.75/168.4	0.74/167.5	0.71/165.2
11.2	0.78/163.9	0.78/163.8	0.77/163.6	0.77/163.2	0.76/162.5	0.73/161.2
11.7	0.79/159.4	0.79/159.3	0.79/159.1	0.79/158.8	0.78/158.4	0.76/158.4

B. Open stub screw varied; other screw fixed at 4 turns.

FREQ (GHz)	RETURN LOSS MAGNITUDE/ANGLE VS OPEN STUB SCREW TURNS					
	0	1	2	3	4	5
10.7	0.78/170.9	0.78/170.8	0.77/170.6	0.76/169.8	0.74/167.5	0.70/159.9
11.2	0.81/165.6	0.80/165.5	0.80/165.3	0.78/164.7	0.76/162.5	0.72/155.0
11.7	0.83/161.1	0.83/161.0	0.82/161.0	0.81/160.5	0.78/158.5	0.73/150.7

passing through resonance (reactive component changing sign) near 12 GHz, this fact was observed from amplifier performance. This means that the full 10.7- to 11.7-GHz frequency band could not be optimized by a simple matching network on the gate and drain terminals. The tunable quarter-wave transformer and open stub dimensions were calculated to match the data in Table 1 at midband. The conductor patterns were then trimmed slightly when the complete LNA was tested. The loss of gain and rise in noise figure near the high end of the band could only be corrected by space feedback.

The electromagnetic field above the quarter-wave transformers is increased because of the higher ground plane height below the transformers. A sloping metal shield is positioned above the LNA module to remove any lid effects above the LNA and to provide feedback from the drain to the gate. This feedback is called space feedback because the feedback path is located in the air above the LNA via the electromagnetic fields, rather than through element coupling on the surface of the substrate. The height and angle of this shield controls the amount of feedback as well as the frequency where the gain response reaches a maximum peak. The space feedback is different from other feedback techniques reported because the rise of the LNA gain is also accompanied by a decrease in noise figure. The rise in gain and decrease in noise figure is limited to a frequency bandwidth of 5 to 10 percent. The gain and noise figure either side of this range are slightly degraded from the values without feedback.

LNA MODULE MECHANICAL DESCRIPTION

Figures 2 and 3 show front and rear views of the LNA module. The leads from the FET package are planar mounted. The gate and drain leads are soldered to the open circuited stub sides of the matching networks. The two source leads are soldered to a U-shaped ground tab that is inserted through slits in the substrate from the ground plane side and bent away from each other on the conductor side of the substrate. The tuner housings are identical for the gate and drain sides and are located by two bosses that fit into holes in the substrate. Johanson tuning screws with 64 threads per inch are modified to provide the correct penetration.

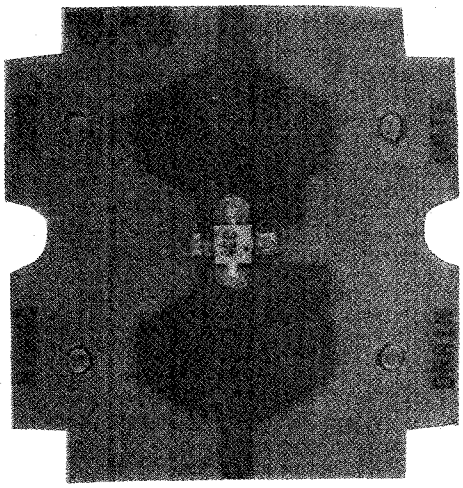

Figure 2. LNA Module, Front View.

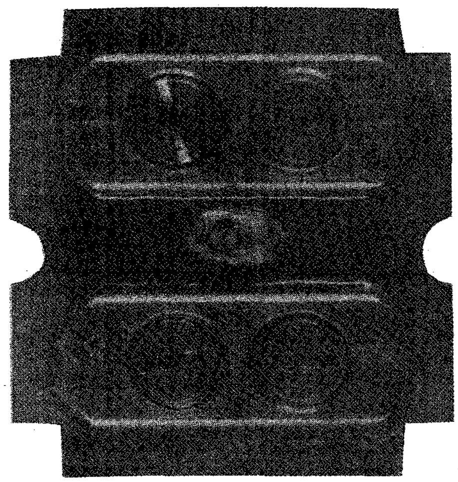

Figure 3. LNA Module, Rear View.

