Low cost and high performance GaAs MMIC solutions for automotive radar

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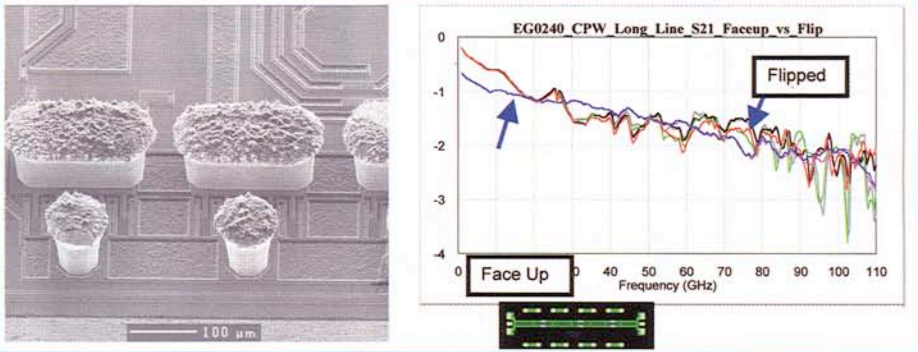
Today's most promising high-volume market for millimetre frequencies can be found in automotive systems designed to offer improved passenger safety and greater driving comfort. Monitoring the surroundings of a car with sensors gathers useful information for such applications. The best sensor principle appears to be radar-based because other solutions like video, laser and ultrasound exhibit performance shortcomings under harsh weather conditions. Typical long-range radar (LRR) systems operate at 77 GHz and can track the road up to 150 m in front of the car. These millimetre frequencies allow for small angular beam widths and low physical dimensions of the antenna and the complete radar sensor. LRR sensors are primarily used to maintain preset vehicle speeds on highways, as well maintaining safe driving distances between vehicles. Furthermore, a combination of LRR with a 24 GHz short-range radar (SRR) system can provide additional valuable data for advanced driver assistance systems.

Figure 1a: SEM photograph of TriQuint's high volume CuFlip™ bump process; measured and modelled losses for a 2.9 mm coplanar GaAs line with CuFlip™ bumps.



The European Commission has approved re-allocation of the 24 GHz frequency band for automotive short-range radar. This means that the frequency band of 21.625-26.625 GHz is allocated for the temporary use of UWB automotive short range radar until mid-2013. From then onwards new cars have to be equipped with SRR sensors that operate in the frequency range from 77-81 GHz (the 79 GHz band). This can potentially create another high volume market for GaAs millimetre wave MMICs.

The basic system concept adopted by most automotive radar sensors is the FMCW (frequency modulated continuous wave) radar with homodyne front-end architecture. A voltage controlled oscillator (VCO) is modulated by a low frequency signal which in most cases has a triangular waveform. The VCO output signal is split into a part that feeds the transmit antenna and another part that becomes the local oscillator signal for the receiver mixer. Utilizing a single oscillator to generate both the transmit (Tx) and the LO signals is the characteristic feature of a homodyne system architecture, which is preferred over other concepts mainly for cost reasons. In practice there are many differences due to modifications and extensions of the basic concept. For example: a lower frequency VCO can be used instead of a fundamental 77 GHz oscillator followed by a number of frequency multiplier stages. The number of transmit and/or receive channels may further vary as a means to measure the azimuth angle of the targets or a low noise amplifier may be included in the receive path in order to improve the receiver sensitivity.

TriQuint Semiconductor has developed a complete 77 GHz GaAs chipset to serve the different radar architectures that are expected to be implemented. Only slight design modifications to the principal designs will be necessary to cover both the 77 GHz LRR and 79 GHz SRR bands. This chip set makes use of the best GaAs technology in terms of performance and cost for each function. In the current chip set generation HBT is used for frequency generation and down conversion; a pHEMT technology is utilized for frequency multiplication and amplification, while VPIN sees application for switching functions. Each of these ICs can be made very compact so that initial cost will be moderate. In the future more highly-integrated versions of the chip set are expected to reduce costs further.

