

Compact, low-cost direction finding and emitter characterisation

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Abstract

A Time Difference Of Arrival (TDOA) direction finding system is described, based on Time to Digital Converter (TDC) chips. The system uses an antenna baseline of only a few metres, making it suitable for installation on small platforms such as UAVs. The construction of a rugged, portable ground-based demonstrator is described, and results are presented from trials against a number of real radar systems. The same TDC chip is used to measure TDOA, pulse width and pulse repetition interval (PRI) of a radar emitter.

Keywords: Direction Finding, Time-to-Digital Converter, TDOA, UAV

Introduction

The Time Difference Of Arrival (TDOA) technique has a number of advantages over other DF techniques, particularly when a low-cost system suitable for UAV or land vehicle installation is considered. However, such an installation constrains the baseline to a few metres at most, demanding high precision in the TDOA measurement.

The use of time to digital converter (TDC) chips, having a resolution of around 100ps, in a TDOA system with a 2m antenna baseline allows in principle a DF resolution of 1°. In practice, the accuracy of the technique will depend also on factors such as the signal to noise ratio and the pulse rise time.

Previous DTC conference papers have described the theoretical investigation and mathematical modelling of the technique [1], equipment build and initial results [2] and trials against a number of real radar emitters [3].

Promising results were obtained during the earlier trials, but a number of limitations in the equipment were identified, which have

been addressed during the current phase of the programme.

Equipment development

A rugged antenna mount with a two metre baseline has been constructed, as shown in figure 1. There is also the facility to attach a digital theodolite to the system to allow an optical measurement of the bearing for comparison with that obtained by TDOA.



Figure 1 TDOA equipment

The new TDC-GPX chip from ACAM [4] allows the unambiguous measurement of

time intervals up to 1.6ms. This is a great improvement over the previous device which was limited to 8 μ s, and allows pulse width and PRI measurements. These measurements are of great benefit in pulse sorting when multiple emitters are present. The new chip is available in a plug-in card that is compatible with the ACAM TDC evaluation module previously used.

A PCI Docking Station [5] has been procured, which allows the ACAM TDC module to be interfaced to a laptop computer. As well as the great saving in weight, the elimination of the desktop PC removes the requirement for mains power.

In order to enhance the portability of the equipment, all components apart from the antennas and the laptop PC have been packaged in a single box, dimensions 400x400x150mm, weight 5 kg. The entire experimental setup is now two-man portable.

The re-packaged system operates from a 12V DC input. The current drawn is around 1.25A maximum, hence a 10Ah battery provides adequate capacity for several hours of operation.

The dynamic range of the equipment has been enhanced by the use of two video amplifier stages, each feeding a separate channel of the TDC.

Finally, new, more user-friendly software has been written using Matlab. This software gives the user a real-time graphical output of bearing, pulse width and PRI measurements, as well as the mean and standard deviation of these measures, on a scan-by-scan basis.

Equipment characterisation

The equipment was characterised using the model 527 RWR test set produced by

ESL's parent company, AAI Corporation. This is fully programmable in RF frequency (from 0.5 to 18GHz), pulse width and PRI. The power output can be programmed to mimic an arbitrary scanning antenna pattern.

The RF output from the 527 was injected directly into the front end of the TDOA equipment (using a power splitter and equal cable lengths for the two channels), to enable the dynamic range and frequency response to be determined. Figure 2 shows that the equipment operates over a dynamic range of around 30dB, albeit with a steady drift in the TDOA measurement. Similarly, figure 3 shows that the TDOA measurement varies with frequency to some extent.

