Laboratory Report 98/01

Laboratory Testing of DTTB Modulation Systems.
DMV - System 3000 COFDM.
Zenith/Harris - 8-VSB.

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Executive Summary

This report presents the results of laboratory testing at the Communications Laboratory of both the DVB - COFDM and ATSC - 8-VSB digital television modulation technologies. The systems have been evaluated under Australian 7 MHz channel conditions, primarily on VHF channel 8. These modulation systems have been evaluated as data pipes and no quality or performance measurements of the proposed video systems have been made.

Using bit error rates system parameters such as Carrier to Noise, Signal levels, Interference protection ratios, Doppler and Static Echo performance have been measured. Subjective assessment of DTTB into PAL interference protection levels has also been performed on a small sample of domestic television receivers. The systems have also been tested through real transmission equipment.

Areas such as UHF performance, Cable operation and Field testing were outside the scope of this investigation.

The laboratory tests have shown some performance differences between the systems however the laboratory tests by themselves do not provide sufficient basis to choose between the DTTB modulation technologies.

The data contained within this report will be one of many inputs to the recommendation of which digital television modulation Australia should adopt in the future.

1Introduction

Digital media is rapidly replacing analog communications technology and recent research has allowed the concept of digital television broadcasting to be implemented. Such systems are already operating on satellite and cable systems around the world, however, the more difficult area of terrestrial transmission has only recently become possible.

Presently there are 3 digital terrestrial television modulation systems being developed around the world.

1. The Europeans are developing an integrated suite of standards for digital television under the DVB project group. The DVB-T COFDM system is the terrestrial member of these standards.
2. The Americans are developing a terrestrial standard for digital television under the ATSC. The ATSC 8-VSB system has been mandated by the FCC for use in the United States.
3. The Japanese are developing the Integrated Services Digital Broadcasting (ISDB) system via research at NHK. The terrestrial variant of ISDB proposes to use Band Segmented Transmission - Orthogonal Frequency Division Multiplex (BST-OFDM) and is still in the very early stages of development. No hardware appears to be available for this system at present.

All of these systems are being developed overseas with the primary focus being on satisfying each regions specific problems. Accordingly any testing of these systems focuses on the system requirements within the developers' region. The broadcasting infrastructure in Australia is different to any of the countries that are developing these systems. The broadcast industry in Australia has an interest in evaluating the performance of these modulation technologies under typical Australian conditions.

This report describes the results of laboratory testing of the European COFDM and American 8-VSB transmission systems, in the context of the 7 MHz Australian broadcasting infrastructure.

Measurements were performed on a DMV System 3000 DVB-T pre-production receiver and a ATSC 8-VSB prototype receiver.

1.1Background

In November 1996 the FACTS engineering specialists' group arranged a demonstration of over the air digital television in conjunction with the ITU-R Study Group 11 meeting in Sydney and the FACTS annual general meeting. This demonstration used the just developed DMV System 3000 DVB-T 7 MHz COFDM equipment. As part of this demonstration NEC Australia and Comsys loaned transmitters to the group to assist with the demonstration.

It was decided at the completion of the demonstration that further testing of the COFDM 7 MHz system should proceed under Australian conditions. The DMV representatives returned the receivers to the UK and the rest of the equipment shipped to the Communications Laboratory in Canberra where the Laboratory test rig described in this report was developed. During this period, initial tests of COFDM into PAL protection ratios were undertaken.

In late February 1997 the VHF receiver arrived back from the UK with upgraded 7 MHz system software and testing of the COFDM system commenced. Initially there were a number of operational system bugs which once corrected required the re-testing of the COFDM into PAL protection ratios.

The objective was to conduct an extensive range of laboratory tests on the 7 MHz COFDM system in a 7 MHz environment and then take the receiver into the field and measure the real field performance of the COFDM system.

In April 1997 the idea of testing the competing ATSC 8-VSB system was proposed and after many e-mails, faxes and conference calls the Zenith “Blue Racks” arrived on the 19th of June 1997. With 2 representatives from both Zenith and Harris present, testing commenced on the 8-VSB system and continued for around a month. Wherever possible, the same measurements that had been conducted on the COFDM equipment were also performed, in a similar manner, with the 8-VSB equipment. The 8-VSB equipment left the Communications Laboratory on 15th of August to return to the USA.

Some retesting of the COFDM equipment occurred after the 8-VSB equipment left to verify the effects of test system changes and improvements that occurred during the course of the 8-VSB system testing.

The COFDM equipment was shipped from the Communications Laboratory to Sydney during the 1st week in September 1997. The DTTB equipment then entered the next test phase with field trials and on air demonstrations of both the 8-VSB and COFDM systems in Sydney.

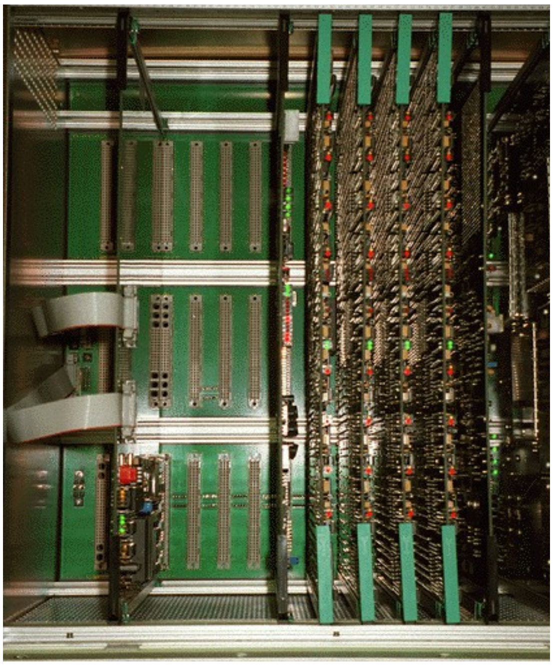
Picture 1 - DMV Equipment Rack

2Equipment Operation

2.1DMV COFDM Equipment

The DMV system 3000 modulation equipment consists of a 19 inch rack frame housing a 12 rack unit modulator, two redundant 4 rack unit multiplexers and two 6 rack unit MPEG encoders (top to bottom in Picture 1). The encoders and multiplexer are controlled via a 10 base-T ethernet connection to the Multiplex Control Computer (MCC). The MCC communicates directly with the multiplexer which in turn relays information destined for the MPEG coders via the 9 pin D-type RS-422 data cables (Taxi Cables). The multiplexer passes the data multiplex to the Coded Orthogonal Frequency Division Multiplex (COFDM) modulator via a RS-422 cable. The multiplex data is asynchronous to the modulator output data rate. The modulator bit stuffs data to achieve a constant data rate on the modulated COFDM output.

The system 3000 modulator uses a 2K IFFT (Inverse Fast Fourier Transform) to produce a COFDM signal with 1705 carriers in a 7 MHz channel. To generate the signal it uses 32 parallel DSP engines mounted on the 4 identical centre boards visible in Picture 2. The modulator is a modified version of the 8 MHz system being used in Europe that has had its system clock rate (36.56 MHz[i]) increased by 7/8 ths (41.78 MHz). It generates an IF centred on 35.3 MHz that is 6.67 MHz wide at around 0 dBm. An internal high level mixer and amplifier allows an external local oscillator at 0 dBm to be applied to mix the signal to VHF or UHF frequencies. Communication and control of the modulator is via a 9600 baud RS-232 data connection to a VT-100 ANSI terminal. This arrangement allows re-configuration of the modulator system parameters such as modulation type, Forward Error Correction (FEC), Guard interval and data source. The modulator can be configured to produce a 2^{23}-1 pseudo random data stream for BER measurement or to use the external data from the multiplexer in the picture transmission mode.



Picture 2 - COFDM Modulator

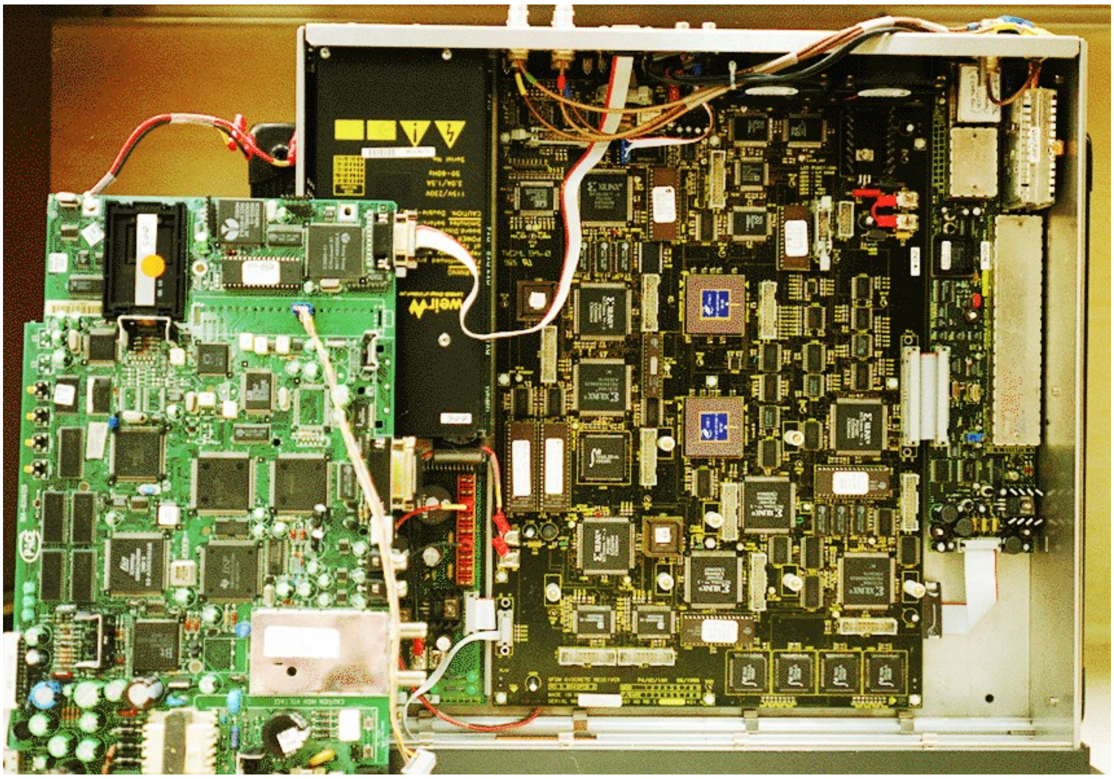
The MCC provides (Picture 3) comprehensive control of the multiplex components and System Information (SI) data streams. Analogue, Serial or Parallel digital inputs for each MPEG coder are selectable along with the desired data rate for each of the stream components. The MCC monitors alarms and allows re-configuration of the multiplex to a real time schedule. It is a PC running a SunOS Unix Kernel

Picture 3 - Laptop for Modulator Control and MCC for Multiplex Control

The system 3000 professional receiver is housed in a 2 rack unit box that contains a COFDM demodulator covering the VHF and UHF bands plus an integral Pace MPEG-2 decoder. Picture 4 shows the back and front view of the commercial COFDM receivers that were tested.

Picture 4 - DMV System 3000 DVB-T COFDM Receiver

The receiver was fitted with a Philips tuner front-end optimised for VHF and offers control via IR remote and an RS232 interface. The Pace MPEG board passes parameters such as channel number and guard interval to the COFDM decoder and is able to monitor the basic viterbi error rate information. All user information except channel number is presented as on screen displays. The receiver provides RGB and Sync/PAL video outputs and has a single 75Ω BNC RF antenna input connector. A 25 pin D-Type female connector is provided for a LVDS transport stream output that allows a number of separate decoders to simultaneously access multiple services within the transport stream. The test unit also has two SMB connectors feeding out TTL clock and data for the BER meter. The BER data is tapped off before the reed solomon decoder. This allows measurement of the DVB Quasi Error Free (QEF) error rate defined in the DVB specification as $2.1\text{x}10^{-4}$ errors. The QEF point is the error rate where the reed solomon code reaches the limit of its correction ability for white noise degradation. The COFDM decoder board has a number of red alarm LEDs at the rear of the unit that indicate various levels of unlock and timing acquisition. A single alarm led on the front panel indicates that the COFDM decoder board is experiencing errors or is unable to decode the RF signal.



Picture 5 - The System 3000 Professional COFDM Receiver

Picture 5 shows the internal boards contained within the DMV receiver. To the left is the Pace MPEG decoder that normally sits over the large discrete COFDM demodulator board. To the right is the tuner board that accommodates the RF front end, synthesiser and A/D converter. Some of the hardware on the Pace decoder such as the power supply, smart card and RF output are not being used. The COFDM demodulator and tuner boards have now been reduced to a set of 3 or 4 chips. This photograph was taken during the software upgrade when the unit was disassembled to change the interleaver EPROM.

2.2Zenith/Harris 8-VSB Equipment

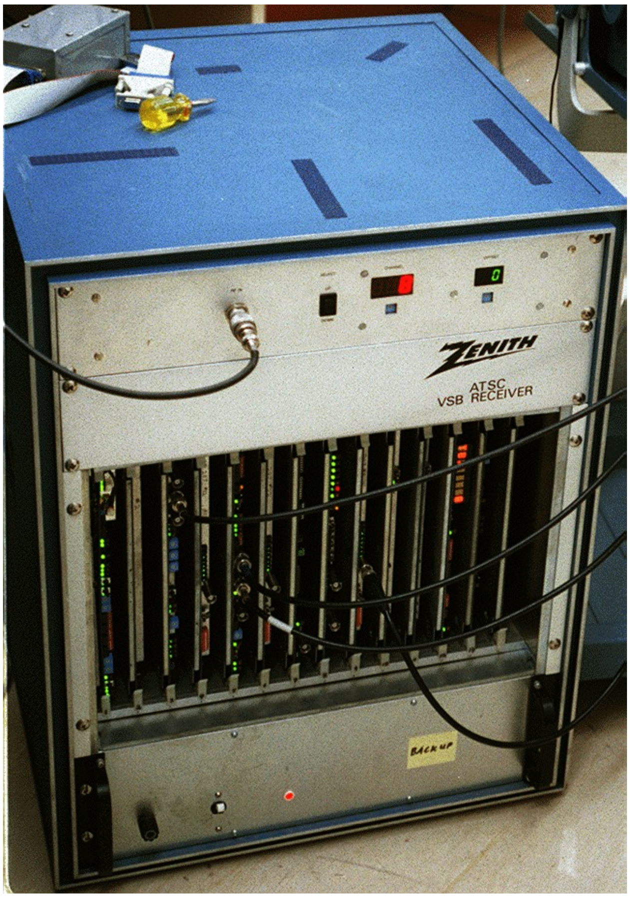
The Zenith 8-VSB equipment is generally referred to as the “Blue Racks” and comprise a half height 19 inch rack for each modulator and receiver. The Zenith modulator generates a 44 MHz IF signal and has an onboard synthesiser and cable TV type upconverter to produce VHF and UHF signals. It can be switched to various internal data sequences such as all zero, random data and the 2^{23}-1 pseudo random sequence.

The Harris CD-1 modulator (Picture 6) is housed in a transmitter rack module containing three 19 inch sliding equipment trays. These trays house the 8-VSB data modulator, up-converter - correction and power supply respectively. The unit generates the 8-VSB signal at a baseband of 10.7 MHz with a bandwidth of 5.3 MHz. Data can be supplied via a BNC serial connector, although this input was not used during the tests. Without a data input, the modulator generates a 2^{23}-1 pseudo random data stream for BER measurement similar to the COFDM equipment. As no video hardware was supplied with the 8-VSB system (MPEG HD encoder and decoder) all tests were done using the pseudo random data stream. The pseudo random data stream is generated at the transport stream input to the equipment and so is subjected to the full gamut of reed solomon and viterbi error correction within the system. This means that the output BER, for the threshold of visibility system failure point, is $3x10^{-6}$. The 10.7 MHz baseband signal is fed to the IF upconverter and becomes a 44.0 MHz IF at the output of the modulator.

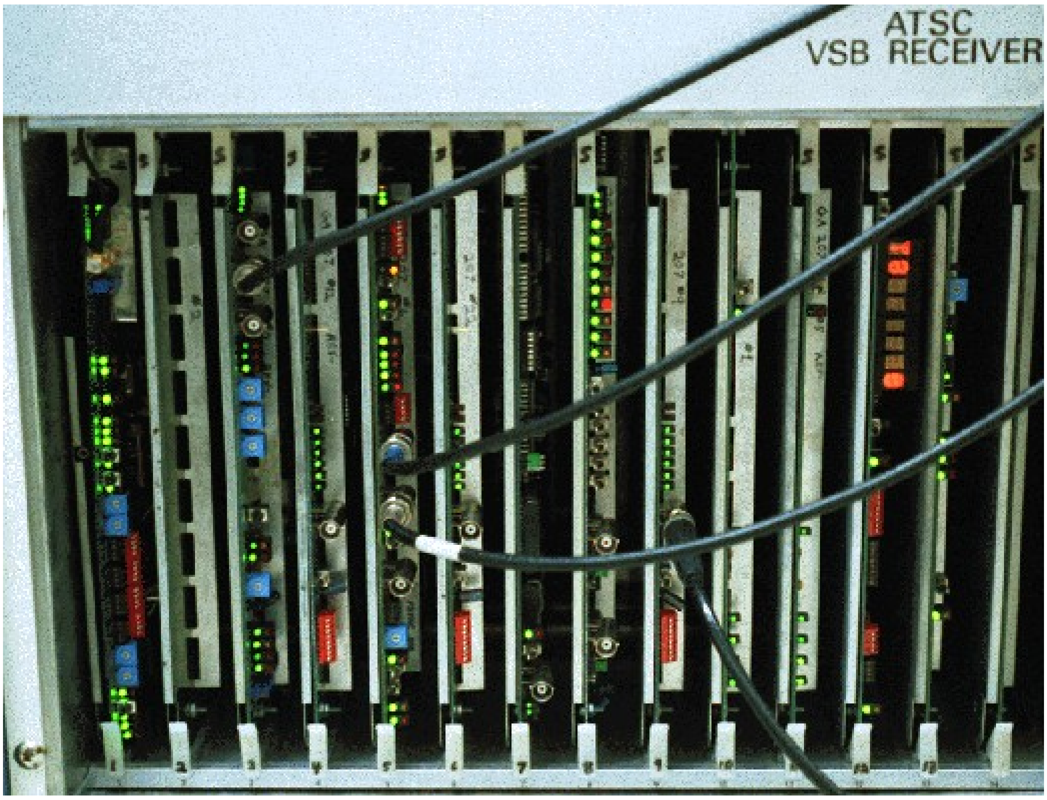
Picture 6 - Harris CD-1 8-VSB Modulator

The CD-1 modulator incorporates Linear and non-linear correctors into the up-converter to pre-correct for downstream transmission system impairments. The transmitters also incorporate these correctors. As these correctors pre-distort the spectrum to make up for exciter, PA and antenna system problems it was decided they were not necessary for the laboratory testing. During the testing the 8-VSB signal was switched between various transmitter and rig signal routing configurations. Online readjustment of these corrector settings was not allowed during the measurements as this could skew the results. These correctors were switched out during the 8-VSB laboratory testing leaving the 8-VSB modulator making a flat 44 MHz IF spectrum..

