DESIGNING ESAs TO MEET PITO5

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Abstract: *The Police Information Technology Organisation (PITO) Automotive Conformance Specification 5[1] puts extremely tight constrains on emissions from aftermarket Electronic Sub-Assemblies (ESAs). Specification 5 is designed to ensure that ESAs are compatible with existing police and fire service radios, particularly that ESAs don't block or quieten (de-sensitise) in-vehicle radios. The police in particular love high-tech gadgets in their patrol vehicles but getting these approved by the Home Office can be an arduous task. This paper explains PITO5 testing and conformance requirements and goes on to describe methods for achieving compliance to the radiated emissions requirements using some examples that the author has worked on*.

Introduction

The Police Information Technology Organisation (PITO) is a non-departmental public body sponsored by the Home Office in the United Kingdom (UK). PITO is responsible for Information Technology (IT) within the police services of England and Wales. Within PITO the Automotive & Equipment Section (A&ES) publish specifications for equipment used in police and fire service vehicles. Although A&ES are sponsored by the Home Office they also liase with the Office of the Deputy Prime Minister (ODPM) responsible for the fire service in England and Wales. A&ES Automotive Conformance Specification 5 (herein referred to as PITO5) relates to the "electromagnetic compatibility (EMC) performance of vehicle mounted, electrically powered equipment, designed for use by the Police & Fire Services of England and Wales". The A&ES term "electrically powered equipment" is virtually equivalent to the automotive directive term "Electronic Sub-Assembly" (ESA). The current revision of PITO5 (issue 9, August 2004) was harmonised with the old automotive directive 95/54/EC[2] in order to minimise a manufacturer's test house costs. PITO specification 5 resulted from EMC work undertaken by the Home Office Validation & Installation Design Group (VIDG) on police vehicles[3]. VIDG was renamed the Automotive & Equipment Section (AES), and was transferred to the Police Information Technology Organisation on 2nd July 2003.

PITO5 lays extremely tight constrains on emissions from aftermarket ESAs intended for use in police and fire service vehicles. It's designed to ensure that ESAs are compatible with existing police and fire service radios, particularly that ESAs don't block or quieten (de-sensitise) those radios. PITO5 also places limits on conducted emissions from ESAs (via an ESA's DC power supply), emissions that both (new and old) automotive (EMC) directives ignore. Furthermore PITO5 adds an Audio Frequency (AF) emissions test not found in any other standard this author has encountered.

PITO5 specifies limits for both the radiated immunity and conducted transient immunity of ESAs. There are significant differences between the requirements of PITO5 and both the new and old automotive directives. These differences are described in section 1.

Section 2 describes, with examples, design techniques used by the author to obtain compliance with PITO5 radiated emission requirements.

PITO5 Overview

PITO5 covers all electronic devices fitted to or used in police and fire service vehicles in the UK except those fitted and supplied as standard by the vehicle OEM at the point of supply. Vehicle EMC requirements are covered by PITO specification 6[4]. It should be noted that neither specification is mandatory. Police authorities specify A&ES certification during procurement.

PITO5 covers devices such as: automatic license plate recognition systems, sirens and flashing light assemblies, cameras, etc. It specifically excludes devices termed 'TLEDs' (Traffic Law Enforcement Devices), which are required to meet the requirements of the Home Office Scientific Development Branch (HOSDB) Speedmeter Handbook[5]. TLEDs are defined as[6]:

1. Speedmeters
   - Hand-held radar speed measuring devices
   - Tripod mounted radar speed measuring devices
   - Pneumatic tube sensor speed measuring devices
   - Piezo sensor speed measuring devices
   - Laser speedmeters
   - Fixed radar speed cameras
   - Automatic distance over time speedmeters
   - Mobile distance over time speedmeters
2. Fixed red light cameras
3. Roadside breath alcohol screening devices
4. Evidential Breath Test Instruments (EBTI)

It should be noted that ESAs that are also TLEDs do no go through PITO5 assessment. They are entirely assessed by HOSDB standards.

Testing to PITO5 used to be done exclusively at the contract EMC workshops at Carterton near Brize Norton. On 1 May 2004 PITO testing was discontinued at Carterton. Manufacturers now have to obtain a test report from an independent commercial test house. The test house used needs to be agreed with A&ES and A&ES will inspect the independent test report before issuing a certificate of compliance. There is no manufacturer self-declaration route available for compliance to PITO5.

In April 2005 A&ES published a supplement[7] to PITO5 principally to clarify the test methods. Both PITO5 and its supplement are currently under review by A&ES. A revised Specification 5 is expected to be issued in late Spring or early Summer 2006. It is expected, among other changes, that the new revision will be harmonised with 2004/104/EC[8].

