A Longer Range Body Scanner

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Abstract

An active Body Scanner using 35 GHz MIMO perimeter array has been developed. The aim is to identify weapons hidden under clothing at much longer ranges than current technology is achieving. The scanner displays images at a frame rate of 10 frames per second to show moving images with a resolving power suited to visualising small weapons out to a range of 10+ metres.

Introduction

Commercially available mm-wave body scanners penetrate clothing to reveal any hidden weapons on a person. They have been adopted for airport screening, but performance is not ideal.

One form requires the person being screened to stand in a cubicle where a vertical array of millimetre wave transmit/receive elements rotates around the body to synthesise a cylindrical aperture. Tomography-like processing forms a high resolution image. But this requires the person's co-operation.

Another form provides stand-off imaging, without co-operation. Such systems typically focus a large aperture down to a narrow point which is raster scanned over the subject. These have a fixed focal length, a narrow depth of focus, and the raster scan leads to a low refresh rate, this requiring the subject to remain stationary. Also, the aperture size for longer range operation becomes too large for fast mechanical scanning [1].

We outline a new approach to imaging at millimetre-wave frequencies using an array of digitally controlled elements to focus on the scene, avoiding mechanical scanning and so allowing a larger aperture. The emphasis is on 3D body images for security screening, but with a much better range and depth of focus than available from current mechanically scanned systems. Whilst a fully-filled phased array might provide a straightforward solution, the cost would be prohibitive.

We have developed several novel techniques towards a more practical system with a much smaller number of elements for a lower cost [2]. The aim is to develop a commercially attractive system offering better performance in terms of operating distance, depth of focus, and refresh-rate, as compared with mechanically scanned systems and their fixed depth of focus. We believe we can produce 10 frames per second to show moving images, with a resolving power suited to visualising small weapons out to a range of 10+ metres. We have fabricated a fully functional 1.28m by 1.28m perimeter array, together with the waveform generator, imaging processor and user interface unit. These have been integrated together with the required firmware and the system is currently being evaluated in terms of resolving power and image fidelity.

