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Results Summary for Australian 7 MHz Laboratory tests
of DVB-T and ATSC DTTB modulation systems.

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Report Compiled by Neil Pickford

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Results Summary for Australian 7 MHz Laboratory tests of DVB-T and ATSC DTTB modulation systems.

During 1997 the DVB-T COFDM and ATSC 8-VSB DTTB modulation systems were evaluated for their performance in the Australian 7 MHz broadcasting environment. FACTS and the Communications Laboratory jointly conducted the measurements which are detailed in this summary. More detailed information can be obtained from the main test reports:

- Laboratory Report 98/01 - Laboratory Testing of DTTB Modulation Systems, DMV - System 3000 COFDM, Zenith/Harris - 8-VSB, January 1998
- FACTS - Field Performance Evaluation Tests of DTTB, January 1998

These tests were conducted on or around VHF channel 8 (191.5 MHz) and employed prototype and demonstration equipment. During the field trial the DTTB signal was located between existing high power PAL transmissions (Ch 7 & 9) and combined into the same antenna system as channel 9. The DVB-T system was a 7 MHz channel implementation while the ATSC system employed the standard 6 MHz bandwidth.

The DVB-T standard allows many variations of Modulation type (QPSK, 16-QAM, 64-QAM), Number of carriers (1705,6815), FEC (1/2 to 7/8) and guard interval (1/32 to 1/4) while the ATSC system has a single modulation mode. Initial laboratory testing indicated that 2K COFDM 64-QAM 2/3 FEC 1/8 Guard Interval was a close match in data rate and interference performance to the ATSC system, so these DVB-T parameters were selected for the majority of the testing.

The majority of the digital modulation system tests were conducted using measurements of the bit error rate (BER) of pseudo random data. The systems were thus evaluated as data pipes. Unfortunately the system error threshold is defined differently for the DVB-T and ATSC systems.

- The DVB-T system BERs are measured before the reed solomon (RS) decoder allowing a high error rate to be measured (2.1×10^{-4}). This translates to a very low error rate (10^{-11}) after RS.
- The ATSC system uses a BER (3.0×10^{-6}) at the transport stream system output. This output error rate has been determined to match the Threshold of Visibility (TOV) when the data is decoded and displayed.

There is debate between the proponents of each system about which method gives the correct results, under different test situations.

Assessment of the interaction of the DTTB systems with existing analog PAL television was observed using both limit of perceptibility and subjective comparison methods.

It should be noted that **the performance measured in these tests represents only one receiver implementation of each modulation standard**. Other receiver implementations may display different characteristics, however both systems do provide performance which is worthy of comparison.

All measurements of PAL power levels used vision sync tip power while all noise, CW and DTTB powers were measured as average power using a thermal power meter.

Results Summary

In this result summary, where figures appear under the DVB-T heading in the comparison lists, the DVB-T system being compared is 2k COFDM 64-QAM 2/3 FEC 1/8 Guard unless otherwise noted.

General System performance

Parameter	DVB-T	ATSC
Data Payload	19.35 Mb/s	19.39 Mb/s
Carriers	1705	1
Symbol Time	256 us	93 ns
Time Interleaving	1 Symbol	4 ms
Reed Solomon code rate	188/204	187/207
IF Bandwidth (3 dB)	6.67 MHz	5.38 MHz
IF centre Frequency	35.3 MHz	44.0 MHz
Receiver AFC range	11.5 kHz	359 kHz
Latency including MPEG coding SDTV 8 Mb/s	37 Frames	Unknown

Payload Bitrate Mb/s

COFDM MOD TYPE	FEC Code Rate	Sys C/N (dB)	Min Sig Level (dBuV)	Calc Rx NF (dB)	Guard 1/4 (Mb/s)	Guard 1/8 (Mb/s)	Guard 1/16 (Mb/s)	Guard 1/32 (Mb/s)
QPSK	1/2	5.4	11.7	4.8	4.35	4.84	5.12	5.28
QPSK	2/3	6.6	13.2	5.1	5.81	6.45	6.83	7.04
QPSK	3/4	7.6	14.8	5.7	6.53	7.26	7.68	7.92
QPSK	5/6	8.7	16.8	6.6	7.26	8.06	8.54	8.80
QPSK	7/8	9.5	19.2	8.2	7.62	8.47	8.96	9.24
16-QAM	1/2	11.2	17.7	5.0	8.71	9.68	10.25	10.56
16-QAM	2/3	13.0	19.6	5.1	11.61	12.90	13.66	14.07
16-QAM	3/4	14.1	20.9	5.3	13.06	14.51	15.37	15.83
16-QAM	5/6	15.5	22.9	5.9	14.51	16.13	17.08	17.59
16-QAM	7/8	16.3	24.9	7.1	15.24	16.93	17.93	18.47
64-QAM	1/2	16.8	23.3	5.0	13.06	14.51	15.37	15.83
64-QAM	2/3	19.1	25.2	4.6	17.42	19.35	20.49	21.11
64-QAM	3/4	20.6	27.5	5.4	19.59	21.77	23.05	23.75
64-QAM	5/6	22.2	30.0	6.3	21.77	24.19	25.61	26.39
64-QAM	7/8	23.7	32.4	7.2	22.86	25.40	26.89	27.71
8-VSB	2/3	15.1	27.2	11.2	-	-	-	19.39

Blue Payload Figures are 188/204 scaled from actual measurement

Red Figures are calculated from the 1/32 Guard interval data

Table 1 - Receiver and Payload Parameter Comparison

- Guard interval affects payload data rate and echo performance but has no impact on general receiver parameters such as C/N & Signal level.
- The Transmission Parameter Signalling (TPS) for COFDM allows the receiver to automatically determine the modulation type and FEC, however in the equipment tested the Guard interval needed to be entered into the receiver. Future implementations are expected to automatically determine the guard interval from the received signal.