The information required to support a submission to A&ES is listed in section 6.2 of PITO5 and is similar to the requirements of annex II B of both automotive directives. Further clarification of the information required in independent test reports is also contained in the supplement[7].

Radiated Emissions

PITO5 emissions testing is based on the method of 95/54/EC annexes VII (broadband) and VIII (narrowband) emissions. Alternatively PITO5 allows the method of CISPR25[9] to be used (there being little practical difference). PITO5 is not concerned with emissions over the entire frequency range and only sets limits for the frequency bands employed by radio receivers in police and fire service vehicles (table 1).

Frequency Band	Start (MHz)	Stop (MHz)	Narrowband Limit (AVG dBuV/M)		Broadband Limit (AVG dBuV/M)	
			PITO5	'e' Mark	PITO5	'e' Mark
VHF (analogue)	70.5	71.5	0	45	10	55
	80.0	84.0	0	44.3	10	54.3
	142	149	6	47.1	16	57.1
	151	157	6	47.5	16	57.5
	168.5	174.3	6	48.2	16	58.2
Tetra	380	400	15	55	24	65
UHF (analogue)	450	470	15	55	24	65

Table 1 – PITO5 Radiated Emission Limits

The emission limits are extremely tight, more than 40 dB below the e-marking limits. They have been set to attempt to ensure that police and fire service radios aren't quietened (de-sensitised) by emissions from equipment fitted to a vehicle wherever that equipment is fitted. This is important because most modern police gadgets are actually systems comprised of two or more units. For example a number-plate recognition system will comprise a black-box computer fitted in the boot of a police car, an LCD touch-screen display fitted to the dashboard and forward and rear pointing cameras mounted in the roof space.

In such cases there are many paths from various emission points of the system and its cabling to the antenna of a police radio system. The path with the least attenuation has to be considered when setting limits for emissions. VIDG arrived at the PITO5 limits from measurements made in and around vehicles. These low limits however cause problems when testing. Figure 1 shows the peak-hold ambients in RadioCAD's Cowden facility with the PITO5 and e-marking narrowband limits superimposed.

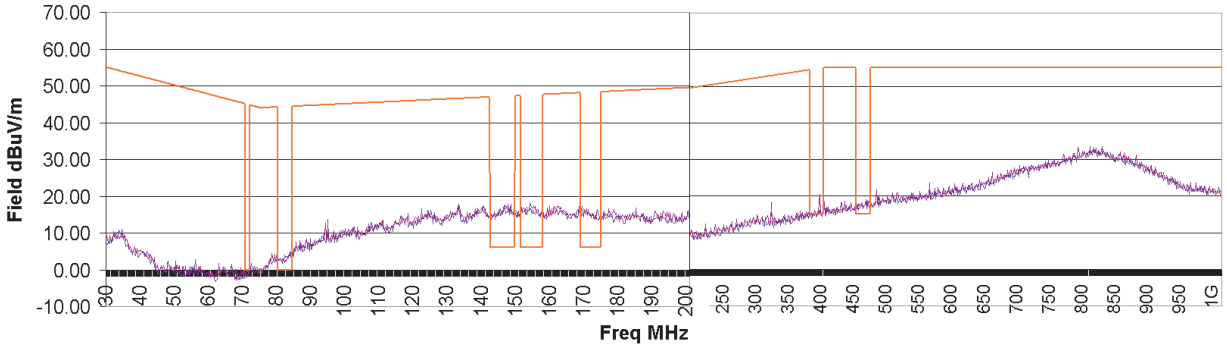

Figure 1 – Ambient conditions at RadioCAD's Cowden facility (120KHz BW)

The ambient noise level reduces naturally when a CISPR average (AVG) detector is used in place of a peak detector. To give further margin the supplement to PITO5 specifies the use of a detector bandwidth of 10 KHz ±2 KHz (CISPR25 specifies 9 & 120 KHz). It is recommended that the bandwidth be selected so that the ambient noise floor is at least 6 dBs below the limit line.

Whereas both automotive directives allow either Open Area Test Site (OATS) or Absorber-Lined Shielded Enclosure (ALSE) measurements, PITO5 insists on ALSE measurements only. The rationale being that measurements are far too sensitive to be carried out successfully at an OATS.

Radiated Immunity

The test method is derived from 95/54/EC although only the 'free field' method is permitted. The Stripline, TEM and BCI methods are not acceptable. Unlike 2004/104/EC both horizontal and vertical antenna polarisations are required. Plate antennas are not permitted and a linearly polarised antenna must be used. In addition a ground plane bench must be used in all cases.