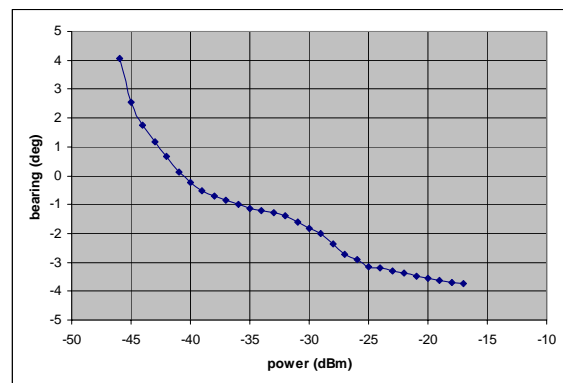


Figure 2 AAI527 at 10GHz RF – variation of measured bearing with power

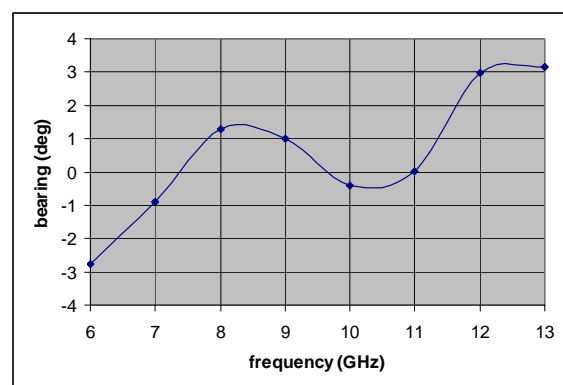


Figure 3 AAI527 at -25dBmz– variation of measured bearing with frequency

Although this level of performance is felt to be adequate for a demonstration system, the

incorporation of an Instantaneous Frequency measurement (IFM) and of pulse amplitude measurement in a production system would allow these variations to be calibrated out.

At RF frequencies below 5GHz, large errors were observed in the bearing measurement. This was largely due to the use of RF amplifiers that were optimised for the 6 to 12 GHz band, and better performance would be expected in a production version of the equipment. However, when an attenuator was inserted in one channel to equalise the signal levels at 3GHz, results at this frequency were comparable with those in figure 2.

Attempts were made to use the 527 transmitting through its antennas as a test emitter, but the low power of the unit made it difficult to set up a realistic geometry (range >> antenna baseline) so it was decided to proceed straight to real emitters.

Trials results –VTS radar

Trials were performed against the Vessel Tracking System (VTS) radar on Southampton Water, close to ESL’s facility at Hamble. As shown in figure 4, the range from the TDOA equipment to this radar is 4.4km.

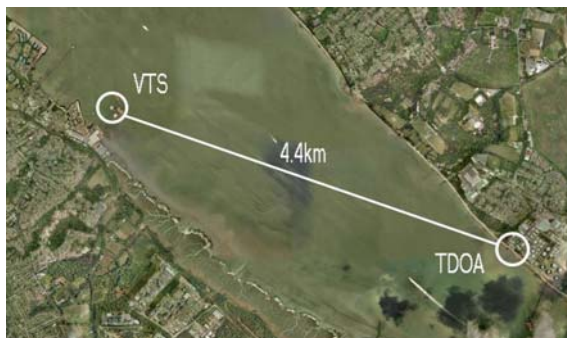


Figure 4 Location of VTS radar and TDOA equipment

The VTS radar operates at X band, with a PRI of around 500µs, a pulse width of nominally 100ns and an antenna rotation period of 2.9s. Several other emitters were observed during the trials, but using the pulse width and PRI measurements it was easy to isolate the pulses from the VTS radar. The results from a single main beam intercept of the radar are shown in figure 5.

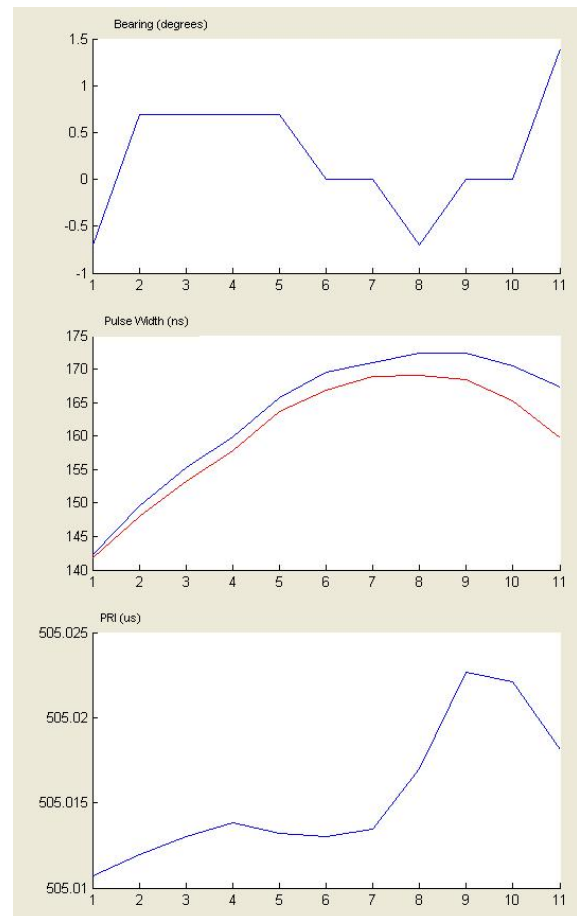


Figure 5 Data from one scan of VTS radar, on boresight of TDOA equipment

From each scan (typically 10 or 11 pulses were received per scan), the mean and standard deviation of the bearing measurements were calculated. As shown in figure 6, these were very consistent from scan to scan. It is noted that due to the high SNR and fast pulse rise time, the standard deviation of the measurements is largely determined by the resolution of the TDC.

