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FINAL TECHNICAL REPORT

MMIC PACKAGE FOR MILLIMETER WAVE FREQUENCY

CONTRACT NO: NAS 3-27813

PREPARED FOR

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TABLE OF CONTENTS

SECTION

1.0

EXECUTIVE SUMMARY

Under a previous program sponsored by NASA Lewis Research Center (NASA/LeRC) in Cleveland, a reliable, high performance, low cost package for high frequency communications electronics was successfully developed. The package has many unique features which include:

- Broadband capability covering 18 to 36 GHz,
- Hermetically sealable
- Adaptability to accept MMIC's of different sizes
- Low cost manufacturability for commercial and military applications.

Taking the next step, NASA Lewis Research Center initiated a program by making use of the existing 18-36 GHz package design as the baseline from which manufacturing, mass production, reliability and quality assurance issues are addressed and perfected. Princeton Microwave Technology, assembled an experienced team in microwave technology, monolithic microwave integrated circuit technology, and ceramics processing technology for the successful transition of the existing package to a commercial product which was manufactured by one of the leading microwave package manufacturing companies in the United States.

The MMIC packages developed under this packaging technology were designed to operate over the frequency range of 18 to 44 GHz. The package design was based on 92% alumina ceramic material using a high temperature co-fired system. Extensive efforts were used to replicate the dielectric constant and dielectric loss properties of the original design material. To this end a dielectrometer was used to verify the properties of materials obtained from major suppliers of HTCC material. It was quickly determined that the availability of the ceramic material with the desired properties was not available and that the data supplied by the suppliers were inconsistent and did not take into account the frequency dispersion of the dielectric constant. The characterization eventually led to the selection of a tape at Microcircuit Packaging of America Inc., and manufacturing of the package followed soon thereafter.

The performance of the packages were measured in an Intercontinental Microwave test fixture up to 40 GHz. The package demonstrated repeatable performance from DC to 40 GHz, with an insertion loss of 1 dB per transition and a return loss of 15 dB at 30 GHz.

The packaging effort performed under this contract was intended to determine the manufacturing issues associated with the packages. Demonstration of the package performance using single stage MMIC amplifiers was accomplished from DC to 30 GHz.

2.0

INTRODUCTION

The objective of the MMIC packaging technology program is to develop a generic packaging scheme that permits low cost and timely insertion of MMIC devices into NASA communications systems.

The development and design of the original package was well documented. A complete design was licensed from Hughes Aircraft. PmT visited Hughes Aircraft and talked to the original designers of the package in order to determine the critical parameters. Their input was to obtain the substrate with a dielectric constant and dielectric loss consistent with the original design. The objective for the manufacturing of the package was to replicate the material characteristics. The ceramic substrates to be used for this program is one of the key elements for the MMIC package. The package designed under the original R & D program used high temperature co-fired ceramic substrates with a dielectric constant of 9.5 provided by Kyocera. PmT contacted many US ceramic substrate manufacturers including MPA, Mistler, Coors, etc. None of the companies had ceramic substrates for co-firing applications with a dielectric constant of 9.5. For example, Coors Ceramic Company, for their production packages, has tape cast substrates with a dielectric constant of 9.1 measured at 1 MHz. The frequency dispersion of dielectric constant was not specified or known.

The limited availability of a substrate with a dielectric constant of 9.5 forced PmT to look at the redesign of the package feed through transition to adapt to a dielectric constant of 9.1. The transition was analyzed using a simple model in Touchstone and confirmed [1], by 3D electromagnetic simulator. The simulations indicated that a dielectric constant of 9.1 for the ceramic substrate will provide a good electrical performance which was very close to the original design. The change in the dimensions of the transition due to the change of the dielectric constant was within the manufacturing tolerance and therefore required no modifications. The only other issue left was to determine if the manufacturer supplied dielectric constant was accurate for our application when frequency dispersion is taken into account.

To determine the accuracy of the value of dielectric constant and its dispersion with frequency we contacted GDK Products Inc., to conduct the appropriate measurements. The GDK measurements system uses a non-destructive method of determining the dielectric constant and loss factor. All samples received from the substrate manufacturers were subject to measurements and it was determined that substrate specified at 1 MHz with a dielectric constant of 9.1 exhibited a dielectric constant of 8.3 GHz at 15 GHz. The frequency of measurement is determined by the thickness of the sample. This was consistent with the majority of the substrate vendors. For example Mistler procured the raw material from Coors and used the 1 MHz values for his formulation. The measurements of Mistler substrate exhibited similar characteristics to that of Coors. The measured properties of the various substrates are documented in section 2.1

To speed up the overall measurement procedure Princeton Microwave utilized a GDK products dielectrometer . This enabled PmT to test a large array of ceramic substrates at a faster rate and provide appropriate feedback to MPA.

Following the selection of the green tape material, MPA was asked to proceed with the manufacture of the package with their standard high temperature co-fired ceramic process. The selected substrate exhibited a dielectric constant of 9.063 at a frequency of 11.484 GHz with a loss tangent of 0.00189. The only other change to the original package design was a change in the layout of the bias ports due to a discrepancy in the earlier design. The modifications are detailed in section 2.2.

2.1 Substrate Material Measurements

A number of substrates were received from Microcircuit Packaging of America, MPA. All of the substrates were processed internally by MPA. The substrates were sent to GDK Products in Cazenovia, NY, by PmT for characterization. Following is the summary of the measurements on the first batch of substrates.

Substrate No.	Dielectric Constant	Loss Tangent	Frequency GHz
1	8.664	.0015	13.0736
2	8.657	.0022	13.0376
3	8.775	.0031	13.0417
3*	8.830	.0026	13.0213
3**	8.889	.0028	13.0194

* Tight Coupling ** Loose coupling during measurement in test cavity [2].

Due to the low dielectric constant, MPA sent more substrates for characterization. The following properties were measured.

Substrate No.	Dielectric Constant	Loss Tangent	Frequency GHz
1 (White)	8.690	.0069	13.0968
2 (White)	7.875	.0061	13.5457
3 (White)	7.450	.0034	14.0669
1 (Black)	8.928	.0022	11.5141
2 (Black)	**9.063**	**.0019**	**11.4840**
3 (Black)	8.932	.0018	11.5510

None of the substrates received from MPA achieved the desired dielectric constant of 9.5. Subsequently a substrate from MPA with a dielectric constant of 9.063 (#2, Black) was selected. Other vendors were not able to provide a substrates with the desired dielectric constant.

In order for our manufacturing to be successful and to meet RF performance requirement with the new substrate a 3D electromagnetic simulation of the package was conducted [1], with a lower dielectric constant. The results of this analysis is detailed in Figure 1. The change of the dielectric constant did not cause a significant of the RF performance. Since the loss tangent was close to the design value, it was decided to place an order with MPA for the package manufacture with the selected tape.