The Body Scanner Radar System Overview

The block diagram of the 128x128 element Body Scanner is shown in Figure 1. The

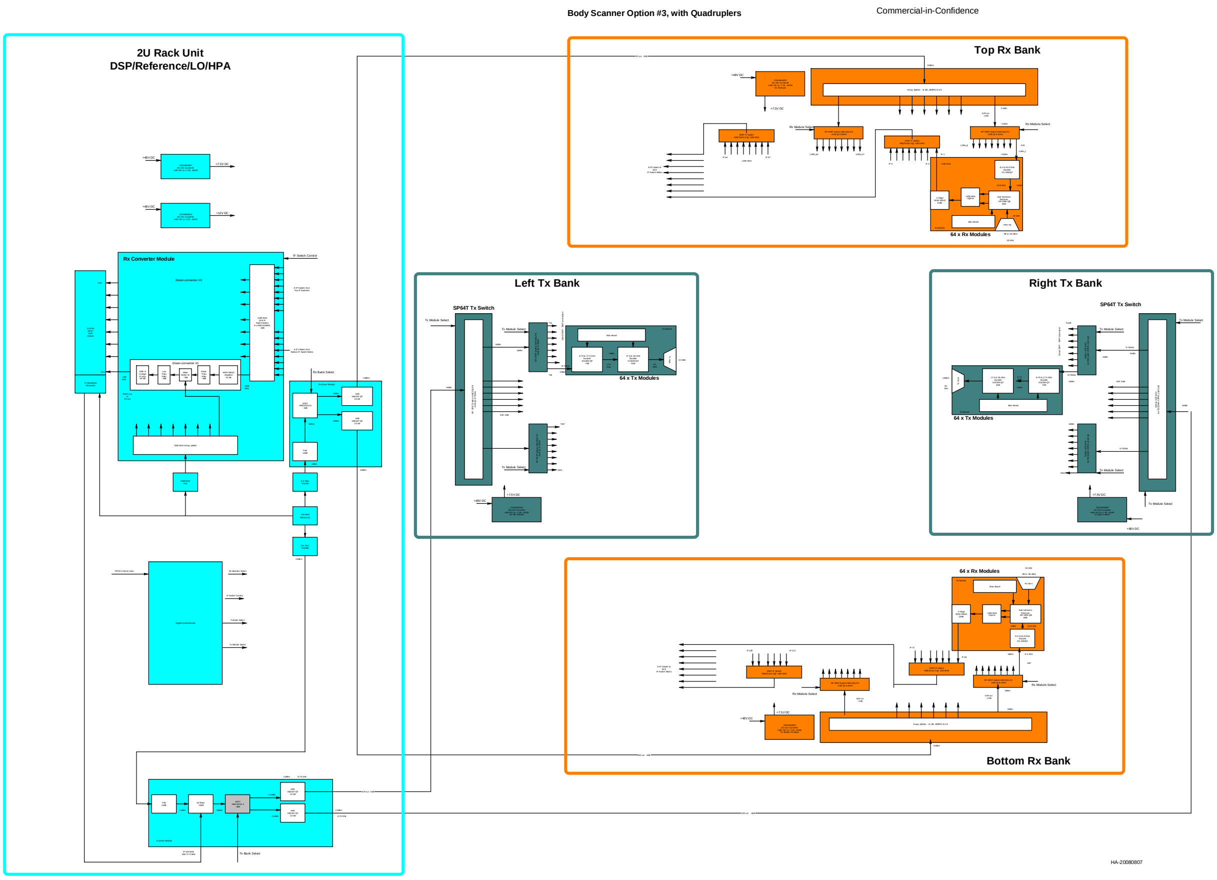


Figure 1 - Block Schematic of the Imaging Radar

array structure is shown as the four blocks on the right of the diagram. These form the four sides of the frame, the vertical sides housing the Tx elements and the horizontal sides the Rx elements. The array operates by transmitting on one transmit (Tx) horn element at a time and receiving on 8 receive (Rx) elements. Switching networks cycle the Tx signal through all the 128 elements in sequence. Receiver switching networks then capture data from a block of 8 Rx horns for each transmission. The Digital Transceiver (FPGA) module has 8 ADC channels to process the 8 Rx signals simultaneously.

The radar system operates at 35 GHz. Pulses of approximately 13 ns width are generated by the Digital Transceiver module. The frequency of the Tx IF signal is 150 MHz with a bandwidth of 37.5 MHz. This is up-converted to 8.75 GHz using a 8.6 GHz Phase–locked Dielectric Resonator Oscillator (PLDRO), locked to a 100 MHz OCXO. The up-converted signal is amplified and switched to either the left or the right Tx bank. It is then switched to one of the 64 Tx modules in that bank using a cascade of two SP8T RF switches acting as a SP64T switch. The Tx module consists of two cascaded MMIC frequency doublers, producing a 35 GHz output, with a bandwidth of 150 MHz. Each Tx module has a WR-28 waveguide output that feeds a Tx horn element.

On the receive side, the received 35 GHz signal is down converted to 1.4 GHz in an Rx module connected to the output of each of the Rx horn elements. The Rx module consists of a MMIC sub-harmonic receiver with an MMIC frequency doubler on its LO port. The LO signal from an 8.4 GHz PLDRO locked to the same 100 MHz reference OCXO, is fed to the Rx module, which is doubled in the MMIC frequency doubler and fed to the sub-harmonic MMIC receiver at 16.8 GHz. Eight Rx modules are fed with 8.4 GHz LO signals at the same time using an eight-way LO power splitter and eight SP8T LO switches. The eight 1.4 GHz IF signals produced in the 8 active Rx modules are switched to the 8-channel second down-converter in the Rack unit. The second down-converter converts the 1.4 GHz IF signal from the Rx modules down to 100 MHz final IF with 150 MHz bandwidth. It uses a 1.5 GHz PLDRO locked to the 100 MHz OCXO reference. The 100 MHz IF signals are then passed to the Digital Transceiver module for further processing.

Array Elements

The Tx and Rx array elements are pyramidal horns. For convenience and manufacturing ease, eight horn elements are machined in one block. All elements are vertically polarised, and are fed by WR-28 waveguides. The Tx horn elements are stacked one above the other. The horn aperture is 19 mm x 19 mm. Figure 2 shows the 8-element Rx antenna block (horizontal) and the Tx antenna block (vertical). The calculated gain of the horn element is 16.67 dB. The simulated pattern of a single horn element using CST Microwave Studio is shown in Figure 3.