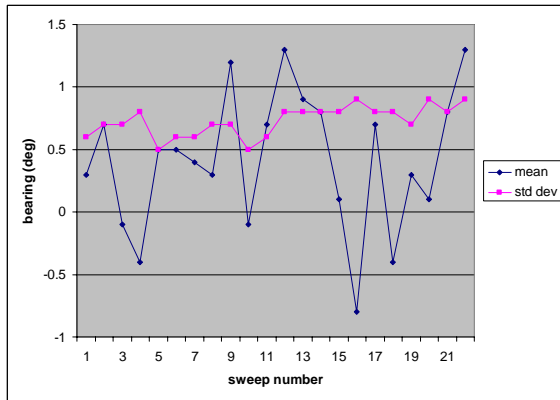


Figure 6 Measurements of 20 successive scans of VTS radar, on boresight of TDOA equipment

The TDOA antenna baseline was then rotated through $\pm 45^\circ$ in 5° steps, and around 20 scans of the VTS radar recorded at each step. The mean value of the bearing measurement was calculated for each position, with the results shown in figure 7. The measured bearing is generally within $\pm 3^\circ$ of the actual bearing (as measured using the theodolite).

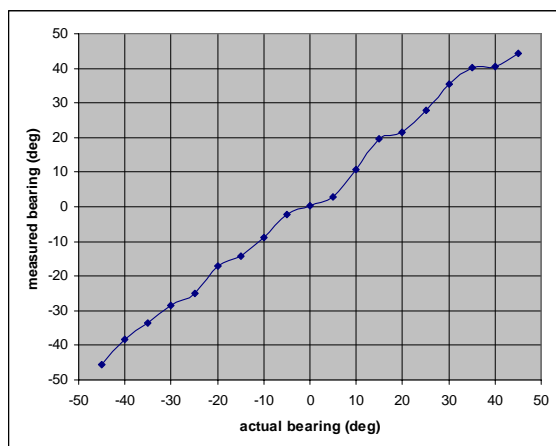


Figure 7 VTS radar- measured bearing as TDOA antenna baseline is rotated

Trials results – Watchman radar

Further trials were conducted against the Watchman surveillance radar at Southampton Airport. In this case the range was around 800m, as shown in figure 8.

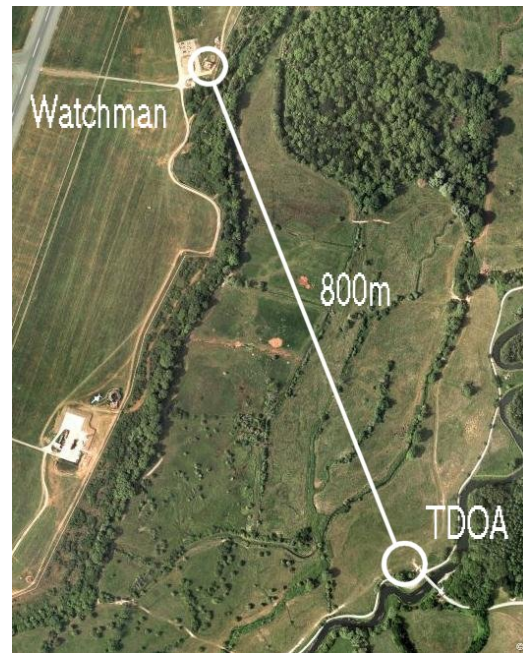


Figure 8 Location of watchman radar and TDOA equipment

The Watchman is an S band radar, transmitting on two frequencies separated by 25MHz. Pulses are transmitted in pairs, with a 400ns pulse on one frequency followed after $42\mu\text{s}$ by a $20\mu\text{s}$ pulse on the other.

Nine level PRI stagger is used, with an average PRI of $909\mu\text{s}$, and after every nine pulse-pairs the frequencies used for the short and long pulses are swapped over [6].

