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Automotive Applications of GaAs Components

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Abstract

The market for GaAs MMICs in motor vehicles is expanding and will become a major area of interest for GaAs component manufacturers. In particular, mm wave MMICs will be used in sensor and communications applications in motor vehicles. This paper outlines some of these applications, their present status and MMICs which have been fabricated and used in them.

Introduction

The manufacture of motor vehicles is one of the worlds largest industries. Over 50 million new motor vehicles are produced each year and the proportion of electronics in each vehicle is increasing rapidly. By the year 2000 the amount of electronics is expected to make up about 20% of the value of a vehicle.

Sensors	Freq. (GHz)
Collision avoidance radar	60, 77
Intelligent cruise control	60, 77
Road condition sensor	24, 60
Speed sensor	24, 60
Passenger detector	-
Obstacle detection	12
Communications & Navigation	
Identification and payment systems	5.8 or lower
Navigation systems	2.4
Mobile broadband communication	60

Table 1 Automotive applications using RF components

RF systems, many of them using GaAs components are increasingly finding their way into automobiles for use in sensor and communication systems operating at frequencies from <1GHz to 77GHz. Millimeterwave frequency systems, particularly for sensors, have good market possibilities in the automotive sector. Table 1 lists the most important applications using RF components. The allocation of frequencies and the requirements of the different systems are such that for each particular application 1 or 2 frequencies are currently being used.

Sensors

Because of the required directivity and antenna size, sensors for automotive applications operate at microwave or millimeterwave frequencies. As yet, only pilot systems are in operation. Large volume implementation of automotive radar sensors will strongly depend on the cost and availability of suitable GaAs MMICs. Most of the pilot or small scale systems in operation are based on hybrid frontend modules using discrete components.

Communication and Navigation

Navigation systems using GPS are already being widely implemented in the market place. GPS receivers typically use a low noise frontend with a GaAs FET or MMIC. In the near future these systems will be linked to mobile phone systems giving an additional market for GaAs components. Identification and payment systems using tags and beacons are in use at a number of different frequencies. Due to the congestion at lower frequencies and the beamforming requirements for beacons, the trend is towards higher frequencies. In the medium term, millimeterwaves are also expected to be used for mobile broadband communications as has been shown in the european MBS demonstration system or the DACAR project [1].

Collision avoidance radar and Intelligent cruise control

As yet, due to high costs, millimetre wave radars haven't penetrated this very large market. However, the cost of mm-wave radars has substantially decreased and road obstacle detection systems are now under development worldwide. Nearly every car manufacturer together with specialist partner companies has a development programme for autonomous intelligent cruise controls (AICC) or collision avoidance systems, e.g. [2,3,4,5]. As a rough estimation about 12 U.S. companies, 11 companies in Europe and at least 5 in Japan are involved.

After installation of collision avoidance radars in Greyhound busses in the U.S., the numbers of accidents dropped by more than 42%. During the last 10 years, prices for electronic circuits and millimetre wave frontends could be lowered due to the progress made in semiconductor technology. Pseudomorphic HFET GaAs processes suitable for 77 GHz applications now show the maturity and potential, which will allow the start of mass production in the near future. Recent market studies predict that system prices of the order of those of anti blocking systems are feasible and about 10 million systems will be sold worldwide in the year 2003.

Company	Freq. (GHz)	Technology
Daimler-Benz	77	7 MMICs
GEC Marconi	77	hybrid MIC, GUNN oscillator
LUCAS advanced engineering	77	frontend by Marconi
Philips Microwave	77	hybrid plastic moulded finline
Celsius Tech Electronics	77	frontend by Philips
SMA (Italia)	77	Gunn DRO plus MMICs
HIT Israel	77	3 MMICs
TRW (USA)	94	1 MMIC
Raytheon	77	MMICs
VORAD	24	hybrid MIC
millitech Corporation (USA)	77	hybrid MIC plus 1 MMIC

Table 2 Published automotive radar systems

Some companies are introducing equipment with hybrid components in order to address the market as soon as possible, but with respect to costs, this can't be the solution for the macs market of the future. Therefore efforts are under way to develop cheaper RF-frontend technologies (MMICs, housings and assembly techniques). Some of these systems and the applied technology are listed in table 2.

