Automotive Radar – From Early Developments to Self-Driving Cars

Mark Walden

Abstract

Automotive radar has been in development for nearly thirty years. In that time it has gone from a luxury item on high end cars and a tool for the haulage industry, to a relatively common option on family vehicles. With the latest developments in SiGe and RF CMOS for high frequency applications, automotive radar may soon be as common-place as SatNav and Anti-lock Braking Systems. This paper seeks to give a taste of the development of automotive radar from Gunn diodes and waveguide, through GaAs MMIC based modules, to single chip solutions.

A brief history of Radar

It is often thought that Radar was invented in the build up to the Second World War, but the first patent that describes something that we today would recognise as Radar dates from about thirty years earlier. In 1904 Christian Huelsmeyer presented a patent for a system that could be used to detect ships in fog [1]. First successfully demonstrated in Cologne, the telemobiloscope, as Huelsmeyer called his invention, could detect ships at distances of up to 3km. The system caused a bell to ring when an object passed into the beam projected by the telemobiloscope. However the system did not provide any range information, and so could only be described as a "RAD" rather than a true RADAR (RAdio Detection and Ranging).


Eigentum des Kaiserlichen Patentamts. Eingefügt der Sammlung für Unterklasse .... Gruppe Nr. ....

KAISERLICHES PATENTAMT.

AUSGEGEBEN DEN 21. NOVEMBER 1905.

PATENTSCHRIFT

— № 165546 —

KLASSE 74 d.

CHR. HÜLSMEYER IN DÜSSELDORF.

Verfahren, um entfernte metallische Gegenstände mittels elektrischer Wellen einem Beobachter zu melden.

Patentiert im Deutschen Reiche vom 30. April 1904 ab.

Figure 1: Title page of Huelsmeyer's patent

In the 1930's with war seeming inevitable, and a war that looked to be waged at least in part in the air, the attention shifted to detecting aircraft. In Britain an effective radar based early warning system "Chain Home" was implemented, following on from research by Watson-Watt, the GPO, and the Air Ministry amongst others. However, Britain didn't have a monopoly on Radar development, with groups from the US, USSR, France, The Netherlands, Japan and of course Germany all working towards a working radar system in supposed secrecy. However this secrecy was dispelled in 1938 when at a luncheon held to honour the visit of Feldmarschall Erhard Milch to England he boasted about German radar to a room full of astonished high ranking RAF officers! Radar developed rapidly during and after the war for the detection of ships and aircraft for both military and civil use.

Automotive Radar

Having used radar to detect ships and aircraft, it was perhaps inevitable that the next focus would be on vehicles. Radar has several potential applications for automotive use such as Automated Cruise Control (ACC), Parking Sensors, Blind spot Checking, etc. It is perhaps not surprising that some of the earliest automotive radars were first available on Japanese vehicles, with Toyota leading the way in the late 1980s followed closely by Nissan and Honda. Systems were available on US and European high end vehicles by the late 1990s. One of the largest early deployments of Automotive Radar, was a Collision Warning System system sold by the Eaton Corporation in the US for truck drivers as a retrofit unit. The system was not a true autonomous cruise control system as it was not connected directly to any of the vehicle's systems. A forward looking monopulse radar operating at 24GHz was mounted on the front of the vehicle and a CPU unit mounted in the cab warned the driver if they were approaching another vehicle too quickly. Several trucking companies rolled the system out across their fleets and reported significant reductions in their accident rates [2].

The early systems operated on a variety of frequencies and with various modulations schemes though the majority of the early systems operated around 24GHz as they were seen as less complicated to design and fabricate and with a greater availability of components. However there was a great deal of research into systems that operated at 77GHz [3,4]. The major advantage with operating at 77GHz is the available bandwidth. This opens up the possibility of using a wideband FMCW (Frequency Modulated Continuous Wave) scheme. The sensitivity of an FMCW radar increases with the bandwidth.