The spot frequencies for use in radiated immunity testing are set out in table 2. NOTE: the table published in PITO5 has been modified in the supplement by relaxing the Tetra frequency interval in order to reduce test house time.

The field strengths employed are not particularly excessive (table 3). Much more stringent levels for Tetra immunity testing are applied to TLEDs (table 4), although not by PITO specification 5. Since TLEDs are used to convict motorists of traffic offences it is important that the readings they give can be relied upon even when those reading are taken in the presence of strong fields emanating from police radios.

Table 4 is a reproduction of table 1 from the 4th Ed of the Speedmeter Handbook[4]. Levels for categories C and D are currently under review. A proposal on the table from Qinteq is that category C have three levels C1= 125V/m, C2=160V/m and C3=200V/m corresponding to whether 1, 2 or 3 Tetra handportables are in use in a vehicle. The category D proposed level is 100V/m. The proposal has yet to be adopted by HOSDB.

VHF (low band) MHz	VHF (high band) MHz	MHz	UHF Tetra MHz	UHF Analogue MHz
70.0	142.0	152.4		
70.4	142.5	152.6		
70.6	143.0	152.8	380.0	450.0
70.8	143.2	153.0	…	…
71.0	143.4	153.2	500 KHz intervals	500 KHz intervals
71.2	143.6	153.4	…	…
71.4	143.8	153.6	400.0	470.0 MHz
71.6	144.0	153.8		
72.0	144.5	154.0		
79.6	145.0	154.2		
80.0	145.5	154.4		
80.2	146.0	154.6		
80.4	146.2	154.8		
80.6	146.4	155.0		
80.8	146.6	155.2		
81.0	146.8	155.4		
81.2	147.0	155.6		
81.4	147.2	155.8		
81.6	147.4	156.0		
82.0	147.6	156.5		
82.4	147.8	157.0		
82.8	148.0	168.5		
83.0	148.5	168.8		
83.4	149.0	170.0		
83.6	151.0	174.0		
83.8	151.5	174.2		
84.0	152.0			
84.4	152.2			

Table 2 – PITO5 Radiated Immunity Spot Frequencies

	Analogue VHF	**Digital Tetra**	**Analogue UHF**
Mounted outside the vehicle	60 V/m	40 V/m	40 V/m
Mounted inside the vehicle	20 V/m	20 V/m	20 V/m
Modulation Type	AM 1KHz @ 80%	Actual/Pseudo Tetra signal	FM 1 KHz @ 1.6KHz dev

Table 3 – PITO5 Radiated Immunity Limits

Note that the modulation types differ from the automotive directives to reflect the modulation types used by the various police and fire service radio systems.

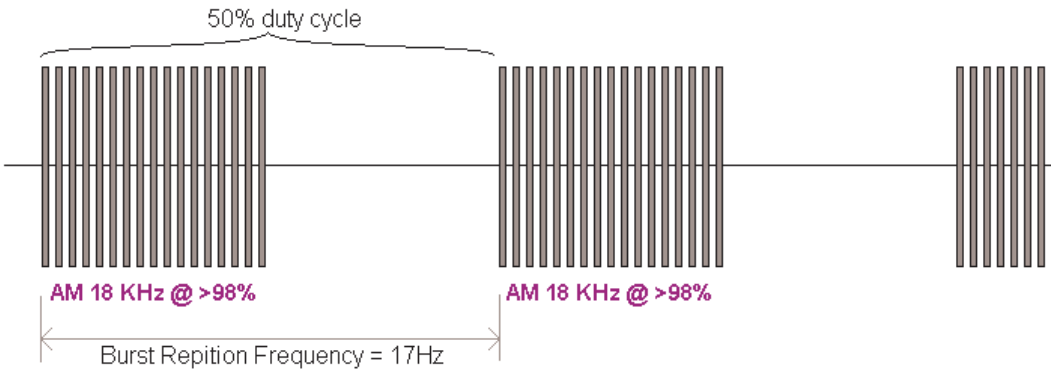

Figure 2 – PITO5 Pseudo-Tetra Modulation

For digital Tetra the modulation type has either to be a Tetra signal[10] or a pseudo-Tetra signal comprising an 18 KHz square wave amplitude modulated waveform to a depth of more than 98% and gated on and off at 17Hz with a 50% duty cycle (figure 2). “The effects of this Pseudo-TETRA signal on EUT’s have been validated with those from a TETRA simulator and demonstrated to produce comparable results”. (PITO5 appendix 6).

