

## PERFORMANCE OF FIVE 30 GHZ SATELLITE RECEIVERS

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Technology development contracts funded by NASA have resulted in five 30 GHz satellite receivers of various design. This paper presents and discusses the results of tests performed at NASA Lewis Research Center to determine the operating characteristics of the receivers and their ability to perform in a digital satellite link.

### Introduction

For the past 10 years, NASA has been developing technology intended to enhance the performance of future satellite communication systems. This work has focused on systems operating at 30 GHz uplink and 20 GHz downlink frequencies. A major part of this technology thrust is the development of 30 GHz low noise satellite receivers. As a result of technology development contracts, five receivers of various design have been delivered. These receiver models have undergone extensive testing at NASA Lewis Research Center to determine their operating characteristics and their performance in a satellite communication system transmitting high rate digital data. In the following sections, the design of the receivers will be described, and the results of performance measurements will be presented and discussed.

### 30 GHz Low Noise Satellite Receiver Designs

The delivery of completed hardware from the five development contracts spanned the time period of 1982 through 1987. Two parallel contracts, under the management of NASA Lewis, were completed in late 1982 by LNR Communications, Inc. and ITT Defense Communications Division. Figure 1 shows the basic functional design of these receivers.<sup>1</sup> Both LNR and ITT used an image-enhanced diode mixer for the receiver front end, followed by a FET IF amplifier. The designs varied in method of local oscillator (LO) generation and operating frequency. The resulting hardware consisted of a complete receiver unit, requiring only dc bias and an LO reference.

NASA Goddard Space Flight Center initiated a contract with Hughes Aircraft Company, Microwave Product Division, which resulted in the delivery of completed receiver models in the fall of 1984. One receiver was sent to NASA Lewis for evaluation

under the Lewis satellite communication system component test program. As shown in Fig. 2, the Hughes design consists of a hybrid combination of GaAs FET microwave integrated circuits (MIC's) developed by Hughes for this project.<sup>2</sup> The receiver front end is a 30 GHz GaAs FET low noise amplifier (LNA) MIC, which is followed by an MIC mixer and an IF amplifier. The LO is an internally generated 22 GHz FET dielectric resonator oscillator. The complete receiver package requires only a dc bias.

These three receivers are generally intended for use in 30/20 GHz satellite communication systems with single-feed satellite receive antenna systems. Such an antenna system may consist of a single feed horn or a feed-horn cluster which would permit a beam-hopping system. This system would consist of an array where different groups of feed horns are switched on to provide receive coverage scanning geographically isolated areas. In all these cases, the received signal is collected and combined to provide an input signal to a single receiver.

For electronically scanned antenna systems, a multi-element phased array antenna is used. This system consists of an array of antenna elements, each connected to an individual receiver which includes controllable phase shifters and variable gain amplifiers. Control of these elements allows the antenna beam to be spatially scanned. Each receiver processes only a portion of the signal incident on the antenna. The receiver outputs are then combined into single received signal. For this type of system, a monolithic microwave integrated circuit (MMIC) receiver is required. Therefore, a development program was initiated by NASA Lewis in 1982. Contracts were awarded to Hughes Aircraft Co., Microwave Products Division<sup>5</sup> and Honeywell Sensors and Signal Processing Lab<sup>6</sup> for the development of a 30 GHz monolithic receiver. The receivers consist of an LNA, mixer, gain control amplifier (GCA), and phase shifter. Although both contractors were to meet the same program goals, Hughes and Honeywell used different design approaches. Honeywell performed all amplification and phase shifting at 30 GHz, while Hughes did the phase shifting at the LO frequency and the GCA at the IF. Extra filtering and amplification were added by NASA Lewis to create a complete satellite

receiver in order to allow testing. The block diagrams of the Honeywell and Hughes MMIC receivers are shown in Fig. 3 and 4, respectively.

#### Test Results

To determine their performance in a high data rate digital satellite transmission system, the receivers were tested in the automated measurement system shown in Fig. 5. The system simulates an end-to-end satellite communications link, operating at a data rate of 220 Mbps. The modulation type is serial minimum shift keying (SMSK). Discrete amounts of noise are added at the system output to allow measurement of the BER as a function of  $E_b/N_0$ .<sup>4</sup> An example of the results of such a measurement is shown in Fig. 6 for the five receivers tested at an input power level of -30 dBm.

A summary of the test results obtained is given in Table I. The RF test data is presented in detail in Refs. 1 to 3, 5 and 6. The BER data given represents the degradation of the measured curve, in dB, compared to the theoretical curve, at a BER of  $10^{-6}$ . For a typical system, the receiver with the highest gain and lowest noise figure should give the lowest BER. At the lower power levels, the BER performance is directly related to the noise figure of the receiver. A BER of  $10^{-6}$  could not be obtained for the Honeywell receiver below a -50 dBm input and for the Hughes MMIC receiver below -30 dBm input because of their high noise figure. The Hughes MMIC receiver performed poorly because the LNA operated optimally at 32-34 GHz; at 30 GHz, the noise figure was very high and no gain was obtained. The Honeywell MMIC receiver used a two-stage LNA. Honeywell's final design will use a six-stage LNA, which will provide a significant gain increase and noise figure reduction. In NASA's tests, the MMIC receivers, consisting of two or more interconnected MMIC fixtures, suffered significantly from interstage mismatch problems.