MOUNTING OF LNA MODULE IN TEST RECEIVER

Figures 4, 5, and 6 illustrate the mounting sequence for the plug-in LNA module into the test receiver. Figure 4 shows the opening in the main board substrate where the LNA module is inserted. The metal ground plate around this opening is common to the main board and also the LNA module at their junctions. The main RF microstrip board is identical in the test receiver as in the down-converter that is to receive the tested LNA module. Also shown are the LNA module, the plastic frame, and the metal shield. Figure 5 shows the LNA module inserted and held in place by two plastic screws after centering in the opening. The plastic frame is then mounted over the LNA module and retained by two screws near the input connector. The final mounting of the LNA shield by two screws is illustrated in Figure 6.

ADJUSTMENT PROCEDURE

Prior to any tuning adjustments, the drain voltage is set for 3 volts and the gate voltage is adjusted for 10 mils of drain current. The two screws in the gate and drain tuners are initially set flush to the outside of the tuner housing. The two gate screws are first alternately advanced into the housing to minimize noise figure with the highest gain possible. After reaching a minimum noise figure and maximum gain, the drain screws are next adjusted primarily for maximum gain while minimizing noise figure. An additional trimming adjustment should reach the optimum screw positions.

PERFORMANCE DATA

Performance of the LNA module in the test receiver, which will be the same as in the down-converter, is plotted in Figure 7. The droop in gain and rise in noise figure at the high end of the band without space feedback clearly would not allow the noise figure objective of 3.5 dB to be achieved. No amount of chip or other tuning means would flatten the noise figure and gain. Use of space feedback, however, provided the necessary correction to easily meet the 3.5-dB noise figure limit and to flatten the gain response. This data is presented first to show the significant improvement on the complete down-converter performance when the LNA gain is increased and the noise figure is simultaneously decreased. Note the loss of normal gain and noise figure caused by the space feedback beyond the range of improvement.

Performance of the LNA module alone is shown next in Figure 8. This data was calculated from the Figure 7 data together with the data taken using the LNA bypass to replace the LNA module. Noise figure was improved by space feedback over the operating bandwidth; however, the gain was sacrificed at the lower end of the band to produce a rise of gain at the high frequency end. The gain peaked beyond the high frequency end of the curve.

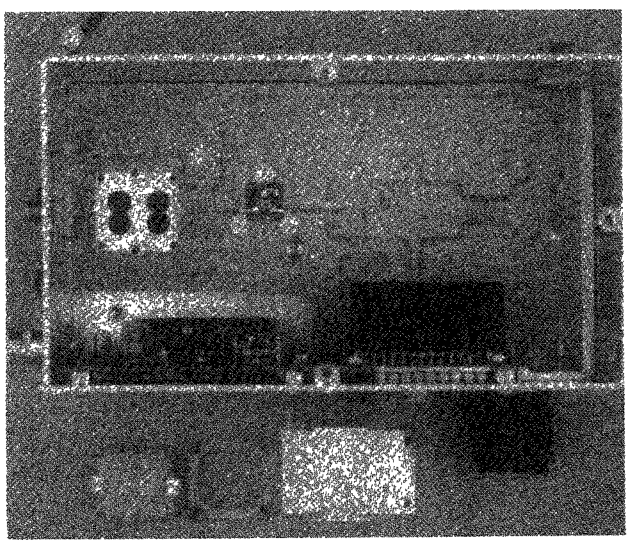

Figure 4. LNA Module Test Receiver Showing Parts Disassembled.

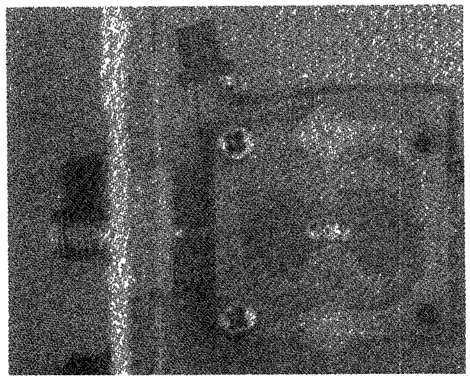

Figure 5. LNA Module and Frame Mounted in Test Receiver.