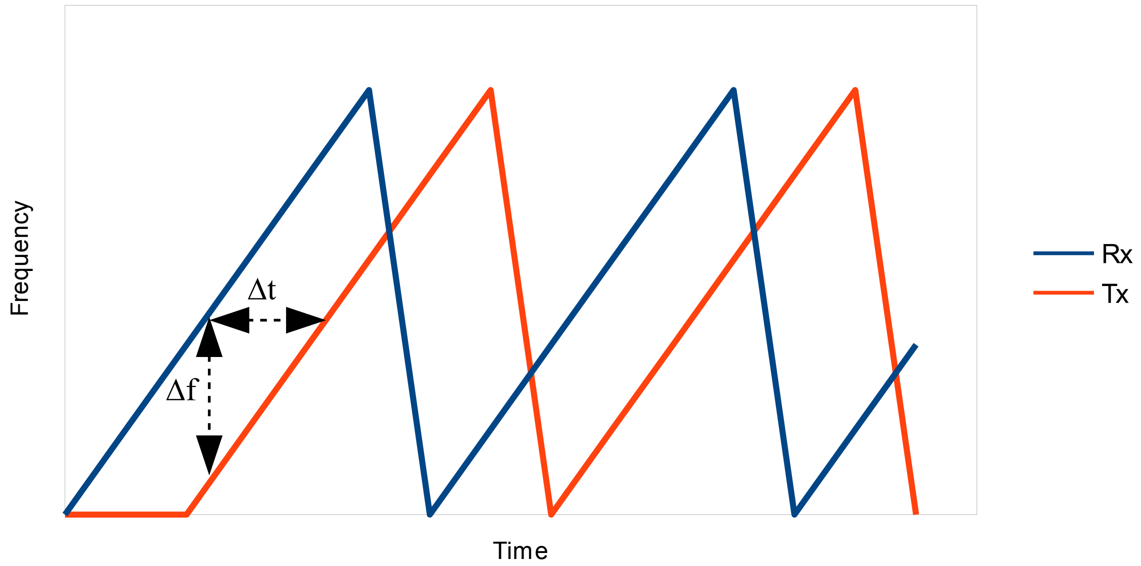

Figure 2: FMCW Radar operation

In an FMCW radar the transmit signal is varied in frequency with time, usually with a linear frequency ramp (represented in figure 2 in blue). This is mixed with the received signal (which will have a similar frequency ramp which is slightly delayed, red in figure 2) to give a single low frequency IF. The IF frequency is directly related to the range of the target and can be determined with relatively simple signal processing techniques and low cost DSP components. The other advantages of 77GHz radars are that they operate in an absorption minima, are reasonably unaffected by weather (precipitation and fog) and have small antennas and hence size which makes them easy to integrate into the vehicle.

Evolution of 77GHz Automotive Radars

The first 77GHz automotive radars owed much to the development of high frequency seeker heads. They used Gunn diodes to produce the mm-wave signal and used waveguide and horn antennas. The systems were bulky, heavy, and expensive, and so were better suited to larger (and generally more expensive) vehicles.

GaAs MMIC Systems

Miniaturisation and the first wave of commercialization arrived with the availability of MMICs that operated at the required frequencies. GaAs pHEMT MMICs led to integrated VCOs, mixers, and amplifiers that required a fraction of the space and could be combined with microstrip circuits and patch antennas. The drive towards MMIC based systems was spear-headed in Europe by two EU supported fifth framework projects, DENSE TRAFFIC and RadarNet [3,4]. The aim of the first project was to develop a Forward Looking Radar Sensor to enable Stop-and-Go Cruise Control and Early Cut-in warning functionality. The aim of the second project was to develop a network of radar sensors placed around the vehicle that could provide a multitude of functions such as adaptive cruise control, parking sensors, blind spot warning, etc. In the case of RadarNet it was hoped that by replacing lower frequency radar sensors and ultrasonic sensors with the 77GHz sensors it would increase the MMIC volumes to a level where there would be a significant reduction in their price.