Generally, substrate via holes and insulating substrates are key enablers for microstrip IC technology, together with routinely used bond wire interconnects. But even moderate wire inductances can affect performance at high frequencies. TriQuint's latest chip set version consists of coplanar MMICs that are based on finite ground coplanar transmission lines. These MMICs can be used either with standard bond wire interconnects or bumps for flip-chip assembly. In combination with a high volume CuFlip™ bump process (see Figure 1) the lowest possible interconnect inductances at millimeter-wave frequencies can be achieved. Measurements have demonstrated that bump transitions with the CuFlip™ process work excellently at 77 GHz. Measurements revealed that flip-chip transition losses are minimal when comparing measurements of flipped transmission coplanar waveguide lines to non-flipped probe level results.

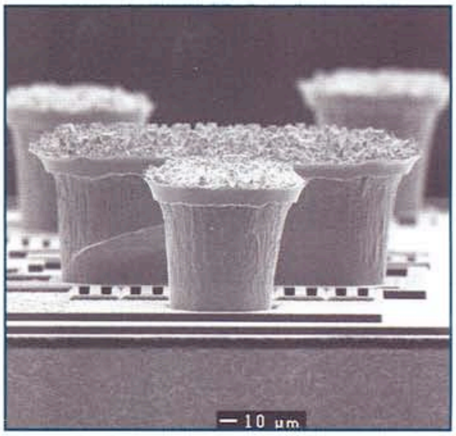
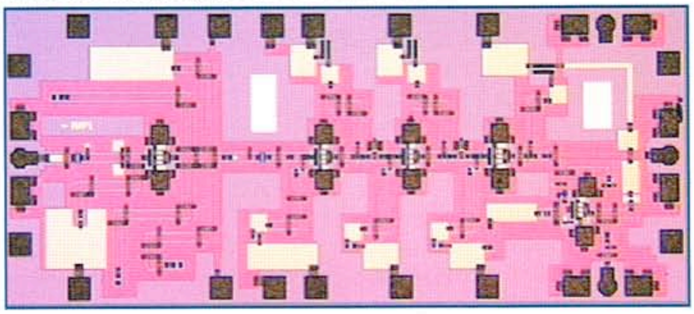


Figure 1b: SEM photograph of TriQuint's high volume CuFlip™ bump process at higher resolution.

Figure 2: Coplanar pHEMT 77 GHz MPA with a 38/76 GHz frequency doubler at the input, die size: 3.1 mm x 1.4 mm.



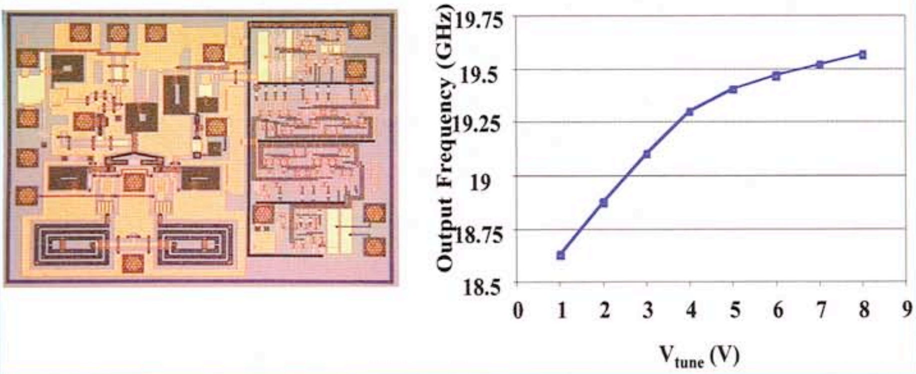
For the amplification and frequency multiplication functions of this chip set a 150 mm millimetre wave pHEMT process is used. This technology is a unique low-cost, optical lithography depletion mode pHEMT process that is optimized for low noise and medium power applications in Ku- through W-Band applications. It features a highly repeatable 0.13 μm self-aligned gate coupled with high density capacitors, epitaxial resistors and three layers of gold interconnect. A key advantage of this pHEMT process is that no electron beam lithography is used during fabrication. This offers a much higher throughput and lower production costs compared to technologies using electron beam lithography for the gate formation. In addition, the coplanar designs require no via hole process and no backside metallization. With typical F_t of 95 GHz at 250 mA/mm the process is ideally suited for cost sensitive 77-81 GHz automotive radar applications.

