The Packaging Advantage for Power Amplifiers

Packaging for semiconductor components is critical when designing for higher speed and higher frequency communications.

By Alan Lindner and Jerry Carter, StratEdge

Demand for higher speed and higher frequency communications continues to accelerate and is resulting in critical demands on packaging for semiconductor components. Historically, high-speed monolithic microwave integrated circuit (MMIC) devices were developed primarily as a resource for the United States military. Their applications required extremely dense, hi-reliability packaging that dictated the use of multichip modules or more conventional chip and wire hybrid assemblies. The modules require extensive hand tuning in order to achieve optimal electrical and thermal performance, and to withstand the ruggedized conditions to which they are exposed. These processes work well for low volume applications that can justify the relatively high costs associated with manual assembly. But military uses have been overshadowed by the explosive growth of applications in the commercial sector.

Requirements for microwave, millimeter-wave, and high-speed digital assemblies are being introduced through telecommunications, radar, and automotive applications. MMICs manufactured from gallium arsenide (GaAs) &#151 including amplifiers, mixers, detectors, attenuators and analog-to-digital converters &#151 are being used in applications such as point-to-point and point-to-multipoint radios, VSAT terminals, automotive radar, high-speed digital communication networks, handset amplifiers, and direct broadcast satellite TV applications. In telecommunications, satellite up- and down-links operate at frequencies from 1 through 30 GHz, while digital radios used in cellular phone infrastructure operate up to 40 GHz. Multiplexer and demultiplexer circuits for fiberoptic communication systems operate through 10 Gbit/s, with 40 Gbit/s under development, demanding bandwidth in excess of 50 GHz. New radar systems are being developed with advanced microwave phased array antennas. Collision avoidance radar and adaptive cruise controls are currently being used for automotive applications in the 24 to 100 GHz range.

These commercial telecommunications opportunities differ from the earlier military applications because most of them require very high volume production of the MMICs and their assemblies. Even some of the military uses are moving into the tens and hundreds of thousands of devices (particularly the phased array radar applications), while most of the commercial telecommunications applications have already moved into the hundreds of thousands plus per year range. Commercial manufacturers are demanding chips that are completely packaged and tested so they are ready to be soldered to the circuit board. It is not economically feasible to manufacture high volume commercial circuits in cleanroom facilities or handle bare die. In each case, packaging provides a means of protection for the chip with the goal of being electrically transparent to the device.

MMIC Packaging

Packaging of microwave and millimeter-wave gallium arsenide chips provides a significant challenge. When a package is designed for an integrated circuit (IC) that has a frequency below 2 GHz, the electrical properties of the package are easier to predict and maintain because you are dealing with a lumped element circuit. However, once the frequency exceeds 2 GHz, we are now working with distributed element circuits.

In most applications, the MMIC is a building block in an assembly. In a microwave front end, it can be a low noise amplifier or a power amplifier. In digital circuits, the MMIC can be the multiplexing or demultiplexing function, limiting amplifier, or driver amplifier. The balance of the components in the assembly may be filters, couplers, mixers, or optical converters. Most, if not all of these components, are available in pre-packaged form or do not require packaging at all.

Traditionally, manufacturers have integrated these components with bare MMIC die in a multichip module or hybrid assembly. They must be assembled in a cleanroom where the die is attached eutectically with gold/tin solder or with silver filled conductive epoxy. The conductors on the die, which range in size from 1 to 4 mil square, are wire bonded with gold wire ranging in size from 0.7 to 1.3 mil diameter. Plasma cleaning is required to remove contaminants and facilitate effective adhesion. Most microwave assemblies also require hand tuning to optimize the performance of the device after final assembly. As a result, commercial companies are demanding chips that are completely packaged and tested so they are ready to be soldered to the circuit board. By purchasing a packaged MMIC, they are provided with a pre-tuned and pre-tested known good device that has lower tuning requirements and higher assembly yields. Packaging provides a means of protection for the chip with the goal of being electrically transparent to the device.

Once the decision to package a MMIC is rendered, there are five common package requirements to consider:

1. The package must provide electrical interconnection between components and subsystem.
2. It must protect the circuit from any corrosive environment (even air or water is corrosive to some circuit components).
3. It must protect the circuit from general contamination or foreign material (that is, particles that may damage components or change electrical response).
4. It must protect the circuitry from mechanical damage.
5. It must provide or assist in thermal management of heat generated by the circuit.