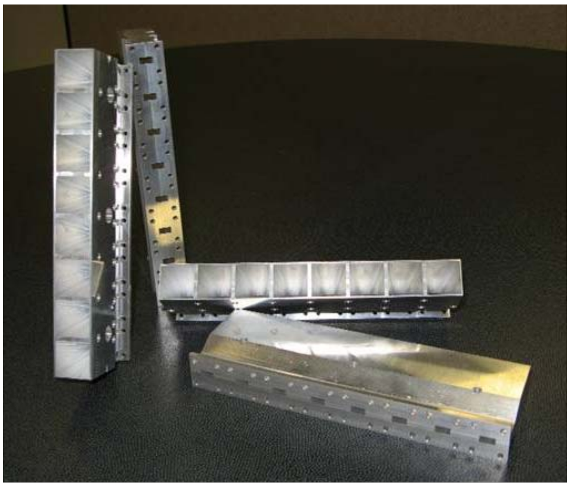


Figure 2 - Pyramidal Horn Antenna Array (Tx and Rx) Elements.

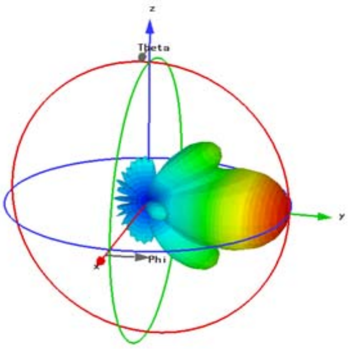


Figure 3 - The Computed Horn Pattern

Transmitter Modules

The Tx module consists of two Mimix Broadband XX1000-QT MMIC frequency doublers in cascade as shown in Figure 4. The input at 8.75 GHz is on the SMA connector at the left, and the 35 GHz output from the second doubler feeds the WR-28 waveguide through a microstrip-to-waveguide transition. The Tx module produces 14 dBm output at 35 GHz with a 0 dBm input at 8.75 GHz. The Tx modules measure 20 x 20 x 47 mm.

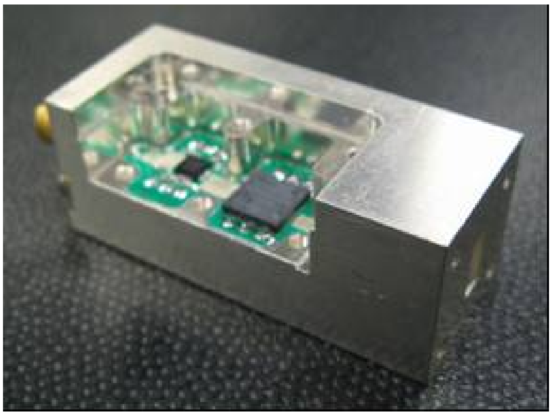


Figure 4. Tx module at 35 GHz. The size of this module is 20 x 20 x 47 mm.

Receiver Modules

The Rx module consists of a WR-28 waveguide-to-microstrip transition feeding into the sub-harmonic receiver MMIC XR1008-QB. The LO signal for the Rx MMIC comes from a frequency doubler MMIC (XX1000-QT) connected to the LO port of the mixer. This doubler is fed with a 0 dBm signal at 8.4 GHz on an SMA connector at the left as shown in Figure 5.

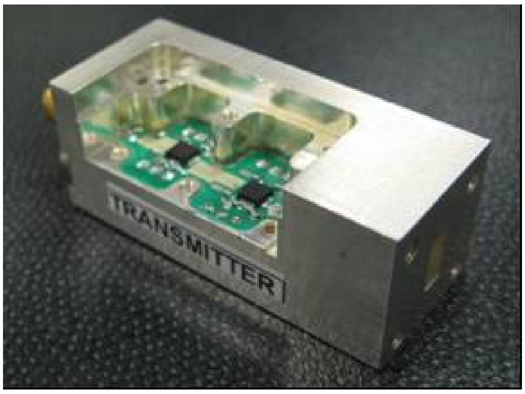


Figure 5. Rx module at 35 GHz. The size of this module is 20 x 20 x 47 mm

The receiver MMIC produces I and Q outputs at 1.4 GHz, which are combined in a hybrid located on the Bias/IF board mounted in the back of the module. The dimensions of the Rx module are 20 x 20 x 47 mm. The Rx module has a conversion gain of about 20 dB. Input power at 35 GHz at the 1 dB gain compression point is -4 dBm. The LO power at 8.4 GHz required for this performance is 0 dBm. The Tx/Rx modules are bolted on to the back of the respective horn element sub-assemblies.

