MILLIMETRE WAVE RECEIVER COMPONENTS USING PACKAGED HEMTS

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ABSTRACT

A narrow band low noise amplifier (LNA) and a mixer at 30 GHz have been developed using packaged commercial HEMTs and waveguide matching circuits. The four-stage HEMT LNA provided 26 dB gain and 2.8 dB noise figure at 30 GHz. The HEMT mixer provided a conversion gain of 0.5 dB with 5 dB noise figure. The design features very simple construction and tuning.

INTRODUCTION

Recent advances in High Electron Mobility Transistors (HEMTs) have made it possible for three terminal active devices, possessing inherent reverse isolation, to be employed at frequencies where two terminal devices were the only option just a few years ago. However, most of the active circuit development in the millimetre wave region using GaAs FETs and HEMTs has been carried out using monolithic microwave integrated circuit technology (MMIC) or using chip devices in hybrid microstrip line circuits on thin alumina or fused silica substrates. MMIC technique requires large initial expenditure and is cost effective only in large quantity production. Hybrid microstrip line technology using chip devices requires die-bonding and wire bonding equipment and expensive clean room facilities for assembly. The advantages of the above techniques are mainly seen in broadband performance of the circuits.

For narrow band millimetre wave applications such as radioastronomy and beacon receivers, combining waveguide circuit techniques and packaged devices can be extremely cost efficient. This paper describes the development of a 30 GHz low noise amplifier and a low noise mixer for a satellite beacon receiver using commercially available packaged HEMTs that are specified only up to 22 GHz by the device manufacturers. A noise figure of 2.8 dB with a gain of 26 dB has been achieved with a four stage low noise amplifier. A 30 GHz mixer with 5 dB noise figure and 0.5 dB conversion gain has been developed using similar techniques. The main features of these circuits are the extreme simplicity of construction and ease of tuning, whilst achieving excellent performance over narrow bandwidths. The same circuit can be used with different HEMTs for cost - performance trade-offs or at different frequencies with slight retuning.

FOUR-STAGE 30 GHz LOW NOISE HEMT AMPLIFIER

The main design consideration was to use the simplest and least expensive construction techniques possible to achieve the specified noise figure of 4 dB and a minimum gain of 24 dB over a 200 MHz bandwidth centred at 30 GHz. The mechanical construction details of the four-stage LNA are shown in figure 1. Each of the first three stages uses a packaged FHR02FH HEMT from Fujitsu while the last stage uses a packaged NE20383 HEMT from NEC. Since it is important to keep the source inductance small in order not to degrade the gain performance, it was first thought that the source leads would have to be directly grounded to the amplifier housing. However, when the device was modelled over its specified frequency range to extract the bond wire inductance values for the source connection, it was found that the added inductance due to the external ground straps on a 0.25 mm thick substrate was much less compared to the internal bond wire inductance. Hence the HEMTs were mounted on a 0.25 mm thick RT-Duroid 5880 substrate with the source leads connected to the ground plane using wrap around straps to simplify the fabrication. The ground strap connections were made as short as possible.

The gate and drain leads are soldered to 50 Ohm microstrip lines on the substrate mounted inside a 4 mm wide channel to prevent waveguide moding. Microstrip-to-waveguide (WR-28) transitions with a short coaxial section are used on both gate and drain sides to connect the waveguide matching circuits. A fixed back short behind the coupling probe into the waveguide is used in order to avoid the mechanical complexity and losses associated with a tuneable back short. The matching circuits in waveguide for input, interstage, and output matching take the form of triple stub tuners, achieved by three screws spaced an eighth of a guide wavelength apart. The amplifier was made out of aluminium and was silver plated.

Bias to the HEMTs is supplied by thin wires soldered to the 30 GHz chokes printed on the substrate. These wires connect the HEMT leads to the constant current biasing circuitry on an epoxy printed circuit board mounted on the other side of the housing. Stabilising circuits were incorporated on this side to prevent oscillations at lower frequencies.

This design technique was successfully used to build single-stage, two-stage, and four-stage LNAs. The single - and two - stage LNAs with FHR02FH devices

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provided 6 dB, 12 dB gains. The four-stage LNA provided a gain of 29 dB at 30 GHz but was later tuned for slightly broader response with 26.5 dB gain as shown in figure 2. The noise figure of the four-stage LNA was 2.8 dB at 30 GHz and the response is shown in figure 3. The LNA was unconditionally stable. The overall dimensions of this LNA including the bias board are 81 mm(L) x 36 mm(W) x 25 mm(H). Five such amplifiers have been built which required very little time and effort for tuning, indicating the repeatability of this design.

Using the NEC NE20383 in the two-stage amplifier and retuning provided a gain of 10.6 dB and a noise figure of 5.5 dB.

