Commercial Applications for GaAs Millimeter Wave MMICs

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ABSTRACT

To date, high-volume commercial applications for GaAs MMICs have been centered around low frequency applications, (<3 GHz) such as cellular phone and WLAN. Additionally, high-performance military phased array radar systems (C-band through-Ku-Band) represent another high-volume application for GaAs MMICs. There are several other current and emerging commercial applications for millimeter wave MMICs including, digital radio RF transceivers, VSAT ground terminal transceivers and electronics for automotive radar applications. None of these applications independently rival the market revenue generated by cellular phone and WLAN applications, but in aggregate, create an excellent opportunity for millimeter wave MMIC suppliers. This paper will describe the current and emerging commercial applications for millimeter wave MMICs. An overview of market conditions, key requirements and packaging expectations will be discussed for each area.

1. INTRODUCTION

Currently, the two most prevalent high-frequency commercial applications for millimeter wave MMICs are digital radio RF transceivers for cellular backhaul and ground terminal transceivers for VSAT. Both applications require high-frequency, high-performance devices ideally suited for GaAs millimeter wave MMIC technology. Digital radio transceivers cover the standard radio bands from 6 GHz through 42 GHz while the current VSAT products are primarily Ku-Band. In the near future, Ka-Band VSAT, emerging E-band radio markets and automotive radar applications will provide additional opportunities for millimeter wave MMICs at frequency bands up through 90GHz. In aggregate, these lower volume millimeter wave commercial markets create an excellent opportunity for MMIC suppliers who can leverage their standard production processes to achieve the required technical performance and price expectations.

2. MILLIMETER WAVE DIGITAL RADIO

Currently, digital radios for cellular backhaul represent the highest volume commercial market for millimeter wave MMICs. Millimeter wave radios operate in licensed frequency bands from 6-42GHz. The market is typically segmented by capacity (high, low, medium) and transmission distance (short-haul and long-haul). The short haul, higher frequency radios (>12GHz) occupy the dominant share, approximately 80% of the total market. In 2003 the worldwide production for radios of all frequencies and capacities was estimated to be 250K units. That is a decline from approximately 350K radios at the peak of the 2000-2001 market [1], see Figure 1. Looking forward, modest growth is expected over the next several years primarily to add capacity to support higher data transmission requirements associated with the 3G cellular infrastructure rollout.

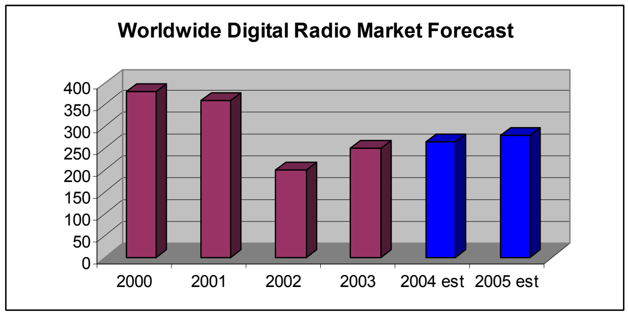

Figure 1. Worldwide Digital Radio Forecast

Generally the GaAs MMIC content of a millimeter wave RF transceiver consists of HPA(s), driver, gain blocks, frequency multipliers, LNA, mixers and often variable attenuators. Time Division Duplex (TDD) systems will also require a T/R switch. GaAs pHEMT is currently the dominant technology for this application. A premium is placed on HPA MMICs that deliver linear power in a compact (therefore inexpensive) footprint. Other functions may be individual or multi-function such as a down-converting mixer with integrated LO and/or RF amplification, or an up-converting mixer with an additional gain stage/driver. Modules may vary in complexity proportional to the frequency of operation and performance requirements. Using a typical bill of materials (BOM) cost, the 2003 total available market (TAM) for the GaAs content of the RF transceiver portion of the radio can be estimated to be approximately $40M. While modest in comparison to the cellular handset GaAs market, the digital radio application represents a stable and steadily growing market for high-frequency millimeter wave GaAs MMICs. Additionally, future radio systems will require

MMIC chipsets to support 60- 90GHz radio bands. Referred to as "E-Band" applications, the FCC recently allocated two licensed bands, 71-76GHz and 81-86GHz for GigaBit wireless communication systems. These systems will permit very high data rate point-to-point interconnectivity over relatively short distances (typically 1-2km). Systems are targeted as an alternative solution to fiber connections in areas where fiber is unavailable or too costly to install. Initial estimates for deployment of these types of radio systems range from 10K/yr, with potential growth to much greater annual quantities. E-band plus the unlicensed 60GHz communication band, afford MMIC suppliers an opportunity and a challenge to deliver cost effective solutions to the radio subsystem suppliers. GaAs MMIC suppliers with strong core business that utilize their standard production processes to produce these higher frequency devices should be able to provide acceptable price/performance solutions.

