MMICS FOR AUTOMOTIVE RADAR APPLICATIONS

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ABSTRACT

The paper discusses trends in automotive radar applications and the use of MMICs in the transceiver design. Forward, rear, and side radar applications are discussed as a function of performance, size, cost, and Federal Communications Commission (FCC) radiation limits. Transceiver design options for each application are presented including choices for the active semiconductors required. GaAs, InP, and SiGe MMICs are design options for each application as are discrete semiconductor devices. Parameters used in device trade-offs, and advantages and disadvantages of each semiconductor technology relative to these parameters, are presented.

INTRODUCTION

There are a variety of applications for microwave/millimeter wave devices in the consumer automotive arena. These include forward looking radar for collision warning and cruise control, side radar for lane change maneuvers, rear radar for backing aid, parking aid, air bag arming, and security systems. For each of these general areas, there are a variety of specialized applications and variations, a variety of waveforms and system architectures, and a variety of component performance specifications. It is beyond the scope of this paper to discuss the specific design approaches, the specific applications, or the approaches for validating the performance parameters. For automotive applications all of these systems face the same generic problems of styling compatibility, size, Federal Communications Commission (FCC) requirements, and cost. Of these, FCC considerations are fixed as a design constraint that must be met, and cost is the highest priority of the other three.

FCC CONSIDERATIONS

There are four primary bands of operation allowed by the FCC for high power, intentional radiators that are governed by Part 15 rules. Although arguments exist that potentially allow operation elsewhere under certain constraints for certain applications, only the bands and major emission characteristics summarized in Table 1 will be discussed.

Frequency	Bandwidth	Power Density @ 3 meters/ sq cm
5.8	150 MHz	663 pW
10.525	50 MHz	1.66 uW
24.125	250 MHz	16.6 nW
46.8	200 MHz	60 uW
76.5	1 GHz	60 uW

Table 1 Primary FCC Operating Bands

There are other operating bands that allow significantly less power over wider bandwidths that could accommodate wide band radar solutions, and there are higher emissions allowed at 5.8 and 24.125 GHz center frequencies over a narrower bandwidth. The point to be made is that frequency allocation regulations are a major factor in automotive radar system design.

OPERATING FREQUENCY SELECTION

Selection of an operating frequency is a series of trade-offs constrained by a number of factors and based on some general assumptions regarding recurring cost. A very important general assumption is that selection of the lowest possible operating frequency will result in the lowest potential recurring cost. A low operating frequency provides many more options to the circuit designer, including use of surface mount discrete microwave components, Si MMICs, SiGe MMICs, and GaAs MMICs. Lower frequency MMICs are fabricated using photolithography instead of more expensive E-beam lithography.

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Assuming that lower frequency is lower cost, selecting the operating frequency for the application is driven by the performance parameters specified for the system. In particular, the zone of coverage will dictate the antenna beamwidth required. Styling issues will determine the maximum aperture size allowed by the vehicle designers. At a given frequency, antenna beamwidth dictates the aperture size, and if the aperture size exceeds the stylist's packaging requirements, the operating frequency selection is forced higher. Operating range will determine the radiated power required, which will eliminate certain bands from consideration based on allowable maximum radiated field strengths.

The point of the discussion thus far is to establish some of the considerations that are used in selecting an operating frequency band and to establish that in general lower frequency is perceived as lower cost.

GENERIC SENSOR PERFORMANCE ISSUES

For most automotive applications, the microwave/millimeter wave active component performance specification is not state-of-the-art. Radiated power levels at the antenna terminals are typically less than 10 mW, and internal power levels are typically less than 30 mW. Receiver noise figure is often 10dB or higher and, except for VCO phase noise and frequency stability, all other active component specifications are readily achievable.

VCO phase noise and frequency stability are the key technical parameters to low cost transceivers at any frequency band. The new millimeter wave allocation at 76 GHz is the largest percentage bandwidth allocated by the FCC for higher power applications, and this bandwidth is only 1.3% (The lower power 5.8 GHz allocation is 2.6%). The design and fabrication challenge for MMICs that integrate the VCO is control of the start frequency. Tuning, whether manual or automated, significantly increases the assembly labor and capital. Additionally, integrated VCOs typically have higher phase noise as a result of lower circuit Q relative to waveguide or dielectric resonator structures.

