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"GaAs PHEMT and InP HEMT MMIC Requirements for Satellite Based Communications Systems"

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Traditionally a majority of the commercial satellite communications systems have been fixed repeaters at C-band and Ku-band. The satellite industry is presently undergoing significant changes in the types of systems that are being fielded. New low earth orbit and geo stationary mobile systems have large numbers of flexible beams at either L-band or S-band through the use of large phased array antennas. On the other end of the spectrum new families of Ka-band satellite systems are utilizing either multibeam or phased array antennas for large numbers of spot beams and are moving to provide broadband capability. At the higher end of the spectrum traditionally reserved for government communications systems commercial satellite operators have filed for use of V-band frequencies. All of these new applications means that satellite manufactures are going to be using ever increasing quantities of MMIC devices at a much broader range of frequencies.

This presentation will focus on the requirements for MMICs for Ka-band and higher frequency satellite payloads. At Ka-band the satellite payloads receive at nominally 30 GHz and transmit at 20 GHz. The low noise figure and high gain requirements for the receivers at 30 GHz are aggressive and hence for many applications the InP HEMT low noise MMIC amplifier is the technology of choice. In satellite payloads, performance is a key requirement and large quantities (1000's) of MMICs are needed detailed on-wafer testing of the MMIC's is an important capability. An example of a two stage InP HEMT MMIC is shown in Figure 1. This MMIC was designed at Boeing Satellite Systems (BSS) and fabricated at HRL Laboratories for operation in a Ka-band (30 GHz) low noise receiver front end. On-wafer measurements of noise figure, gain, return loss, and phase have been made on large quantities of this Ka-band low noise InP HEMT MMIC's. Noise figure, gain, return loss, and phase data from 554 MMIC's from a single InP HEMT wafer are shown in Figures 2, 3, 4, and 5, respectively. The data is very tightly grouped with 85% of the MMICs having noise figure in a 0.2 dB range and 93% of the MMICs with gain in a 3 dB range.

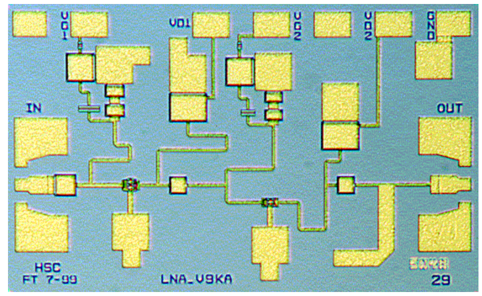

Figure 1. Photograph of two stage Ka-band InP HEMT MMIC LNA.

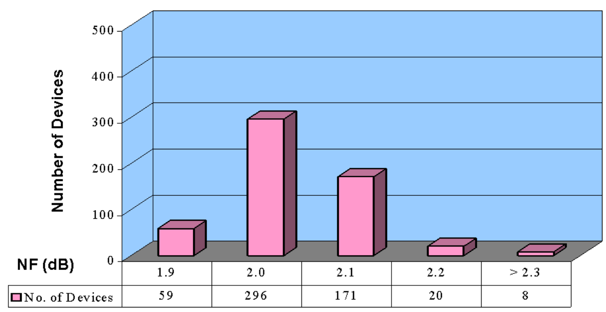

Figure 2. Noise figure distribution for 554 InP HEMT two stage Ka-band MMICs measured with an automated on-wafer RF probing system.

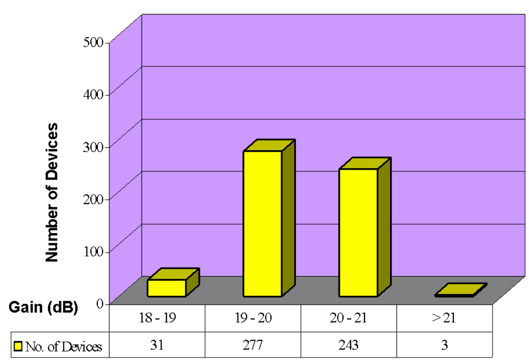

Figure 3. Gain distribution for 554 InP HEMT two stage Ka-band MMICs measured with an automated on-wafer RF probing system.

