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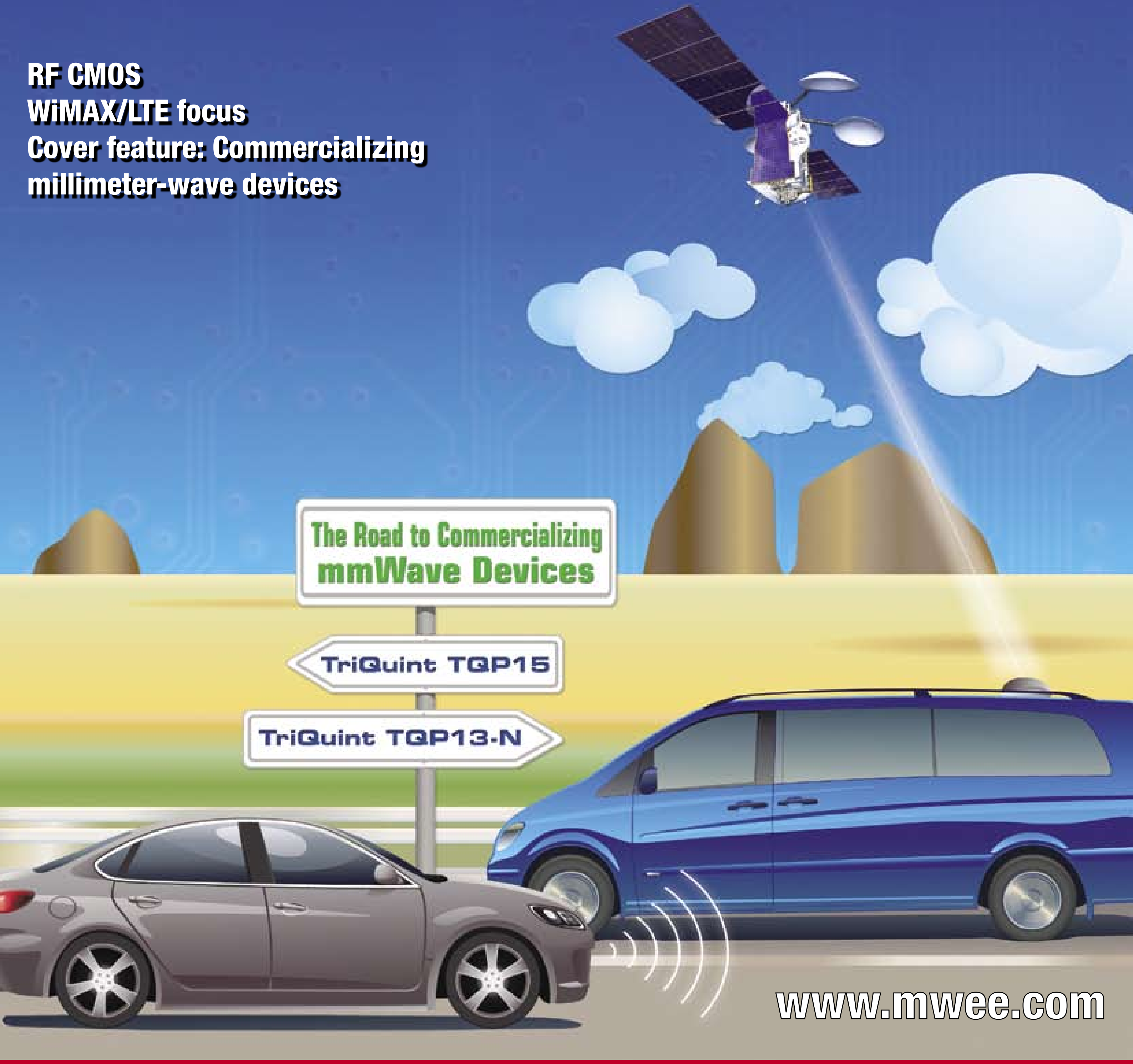

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Commercializing millimeter-wave devices — Innovative GaAs optical lithography