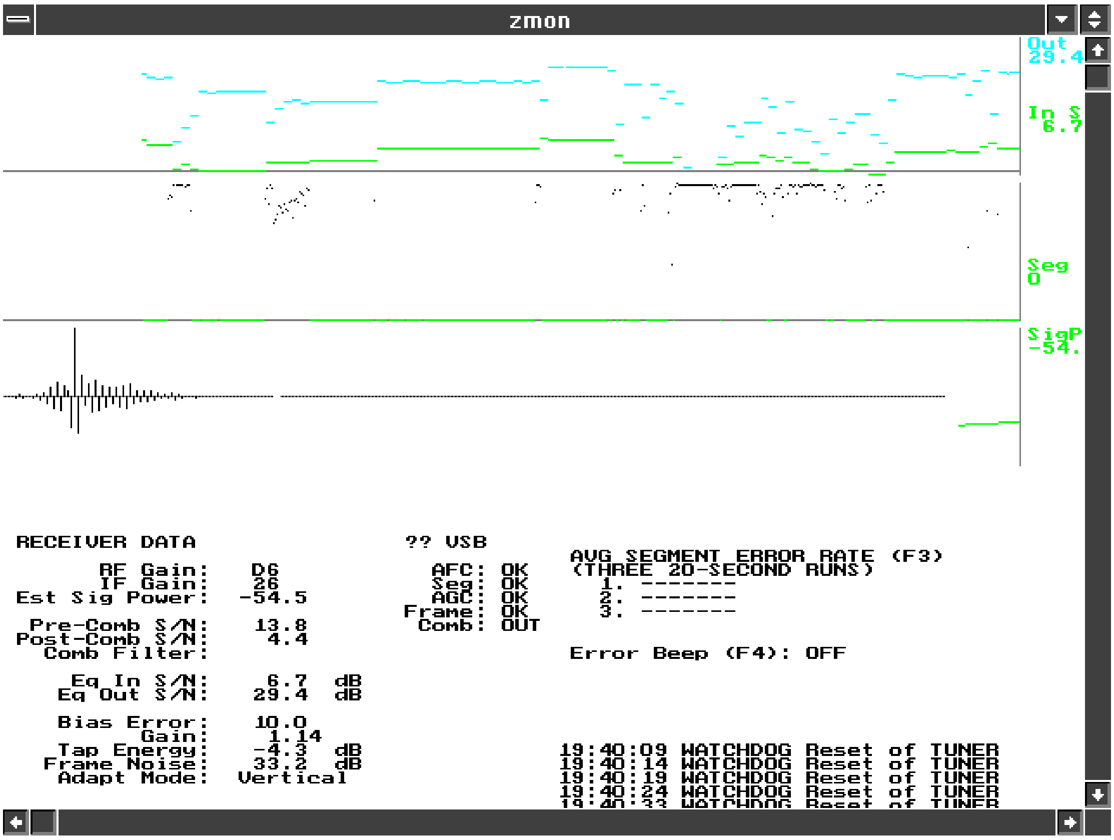
The Zenith ATSC receiver consisted of a blue card rack with 14 cards installed (Picture 7 and Picture 8). A single N-Type 50Ω unearthed RF input was provided with switching for channel number and frequency offset on the front panel. The rear panel provided a serial interface for communication with the system cards via a laptop computer, a 37 pin D-Type female connector for Grand Alliance data output and BNC connectors for TTL BER clock & data. The front of the rack was open revealing many led indicators showing the status of the various parts of the system. When the system has locked on to a signal and working correctly the majority of the LEDs are green. On the right side of the card rack a LED display reads out the Segment error rate.



Picture 7 - ATSC 8-VSB Receiver Rack



Picture 8 - ATSC 8-VSB Card Rack



```
RECEIVER DATA                      ?? VSB
                                                AVG SEGMENT ERROR RATE (F3)
       RF Gain:    D6               AFC: OK     (THREE 20-SECOND RUNS)
       IF Gain:    26               Seg: OK        1. --------
Est Sig Power:   -54.5              AGC: OK        2. --------
                                  Frame: OK        3. --------
  Pre-Comb S/N:    13.8              Comb: OUT
Post-Comb S/N:     4.4
  Comb Filter:                                  Error Beep (F4): OFF

    Eq In S/N:     6.7   dB
   Eq Out S/N:    29.4   dB

   Bias Error:    10.0
         Gain:     1.14
   Tap Energy:    -4.3   dB                    19:40:09 WATCHDOG Reset of TUNER
  Frame Noise:    33.2   dB                    19:40:14 WATCHDOG Reset of TUNER
   Adapt Mode:   Vertical                      19:40:19 WATCHDOG Reset of TUNER
                                               19:40:24 WATCHDOG Reset of TUNER
                                               19:40:33 WATCHDOG Reset of TUNER
```

Picture 9 - ZMON 8-VSB Demodulation Monitor Program

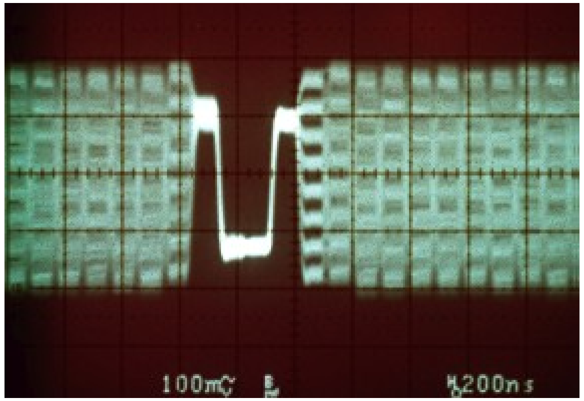
The serial interface on the back of the receiver was used to interface a laptop PC for monitoring the state of the demodulator and equaliser. Picture 9 is a screen capture of the ZMON program that reads out the real time system performance parameters. The key parameter was the S/N out of the equaliser. If this number was less than 20 dB then the system was finding the signal difficult to demodulate. Facilities are provided to measure three 20 second periods for segment errors, and a graphical display of the equaliser taps is presented. Picture 9 shows a real on air echoed environment.

The cables that can be seen connected to the front of the card frame in Picture 8 are used to provide a data constellation type display on an analog CRO. This CRO is triggered at segment rate (equivalent to PAL line rate) to display the segment sync and 188 byte data segments, or at Frame sync rate (equivalent to PAL Field Rate) to display the Frame Sync every 24.5 ms.

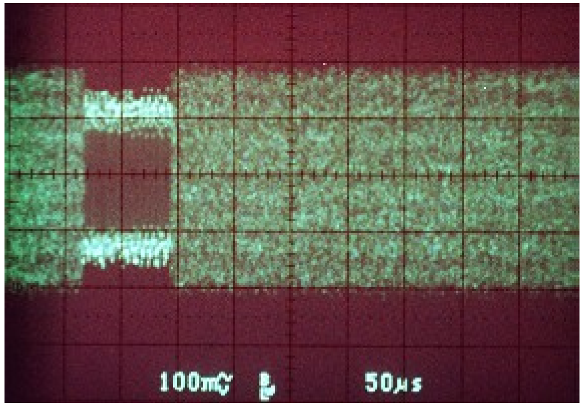
Picture 10 and Picture 11 show the segment sync before and after the receive equaliser with an unimpaired 11 mV input signal. Similarly Picture 12 and Picture 13 show the data at Frame rate with no impairment. The two level pseudo random data contained within the frame sync is used as a training sequence by the receiver equaliser to compensate for channel signal impairments.

Picture 14 and Picture 15 show the Frame sync with the system operating at a C/N threshold of 14.3 dB. The equaliser is unable to restore the data eye sufficiently and so the system produces errors in the data due to no data eye.

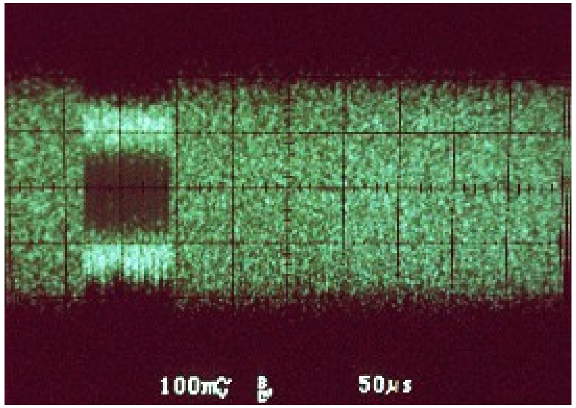
Note: Segment syncs occur in the place of the first byte of the 188 byte MPEG packet and are the digital equivalent of line syncs in PAL television. Similarly digital Frame syncs occur at a 24.5 ms rate and are analogous to the PAL vertical blanking interval



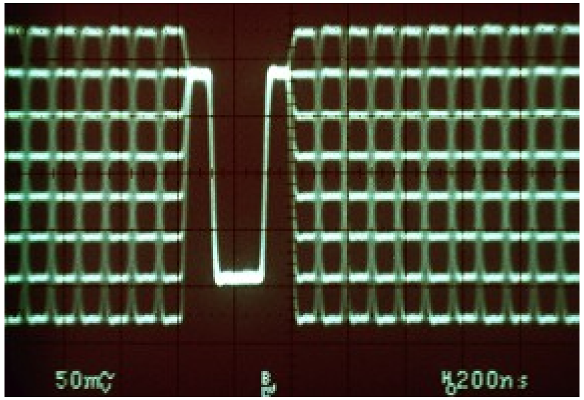
Picture 10 - 8-VSB Segment Sync Before Equaliser - No Impairment



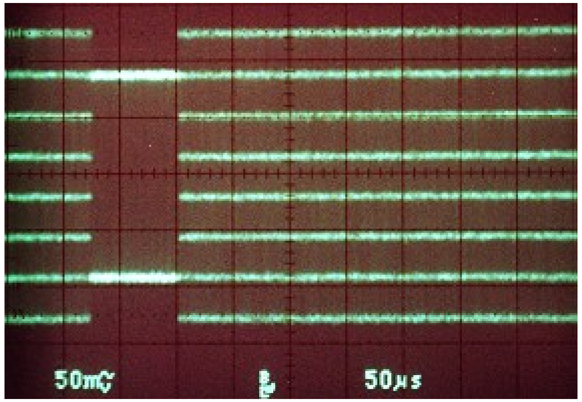
Picture 12 - 8-VSB Frame Sync Before Equaliser - No Impairment



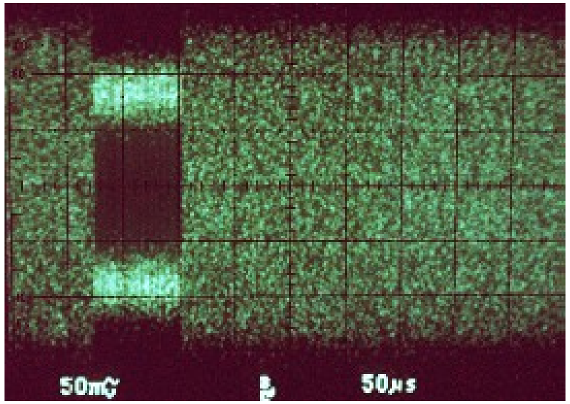
Picture 14 - 8-VSB Frame Sync Before Equaliser - At C/N Threshold



Picture 11 - 8-VSB Segment Sync After Equaliser - No Impairment



Picture 13 - 8-VSB Frame Sync After Equaliser - No Impairment



Picture 15 - 8-VSB Frame Sync After Equaliser - At C/N Threshold

2.3Transmission Equipment

Two transmitters were loaned to the specialists' group for generating real transmissions of digital television. These transmitters were supplied by NEC Australia and Comsys. They were used during the laboratory testing to provide a real indication of the digital system typical real transmission performance and to transmit high level signals into the echo delay systems. The laboratory testing of these transmitters was not intended as a comparison of the transmitter manufacturers' performance as the tests sought to define typical equipment operation and not an ultimate one off performance. Picture 18 shows the two transmitters set up in the main laboratory shielded area net to the echo combination attenuators.

NEC Australia supplied a NEC PCN-16R2D 200 Watt DTTB transmitter. This transmitter had originally been designed as a 1.25 kW analog PAL vision transmitter that was then modified for COFDM service as a VHF Digital Radio Broadcasting transmitter. The DTTB model is a further evolution and re-marking of the equipment for Digital Television at the 200 Watt level. The transmitter was configured for 3 phase 415 volt operation drawing under 2A per phase. The PA is a single broad band amplifier module fed from an exciter containing a LO module (not used), IF up converter and pre-corrector. During the first COFDM demonstration in November 1996 the exciter was aligned for VHF channel 8 operation. These adjustments were not changed during the laboratory testing. To change the frequency of operation this transmitter required the retuning of filters on the upconverter module only. A second pre-tuned upconverter board was supplied by NEC allowed the transmitter to be moved to channel 6 VHF for the field test program.

Comsys supplied a Harris EL-2000 1 kW digital transmitter. This transmitter was a 4 kW analog television transmitter that had been modified for digital operation. The transmitter was configured for single phase operation on 240 Volts @ 50 Hz and drew around 20A from the supply. A total of five 1 kW PA modules are utilised in this device with one acting as a driver for the other four. A coaxial hybrid ring combiner is used to combine the output of the four PAs using tuned length sections for VHF channel 8. The exciter contained an up converter, linear and non linear IF correctors, fixed bandpass filtering and digital power control. The high number of frequency sensitive components in this transmitter caused it to only be used on channel 8 VHF during the Laboratory and Field test programs. During the 8-VSB testing Harris engineers fitted this transmitter with two sets of IF correctors switched by relays. This allowed separate IF pre-correction of the 44 MHz 8-VSB and 35.3 MHz COFDM signals.

3 Tests and Measurements

3.1Test Rig

A large static test rig was developed for the laboratory tests of the two modulation systems. Where possible all the tests have been equally applied in the same manner to both the 8-VSB and COFDM systems. Picture 16 shows a view of the main test rig assembled in the shielded room during 8-VSB testing. Picture 17 shows the two modulators side by side. Figure 3.1.1 shows the majority of the equipment and its configuration for use in the tests. Figure 3.1.2 shows the configuration of the 8-VSB modulation equipment during the 8-VSB testing. The 8-VSB equipment did not require any video source encoding equipment as it was only tested as a data modem. As the 8-VSB modulator did not have a suitable mixer a ZP-5H high level mixer was used to convert the 44 MHz IF up to 191.5 MHz. An extra ZHL-2 amplifier was also added to achieve IF and RF signals at the same power levels as those that had been produced by the previously tested COFDM equipment.

Since testing using bit error rates can be a long process a HP9836 instrument control computer was used to control all significant signal generators, attenuators, noise sources, BER meter and power meter. All items shaded yellow in Figure 3.1.1 were able to be controlled from the 9836. A record of all automatic measurements was printed on paper as well as recorded on disk for later processing into the charts that are presented later in this report.

The test rig was distributed between a number of separate locations.

- The main desired and unwanted signal paths including all modulators were located together in a large shielded room. (Picture 16 and Picture 17)
- The DTTB receiver was located in a separate smaller shielded room on the other side of the lab.
- Channel 8 transmission equipment was located in the more open environment of the main laboratory (Picture 18) with link equipment and the 1500 metre coaxial delay located near the roof of the laboratory.
- A translator site was established at the University of Canberra (2.5 km Distant) which translated the radiated channel 8 VHF signal from the lab up to channel 44 UHF for return back to the lab. This link allowed the generation of a long echo and gave insight into the ability of the modulation schemes to handle a translation. (Picture 19 and Picture 20)

The signal on test was split two ways for all measurements at the test splitter, allowing simultaneous measurement of the DTTB signal parameters while the receiver was under test. A single common N-Type cable was used on the measurement port and moved when necessary between the spectrum analyser and the power meter. During all tests this measurement port was terminated by a device with a 50 ohm load impedance.

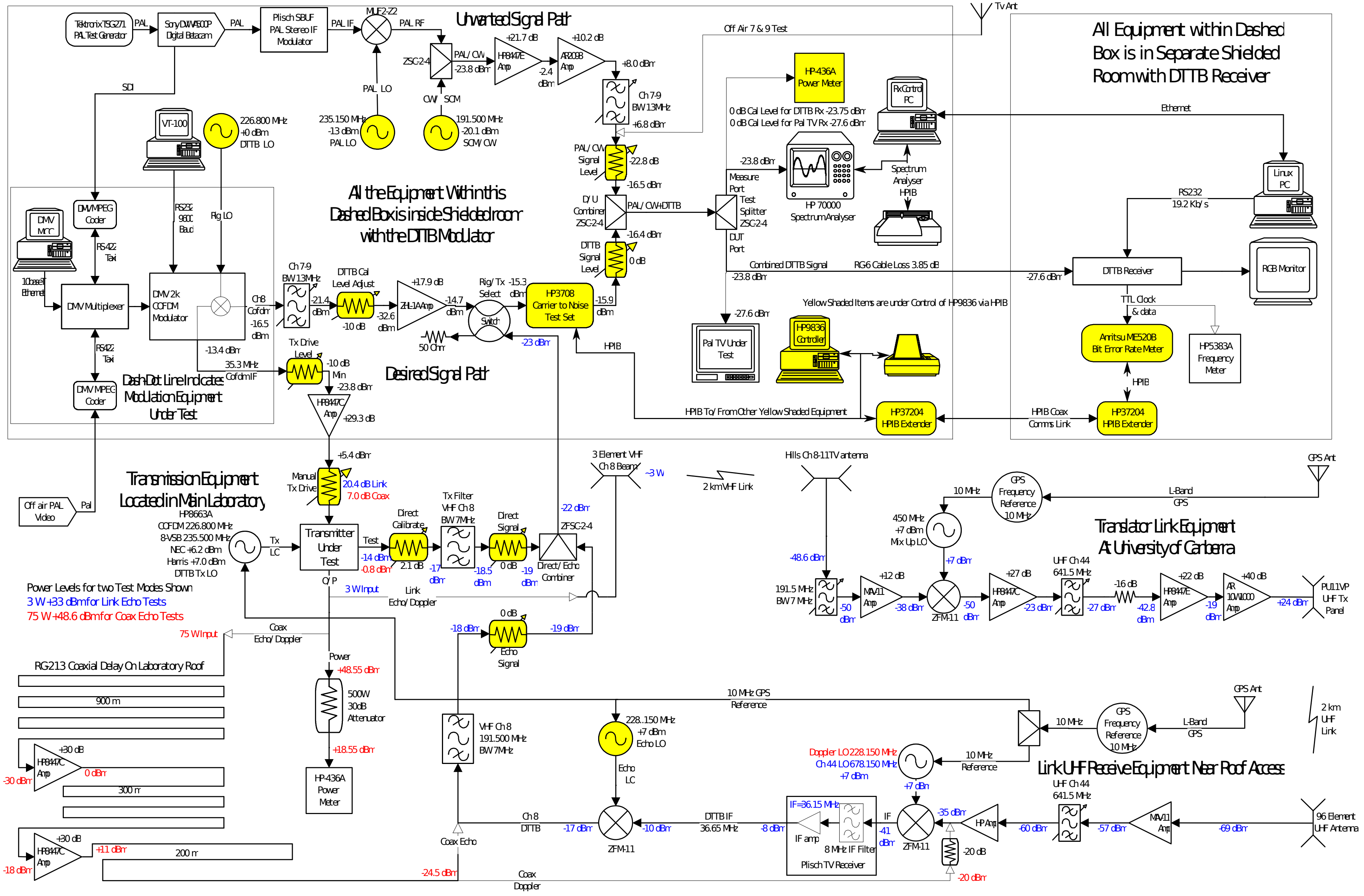


Figure 3.1.1 - DTTB Laboratory Test Rig

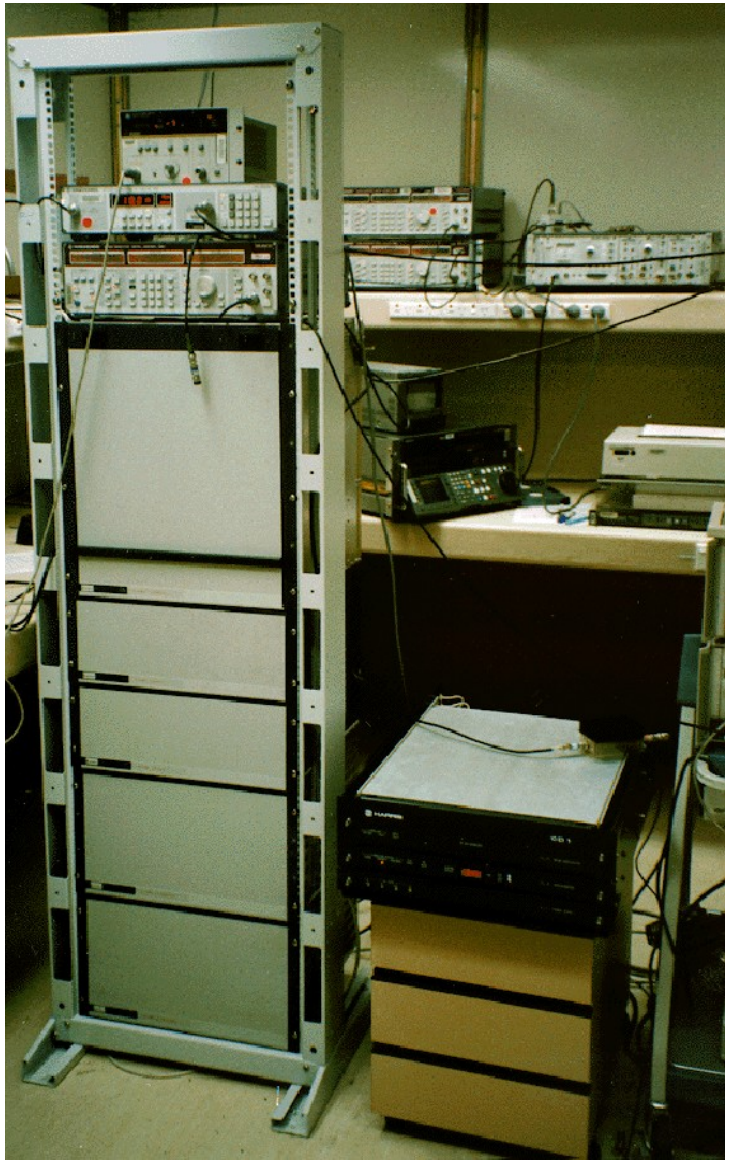
Picture 16 - Main DTTB Test Rig in Shielded Room

Equipment Upper Level Left to Right

C/I Test Set with TV Colour Analyser on top, Desired and Undesired Attenuator stack and combiners, ZHL-1 DTTB signal Amp, Tunable telonic filters with Rig/TX switch on top, DMV Modulator with DTTB LO, Tx Drive Attenuator and Power meter on top, PAL & SCM signal generators, and PAL Modulator.