AWGN Receiver Performance

Parameter	DVB-T	ATSC
Carrier to Noise Threshold (in native system bandwidth)	19.1 dB	15.1 dB
Simulated Theoretical C/N for optimum system	16.5 dB	14.9 dB
Minimum Signal Level	25.2 dBuV	27.2 dBuV
Apparent receiver noise figure	4.6 dB	11.2 dB
Input Signal Level where Carrier to Noise Threshold degrades from system threshold by 1 dB	34 dBuV	35 dBuV

- C/N difference suggests 4 dB more power required for DVB-T to achieve the same coverage as ATSC.
- Better C/N performance of the ATSC system is largely offset by poor noise figure at edge of coverage for Gaussian Noise
- The ATSC C/N is very close to the theoretical C/N of 14.8 dB however the DVB-T implementation is still over 2.5 dB higher than the theoretical margin.
- Other DVB-T modes have different C/N Thresholds and Data Rates See Table 1

Multipath & Flutter

Parameter	DVB-T	ATSC
Single 7.2 us Coax pre ghost	0 dB	-13.5 dB
Single 7.2 us Coax post ghost	0 dB	-2.2 dB
Single 17.2 us Translator link pre ghost	-3 dB	-16.2 dB
Single 17.2 us Translator link post ghost	-8 dB	-8.4 dB
Echo correction range	±32 us	+3 to -20 us
Doppler single echo performance (-3 dB echoes)	±140 Hz	±1 Hz

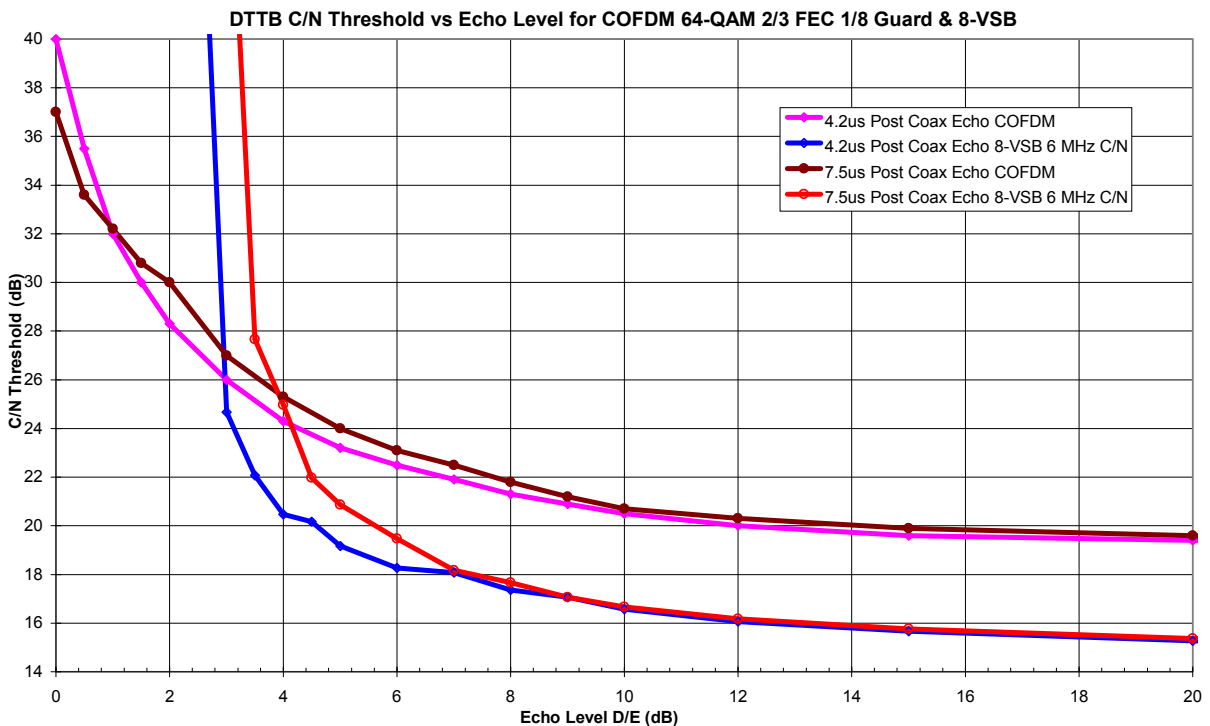


Figure 1 – DTTB C/N Threshold vs Echo Performance

- The ATSC system has two equaliser modes and intelligently switches to fast mode when short variable echoes are detected. Fast mode increases doppler performance to 5 Hz but results in a degradation of system C/N threshold. The laboratory tests did not cause a change into fast mode, and only represent measurement of the normal slow equalisation mode.
- 8 VSB degrades more rapidly when multipath echo exceeds -7 dB
- COFDM works up to 0 dB in a white noise environment but in this condition is very fragile.