Integration

The Body Scanner Array system is built up as a 1.3 m x 1.3 m square frame with the 64 antenna elements and microwave modules per side per side together with the associated switches as shown in Figure 6.

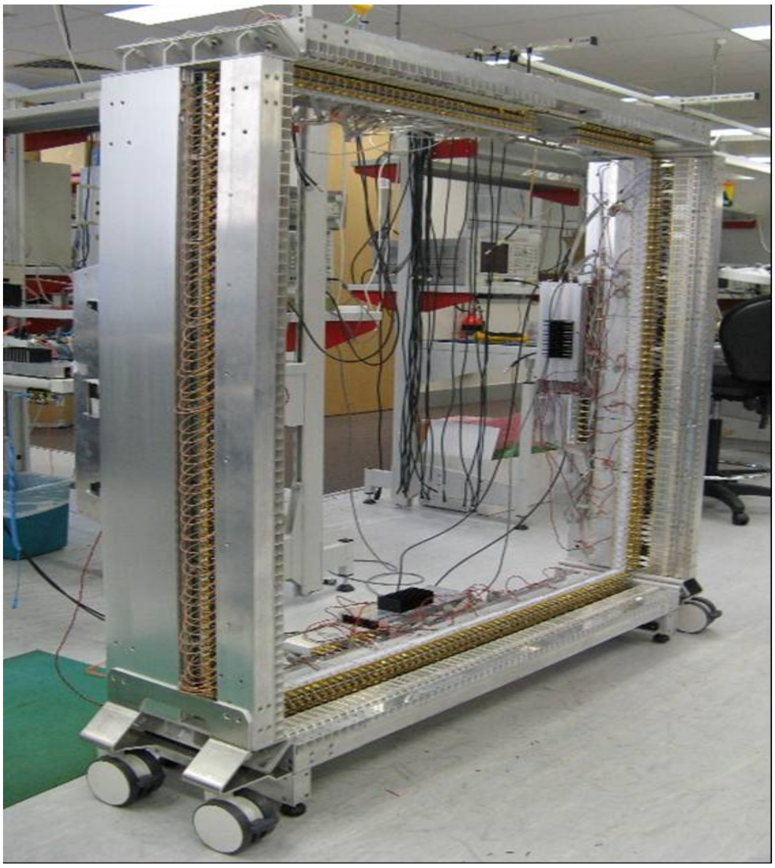


Figure 6. The128 x 128 Element Perimeter Array

The rest of the system consisting of the Up-converter, Tx switch / Driver amplifier, Rx switch / Driver amplifier, the 8-channel

Down-converter, the phase-locked DRO local oscillators, the Digital Transceiver FPGA and the power supply are integrated into a rack unit that fits under the lower Rx bank of the array frame. This rack unit is shown in Figure 7.