At higher power levels, the noise figure was not a factor in BER performance except for the Hughes MMIC receiver. The most important factor above -50 dBm was the frequency response of the combined receiver and test system. Due to the various output operating frequencies of the receivers, it was not always possible to test them at their optimum design frequency and the band center of the test system simultaneously. Therefore, the variation of BER results between the receivers at the higher power levels does not necessarily indicate significant performance differences. We consider any BER degradation less than 3.0 dB to indicate acceptable receiver performance.

#### Conclusion

In general, digital satellite communication systems are required to provide a maximum BER of

$10^{-6}$ . The Hughes MMIC receiver is the only one which did not meet this criteria at the power levels tested. The other receivers met this criteria with a maximum  $E_b/N_0$  degradation of 2.6 dB for an input power of -30 dBm. System performance degradation is observed when the receiver input power is reduced to the noise figure limit of the receiver. Thus, the receiver noise figure is a limiting factor in system performance. The three hybrid receivers performed well for input powers as low as -50 dBm.

The MMIC receivers performed poorly relative to the hybrid receivers. Since an MMIC scanning antenna system would combine the outputs of many MMIC receivers, the system  $E_b/N_0$  obtained would be higher than for each individual receiver. Therefore, adequate system performance may still be obtained with these receivers. In addition, further improvements in MMIC design and optimization are likely to improve performance.

#### References

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2. Watkins, E.T., and Schellenberg, S.M., "Hybrid Microwave Integrated Circuit Ka-Band Low Noise Receiver," (NASA Contract NAS5-26731) Hughes Aircraft Co., Microwave Products Division, Torrance, CA, 1984.
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TABLE I. - SUMMARY OF TEST RESULTS FOR FIVE 30 GHz SATELLITE RECEIVERS

Parameter	Receiver				
	LNR Communications 1982	ITT Defense Communications 1982	HAC Microwave Products Division 1984	Honeywell Sensors and Signal Process Lab 1987	HAC Microwave Products Division
Input band, GHz	27.5 to 30.0	27.5 to 30.0	27.5 to 30.0	27.5 to 30.0	27.5 to 30.0
Output band, GHz	3.7 to 6.2	2.3 to 4.8	5.5 to 8.0	4.5 to 7.0	3.0 to 5.5
LO frequency, GHz	23.8	25.2	22.0	23.0	24.5
Gain (maximum), dB	22	19	41	13	-5.2
Gain variation over 2.5 GHz, dB	3.8	4.8	5.2	5.2	5.0
Noise figure (minimum), dB	5.8	6.8	3.7	14.0	>20
Input VSWR (Max. over 2.5 GHz)	2.3:1	3.4:1	3.1:1	3.6:1	>10:1
Output VSWR (Max. over 2.5 GHz)	1.7:1	1.4:1	2.3:1	8.5:1	3.8:1
1 dB Compression point midband (input), dBm	-7	-8	-27	-3	-2
BER degradation, -30 dBm In, HPA saturated, dB	1.1	2.0	2.6	0.9	6.8
BER degradation, -40 dBm In, HPA saturated, dB	1.0	2.1	1.5	2.5	-----
BER degradation, -50 dBm In, HPA saturated, dB	1.2	2.5	2.5	18.4	-----
BER degradation, -60 dBm In, HPA saturated, dB	3.8	6.6	2.5	-----	-----
Dynamic range at -10 dBm input, dB	N/A	N/A	N/A	>13	>18
Insertion phase envelope as a function of gain, deg	N/A	N/A	N/A	$\pm 10$	$\pm 15$
Gain envelope as a function of phase state, dB	N/A	N/A	N/A	$\pm 2$	$\pm 2$
Phase shift/phase shift increment, deg	N/A	N/A	N/A	360/11.25	180/Continuous
Design topology	Hybrid	Hybrid	Hybrid - MIC	Multiple-chip MMIC	Multiple-chip MMIC

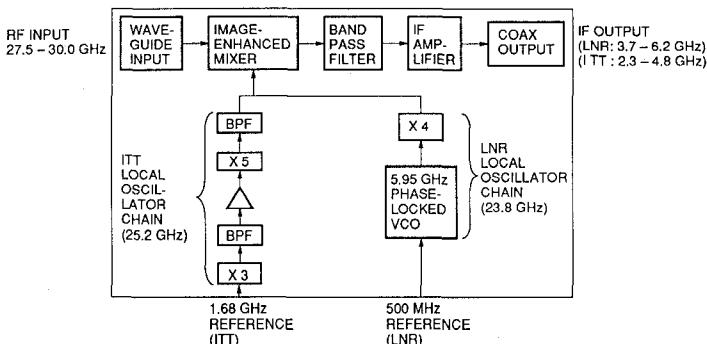
<sup>a</sup>Hughes measurement

Figure 1. - Functional block diagram for the LNR Communications, Inc., and ITT Defense Communications 30 GHz low noise receivers.