Equipment Lower Level Left to Right

HP9836 Instrument controller, NEC TV, laptop for COFDM modulator Control, Multiplex Control Computer, DMV Encoders and Modulator, Harris CD1 Modulator, HP70000 Spectrum Analyser & Power meter with Remote Receiver Control PC on Top, Tektronix real time Spectrum analyser, Colour Printer and HP Plotter.



Picture 17 - The Two DTTB Modulators Tested

DMV System 3000 Left and Harris CD-1 Right
On Shelf behind Digital Betacam, TSG & Printer

Picture 18 - The Transmitters and Echo Path Equipment

Echo Attenuator Stack on Left Shelf,
NEC PCN-16R2D Tx and Harris EL-2000 Tx both with Loads on Top.

Picture 19 - Channel 8-44 Translator Equipment
in Final Configuration

Picture 20 - Translator Site with antennas
(L-R VHF Ch 8-H, GPS, UHF Ch 44-V)

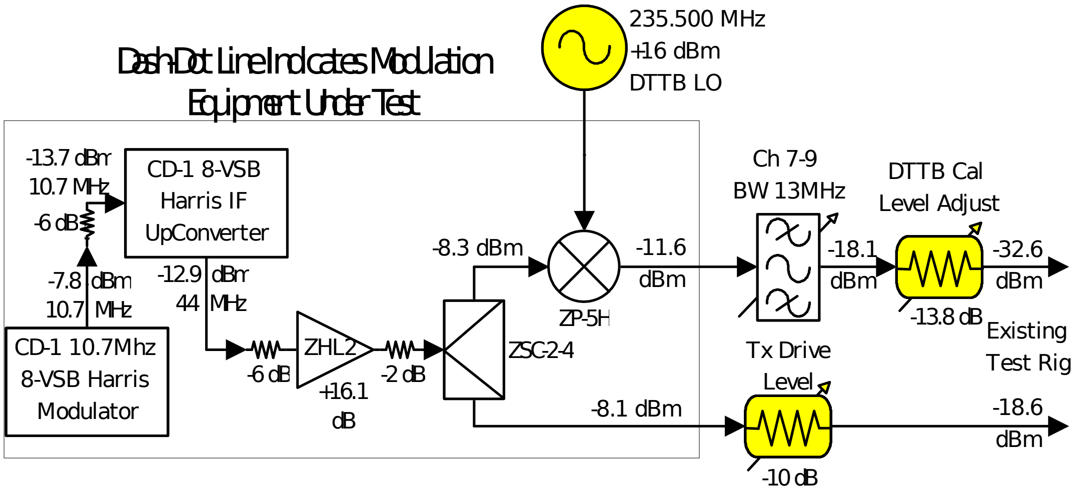


Figure 3.1.2 - 8-VSB Modulation Equipment Interface to Test Rig

The standard calibration signal level of 11.2 mV in 75 ohms was established after determining that the maximum linear noise performance of the wanted signal path in the test rig was around 10 dB higher. A standard test rig signal level of -27.6 dBm measured in 50 Ω at the receiver was used. This level represented the maximum wanted signal level that was applied during any measurement. All signal sources were calibrated to this level and then attenuation added to achieve other relative signal levels.

All DTTB, noise and CW signal power levels were calibrated and measured using a single 50 Ohm HP436A thermal power meter connected to the HP70100A spectrum analyser power measurement plug-in.

All PAL signal levels were measured as peak vision sync power using the 50 Ohm HP70000 spectrum analyser with a 3 MHz resolution bandwidth using the max hold function at the measurement port.

The two DTTB systems tested have differing ways of defining their failure point. During the tests the following values were used:

COFDM - $2.1\text{x}10^{-4}$ errors after viterbi decoding but before Reed Solomon error correction was applied.

8-VSB - $3.0\text{x}10^{-6}$ errors after Reed Solomon error correction at the final system data output.

Additionally measurements of the COFDM picture failure points were recorded for a range of measurements to give a comparison with the output error point of 8-VSB which is defined as the Threshold Of Visibility (TOV).

As the DTTB receiver and BER meter were located in a separate shielded room from where most of the system adjustments were taking place the HP9836 computer was used to audibly report the measured error rate after every BER measurement. This was done using a series of 2 or 3 short tones. The first tone, representing the threshold error rate, and the second tone, the measured error rate. Using this method manual adjustment of system parameters was able to be done without having to look at the computer. If the BER measured within a small tolerance of the threshold error rate then a third pip was sounded.

3.2DTTB into PAL Interference

The PAL into DTTB interference was measured using subjective ITU Rec 500 Conditions (5H viewing distance & 70 cd/m² peak luminance adjusted using Pluge) and computer control of the protection ratio adjustment.

Measurements were initially conducted at 11 mV and 1 mV PAL input levels however as the results were very similar only 1 mV levels were recorded when the results were repeated due to an initially incorrect COFDM signal. Three subjective results were recorded for each frequency offset between the PAL & COFDM signals. These were:

1. Subjective Comparison Method level 30 (SCM30)
2. Subjective Comparison Method level 40 (SCM40)
3. Limit of Perceptibility (LOP).

The SCM signal is a CW carrier added to the PAL signal with a non precision offset of +10.416 kHz. The RF level of the SCM interference carrier was adjusted to be the same as the PAL Vision carrier then reduced by 30 or 40 dB for the SCM30 and SCM40 levels respectively. The SCM30 and SCM40 values roughly equate to Grade 3 and Grade 4 picture impairments.

When evaluating the interference impairment, the stereo sound carriers were only taken into account for the LOP evaluation. SCM measurements disregarded any audio system impairments.

During evaluation the observer controlled via the computer the switching of the SCM carrier on or off and a momentary 10 dB block increase or decrease in the DTTB protection ratio being applied.

The protection ratio was adjusted by means of the keyboard knob on the HP9836 computer that controlled the COFDM signal level attenuator in 0.5 dB steps. The protection ratio was adjusted by the observer until an acceptable match with the SCM interference was obtained or the LOP was reached. When the observer determined that the interference was at the correct level the value was logged by the computer and the next test or frequency offset selected.

All three measurement types were evaluated at each frequency offset sequentially, forcing the observer to approach each measurement from the previous measurement value which was usually significantly different. This method caused the observer to make independent evaluations for each measurement type. Values were plotted for a DTTB centre frequency offset of -8 to +8 MHz in various steps shown in the results thus developing a full adjacent channel protection curve. A total of 6 late model television receivers were tested. All the receivers had electronic varactor based tuners and were less than 5 years old. One television receiver was of the widescreen 16:9 type with a 100 Hz scan. Two expert observers assessed each of the receivers performance and their results have been averaged.

Due to time constraints the 8-VSB system was only measured at co channel and three values about the adjacent channel. Accordingly a plot of the 8-VSB results is not provided as there are too few points to construct a reasonable plot.

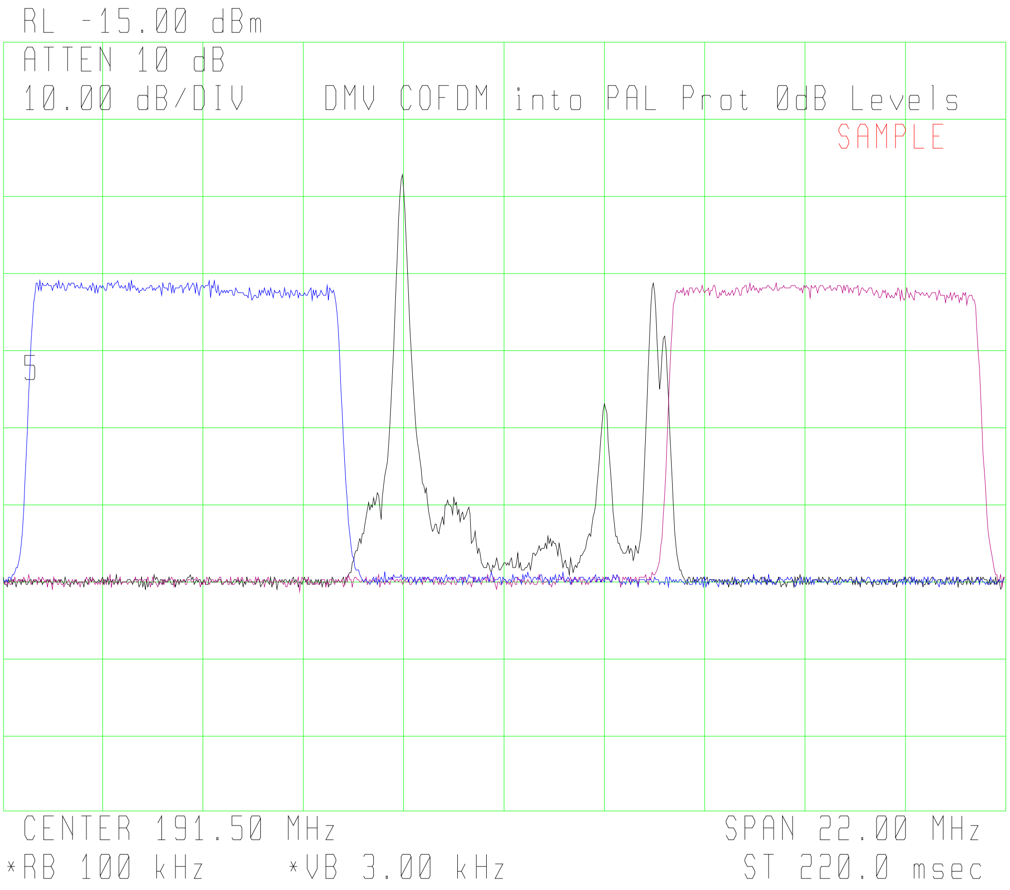


Figure 3.2.1 - 7 MHz DTTB (COFDM) adjacent to PAL at equal power levels

Figure 3.2.1 shows the 7 MHz spectrum occupancy with a PAL wanted channel flanked by two COFDM digital signals at equal[1] power levels. Generally the results show that this situation would produce interference at around the limit of perceptibility for the 6 television receivers tested. Note that the second stereo sound carrier is very close to the lower edge of the COFDM signal for the upper adjacent channel interference case. This appears to be the most sensitive phenomenon for the two stereo receivers that were tested. The stereo TV receivers were measured in stereo for the main measurement and then later re-measured while locked in mono mode. All the television receivers tested were less than 5 years old and had 38.9 MHz European IFs. As there were only two observers for each of the 6 receivers some variability in the results is expected from the small sample.

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[1] PAL power measured at peak sync and Digital measured as average power.

Compilation of 7 MHz COFDM into PAL Average Protection Ratio Data for Limit of Perceptibility								Report 94/28 7 MHz Noise Avg	Report 96/22 HD-Divine COFDM
LOP	Television Receiver Tested								
Frequency	A	B	C	D	E	F	Average		
-7.5	3.8	-0.8	0.5	7.5	3.3	1.5	2.6	-1.9	
-7.0	4.5	-1.0	2.0	10.0	3.3	2.3	3.5	4.4	-0.2
-6.5	17.8	2.5	16.0	13.0	18.0	18.3	14.3	18.4	13.5
0.0	50.8	50.0	50.0	50.5	51.0	50.5	50.5	53.6	53.7
6.5	23.8	31.8	18.0	31.0	23.5	19.3	24.5	16.3	15.0
7.0	0.8	6.3	0.3	7.8	0.3	18.0	5.5	5.3	0.3
7.5	1.0	-1.5	0.0	1.5	1.0	15.0	2.8	1.4	
MHz	dB	dB	dB	dB	dB	dB	dB	dB	dB

[2] [ii] [iii]

Table 3.2.1 - COFDM into PAL Protection for LOP

Compilation of 6 MHz 8-VSB into PAL Average Protection Ratio Data for Limit of Perceptibility								Report 94/28 7 MHz Noise Avg
LOP	Television Receiver Tested							
Frequency	A	B	C	D	E	F	Average	
-7.5	4.4	1.3	5.8	12.2	5.5	3.3	5.4	-1.9
-7.0	4.3	0.3	4.3	12.3	6.0	0.3	4.6	4.4
-6.5	4.7	0.8	7.8	13.7	7.0	1.8	5.9	18.4
0.0	49.9	50.7	51.3	54.6	51.3	49.8	51.2	53.6
6.5	5.1	14.3	6.8	12.2	5.3	10.5	9.0	16.3
7.0	3.1	1.0	5.8	8.3	3.0	8.8	5.0	5.3
7.5	1.6	-1.3	2.3	3.9	1.0	5.3	2.1	1.4
MHz	dB	dB	dB	dB	dB	dB	dB	dB

Error: Reference source not found

Table 3.2.2 - 8-VSB into PAL Protection for LOP

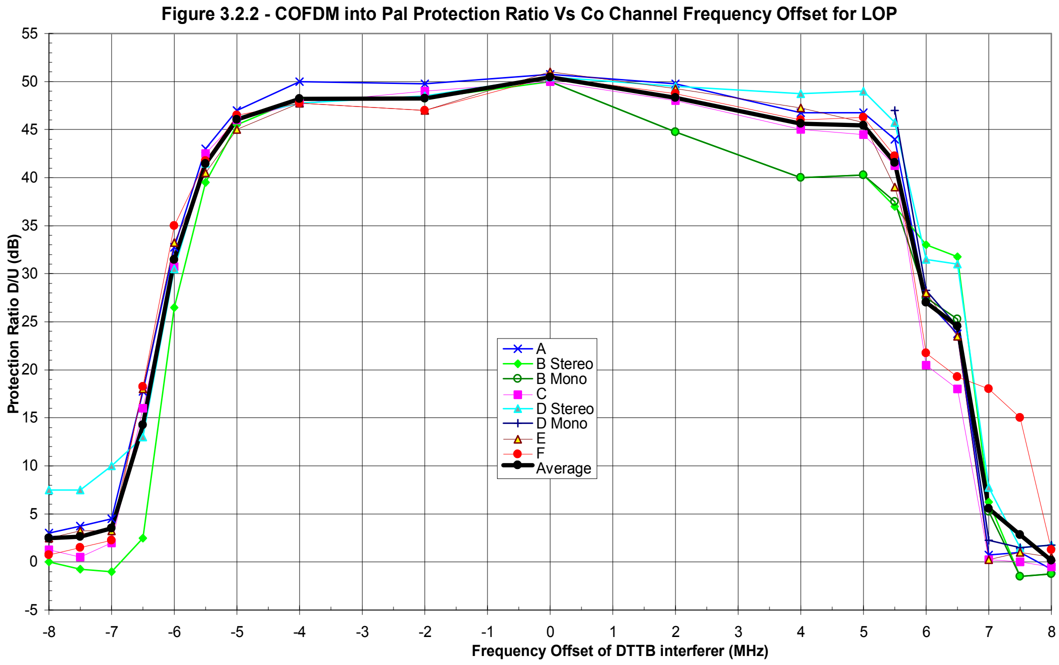

Figure 3.2.2 - COFDM into PAL protection for 6 TV receivers at LOP

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[2] Communications Laboratory Reports 94/28Error: Reference source not found and 96/22Error: Reference source not found are detailed in the Bibliography

Table 3.2.1 and Table 3.2.2 detail the average results for the Limit of Perceptibility (LOP) subjective assessment. Figure 3.2.2 plots the curve for the COFDM measurement. The LOP measurement included both sound and vision effects. The impairments noticed around the LOP level were very subtle and only discernible by switching the interferer in 10 dB steps. In many cases mid channel the LOP interference manifested itself as luma or colour noise in the darker saturated colours such as violet and blue. In the area of 5 to 6.5 MHz on the upper adjacent channel side, loss of quieting in the sound channel was observed as the LOP effect. In the lower adjacent channel, vision channel phenomena were dominant with no sound related effects being noted.

From these measurements just over 50 dB of protection is required for co-channel operation of adjacent service area Digital and Analog PAL services. For Adjacent channel operation the upper adjacent channel is the most sensitive location with an average requirement for 5-5.5 dB protection. It is surprising that both DTTB systems are so close for the adjacent channel case as the 8-VSB had an additional 500 kHz of quiet spectrum on each side of the channel to separate it from the PAL signal.

Comparison of the results obtained agree well with previously measured simulated noise results and the HD-Divine tests. This shows that the DTTB signals are a reasonable approximation to white noise.

Table 3.2.3 and Table 3.2.4 detail the average results for the Subjective Comparison Method 40 dB level (SCM-40) assessment. Figure 3.2.3 plots the COFDM into PAL protection curve for SCM-40. It is important to note that the SCM technique is only a measure of picture impairment and where sound was being influenced it was muted to prevent distraction. This only affected the 5 to 6.5 MHz measurements. The SCM-40 measurement roughly equates to a grade 4 picture, however in practice during this measurement the 40 dB SCM interferer was only just visible on the television receivers being assessed. This meant that the interference from the DTTB system was also adjusted to the just visible level. Unlike the LOP measurement an observer was able to look away from the picture and still just see the interference when he again looked at the screen.

The data from this measurement shows about a 4 dB difference between the systems with the 8-VSB signal requiring the higher degree of protection.