Figure 7. Rack Unit with Digital Transceiver and RF Up- and Down-Converters

Radar Imaging

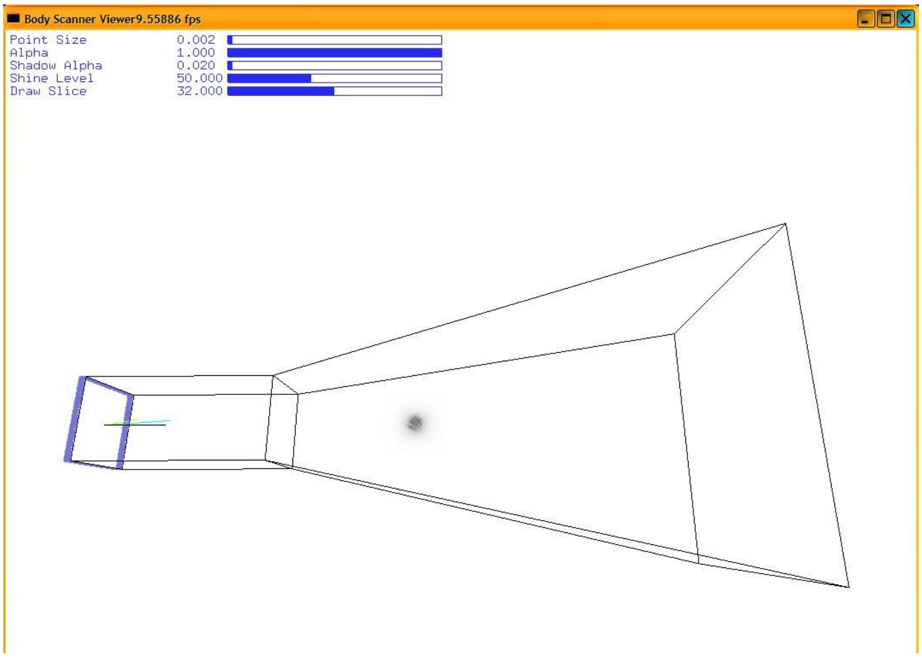
The system is based on time multiplexed MIMO radar concept. The waveforms transmitted from the each of the 128 transmit antennae and reflections from targets are obtained by the 128 receive horns. Total capture time has to be minimised to avoid the defocusing effect of moving scenes. For this reason we do not use pulse to pulse integration to achieve additional gain. With this constraint we capture all 16384 waveforms is 512uSec. Within this time a normal walking personnel at 4m/sec will move only a small fraction of a wavelength. For each point in the viewed volume the waveforms are summed with the proper phase due to antennae patterns and paths travelled. This provides an intensity of the reflection at that point in space. This method generates a three dimensional image with fine cross range resolution and coarse resolution in range (caused by the depth of focus).

We have developed techniques for reducing the computational load demanded by this focussing process, enabling us to reach a rate of 10 frames per second. We perform this focussing process on a GPU processor using the CUDA platform from NVIDIA. A range slice at a given distance can be processed to view the image, and the slice can be tracked in range to follow a person walking. We have also developed an alternative approach where the resultant 3D intensity data is visualised using the techniques described in [3]. This method employs alpha blending and shading to show scalar field data in 3D. An example of this view is shown in Figure 8. View angle, perspective, and shading can be easily adjusted by the operator to suit good 3D visualisation.

Future Work

Whilst this system was designed initially as a stand-off body scanner the potential for another quite different application has emerged. This is for an imaging system to aid helicopter pilots when landing in ‘brown-out’ conditions. This is where rotor downwash raises sand and dust clouds which totally obscure the pilot’s vision. Towards this application we plan to demonstrate an ability to imaging through representative sand clouds generated in controlled conditions under the sponsorship of the UK MoD CDE program. Work undertaken for this demonstration has allowed us to improve and ruggedise the system.

We are also developing another version with a much wider field of view, but with lower resolution. A leading edge tracker will act as a multi-beam radar altimeter,



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Alpha               1.000
Shadow Alpha        0.020
Shine Level         50.000
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Figure 8. Showing the Square Array, the Volume Captured, and a spherical image at 5m

measuring the distance to the nearest reflector in each of the many beams. This will produce a two dimensional profile of the ground to asses suitability for a safe landing. It will also define an envelope outlining the clear air space to the front and sides of the helicopter for rotor clearance and collision avoidance. This work is sponsored by the UK MoD EMRS DTC Program.

Conclusions

An experimental Body Scanner under development at Teledyne Australia offers a real-time stand-off screening capability. This is based on the MIMO radar technique, operating at 35 GHz. with 128 (Tx) x 128 (Rx) antenna elements forming a perimeter array and viewing a 28 by 28 degree sector. The processor will display images with 128 by 128 cross-range pixels at a rate of 10 frames per second and with a resolving power sufficient to identify concealed weapons out to a range of 10+ metres.

We anticipate showing early test results at the 2009 DTC Conference.

References

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3. Balázs Domonkos; Balázs Csébfalvi, “Interactive Distributed Translucent Volume Rendering”, *WSCG 2007 conference proceedings*, ISBN 1213-6964, WSCG’2007, January 29 – February 1, 200

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