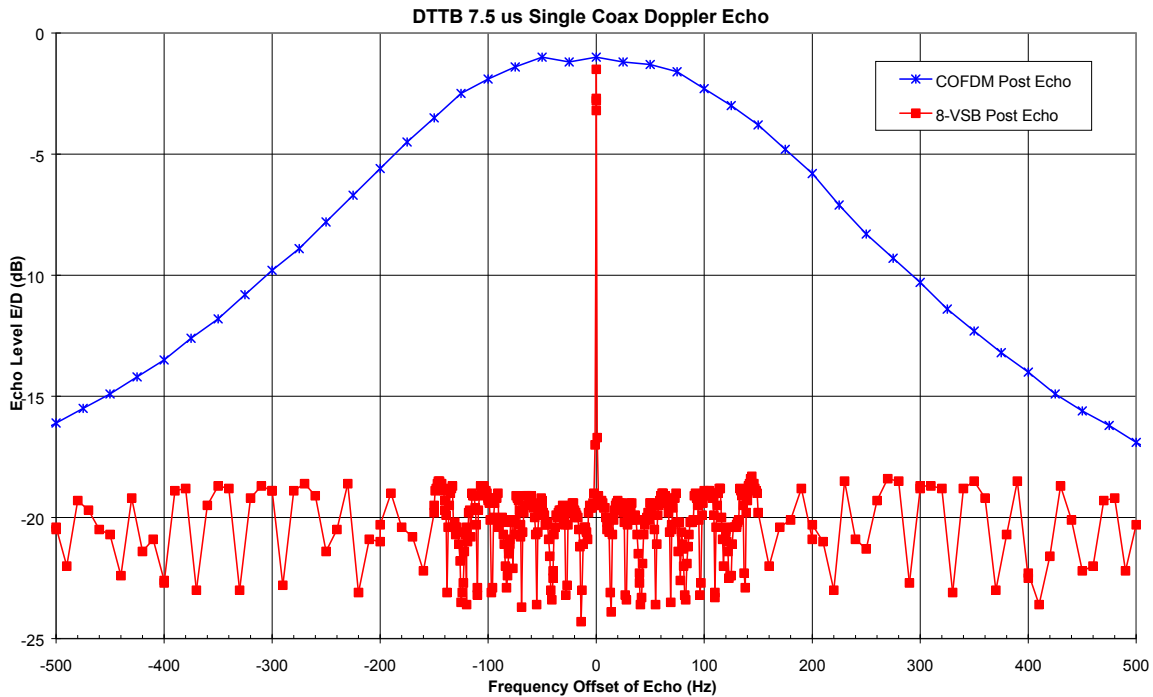


Figure 2 - DTTB Doppler Echo Performance

Transmission System

Parameter	DVB-T	ATSC
Transmitter/Translator Linearity & Inter-mod Sensitivity	Low	High
Group Delay / Combiner / Filter Sensitivity	Low	< 50 ns
Suggested Transmission System performance maintenance strategy	Manual Maintenance same as PAL	Automatic Dynamic pre-corrector
Gap Fill coverage - System Strategy	IF Translator or SFN	Digital Repeater

During the conduct of the testing much effort was expended by the ATSC proponents on pre-correction and alignment of the transmission system. The 8-VSB system initially did not work through the translator link even though both PAL & COFDM had been successfully operated through the translator previously. After improvement of the link, to allow the 8-VSB system to operate, a remeasure of the COFDM system showed no change in system performance. The use of the translator link in the Laboratory testing showed the sensitivity of the ATSC 8-VSB system to non-linear translator equipment.

- ATSC very sensitive to transmission impairments as it uses up correction capacity in the receiver equaliser.

- ATSC equaliser has to correct the response characteristic of the whole channel.
- DVB-T equaliser uses pilot carriers spread throughout the spectrum to equalise the channel in small 16-50 kHz sections. Using this technique even severe group delay distortions do not affect individual data carriers which only occupy 1-4 kHz of spectrum.
- Zenith representatives suggested during the Laboratory testing that transmission systems should operate without using a transmitter output filter to avoid group delay problems with 8-VSB. The 6 MHz 8-VSB system operating in a 7 MHz channel helps this situation.
- If using existing PAL vision transmitters:
 - ⇒ Recalibration of metering will be necessary (Peak to Average)
 - ⇒ AGC / AFC and protection systems may require modification

Impulse Noise

Parameter	DVB-T	ATSC
Impulse Sensitivity (Differential to PAL grade 4)	9-14 dB	17-25 dB

- Impulse noise is very difficult to measure & characterise.
- It mainly affects the lower VHF frequencies
- ATSC can handle fixed level impulsive interference at a signal level which is 8 to 11 dB lower than DVB-T
- ATSC only has a few data symbols affected by any normal impulsive phenomenon
- The DVB-T COFDM demodulation (FFT) spreads the energy from a broad spectrum impulse across all carriers leading to massive data loss when the impulse is large enough.

In Figure 3 below the **Blue ATSC** signal is able to cope with the impulse noise at a lower DTTB signal level than the **Purple DVB-T** system.