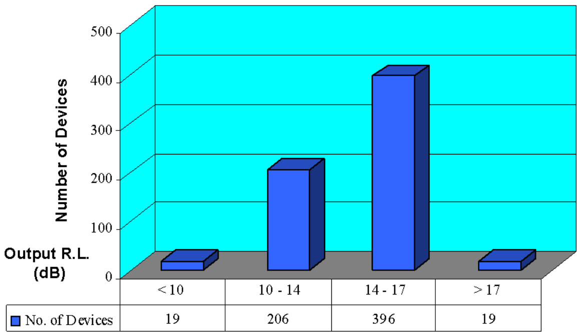

Figure 4. Output return loss distribution for 554 InP HEMT two stage Ka-band MMICs measured with an automated on-wafer RF probing system.

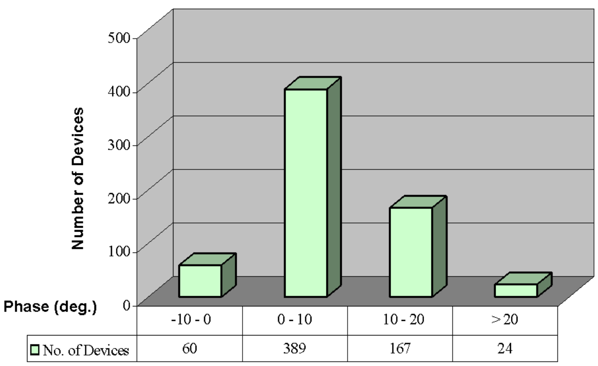

Figure 5. Phase distribution for 554 InP HEMT two stage Ka-band MMICs measured with an automated on-wafer RF probing system.

For Ka-band applications where noise figure is not a requirement GaAs PHEMT MMIC's are utilized in nonlinear applications or to provide higher output powers. GaAs PHEMT MMICs, a more mature technology, also provide a lower cost solution for large quantities. Once again screening of the RF performance is an important selection criteria in satellite applications where passband gain flatness, return loss, and device uniformity requirements can be strict. An example of a Ka-band GaAs PHEMT MMIC is a Ka-band to S-band downconverter mixer that follows the InP HEMT MMIC low noise front end. The PHEMT process is chosen for the larger breakdown voltage, lower cost, and excellent process uniformity. An HP 84000 automatic wafer probe station is used for on-wafer DC and RF data measurements. A plot of the conversion loss of the 435 MMIC mixers for a GaAs PHEMT wafer is shown in Figure 6. The median conversion loss is –9 dB with 90% of the MMICs better than –9.9 dB. A pass/fail wafer map for the Ka-band to S-band mixer MMIC is shown in Figure 7 where 43% of the MMICs in this wafer passed all DC and RF requirements.

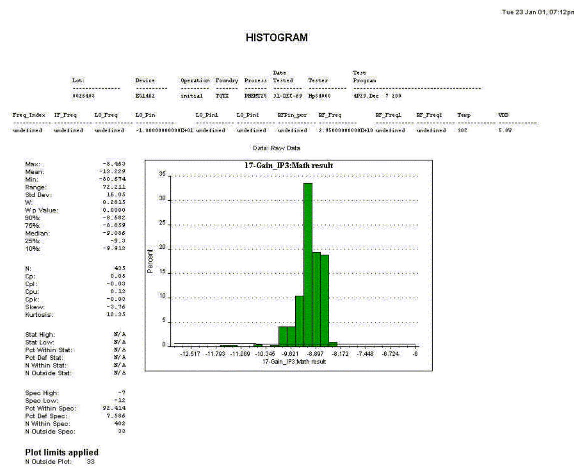

Figure 6. Plot of Ka-band to S-band MMIC mixer conversion loss for 435 MMICs from a single GaAs PHEMT wafer.