Packaging for RF transceivers has traditionally relied upon chip and wire multi-chip module (MCM) technology. This requires placing multiple MMICs and/or discrete devices on a metal-backed carrier with a topside substrate printed circuit board (PCB). PCB material is typically alumina or laminate-based soft board for high frequency modules. Filters, couplers and interconnect traces are usually printed features on the PCB. Figure 2 illustrates a millimeter wave radio transceiver board populated with GaAs MMICs, passive components (capacitors) and printed filters.

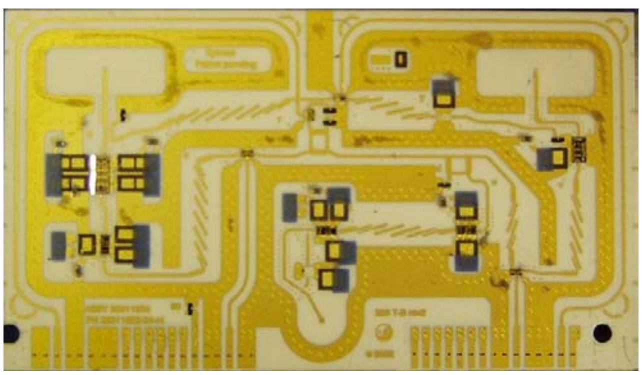

Figure 2. Typical RF Transceiver PCB
(Photo Courtesy Xytrans)

The PCB assembly is then installed into/onto the higher level radio module housing and covered with a lid for protection and shielding.

While MCM technology has been the choice for higher-frequency, high-performance transceiver products, this approach requires a staff of highly skilled microwave engineers, and technicians. In recent years there has been a growing availability of surface-mount-technology (SMT) packaged MMIC devices. Individually packaged SMT MMICs allow the module assembly to be implemented with techniques similar to mass consumer market products (ie. cell phone). Automating the assembly process using industry standard SMT packaged devices to standard PCB material, is an approach that, at least in theory, may yield lower cost RF transceivers. In practice there remain significant trade-offs and limitations to consider when utilizing one approach versus the other. In general, low cost, industry standard packaging technology can be utilized for small signal, lower frequency products without significant price or performance degradation. As the frequency and power levels increase, and in cases where performance cannot be compromised, MCM continues to be the higher performance solution.

3. VSAT GROUND TERMINAL TRANSCEIVERS

Today's VSAT ground terminal market represents another application ideally suited for millimeter wave MMICs. The VSAT market can be divided into two product segments; with up-link frequency plans for Ku-Band at 13.75 to 14.5 GHz and Ka-Band at 29.5 to 30 GHz. MMICs can be delivered either as bare die or packaged products to this market but the dominate customer preference is for a packaged, tested part. This preference for a packaged product applies to both the Ku-Band systems and the Ka-Band systems. Package technology and style varies greatly. Much of the market is currently using a de-facto standard form factor that is a ceramic on metal leaded package technology. The dominate trends for packaging in this market is to move towards lower cost material solutions for the packages to reduce the end product cost, and also to enable a surface mount assembly solution. Most VSAT radio suppliers are working to reduce the cost of their electronics by implementing surface mount assembly where possible, which enables the use of contract assembly for much of the RF portion of the transmitter. Figure 3 illustrates current package styles for multi-watt Ku-Band VSAT HPA transmit MMICs.