Figure 2 displays a photograph of a 77 GHz coplanar 3-stage medium power amplifier (MPA) with a 38 to 76 GHz frequency doubler on the input. The MPA delivers a saturated output power of 16 dBm at 77 GHz and a linear gain of 12 dB. In order to drive the receive mixer a coupled 77 GHz output port with 12 dBm is provided on chip.

Radar sensor performance to a large extent depends on the quality of the signal source; hence low phase noise is a key requirement for the oscillator. Transistors and diodes implemented in a GaAs/InGaP HBT MMIC process have demonstrated lower intrinsic 1/f noise at baseband frequencies and inherent lower free-running phase VCO noise performance compared to GaAs pHEMT processes. The VCO and receive mixer design were therefore conducted on a 150 mm high volume and low cost HBT process. This technology offers three levels of interconnecting metal and high density capacitors to keep die sizes small. The metal layers are encapsulated in a high performance dielectric that allows wiring flexibility.

A coplanar 19 GHz HBT VCO MMIC design with 8:1 prescaler is shown in Figure 3. A push-push topology was selected for this VCO. The principal of this type of oscillator is to cancel out the first harmonic by combining two single-ended oscillators anti-phase while the second harmonic, which is inherently apparent in any oscillator, is coupled out. This approach is particularly useful if the frequency is so high that a fundamental oscillator is beyond the capabilities of the given MMIC process. The push-push concept in this VCO design is not only for second-harmonic generation but also to provide a differential output to the 4:1 divider circuit at the first harmonic frequency. The measured output power of this 5 V single supply VCO is greater than 2 dBm. It provides a tuning range of approximately 1 GHz as can be seen in Figure 3. A running VCO showed a phase noise performance of –110 dBc/Hz at 1 MHz offset. A typical radar will include some additional circuitry to stabilize the oscillation frequency and to linearize the tuning characteristic of the VCO. The circuitry can

Figure 3: Photograph of a coplanar 19 GHz HBT VCO with 8:1 prescaler (die size: 1.3 mm x 1.7 mm) and its voltage contol of the output frequency.



be implemented inexpensively since it uses a 2.4 GHz prescaled output from the VCO MMIC.

In addition to transmitter power and antenna gain, the receiver sensitivity is the most important parameter which limits the maximum range of the radar sensor. For a homodyne radar architecture this sensitivity mainly depends on the noise figure of the mixer. At kilohertz frequencies the noise at the mixer output port is not dominated by thermal noise or shot noise of the semiconductor devices. Instead, the receiver sensitivity is limited by 1/f noise of the semiconductor devices used in the mixer circuit. The strength of 1/f type is very dependent on the semiconductor technology used and may vary orders of magnitude between one technology to the next. 1/f type of noise can be particularly strong in GaAs pHEMT components dominating the noise performance at frequencies up to at least 10 MHz. GaAs HBT technology is known to have superior 1/f noise performance compared to pHEMT devices.

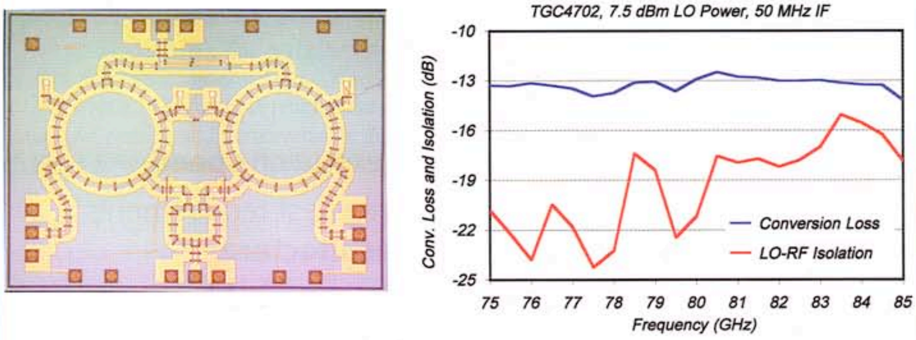


Figure 4: Photograph of a coplanar 77 GHz downconverting I/Q HBT mixer (die size: 1.9 mm x 2.1 mm) and its converison loss and LO-RF isolation performance.