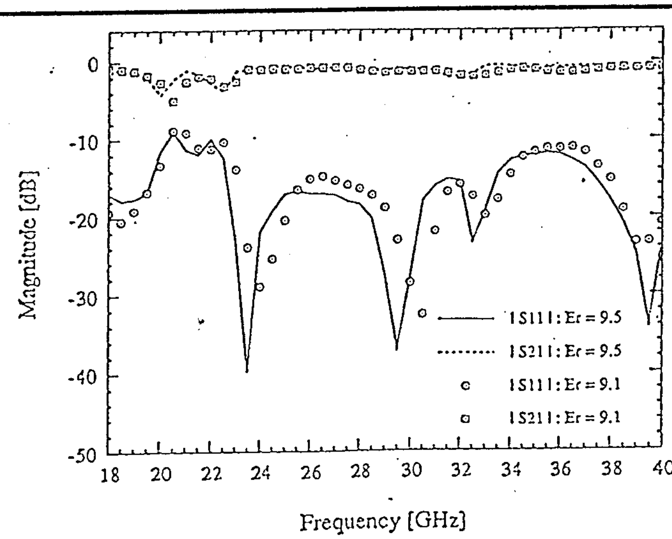


Figure 1: 3D Analysis of the Ceramic Package

2.2 Package Fan-out Design

The mechanical layout of the original package was conducted by MPA before manufacture. A flaw was discovered in the fan-out pattern associated with the bias lines at the corner. The flaw, detailed in Figure 2, was due to the slant lines having an angle that interfered with the stress relieving circles at the corners of the cavity. To alleviate this problem without affecting the RF performance of the package, the following modifications were agreed upon with MPA. Basically, the dimension 0.015 has been changed to 0.040 as shown in Figure 3. This change will not affect the location of the visa which are critical to the RF performance of the package.

There were some inconsistencies also with the dimensions of the transition as shown in Figure 4. The first inconsistency was the length of the transmission lines at the inside edge of the substrate next to the cavity. If we subtract 0.064 from 0.076, the length should be 0.012 instead of 0.016. The second inconsistency was the length of the transmission lines at the outer edges of the substrate. This dimension , shown in Figure 4, was 0.026 whereas in Figure 3 it was 0.030. It was ascertained that 0.026 was the correct dimension and therefore it was modified as shown in Figure 3.

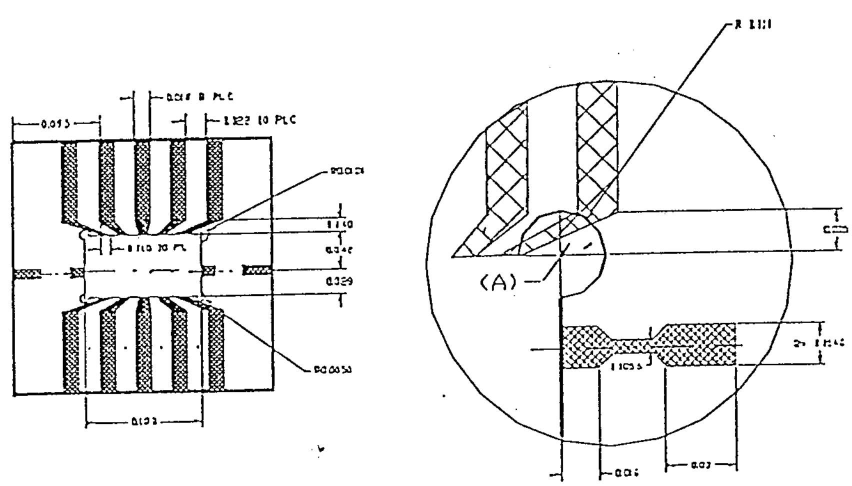


Figure 2: Package Corner Detail

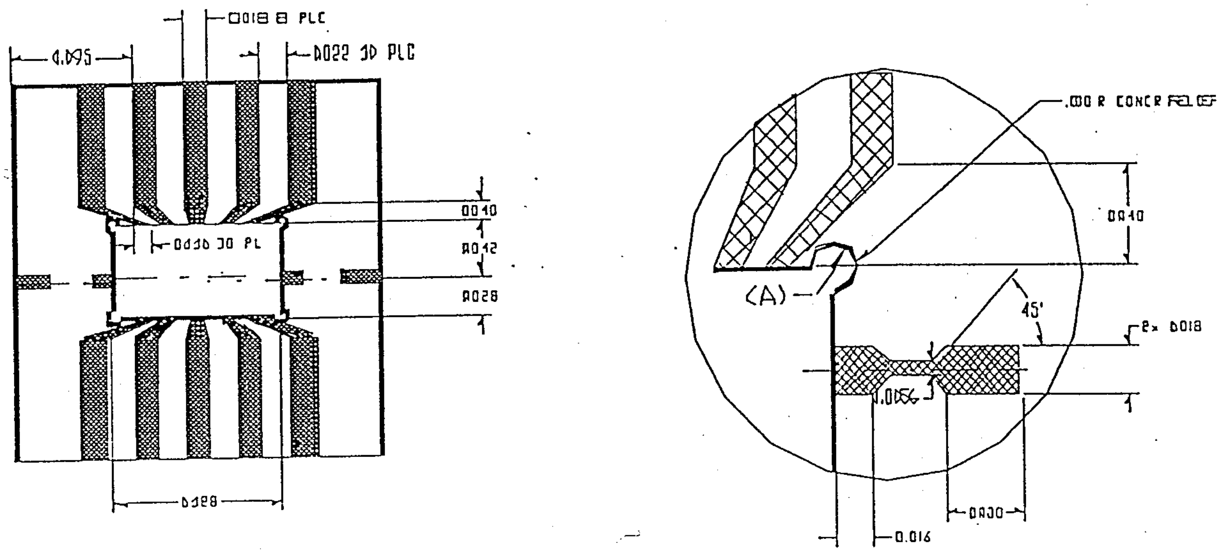


Figure 3: Package Corner Detail Showing Modified Corner

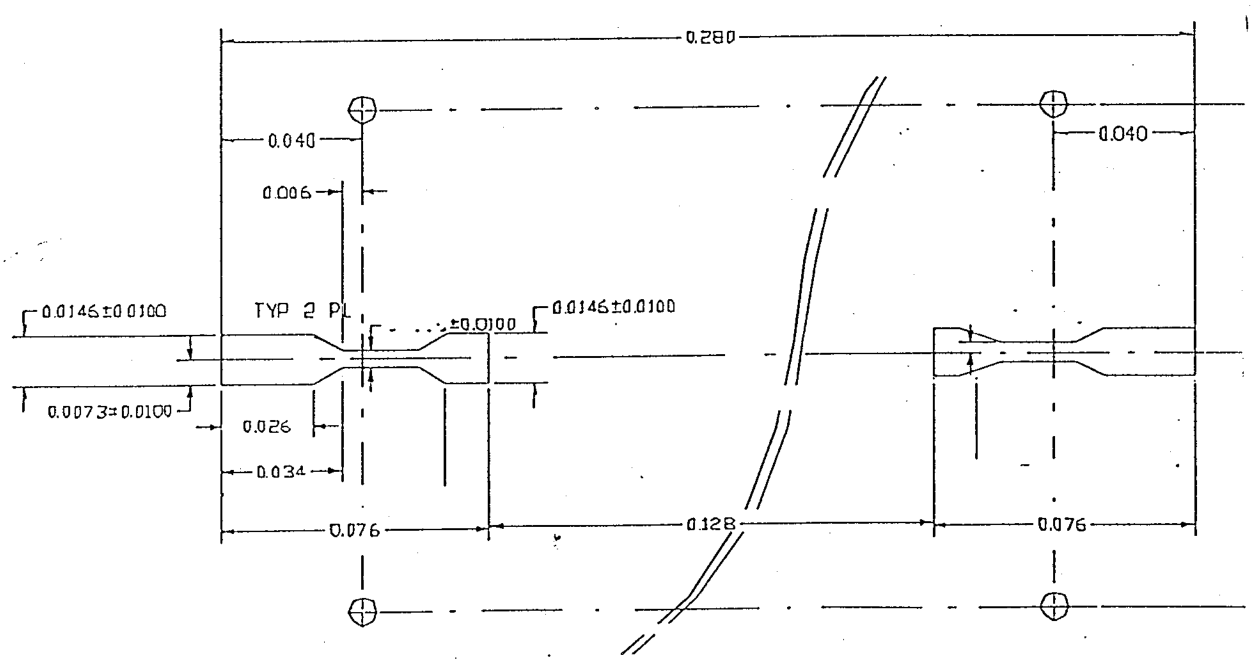


Figure 4: Transition Design

2.3 Fabrication

The existing baseline package designed by Hughes Aircraft Company (Hughes package) takes advantage of the maturity of the co-firing process technology for hermetically sealable MMIC packages. However, the co-fired ceramic process does have limitations on resolution associated with printing process and co-firing process. With the Hughes package, such problems have already been addressed and resolved satisfactorily.