Category	Definition	Field strength V/m	Comment
A	Hand-held attended actively operated devices and not operated within vehicles	65	Can be operated to within 0.2 m of a personal 1 W TETRA radio antenna and 1.5 m of a 3 W vehicle mounted TETRA radio antenna
B	All other (non-category A) attended actively operated devices and automatic supervised devices not operated within vehicles	20	Can be operated to within 1 m of a personal 1 W TETRA radio antenna and 4 m of a 3 W vehicle mounted TETRA radio antenna.
C	Hand-held devices operated within vehicles and not connected to the vehicle	x(1)	Field enhanced by internal vehicle reflections One operator carried 1 W TETRA radio operating inside the vehicle with its antenna at least 0.2 m from the device
D	Vehicle mounted devices with an external antenna	x(1)	No operator carried TETRA radios operating inside the vehicle Can be operated to within 1 m (line of sight) of the antenna of a 3 W vehicle mounted TETRA radio

Note 1 Level as set by HOSDB

Table 4 – TLED Radiated Tetra Immunity Limits[4]

Conducted Transient Emissions

PITO5 sets limits for conducted emissions emanating from an ESAs DC power supply port. The method is specified in ISO 7637-1:1990[11] section 3.3. It requires an oscilloscope to measure transients induced when the ESA is powered up and down though an Artificial Network (AN) (figure 3).

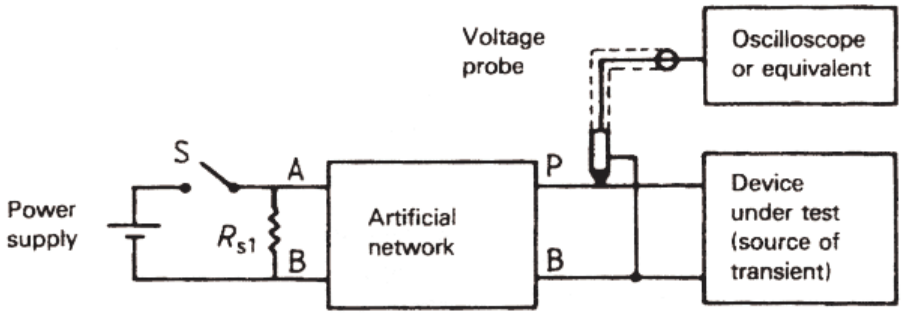

Figure 3 – Transient Emission Measurement Set-up

This testing is identical to 2004/104/EC which calls up ISO 7637-2:2002. The limits differ however (table 5).

Pulse Polarity	12V systems		24V systems	
	PITO5	'e' Mark	PITO5	'e' Mark
Positive	+ 50 V	+ 75 V	+ 50 V	+ 150 V
Negative	- 50 V	- 100 V	- 50 V	- 450 V

Table 5 – Conducted Emission Limits

Conducted Transient Immunity

Although specified these tests are not currently mandatory for PITO5 conformance.

PITO5 calls up ISO7637:1990 part 1 for 12V systems and presumably calls up part 2 for 24V systems although the specifications only states "the test pulses are different for 24V systems". 2004/104/EC calls up the later revision ISO 7637-2:2002. Both specifications require immunity test level III but with different functional status requirements (table 6). Additionally PITO5 includes the notorious load dump pulse (pulse 5), which 2004/104/EC curiously omits.

Test Pulse (ISO7637-1:1990)	Test Level	Duration /no. pulses	Functional Status (required to pass)		
			PITO5	2004/104/EC immunity related	2004/104/EC not immunity related
1	-75 V	5000	B	C	D
2	+75 V	5000	B	B	D
3a	-100 V	1 hour	B	A	D
3b	+75 V	1 hour	B	A	D
4	-6 V	5	C	B / C	D
5	+66.5 V	5 (1 minute separated)	C	Not tested	

Table 6 – Transient Immunity Requirements

Continuous Conducted Emissions (AF Emissions)

Audio Frequency (AF) induced on power lines is known to cause wining in police radios[1], therefore PITO5 specifies a unique test for conducted AF emissions from an ESA. The test set-up is the same as for conducted transient emissions (figure 3), except that a 300 Hz to 3.4 KHz bandpass filter is inserted between the measurement probe and oscilloscope. Since most oscilloscope probes are high impedance the author prefers to use a 50Ω filter in shunt with the AN, and a 50Ω terminated oscilloscope. NB: the AN shunt impedance Z_{PB} @ 1 KHz is > 1.5 KΩ.

The limit for AF emissions is 200mV peak to peak.

There are problems with the test however. The standard AN specified in figure 4 of ISO 7637-1:1990 has virtually zero impedance at audio frequencies. Therefore the measured voltage depends on the DC supply source impedance, which is not guarantied to be repeatable from one installation to another. The author's current practice is to use a 'typical' lead-acid 12V car battery. PITO5 doesn't specify the telecoms filter characteristic precisely.