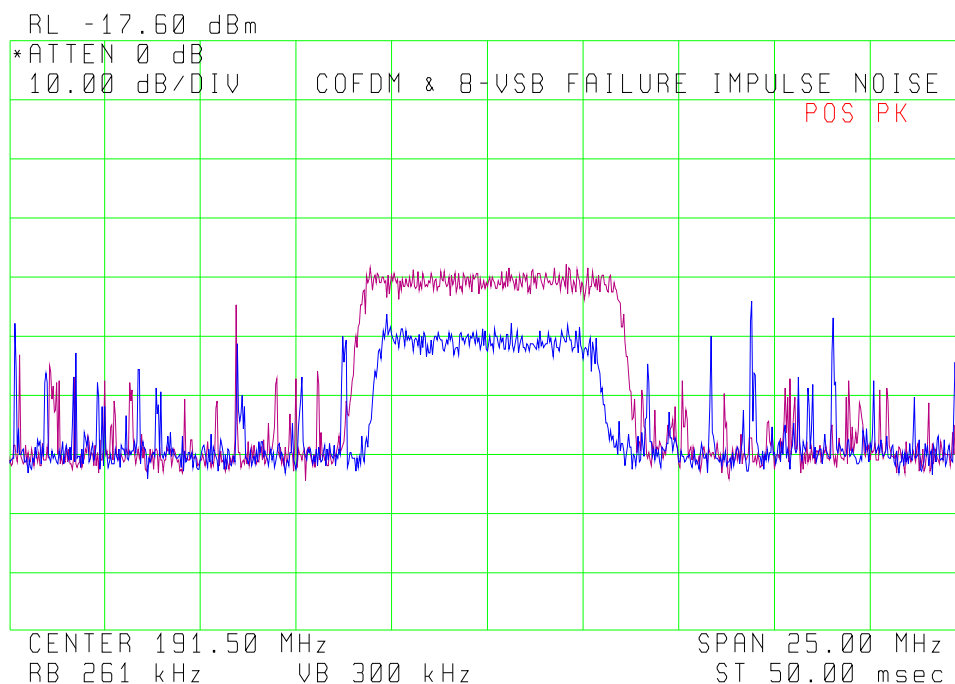


Figure 3 - DTTB Best Impulse Noise Performance

DTTB into PAL Interference

The DTTB systems were used as interferers to a fixed channel 8 PAL B service at the adjacent channel and co-channel positions. The Subjective Comparison Method (SCM) was used for the evaluation of protection ratio values. Using SCM the observer compares the interfered test picture with the interference level of a known sinewave interferer defined in ITU-R Rec 655. SCM levels of 30 and 40 dB were measured along with a Limit Of Perceptibility (LOP) evaluation. These measurements equate to Tropospheric, Continuous and Limit of Perceptibility interference measurements respectively detailed in ITU-R Rec. 655. A frame from an electronic graphic tape sequence containing saturated colour and luma gradations was used as a static PAL test frame. The PAL sound carriers were unmodulated during the subjective evaluation phase of the test however during setup the sound carriers were modulated with 400 Hz test tone and the receiver volume adjusted to a normal ambient level. Sound interference was only observed during the LOP evaluations as SCM is not applicable to sound.

DTTB into PAL B Protection D/U (dB)							
System Test Description		Mean	StdDev	Num	Min	Median	Max
DVB-T 7 MHz Tropospheric Interference	Ch 7 lower adj. ch.	-9.5	3.3	12	-14.0	-10.0	-4.0
	Ch 8 Co-Channel	35.8	1.4	12	33.5	36.0	38.5
	Ch 9 upper adj. ch.	-10.6	4.9	12	-20.0	-10.0	-3.0
DVB-T 7 MHz Continuous Interference	Ch 7 lower adj. ch.	-5.3	3.8	12	-9.5	-6.5	2.5
	Ch 8 Co-Channel	41.1	2.0	12	38.5	40.8	45.0
	Ch 9 upper adj. ch.	-6.4	4.3	12	-14.0	-6.8	1.0
DVB-T 7 MHz Limit of Perceptibility	Ch 7 lower adj. ch.	3.5	3.8	12	-2.5	2.8	10.0
	Ch 8 Co-Channel	50.4	0.9	14	48.5	50.3	52.0
	Ch 9 upper adj. ch.	5.1	5.8	16	-1.0	3.8	20.0
ATSC 6 MHz Tropospheric Interference	Ch 7 lower adj. ch.	-7.0	3.4	15	-12.5	-7.0	-2.0
	Ch 8 Co-Channel	38.7	2.6	41	34.5	38.5	44.0
	Ch 9 upper adj. ch.	-7.1	3.5	17	-14.0	-6.0	-3.5
ATSC 6 MHz Continuous Interference	Ch 7 lower adj. ch.	-0.9	4.3	15	-5.5	-2.0	8.0
	Ch 8 Co-Channel	45.5	2.2	41	41.0	45.0	50.5
	Ch 9 upper adj. ch.	-0.3	2.9	17	-5.5	0.0	3.0
ATSC 6 MHz Limit of Perceptibility	Ch 7 lower adj. ch.	5.0	4.4	15	0.0	4.0	13.0
	Ch 8 Co-Channel	51.4	2.5	41	47.0	51.5	56.5
	Ch 9 upper adj. ch.	5.4	3.1	17	0.0	4.5	10.5

Table 2 - DTTB into PAL B protection ratios, VHF Band III

The data has been obtained from an analysis of each of the individual measurements taken and is presented with the statistical variations observed. The analysis of this data varies from the original Lab Test Report 98/01 since the average data in that document was derived by averaging mean test data without regard to the number of samples in each test.

- DVB-T seems to cause marginally less interference to PAL for both the Co and adjacent channel situations
- DTTB Co channel signals need to be kept at least 46 dB on average below the Wanted PAL level to ensure Grade 4 reception
- DTTB Adjacent channel signals need to be kept on average at or below the Wanted PAL level to ensure Grade 4 reception

PAL into DTTB interference

The DTTB systems were fixed on the centre of channel 8 (191.5 MHz) while the interfering PAL B was moved between the adjacent channel positions either side of the normal channel 8 vision carrier frequency (189.25 MHz). The interference measurements were made by increasing the PAL-B power level, while measuring the error rate of a pseudo random data stream through the DTTB system under test, until the system reached the failure point.

DTTB System Parameters			PAL into DTTB Protection (D/U)		
DTTB TYPE	CONSTELLATION MODULATION	FEC Code Rate	Ch 7 Lower Adj Ch (dB)	Co Channel (dB)	Ch 9 Upper Adj Ch (dB)
DVB-T-7	COFDM QPSK	1/2	-44.8	-13.0	-49.2
DVB-T-7	COFDM QPSK	2/3	-44.5	-8.4	-47.0
DVB-T-7	COFDM QPSK	3/4	-43.7	-4.0	-45.3
DVB-T-7	COFDM QPSK	5/6	-42.3	3.1	-43.3
DVB-T-7	COFDM QPSK	7/8	-40.8	9.7	-42.0
DVB-T-7	COFDM 16-QAM	1/2	-43.5	-8.8	-46.1
DVB-T-7	COFDM 16-QAM	2/3	-42.1	-2.3	-43.3
DVB-T-7	COFDM 16-QAM	3/4	-40.2	3.3	-41.2
DVB-T-7	COFDM 16-QAM	5/6	-37.0	9.9	-39.1
DVB-T-7	COFDM 16-QAM	7/8	-35.2	16.9	-37.3
DVB-T-7	COFDM 64-QAM	1/2	-41.2	-3.1	-41.7
DVB-T-7	COFDM 64-QAM	2/3	-35.4	1.4	-37.5
DVB-T-7	COFDM 64-QAM	3/4	-35.0	10.8	-35.9
DVB-T-7	COFDM 64-QAM	5/6	-31.2	17.1	-33.1
DVB-T-7	COFDM 64-QAM	7/8	-28.9	22.6	-30.8
ATSC-6	8-VSB 8-AM	2/3	-38.6	9.1	-38.7

Note: All DTTB variants used uniform modulation constellations.