By Mike Peters, TriQuint Semiconductor, Inc., Marketing Director, Commercial Foundry Business Unit

Introduction

As high Radio Frequency (RF) wireless applications become increasingly integrated into our everyday lives, the demand for cost-effective semiconductor components to enable these systems continues to grow. New automotive radar, wireless video enabled devices, mobile satellite TV, and advanced Millimeter Wave (mmWave) imaging systems are just a few of the newest high-frequency wireless offerings. In order for these products to further drive into mainstream high-volume usage, the semiconductor industry must achieve the high-performance demands of these applications while evolving the cost structure from a historically high-cost base to a more cost-effective solution. TriQuint Semiconductor's Commercial Foundry Business Unit is developing and delivering new Gallium Arsenide (GaAs) processes which enable the more cost-effective generation of Radio Frequency Integrated Circuits (RFICs) needed for these applications.

Leveraging foundry history

TriQuint has been offering GaAs foundry services for more than 25 years. During this time, the process technology, manufacturing methodology, design tools and applications support infrastructure have been well-established and proven. As customers look for the most time-efficient and cost-effective methodology to participate in these emerging markets, TriQuint offers the most complete and trusted Gallium Arsenide foundry services in the industry.

GaAs pHEMT (Pseudomorphic High Electron Mobility Transistor) devices are well suited for mmWave markets. Foundry processes required for mmWave applications typically require cutoff frequencies (f_T) in the >75 GHz range. Semiconductor device physics show that small (0.25 µm and below) gate lengths are required to achieve these frequencies. Historically, these sub-micron feature sizes have been manufactured using e-beam lithography which enables excellent device performance, but at a high cost point due to expensive capitalization requirements and slow cycle time. Though e-beam is still the preferred process for the ultimate high-performance applications, TriQuint has created an optical photolithography-based process technology that provides a low-cost alternative for mmWave applications. TriQuint's optical lithography is well suited for more cost-effective, high-volume production creating gate lengths of 0.25, 0.15 and 0.13 µm. The evolution of these TriQuint processes is shown in Figure 1.

Performance requirements

The available foundry process technologies must be able to build transistors and other devices that meet the required performance needs for the mmWave market. Two key RFIC building blocks are Low Noise Amplifiers (LNAs) and Power Amplifiers (PAs). Slightly different optimizations are required for each of these blocks; therefore TriQuint has developed two GaAs process technologies to address these requirements, TQP13-N and TQP15. Each incorporates depletion mode pHEMT transistors along with flexible interconnect schemes, passive devices and backside vias. This allows for a complete RFIC solution to be constructed on a single die, see Table 1.

RF characteristics

In order to optimize for a particular application, different RF parameters are often considered. TriQuint's TQP13-N, 0.13 µm gate length process, has been designed with LNAs in mind, where Noise Figure (NF) is of particular importance. Figure 2 shows measurement of NF as well as its match to design kit models. The low NF of less than 0.5 dB at 15 GHz is well suited for LNAs.

TriQuint's TQP15, 0.15 µm gate length process, with its higher breakdown voltage (~14 V typical), has been designed for medium power amplifiers. Load pull measurements are

Process	TQP13-N	TQP15
Wafer Size	150mm	150mm
Photolithography	Optical	Optical
Technology	pHEMT	pHEMT
Critical Dimension (µm)	0.13	0.15
Mask Layers, w/o svia	12	13
Metals	2-AB	2-BCB
MIM C/A (fF/um^2)	0.34	0.6
TFR (ohms/sqr.)	50	50
Bulk R (ohms/sqr.)	105	100
Transistor Type	D	D
Vdd ref (V)	3.0	3.0
Vp (V)	-0.3	-1.0
Idss (mA/mm)	100	300
Idh Max (mA/mm)	500	550
Gm (mS/mm)	1000	400
BVGD (V) min	6.0	12

Table 1: Performance characteristics of TQP13-N and TQP15.