Result Classes

PITO5 defines five classes of pass. ESAs that meet all requirements of the specification are class 1, whereas those that fail some of the requirements with what A&ES consider "minor non-compliances" are class 2 and above.

CLASS 1 = fully meets the specification.

CLASS 2 = meets the specification with minor non-compliances (these being listed below).
- A = narrowband emissions exceeding the limit in some bands and may cause interference on an allocated radio channel.
- B = broadband emissions exceeding limit, but may be acceptable in operational conditions.
- C = The unit tested requires modification to non-essential electronic equipment.
- D = Excessive output ripple voltage.
- E = Has susceptibilities but should not affect operational requirements.

CLASS 3 = for fire service use only.

CLASS 4 = code no longer used.

CLASS 5 = for police covert use only.

The class of pass with any letter codes will be printed on the rear of the conformance certificate issued by A&ES.

A&ES have traditionally given ESAs with minor non-compliant analogue band emissions a class 2 pass. The conformance certificate would list non-compliant frequencies so that police forces could check to see if they used those frequencies or not. Then the Tetra band was added to PITO5 and A&ES now require full compliance in this band. Some minor non-compliances in the analogue bands may still be permitted. This approach is taken because the police forces have no control over channel allocation in the Tetra band. Given that Tetra is gradually replacing analogue technologies the manufacturing industry has been pushing for a 'Tetra Only' class within PITO5. This would be a class that has all of the analogue radio band requirements removed. A&ES's position on this is that although in time the legacy bands will be dropped, there remain many users of complex equipments using the analogue bands. Therefore these bands will, for the time being, continue to be included in PITO5.

Designing for Compliance to PITO5 Radiated Emission Requirements

PITO5 sets very demanding levels for radiated emissions from ESAs in the bands used by police radios. Some minor non-compliances are allowed in the analogue bands. These will be listed with the A&ES conformance certificate so that a police force can decide whether these non-compliances affect them or not. A&ES will not accept any non-compliances in the Tetra band (380 to 400 MHz).

The author has found that the following three techniques have proved sufficient to ensure PITO5 radiated emissions compliance in the past:

(i) Accepted good EMC design practice for PCBs, enclosures, cable and connectors.
(ii) Use of spread-spectrum clocks to turn narrowband emissions into broadband emissions.
(iii) Moving narrowband clock harmonics by replacing reference crystals.

Technique (i) is well beyond the scope of this paper being the subject of numerous technical books and papers. Good EMC design of a product is the necessary starting point for compliance to any standard. For this reason the author usually performs an e-marking emissions preview of a product prior to accepting any development contract for PITO5 compliance. For example figure 4 shows the preview emissions profile of a commercially available far-eastern LCD touch-screen.

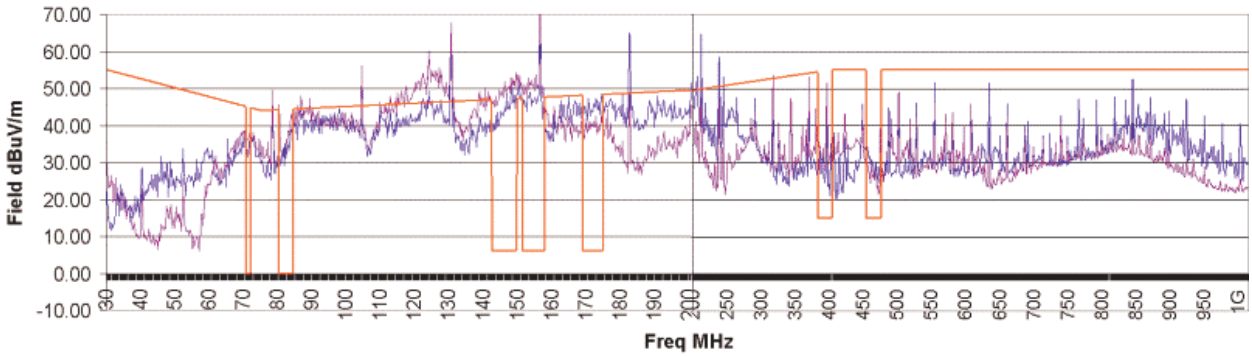

Figure 4 – Radiated Emissions from a poorly designed LCD touch-screen

Needless to say this component is not suitable for use in any system destined for the police. A good starting point is a system that already comfortably meets the automotive directive radiated emission requirements. Figure 5 shows a well-engineered PC based camera, LCD-touchscreen system designed for number-plate recognition and time-distance speed measurement.