Table 3 - PAL B into DTTB protection ratios, VHF Band III

- Out of channel performance is very dependent on receiver design. It is interesting to note that the narrower ATSC system achieves very similar out of band / adjacent channel performance to DVB-T.
- ATSC is nearly 8 dB worse than DVB-T when subjected to interference from Co-Channel PAL transmissions
- In situations where Co-Channel DTTB and PAL signals exist the DTTB into PAL interference will be the dominant factor, providing directional antennas are used.
- If a DTTB frequency offset was being considered for use, the data indicates that moving up in frequency is preferable to moving down.

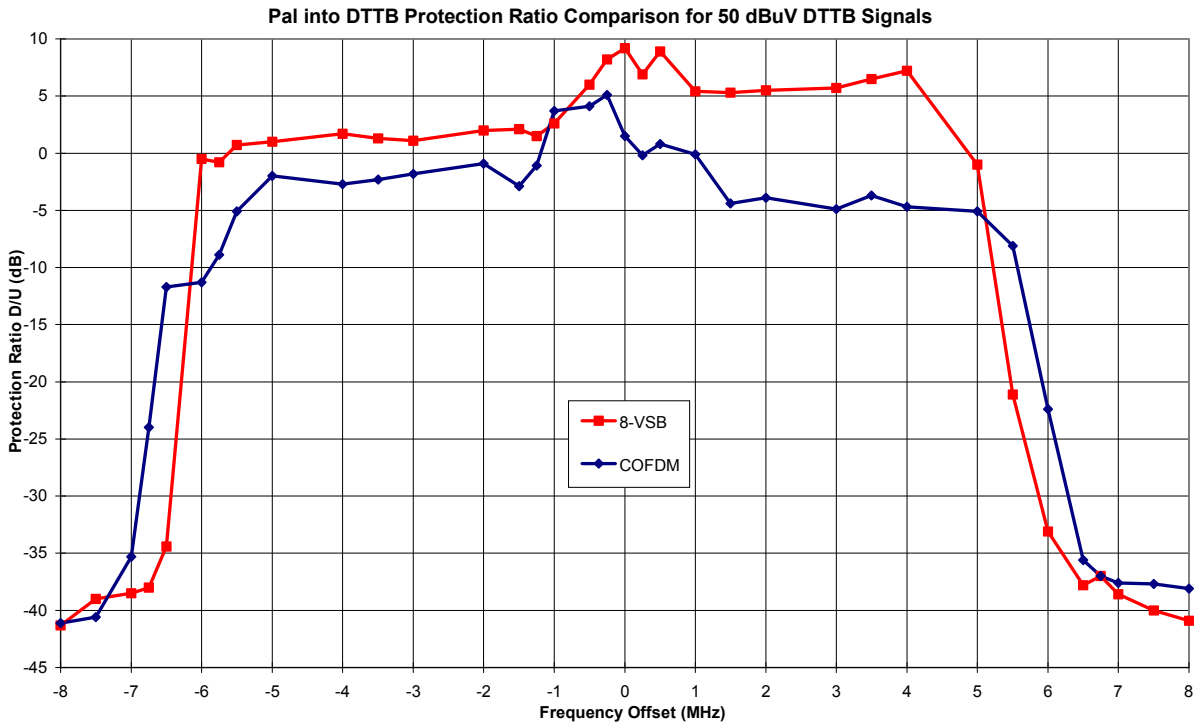


Figure 4 - PAL-B into DTTB ACI & CCI protection

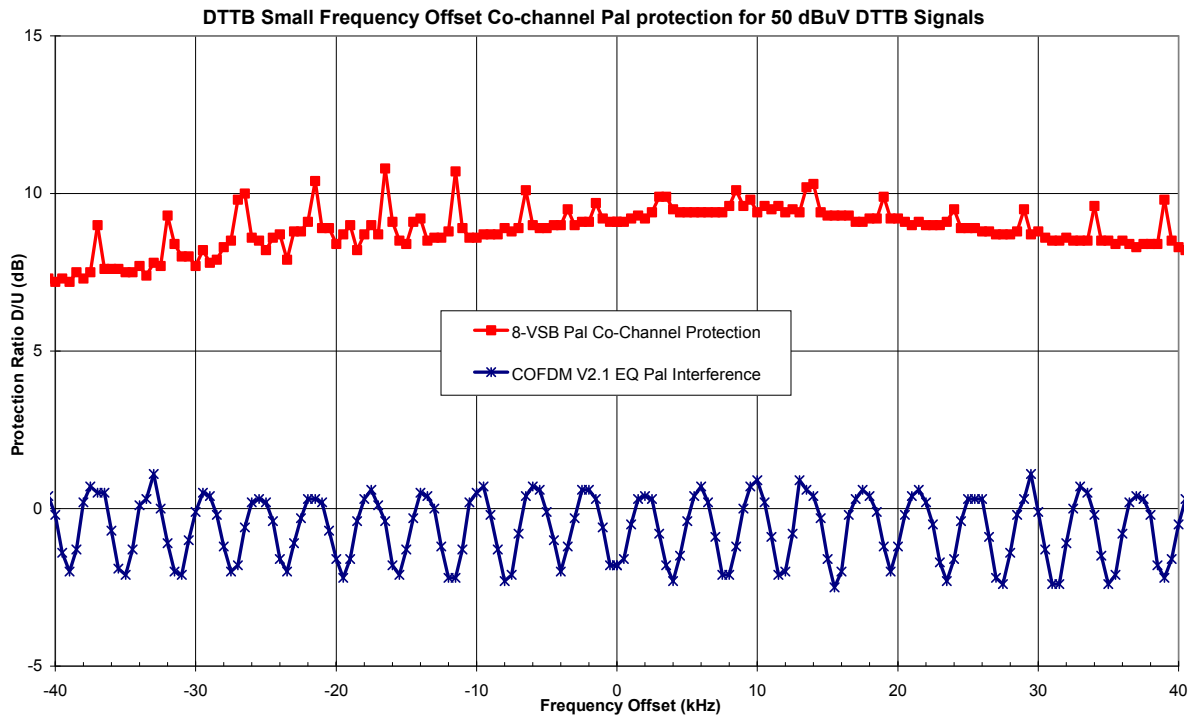


Figure 5 - PAL-B into DTTB Co Channel protection

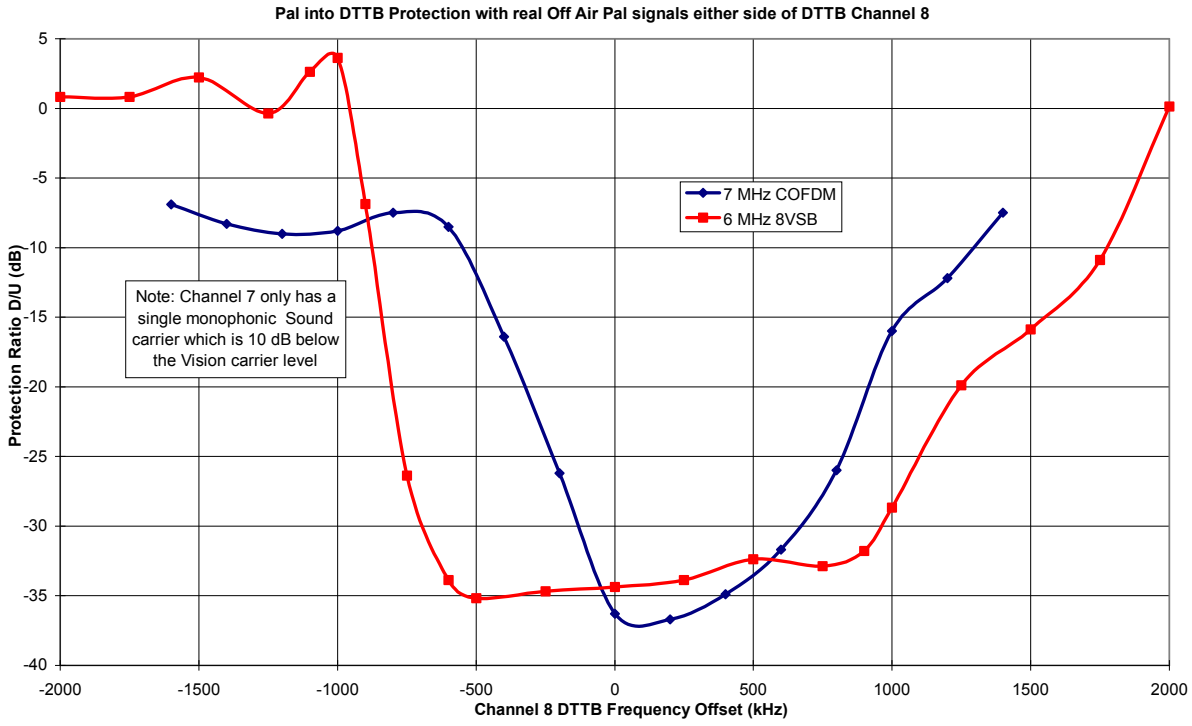


Figure 6 - Off air PAL into DTTB protection

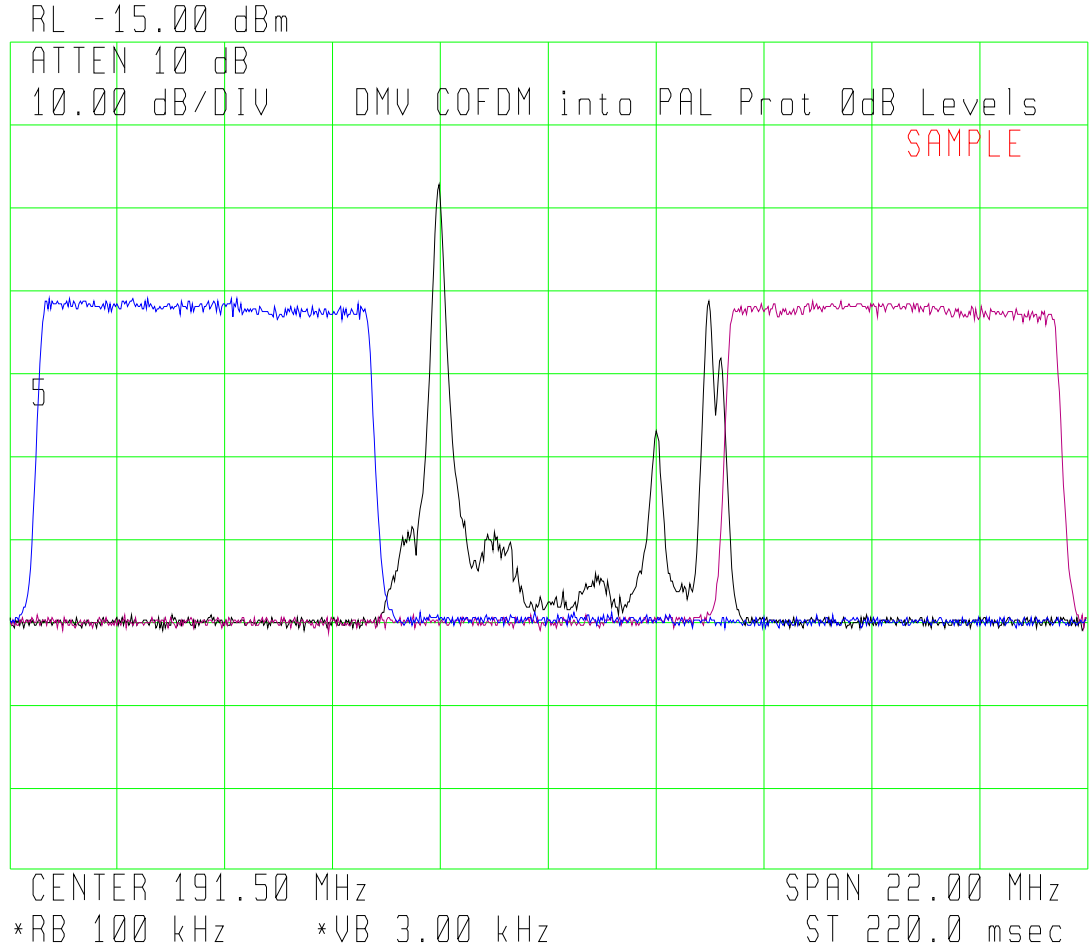


Figure 7 - Adjacent PAL-B & 7 MHz COFDM signals at 0 dB relative to each other

CW into DTTB interference

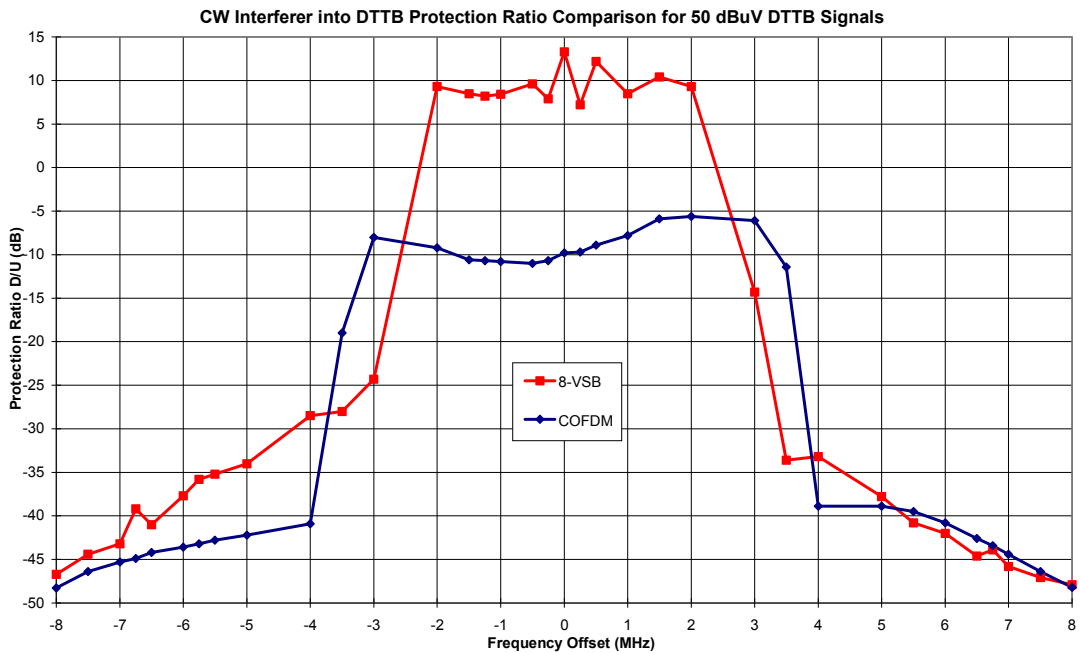


Figure 8 - CW interference into DTTB protection