This design technique was investigated at even higher frequencies into the millimetre wave region using the same amplifier module. The four-stage amplifier provided gains of 18 dB, 15 dB, and 12 dB when tuned to 32 GHz, 34 GHz, and 36 GHz respectively using only the tuning screws. It was concluded that even better performance can be obtained at these frequencies by designing printed chokes and the triple stub tuners for the respective frequency of operation. The noise figure was not measured at these frequencies for lack of a local oscillator at these frequencies.

30 GHz HEMT MIXER

A single-stage amplifier module of the type described above was used as a mixer by feeding the drain port with the local oscillator (LO) signal, the gate port with an RF signal, and extracting the IF output through the bias network connected to the drain. The HEMT was operated in the novel nonlinear mode described by Tomasetti [1]. Operation of the HEMT mixer in this mode is easy since only one supply voltage is required. In this mode the source is at ground potential at DC and RF, a negative voltage close to the pinch-off value is applied to the gate and no DC voltage is applied to the drain which is simply connected to the ground through a resistor. The HEMT operates near pinch-off during one half of the LO cycle and full conduction in the reverse direction during the other half of the LO cycle providing the required nonlinearity in the drain current.

With an LO frequency of 29.29 GHz and RF frequency of 30 GHz, the mixer with the Fujitsu FHR02FH exhibited a noise figure of 5 dB with a conversion gain of 0.5 dB. The conversion gain response is shown in figure 4. The noise figure response is shown in figure 5. The dependence of noise figure and conversion gain on the gate voltage is shown in figure 6. The 1 dB compression point occurs at -4 dBm RF power level as shown in figure 7.

The same module with a Fujitsu FHX15LG, which costs about half as much as an FHR02FH, exhibited a noise figure of 6.5 dB and a conversion loss of 0.5 dB. With the very inexpensive MGF4313 HEMT from Mitsubishi, the same mixer exhibited a noise figure of 9 dB and a conversion loss of 3 dB.

CONCLUSIONS

Millimetre wave receiver front end components such as low noise amplifier and mixer have been developed for narrow band applications using packaged HEMTs and inexpensive fabrication techniques. Performance of packaged HEMTs, specified to 22 GHz, has been investigated up to 36 GHz with good results. Better performance can be expected with packages specifically developed for use at millimetre wave frequencies.

ACKNOWLEDGEMENTS

The contribution of Roger Western in tuning and measuring the above components is gratefully acknowledged.

REFERENCES

[1] Tomasetti, G., "An unusual mixer", Proc. European Microwave Conf., pp.754-759, Dublin, 1986.

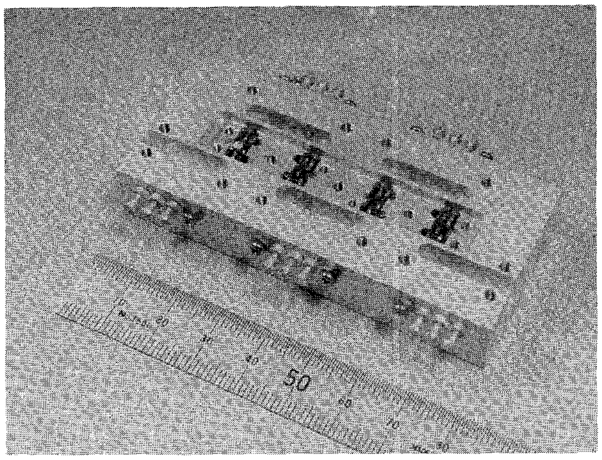

Fig.1 Photograph of the four-stage 30 GHz LNA with the top plate removed

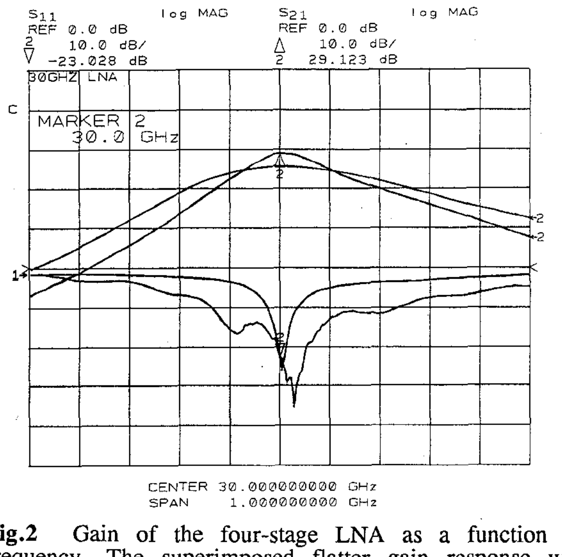

Fig.2 Gain of the four-stage LNA as a function of frequency. The superimposed flatter gain response was obtained by trading off 2.5 dB of gain for increased bandwidth.