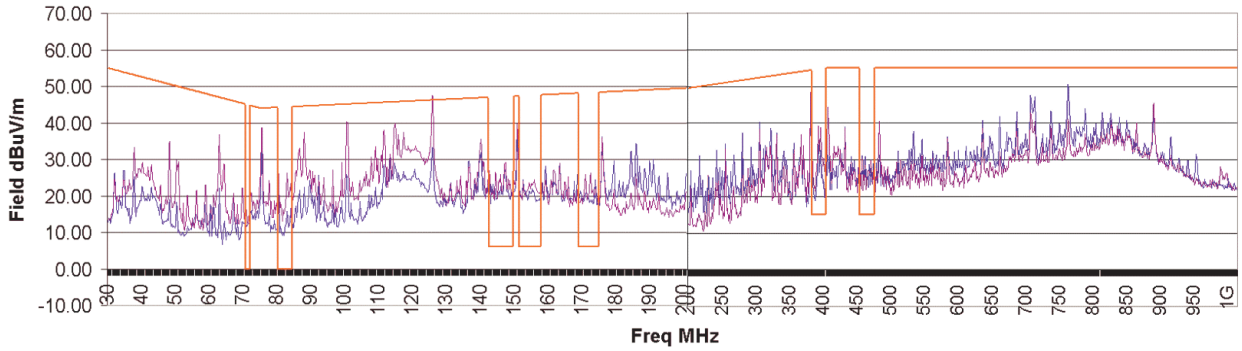

Figure 5 – Radiated Emissions from a well-designed system

The figure shows a peak hold horizontal and vertical ‘quick scan’. The horizontal peak at 128 MHz, which appears to cross the e-marking limit, passes comfortably when investigated formally with AVG and QP detectors.

Step 1 – Reducing Tetra band emissions using technique (i)

Once a candidate device or system has been selected it necessary first to investigate in detail the emissions in the Tetra band. Figure 6 shows the radiated emissions of the same system previewed in figure 5. In this preview an AVG detector has been used with a 120 KHz bandwidth. Although this is much wider than recommended it allows a preview scan to be completed more quickly.

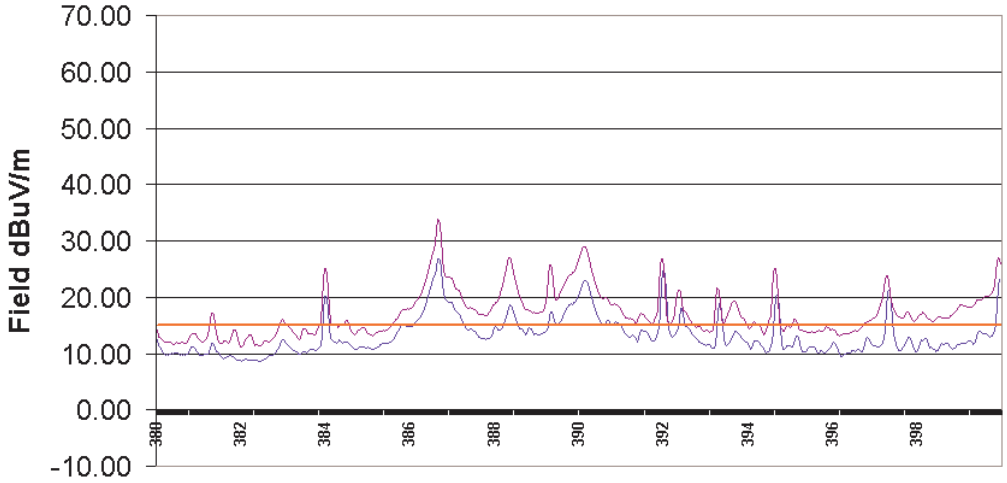

Figure 6 – Radiated Emissions in Tetra band.

As it turned out in this example these emission came predominantly from the LCD touchscreen and were very data dependent. For this reason techniques (ii) and (iii) above were of no use in reducing the emissions. It was found that careful screening of the LCD unit and bonding of its screen video cable was necessary to reduce these emissions significantly.

Step 2 – Spreading processor clocks, technique (ii)

Disconnection the LCD and cameras it was now possible to look at the emission from the PC alone (cables still attached, figure 7).