Compilation of 7 MHz COFDM into PAL Average
Protection Ratio Data for Subjective Comparison Method 40 dB

SCM40	Television Receiver Tested						
Frequency	A	B	C	D	E	F	Average
-7.5	-5.5	-8.3	-7.3	0.5	-9.0	-6.5	-6.0
-7.0	-5.0	-7.0	-6.8	2.3	-8.3	-7.0	-5.3
-6.5	4.8	-6.0	6.8	5.0	8.0	8.3	4.5
0.0	39.8	44.3	39.8	42.3	40.3	40.5	41.1
6.5	-5.0	-6.3	-4.8	-6.3	-10.8	2.0	-5.2
7.0	-6.3	-7.8	-6.0	-6.8	-12.8	1.0	-6.4
7.5	-7.8	-7.5	-7.5	-7.5	-11.5	-2.0	-7.3
MHz	dB	dB	dB	dB	dB	dB	dB

Table 3.2.3 - COFDM into PAL Protection for SCM-40

Compilation of 6 MHz 8-VSB into PAL Average
Protection Ratio Data for Subjective Comparison Method 40 dB

SCM40	Television Receiver Tested						
Frequency	A	B	C	D	E	F	Average
-7.5	-2.3	-4.0	-0.8	5.0	-3.0	-3.8	-1.5
-7.0	-0.9	-4.8	-2.0	6.5	-2.8	-5.3	-1.5
-6.5	-0.7	-4.3	0.8	6.5	-1.8	-2.3	-0.3
0.0	44.4	46.6	45.0	48.2	43.9	44.0	45.4
6.5	0.1	4.5	0.3	4.2	-4.0	3.3	1.4
7.0	-1.8	-3.8	0.3	2.8	-4.3	1.5	-0.9
7.5	-3.8	-6.3	-3.8	0.3	-7.0	2.0	-3.1
MHz	dB	dB	dB	dB	dB	dB	dB

Table 3.2.4 - 8-VSB into PAL Protection for SCM-40

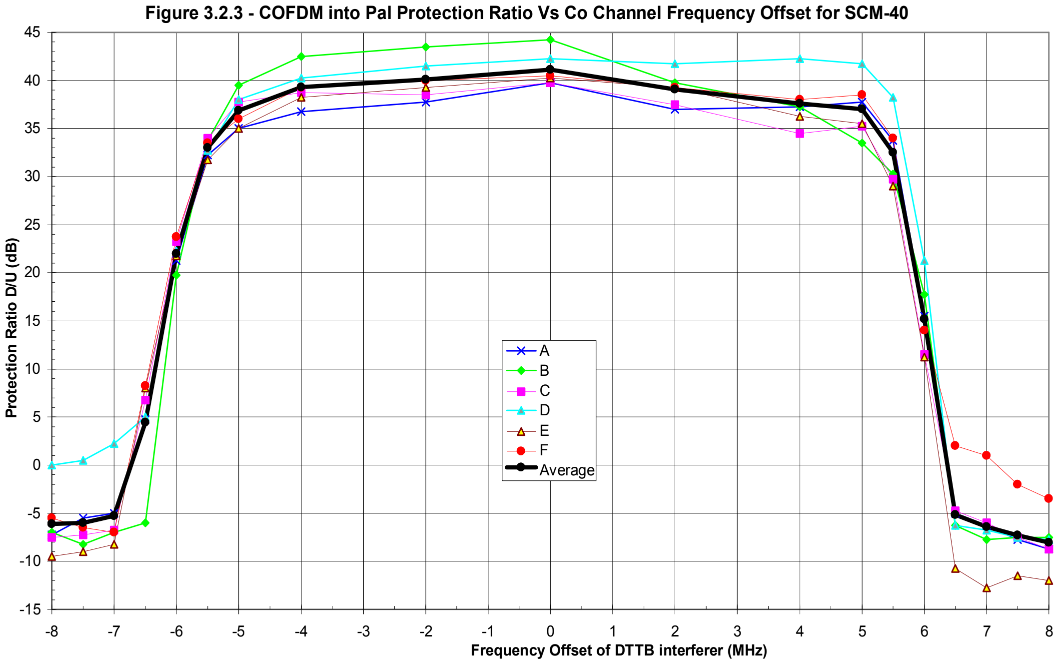

Figure 3.2.3 - COFDM into PAL protection for 6 TV receivers at SCM-40

Compilation of 7 MHz COFDM into PAL Average
Protection Ratio Data for Subjective Comparison Method 30 dB

SCM30	Television Receiver Tested						
Frequency	A	B	C	D	E	F	Average
-7.5	-8.5	-12.3	-11.0	-5.5	-13.5	-11.3	-10.3
-7.0	-7.0	-13.0	-10.0	-4.5	-12.0	-10.3	-9.5
-6.5	-1.5	-10.3	0.8	-1.3	2.3	1.5	-1.4
0.0	34.8	36.5	35.3	37.0	34.8	36.5	35.8
6.5	-7.3	-10.8	-7.8	-10.3	-16.3	-1.0	-8.9
7.0	-8.5	-14.0	-8.8	-11.0	-18.0	-3.5	-10.6
7.5	-9.8	-15.5	-10.3	-12.0	-17.5	-7.0	-12.0
MHz	dB	dB	dB	dB	dB	dB	dB

Table 3.2.5 - COFDM into PAL Protection for SCM-30

Compilation of 6 MHz 8-VSB into PAL Average
Protection Ratio Data for Subjective Comparison Method 30 dB

SCM30	Television Receiver Tested						
Frequency	A	B	C	D	E	F	Average
-7.5	-6.1	-9.0	-6.3	-4.0	-12.5	-9.8	-7.9
-7.0	-5.1	-10.0	-6.3	-3.0	-11.3	-10.5	-7.7
-6.5	-3.9	-10.8	-3.8	-2.3	-8.5	-7.5	-6.1
0.0	39.2	40.0	39.1	40.4	36.7	37.1	38.7
6.5	-4.1	-5.5	-4.3	-5.3	-11.0	-0.8	-5.2
7.0	-5.9	-12.0	-5.8	-5.2	-13.8	-4.0	-7.8
7.5	-6.5	-12.3	-7.0	-8.8	-14.5	-3.5	-8.8
MHz	dB	dB	dB	dB	dB	dB	dB

Table 3.2.6 - 8-VSB into PAL Protection for SCM-30

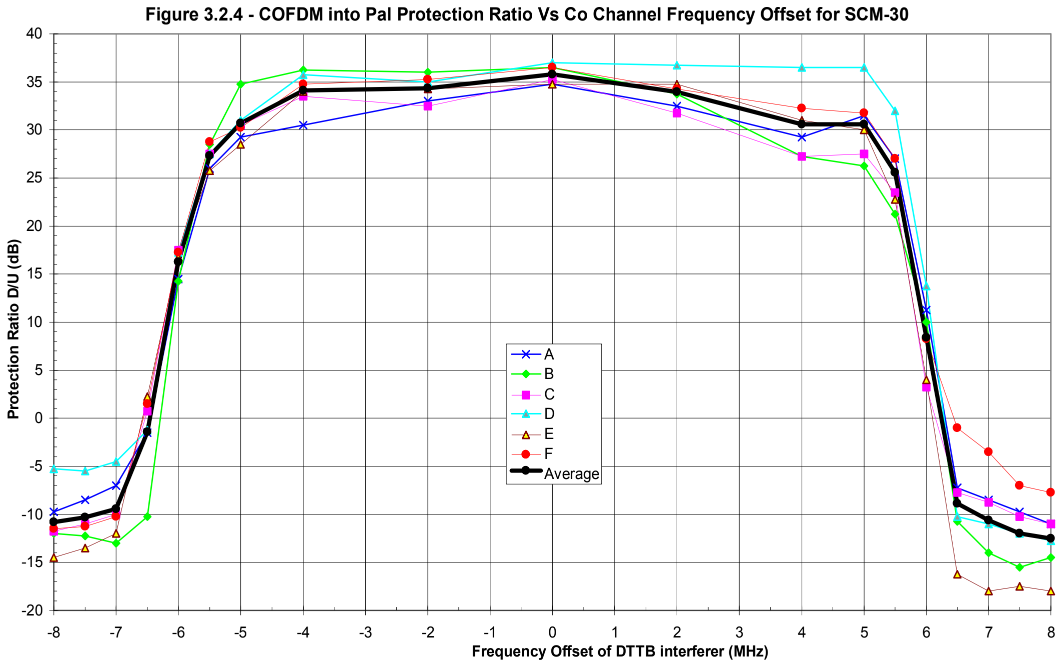

Figure 3.2.4 - COFDM into PAL protection for 6 TV receivers at SCM-30

Table 3.2.5 and Table 3.2.6 detail the average results for the Subjective Comparison Method 30 dB level (SCM-30) assessment. Figure 3.2.4 plots the COFDM into PAL protection curve for SCM-30. The SCM-30 measurement roughly equates to a grade 3 picture. During this evaluation the SCM interferer was clearly visible on the picture as line pairing. It was found easiest to adjust the DTTB interferer level with the SCM interferer still present to achieve an equivalent annoyance level. By Observing the noise vs line pairing the relative levels were adjusted until neither were felt to be dominant. It was found that these values were reasonably repeatable to within 1-2 dB

At the SCM-30 level the PAL system required a 2-3 dB higher protection from the 8-VSB system. It is felt that this level would be the maximum permissible impairment that could be imposed on PAL viewers during a PAL to DIGITAL simulcast transition.

For co-channel adjacent service area operation a protection of 39 dB is required for 8-VSB while the upper adjacent channel is again the most sensitive position requiring a protection of -5 dB from 8-VSB

The average data presented above has been obtained by averaging the results of each individual assessors assessments, then averaging across assessors and receivers to arrive at a final average. Averaging mean test data without regard to the number of samples in each test can cause incorrect comparisons where the number of samples varies. A more rigorous statistical analysis of the data has now been completed and is presented in Table 3.2.7 below. Tropospheric interference is the SCM-30 data while Continuous interference is the SCM-40 data.

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 3.2.7 - Statistical DTTB into PAL B protection ratios, VHF Band III

The Statistical analysis shows only a small error (< 1 dB) in the average results while providing a useful indication of the worst case condition (Max).

3.3PAL into DTTB Interference

The PAL into DTTB interference protection ratio was measured using the PAL/CW attenuator to adjust the level of the PAL signal that was combined with the DTTB system under test. The test was conducted at various offset frequencies between -8 and +8 MHz including the co-channel condition allowing a plot to be drawn. Additionally the test was conducted at 4 different DTTB signal levels from moderate to weak.

The PAL interferer used in the tests was generated by a Rhode & Schwarz test modulator making a standard PAL system G signal. The vision was modulated with a 100% colour-bar and each of the two stereo sound carriers had a 1 kHz tone modulation applied[3].

The PAL IF signal was upconverted to the channel 8 area using a SMH signal generator as the local oscillator under computer control. The PAL signal was turned on and off by switching the LO signal on and off when required. The resulting band III VHF signal was amplified to approximately 200 mV before being filtered by a 190 MHz adjustable Telonic filter with a bandwidth of 13 MHz. The PAL signal was then attenuated and combined with the DTTB signal before being split in the test splitter and applied to the receiver and the measurement equipment.

The filter was marked for three different positions: High, Centre and Low. The centre channel position centred the filter on 191.5 MHz while the High and Low positions were around 5 MHz away from the centre of channel 8 (191.5 MHz). This was done so that when using the PAL signal with a frequency offset as an interferer about or past the adjacent channel position no truncation or distortion of the PAL RF signal occurred.

The PAL signal level was calibrated to the 0 dB rig level by measuring the level of the vision carrier sync power using the HP spectrum analyser. These measurements were done using a 3 MHz resolution and video bandwidth with a span of 10 MHz about the vision carrier (189.25 MHz) using the max hold function. The PAL level was adjusted to -23.75 dBm at the spectrum analyser using the PAL attenuator. This level equated to -27.6 dBm at the DTTB receiver input after the 3.85 dB RG6 cable loss. The PAL attenuator level (22.9 dB) was programmed into the measurement software so that the protection ratio could be recorded by calculation from the DTTB and PAL attenuator levels.

The DTTB signal was adjusted for -23.75 dBm at the measurement point using a HP436A Thermal Power meter when the DTTB attenuator was set to 0 dB.

The test was conducted in 3 stages corresponding to the position of the PAL channel filter.:

Lower -8 to -3 MHz Centre -2.5 to +2.5 MHz Upper +3 to +8 MHz

After each stage the test program halted and waited for the operator to adjust the filter to the next stage. The results from the three stages were combined to form the plotted charts.

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[3] Note: During some of the early COFDM testing the sound carriers were un-modulated.

The test procedure was:

1. Set the PAL frequency for the measurement from a data table.
2. Set the DTTB signal level to 20,30,40 or 45 dB below the calibration level.
3. Switch on the PAL signal LO
4. Set the PAL signal attenuator to give a protection ratio of 102.4 dB.
5. Measure DTTB error rate
6. If the error rate does not exceed the failure point step the protection level down by 25.6 dB and repeat measurement (Step 5).
7. When error rate is exceeded halve the attenuation step size and change the direction of the step in a binary search pattern.
8. continue measuring the BER in this manner until the attenuator step size reduces to less than 0.1 dB (repeat 5-7)
9. Compare the final BER with the result of the previous bit error rate. The rate that is closer to the system BER failure point is reported as the result.
10. Switch to CW signal and repeat entire measurement (4-9)
11. Step to next DTTB signal level (lower) and repeat (2-10)
12. When all 4 signal levels have been measured move PAL signal to next frequency and continue measurement (1-11) until no more offset frequencies within the filter range remain to be measured.

This test was repeated using:

1. The basic test rig as the signal source
2. The NEC transmitter at around 200W (rated output power)
3. The Harris transmitter at around 200W (reduced power)
4. The Harris transmitter at 600/900W (near rated power)

In the case of COFDM different modulation types were also measured.

Figure 3.3.1 shows the PAL into DTTB protection for both modulation systems. This measurement was performed on the test rig with both PAL sound carriers modulated by a 1 kHz tone to 50 kHz deviation. The COFDM data is for the version 1.0 receiver equaliser. For adjacent channel PAL interference (ACI) the 8-VSB system performs 1-3 dB better than COFDM however at the co-channel interference (CCI) point COFDM has a margin of 7 dB over the 8-VSB system. Both DTTB signals required the CCI PAL signal to be less than the digital signal.

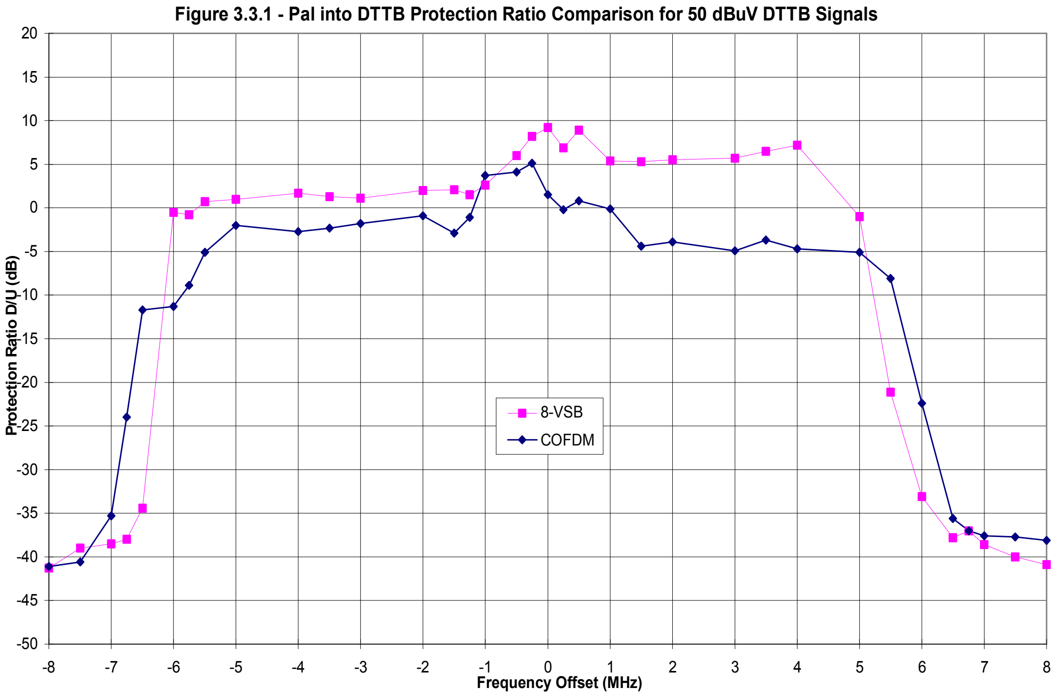


Figure 3.3.1 - PAL (sound modulated) into DTTB protection at 50 dBuV input level

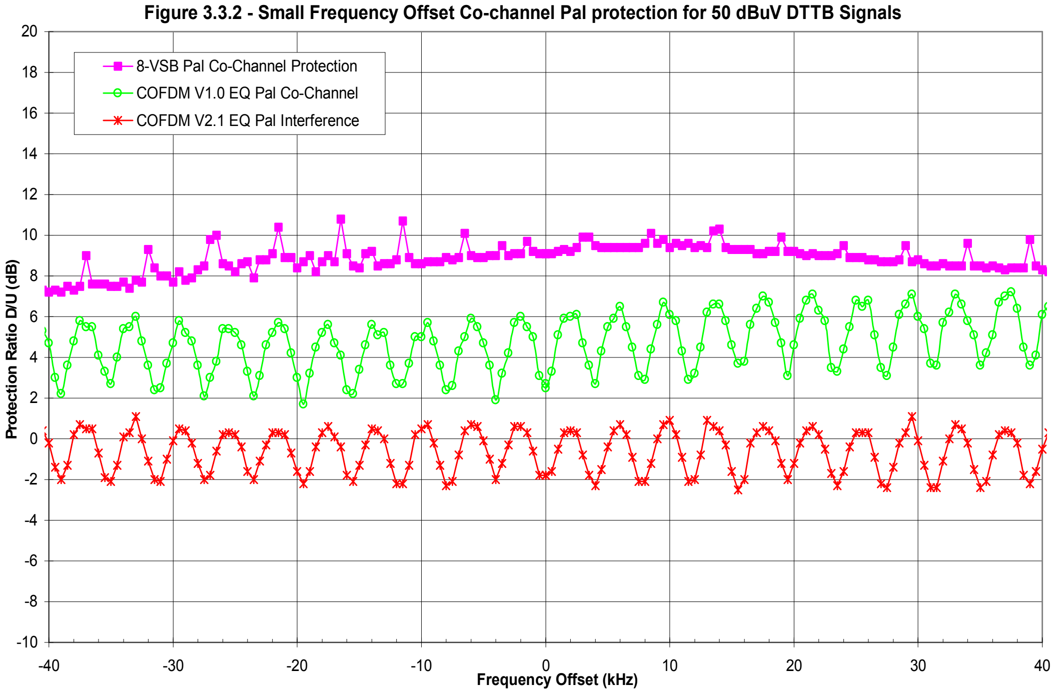


Figure 3.3.2 - Co-Channel PAL into DTTB protection for small frequency offsets

Figure 3.3.2 is a close in plot of the CCI for both modulation systems. The 8-VSB system has a fairly smooth response with the occasional peak, which are thought to be critical equaliser frequencies. The 8-VSB receiver has a CCI filter which is designed for use with the NTSC system. This was not switched on during these tests. The COFDM system displays a cyclic CCI protection variation reflecting the orthogonal carrier spacing with the exact co-channel position producing the optimum result. The version 2.1 COFDM equaliser software further reduces the CCI impact by 4.5 dB allowing the analog transmission to be around 2 dB greater than the COFDM signal. There does not appear to be any clear optimum location for a precision offset co-channel operation of PAL and DTTB services from this data.

