A 30 GHz MONOLITHIC RECEIVER*

L.C.T. Liu**, C.S. Liu, J.R. Kessler, and S.K. Wang

Hughes Aircraft Company
Microwave Products Division
P.O. Box 2940, Torrance, CA 90509-2940

ABSTRACT

Several monolithic integrated circuits have been developed to make a 30 GHz receiver. The LNA chip has 7 dB noise figure with 14 dB gain. The IF amplifier has 13 dB gain with 30 dB control range. The mixer and phase shifter have conversion loss and insertion loss of 10.5 dB and 1.6 dB, respectively.

INTRODUCTION

Monolithic microwave integrated circuits (MMICs) are becoming easier to manufacture and potentially less costly due to recent advances in GaAs material and processing (1-2). However, at frequencies above 30 GHz, monolithic technology is not yet mature, and only a few papers have been published (3-6). Monolithic IC development at these frequencies is hampered by a number of problems including device performance, device measurement and modeling, monolithic component realization, and IC measurement.

In this paper we describe the systematic development of a 30 GHz receiver using monolithic chips for a communication antenna feed array (8). This includes the design, fabrication, and measured results of each submodule chip, and the complete receiver module. This is the first Ka-band receive module using all monolithic chips. This is the first step towards fabricating an entire module on a single GaAs chip.

RECEIVER DESIGN

The object of this work was to develop a 27.5 to 30 GHz receiver module for use in a phased array antenna. The modules need variable gain and phase so that the beam can be aimed in any direction. Figure 1 shows the system block diagram of the receiver module. A two-stage low-noise amplifier (LNA) sets the noise figure of the system, a mixer chip downconverts the signal to an IF band of 4 to 6.5 GHz, a five-bit phase shifter is used at the LO frequency, and a variable gain IF amplifier provides amplitude control. Using the phase shifter at the LO frequency minimizes phase errors due to frequency and amplitude variations. The design goals of this receiver were 5 dB noise figure, 10 dB gain, and six gain states.

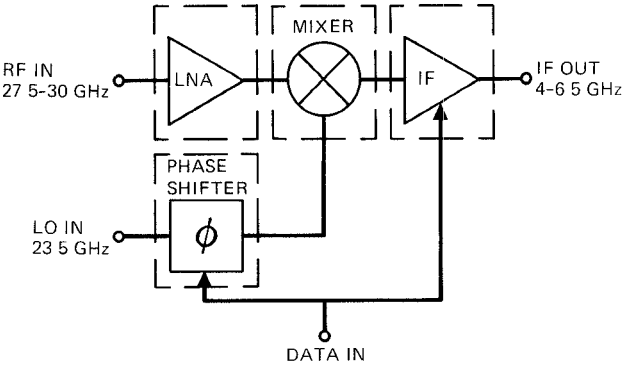

Figure 1 Receive module block diagram.

All four monolithic submodule chips have been developed, and can be directly integrated to form a receiver module as shown in Figure 2. The details of each chip and the receiver integration will be discussed in the following sections.

LOW NOISE AMPLIFIER CHIP

The low-noise amplifier design has been presented before (3). The amplifier chip shown in Figure 3 uses two 0.25 x 150 um FETs. They were fabricated using an active layer produced by silicon ion implantation at 100 keV into a LEC substrate. The gate structure was written by electron-beam lithography in multilayer resist. MOM capacitors were used for both RF bypass and dc blocking applications. High airbridges fabricated on 4 um thick photoresist were used to connect the source pads and to interconnect the microstrip lines to the top plate of the MOM capacitors. The amplifier uses via hole grounding. The LNA chip has demonstrated an average noise figure of 7 dB with an associated gain of 14 dB at 30 GHz. The gain response and the noise figure of this amplifier are illustrated in Figure 4. This is the first reported monolithic LNA operating at Ka-band frequencies.

*This work was supported in part by NASA Lewis Research Center under Contract NAS3-23357.
**Dr. Liu is currently at TRW.

