Recent Test Results of a Flight X-Band Solid-State Power Amplifier Utilizing GaAs MESFET, HFET, and PHEMT Technologies

Elbert Nhan, Sheng Cheng, Marshall J. Jose, Steve O. Fortney, and John E. Penn
The Johns Hopkins University Applied Physics Laboratory
11100 Johns Hopkins Road
Laurel, MD 20723-6099
Tel: 240-228-7702
Fax: 240-228-6696
elbert.nhan@jhuapl.edu

Abstract

In support of the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft that The Johns Hopkins University Applied Physics Laboratory (JHU/APL) is currently building under NASA's Discovery Program, an onboard telecommunication system has been designed and will be assembled at JHU/APL. One of the main components of the system is an X-band solid-state power amplifier (SSPA) operating at 8.433 GHz that supports various downlink antennae including an eight-element phased array. This SSPA subsystem is comprised of over 40 hybrid devices, each of which along with internal matching circuits contains one of the following five different GaAs part types manufactured by Triquint Semiconductor, Inc.: (1) 8810 Metal-Semiconductor Field Effect Transistor (MESFET) Gain Block Amplifier Microwave Monolithic Integrated Circuit (MMIC), (2) 4230 Heterostructure Field Effect Transistor (HFET) Amplifier, (3) 4240 HFET Amplifier, (4) 9083 Pseudomorphic High-Electron-Mobility Transistor (pHEMT) High Power Amplifier MMIC, and (5) 6336 MESFET Phase Shifter MMIC. The hybrid package has been custom-designed at JHU/APL specifically for spaceborne applications. In this paper, we will discuss the 168-hour burn-in and 1000-hour life tests for the hybrids that have been undergoing device screening and space qualification testing. For the approximately 140 samples that were screened in the burn-in test, there were minor shifts in certain device parameters such as the 1-dB compression and power gain, although the DC drain and gate currents showed negligible changes. Such initial parameter shifts are typical of devices settling into their stable long-term useful-life behaviors. At present, the life test is in progress and interim test results will be presented at the Workshop. All preliminary indications point to sufficient device reliability for the MESSENGER space mission. This work demonstrates the viability of employing a blend of proven (MESFET) and recently matured (PHEMT and HFET) technologies for space hardware.

Introduction

The JHU/APL Space Department is responsible for developing a complete onboard telecommunication system for the MESSENGER spacecraft. Among the subsystems, an SSPA, with a center operating frequency of 8.433 GHz, amplifies the downlink signal from the transponder and outputs it to various low gain, fanbeam and an eight-element phased array antenna through direct or switched RF connections. Two redundant versions of the telecommunication system are employed with cross strapping to ensure the required level of system reliability. The SSPA utilizes a combination of proven and advanced commercial GaAs technologies of MESFET (8810 and 6336 MMICs), HFET (4230 and 4240 discrete microwave transistors), and pHEMT (9083 MMIC), all available from the Triquint Semiconductor Standard Product Line. The five major building blocks of the SSPA mentioned have been subjected to a rigorous screening and qualification regimen as part of the standard parts processing flow prior to being incorporated into the final assembly for the SSPA.

Hybrids Packaging Design

Packaging is critical in providing protection for a high-frequency device from the environment to maximize its useful life. For the SSPA hybrid devices, a special space-qualifiable housing has been designed by JHU/APL and fabricated by Kyocera. CuMo is used for the base of the package for its excellent thermal conductivity as well as its coefficient of thermal expansion (CTE) match with a GaAs MMIC or transistor, making the package suitable for high power application. KOVAR, another material with excellent CTE match with GaAs, makes up the walls and lid of the package. Alumina and thin film materials are used for signal feedthroughs, and the entire package is covered with a gold plated finish. Particle/humidity as well as hydrogen getter substances are attached to the inner

surface of the gold-plated KOVAR lid to safeguard the active die from potentially damaging hydrogen and moisture that could limit the reliability of the GaAs device. The lid is then secured over the top of the package by welding to hermetically seal the entire package.