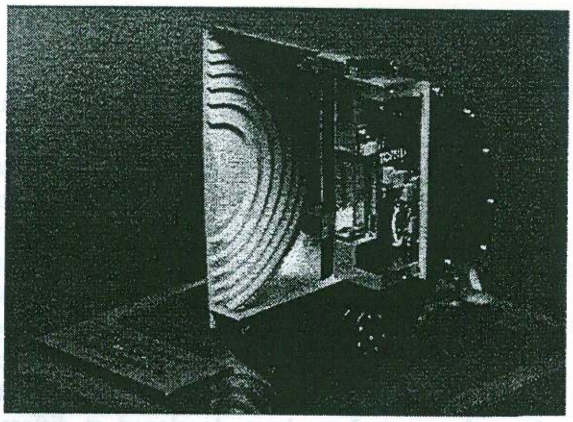

Fig. 1 A cut-open view of a 77GHz collision avoidance radar (Daimler-Benz Aerospace)

Fig. 1 shows a photograph of a collision avoidance radar front end manufactured by Daimler Benz Aerospace and using a custom set of GaAs MMICs for the RF module[6,7]. This is a compact coherent pulse radar with a dielectric lens antenna system. The radar concept uses a pulse Doppler scheme where the IF frequency is 180MHz. The RF module employs a total of 7 GaAs MMICs for VCO, buffer amplifier, frequency doubler, mixer and switch functions. Signal generation is carried out at 38GHz in order to fulfill the phase noise requirements of the system. The complete system has 3 switchable beams and has been successfully road tested under extreme conditions.

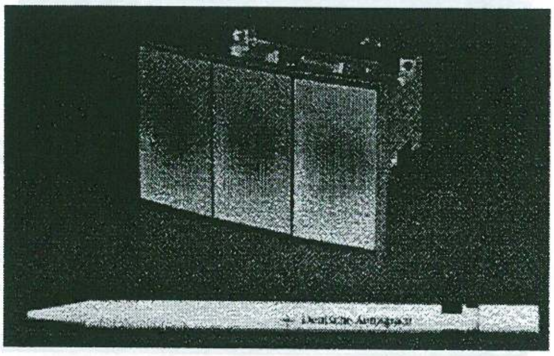

Fig. 2 An intelligent cruise control radar using discrete RF components (Daimler-Benz)

Fig. 2 shows a photograph of an intelligent cruise control radar built using discrete components [4]. Here FM-CW transmission has been combined with amplitude monopulse techniques. Signal generation is with GaAs Gunn diodes and Si Schottky diodes were used for the mixers. Such systems work well for intelligent cruise control and are still a major competitor for GaAs MMIC based systems.

Microwave doppler speed sensors

Future onboard traffic control systems require true ground speed information for ABS, or car navigation systems. As early as 1972 Texas Instruments and General Motors, fabricated and tested a 55 GHz speedometer utilizing Silicon IMPATTs and Schottky barrier diodes [8]. More recent Doppler systems at both 24 and 61 GHz, have shown, that at least two independent sensors should be employed to correct the systematic measurement error due to vehicle movements. Several sensors have been developed at different Institutes and Companies in cooperation with the major car manufacturers in Europe [9,10,11].

24 GHz Daimler-Benz MDS module

Daimler-Benz has fabricated a series of prototypes of 24GHz speed sensors using 0.25µm MESFET technology. The prototypes were successfully road tested. During development different MMICs were used for the different functions, For series production, the different functions have to be integrated. The Oscillator MMICs used for this application had an output power of 16mW which is easily sufficient for this short range application.