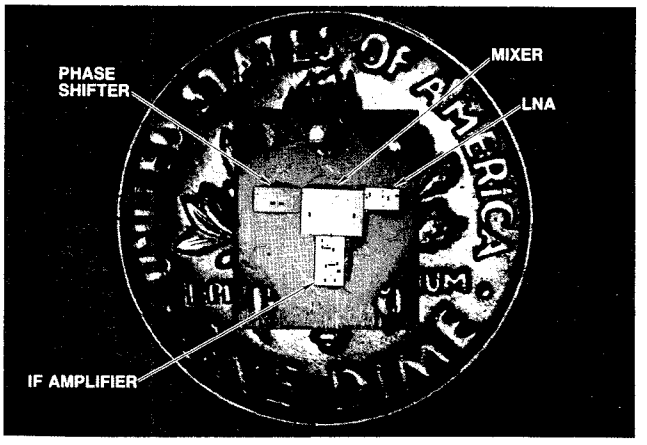

Figure 2 30 GHz receiver module using monolithic chips.

IF AMPLIFIER

A two-stage resistive-feedback IF amplifier was developed to operate from 2 to 6.5 GHz. The schematic of the amplifier is shown in Figure 5. Microstrip transmission lines were used for RF matching because of their low loss, low dispersion, and useful impedance range. The amplifiers used two 0.8 x 300 um gate FETs. The FET equivalent circuit model was calculated from the measured S-parameter data of discrete FETs.

MOM overlay capacitors were used for RF bypassing and dc blocking. Airbridges were used to interconnect the source pads and to connect the microstrip lines to the top plate of the overlay capacitors. a substrate thickness of 0.1 mm was chosen to facilitate the fabrication of via hole with high yield. The via hole ground allowed greater flexibility in the layout of the amplifier because grounds can be placed almost anywhere on a circuit rather than only at the substrate edges. In addition, it could lower the source grounding inductance and reduce the time required to mount the amplifier circuit. The circuit was analyzed using computer simulation and FET equivalent circuit models. The completed amplifier chip is shown in Figure 6, and the entire chip size is 1.1 x 1.9 x 0.1 mm.

The passive components include thin film resistors, MOM and interdigitated capacitors, spiral inductors, and via holes. The MOM capacitors and the resistors were fabricated with tantalum pentoxide and tantalum nitride films, respectively.

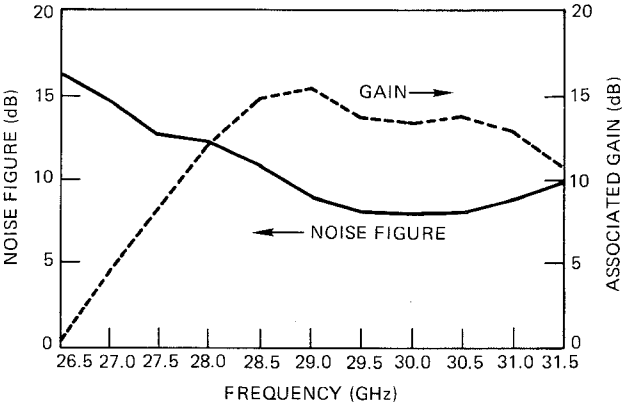

Figure 4 Ka-band monolithic LNA performance.

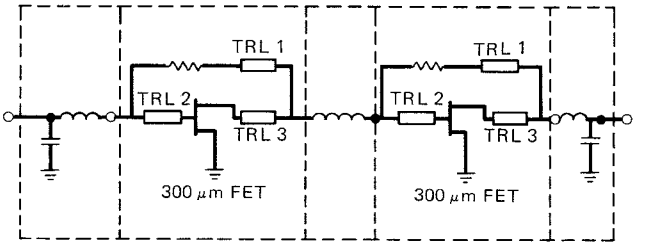

Figure 5 Schematic of the IF amplifier design.