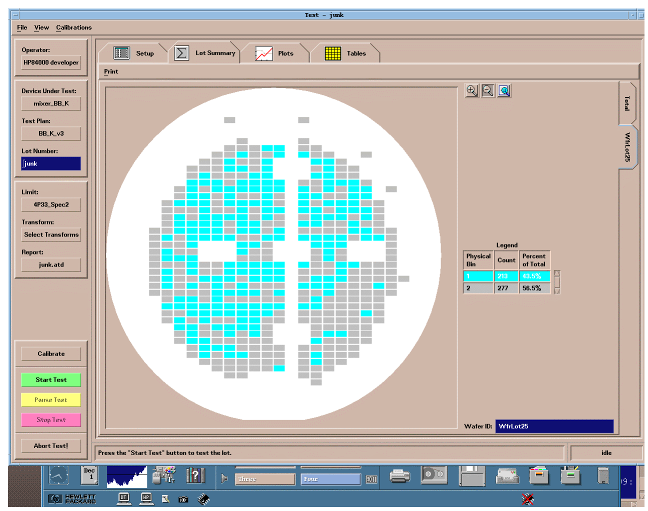

Figure 7. Pass / fail wafer map of Ka-band to S-band MMIC mixer for 435 MMICs from a single GaAs PHEMT wafer.

For the transmit side of the Ka-band payload, a 20 GHz MMIC amplifier was designed by BSS and fabricated utilizing a 0.25 μm GaAs PHEMT fabrication process. A large number of wafers have been fabricated and tested using the HP84000 automatic test station at BSS. A plot of the RF gain for 3358 20 GHz MMICs is shown in Figure 8. The median value of the gain is 26.6 dB with the 10% and 90% points at 25.8 and 27.4 dB, respectively. The standard deviation of this data set is 0.55dB.

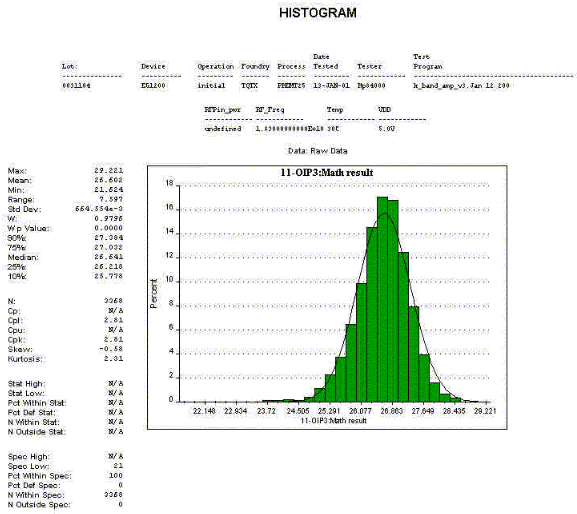

Figure 8. Gain distribution plot for 3358 Ka-band GaAs PHEMT MMIC amplifiers.

Future commercial satellite payloads will operate at V-band with receive at 50 GHz and transmit at 40 GHz. BSS has designed a number of MMICs at both Q-band and V-band for a number of applications.[1,2] A two stage InP HEMT low noise MMIC was designed to meet the EHF communications receiver requirements at 44 GHz. The broadband gain of a large group of these MMICs measured on-wafer is shown in Figure 9. With fixed bias conditions, 46% of the Q-band two stage MMICs measured had greater than 16 dB gain from 42 GHz to 48 GHz.

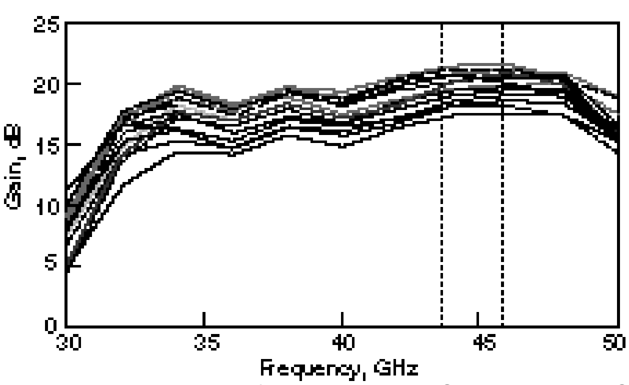

Figure 9 Measured data from a two stage Q-band LNA MMIC design

The noise figure and gain of a single two stage Q-band MMIC was measured in a fixture over a narrower bandwidth centered at 44 GHz as shown in Figure 10. For this sample an excellent minimum noise figure of 1.8 dB was measured with 20 dB of associated gain.