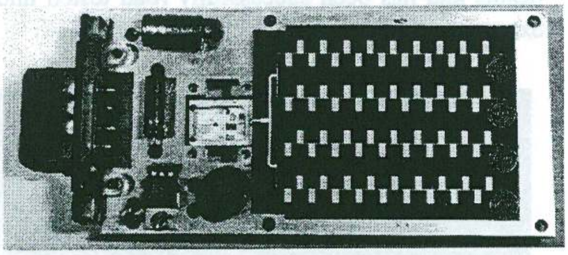

Fig. 3 A prototype of a doppler speed sensor

A photo of the developed sensor is shown in fig. 3.

51 GHz Daimler-Benz SIMMWIC velocity sensor

A simple velocity sensor, taking advantage of the recent advances in Si MMIC technology, i.e. SIMMWIC (SIlicon MilliMeter Wave Integrated Circuits), has also been developed by the Daimler-Benz Research Institute of Ulm, Germany (see Fig.4) [12]. Basically this simple sensor consists of three components only: the millimeterwave chip, the antenna system and the signal processing. The employed millimeterwave chip is a SIMMWIC oscillator/transmitter, operating in the self-mixing mode, thus no external mixer is required. The MDS (Minimum Detectable Signal) of such an IMPATT oscillator at 51 GHz with an output power of -10 dBm can be as low as -145 dBm, 10 kHz off carrier. The frequency of 51 GHz was chosen arbitrarily, due to the availability of test samples; other frequencies, e.g. 61 GHz, are easily achievable.

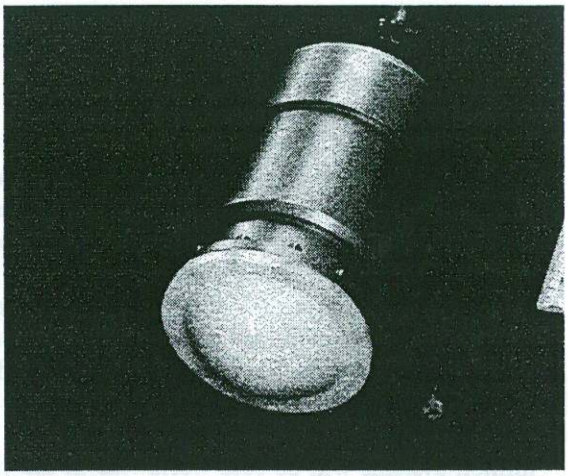

Fig. 4 A mm wave speed sensor using SIMMWICs (Silicon MMICs)

The work carried out at Daimler-Benz on Doppler speed sensors has shown definite advantages for the mm wave frequency range. The Frontend for mm wave sensors can be fabricated using either Si or GaAs. Large volume implementation of Doppler speed sensors will require a highly integrated MMIC front end, cheap housing and antenna technology and increased functionality when compared to conventional mechanical or Hall sensor based systems. The fact that the Doppler system measures the real speed over ground and not just the speed of the wheels or the transmission is not sufficient to justify their widespread introduction into automobiles.

MMICs for automotive applications

There are good opportunities for GaAs MMICs in the applications mentioned above [13,15].

Oscillators

GaAs Gunn diodes are used as the signal source in many pilot systems. Gunn diodes exhibit 77GHz phase noise of about 80 to 85 dBc/Hz at 100kHz off carrier making them the most frequency stable source available at the present time. The disadvantages of Gunn diodes is that they cannot be easily integrated, they have a low efficiency and they are not cheap. MMIC based VCOs show approximately 20dB worse phase noise performance than Gunn diodes. MESFETs are somewhat better than PHEMTs. A solution using signal generation at

38GHz and then doubling up to 77GHz seems to give the best MMIC performance at the present time. HBTs, because of their vertical structure have exhibited lower phase noises. In the future HBT MMIC VCO may well be the best alternative for both sensor and communication applications.