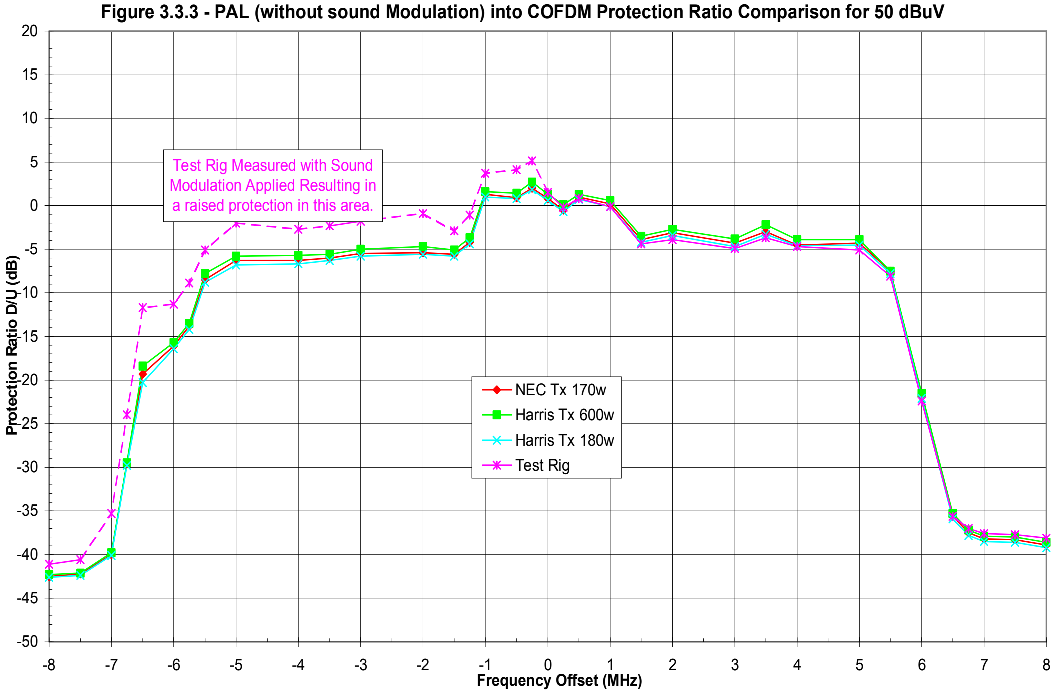


Figure 3.3.3 - PAL into COFDM protection for real transmission hardware

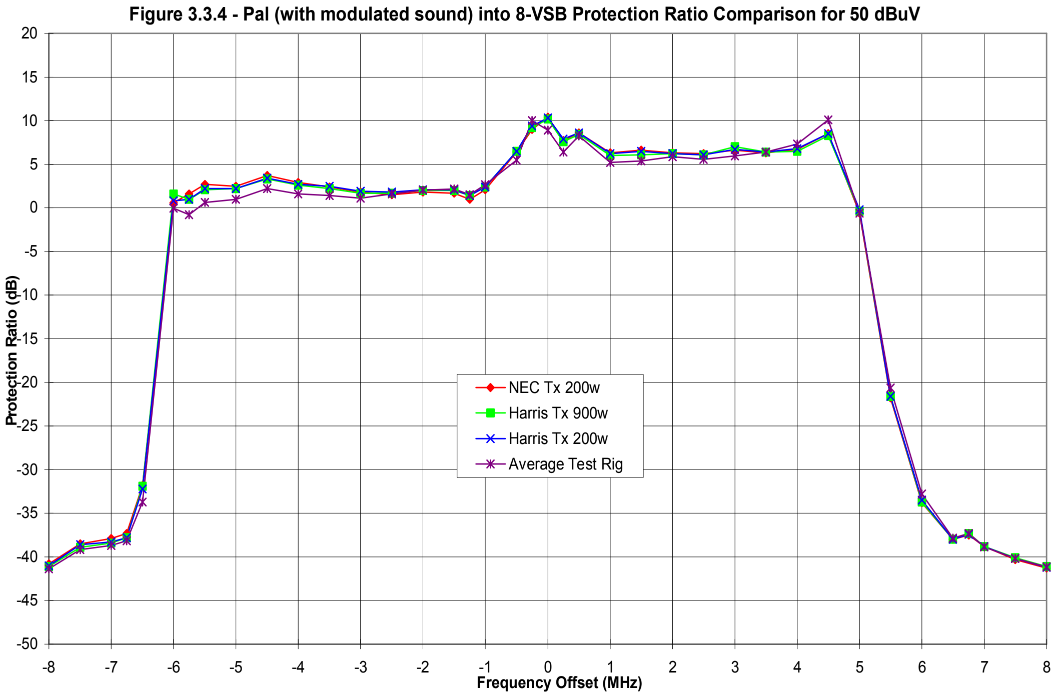


Figure 3.3.4 - PAL into 8-VSB protection for real transmission hardware

Figure 3.3.3 and Figure 3.3.4 show the impact of real transmission equipment on the CCI and ACI PAL performance. Generally a degradation in performance of around 1 dB is observed for the signals through the real transmitters over the normal rig performance.

The transmitter measurements shown in Figure 3.3.3 were performed with no audio modulation on the interfering PAL sound carriers. This affects the lower adjacent channel part of the curves where the sound carriers have a significant impact on the COFDM signal. The rig measurement which includes modulated sound carriers has been dashed in this area.

3.4CW into DTTB interference

The CW into DTTB interference test was used to determine the effect of a narrow-band interferer within or about the DTTB channel. The SCM signal generator was used to generate an unmodulated CW carrier at various offsets ranging from -8 to +8 MHz about the centre of channel 8.

As the test requirements for this measurement are very similar to the PAL into DTTB measurement the two were conducted simultaneously. The PAL signal was switched off using its LO generator and the CW was switched on by setting the output level of the SCM signal generator. The test procedure is covered in the PAL into DTTB test method in section 3.3.

An advantage of alternately measuring the CW and PAL interferers, with each DTTB system, was that the equalisers within those systems were forced to readjust to a differing signal type every alternate measurement, and so could not track the test. It is felt that this approach achieved more repeatable results in the presence of adaptive equalisation techniques.

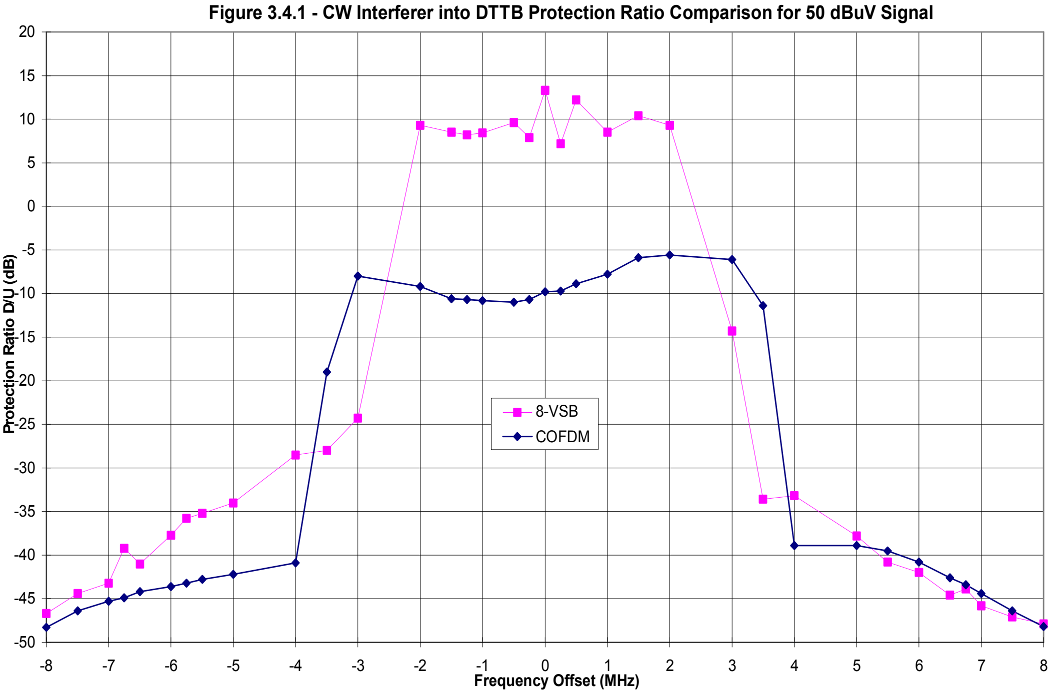


Figure 3.4.1 - CW into DTTB protection for 50 dBuV input

Figure 3.4.1 shows the CW into DTTB protection plot for both modulation systems. The narrow band CW interferer was much more destructive with the 8-VSB system than the COFDM system. A difference of 17 to 23 dB separates the systems with the 8-VSB requiring any interference of this type to be around 10 dB below the digital signal level. The COFDM system could cope with in channel interference to 6 dB over the COFDM power level.

The 8-VSB system showed increased sensitivity around the channel centre due to a beat with the “Nyquist” sampling frequency used in the receiver equaliser.

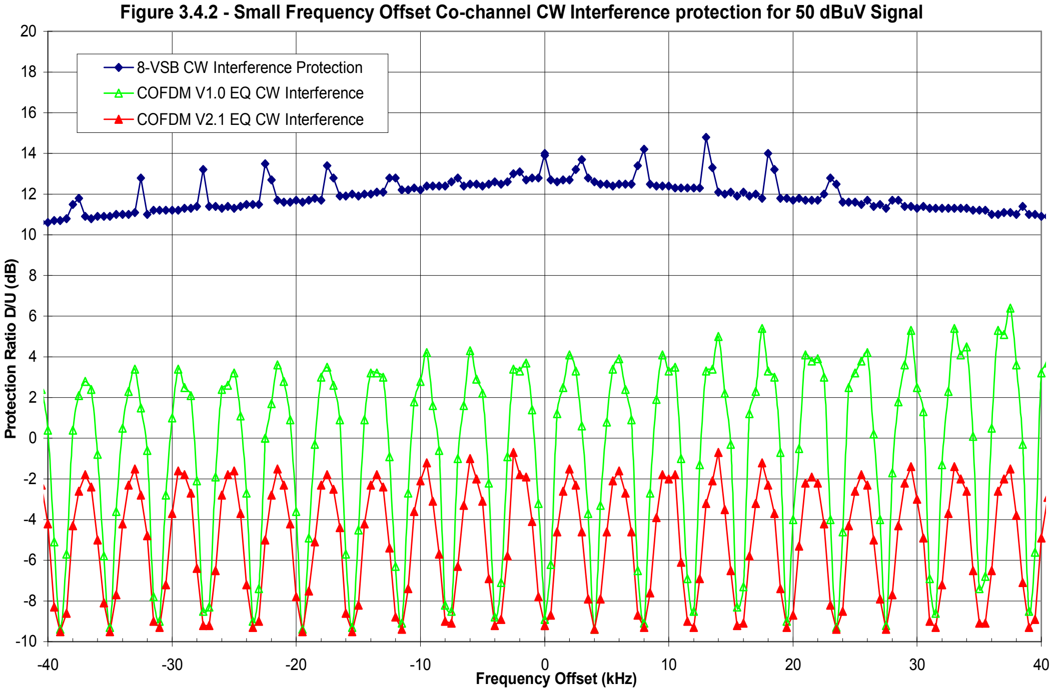


Figure 3.4.2 - Co-Channel CW into DTTB protection for small frequency offsets

Figure 3.4.2 shows the close in performance of the two DTTB technologies when exposed to a CW interferer. Again the 8-VSB critical equaliser frequencies are evident along with the cyclic COFDM performance which is a direct reflection of the COFDM systems orthogonal carrier spacing. When the CW interference falls at the worst location the CW protection is degraded by up to 15 dB with the version 1.0 equaliser. The version 2.1 equaliser was able to reduce this variation to 8 dB.

If a mean value for protection is chosen for COFDM (-2.5 dB) and 8-VSB (+13 dB) at mid channel there is a difference of 15.5 dB between the systems.

Once again the data does not reveal any optimum location for a known CW interferer within the DTTB channel.

Figure 3.4.3 and Figure 3.4.4 compare the performance of each DTTB system when passed through real transmission hardware for CW interference. No clear trend or difference was observed for the COFDM system and apart from additional sensitivity around the centre channel and pilot frequencies the 8-VSB system did not show significant performance degradation. Sensitivity in the region of the pilot increased by 5 dB and around centre channel by 3 dB.

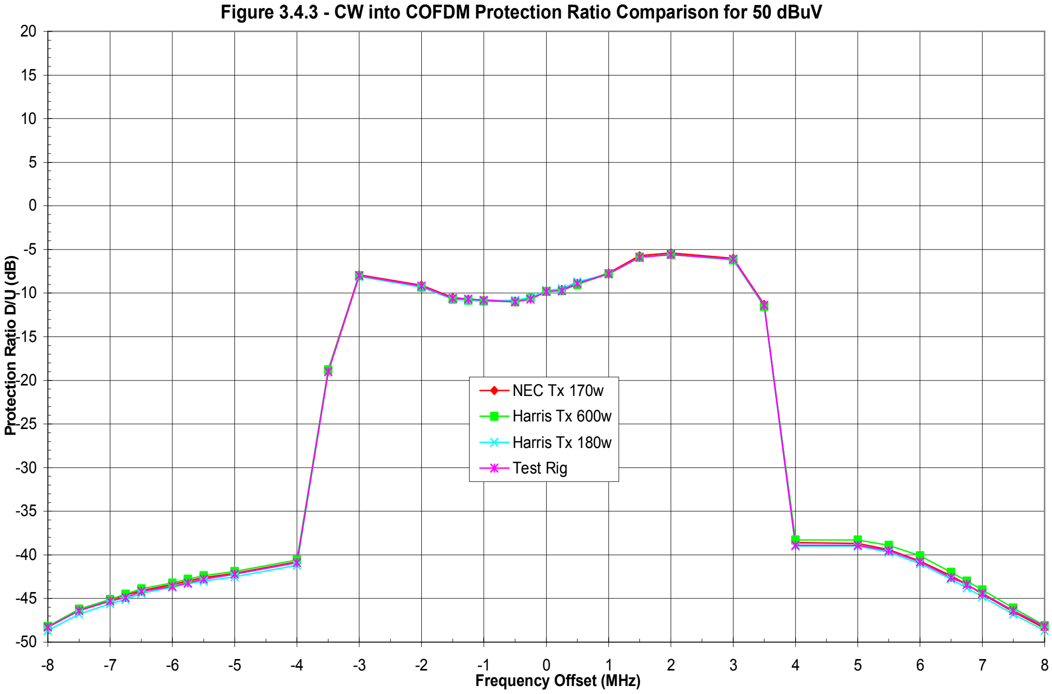


Figure 3.4.3 - CW into COFDM protection for real transmission hardware

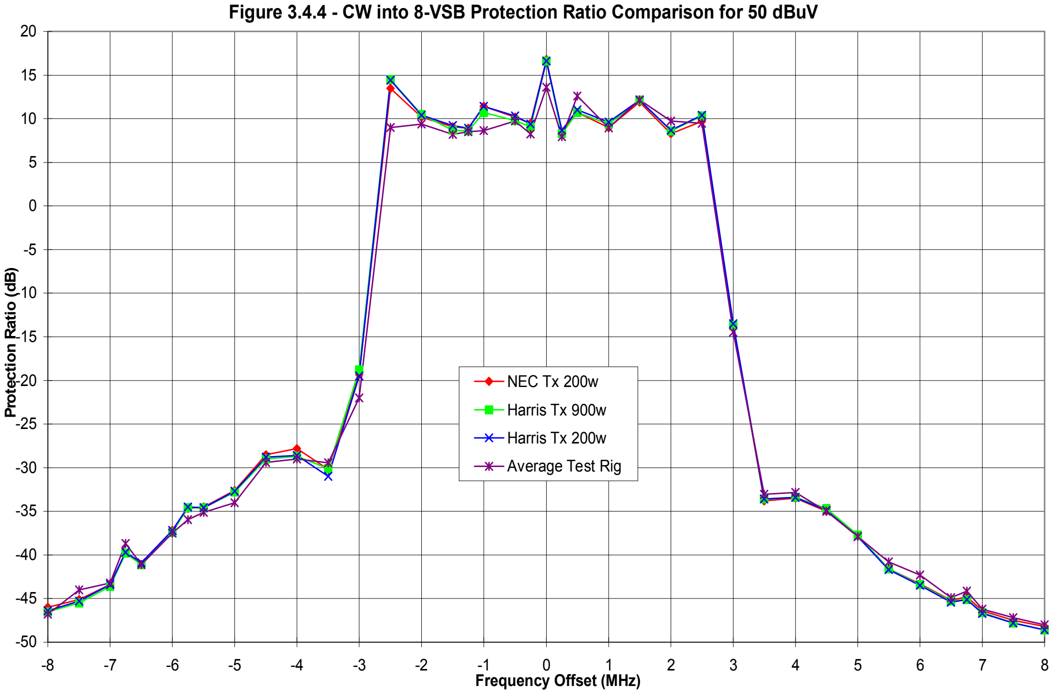


Figure 3.4.4 - CW into 8-VSB protection for real transmission hardware

3.5C/N Threshold

The carrier to noise threshold is one of the basic system measurements that is repeated during most of the test program measurements. It forms the basis of determining the margin above the error threshold that the system is operating. The carrier to noise threshold was measured using a HP3708 C/I test set that was inserted in the DTTB signal path before the D/U combiner.

The test set measures the power of the incoming DTTB signal and then mixes in broadband white noise to achieve the set carrier to noise ratio. The broadband noise source is 200 MHz wide allowing the measurements at channel 8 to fit within the baseband capabilities of this instrument. The test set determines the broadband noise level to apply by measuring the applied signal power and by being told what system bandwidth is being assumed. For the testing of both DTTB systems a system bandwidth of 7 MHz was selected. Although the 8VSB system is a 6 MHz system during the testing we regarded each system as a black box that was to be accommodated within a nominal 7 MHz band plan. To scale the C/N measurements from a nominal 7 MHz to 6 MHz bandwidth a 0.7 dB correction can be applied to the absolute C/N measurements.

Test procedure for C/N Threshold was

1. Set C/N set to a high C/N above 50 dB
2. Set wanted signal level to 27.6 dBm (0 dB)
3. Set C/N step size to 12.8 dB decreasing
4. Measure receiver error rate
5. If error rate is less than threshold then step C/N 12.8 dB
6. Measure receiver error rate
7. If error rate has not crossed threshold then step C/N repeat step 6
8. If error rate exceeds threshold then
   halve C/N step and reverse step direction
9. Repeat from step 6 until step size is less than 0.1 dB
10. Compare final and previous measurements and
    report C/N level closest to the threshold error rate.

DTTB System	COFDM	8-VSB
Test Rig Beginning (7 MHz)	19.15 dB	14.3-14.4 dB
NEC Tx 180 W	19.3 dB	14.5 dB
Harris Tx 180 W	19.2 dB	14.5 dB
Harris Tx 600/900 W	19.9 dB	14.3 dB
Test Rig End (7 MHz)	19.4-19.6 dB	14.35 dB
Test Rig (6 MHz)	NA	15.1 dB

Table 3.5.1 - Summary of DTTB C/N Thresholds

Table 3.5.1 above summarises the C/N Thresholds that were measured for each system during the majority of the measurement program.