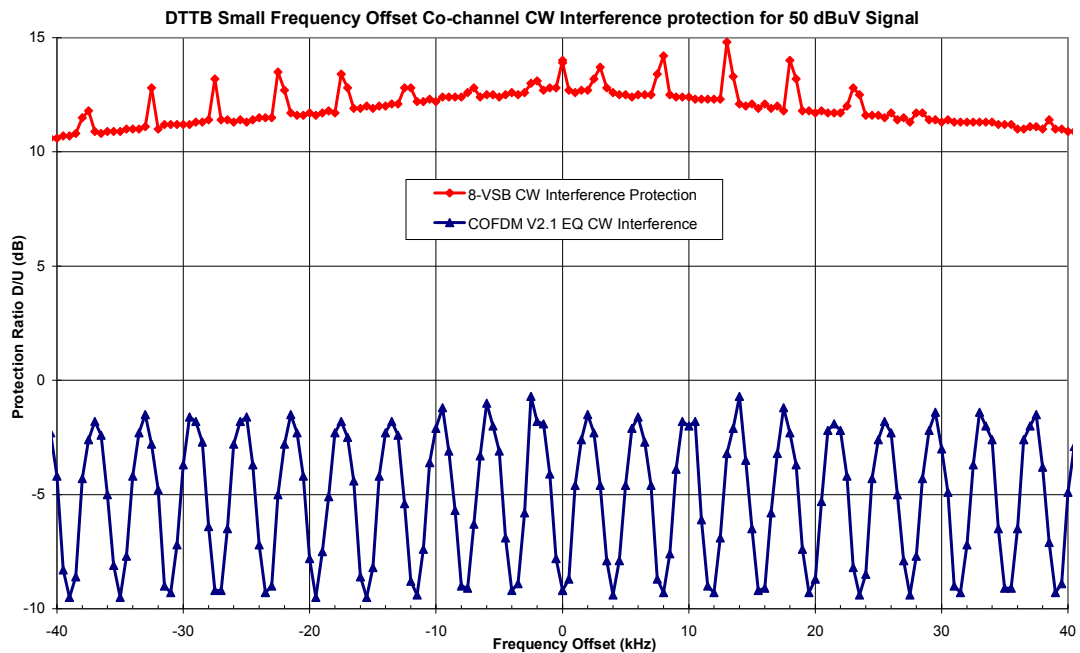


Figure 9 - CW into DTTB protection centre channel

- DVB-T is on average 15.5 dB less sensitive across the channel to general CW type interferers than ATSC
- The DVB-T orthogonal carrier spacing is evident for DVB-T in this measurement with a variation of over 8 dB. If known CW interferers are likely then a frequency offset of less than 4 kHz may assist system performance.
- ATSC has occasional peaks due to critical equaliser responses.
- The DVB-T response above was obtained from the improved equaliser which was provided near the end of the tests, showing continuing improvement in performance of the DVB-T implementation.

DTTB into DTTB interference

The wanted DTTB signal was fixed on the centre of channel 8 (191.5 MHz) while the interfering DTTB signal was moved between the adjacent channel positions either side of the centre of channel 8 (191.5 MHz). The interference measurements were made by increasing the interfering DTTB power level, while measuring the error rate of a pseudo random data stream through the DTTB system under test, until the system reached the failure point.

