Development of BLightER, a cost sensitive, high performance FMCW Radar

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***Abstract* — This paper describes the unique design methodology used by Plextek to design BLightER, a portable and lightweight, low cost radar. By designing the radar using components and technologies that offer significant cost and availability advantages, a highly cost-effective radar design has been achieved.**

I. INTRODUCTION

The defence equipment market is characterised by its plethora of expensive, custom-designed systems. Electronic equipment is generally designed to satisfy a specific goal, this being specified by end-users, defence organisations or systems providers.

In designing a system that tries to achieve all elements of the performance envelope, unusual architectures and new specialist technologies are often required. Each specific requirement can add to the cost of the equipment either through increased component cost or increased processing or qualification effort.

Fig. 1. The radar consists of a single portable unit containing all elements of the FMCW radar. A standard wireless link provides a low cost interface to a laptop or PDA (shown).

There is much comment on the use of "off-the-shelf" technology, whether it be Commercial (COTS) or Military (MOTS) grade. Off-the-shelf technology is supposed to offer lower costs and faster development timescales due to much of the design work having already been completed. The classic problem with the COTS based procurement model is that requirements are often still not changed to fit the available technology and therefore the equipment still requires customisation. The cost of customising an existing piece of equipment can often be close to that of developing the equipment from new.

Instead of designing equipment up to a desired specification, Plextek's radar design team took a very different approach. The team were asked the question, "What readily available, low-cost technology can be used and what level of performance will that achieve?" If this is applied to all aspects of the radar design then some interesting product characteristics are achieved.

The most important characteristic is that using low-cost design techniques and components allows a product to be developed that costs a fraction of existing systems. Although the radar does not offer the same level of performance as conventionally designed military radar, additional units may be used to provide the coverage expected of the previous systems. The lower price tag also offers the opportunity to use the radar in applications that would traditionally have been prohibitive by cost, such as perimeter security or installation monitoring.

II. ARCHITECTURE OF RADAR HARDWARE

The integrated radar consists of a number of standard system blocks including: Antennas, Transmitter, Receiver, Signal Processing, Data Processing and Display. Novel features of each sub-system are described below.

A. Antenna Selection

When reviewing the selection of antennas used on existing portable radar, it became apparent that standard design approaches are generally used. In most cases a conventional dish antenna is used in conjunction with mechanical steering. Such an antenna obviously offers near optimum characteristics - low loss, low sidelobes, but it can be bulky and requires a mechanical steering structure.

Over the past decades, much work has been performed on antenna structures that offer a frequency sensitive squint. Their implementation however, especially at microwave frequencies, has been hampered by the lack of suitable materials. It is now possible to model and design simple antenna structures on microwave substrates to create antennas that offer adequate performance for many applications. Significantly

though, they are simple, cheap and very robust as well as obviating the need for mechanical rotation.

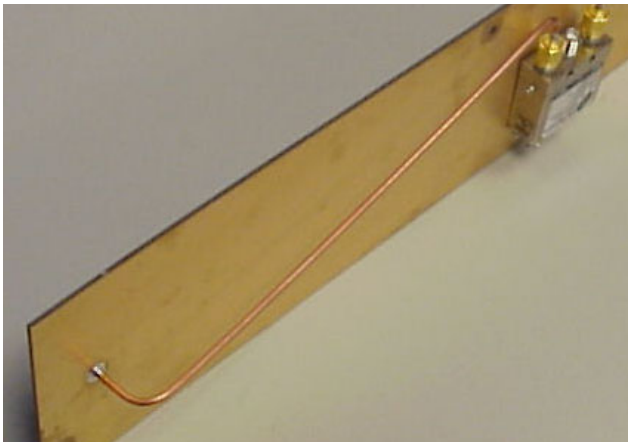

Fig. 2. This view of a printed antenna panel shows a feed point and a switch module. The panel is cheap to manufacture using standard RF PCB substrates.

The appropriate radar band was selected on the basis of bandwidth availability, required scan angle and compactness of antenna for a given beam width. The 15-17GHz Ku band is a good place to start and can offer a 3° beamwidth for an antenna approximately 40cm long.