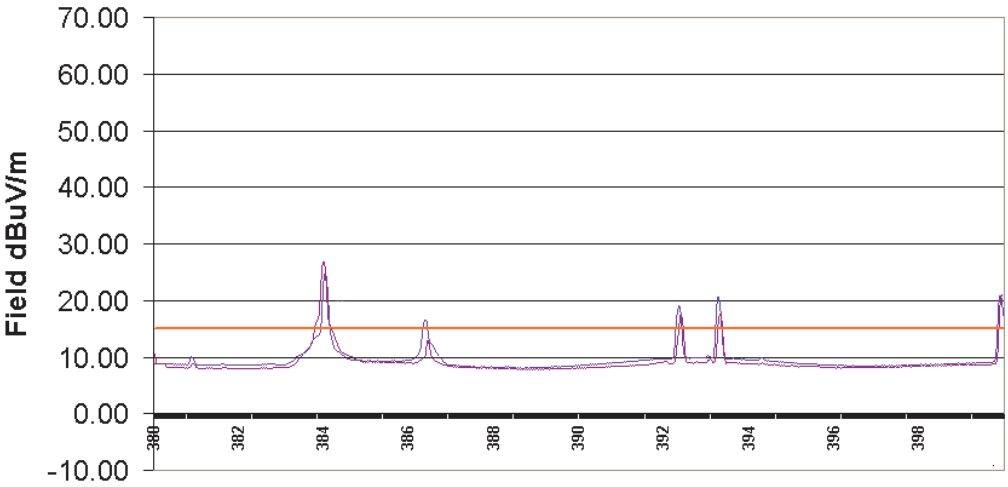

Figure 7 – Radiated Emissions in Tetra band (PC only).

It was possible to reduce the largest emission (because it was a harmonic of the main processor clock) simply by enabling spread-spectrum in the PC bios (figure 8).

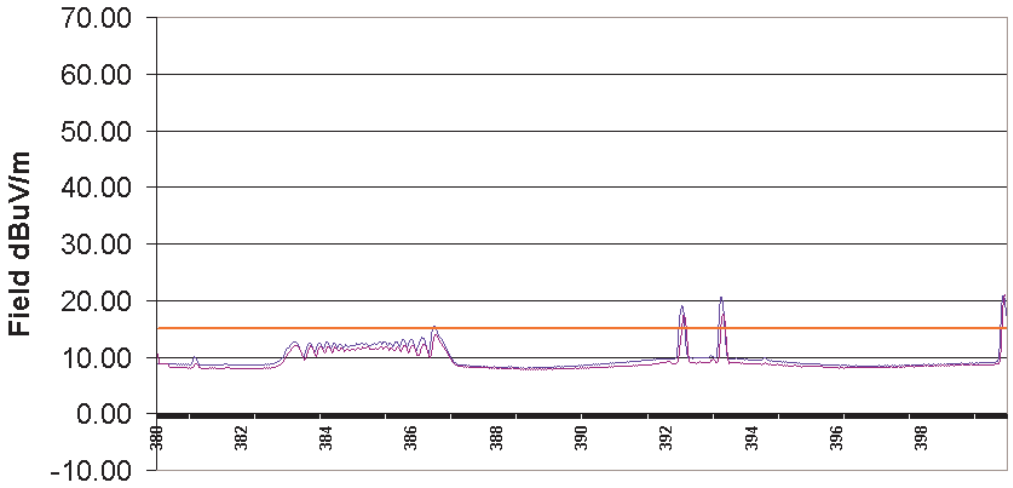

Figure 8 – Radiated Emissions in Tetra band (PC only, SS clock).

This preview AVG scan is still with 120 KHz BW (for speed) and with the narrow-band limit showing. QP measurements on the spread clock against the broadband limit showed this clock harmonic to be within PITO5 limits.

Step 3 – Moving IO clocks, technique (iii)

The remaining spikes (figure 8) were traced to harmonics of clocks used on internal IO cards within the PC. To move these harmonics out of band custom crystals are needed with frequencies very slightly higher than the default crystals. This pushes the remaining spikes up and out of the Tetra band. Had the spikes been in the bottom half of the band, crystals with slightly lower frequencies would have been required. Before changing crystals it's important to check that critical parameters, such as communications baud rates, will not be pushed out beyond acceptable limits. In this case a worst case 2% up-shift is necessary, which at the time of writing hasn't been tested.

Putting the system together again the emissions of figure 9 were recorded.