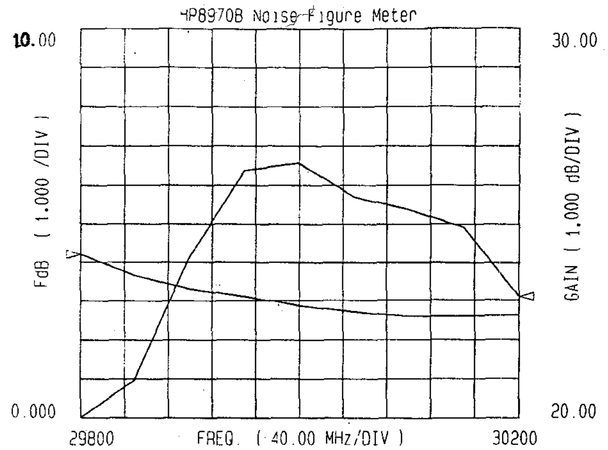

Fig.3 Noise figure response of the four-stage LNA.

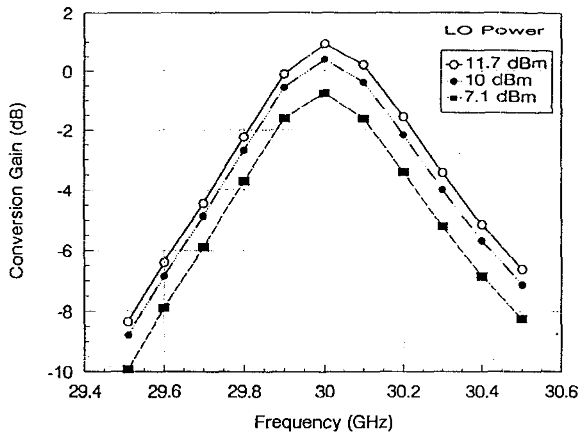

Fig.4 Conversion gain response of the mixer (V_{GS} = -0.45 V, LO Frequency = 29.29 GHz, IF = 710 MHz)

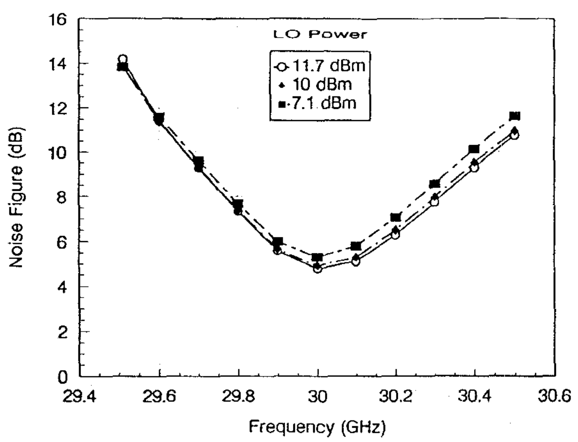

Fig.5 Noise figure response of the mixer (V_{GS} = -0.45 V, LO Frequency = 29.29 GHz, IF = 710 MHz)

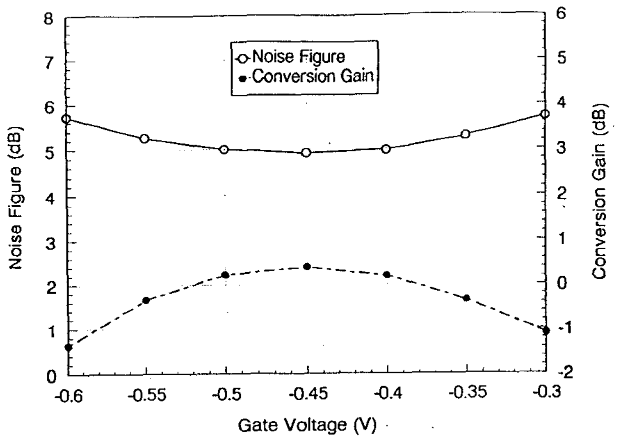

Fig.6 Mixer conversion gain and noise figure vs gate voltage (LO Power = 10 dBm, RF=30GHz ,LO Frequency=29.29 GHz, IF=710 MHz)

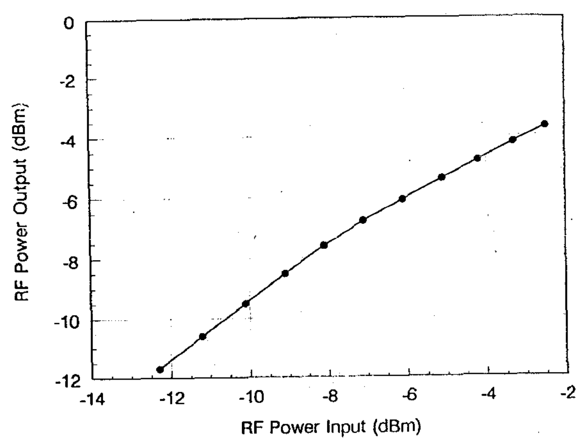

Fig.7 Mixer transfer characteristics (LO power = 10 dBm, V_{GS} = -0.45 V, RF = 30 GHz, LO Frequency=29.29 GHz, IF = 710 MHz)