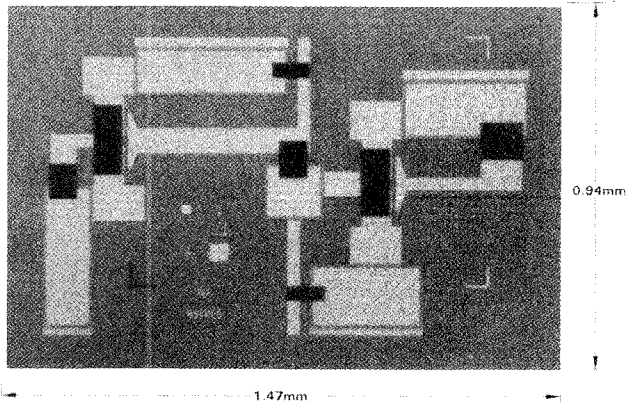

Figure 3 27.5 30 GHz monolithic low noise amplifier.

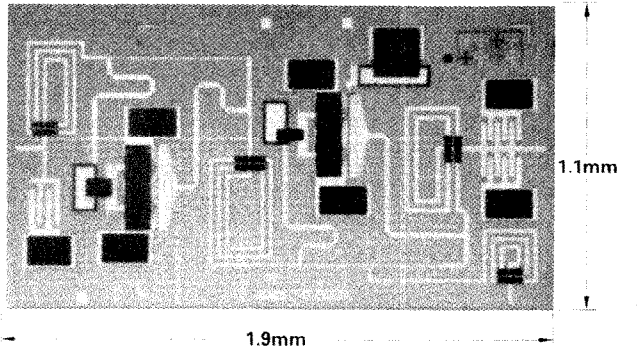

Figure 6 Photograph of the IF amplifier chip.

The active devices are a standard MESFET and a dual-gate MESFET with 0.8 x 300 um gate fingers fabricated by contact photolithograph. Varying the bias of the second gate of the dual-gate MESFET controls the gain. Measured data show that this amplifier has a gain control range of over 30 dB with a maximum gain of 13 dB (Figure 7). The noise figure was less than 5 dB across the band at all gain levels.

MIXER

The balanced mixer (Figure 8) consists of a pair of Schottky barrier diodes and a Lange coupler. A single-pole low-pass filter with quarter wavelength stubs is employed in the IF port to reject RF and LO frequencies. Since the goal is to integrate diodes with FETs on the same GaAs chip for future single chip receive modules, a selective and multiple-charge ion implantation was used to fabricate the diodes. A N/N^+ implant profile with a heavy selective N^+ implant in the ohmic area was used. The resulting diodes had a cutoff frequency of up to 550 GHz and an ideality of 1.2. The measured data indicates that the mixer has a conversion loss of about 10.5 dB across the frequency band (Figure 9).

PHASE SHIFTER

The phase shifter consists of an interdigitated Lange coupler together with a pair of GaAs Schottky barrier diodes to form a small, high-yield transmission phase shifter as shown in Figure 10. The varactor diodes were fabricated on an active layer formed by multiple-charge ion implantation into a LEC substrate. The cut-off frequencies of these devices range up to 450 GHz. In addition, a 3 to 1 capacitance swing is obtained by varying the bias voltage. The five-bit phase shift at 23.5 GHz can be accomplished with the diode bias voltage varying from 0 to 8 V, as shown in Figure 11. The insertion loss is 1.6 dB at the highest point of reverse bias (8 V).