The W/Ni/Au Metallization on system used for the Hughes package is generally accepted as a good choice for this application. PmT instructed MPA to use the same Metallization or the conductors, the ground planes and to fill the RF vias. The High Temperature Co-fired Ceramic process flow used by MPA is detailed below. The process is very similar to that used by Kyocera for first package. Figure 5 is a typical process flow diagram for ceramic package fabrication. Understanding the co-fire ceramic process enables the designer to appreciate the dynamics and complexities inherent in the technology. The details below provides an overview in terms of process which will be expanded to specific design parameters.

Ceramic Slurry

The Co-fire multilayer process begins by milling precise amounts of raw materials into a homogenous slurry. This mixture, which has the consistency of latex paint, is principally Alumina (aluminum oxide, Al_2O_3), and fluxes with small amount of organic binders and solvents.

Casting

The slurry is poured onto a mylar sheet and then passed under a doctor blade to produce a uniform strip of specified thickness. When dried this strip becomes a ceramic filled plastic tape with the look and feel of thick vinyl.

Cutting

The sheets of "green" (unfired) ceramic tapes are cut into cards. Alignment holes are punched in each card to ensure accurate layer to layer alignment during subsequent operations. Exact registration becomes more critical as circuits densities increase.

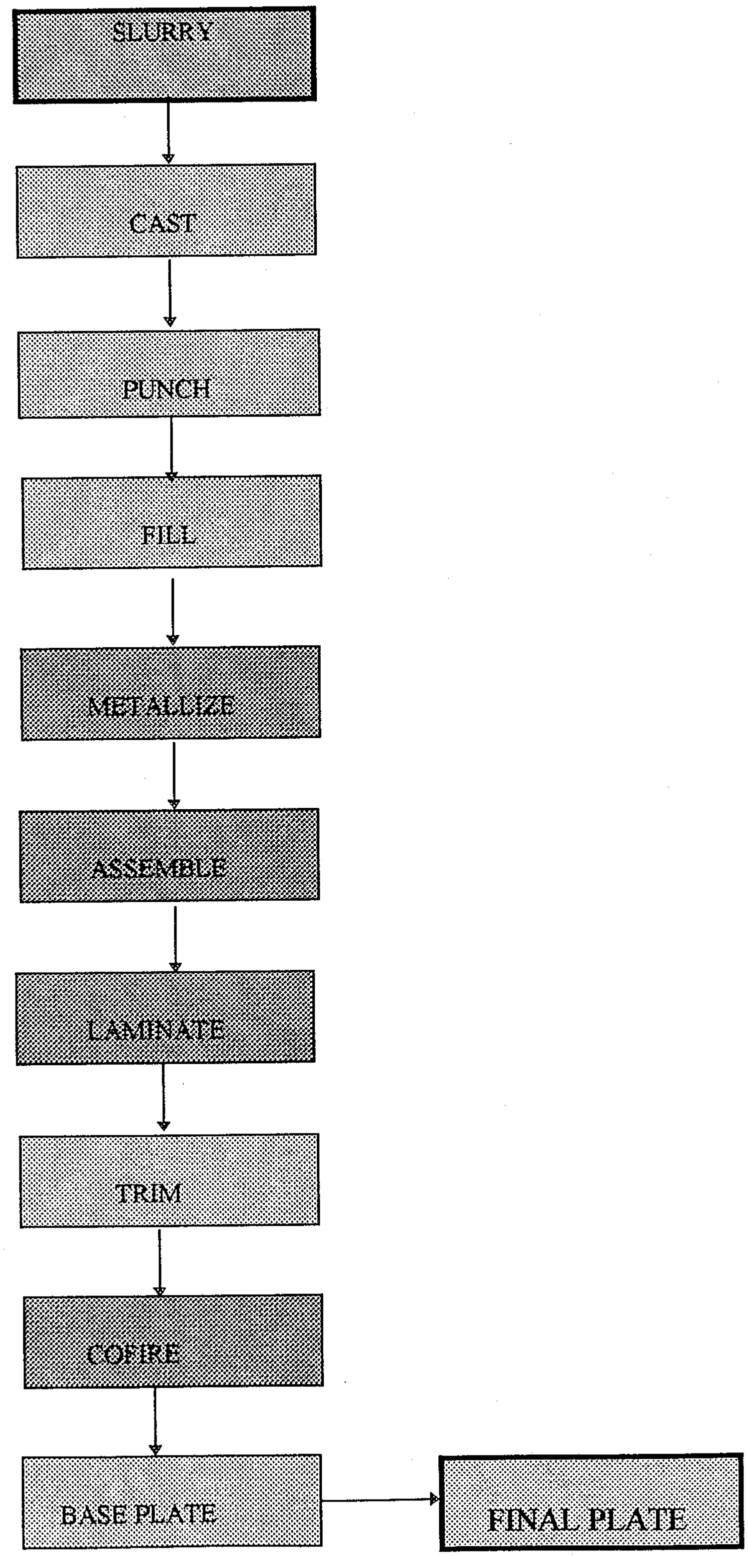


Figure 5: Flow Process for Ceramic Package Manufacture

Punching and Filling

Via holes, cavities and notches are filled in the cards as required. The vias are filled with tungsten paste, a mixture of metal powder and organics that become conductive when fired. Although other metals, such as copper, are better electrical conductors, their melting points are lower than +1600 °C necessary to co-fire alumina ceramics. Tungsten combines a satisfactory level of electrical conductivity with a sintering point and shrink rate compatible with alumina.

The standard filled via will carry the electrical signal from one metallized layer to the next. When densities dictate via diameters of 0.010" or less, process precision is essential. The bore-coated via, a large open via with a metallized ID coating, can function either as a castellation or as a receptacle for interconnecting wires or pins. These vias are punched in the same manner as standard vias but coated by a proprietary process.

The diameter of via holes in this package will be 0.008±0.001 although MPA has a capability 0f 0.005 inch.

Screening

Conductive circuits are printed onto the ceramics tape by forcing tungsten paste through an open mesh metal screen. The circuit pattern for each artwork layer is made into a screen by the same photolithographic process used in thick film and other screen printing techniques. The artwork, is adjusted by interamics to allow shrinkage during firing. MPA uses a 325 mesh/inch screen. The straight line width is with in 0.125 mil after thick inks are filled. The ink is 0.005 inch away from any edge of the substrate. The tolerance on printing linear lines is ±0.005 nch.