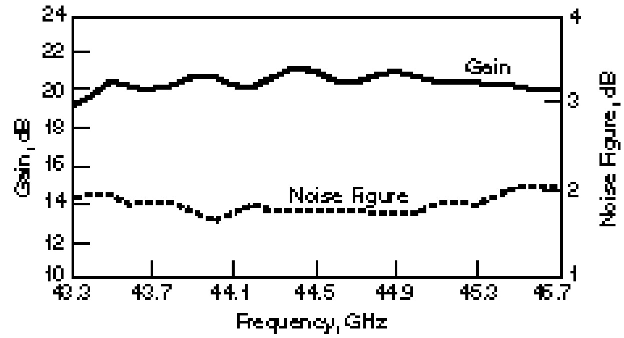

Figure 10 Measured data from a two stage Q-band LNA MMIC design

At V-band a four stage InP HEMT MMIC low noise amplifier was designed and fabricated. Measurements were made in a fixture from 59 GHz to 65 GHz and the noise figure and gain is shown in Figure 11. The gain per stage has reduced significantly at this frequency and the minimum noise figure is now 2.5 dB.

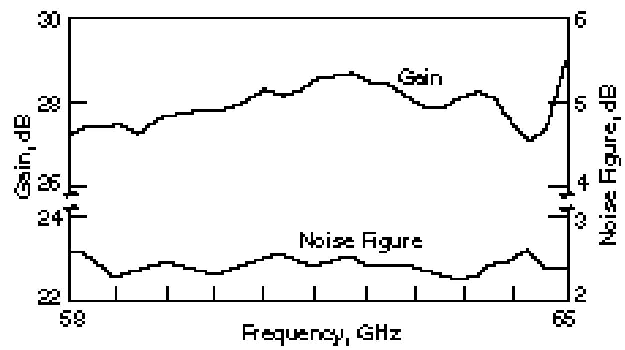

Figure 11 Measured data from a four stage V-band LNA MMIC design

For satellite payload applications, where 15-20 operation lifetimes are common and on-orbit replacement is not an option, reliability is key requirement for both InP HEMT and GaAs PHEMT MMICs. While there is a significant amount of reliability on GaAs PHEMT MMICs there is very limited lifetest data on InP HEMT MMICs. BSS has performed a very detailed DC and RF thermally accelerated lifetest[3] on a two stage Ka-band InP HEMT low noise MMIC that was described earlier in this paper. The lifetest carrier was fixtured to allow periodic DC and RF measurements to be performed on the MMICs. The lifetest was performed at two temperatures, 190C and 210C, with 10 samples at each temperature. The change in the RF data for the noise figure, gain, and phase of the two stage InP HEMT MMICs is shown in Figures 12, 13, and 14, respectively for the 190C data set. The data is all well behaved and the test was extended out to 3000 hours. The most significant changes were in the gain. With an arbitrary failure criteria of 1 dB gain reduction selected, an MTTF = 7×10^6 hours and an EA=1.13 eV was obtained.