There are a number of requirements driving the design of the package. Suitable material must be selected to work with GaAs MMICs. Thermal and mechanical considerations must be made for the MMIC, package, and assembly to work in concert. The techniques to assemble and test the package must be addressed, and for commercial applications, low costs need to be achieved. The package must be electrically transparent to the device. Mismatches caused by the interconnections from the internal circuitry to the next assembly must be minimized through sound microwave transmission line design.

Choice of Packaging Materials

The proper materials must be chosen to package GaAs devices. The die attach base, the electrical interconnect circuit, and the cover material must all have coefficients of thermal expansion (CTE) that closely match the CTE of the GaAs chip. This prevents the GaAs chip from cracking or lifting off of the package during thermal cycling. For many applications that require high thermal dissipation, the die attach base must also possess excellent thermal conductivity. All the materials must be carefully selected for proper electrical characteristics at the microwave or millimeter-wave frequency of the MMIC. This requirement normally precludes the use of plastic packages because of their relatively high electrical loss characteristics at microwave frequencies. A standard construction that has been employed for these packages for several years utilizes a copper-tungsten or copper-moly composite metal base with a 96% alumina ceramic electrical circuit layer.

Electrical Circuit Design Considerations

Microwave, millimeter-wave, and high-speed digital circuits cannot just be placed in most contemporary packages and expected to work. Microwave packaging faces one fundamental fact driving unique requirements: the frequency is high enough that the electrical wavelength approaches the physical dimensions of the components. Below 2 GHz, the wavelength of the signal is much larger than the circuit dimensions; thus the circuit is described in lumped electrical values of resistance, capacitance, inductance, and conductance. At microwave frequencies, the circuits are transmission lines that propagate as electric and magnetic fields. Element definition is impedance and electrical length. The impedance is defined by the dielectric constant of the material and dimensions of the conductor elements. For lowest loss transmission from one circuit to another, the impedance must be matched, with the standard impedance being 50 ohms.

Designing electrical circuit transitions for microwave and millimeter-wave frequencies requires the use of fundamental electromagnetic equations and is assisted by linear and three-dimensional simulation tools. The conductors in the electrical circuit layer must have high electrical conductivity to reduce transmission losses. This is achieved through the use of gold as a conductor and by not using, or not having, an exposed refractory layer. The alumina ceramic substrate material must be held to tight mechanical tolerance and dimensional stability. Co-fired ceramic technology has generally been precluded from use at millimeter-wave frequencies because of the large shrinkage associated in processing that results in poorer electrical yields. Network analyzers used in conjunction with custom fixturing can verify the performance of the electrical circuit transitions.

Leaded and Leadless Packages

The ease of attaching a package to an assembly results in shorter manufacturing times. Leaded packages allow the leads to be soldered in place, and are available in frequency ranges from DC to 23 GHz and 26.5 to 31 GHz. Leadless packages can operate in excess of 50 GHz, but require wire or ribbon bonding as the external means of attachment (Figure 2).

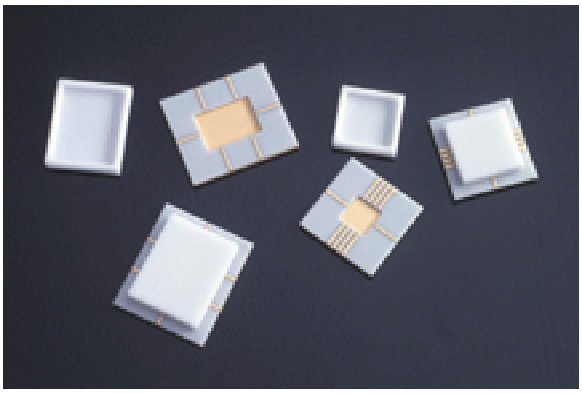

Figure 2. SE50 Product Family

A Case History

Transcom is a Taiwan-based semiconductor manufacturer that designs and manufactures GaAs MMICs specifically for microwave systems including VSAT (Very Small Aperture Terminals) amplifiers. VSAT provides high quality two-way, voice, data, and video communications at speeds up to 64 kbps that operate at microwave frequencies of 5.5 to 6.5 GHz and 14 to 14.5 GHz. Transcom's power amplifiers are typically used in the satellite base station terminals, and are situated behind the antennae to boost the transmission signal back to the satellite dish. The market for these VSAT amplifiers requires packaged MMICs so they can be soldered to their assembly. Although Transcom packages its own die, they looked to StratEdge, a San Diego, California company, to manufacture the package.