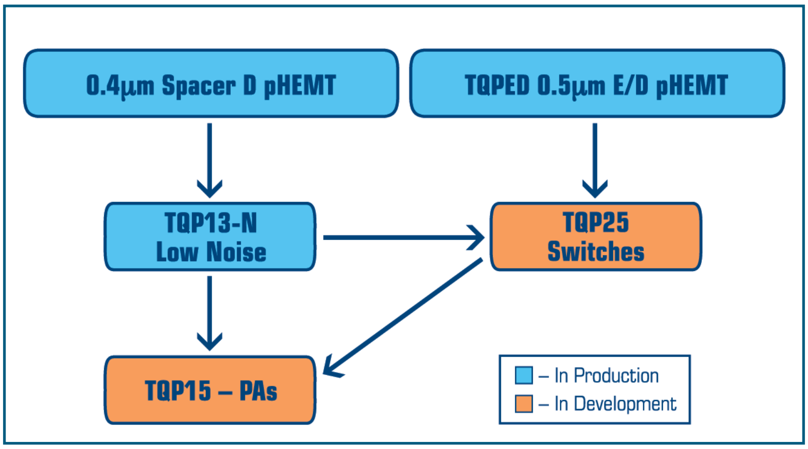


Figure 1: Evolution of mmWave optical foundry processes.

used to characterize device power amplifier capability. Figure 3 shows data at 21 GHz with gain between 9 and 10 and a TOI to P1dB ratio of ~10.

To illustrate the market fit and process capability, a 40 GHz PA has been designed and incorporated into the TQP15 process development mask set. This demonstrates complete RFIC performance and characterizes the effect of nominal process variation on amplifier performance.

Table 2 defines the operating parameters of the 40 GHz power amplifier, while the data plotted in Figure 5 shows the results of a simulation of a single-ended, three-stage, high-power amplifier operating at 40 GHz from a three-volt power supply. The design uses a low-cost, two-metal layer microstrip line matching with standard MIM capacitors and 90 µm substrate vias on a 100 µm thick GaAs substrate.

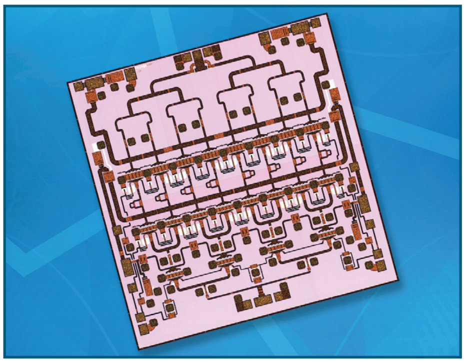
Manufacturability

In order for a GaAs foundry process to be usable by design teams, as well as capable in full high-volume production, manufacturability requirements need to be built in from the beginning of process development. Incorporating already established process control modules allows the optical technologies to stabilize quickly in production. TQP13-N has already been released to production and its production stability has been well-established, with more than three years of production history. In bringing up the new TQP15 process, device statistics are being established by running multiple small lots and characterizing lot-to-lot and across wafer variation. Previously developed test structures and data collection methodologies modified for TQP15 are incorporated and integrated into the high-volume manufacturing flow.

Design tools

Equally as important as the performance of the devices is the usability and accuracy of the simulation and layout tools. TriQuint supports multiple commercial EDA (Electronic Design Automation) platforms such as Agilent ADS and AWR Microwave Office as well as providing custom-developed simulation models. These model design kits have an established history of accuracy and reliability and are an excellent complement to TriQuint's advanced manufacturing processes.

Figure 4: A die photo of a 40 GHz PA.



Commercializing mmWave RFICs

Addressing the growing mmWave market component performance and cost points requires innovative semiconductor technologies. TriQuint's new optical lithography foundry processes make these technologies available to the RF design and product development community. These technologies, combined with superior design tools and applications support, will enable the expansion of the mmWave RFICs into the commercial marketplace.

Acknowledgements

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Figure 2: TQP13-N Noise Figure measured versus modelled.