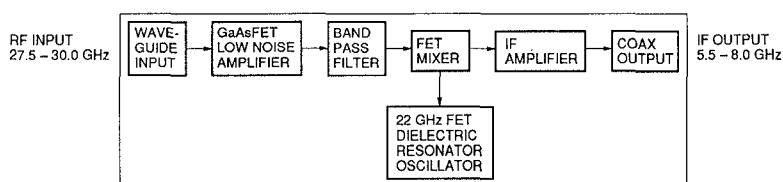


Figure 2. - Functional block diagram for the Hughes Hybrid - MIC 30 GHz low noise receiver.

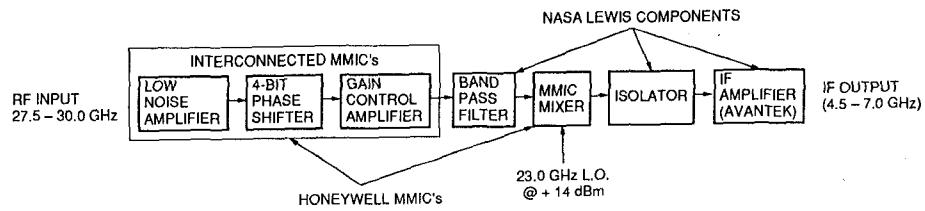


Figure 3. - Honeywell MMIC receiver test configuration.

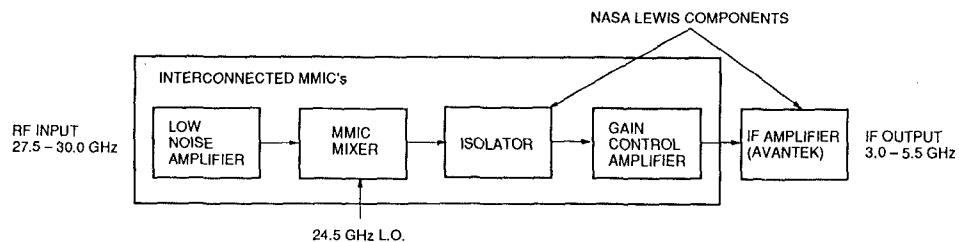


Figure 4. - Hughes MMIC receiver test configuration.

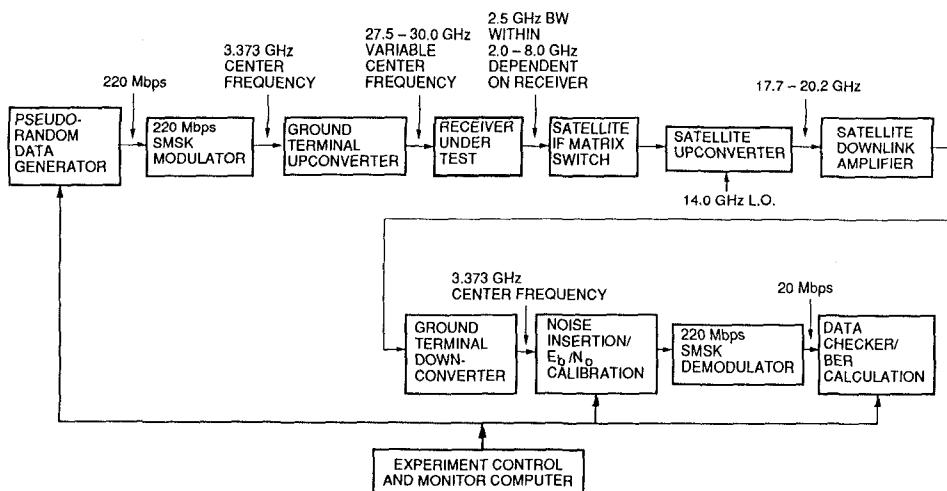


Figure 5. - Block diagram of the receiver BER measurement system.

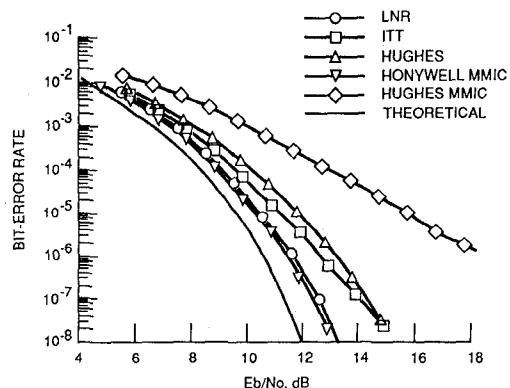


Figure 6. - Measured BER curves, for the LNR, ITT Hughes Hybrid-MIC, Honeywell MMIC, and Hughes MMIC receivers. Input power to the receivers is -30 dBm, and the satellite high power amplifier is in saturation.