RECEIVER INTEGRATION

As shown in Figure 2, these four monolithic submodule chips can be directly connected with bond wires and can be mounted on a compact test carrier. We

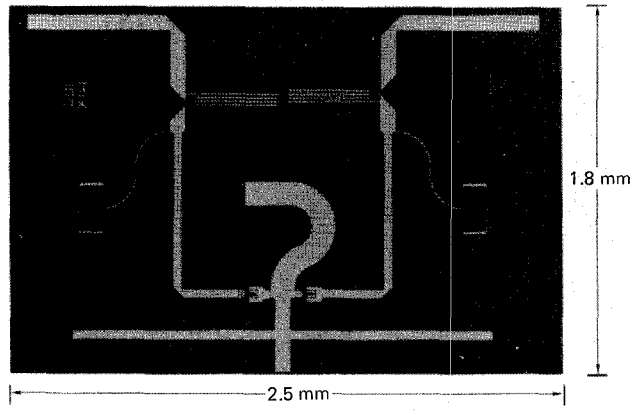

Figure 8 Photograph of a Ka-band monolithic mixer.

are currently fabricating a test carrier and a housing which will provide all the necessary blocking capacitors and bias lines to facilitate the receiver evaluation. The results of this evaluation will be presented at the conference.

Our goal is to integrate all the submodules into one chip. To do this, we have to fabricate FETs and diodes on the same wafer. Multiple ion doses and energies will be selectively implanted into a LEC substrate to form the active areas for the FETs and diodes. These active areas can be isolated with proton bombardment. Fabrication of the passive components is a standard MMIC process.

CONCLUSION

Four monolithic chips for a 30 Ghz receiver module have been developed for communication antenna feed arrays. A selective and multiple-charge ion implantation technique has been developed which permits the

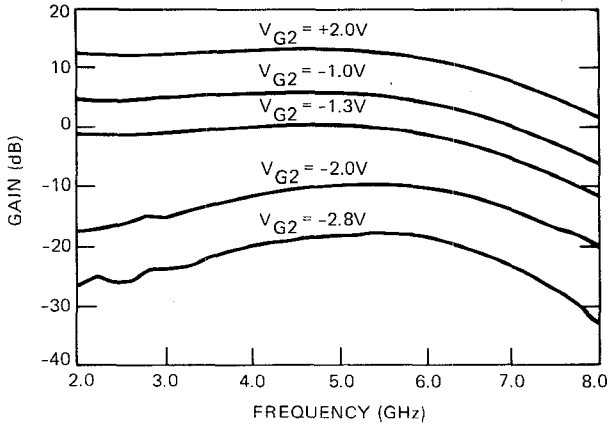

Figure 7 Measured performance of variable gain IF amplifier.

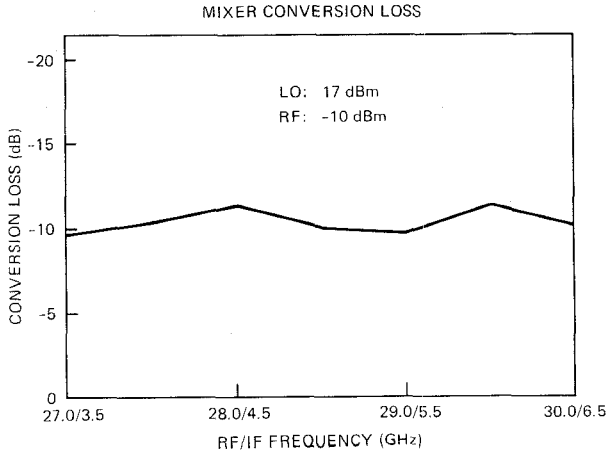

Figure 9 Measured conversion loss of the Ka-band monolithic mixer.

Output Return Loss vs AGC.

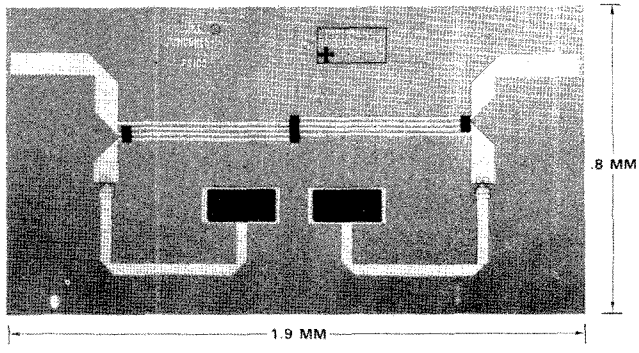

Figure 10 Photograph of the Ka-band monolithic phase shifter.

integration of both diodes and FETs on the same chip. This technique holds the promise of making a fully monolithic receiver module. This single chip approach has the potential for inexpensive fabrication of receiver modules. This in turn shall promote the use of future satellite communication systems which require large quantities of identical receiver modules.