The 0.25µm MESFET VCO with integrated buffer amplifier shown in Fig.5 was used successfully as a signal source for the collision avoidance system shown above. The phase noise would not have been sufficient for an FM-CW system

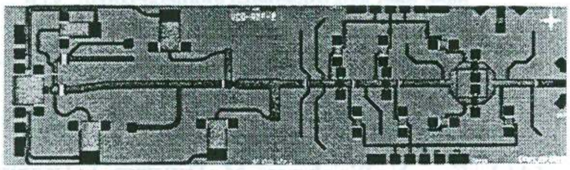

Fig. 5 A 38GHz MESFET VCO

Doublers

The use of signal generation at lower frequencies in order to improve the phase noise characteristics makes the use of a frequency doubler necessary. Good frequency doublers with between 6 and 8dB conversion loss for Ka-Band to W-Band frequency doubling have been fabricated by a number of different manufacturers. The circuits use either Schottky varactor diodes or FET devices as the active components. For sensor applications such as collision avoidance radar or speed sensors, the output powers required are low so that despite the losses caused by frequency multiplication, the required signal levels can be obtained. Fig. 6 shows a Schottky diode frequency doubler which exhibited 7dB conversion loss.

A series of different oscillators and frequency multipliers fabricated in 0.15µm PMHEMT technology for the generation of 77GHz signals has recently been published by Thomson[14].

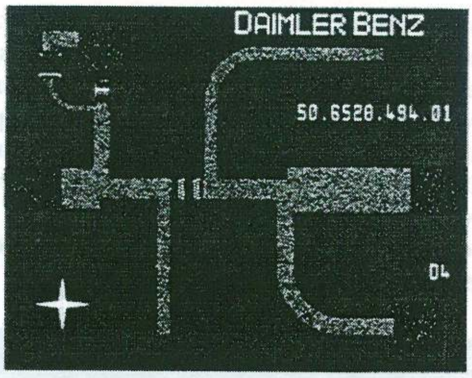

Fig. 6 A Schottky varactor diode doubler

Mixers

Mixers for 77GHz operation have been fabricated either using specific diode MMIC processes or short gate length PHEMT processes. Fig. 7 shows a diode mixer fabricated for the collision avoidance radar system shown above. Typically 6-7dB conversion loss can be obtained with diode mixers. Mixers using PHEMTs as the non-linear component usually have somewhat inferior performance. This can be compensated for, by integration of LNAs in front of the mixer.

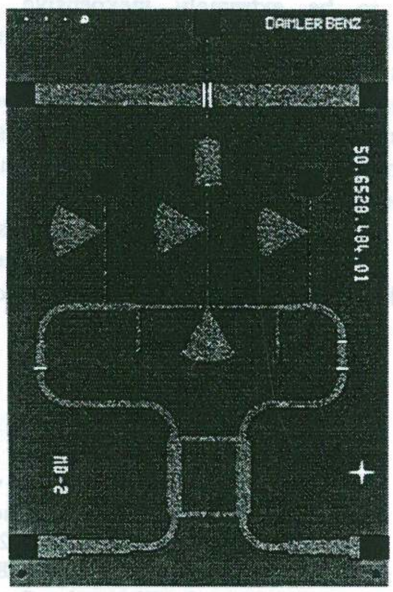

Fig. 7 A diode mixer MMIC for collision avoidance radar.

Switches

Collision avoidance radars using pulsed systems require switching circuits for switching between the different beams. Such switches can be fabricated either by using Schottky diodes or PIN diodes. PIN diodes show superior performance, however, PIN diode MMICs have the disadvantage that they cannot be integrated with other MMICs and they require fairly high currents for switching from one state to the other. For good overall systems performance where a number of switching functions are used, the switches can be a critical component. Insertion losses of <1dB and isolations better than 20dB have to be obtained. Fig. 8 shows a three way switch MMIC fabricated in Schottky diode technology which was used to switch between the beams of a collision avoidance system.