Assembly and Lamination

Screened layers are inspected, aligned and laminated under high pressure and low temperature into one assembly. This assembly may be comprised of a single unit, or include multiple repetitions of the same product. The multiple units are processed as a single assembly from punching through lamination.

Scoring and Side Screening

A high precision score tool is used to form single units or to separate multiples. This tool is also used to partially score green ceramic structures to allow plating interconnects to be snapped off after firing. When conductor pads are required on the side of the product, additional screening operations are performed on the laminated, trimmed units.

Firing and Flattening

The ceramic structure is cofired at approximately 1600 °C in a carefully controlled reducing atmosphere. During the firing process the product shrinks approximately 20 percent (linear) for a total volume reduction of 40 percent. A subsequent high temperature operation may be used to achieve .002 inches per inch flatness or better. MPA has a ±0.8% dimensional control using the HTCC .

Base Plating

Base finish material, nickel, was electrochemicallyl applied to all exposed tungsten Metallization to improve performance, prepare the surface for subsequent braze operations and prevent oxidation of conductors pads.

Brazing

Brazing is used to join metal components to the nickel plated ceramic structure. Carbon or ceramic braze fixtures are utilized to properly position metal components in relation to the ceramic structure as it is processed through a braze furnace. Copper-silver eutectic is the most widely used material for brazing. It forms a strong hermetic joint. When thermal expansion mismatch between alumina ceramic and the metal component (Kovar or Alloy 42) being significant, an indium-copper-silver eutectic was used.

Final Plating

Electrolytic plating requires that all exposed circuits be connected electrically by means of a lead frame, plating bus or a combination of the two. Gold was used as the final plating material.

Final Inspection

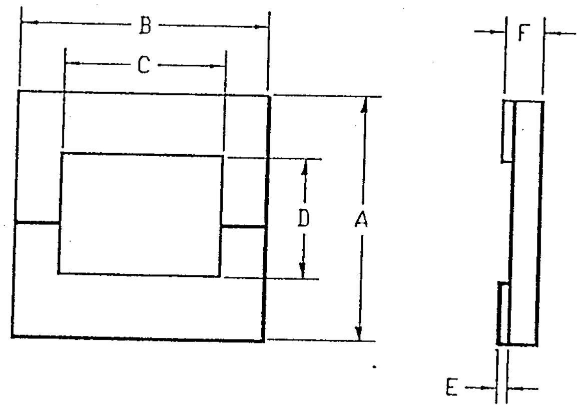
A product specification is used to define sample size and testing procedure and supplement inspection parameters included in a product drawings. A certificate of compliance, test reports and first article documents were provided .

All packages delivered are checked for hermeticity. The packages achieve typically 1 x 10^{-8} cc/sec of Helium.

Since the ceramic package has Kovar material for the package base, and the size is of the same order, it will no change in thermal resistance significantly. However, the ceramic substrate offers a very close match in thermal coefficient of expansion (TCE = 6.7 PPM per degree C). Therefore, the stress level will be acceptable even for the larger size package. For high power dissipation (higher than 2 watts), copper-tungsten material is perfectly matched with ceramic in term o£ thermal coefficient of expansion and provides much lower thermal conductivity.

2.4 Mechanical Measurements

Two hundred packages were received from MPA. Incoming inspection of the packages were performed. Each package has been given a serial number. Dimensional measurements were performed on more than 10 % of the packages. The samples were randomly chosen. The following dimensions were measured.



A - Package external width

B - Package external length

C - Package cavity length

D - Package cavity width

E - Cavity depth

F - Package height

Figure 6: Package Dimension Measurements

PAK No.	A	B	C	D	E	F
0006	0.285	0.284	0.168	0.107	0.032	0.044
0007	0.285	0.285	0.169	0.107	0.031	0.043
0008	0.285	0.285	0.162	0.106	0.030	0.043
0009	0.285	0.285	0.169	0.110	0.031	0.043
0011	0.284	0.285	0.165	0.110	0.032	0.043
0012	0.284	0.285	0.169	0.108	0031	0.042
0013	0.283	0.283	0.166	0.109	0.034	0.041
0014	0.285	0.285	0.167	0.108	0.032	0.043
0015	0.285	0.285	0.168	0.106	0.031	0.043
0016	0.285	0.285	0.169	0.107	0.032	0.044
0017	0.286	0.286	0.169	0.107	0.032	0.045
0018	0.284	0.284	0.168	0.108	0.030	0.043
0019	0.285	0.285	0.169	0.105	0.031	0.043
0020	0.284	0.284	0.167	0.107	0.031	0.042
0031	0.286	0.285	0.167	0.106	0.031	0.042
0032	0.285	0.285	0.167	0.106	0.033	0.043
0041	0.285	0.285	0.168	0.105	0.032	0.043
0042	0.285	0.286	0..169	0.105	0.034	0.043
0051	0.285	0.285	0.170	0.110	0.030	0.042
0052	0.285	0.285	0.169	0.107	0.035	0.044
0061	0.285	0.285	0.167	0.106	0.032	0.043
0062	0.285	0.285	0.169	0.109	0.035	0.044
0071	0.285	0.285	0.169	0.106	0.035	0.042
0072	0.285	0.285	0.167	0.106	0.035	0.043
Max Δ	0.004	0.003	0.008	0.005	0.005	0.004

Based on the measurements, the mechanical dimensions for the package were within the full design dimensions.

2.5 Electrical Measurements

An Intercontinental Microwave Test fixture was used to conduct RF measurements. Fifteen mil alumina substrates with 50 Ohm lines were soldered in the packages. After full calibration of the Network Analyzer with the Intercontinental test fixture, the insertion loss and return loss of the packages were measured. The packages showed good performance characteristics. Basically, the return loss was better than 15 dB from DC to 35 GHz. This means that the match provided by the transitions is extremely Broadband. The insertion losses including both the input and output ports averaged less than 1 dB from DC to 18 GHz , or less than 0.5 dB per transition. The insertion loss increased above 32 GHz. The measurements were repeatable.

Princeton Microwave Technology has successfully demonstrated the manufacturability of the package, which was the primary objective of this program. The measured performance of the package is detailed in Figures 7 to Figures 12 .

Figure 7 and 8 detail the insertion loss and return loss of package 001. The insertion loss includes the loss associated with a 15 mil alumina, 0.110 inch long, bond wires and the two transitions. The measurements were conducted in the Intercontinental Microwave test fixture.

Figures 9 and 10 detail the insertion loss and return loss of package 002.

Figures 11 and 12 detail the insertion loss and return loss of package 003.