Test Plan

To assess the long-term reliability of the hybrids, a test flow with the following steps are shown below:

1. Temperature cycling.
2. Constant acceleration.
3. PIND test.
4. Helium pressurization.
5. Fine and gross leak tests.
6. Perfluorocarbon pressurization test.
7. X-ray radiographic test.
8. Pre-burn-in electrical test.
9. Burn-in test for 168 hours.
10. Post-burn-in electrical test.
11. External visual inspection.
12. Life test for 1000 hours.
13. Post-life test electrical verification.
14. Data review.

Test Results

The 168-hour burn-in test has been completed on all samples. As can be seen in the viewgraphs (slide number 19), there was no significant parameter degradation. The 1000-hour life test is currently in progress, and the test results will be presented at the Workshop. All post-burn-in device samples were electrically functional, and changes between the pre- and post-burn-in S-Parameters, power gain, and 1-dB compression were tolerable and within system design limits.

Summary and Conclusion

Custom-packaged hybrid GaAs MMICs and discrete transistors commercially available from Triquint Semiconductor have been subjected to rigorous screening and qualification for space applications. The test results indicated that these devices are sufficiently robust and reliable for use in spaceborne applications.

2002 GaAs Reliability Workshop
Monterey, CA
10/20/02

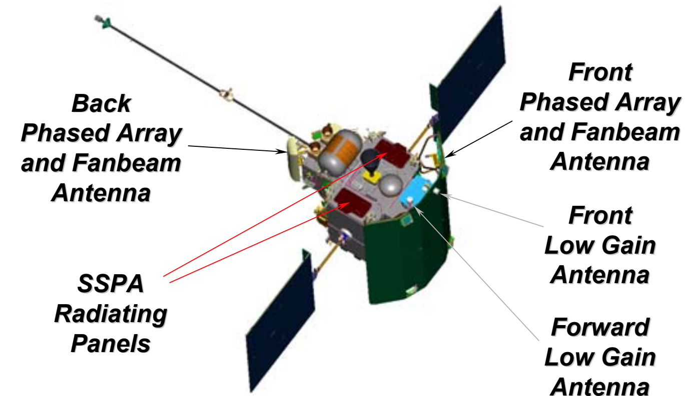
Recent Test Results of Commercial GaAs MESFET, HFET, and PHEMT Devices for Use in a Flight Solid-State Amplifier

Elbert Nhan, Sheng Cheng, Marshall J. Jose,
Steve O. Fortney, and John E. Penn
The Johns Hopkins University
Applied Physics Laboratory
11100 Johns Hopkins Road
Laurel, MD 20723-6099
Tel: 240-228-7702
Fax:240-228-6696
E-Mail: elbert.nhan@jhuapl.edu

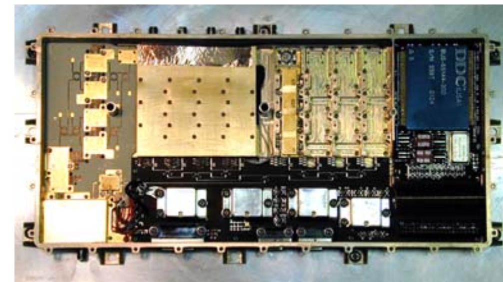
Outline

- Introduction
- Solid-State Power Amplifier (SSPA)
- Commercial GaAs MMICs and Discrete Device Types Used in SSPA
- Custom-Designed Hybrid Device Housing
- Hybrids Qualification and Screening Test Methodology
- Burn-In Test Results
- Life Test Results
- Conclusion

Introduction



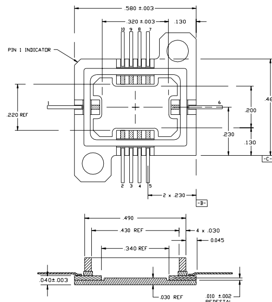
SSPA Pre-Flight Model

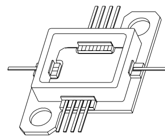


SSPA Hybrid Overview

- A single hybrid package design is used to house 5 different type of devices individually:
  - 8810 Gain Block Amplifier MMIC
  - 4230 HFET Amplifier
  - 4240 HFET Amplifier
  - 9083 High Power Amplifier MMIC
  - 6336 Phase Shifter MMIC
- 41 hybrids are needed in each SSPA.
- Total count of flight hybrids to be built prior to screening is 276, assuming 50% total yield.