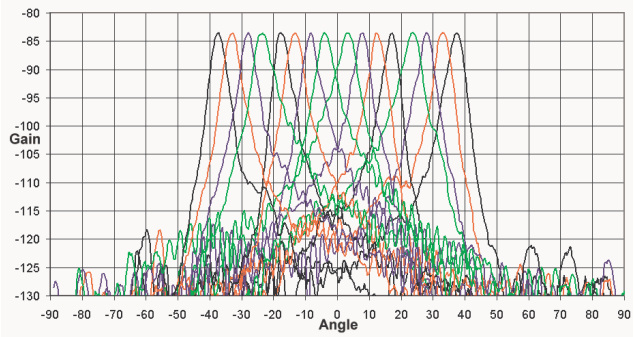

Fig. 3. Simple printed antennas can be used to create usable beam structures.

B. Transmitter Component Selection

The transmitter for an FMCW radar requires a spectrally pure CW source at much lower powers than a traditional pulsed Radar. The choice of the J/Ku band also happens to well match satellite VSAT communication systems, resulting in a relative abundance of useful microwave components.

As an example, rather than buying a pre-packaged transmitter module at a cost of some €1500 to €3000, a single 2 Watt Power Amplifier can be purchased for approximately €60. Admittedly, this needs packaging, but it offers a lower cost, high performance solution that can be more closely integrated with other components.

C. Receiver Design

The receiver system, including the homodyne mixer, requires great care in its design. Huge dynamic ranges are encountered with an FMCW system, and unfortunately, saturation from any return signal will be catastrophic for all other radar returns hidden beneath the saturating signal. The LNAs, Mixers and filters must all be able to cope with a dynamic range well in excess of 100dB. Fortunately, commercial satellite band components offer adequate performance at very reasonable cost.

D. Frequency Synthesis Solutions

The radar contains a number of features that make it covert. Firstly, its transmitter power is only around 2W, not dissimilar to standard mobile telephones. More importantly, the mode of operation using an FMCW chirp modulation combined with a broad-spectrum frequency band usage makes the radar difficult to detect.

Fast hopping, broad band synthesizers are not new, however the availability of digital waveform generation using FPGAs and commercial chip sets now allows greater freedom in the selection and programming of transmitter frequencies and waveforms. (FPGAs – Field Programmable Gate Arrays can be considered as user programmable hardware offering high performance and advanced digital hardware design but with software programmability)

In common with the signal processing section below, the aim is to design a system initially offering abundant resources then select and fine tune a lower cost technology for production units. Plextek used a high performance FPGA based frequency synthesizer to develop an optimum frequency regime. Given precise design requirements a commercial device can be selected to offer a better value, smaller, but possibly compromised solution.

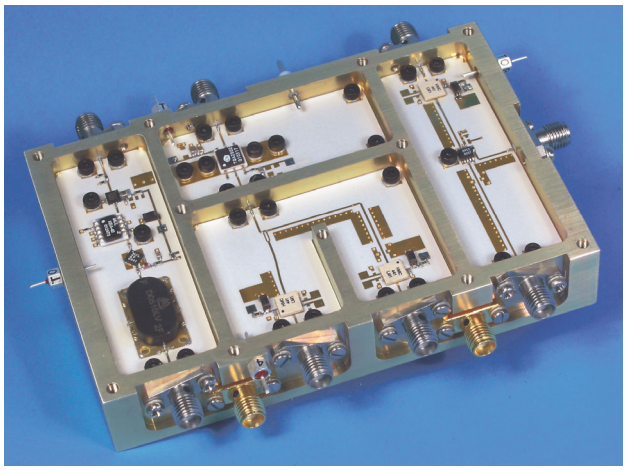

Fig. 4. The custom designed transceiver module including a low cost Power Amplifier on the left.

E. Signal Processing Platform

The radar is designed to provide detection of moving targets. By reducing the radar target information output to an absolute minimum, the communications infrastructure for either a single or multiple radar deployment can be significantly rationalised. To achieve

this, significant signal processing is required to cleanly detect valid targets yet suppress clutter and other false alarms.

To minimise development timescales and costs, an in-house designed DSP card is used to provide an abundance of signal processing resource. Front-end processing, characterised by fast and repetitive number-crunching, uses an FPGA (Field Programmable Gate Array) while the more adaptive and flexible processing functions are contained in a high performance micro-processor (The Motorola MPC7410).