Meeting FCC frequency allocations is the largest cost driver in any automotive radar design. The inherently narrow bandwidth allowed by the FCC at any frequency removes a generic MMIC advantage of broad band performance achieved by elimination of circuit, wire-bond, and package parasitics. Broad band performance has been found to be more of a detriment than an asset for the transmitter circuits. Receivers can still reap the benefits of broad band operation.

In those applications which require multiple channels, MMICs reduce the difficulty of routing power, control, and tuning traces across channels. The MMIC will also reduce the cumulative effect of parasitics through multiple stages of amplification or circuit function, an increasingly important function at higher frequencies.

TRANSCEIVER COST TARGETS

As stated earlier, cost is the single most important parameter that must be met in automotive applications. Numerous marketing clinics have been performed by all of the major automobile manufacturers. These clinics have established a cost target for the variety of applications being pursued. Based on these clinics, forward radar is the system that appears to have the highest cost tolerance in terms of consumer acceptance vs. option cost. From the clinics, it is clear that transceiver cost targets must be less than $25 for all applications except forward, and must be less than $40 for forward radar. This cost is for the complete transceiver assembly, including all assembly and test labor, yield losses, components, substrates and housings.

It is important to emphasize that these cost targets are applicable for introductory production volumes, perhaps 20,000 to 100,000 annually, and are not "high volume" per year commitments. The concern is that if the option is "too expensive" at the start, consumer acceptance will not be sufficient to drive the production volumes upward, allowing attendant volume cost reductions. Production introduction investments, where the unit cost is subsidized by the manufacturer until volumes increase, cannot be maintained in the long term.

DESIGN TRENDS

Design trends are to use the lowest frequency option in all applications. This means that discrete components and silicon MMIC or ASIC designs will be very competitive with regard to performance, volume, and recurring cost for many automotive applications. Arguments can be made that the repeatability and yields of discrete components, coupled with automated packaging and assembly, are such that the combined circuit cost is low enough to meet design to cost requirements. This argument is supported by the work done by many suppliers on direct broadcast low noise amplifiers, where circuit assembly times and yields have resulted in manufacturing costs less than $30 for the completed assembly operating at 12.5 GHz. It must also be noted that there is continued effort to develop MMICs for this application, anticipating that the resulting multi-function chip will be a cost effective replacement for the discrete components.

For devices such as security systems and air bag arming, physical volume is a significant driver, and Si or SiGe MMICs and ASICs will be a factor. Volume is not a critical factor for applications where the antenna size is greater than the area required by the microwave components.

Design non-recurring cost and cycle time are also factors in selecting the design technology. In this respect GaAs and InP MMICs are not yet competitive with other technologies. Design costs and design cycle times are too high, and foundry fabrication cycles are too long. For frequencies less than 20

GHz, the discrete component performance is acceptable and the NRE and development time is significantly less than for GaAs or InP MMICs. Additionally, the processing yields, processing cost per wafer, and wafer size (resulting in more chips per wafer) are lower for silicon.

Clear performance advantages exist for GaAs and InP MMICs at frequencies above 30 GHz based on current technology. Yet, it is not clear that the potential cost advantages can be realized. Although processing costs are being reduced and circuit design technology has significantly reduced MMIC size, the processing costs and yields are not yet consistent with automotive market price targets. The inability to effectively produce narrow band oscillators on MMIC chips has forced many high frequency designs to use Gunn diode oscillators.

CONCLUSION

Federal regulations play a significant role in selecting operating frequencies and design options for automotive microwave/millimeter wave MMIC applications. The inherent MMIC advantage of broad band operation is not required by most automotive applications (wide band modulation is a potential application for broad band components). The GaAs and InP MMIC yields, recurring costs, and non-recurring costs have not decreased as rapidly as expected. The trend for automotive devices at the present time is to look for the lowest possible operating frequency. This is an advantage for discrete components and silicon MMICs and ASICs. GaAs and InP MMICs still have a natural home at frequencies greater than 30 GHz if they can meet cost targets for the completed transceiver. Additionally, there will be continued pressure to further reduce the size and increase the performance of many of the short range applications such as side and rear. This can be accomplished in many design approaches by increasing the operating frequency. However, migration of these short range applications to frequencies greater than 30 GHz will probably not occur until MMIC yield and cost targets have been successfully demonstrated.