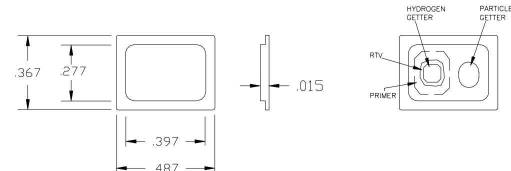
SSPA Hybrid Package





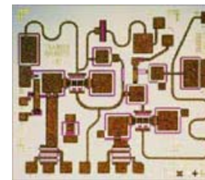
- Cu/Mo base for thermal conductivity & CTE match to GaAs, Kovar wall and leads, Alumina and thin film signal feedthroughs. Gold plated finish.
- Designed by JHU/APL, manufactured by Kyocera.

Hybrid Package Lid



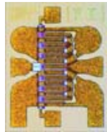
- Gold plated Kovar lid.
- Particle getter is also the humidity getter.
- Hybrid package hermetically sealed by welding lid to the package wall.

8810 MMIC Specifications



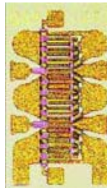
- 2-Stage, General Purpose Gain Block Amplifier
- TriQuint Semiconductor Standard Product
- GaAs MESFET Technology
- Single +5V Supply
- Unconditionally Stable
- Frequency Range: 2 – 10 GHz
- Typical Small Signal Gain: 17 dB
- Typical P_{1dB}: 17 dBm
- Die Size: 0.074 x 0.065 x 0.006 in.

4230 HFET Specifications



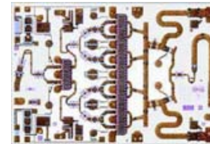
- 0.5 um Gate, 1.2 mm Total Periphery Single Transistor
- TriQuint Semiconductor Standard Product
- GaAs HFET Technology
- For +8V Operation at 8.5GHz:
  - Nominal Pout = 28.5 dBm
  - Nominal Gain = 10 dB
  - Nominal PAE = 55%
- Die Size: 0.023 x 0.028 x 0.004 in.

4240 HFET Specifications



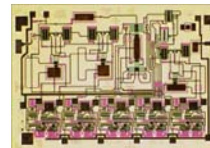
- 0.5 um Gate, 2.4 mm Total Periphery Single Transistor
- TriQuint Semiconductor Standard Product
- GaAs HFET Technology
- For +8V Operation at 8.5GHz:
  - Nominal Pout = 31.5 dBm
  - Nominal Gain = 10 dB
  - Nominal PAE = 56%
- Die Size: 0.023 x 0.039 x 0.004 in.

9083 MMIC Specifications



- 2-Stage Power Amplifier, with On-Chip Active Gate Bias Circuit
- TriQuint Semiconductor Standard Product
- 0.25um GaAs pHEMT Technology
- Frequency Range: 6.5 – 11.5 GHz
- For 7V Operation, P_{out} = 37dBm, PAE = 40%
- Typical Small Signal Gain: 19 dB, Input Return Loss: 12 dB, Output Return Loss: 9 dB
- Die Size: 0.178 x 0.120 x 0.004 in.