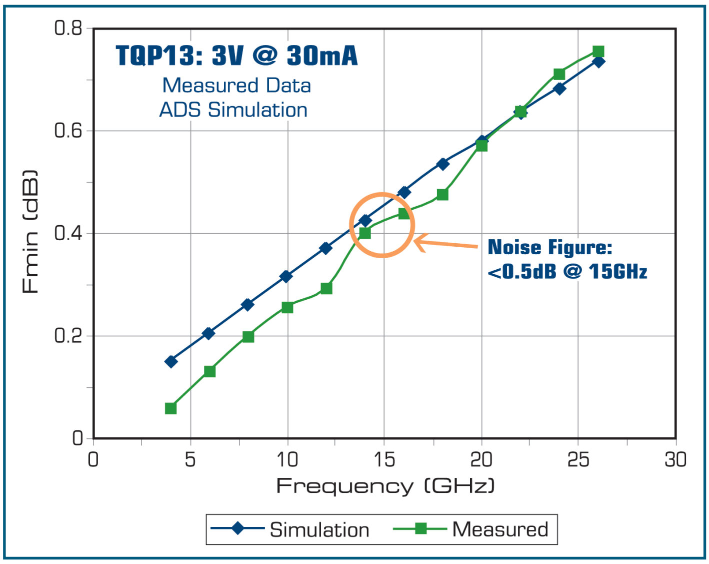

Table 2: Operating parameters of the 40 GHz power amplifier.

Frequency	Pout	Die Area	Power Density	Small Signal Gain	PAE	Vds	Idsq
(GHz)	(dBm)	(mm^2)	(mW/mm^2)	(dB)	(%)	(V)	(mA)
40	32.45	9.58	183	15	29.5	3.0	1655

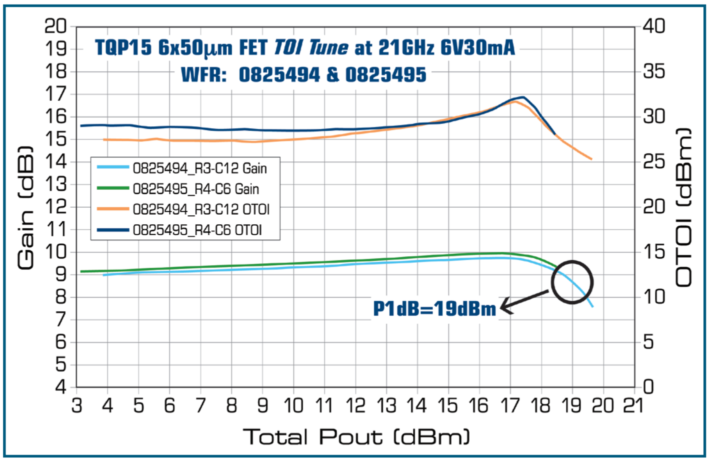

Figure 3: TQP15 load pull measurements.

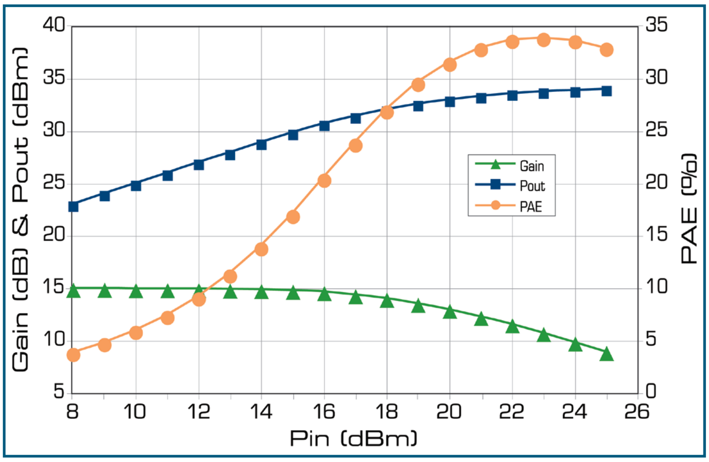

Figure 5: Simulation data of a single-ended, three-stage, 40 GHz PA.