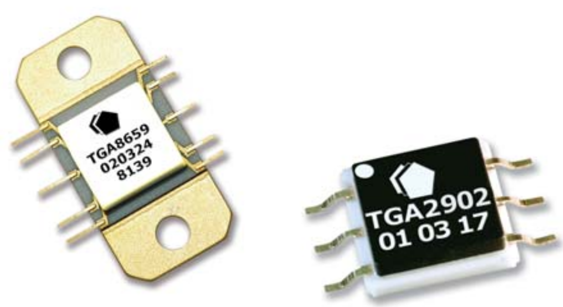

Figure 3. TriQuint Ku-Band HPA MMIC Package Options
(L)4W Flange Lead and (R)2W Low Cost Surface Mount

In the more mature Ku-Band systems, the primary application for GaAs MMICs is the output PA stage of the transmitter. For this function, the high frequency performance for power, efficiency, and gain requires the advantages that compound semiconductor technology offers. A broad product line supplier can meet the needs of almost any radio manufacturer with packaged product solutions at output power levels of 1W, 2W, 4W and 8W. The majority of the unit volume is at the 2W HPA power level. This component is typically used for a 1W transmitter application. In these systems the receive function is generally accomplished with a discrete Low Noise Block (LNB) element which has been driven far down the cost learning curve by the Direct Broadcast by Satellite (DBS) market. An integrated MMIC approach on the receive side of these radio links is generally not cost effective.

Satellites with available Ku-Band transponder capacity exist in orbit world-wide for Ku-Band systems. This makes Ku-Band system deployments the only practical way to implement a broadband link by satellite in most of the world. New system deployments in Europe and in Asia promise attractive growth in component demand over the next few years. For these reasons, the Ku-Band market is expected to have strong demand from 2004 through 2008. This market segment currently consumes in excess of 300,000 packaged HPA MMICs a year. Growth in demand is expected to exceed 500,000 packaged HPA MMICs after 2005.

Ka-Band systems are being deployed in North America in 2004. Both Spaceway and WildBlue plan to start Ka-Band service in 2004. The critical step that will create ground terminal demand for each is the satellite launch. At this time, both systems plan to launch their initial satellites during the first half of 2004 and begin offering two way services by satellite in the second half of 2004.

Ka-Band systems have significant advantages in data rate and service cost per bit once the orbital infrastructure is in place. Requirements for the ground terminal RF components are similar to the Ku-Band systems in that the GaAs MMIC functions are desired in a packaged form factor. Solving the MMIC packaging problem at 30 GHz is much more challenging, especially when the cost targets these systems demand to support large scale consumer deployment are understood. A surface mount solution is practical for Driver and Pre-Driver functions but may not be practical for the higher power output stages due to thermal and RF performance considerations. An acceptable approach for the high power output stages appears to be a "carrier package" solution, shown in Figure 4, which offers minimal RF and thermal performance penalties while enabling low cost packaging and assembly.

While the obvious application for the GaAs MMIC is in the output PA stage of the transmitter, other functions such as the driver amplifier, mixer and pre-driver are also potential applications for a compound semiconductor solution. Since these systems have not yet been deployed, the product needs are still emerging. A broad product line of packaged HPAs with power levels of 2W, 4W and 8W is expected to meet all of the system ground terminal requirements. Like the Ku-Band systems, the receive side of the radio link can be cost effectively solved with a discrete approach. It is believed the current Ku-Band LNB manufacturing infrastructure can readily support the downlink 20 GHz frequency plan needs for this receive application.

Figure 4. TriQuint Ka-Band 4W HPA MMIC In Carrier Style Package

As the new systems in North America are deployed, the Ka-Band market is expected to have very strong demand from 2004 through 2008. If the service providers can execute their business plans, unit shipments are expected to exceed a rate of 500,000 per year in 2005. The potential for up to 1.5 M units per year after 2005 exists if the combination of broadband services and direct broadcast video is successful. Since at present there are more than 18 Million direct broadcast by satellite subscribers in the North America, this appears to be a feasible number.

Further growth is expected world wide as Ka-Band systems are deployed in additional market areas. Plans exist for future systems in Europe, Asia and South America. The success of the new North American systems between 2004 and 2006 and the general state of the telecom recovery will determine the availability of the capital investment funds to support this world wide expansion. The overall factors of growing broad band demand and the complementary nature of the two way satellite link to ground based infrastructure, points to future world wide demand growth for millimeter wave GaAs components in these market segments.