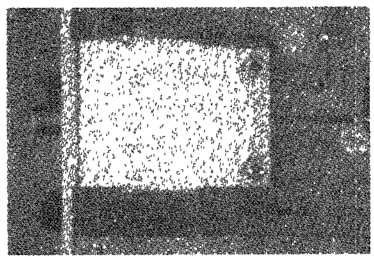

Figure 6. Final Assembly of LNA Module in Test Receiver.

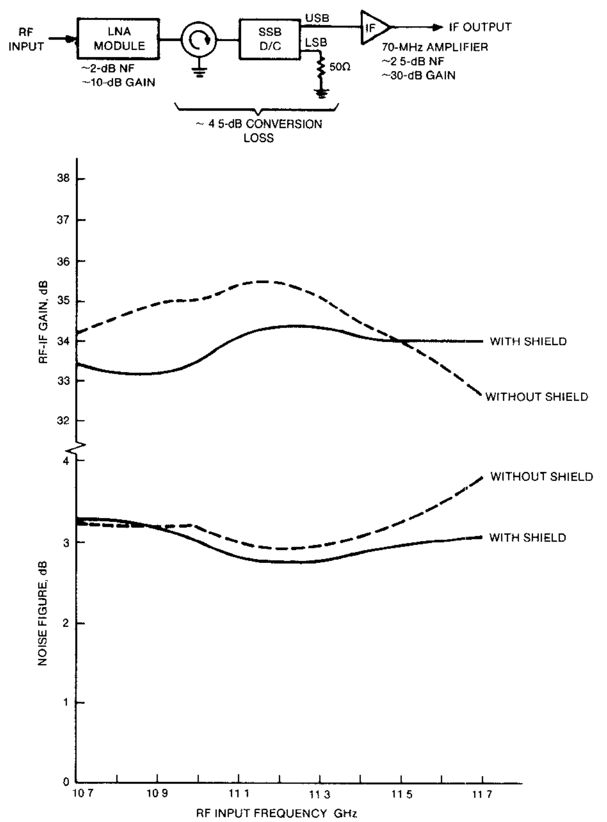

Figure 7. 11-GHz Test Receiver Performance with LNA Module.

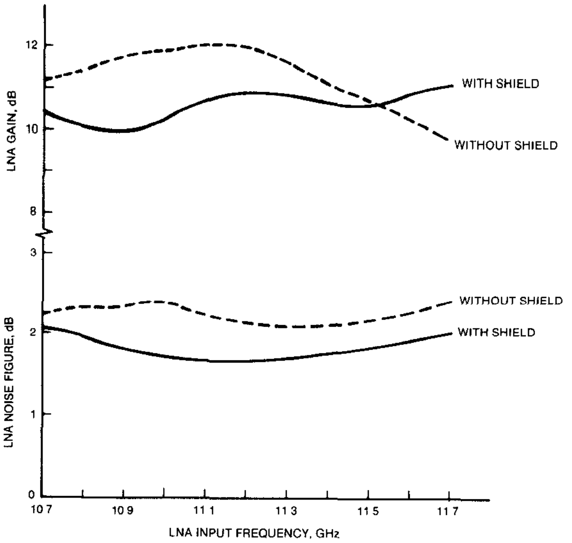

Figure 8. LNA Module Corrected Gain and Noise Figure.

CONCLUSIONS

The concept of plug-in 11-GHz LNA modules have been proven through production testing. No contact problems have been observed from the pressure contact below the plastic frame around the LNA cutout that establishes the ground plane continuity. The change of noise figure and gain from the test receiver used to tune the LNA modules to any random down-converter it is plugged into is insignificant. The LNA module is tuned at one frequency to cover the 10.7- to 11.7-GHz frequency band.

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REFERENCES

(1) Luxton, H. E., "Gallium Arsenide Field Effect Transistors — Their Performance and Application up to X-Band Frequencies," 4th European Microwave Conference Proceedings, 1974, p 94.

(2) Soares, R. A., Turner, J. A., "Tunable X Band GaAs F.E.T. Amplifier," Electronics Letter, Vol. 11, No. 19, September 18, 1975, pp 474-475.

(3) Soares, R. A., "Novel Large Signal S-Parameter Measurement Technique Aids GaAs Power Amplifier Design," 7th European Microwave Conference Proceedings, 1977, pp 113-117.

(4) Soares, R. A., "Design of K-Band Slug Tuners," IEEE Proceedings, Vol. 128, Pt H, No. 3, June 1981, pp 146-150.