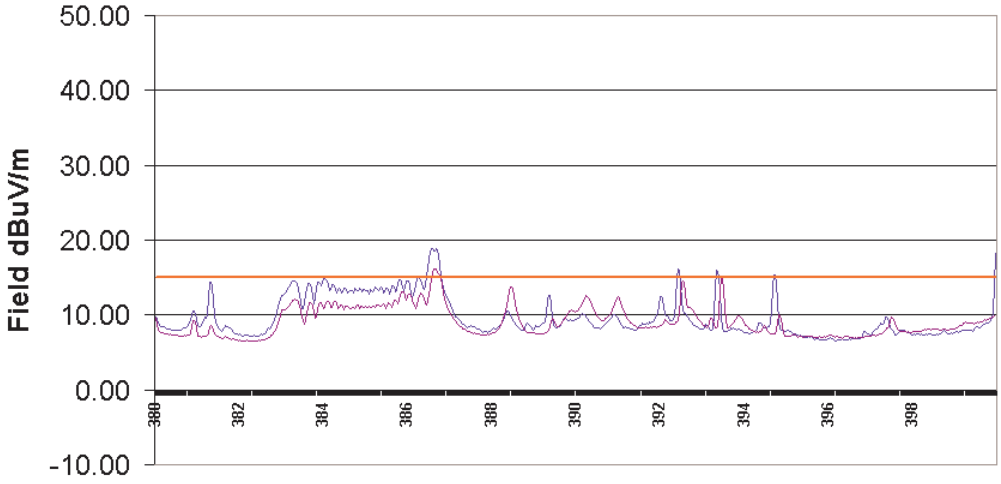

Figure 9 – Radiated Emissions in Tetra band (modified unit*).

This preview shows that this unit is now very nearly compliant if not compliant. Formal measurements would be needed to establish the fact.

* - IO clock harmonic emissions have been reduced by unplugging offending cables in this preview example.

Conclusion

PITO5 testing requirements have been discussed and compared with both the old and new automotive EMC directive requirements for ESAs. The additional Tetra immunity requirements placed on TLEDs by The HOSDB Speedmeter Handbook have also been discussed. Finally the author has shown three practical techniques for making ESAs compliant to the exacting emissions requirements of PITO5.

References

[1] Automotive Conformance Specification 5 (Issue 9), *A specification relating to the electromagnetic compatibility (EMC) performance of vehicle mounted, electrically powered equipment, designed for use by the Police & Fire Services of England and Wales.* PITO Communications Directorate Automotive & Equipment Section, August 2004.

[2] Commission Directive 95/54/EC of 31 October 1995 adapting to technical progress Council Directive 72/245/EEC on the approximation of the laws of the Member States relating to the suppression of radio interference produced by spark-ignition engines fitted to motor vehicles and amending Directive 70/156/EEC on the approximation of the laws of the Member States relating to the type-approval of motor vehicles and their trailers, Official Journal of the EU NO. L266, 08/11/1995 P.0001-0066

[3] *Home Office National Asset Register* Chapter 4, HM Treasury 2000.

[4] Automotive Conformance Specification 6 (Issue 8), *A specification relating to the electromagnetic compatibility (EMC) performance of motor vehicles for use by the Police & Fire Services of England and Wales.* PITO Communications Directorate Automotive & Equipment Section, August 2004.

[5] The Speedmeter Handbook (Fourth Edition), *A Guide to Type Approval Procedures for Speedmeters Used for Road Traffic Law Enforcement in Great Britain*, Home Office Scientific Development Branch (HOSDB) Publication No. 15/05, 24 August 2005.

[6] EMC Testing of Traffic Law Enforcement Devices, specifically relating to potential TETRA and GSM interference, Colin Snow & Malcolm Rich QinetiQ, *EMC Compliance Journal,* September 2002.

[7] Supplement to Automotive Conformance Specification 5 (Issue 9), PITO Communications Directorate Automotive & Equipment Section, April 2005.

[8] Commission Directive 2004/104/EC of 14 October 2004 adapting to technical progress Council Directive 72/245/EEC relating to the radio interference (electromagnetic compatibility) of vehicles and amending Directive 70/156/EEC on the approximation of the laws of the Member States relating to the type-approval of motor vehicles and their trailers,

[9] CISPR25 edition 2.0:2002, R*adio disturbance characteristics for the protection of receivers used on board vehicles, boats and on devices - Limits and methods of measurement*. International Electrotechnical Commission (IEC).

[10] ETSI ETS 300 392-2 ed.1 (1996-03) *Terrestrial Trunked Radio (TETRA);Voice plus Data (V+D);Part 2: Air Interface (AI)*

[11] ISO 7637-1:1990 *Road vehicles – Electrical disturbance by conduction and coupling – Part 1: Passenger cars and light commercial vehicles with nominal 12 V supply voltage – Electrical transient conduction along supply lines only.*

Biographical Notes

Tim Jarvis is an independent consultant. His company RadioCAD Limited (http://www.radiocad.com/) assists clients in designing electronic products for compliance with European directives and worldwide standards. Tim has worked in the electronics industry since 1983 and specialises in RF design and EMC with a particular interest in automotive ESAs. t.jarvis@radiocad.co.uk.