During the main COFDM system tests the C/N threshold remained at around 19.2 dB. Sometime after the Parliament house demonstration, which occurred in May 1997, a system software upgrade and re-earthing of the tuner area to stabilise the receiver noise figure the C/N threshold increased by up to 0.4 dB. None of these events can be directly attributed to this change however it may be due to a combination of these factors.

An 0.1 to 0.2 dB increase in the C/N threshold was observed for measurements where the transmitters were operating. The Harris 600 W COFDM case was an exception to this. In this case a 0.7 dB shift was observed. The Harris 600 W COFDM measurement was done during the early COFDM testing before the Harris transmitter pre-equaliser had been optimised.

A measurement of the 8-VSB C/N threshold with the test set programmed for 6 MHz operation is included to confirm the 0.7 dB theoretical shift between the 6 MHz and 7 MHz channel cases.

3.6Minimum Signal level

The minimum receiver level was measured by attenuating the signal level being sent to the receiver from the maximum receiver level of -27.6 dBm. The attenuator value at the failure point is subtracted from this calibration level to determine the minimum received signal level.

Test procedure for Minimum Signal Level was:

1. Set C/N set to a high C/N above 50 dB
2. Set wanted signal level to 27.6 dBm (0 dB) and unwanted signals off
3. Set DTTB signal level attenuation step size to 6.4 dB
4. Measure receiver error rate
5. If error rate is less than threshold then step DTTB level 6.4 dB
6. Measure receiver error rate
7. If error rate has not crossed threshold then step DTTB level
   and repeat step 6
8. If error rate exceeds threshold then
   halve DTTB level step and reverse step direction
9. Repeat from step 6 until step size is less than 0.1 dB
10. Compare final and previous measurements and
    report DTTB signal level closest to the threshold error rate.

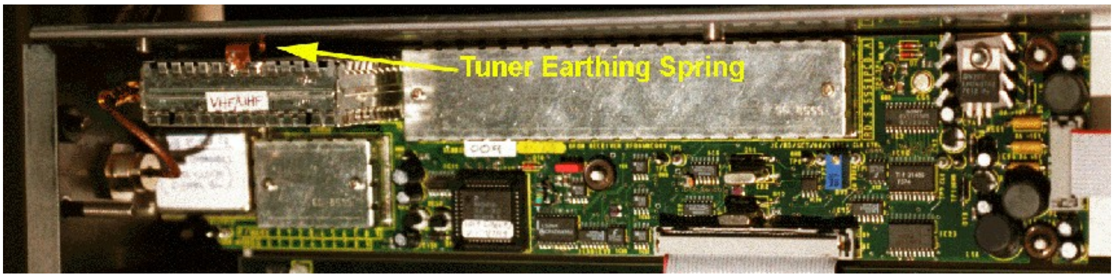
Some problems were experienced with varying minimum received signal levels when the receiver was co-located with the modulation equipment. The receiver was subsequently separated into its own shielded environment. Both the Rig and transmitters were used with this measurement.

When minimum received signal levels were measured with a transmitter operating some signal was picked up in the cables running to the shielded room with the receiver in it. Minimum received levels were slightly higher under these conditions. Table 3.6.1 is a summary of the minimum signal levels obtained during the measurement program. Unfortunately I missed the measurement of the NEC transmitter @ 200 W due to distractions related to the Harris transmitter alignment.

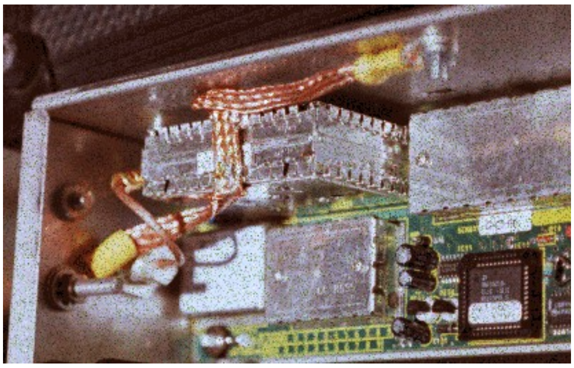
DTTB Conditions	COFDM (dBuV)	8-VSB (dBuV)
Test Rig	25.1	27.2
NEC Tx 200W	25.3	-
Harris Tx 200W	25.2	27.2
Harris Tx 600/900W	25.8	28.25

Table 3.6.1 - Summary of Minimum Signal Levels

The COFDM receiver's minimum signal level continued to fluctuate over the entire measurement program. When the receiver was left alone it remained stable but when the box was disturbed, variations would occur. This is attributed to earthing effects around the tuner on the front end board that had a copper earthing "coil" soldered to the side of the case to make contact with the chassis wall (Picture 21). This was later augmented with copper braid securely bolted at two separate points to the back and side chassis walls (Picture 22). This modification caused the tuner noise figure to become more stable, however further improvement could be obtained by touching or flexing the tuner with a hand while the main chassis lid was removed.



Picture 21 - COFDM Tuner Earthing - Original State



Picture 22 - COFDM Tuner Earthing Improvement

3.7Spot Measurements

The HP9836 computer was set up to perform Minimum signal level, C/N threshold and spot measures of co and adjacent channel PAL into DTTB performance. These measurements were performed on both the rig and each transmitter with the various modulation modes available.

Since the COFDM system has a large range of modulation modes, each was evaluated for data rate to confirm the payload capacity. The Modulator and receiver were programmed to each FEC, Guard interval and Modulation type in turn. When the receiver locked, the frequency of the data clock signal was measured using a frequency counter and this frequency noted. Since the RS coding for the COFDM system was by-passed during this test the result was scaled by the RS code factor 204/188.

					Payload Bitrate Mb/s				Pal C/I Protection			
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)	Lower Adjacent Ch (dB)	Pal/Cofdm Co Chan Max (dB)	Pal/Cofdm Co Chan Ctr (dB)	Upper Adjacent Ch (dB)
QPSK	1/2	5.4	11.7	4.8	4.35	4.84	5.12	5.28	-44.8	-12.8	-13.0	-49.2
QPSK	2/3	6.6	13.2	5.1	5.81	6.45	6.83	7.04	-44.5	-5.1	-8.4	-47.0
QPSK	3/4	7.6	14.8	5.7	6.53	7.26	7.68	7.92	-43.7	1.1	-4.0	-45.3
QPSK	5/6	8.7	16.8	6.6	7.26	8.06	8.54	8.80	-42.3	5.8	3.1	-43.3
QPSK	7/8	9.5	19.2	8.2	7.62	8.47	8.96	9.24	-40.8	8.0	9.7	-42.0
16-QAM	1/2	11.2	17.7	5.0	8.71	9.68	10.25	10.56	-43.5	-8.0	-8.8	-46.1
16-QAM	2/3	13.0	19.6	5.1	11.61	12.90	13.66	14.07	-42.1	1.1	-2.3	-43.3
16-QAM	3/4	14.1	20.9	5.3	13.06	14.51	15.37	15.83	-40.2	6.0	3.3	-41.2
16-QAM	5/6	15.5	22.9	5.9	14.51	16.13	17.08	17.59	-37.0	11.2	9.9	-39.1
16-QAM	7/8	16.3	24.9	7.1	15.24	16.93	17.93	18.47	-35.2	14.7	16.9	-37.3
64-QAM	1/2	16.8	23.3	5.0	13.06	14.51	15.37	15.83	-41.2	-3.3	-3.1	-41.7
64-QAM	2/3	19.1	25.2	4.6	17.42	19.35	20.49	21.11	-35.4	3.7	1.4	-37.5
64-QAM	3/4	20.6	27.5	5.4	19.59	21.77	23.05	23.75	-35.0	12.0	10.8	-35.9
64-QAM	5/6	22.2	30.0	6.3	21.77	24.19	25.61	26.39	-31.2	18.4	17.1	-33.1
64-QAM	7/8	23.7	32.4	7.2	22.86	25.40	26.89	27.71	-28.9	23.1	22.6	-30.8
8-VSB	2/3	15.1	27.2	11.2	-	-	-	19.39	-38.6	2.6	9.1	-38.7

Blue Payload Figures are 188/204 scaled from actual measurement

Minimum Signal Levels are for 50 Ohms

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

The Yellow Background COFDM 64QAM data indicates the selected modulation type

Table 3.7.1 - Spot Measurements of System Parameters

Table 3.7.1 details the combined spot measurements for all the modulation combinations of the DVB COFDM system and the single 8-VSB mode. The COFDM and 8-VSB parameters highlighted in yellow are the system parameters that were in use for the majority of test data presented in this report. The 64QAM 2/3 FEC 1/8 Guard COFDM set closely matches the 8-VSB payload data rate of 19.39 Mb/s. Although the 16QAM 7/8 FEC 1/32 Guard COFDM set comes close to achieving the 8-VSB C/N and data rate it was decided that the forward error correction was not strong enough to handle field impairments.

It was found during early testing that the guard interval duration had no effect on PAL CCI and PAL ACI.

The noise figure in the above table has been calculated from the measured C/N threshold and minimum signal levels (dBW) using the formula given in the DVB specification[iv]. System bandwidths of 7 and 6 MHz have been used for the COFDM and 8-VSB systems. The C/N threshold expressed in the table and used to calculate the 8-VSB noise figure is the 6 MHz value from Table 3.5.1. As previously noted there was variation in the measured minimum signal levels for the COFDM equipment. The figures in Table 3.7.1 are typical of the lowest values measured. Minimum signal level voltages are expressed across 50 Ω

The 8-VSB and COFDM systems provide similar PAL ACI ratios, while the COFDM system is around 5 dB better for PAL CCI. The co-channel max column data was measured 1 MHz below the CCI position where COFDM exhibited its worst co-channel performance. This corresponds to the point where the PAL vision carrier enters the lower edge of the COFDM signal.

3.8Echo Performance

As the laboratory does not have access to a multipath ghost simulator both a coaxial cable and on-air translator links were used to generate single echoes to allow basic simple ghost performance of the systems to be measured.

3.8.1Coax Echo

The NEC transmitter drive level was set to obtain an average output power of 75W to drive the 1500 metres of RG-213 Coaxial cable laid on the laboratory roof. Two HP amplifiers provided 60 dB of amplification during the final 500 metres of coax. The coaxial cable provided various echoes up to a maximum of 7.2 us. To get shorter echoes the final coaxial cable connection on the roof was moved to connections in the coax closer to the transmitter.

The echo signal level was calibrated using the following procedure:

1. The test rig was switched for external signals and the unwanted signal chain switched off. The wanted signal attenuation was reduced to zero and the C/N was set to more than 50 dB.
2. The power level of the returned echo signal from the coax was measured at the receiver measurement point with the echo attenuator at 0 dB and the direct attenuator at 130 dB. The echo level was generally in the region of -30 to -40 dBm
3. The direct and echo attenuator levels were then swapped so that they had 130 and 0 dB respectively.
4. The power level at the measurement port was again measured and the direct calibration attenuator adjusted to match the received power level from the coax. This achieved the 0 dB echo level for the measurement.
5. The echo level and direct level were rechecked every 5 measurements to ensure that the relative levels were maintained.

If the returned signal from the coaxial cable was too high at the shorter cable lengths then the drive level to the NEC transmitter was decreased by 20 dB making an input signal of around 1 Watt. Additionally if the test output level of the transmitter did not produce enough signal to achieve the 0 dB calibration described above then 20 to 40 dB of attenuation was set as the minimum value on the echo attenuator and the measured echo ratios adjusted accordingly after calibration.

The echo level measurement was performed as follows:

1. The direct signal level attenuator was set to 0 dB and then the echo level attenuator was slowly decreased from maximum attenuation while monitoring the output BER of the receiver.
2. As the echo failure point was approached the attenuator step size was decreased.
3. When the echo caused failure of the receiver the relative echo level was recorded.

4. If a 0 dB echo level was achieved then the C/N set was used to degrade the combined 0 dB signals to measure the Noise margin at this condition.
5. Once the post echo measurement was complete, Steps 1-4 were then repeated with the direct and echo attenuators function swapped to measure the pre echo performance in a similar manner.

	Echo Level					
Echo Delay & Type	Guard 1/4 (dB)	Guard 1/8 (dB)	Guard 1/16 (dB)	Guard 1/32 (dB)	C/N Threshold (dB)	Rx Level (dBm)
7.48us Post Echo 1st Measure	-0.6	-1.6	-0.8	-4.4	19.3	-45.55
7.48us Pre Echo 1st Measure	-0.7	-1.4	-1.4	-5.1	19.8	-45.55
7.48us Post Echo 2nd Measure	0	0	0	-4.3	19.5	-49.45
7.48us Pre Echo 2nd Measure	0	0	0	-5.3	20.4	-49.45
0 dB C/N Threshold (dB)	32	37	33	-		
5.71us Post Echo	0	-0.6	0	0	19.2	-44.65
5.71us Pre Echo	0	-0.6	0	0	19.3	-44.65
0 dB C/N Threshold (dB)	37	-	40	38		
4.18us Post Echo	0	0	0	0	19.3	-42.15
4.18us Pre Echo	0	0	0	0	19.4	-42.15
0 dB C/N Threshold (dB)	41	40	40	45		
1.71us Post Echo	0	0	0	0	19.3	-42.65
1.71us Pre Echo	0	0	0	0	19.4	-42.65
0 dB C/N Threshold (dB)	39	40	36	39		
0.38us Post Echo	0	0	0	0	19.3	-37.8
0.38us Pre Echo	0	0	0	0	19.3	-37.8
0 dB C/N Threshold (dB)	36	36	37	37		

Table 3.8.1 - COFDM Coax Echo Levels for Various Echo Delays

Table 3.2.1 details the measurements of coax echo level on the COFDM system. Where the system achieved a 0 dB echo the C/N threshold to failure shows that the system is on the verge of failure when dealing with a 0 dB echo. The longest echo was measured twice with the first measurement showing the system not handling 0 dB echoes. The second measurement which achieved 0 dB was recorded later while plotting the echo spectrums. The C/N Threshold column indicates the C/N with only the direct signal (Post echo) or Echo signal (Pre echo) present.

Originally it was thought that the 1/32 guard interval of the system being tested was 7 us. The standard specifies 7 us for the 2k 8 MHz system however since the symbol time increases by 8/7 ths with the change from 8 to 7 MHz then the guard interval also increases accordingly. This means that the 1/32 guard interval of the 2k system tested was actually 8 us. This was discovered after testing was completed. Table 3.8.2 details the system timings for 2k and 8k 7 MHz COFDM systems.

The 7.5 us of coax echo did not extend the system outside the guard interval. The results do however show a degradation in echo performance as the guard interval is approached.

7 MHz System Times	2k COFDM System	8 k COFDM system
1/32 Guard Interval	8 us	32 us
1/16 Guard Interval	16 us	64 us
1/8 Guard Interval	32 us	128 us
1/4 Guard Interval	64 us	256 us
Symbol Time	256 us	1024 us

Table 3.8.2 - 7 MHz COFDM System Timings

Figure 3.8.1 and Figure 3.8.2 show the COFDM system spectrum with short 0 dB single echoes applied. At these levels the system maintained lock although the system C/N threshold increased to over 32 dB making it less robust.

It should be noted that only very short echoes produced the severe notches observed in these spectrum plots. As the echo length increased the number of notches increased, however the width and depth of the observed notches decreased. At longer echoes the resolution of the analyser prevents observation of the notches.

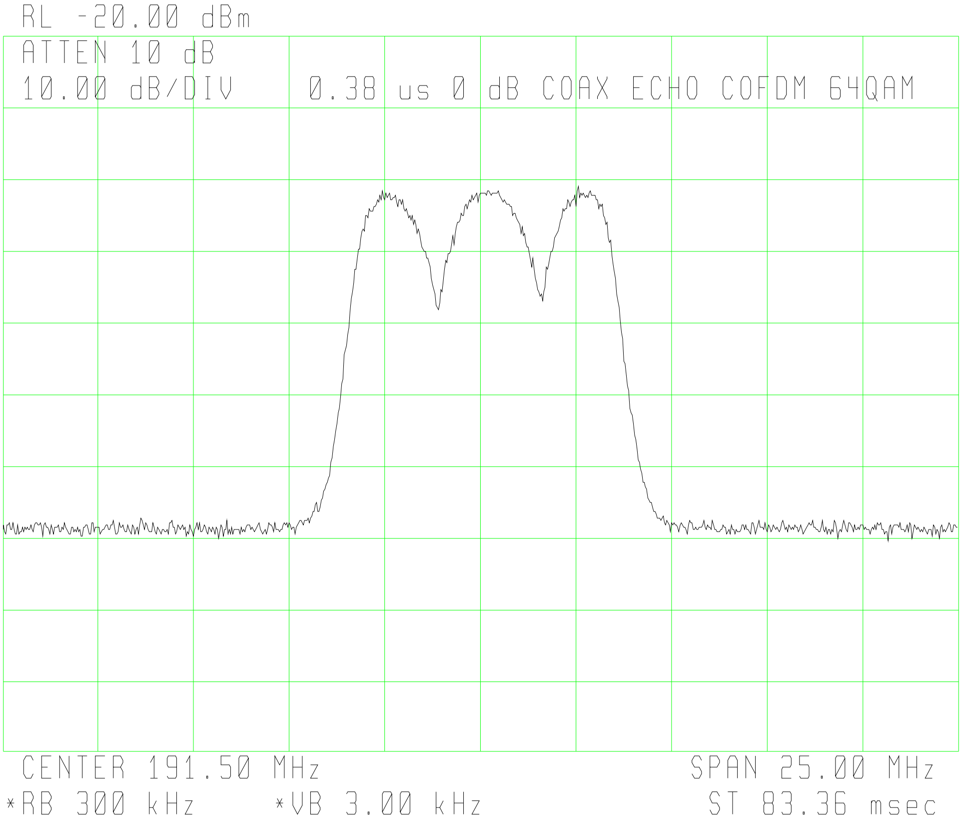


Figure 3.8.1 - Spectrum of COFDM 0.38 us 0 dB coax echo

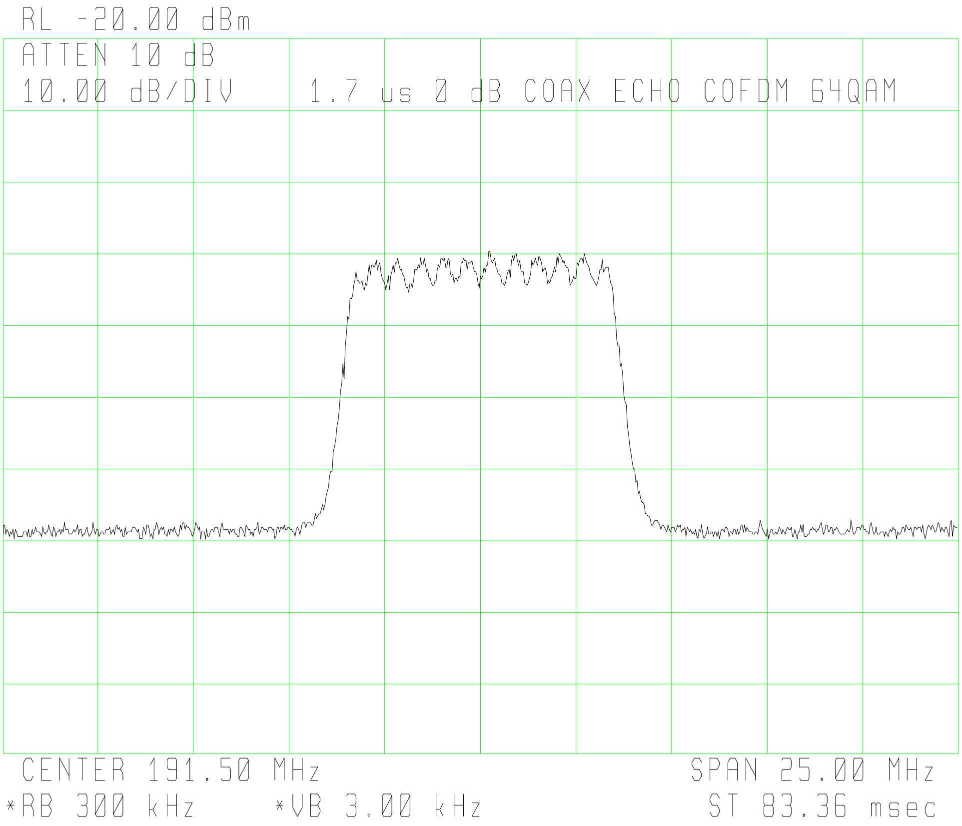


Figure 3.8.2 - Spectrum of COFDM 1.7 us 0 dB coax echo

Echo Delay & Type	8VSB Echo (dB)	C/N Threshold (dB)	Rx Level (dBm)	Relock Level (dB)
7.48us Post Echo	-2.2 & -3.1	14.4	-46.7	-4.2
7.48us Pre Echo	-13.5	14.8	-46.7	
5.705us Post Echo	-2.1	14.4	-42.8	
5.705us Pre Echo	-13.8	14.8	-42.8	
4.18us Post Echo	-4.4 & -2.0	14.4	-38.9	-4.4
4.18us Pre Echo	-13.8	14.6	-38.9	
1.705us Post Echo	-2.0 & -0.6	14.5	-33.7	-6.0
1.705us Pre Echo	-7.1 & -7.0	14.5	-33.7	
0.38us Post Echo	-0.8 & -1.3	14.5	-45.1	
0.38us Pre Echo	-1.8 & -1.8	14.6	-45.1	

Table 3.8.3 - 8-VSB Coax Echo Levels for Various Echo Delays

Table 3.8.3 details the measurements of single echo performance on the 8-VSB system. Echo levels up to around -2 dB can be tolerated however as the system equaliser only has 3 us of advanced taps it cannot cope with long pre echoes. Some variation with equaliser lockup was observed with the 1.71 us post echo yielding -0.6 and -2.0 dB measurements in repeated measurement cycles.