6336 MMIC Specifications

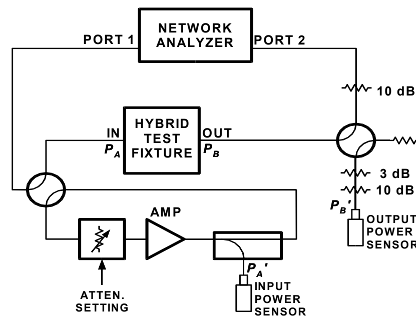


- 5-Bit Phase Shifter, with On-Chip CMOS Compatible Drivers
- TriQuint Semiconductor Standard Product
- GaAs MESFET Technology
- Frequency Range: 6 – 18 GHz
- Typical Insertion Loss: 9 dB
- Typical Input Return Loss: 9.5 dB
- Typical Output Return Loss: 7.0 dB
- Max Continuous Input Power: 1 W
- Die Size: 0.140 x 0.100 x 0.004 in.

Flight Hybrid Screening Steps

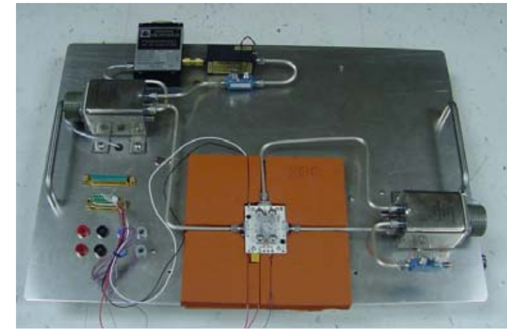
1	Temperature Cycle, -65 to +150°C, 10 cycles
2	Constant Acceleration, 3000 g, Y1 Axis, 1 minute
3	PIND Test, 20 g peak at 130 HZ
4	Helium Pressurization at 60 PSI, 4 hrs min., 1 hr dwell.
5	Fine Leak Test, Max leak rate = 5 x 10^{-8} atm cc/sec He
6	Perflourocarbon Pressurization, at 45 PSI min, 4 hrs. min.
7	Gross Leak Test, no bubbles, Fluid at 125°C
8	Radiographic (X-ray), Y-axis view only
9	**Pre-Burn-in Electrical**
10	Burn-in, Temp = 125 to 130°C, Time = 160 Hrs. min
11	**Electrical Test, at 20°C, must be completed within 96 hours out of burn-in.**
12	External Visual Inspection
13	QA Data Review
14	**Life Test, Temp = 125 to 130°C, Time = 1000 Hrs. min, 5 samples per hybrid type**
15	**Electrical Test, at -30°, 20°, and 70°C**
16	Life test Data Review
17	Deliver to Next Assembly

Hybrid Test Setup



- **Setup permits power sweep & measurement of s-parameters without disturbing device-under-test**