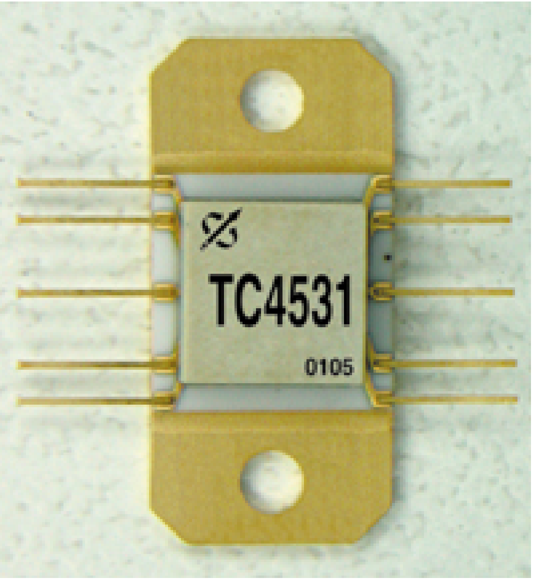

Figure 1. Transcom Ku Band MMIC Package

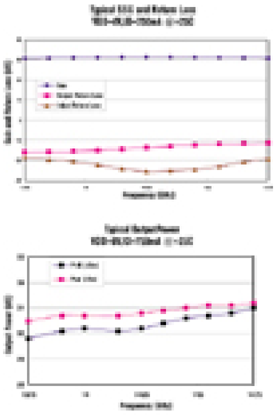

Figure 4. Electrical Performance Chart of Transcom Packaged Amplifier

Transcom's TC4531 is a four stage GaAs PHEMT power amplifier MMIC that is designed for use as an output stage or a driver in a Ku Band VSAT ODU (outdoor unit). The packaged amplifier provides a minimum of 30 dB gain and delivers 1 watt of output power from 13.75 to 14.75 GHz. Transcom packaged two MMICs together to achieve the four stage amplification (Figures 1 and 4). The finished packaged device is readily tested using a commercially available clamshell-style electrical test fixture that will operate in excess of 20 GHz (Figure 3).

Figure 3. Product Testing on a Network Analyzer

The StratEdge package utilized by Transom is a shrink-less, post-fired ceramic package specifically designed to work at Ku Band with almost no electrical loss (Figure 5). The base material of the package is nickel and gold plated copper-tungsten composite which provides excellent thermal cooling of the Transcom semiconductors and a coefficient of thermal expansion matched to the GaAs chips. This allows the chips to be soldered directly to the base metal using gold tin solder resulting in high reliability thermal cycling performance. The ceramic RF layer of the package incorporates a patented microstrip-imbedded microstrip-microstrip transition design.

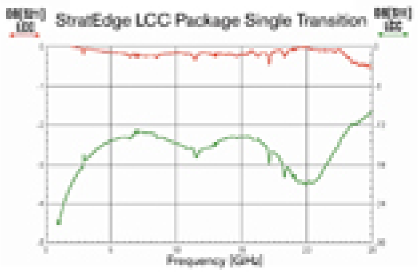

Figure 5. Electrical Performance Chart of the StratEdge Package Transition

The high power MMICs are mounted along with four decoupling capacitors into the StratEdge bolt-hole package. The flanges on each end of the package allow it to be screwed down to the next level of the assembly, providing a good thermal transfer path from the chip through the copper-tungsten base and into the metal housing of the assembly. The metal base of the package also provides the RF ground for the package and chips, a critical requirement for the transparent electrical performance of the package.

The standard configuration of the StratEdge package is a total of ten leads (5 per side), one each for RF in and RF out, with the remaining eight for various DC and low frequency signals. Custom designs of the package are also available including special lead and cavity configurations. The package is supplied with a raised plastic lid with a B-staged epoxy preform attached which meets the leak rate testing requirements of MIL-STD 883 to minimize problems associated with moisture and contaminants. The electrical integrity and performance of the Transcom IC are enhanced by the characteristics of the StratEdge package.

Summary

Packaged GaAs MMICs fulfill the needs of today's microwave, millimeter-wave, and high-speed digital assemblies. Packages that meet the mechanical and thermal requirements have successfully achieved the goal of being electrically transparent to the chip. The use of packages to house a GaAs MMIC device allows ease of installation at the higher assemblies. The precise chip attach and wire bonding is performed in a package instead of on a board so that the package can then be tested as a component. The packages are very rugged and provide a high level of protection to the fragile GaAs chip. These packages have been successfully used in high volume production applications on the order of hundreds of thousands per year since the mid-1990's.

Tim and Jerry work at Stratedge in San Diego.

Source URL (retrieved on *03/06/2015 - 12:55am*):
http://www.wirelessdesignmag.com/product-releases/2001/08/packaging-advantage-power-amplifiers