DTTB System Parameters			DTTB into DTTB Protection (D/U)		
DTTB TYPE	CONSTELLATION MODULATION	FEC Code Rate	Ch 7 Lower Adj Ch (dB)	Co Channel (dB)	Ch 9 Upper Adj Ch (dB)
DVB-T-7	COFDM 64-QAM	2/3	-28.3	20	-28.5
ATSC-6	8-VSB 8-AM	2/3	-30.4	14.6	-32.2

Note: All DTTB variants used uniform modulation constellations.

Table 4 - DTTB into DTTB protection ratios, VHF Band III 7 MHz channels

- The co-channel protection of both digital systems approximates to the system carrier to noise threshold.

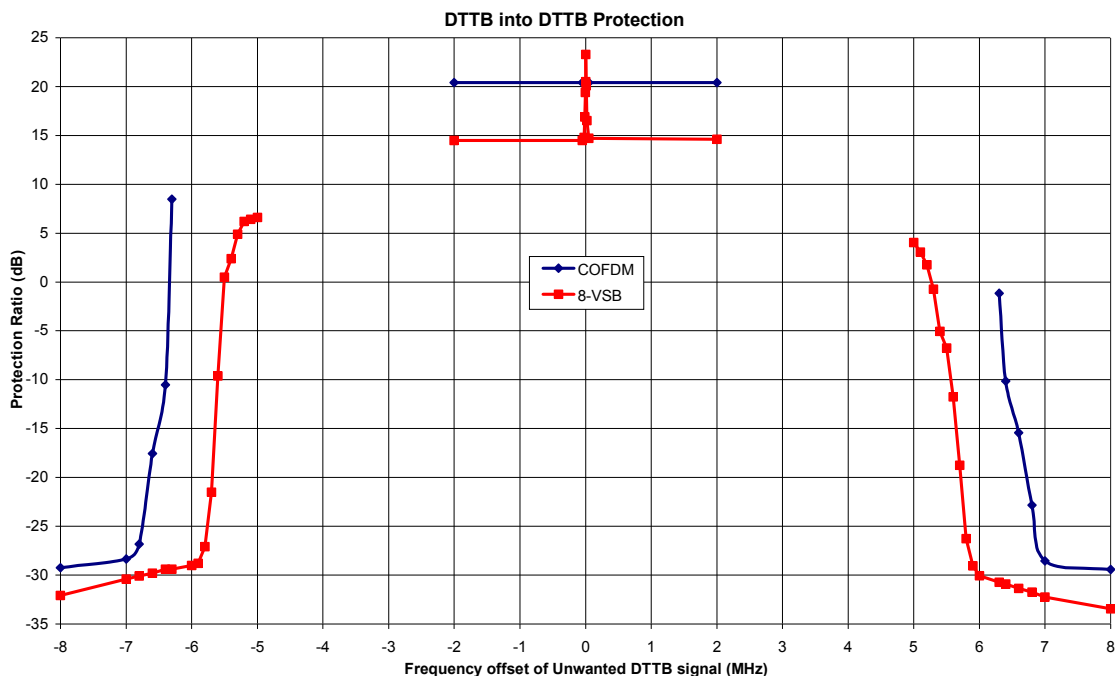


Figure 10 - DTTB into DTTB Protection

Conclusion

- The assessment of the results presented in this summary depends largely on the specific system requirements of the broadcaster and the viewers.
- The implementation and performance of both digital terrestrial transmission systems are still being improved

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Relevant Comments

The following comments relate to items which were not measured but reflect input received from various sources.

It has been suggested by DVB that there may be up to 1.5 dB variation between the two methods if BER measurement used in the tests in the case of some types of impairment.

Relevant Comments - Multipath & Flutter

NDS have commented that a longer channel estimation filter has now been designed for their COFDM receiver which results in better AWGN performance in the presence of strong echoes.

Relevant Comments - Transmission system

The ATSC transmission system Dynamic Pre-corrector proposed for each transmitter will be difficult to apply in the combined antenna systems used in Australia.

Relevant Comments - Impulse Noise

DVB have indicated that Input signal clipping and AGC techniques can be used to minimise the impact of impulsive interference.

Relevant Comments - PAL into DTTB interference

NDS claim that the latest DVB-T receiver implementations have improved the Co-Channel performance further.

Relevant Comments - Conclusion

The DVB-T system, being a newer technology that has not even achieved it's own theoretical performance, shows more scope for achieving future advances in performance and application.

If flexible operation (Fixed/Mobile, Data Rate) and interoperability (cable & satellite) are significant criterion then the DVB-T system seems to offer the best transmission solution.