While measuring the 8-VSB echo performance it was noted that the system locked into a high error state when echo levels just over the failure point were applied. When this phenomenon occurred the echo level was decreased until the system relocked normally and the relock echo level was noted.

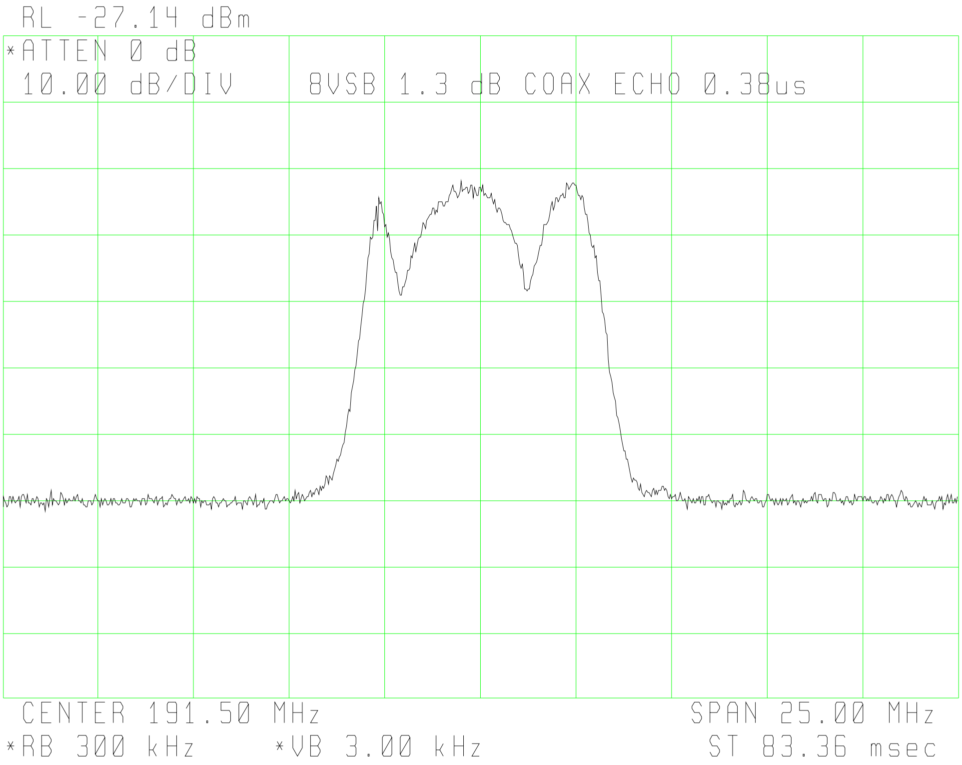


Figure 3.8.3 - Spectrum of 8-VSB 0.38 us -1.3 dB coax echo

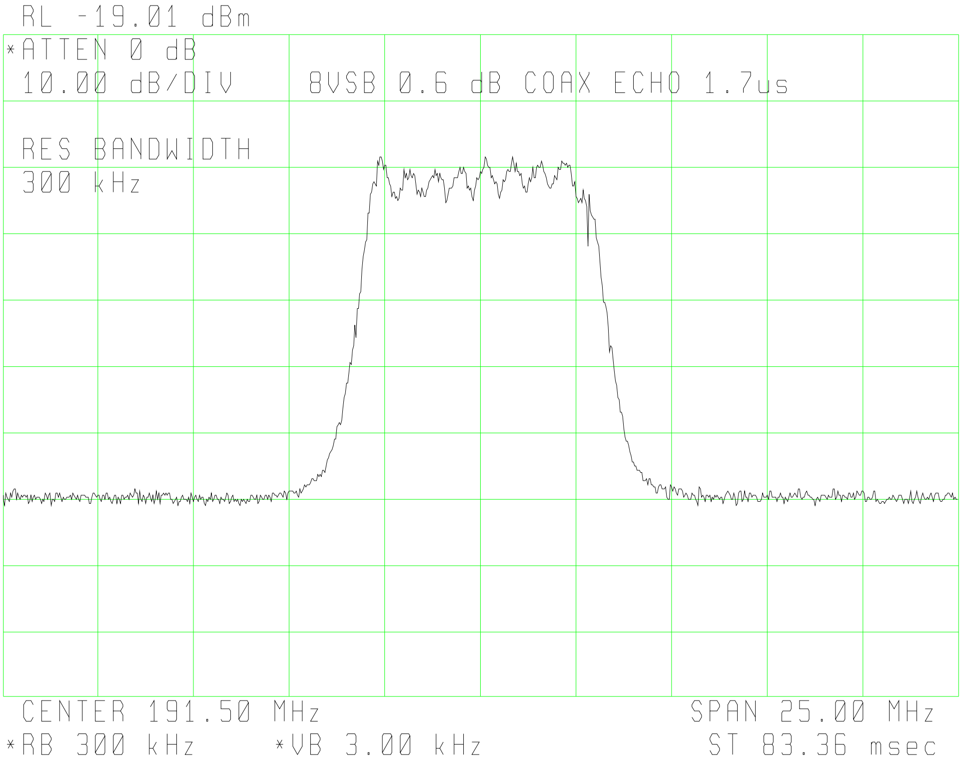


Figure 3.8.4 - Spectrum of 8-VSB 1.7 us -0.6 dB coax echo

Figure 3.8.3 and Figure 3.8.4 show the 8-VSB system spectrum with short near 0 dB single echoes applied. At these levels the system was at it's failure point.

3.8.2Link Echo

Measurement of the echo performance over the link was similar to the measurement of the coax echo except for the path which the signal traversed. Figure 3.1.1 details the final configuration of the link with the blue figures indicating the typical signal levels along the path.

The system was re-cabled to allow the NEC transmitter to radiate a 3 watt horizontally polarised channel 8 DTTB signal approximately 2.5 km to the University of Canberra.

The signal was originally received, filtered, amplified at a 36 MHz IF and then transposed to channel 44 UHF.

In the second modified final version of the link a single up conversion from channel 8 VHF to channel 44 UHF was used.

The upconverted signal was then radiated back to the lab using a vertically polarised UHF transmit panel. The UHF signal was received at the lab, converted to 35.2 MHz IF and finally converted back to channel 8 VHF in the test lab adjacent to the transmitter for combination with the direct transmitted signal.

Tight filtering of the signal at channel 8 was required to keep the vertically polarised channel 7 and 9 off-air broadcast signals out of the system. A television antenna 5 metres from the transmit antenna was used to check no interference was observable to the channel 7 & 9 Black Mountain broadcast transmissions.

In the initial version of the link during the COFDM measurements one oscillator remained unlocked because of phase noise problems. Thus fine adjustment of the final conversion frequency was undertaken using a Tektronix real time spectrum analyser just before each echo level measurement to ensure that the echo was kept within 1 Hz of the original frequency.

In the final link configuration all conversion oscillators were locked to a HP GPS 10 MHz frequency reference.

The echo and direct signal levels were calibrated as per the coax calibration procedure. Values for pre and post echoes were recorded.

The link delay was measured by transmitting analog television signals across the link. The difference in received sync pulse timings between the direct and echo paths determined the echo to be 17.2 us.

Since the link is a real live signal transmission path some variation in the received signal level was evident which caused the received echo levels to fluctuate. The echo level calibration was re-checked at intervals during the measurement and the level used was the average of the fluctuation observed.

When measuring 8VSB signals the error rate was monitored for around ten, 7 second measurements. If the error rate went below the failure threshold in more than one of the measurements then the interfering echo level was reduced.

17.18 us Link Echo Type	Guard 1/4 (dB)	Guard 1/8 (dB)	Guard 1/16 (dB)	Guard 1/32 (dB)	C/N Threshold (dB)	Rx Level (dBm)
Post Echo (High Phase Noise)	-1.1	-8.8	-9.0	-10.1	19.1	-39.5
Pre Echo (High Phase Noise)	-1.5	-3.0	-11.0	-12.6	22.5	-39.5
Post Echo (Low Phase Noise)	-1.5	-8.8	-9.4	-10.0	19.1	-42.6
Pre Echo (Low Phase Noise)	-1.4	-2.8	-10.3	-12.0	22.5	-42.6
Post Echo (GPS Locked)	-1.5	-9.3	-9.9	-10.7	19.1	-37.3
Pre Echo (GPS Locked)	-2.0	-3.2	-9.9	-11.5	21.7	-37.3
Post Echo (After 8-VSB Test)	-1.5	-8.0	-8.6	-10.1	19.4	-41.9
Pre Echo (After 8-VSB Test)	-2.2	-3.0	-9.7	-11.4	21.3	-41.9

Table 3.8.4 - COFDM Link Echo Levels

Table 3.8.4 details the COFDM link echo levels that caused system failure for the various link configurations. The two rows are the figures measured after the final link modification at the conclusion of the 8-VSB tests. The link echo signal exhibited a C/N threshold around 2 dB higher than the direct signal.

The results show little variation across the various link configurations (impairments) indicating that the COFDM system performance was not severely affected by phase noise, frequency stability or mixer intermodulation.

The link delay of 17.2 us exceeded the 1/32 and 1/16 th guard intervals however the performance at the 1/8 th guard interval is curious. In this condition the system could handle pre echoes 5 dB greater than post echoes. With a 32 us Guard interval these should have been around 1-2 dB.

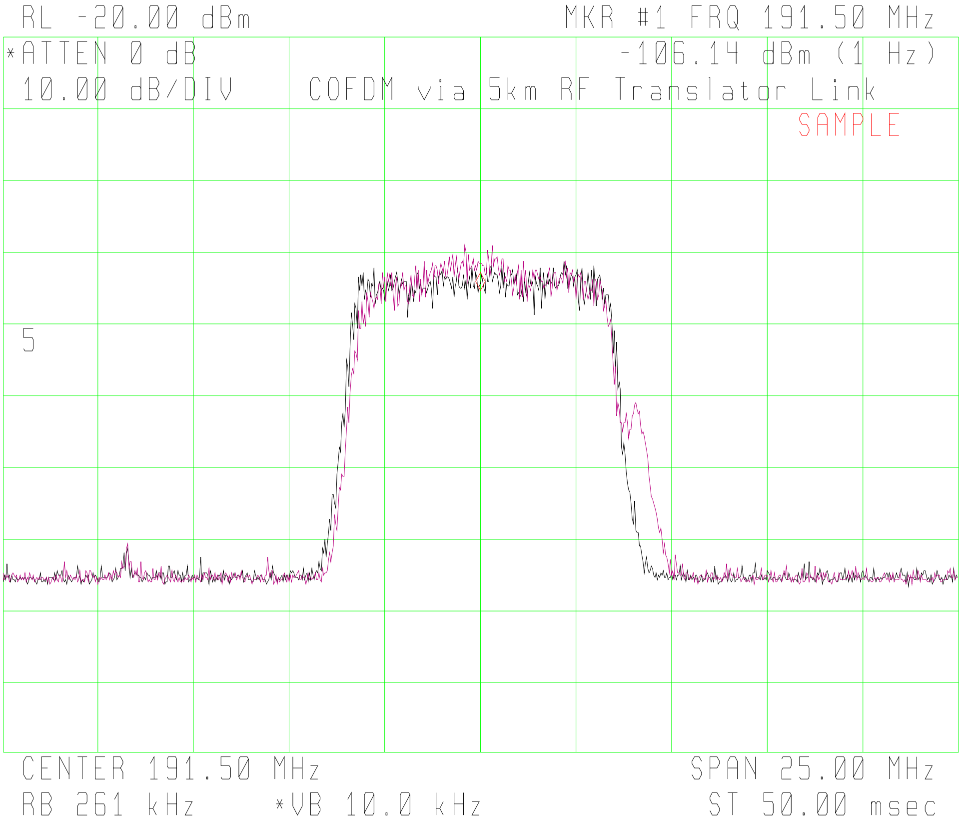


Figure 3.8.5 - COFDM Returned Link Echo and Direct Echo Spectrum

Figure 3.8.5 shows the received spectrum direct and delayed echoes at 0 dB reference levels The vestige of the adjacent channel 9 PAL vision carrier can be seen in upper part of the violet delayed echo spectrum. At times the Sound carriers of channel 7 were visible also. As described earlier the signal levels fluctuated with path conditions such as humidity, temperature and wind.

17.18 us Link Echo Type	Echo Level (dB)	C/N Threshold (dB)	Rx Level (dBm)
Post Echo (Original Link)	-19.9	14.5	-43.4
Pre Echo (Original Link)	-23.0	18.0	-43.4
Post Echo (Original Link -5 dB)	-20.0	14.5	-48.4
Pre Echo (Original Link -5 dB)	-22.9	18.1	-48.4
Post Echo (Original Link +3 dB)	-19.9	14.5	-40.7
Pre Echo (Original Link +3 dB)	-27.9	18.4	-41.1
Post Echo (Improved Link)	-8.4	14.4	-40.3
Pre Echo (Improved Link)	-16.2	15.5	-40.3

Table 3.8.5 - 8-VSB Link Echo Levels

Table 3.8.5 details the link echo measurements recorded for the 8-VSB system. The top 6 rows in this table indicate measurements of the link in it's original condition (end of COFDM tests) where the phase noise had been removed and the oscillators GPS locked.

The Zenith engineers were concerned about the performance of the link which indicated non-linear mechanisms were present. The measurements in the centre of Table 3.8.5 for transmit power level changes were recorded to identify if any equipment was being overloaded in the link transmission system. These measurements did not indicate any significant change in the system parameters with power level.

The field test receiver was transported to the translator site and measurements made of 8-VSB performance in the middle of the translator chain. After many measurements at various points it was determined that the up-conversion mixer was being driven too hard and causing a low level intermodulation to occur.

A receiver incorporating AGC would normally avoid this problem, so the link translator was reconfigured with the bulk of the signal amplification after the up-conversion mixer. The 8-VSB performance of the link then improved to acceptable levels.

The final 2 rows in Table 3.8.5 give the performance of the 8-VSB system subject to the 17.2 us link echo. The post echo level is very similar to that measured on the COFDM system. The pre echo could not be accommodated since it is outside the 8-VSB receive equaliser range.

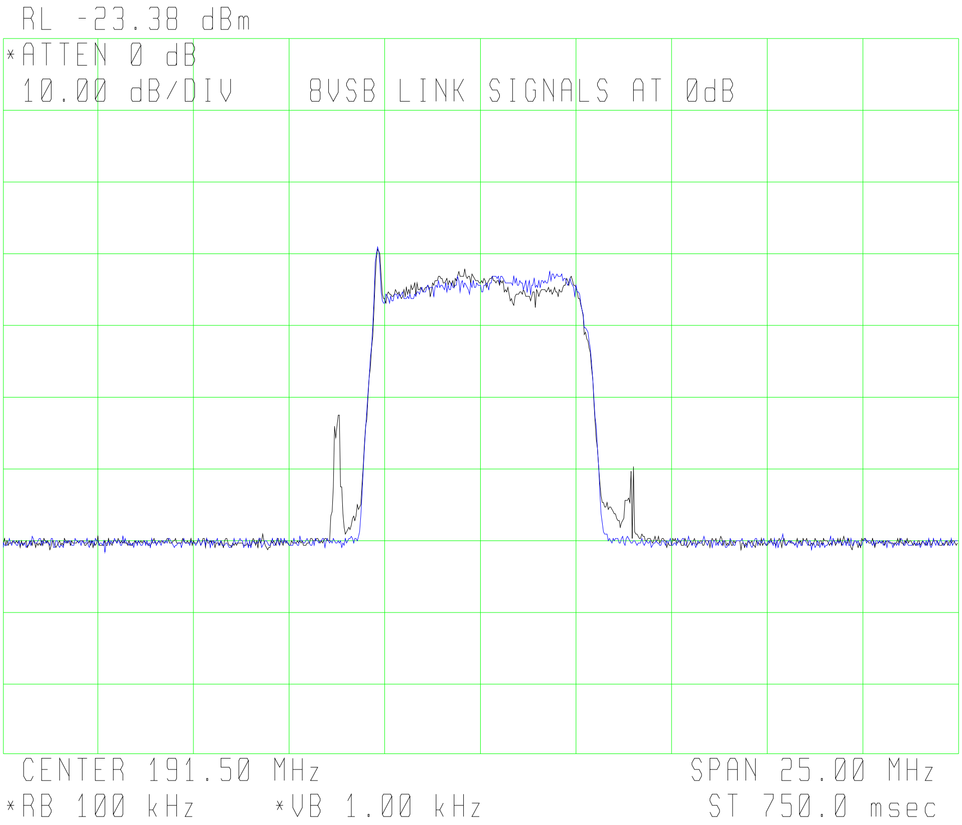


Figure 3.8.6 - 8-VSB Returned Link Echo and Direct Echo Spectrum

Figure 3.8.6 is the spectrum plot of the final link echo (black) and the direct signal (blue). Again the sound carrier (mono) of channel 7 and vision carrier of channel 9 are visible in the returned signal. Special notches were tried at the translator site to reduce the ingress of these signals however the notches also rounded the edge of the DTTB channel spectrum, and were unable to significantly reduce the ingress of channels 7 & 9.

3.9Echo Level vs C/N Threshold

The Echo level which causes the receiver to reach its failure point was measured and then the echo level was decreased in small increments and white noise applied to bring the system back to the failure threshold. The echo level continued to be reduced in varying increments until the normal system white noise threshold was reached. During this measurement where significant fluctuation was observed repeated measurements were taken and if the error threshold was being exceeded in more than 1 out of 5 measurements the applied C/N level was increased until less than 1 out of 5 measurements fell below the error threshold.