Hybrid Test Plate

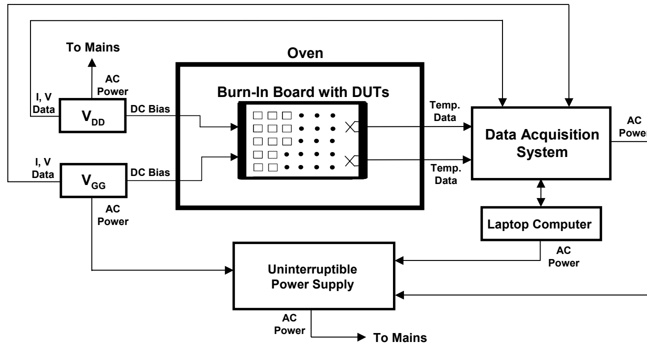


- **Temp. controlled air-jet rests on test fixture cushion**

Hybrid Testing Software

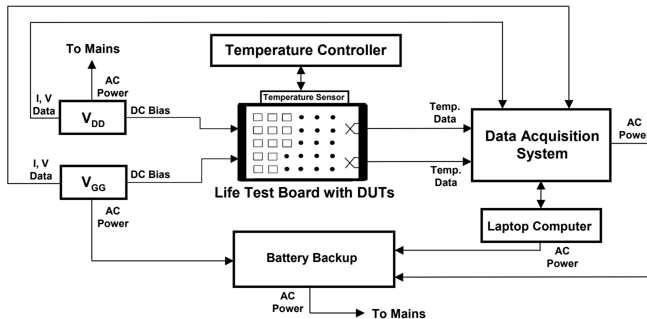
- Labview employed to provide simple GUI for operator.
- Matlab and Excel programs used for number crunching and other tasks.
- Quantities recorded:
  - S-parameters
  - P_{OUT} vs P_{IN} including compression point
    - Also used to “tune” for the best bias point on some units
  - Phase constellation for phase shifters
- Data acquired and archived offline.

Burn-In Test Setup



- 4-Wire Voltage Sense Wiring of the Power Supplies Used.

Life Test Setup



- 4-Wire Voltage Sense Wiring of the Power Supplies Used.
- DUTs Were Terminated With 50-Ohm Loads.
- Thermocouples Were Attached to Selected Devices.

Burn-In Test Results (pre- and Post-Burn-In Changes)

Hybrid Type	Stat. Type	Sample Size	Δ S11	Δ S21 (dB)	Δ S22	Δ Gain (dB) Pout=16.3 dBm	Δ $I_{+6.5V}$ (mA) Pout=16.3 dBm	Δ P_{out} dBm) @ P_{1dB}	Δ $I_{+6.5V}$ mA) @ P_{1dB}	Δ I_{-5V} (mA) @ P_{1dB}
4230	Ave.	29	-0.00698	-0.2624	0.02426	-0.2563	-1.8207	-0.2616	-0.5284	-0.0552
4230	S.D.	29	0.07075	0.4855	0.07501	0.4949	0.6067	0.4181	2.2816	0.2131
4240	Ave.	15	0.02225	-0.0730	0.07033	0.0614	-16.500 **	0.3103	-4.0741**	0.0000
4240	S.D.	15	0.01541	0.0747	0.10712	0.0955	6.5995 **	0.2959	1.2652 **	0.0000
8810	Ave.	31	0.01431	0.0513	0.01699	---	---	-0.4297	0.6683	---
8810	S.D.	31	0.09213	0.5469	0.01997	---	---	0.1541	1.2631	---
9083 (+6.5V)	Ave.	43	-0.0004	-0.1861	-0.00780	---	0.4311 A (I_{-7V_Q})	0.8688 dB * Compression	0.0053 A * (I_{-7V})	0.0930 mA (I_{-5V})
9083 (+6.5V)	S.D.	43	0.02039	0.3110	0.03499	---	0.0381 A (I_{-7V_Q})	0.4159 dB * Compression	0.0220 A * (I_{-7V})	0.7176 mA (I_{-5V})
6336	Ave.	38	0.02870	0.0600	0.0239 ° (Δ S21ϕ)	0.00380 (S22)	1.1118 ° (Abs. Mid ϕ)	-0.2779 ° (ϕ Error)	0.0263 mA (I_{-5V})	-0.1316 mA (I_{-5V})
6336	S.D.	38	0.04040	0.0943	0.0784 ° (Δ S21ϕ)	0.04011 (S22)	2.5235 ° (Abs. Mid ϕ)	0.4238 ° (ϕ Error)	0.2835 mA (I_{-5V})	0.4140 mA (I_{-5V})

** @Pout = 34.8 dBm*

*** @ VDD = +7 V*

Life Test Results

Life test is in progress. The interim test results will be presented at the 2002 GaAs REL Workshop.

Conclusion

- GaAs MMIC and Discrete Hybrid Devices Utilizing MESFET, HFET, and PHEMT Technologies Successfully Developed for Space Applications.
- Specially Designed Hybrid Package Enables Survivability in Space Environment.
- Burn-In Test Performed Showed Little or No Parameter Degradation.
- Life Test Is in Progress With Updated Results Presented at This Workshop.
- A Combination of Proven and Recently Matured Technologies May Be Implemented in Space Hardware.