For production units, this high performance and power hungry platform will be replaced with lower cost commercial components. Modern mobile telephones with their audio processing and gaming engines provide enormous amounts of processing power at low cost and using very little power. Furthermore, communications technology currently being designed into automotive electronics to satisfy the rapidly expanding telematics industry provides the same technology in more robust packaging, suited to the harsh environments expected of the radar.

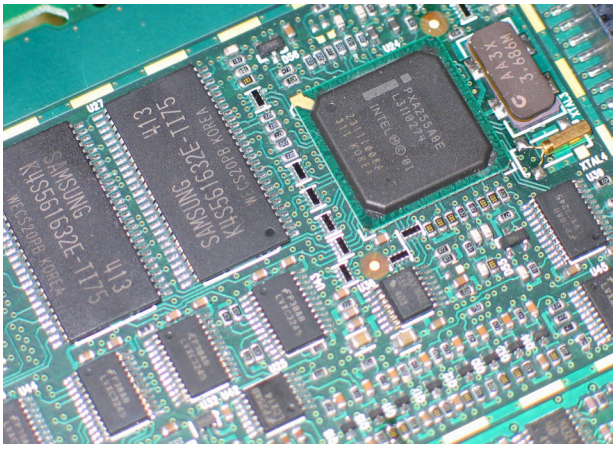

Fig. 5. This automotive communications hub includes a Intel microprocessor containing an ARM9 core. This low cost, low power sub-system is ideal for data processing and networking applications in harsh environments.

Microprocessors containing the ARM9 core offer clock speeds equivalent to mid-range PCs, yet come integrated with a wealth of interfaces necessary to support the radar design.

F. Standard interfaces

The radar includes a number of additional facilities that make the radar easier to install and use. Rather than designing custom interfaces, the emphasis has again been placed on using modules wherever possible. Such modules de-risk the development programme and offer considerable savings in parts and design cost.

For a portable radar, the ability to use it immediately after deployment can be a major benefit. To support this both GPS and Digital Compass modules are fitted. Once placed on the ground, the radar knows where it is and which way it is pointing.

A €20 GPS module is cheap enough to be fitted as standard even if it is not required for fixed installations.

Digital compasses are available in a range of technologies all offering different price/performance trade-offs. The printed antenna technology used in the radar offers limited angular accuracy and therefore a lower performance compass matched to the accuracy of the antenna offers a more affordable solution.

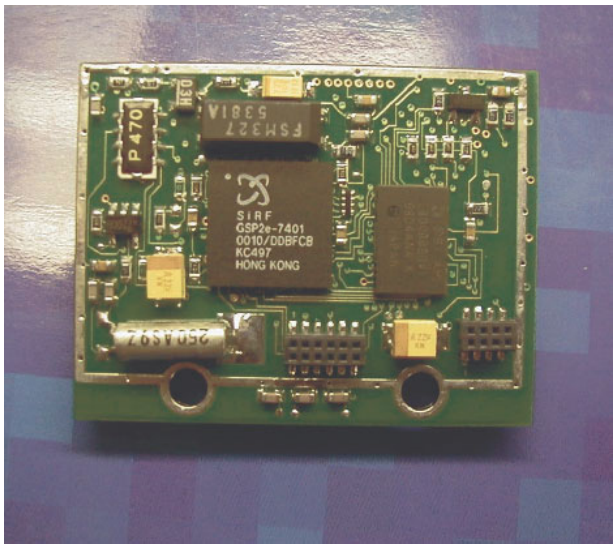

Fig. 6. GPS modules are available for as little as €20. This module from SiRF measures only 38mm x 30mm.

One of the radar's capabilities is the ability to communicate with other sensors and the user display using wireless and wired networks. It is tempting to design a custom wireless interface for such a security product that offers longer operating range and possibly more data security. However, the availability of Personal Computer products, with all the drivers and applications developed and generally debugged, at minimal prices offers a perfectly adequate solution for most applications.

For the basic radar wireless networking, the use of a range of the IEEE802.11 wireless standards offers a high performance, secure interface encapsulating thousands of man-hours worth of hardware and software development in a $20 solution. Standard Operating Systems then allow networking protocols and facilities to be layered on top of the wireless link to provide endless networking capabilities using TCP/IP.