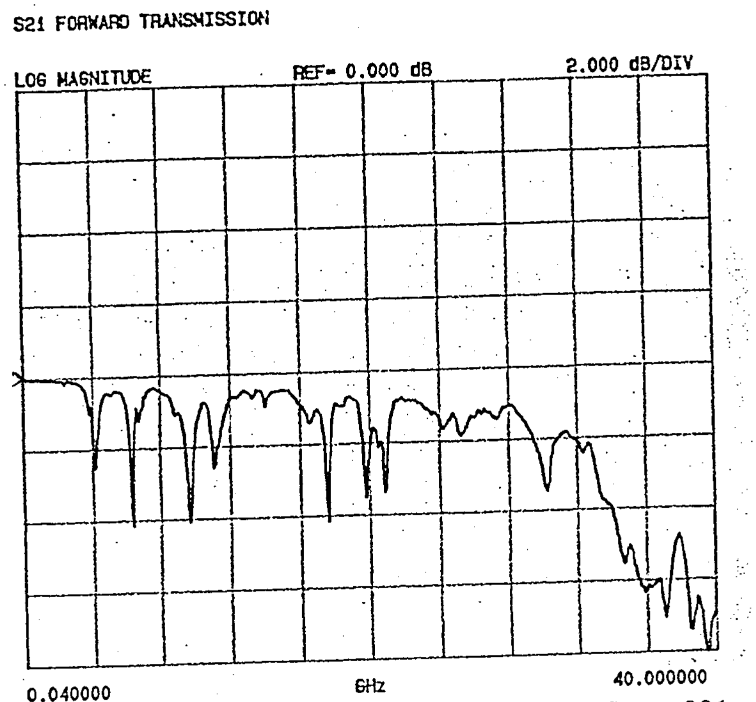


Figure 7: Forward Transmission of package 001

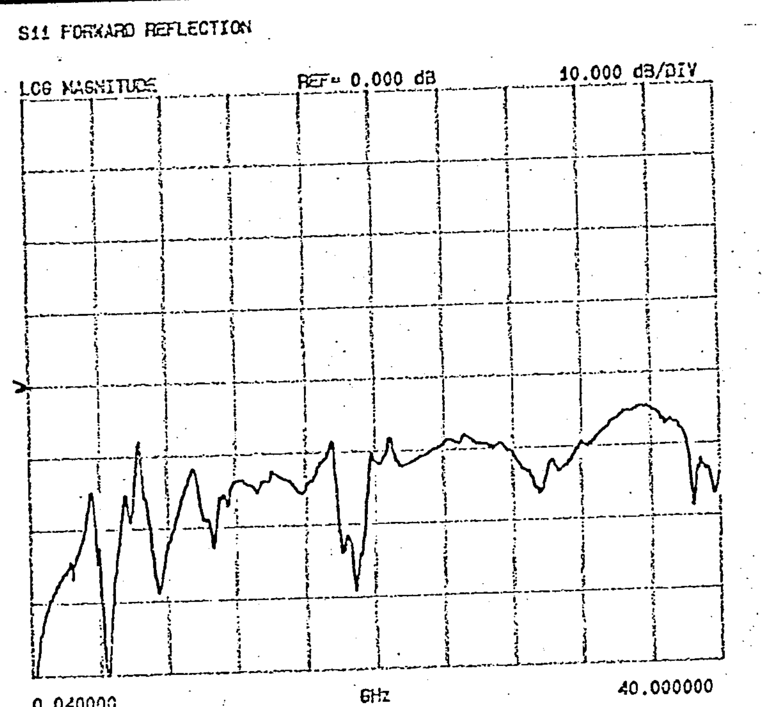


Figure 8: Forward Reflection of package 001

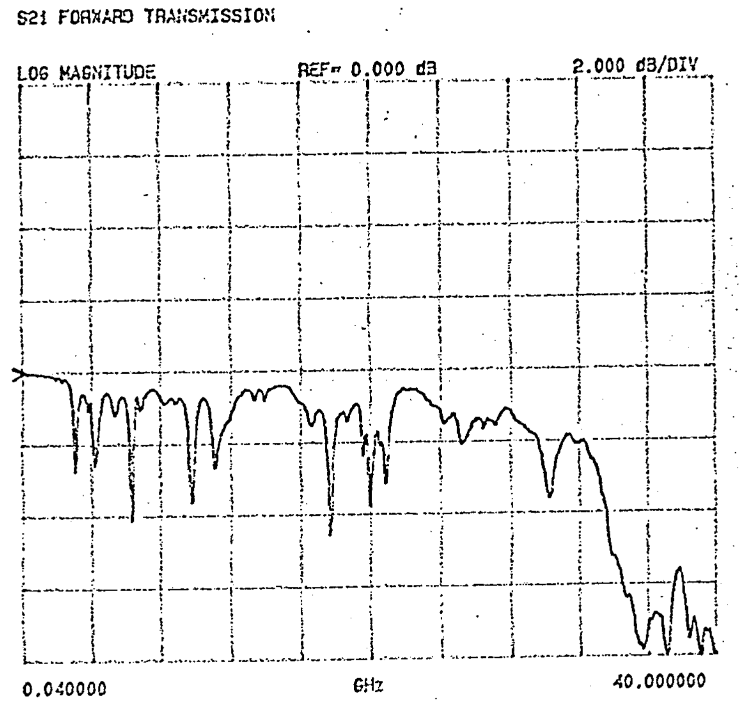


Figure 9: Forward Transmission of package 002

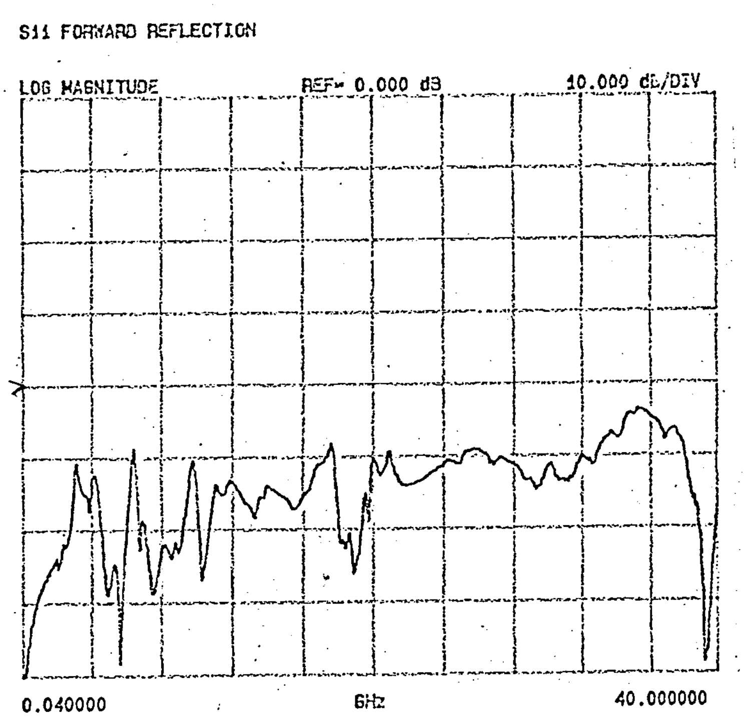


Figure 10: Forward reflection of package 002

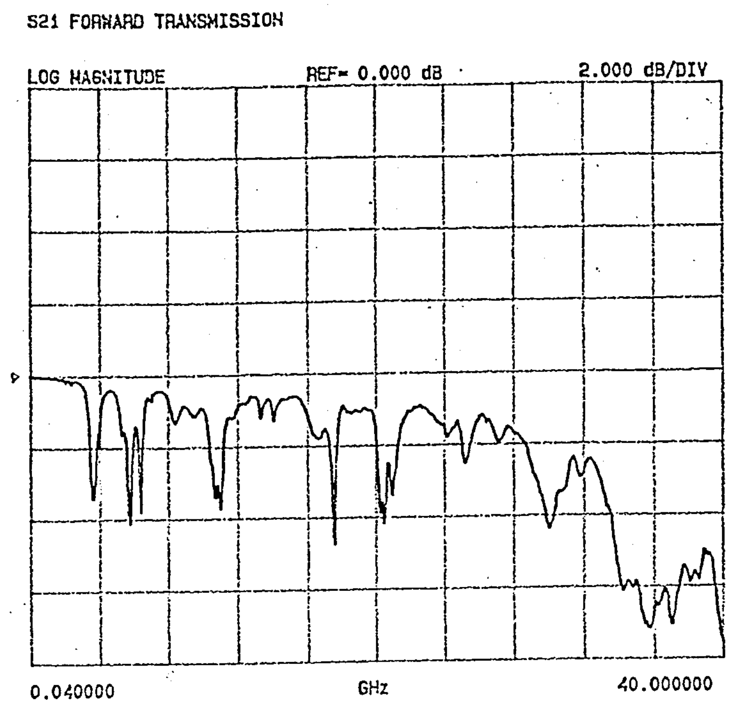


Figure 11: Forward Transmission of package 003

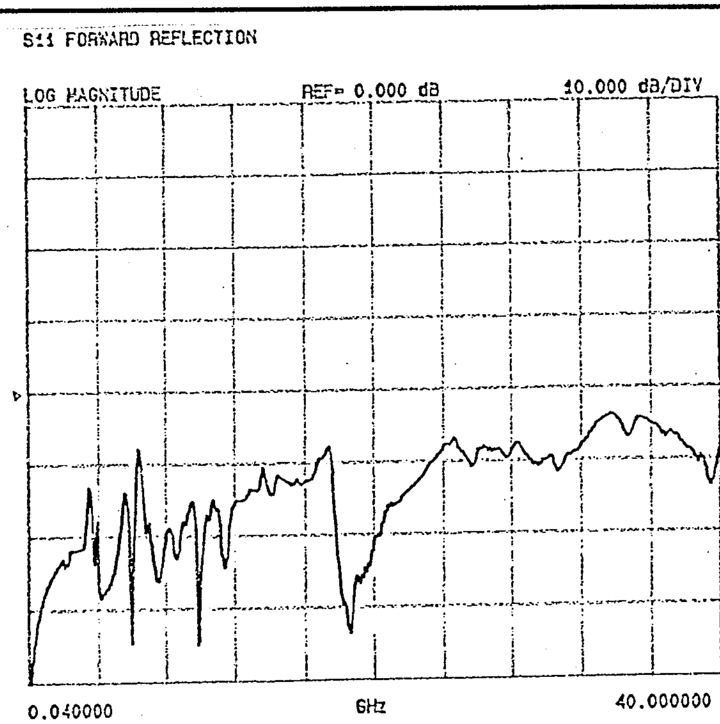


Figure 12: Forward reflection of package 003

2.6 MMIC Amplifier insertion into Package

Three different MMIC amplifiers were assembled into the MMIC package. The first MMIC was a 2.4 dB noise figure, low noise amplifier made by Texas Instruments. The amplifier requires a single bias for operation. The second amplifier was LMA422 from Litton Industries, with a gain of 20 dB . Both amplifiers are designed for the 28 GHz LMDS bands. The third amplifier measured was a HP distributed amplifier which has a gain of 8 dB from 2 to 26.5 GHz.

All three MMICs were epoxy attached in the package and connected to the package input and output using 0.8 mil gold wire.

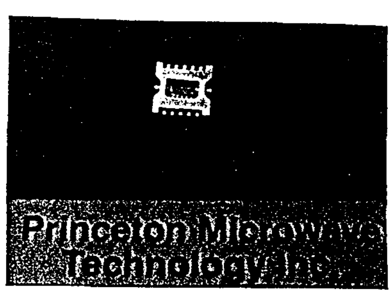
Figure 13 shows the measured performance of the TI low noise amplifier.

Figure 14 shows the measured performance of the Litton MMIC amplifier.

Figure 15 shows the measured performance of the HP MMIC amplifier.

The measured performance of the amplifiers demonstrate the wideband performance of the MMIC package.

The photograph below shows a MMIC mounted into a package.