The scan period is approximately 4s, with an antenna beamwidth of 1.5° , which gives around 20 pulse-pairs per scan within the antenna beamwidth. Figure 9 clearly shows the alternation between long and short pulses, and the nine level PRI stagger (the lower level of the PRI graph is the $42\mu\text{s}$ interval between the short and long pulses).

The mean value of the bearing measurements for this scan is 3° , with a standard deviation of 7° . However, it can be seen that due to the poor matching of the RF channels, the two frequencies give very different results. The individual frequencies give mean values of 9° and -4° , with

standard deviations of 2° in each case. Hence it is seen that if channel matching can be improved, or suitable frequency calibration implemented, the standard deviation of the measurements will be greatly reduced.

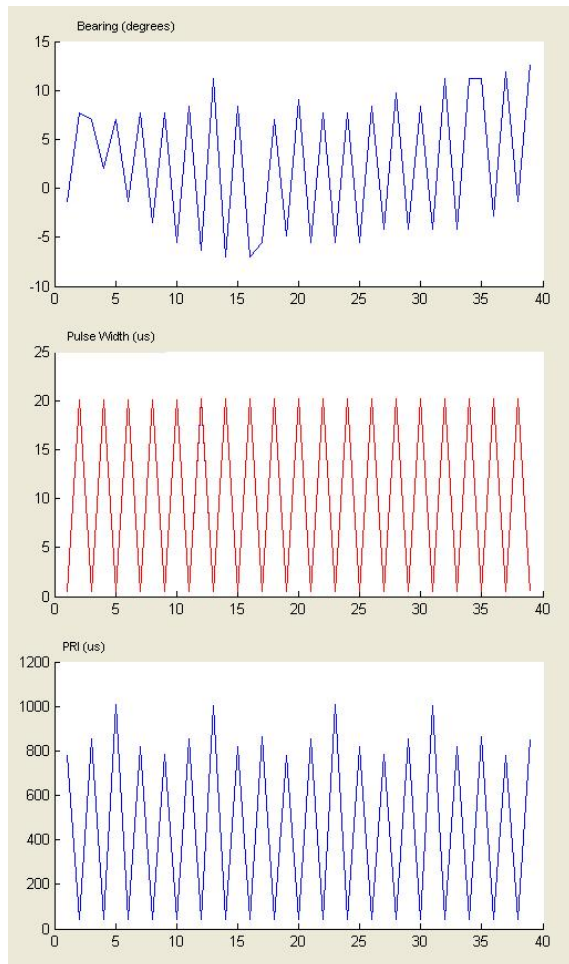


Figure 9 Data from one scan of Watchman radar, on boresight of TDOA equipment

The TDOA antenna baseline was then rotated through $\pm 40^\circ$ in 10° steps, and around 10 scans of the Watchman radar recorded at each step. The mean value of the bearing measurement was calculated for each position, with the results shown in figure 10.

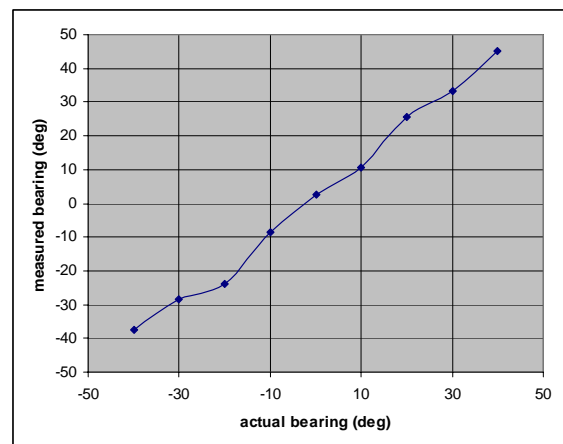


Figure 10 Watchman radar- measured bearing as TDOA antenna baseline is rotated

Conclusions

The modifications to the trials equipment greatly enhanced the mechanical stability and the portability. The extended time period capability allowed the unambiguous measurement of pulse width and PRI, which greatly assisted pulse sorting when multiple emitters were present. Measured bearings were consistent from scan to scan of the emitter, and within a few degrees of the actual bearing.

Future development

Miniaturisation of the equipment is required, in order that it may be mounted on platforms such as a UAV. As discussed earlier, incorporation of an IFM is highly desirable, as is integration with GPS/INS data. This will entail the design and construction of dedicated hardware to replace the TDC module currently used. A particular concern is to ensure the correct association of TDC and IFM pulse reports.

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