G. User Interface

For the user interface, the almost universally available Microsoft Internet Explorer was chosen. The radar itself contains a web server that serves up a radar specific Java Applet to a PC or PDA. The Java Applet runs within Internet Explorer and provides a user display and interface. Radar data and information from other embedded sensors, including GPS and Compass, is transferred from the radar to the Java Applet for the operator to view. Connection between the radar and the PC or PDA is either by 10/100Mb Ethernet or

IEEE802.11 wireless connection. This means that almost any PC or PDA with a network connection and Internet Explorer can operate the radar without any additional software even over the Internet and at absolute minimum cost.

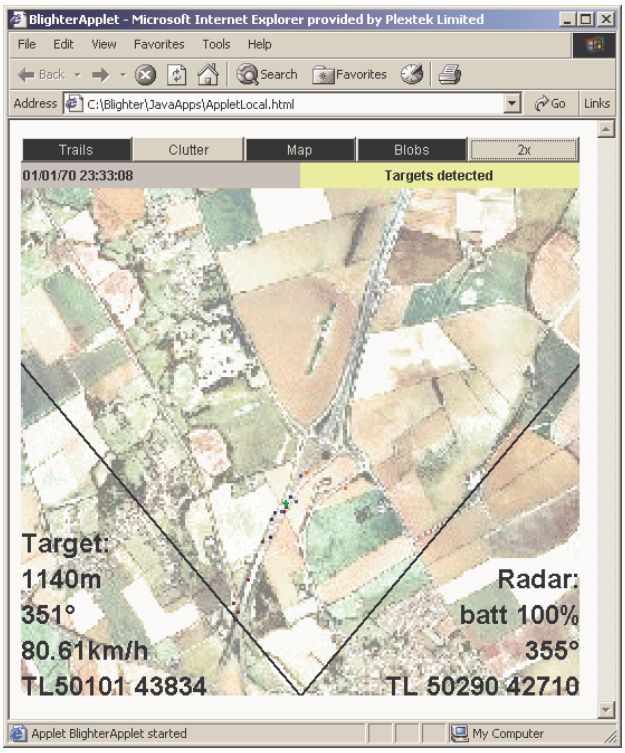

Fig. 7. A Java Applet is downloaded from a web-server built into the radar and is displayed within Microsoft Internet Explorer on the laptop or PDA.

III. Performance

By taking the approach of using technology that is common and readily available rather than developing custom solutions, Plextek has had to face certain compromises in the design of the radar mainly affecting performance.

The portable radar market is by no means large, but it is characterised by a small number of well matured products that over the years have had many millions of Euros pumped into their development. Some of their specialised features include:

1) High transmit power for long range detection of potentially 10's of km.
2) Multiple radar modes optimised for particular applications. Eg long range sensitivity vs minimum range capability.
3) Complex user interfaces that provide every conceivable configuration option.
4) Robust construction suited to every climate.

Considering the standard technology being used for this radar, there is little chance of being able to match the characteristics of these radars. The major compromise is radar detection performance.

The combination of more lossy antenna, low transmit power, commercial frequency synthesis losses and limited signal processing budget mean that this radar may only be able to detect a man at about 2km compared to ranges as high as 10km for some systems.

Despite the performance loss, there are some benefits in a small number of crucial areas:

1) Cost – Using standard components, materials, processes and technology allows the BOM (Bill of Materials) cost to be driven down dramatically.
2) Weight – Using mobile phone type technology allows significant weight savings as the components, their enclosure and battery can all be much smaller
3) Compactness – the simple antenna technology combined with the compact electronics allows the unit, display and battery to be carried comfortably by one man.

IV. Conclusion

Plextek's unique approach, applying standard and easily obtainable components and technologies, has allowed it to develop an extremely cost effective portable radar system that offers performance falling only slightly short of other considerably more expensive systems.

Modern microwave materials and techniques allow low cost antennas to be fabricated. Selection of a frequency band near to that used for satellite communication provides a wealth of low cost yet high performance components. Use of signal processing technology that provides abundant resources minimises development time and allows radar algorithms to be optimised with ease.

Combined with a user interface based around a web browser, the radar offers rapid, adaptable development with easily available and low-cost components and wireless access via a PDA.

Acknowledgement

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