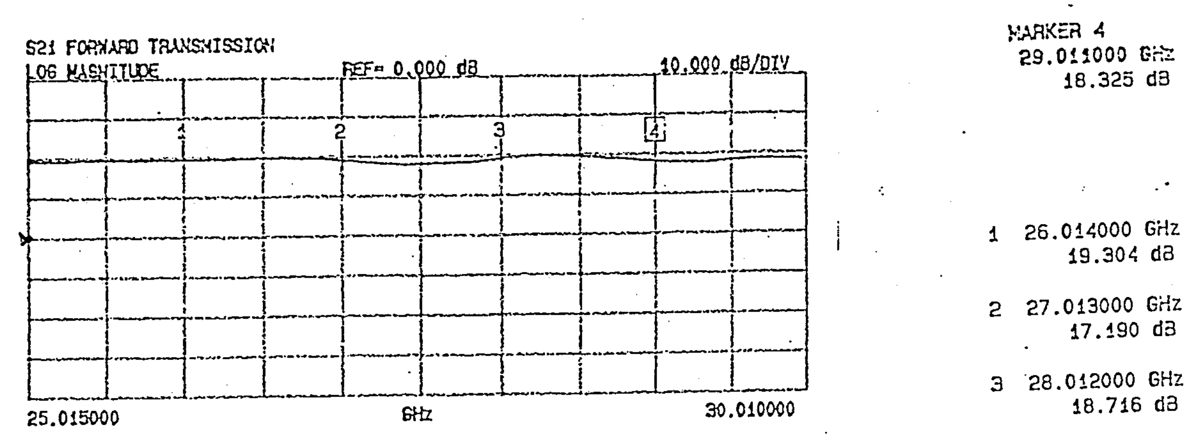


Figure 13: Measured performance of Litton LMA422 MMIC Amplifier

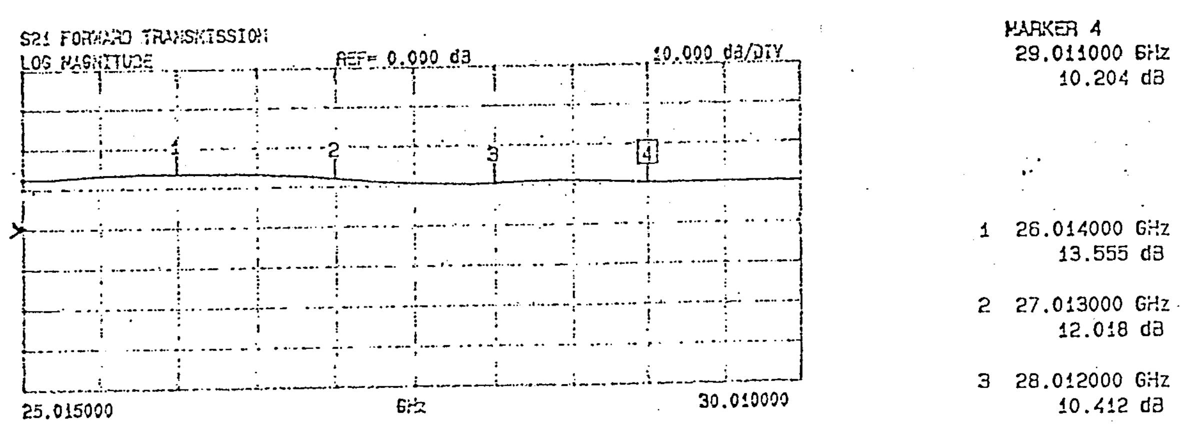


Figure 14: Measured performance of TI low noise MMIC Amplifier

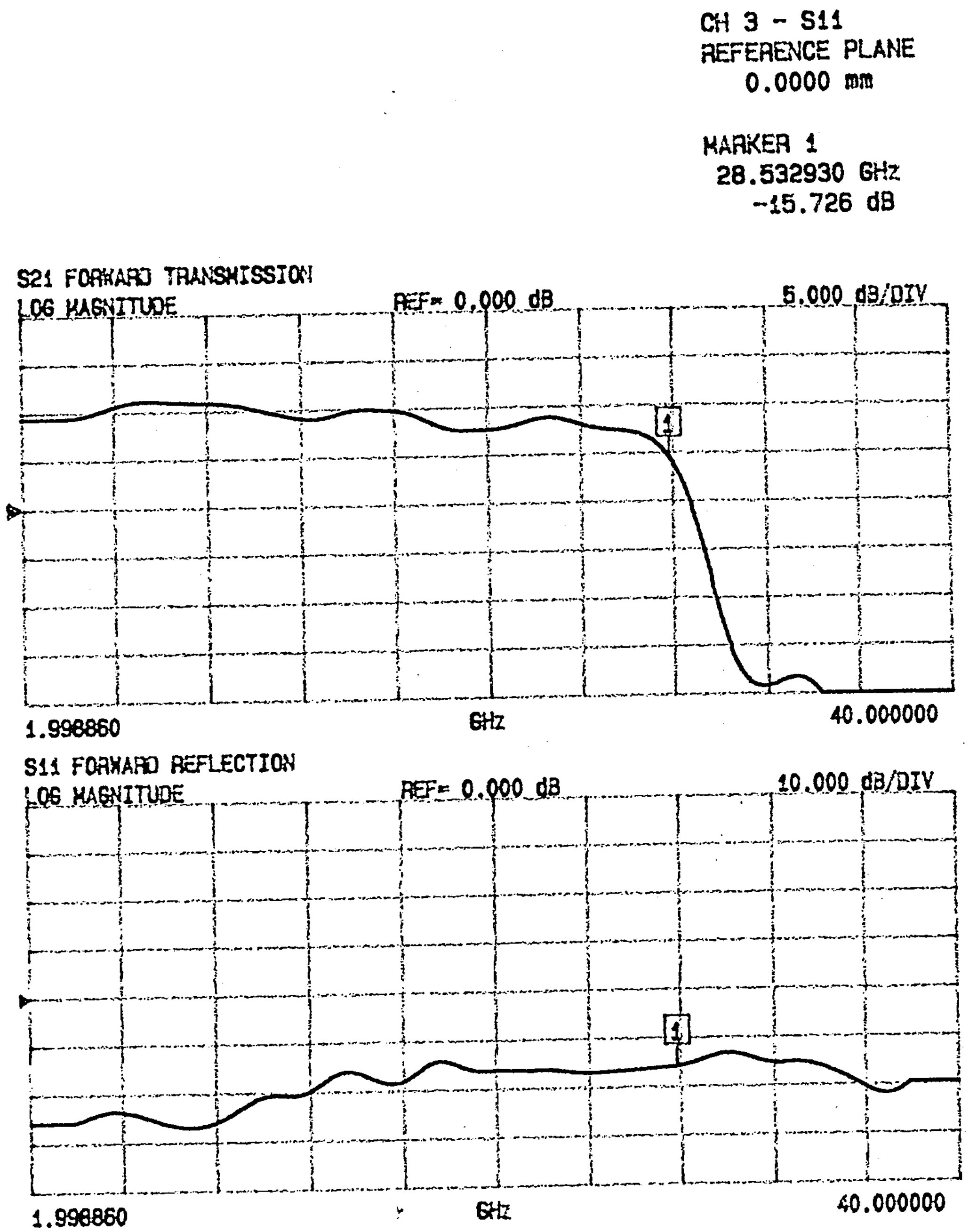
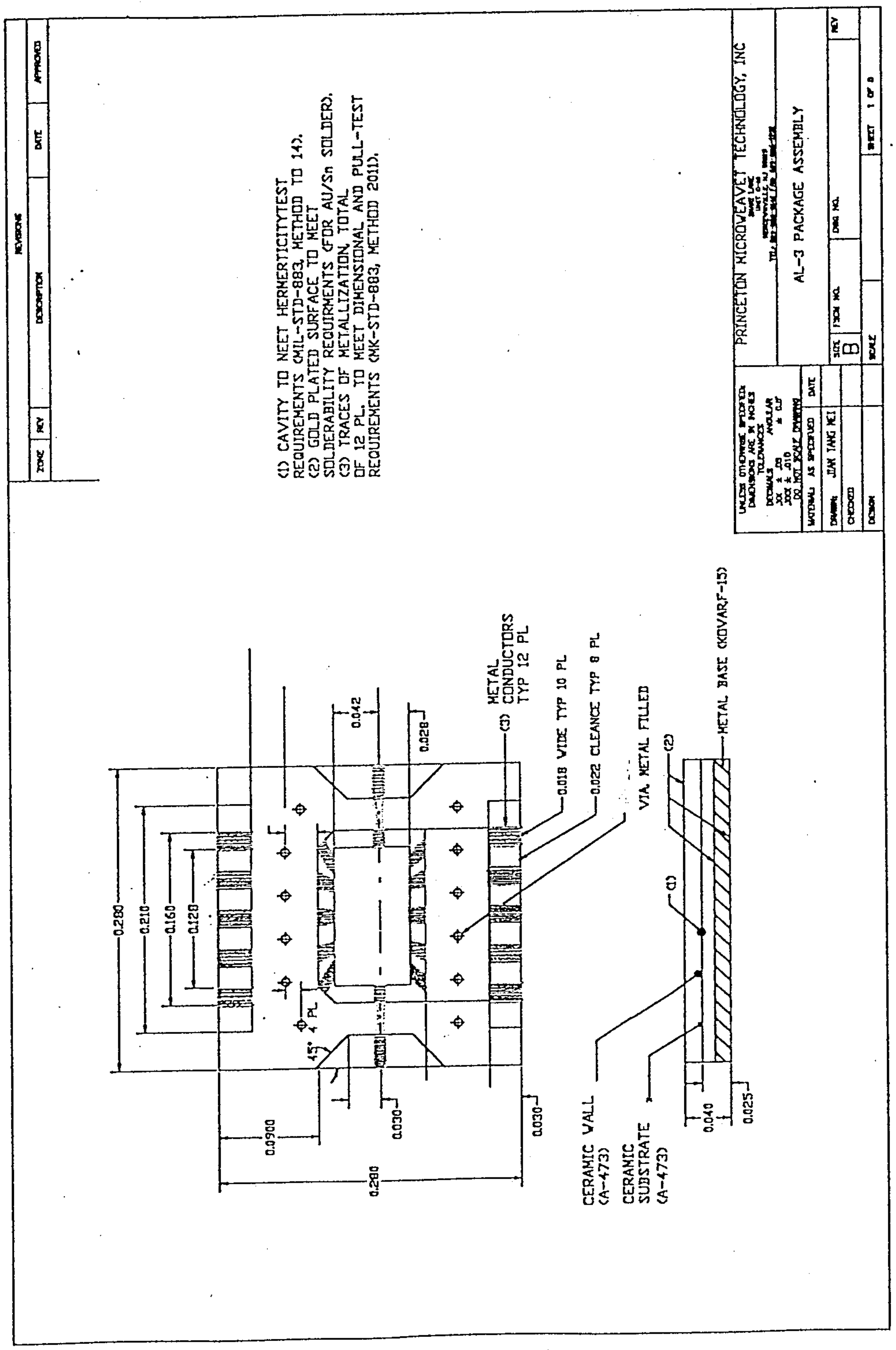


Figure 15: Measured performance of 2-26.5 GHz HP MMIC

2.7 Package Layout

The drawing below details the package layout.