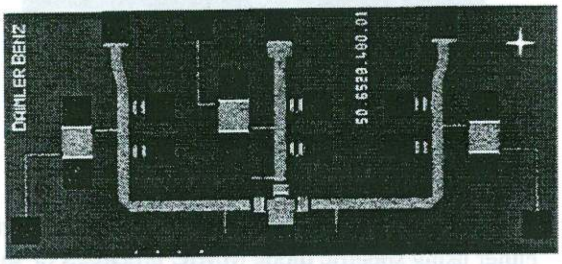

Fig. 8 A 3 way antenna switch MMIC

GaAs MMICs for future systems

The automotive market is a highly cost competitive market so that frontends for sensor and communications applications in that market will have to be extremely inexpensive. Multichip modules will not be able to meet the required price levels. Integrated mm wave front ends have been demonstrated, but do not yet show the required performance. For many applications in the automotive sector, short gate length PHEMT processes will play an important role in the future. More progress has to be made as regards the phase noise of the signal generator and the integration of switching functions which are required for many of these systems.

References

[1] Moss, C. R.: The DACAR millimetre wave vehicle communications link, Workshop 21st EuMC, Stuttgart 1991, Proc. [35], 112 - 121.

[2] Stove, A.: 80 GHz automotive radar, 8th Int. Conf. on Automotive Electronics, Oct. 1991, London, England, 145 - 149. August/September 1994, 17-21.

[3] HIT Limited - Highway Information Technologies, Kibbutz Yifat 30 069, Israel, data sheet 1994.

[4] Tempomat-Radar, A Product for more Comfort and more Safety in Road Traffic, Daimler-Benz Aerospace AG, Sensor Systems Division, Ulm, data sheet, 1994.

[5] AICC, A radar sensor for intelligent cruise control, data sheet, CelsiusTech AB, S-175 88 Järfälla, Sweden, 1994.

Eriksson, L., H.: A radar sensor for automatic AICC, IEEE Vehicular Technology Conference, Stockholm 1994.

[6] Ulke, W., Adomat, R., Butscher, K., Lauer, W.: Radar based automotive obstacle detection system, SAE Int. Congress, Detroit, MI, USA, Feb. 28 - Mar. 3, 1994, 41-53.

[7] Daimler-Benz out front in forward-looking collision warning, The Hansen Report - Automotive Electronics, April 1994, p.1ff

[8] Hyltin, T.M., Fuchser, T.D., Tyson, H. B., Regueiro, W. R.: Vehicular radar speedometer, SAE Int. Automotive Eng. Congress and Exposition, 1973, Detroit, MA, USA, paper 730 125, 1-36.

[9] Lissel, E.: Geschwindigkeits- und Wegsensor nach dem Mikrowellen-Doppler-Prinzip, VDI Berichte No. 687, 1988, 257 - 275.

[10] Kehrbeck, J.; Heidrich, E,; Wiesbeck, W.: Planar microwave Doppler-sensors for car speed monitoring, Workshop 21st EuMC, Stuttgart 1991, Proc. [35], 129-134.

[11] Kees, N., Weinberger, M., Detlefsen, J.: Doppler measurement of lateral and longitudinal velocity for automobiles at millimeterwaves, IEEE MTT-S Symposium 1993, Atlanta,GA, USA, 805-808.

[12] Dämbkes, H., Luy, J.-F.: Millimeterwave components and systems for automotive applications, Microwave Engineering Europe, Dec./Jan. 1996, 43-48.

[13] Colquhoun, A., Schmidt, L.-P.: MMICs for automotive and traffic applications, GaAs IC - Symposium 1992, Miami, Fl., USA.

[14] M. Camiade, C. Dorlens, V. Serru, P. Savary and J.C. Blanc.: „Generic MMIC chip set for automotive radar application at 77GHz",

[15] Raffaelli, L.; Stewart, E.: mmW monolithic components for automotive applications, Microwave Journal, Vol.35, No.2, Feb. 92, 22-32.