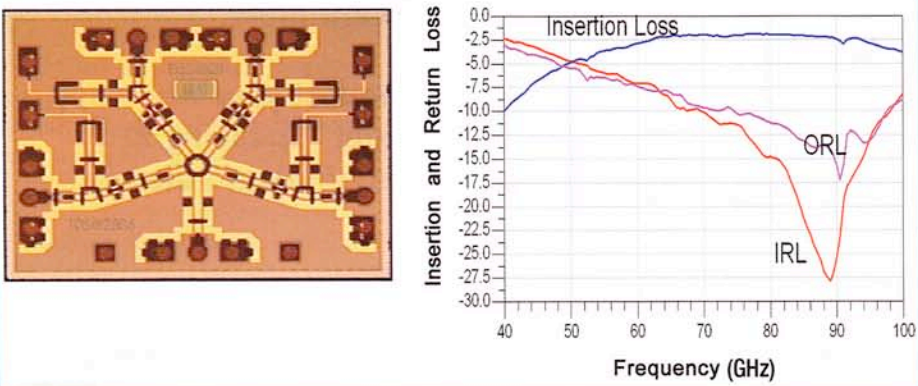


Figure 5: Photograph of a coplanar 77 GHz SP4T VPIN switch (die size: 1.8 mm x 1.3 mm) and its return and insertion loss performance as illustrated in the accopanying plot.

Figure 4 includes a photograph of an HBT receiver down converter mixer that operates from 76-77 GHz. This I/Q mixer employs 'rat-race' couplers and provides a conversion loss lower than 14 dB for a LO input power level of 7.5 dBm. The LO-RF isolation is better than 20 dB in the band of interest as illustrated by the accompanying performance plot.

For the 77 GHz antenna switch (see example of a coplanar SP4T switch in Figure 5) low RF loss, good isolation and low VSWR are required. GaAs PIN technology appears to be an excellent technology to meet these requirements because it provides low off-state capacitances, low on-state resistances and a high cut off frequency of the PIN diode elements. A 100 mm GaAs Vertical PIN process was used for 77 GHz SP3T, SP4T and SP5T designs. The passives of this process include 2 thick-metal interconnect layers, precision TaN and GaAs resistors, MIM capacitors and through-substrate vias. In addition the via-under-capacitor process aids in size compaction and offers excellent grounds at higher frequencies.

Figure 5 shows a coplanar SP4T VPIN switch design with an insertion loss lower than 2.5 dB and an isolation better than 24 dB from 75 to 82 GHz.

Summary and conclusions

Gallium Arsenide technology represents the optimum choice for 77 GHz long-range radar applications because the various processes documented in this article are shown to provide excellent performance of each single MMIC function as well as a system solution for the complete radar front-end. In addition, these specialized technologies can provide the needed performance for automotive radar depending on the frequency, power or noise requirements at low production costs. For 77 GHz radar front-end TriQuint developed a coplanar chip set utilizing high performance, low-cost GaAs pHEMT, VPIN and HBT production technologies. All MMICs within this chip set are suitable for commonly used bond wire manufacturing processes and also for flip-chip mounting, whereas the latter technique has the potential for a significant assembly cost reduction. In near future TriQuint will assemble a complete 77 GHz radar front-end using the coplanar chipset and flip-chip mounting. Standardized RF front-end prototypes, the essential 'building blocks' of the solution, will then be made available for evaluation purposes.

Company Information

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