4. AUTOMOTIVE RADAR

Automotive radar is emerging as the next high-volume application for millimeter wave MMICs. Today, two classes of systems are in limited production: (1) long-range radar, performing the forward-looking functions, Autonomous Cruise Control (ACC) and Collision Warning / Collision Avoidance, and (2) short-range radar for side-looking and rear-looking sensors for lane-change warning, backup warning and parking assistance. Such systems are currently being deployed, although typically restricted to high-end automobiles. Current design efforts are focused on cost reductions to allow widespread use. By 2010 system deployment is expected to be pervasive. Market Growth projections show penetration to grow from < 1% today to a significant fraction of the 30M annual automobile market by 2008. Beyond that point usage could grow until virtually all vehicles have up to 5 such systems installed. Total millimeter-wave MMIC usage should approach 100 million per year.

Low-cost MMICs and associated packaging are a must for the auto radar application. To minimize MMIC cost, the size and number of chips will shrink. It is expected that more highly integrated millimeter-wave RF chips will be teamed with silicon baseband chips in a simplified architecture. Previously automotive radar systems have been built at 19 GHz, 24 GHz, 60 GHz, and 77 GHz. As the cost of the 77 GHz systems decline, that frequency is expected to dominate for both short-range and long-range systems. Figure 5 shows the block diagram of a section of a 77-GHz long-range radar.

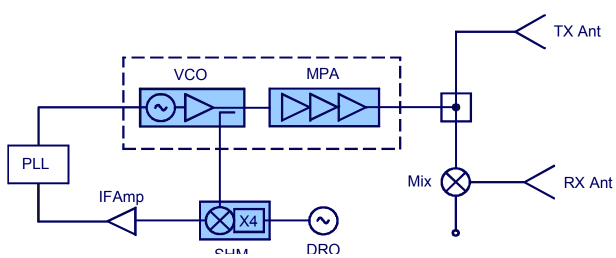

Figure 5. Block diagram for the RF section of a typical 77-GHz FMCW radar. Multiple channels of this type are typically used.

Three MMIC chips provide the transmit power tied by a phase-locked loop to a low-noise dielectric resonator oscillator at 19 GHz. An example of the f/4 subharmonic mixer MMIC for this system is shown in Figure 6. This compact chip is fabricated using a standard production low-cost 0.15-micron PHEMT process technology. It can readily be integrated with voltage-controlled oscillator and the medium power amplifier on a single chip using the same process technology. Once that level of integration is achieved, only a single 77 GHz interconnection is needed, alleviating the packaging difficulty. Over time, the process technology used for the RF section of automotive radars is likely to migrate to MHEMT or other higher f_T processes.

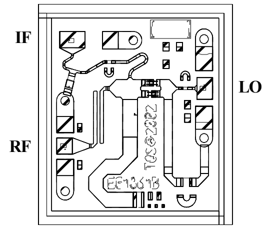

Figure 6. 77-GHz MMIC subharmonic mixer.

Packaging techniques for the RF function at 77 GHz is still being evaluated. Most systems to date have been built using chip and wire techniques interfacing with microstrip circuit boards. The large bond-wire inductance for that technique is a significant disadvantage, but that disadvantage is alleviated significantly by high levels of MMIC integration. Flip-chip MMICs offer an elegant solution the bond-wire inductance limitation, but require a better performance and feature size than is generally available in circuit board technology. Perhaps the ultimate approach will be a chip-on-board circuit card with integrated radiating elements, a small number of 77 GHz MMIC chips, a DRO and a silicon baseband chip.

5. CONCLUSIONS

Today, commercial markets for millimeter wave GaAs MMICs taken individually may be considered “niche” or “boutique” in nature due to their limited TAM. However, in aggregate, they represent a respectable market and with demand growing for broadband connectivity, the expectation is for the world wide demand for millimeter wave GaAs components to increase for all these market segments over the next several years. As the emerging automotive radar, Ka-band ground terminal and E-band radio markets mature, GaAs MMIC suppliers will find both opportunity and challenge to provide the cost effective MMIC and packaging solutions required to enable these markets to grow to their full potential.

ACKNOWLEDGEMENTS

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[1] CIBC World Markets, Digital Microwave Point-to-Point Radio Market 2001 Review - February 10, 2004