Broadly two schemes emerged [5], those using a fundamental frequency oscillator and those that used a lower frequency oscillator and multipliers. Potentially the fundamental scheme provides the cleaner signal, however there are several disadvantages to this approach. Firstly controlling the oscillator at such high frequencies to give adequate phase noise is difficult. Secondly there is not much gain available and circuit losses and chip/substrate interfaces (bond wires or flip chip bumps) can be hard to compensate for. With a lower frequency VCO, the device can be controlled using a high end DDS chip which may even be capable of providing the necessary frequency ramp. Also if the final frequency multiplication stage is left to quite late in the chain, then any amplification that is required can be achieved with fewer gain stages.

As previously mentioned, the size of the antenna for a 77GHz system is quite small allowing for relatively simple integration. Patch antennas can be readily designed on a range of substrates, removing the need for horn antennas and bulky feed arrangements. Patches can be arranged in series or parallel fed arrays to give a degree of beam-shaping. These can be readily simulated using commercially available 3D EM simulators, although the properties of the substrate (ε_r and particularly tanδ) are not generally provided by the supplier at such high frequencies and some degree of design optimisation should be allowed for [6]. The beam-shaping is important particularly for automotive applications as one needs a particular field of view. By their nature, cars do not present a very great radar cross-section from the rear, and so the beam should be shaped to aim for the parts where the most metal is present (generally between the top of the bumper and the bottom edge of the rear window). Also for intelligent cruise control, the radar should only respond to vehicles that one is approaching, and not to oncoming traffic. Also the beam needs to be off the road surface else manhole and drain covers may cause false targets, and the beam should not be too wide else street furniture (signs, lamposts, fences etc.) may cause problems.

Silicon System on Chip

Until relatively recently the 77GHz systems were the preserve of GaAs MMIC, particularly those based on sub-micron gate length PHEMTs. Silicon devices simply didn't operate that high in frequency. However the introduction of commercial communications systems at 60GHz (e.g. 802.11ad and Wireless HDMI) gave the impetus to the development of high frequency silicon with its potential for high volumes and low cost. It was only a matter of time before 77GHz radar components started to appear fabricated in SiGe and RF CMOS. Once the major building blocks had been successfully developed [7] it was not long before single chip radar solutions were announced [8]. Once these are commercially available, with the anticipated volumes and price point, 77GHz radar will be poised to not only make it into run-of-the-mill cars, but to be used in a wide range of industrial and domestic applications.

Competing technologies

Automotive radar has had to compete with a variety of technologies such as ultrasound, Lidar, and computer vision systems. Each of these has its advantages and disadvantages. Ultrasonics has provided a relatively low cost if limited capability for short range applications such as parking assist. Lidar offers similar capability to long range radar systems, but can its performance can be reduced in certain weather conditions. In the future it may be that rather than one technology winning out, a fusion of sensor data drawn from the different technologies will provide a complete view. It is highly likely that “self-drive” vehicles will require many and redundant systems to provide the assurance demanded by the insurance industry and the consumer before they are generally accepted.

Conclusion

Automotive radar has been in development for nearly thirty years. In that time it has passed from bulky waveguide based solutions, through GaAs MMIC led miniaturisation to low cost highly integrated SiGe and CMOS solutions. With the advent of truly chip solutions, once these are commercialised, automotive will become as common, a perhaps as essential to the driver as ABS and SatNav.

References

[1] German Patent DE165546

[2] D. McGuffie, “Comfort zone: Eaton VORAD is putting radar technology to work to help drivers avoid accidents” Modern Brewery Age, Jan 1996

[3] http://www.transport-research.info/web/projects/project_details.cfm?id=7116

[4] http://www.transport-research.info/web/projects/project_details.cfm?id=15358

[5] M. Walden, A Garrod, “A European Low Cost MMIC based Millimetre-Wave Radar Module for Automotive Applications, Proc. EuMC2003, Oct 2003.

[6] K. Moore *et al*, “Making Waves,” ANSYS Advantage - Volume VIII, Issue 3, 2014

[7] http://www.infineon.com/cms/en/product/sensor-ics/radar-solutions-in-automotive/channel.html?channel=db3a30431ddc9372011e213568da414b

[8] Hoang Viet Le et al., “A CMOS 77 GHz Radar Receiver Front-End” 8th EuMIC, Nuremberg, Germany, October 2013.