2.8 Package Data Sheet

Princeton Microwave Technology has begun the marketing of the MMIC package. The preliminary data sheet is detailed below.

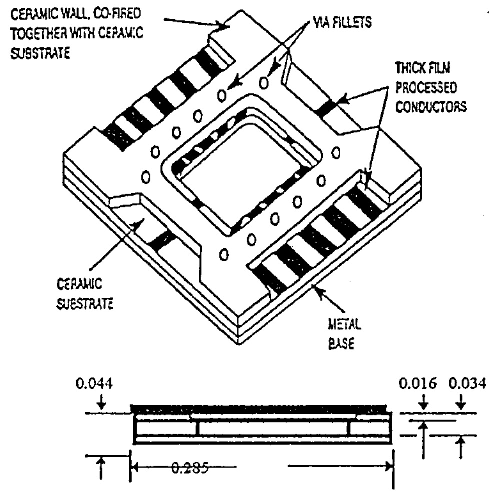
PRINCETON MICROWAVE TECHNOLOGY, INC.
3Nami Lane, Unit C-10, Mercerville, NJ 08619
Tel: (609 586-8140)
FAX: (609) 586-1231

LMDS PACKAGE

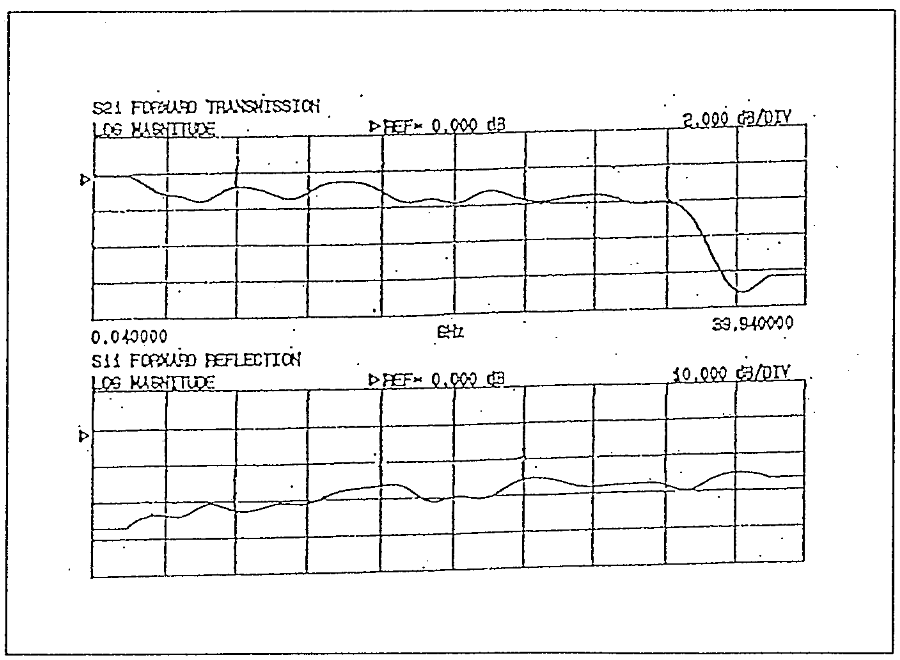
FEATURES:

- Low Cost
- DC-32.GHz Operation
- Insertion Loss < 1.0 dB/Transition
- Return Loss > 15 dB
- 50-ohm Input/Output Ports
- 10 DC I/O Ports
- Hermetically Sealable
- High Thermal Efficiency
- Cavity Size (125 x 70 mils)*
- Low RF Leakage/Radiation
- Gold Plated Copper Tungsten Base

* Cavity size can be customized



PMT-40/125 Transmission Characteristics (Both I/O Transitions)



OPTIONS:

- More Than Two RF Ports
- Locations of RF I/O Ports
- Multi-Cavity Package with High RF Isolations
- Multichip Module Configurations with High RF Isolations
- Thickness and the material of the cover can be specified

3.0

CONCLUSIONS

Princeton Microwave Technology has successfully demonstrated the transfer of technology for the MMIC package developed under contract No. NAS3-25486. During this contract the package design was licensed from Hughes Aircraft Company for manufacture within U.S. A low cost hermetically sealable, high performance package has been manufactured with a typical insertion loss of less than 1 dB per transition up to 32 GHz and a return loss better than 15 dB. The low cost package can encompass a large number of existing MMICs with a size of 100 mils by 50 mils. The performance of the package has been demonstrated by assembling three different MMIC amplifiers into the package and measuring their performance. Two of the MMIC amplifiers , designed for the Local Microwave Distribution System, LMDS, at 26 GHz to 30 GHz exhibited measured data consistent with the device data. The third MMIC amplifier was a broadband distributed amplifier for the DC to 26 GHz bandwidth. The measured performance of the amplifiers showed good performance upto 27 GHz.

The measured performance of the package, when used with an alumina 50 Ohm line, does show resonances within the band, as detailed in Figures 7 through 12. However in the broadband amplifier measurements the resonances were not observed, and maybe due to the loading of the cavity with a higher dielectric constant of GaAs.

Preliminary prices from the manufacturer for a higher quantity has been obtained. In quantities of 25,000 pieces the package price will be under $2.00. For a quantity of 1000 pieces the price of the package will be under $5.00. In conclusion a low cost MMIC package has been manufactured. The main effort in this program was focused on procuring the ceramic material with the right characteristics. The continuing development and manufacturing of the MMIC package will involve this type of interaction, between the package manufacturer and design center.

The MMIC package is presently being marketed in the US and will be made available to NASA and other users.

REFERENCES:

[1] Private communication between Mr. Steve Yuan and University of Michigan

[2] Non-Destructive Permittivity Measurement of Substrates.
G. Kent. GDK Products .1995 Stanley Road , Cazenovia, NY 13035

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13. ABSTRACT ***(Maximum 200 words)***

Princeton Microwave Technology has successfully demonstrated the transfer of technology for the MMIC package developed under contract No. NAS3–27813. During this contract the package design was licensed from Hughes Aircraft Company for manufacture within the U.S. A major effort was directed towards characterization of the ceramic material for its dielectric constant and loss tangent properties. After selection of a ceramic tape, the high temperature co-fired ceramic package was manufactured in the U.S. by Microcircuit Packaging of America, Inc. Microwave measurements of the MMIC package were conducted by an intercontinental microwave test fixture. The package demonstrated a typical insertion loss of 0.5 dB per transition up to 32 Ghz and a return loss of better than 15 db. The performance of the package has been demonstrated from 2 to 30 Ghz by assembling three different MMIC amplifiers. Two of the MMIC amplifiers were designed for the 26 Ghz to 30 Ghz operation while the third MMIC was a distributed amplifier from 2 to 26.5 Ghz. The measured gain of the amplifier is consistent with the device data. The package costs are substantially lower than comparable packages available commercially. Typically the price difference is greater than a factor of three. The package cost is well under $5.00 for a quantity of 10,000 pieces.

14. SUBJECT TERMS
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