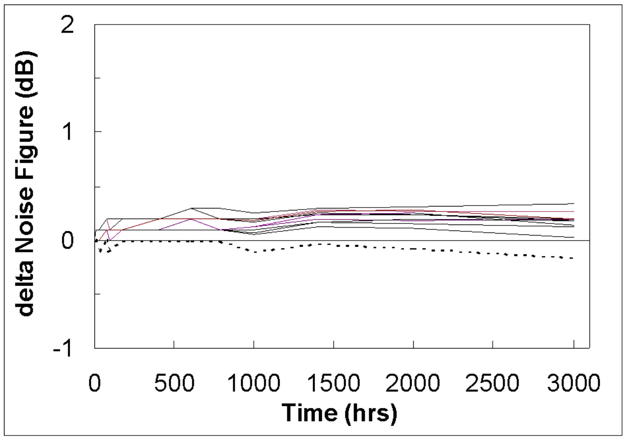

Figure 12 Noise figure variation during a thermal accelerated lifetest for a two stage low noise InP HEMT MMIC at 190C.

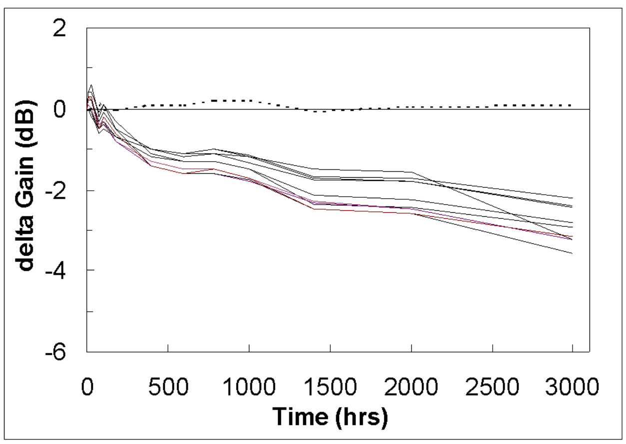

Figure 13 Gain variation during a thermal accelerated lifetest for a two stage low noise InP HEMT MMIC at 190C.

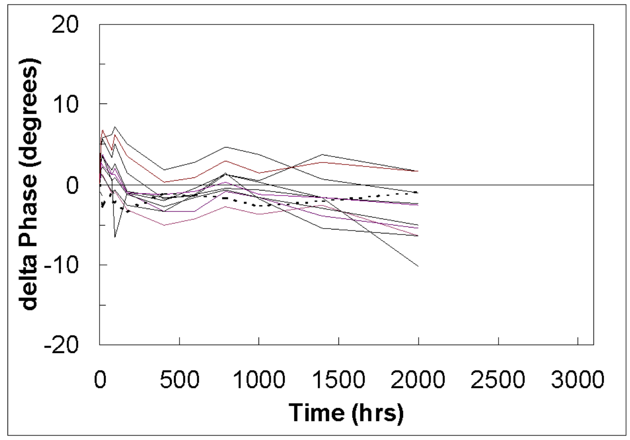

Figure 14 Phase variation during a thermal accelerated lifetest for a two stage low noise InP HEMT MMIC at 190C.

In conclusion, satellite communications systems are presently utilizing large quantities of high reliability Ka-band MMICs fabricated in both InP HEMT and GaAs PHEMT foundries. Future system will utilize V-band MMICs operating at 40 GHz and 50 GHz.

References:

1. "Frequency translation MMICs using InP HEMT Technology", Tran, L.; Delaney, M.; Isobe, R.; Jang, D.; Brown, J. Microwave and Millimeter-Wave Monolithic Circuits Symposium, 1996. Digest of Papers., IEEE 1996 , 1996 , Page(s): 193 –196

2. "High performance, high yield millimeter-wave MMIC LNAs using InP HEMTs",Tran, L.; Isobe, R.; Delaney, M.; Rhodes, R.; Jang, D.; Brown, J.; Nguyen, L.; Le, M.; Thompson, M.; Liu, T. Microwave and Millimeter-Wave Monolithic Circuits Symposium, 1996. Digest of Papers., IEEE 1996 , 1996 , Page(s): 133 –136

3. "Ka-band InP HEMT MMIC Reliability", Paine, B.; Wong, R.; Delaney, M. Schmitz A.; Walden,R. GaAs Reliability Workshop, 2000., Proceedings , 2000 , Page(s): 21-44