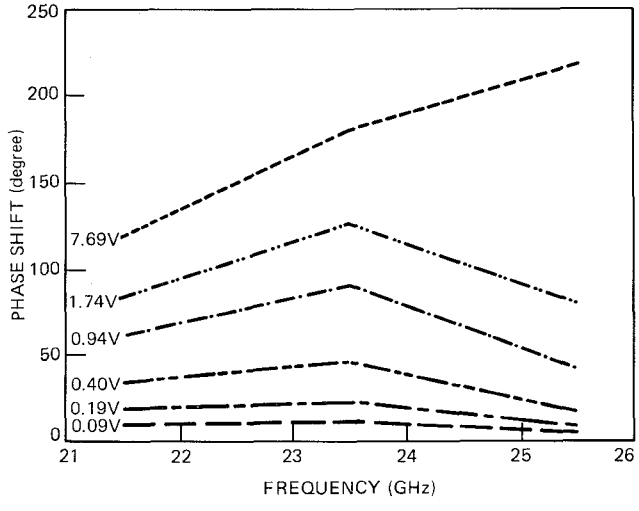

Figure 11 Measured performance of the monolithic phase shifter.

ACKNOWLEDGEMENTS

The authors wish to thank P. Asher and P. Riemenschneider for their technical support. We also thank L. Brown, L. Cochran, A. Gomex, D. Hynds, M. Rex, D. Rezzuti, M. Siracusa, and G. Vitale for their assistance.

REFERENCES

1. S. K. Wang, C. D. Chang, M. Siracusa, L. C. T. Liu, R. G. Pauley, P. G. Asher, and M. Sokolich, "Production Technology for High-Yield, High Performance GaAs Monolithic Amplifiers," IEEE Trans. Microwave Theory Tech., December 1985.

2. S. K. Wang, D. C. Wang, C. D. Chang, L. C. T. Liu, M. Siracusa, and K. G. Wang, "GaAs MMIC Producibility," 1985 Producibility of Microwave and Millimeter-Wave Integrated Circuits Conference, Nov. 1985, Redstone arsenal, Alabama.

3. L. C. T. Liu, P. Riemenschneider, S. K. Wang, and H. Kanber, "A 30 GHz Monolithic Two-Stage Low Noise Amplifier," Technical Digest, 1985 IEEE GaAs IC Symposium, pp. 7-10, November 1985, Monterey, California.

4. R. G. Pauley, P. G. Asher, J. M. Schellenberg, and H. Yamasaki, "A 2 to 40 GHz Monolithic Distributed Amplifier," Technical Digest, 1985 GaAs IC Symposium, November 1985, Monterey, California.

5. D. W. Maki, J. M. Schellenberg, H. Yamasaki, and L. C. T. Liu, "A 69 GHz Monolithic FET Oscillator," Digest of IEEE 1984 Microwave and Millimeter-Wave Monolithic Circuits Symposium, pp. 62-66, May 1984.

6. H. Q. Tserng and B. Kim, "A 115 GHz Monolithic GaAs FET Oscillator," Technical Digest, 1985 IEEE GaAs IC Symposium, pp. 11-13, November 1985, Monterey, California.

7. B. E. Spielman, "Monolithic Millimeter-Wave Integrated Circuits," Technical Digest, 1985 IEEE GaAs IC Symposium, pp. 3-6, November 1985, Monterey, California.

8. G. Anzic and D. J. Connolly, "20 and 30 GHz MMIC Technology for Future Space Commuication Antenna Systems," Technical Digest, 1984 IEEE GaAs IC Symposium, pp. 189-192, October 1984, Boston, Massachusetts.