Figure 3.9.1 presents the overall DTTB echo performance comparison between the two systems. The COFDM measurements are indicated with filled markers while the 8-VSB measurements have hollow markers for the corresponding measurement. The C/N vs Echo level plot gives an indication of what level of echo starts to affect the performance of the system by increasing the C/N threshold requirement. If a 1 dB increase in the C/N threshold is defined as a arbitrary point then for coaxial echoes the COFDM system degrades 1 dB at -11 dB echo level and the 8-VSB system reaches the same degradation at -12 dB. Comparing the link post echo performance yields around -17 dB for COFDM and -14 dB for 8-VSB.

As the 8-VSB system is outside it’s equaliser range there is no point in comparing the pre-echo performance in this way.

Again the different BER measurement methods is evident for the higher echo levels with 8-VSB having a very steep slope at it’s failure point.

The 17.2 us COFDM link echo performance shows the significant difference between pre and post echo performance at the 1/8th Guard interval. This may be in some way attributable to the increased C/N margin of the link signals which is obvious at the -25 dB echo level edge of the plot.

Figure 3.9.2 presents the data for COFDM coaxial echoes only. The variation of the guard interval shows relatively similar performance while well within the guard interval time however as the guard interval is reduced (1/32 = 8 us) close to the echo delay the system performance is degraded.

Variation in the C/N threshold begins when the echo level exceeds the noise threshold level.

Figure 3.9.3 presents the data from the link measurements. Two coax measurements are presented on this plot as a reference point for comparison of the link and coax echo performance. As was obvious in the echo level measurements in the previous section the 1/4 guard interval measurement is similar in performance to the coaxial delay however the 1/8th guard interval (32 us) post echo measurement which is well within the echo delay shows a similar plot to those where the guard intervals is exceeded by the echo delay. The pre echo plot at 1/8th demonstrates this condition is closer to what would be expected.

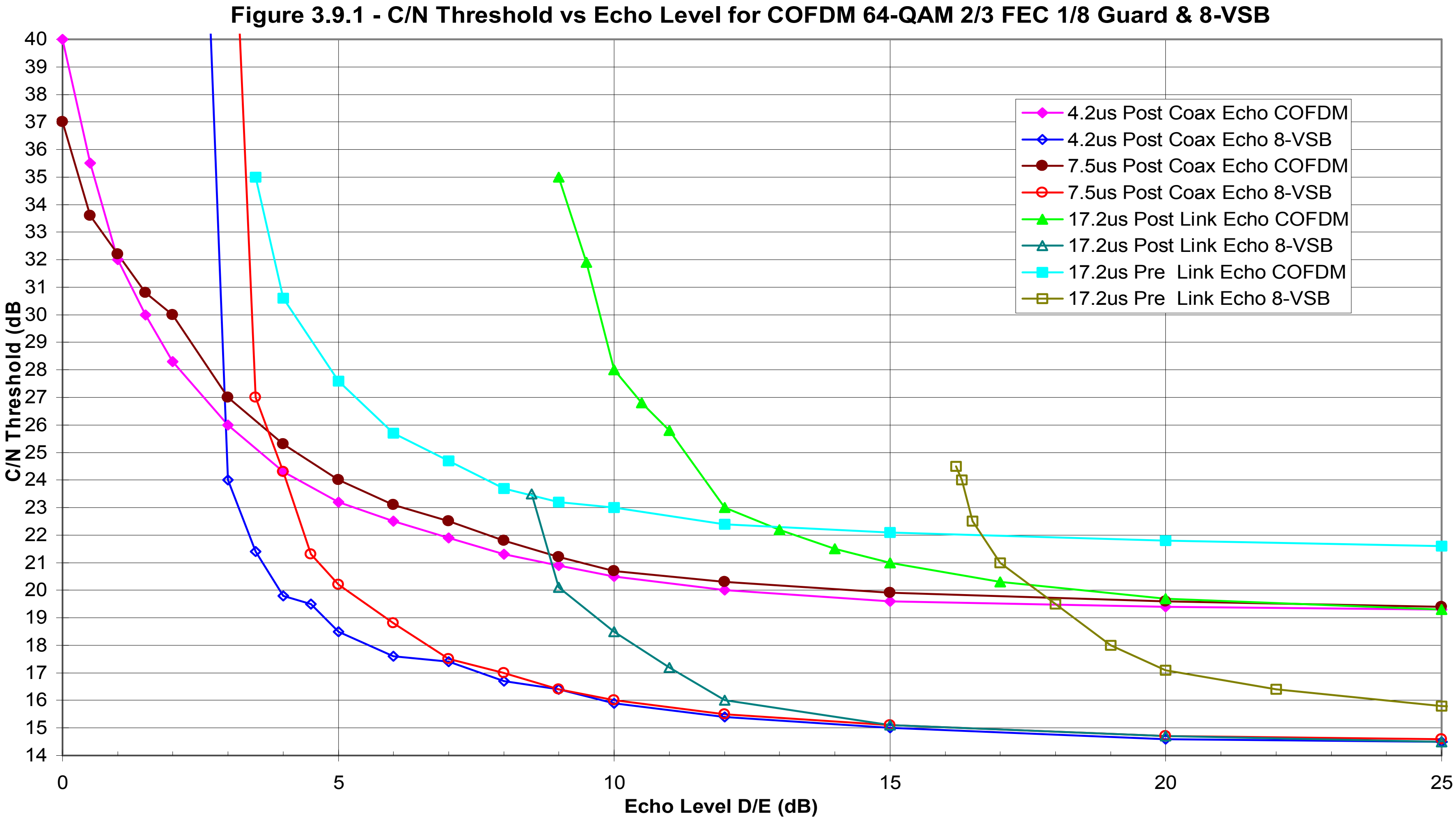


Figure 3.9.1 - DTTB Echo Performance Comparison

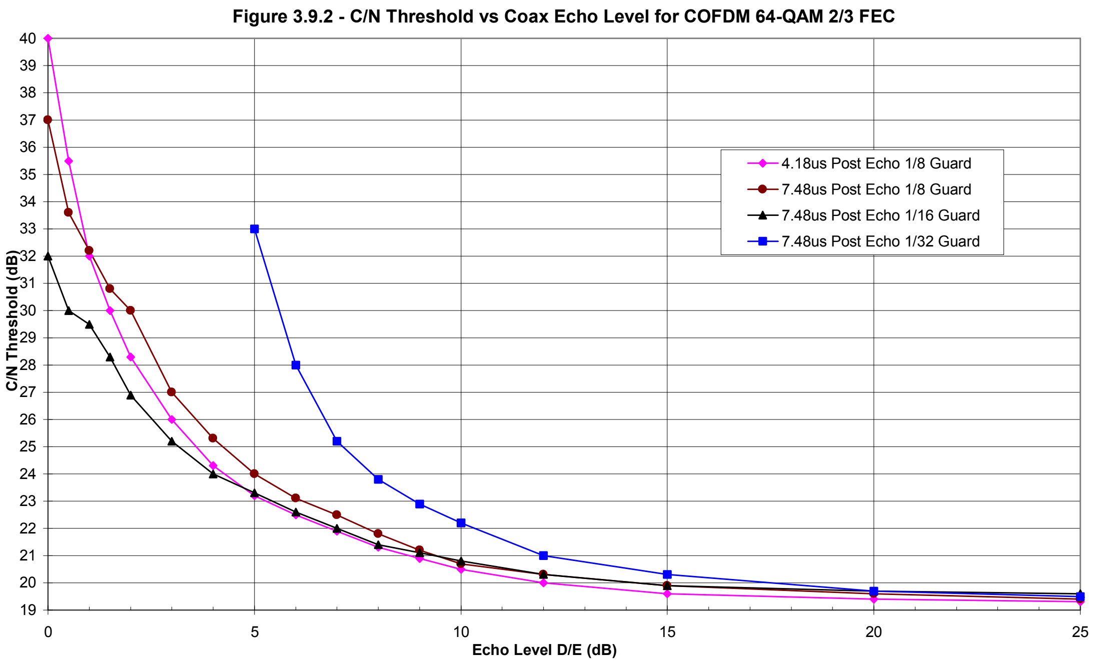


Figure 3.9.2 - COFDM C/N vs Coax Echo Level

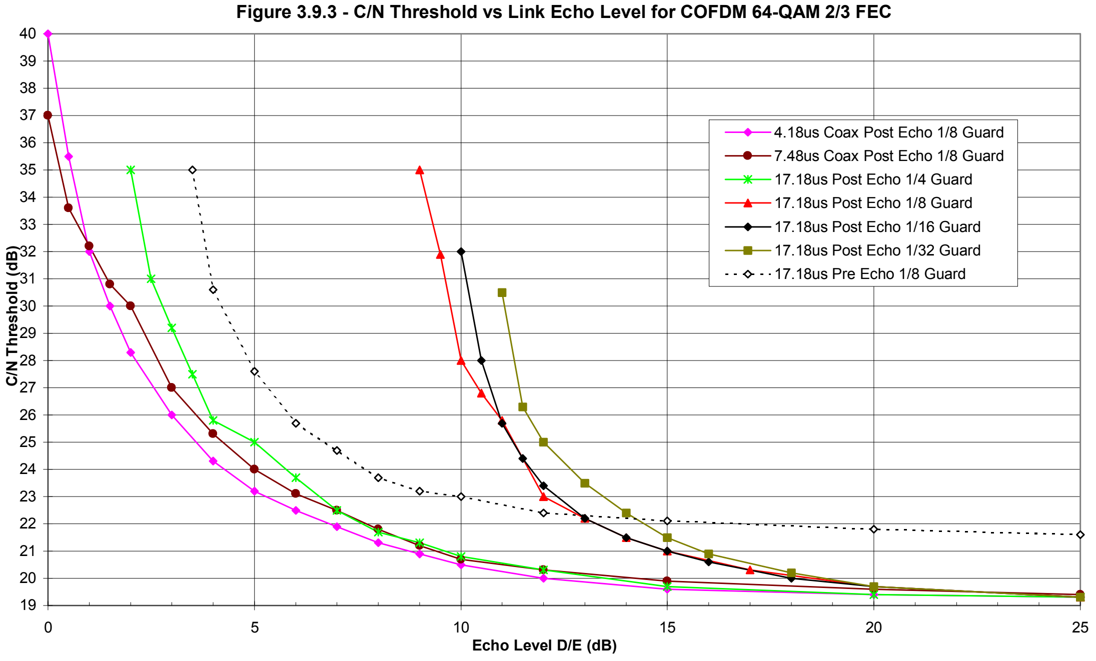


Figure 3.9.3 - COFDM C/N vs Link Echo Level

Figure 3.9.4 presents the measured data for the 8-VSB system. Early measurements of the original link (light green & purple) show the poor performance of the system through the original translator. After correction of the mixer intermodulation problem the post echo curve shows the system able to deal with 8.5 dB echoes. This is still 5 dB short of the short coaxial cable echo performance, however most high level echoes tend to be of shorter delay.

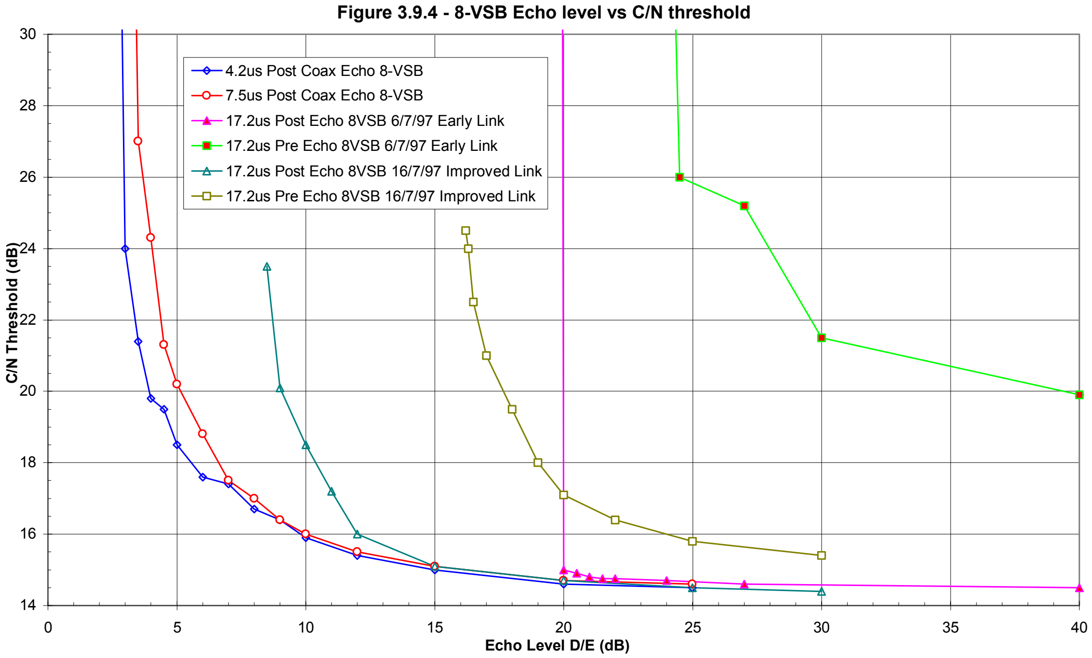


Figure 3.9.4 - 8-VSB C/N vs Echo Level

3.10Co-Channel DTTB

As only a single COFDM modulator was available it was not possible to measure Co-Channel COFDM performance with independently generated signals. The COFDM co-channel performance was measured using the Link echo signal with a small frequency offset.

The 8-VSB equipment was supplied with both a Harris and Zenith modulator so measurement of the co-channel performance using the same or two different modulators was possible.

Accordingly for the conduct of this measurement different test procedures were adopted for the two DTTB systems.

3.10.1COFDM-COFDM Precision Frequency Offset

The Link echo signal was used to measure the Co-Channel performance in a similar manner to the Doppler performance measurement in Section 3.13. The Link provided a delay of 17.2 us for the interfering signal.

The NEC transmitter drive level was set to obtain an average output power of 3W into the Link. The returned link echo was mixed back to the normal channel 8 frequency using a signal generator within the main test rig under control of the test computer.

The frequency of the final link up conversion from 36 MHz was varied in 1 Hz steps to shift the frequency of the returned link echo signal. All signal generators were locked to the same 10 MHz GPS derived reference signal.

The shifted echo and the direct signal from the transmitter were combined through attenuators and the resulting combination fed to the receiver and a power meter through the normal test rig.

The power meter was used to compare the echo signal to the direct signal and adjust the direct signal calibration attenuator to achieve a 0 dB relative echo level. The signal level measured at the rig measurement point was around -38 dBm.

The 0 dB calibration was checked and adjusted if necessary before each measurement. All measurements were performed manually.

The echo level was slowly increased until system failure occurred for each doppler frequency offset. The echo differential was recorded as the result. Measurements were carried out for the post echo case only (direct signal at 0 dB echo signal varies). The frequency offset was adjusted alternately between positive and negative offsets during the manual measurement. The performance was plotted for frequencies out to ±200 kHz. A fine resolution of 25 Hz was used below ±100 Hz and 100 Hz steps were used out to ±1500 Hz offset.

It was initially thought that the link delay would contribute to making the co-channel signal more hostile in this measurement, however we would have needed to reduce the Guard interval to 1/32 to achieve the most hostile interferer. Later measurements with small coaxial delays showed similar results, indicating use of the long link delay was not crucial to this measurement.

The result of this measurement is presented in Figure 3.10.1. It shows a Sin(X)/X type curve with a flat portion at the co-channel position which extends ±75 Hz. The protection level measured at co-channel was +8.8 dB which is consistent with the post link echo measurements. After the 8-VSB measurements were complete the co-channel interference echo was remeasured using the 8-VSB method described in section 3.10.2 below. This single measurement yielded a co-channel echo failure level of 1.1 to 1.9 dB using the 8-VSB measurement method. This shows that the Link system was degrading the on channel echo performance by around 7 dB.

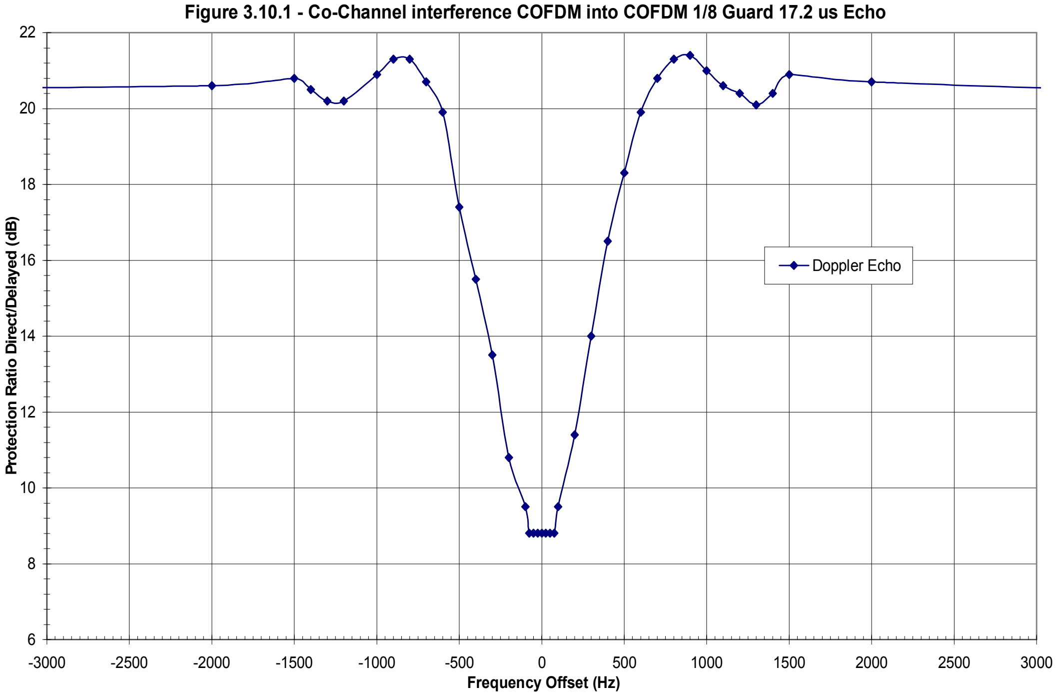


Figure 3.10.1 - COFDM into COFDM co-channel interference

Beyond the ±2 kHz offset the sustainable co-channel interference level asymptotes to 20.4 dB at 200 kHz which is around the system C/N threshold. During this test the Direct signal C/N threshold was 19.1 dB and the Link signal C/N measured as 21.7 dB. The value of 20.4 dB lies at the midpoint between these two system C/N values.

Although a separate COFDM signal was not available to carry out this co-channel test, the small frequency offset result shows that the interference caused by a non-synchronous COFDM signal approximates to white noise.

3.10.2Precision Frequency offset 8-VSB Interferer

A 2 port hybrid combiner was placed in the position of the Rig/External coaxial switch to combine the Rig signal with that being produced by the NEC transmitter test output. The NEC transmitter drive level was set to obtain an average output power of 150W into the 500W dummy load, the direct attenuator set to 0 dB and the echo attenuator set to 130 dB. The Rig DTTB drive attenuator was then increased to maximum while the transmitter calibration attenuator was adjusted to obtain a power level of -23.75 dBm at the measurement point. The Direct level attenuator was set to maximum.

The Rig Drive attenuator was set to achieve -23.75 dBm at the measurement point.

When this was achieved both the Rig drive level and the direct transmit signal attenuators were increased by 30 dB to give a signal level of -53.75 dBm from each source and achieve a 0 dB relative signal. The value of the Rig drive level attenuator was noted and its value subtracted from subsequent measurements to determine the relative signal levels.

The Rig drive attenuator was reduced to 130 dB and the main DTTB local oscillator frequency varied to frequency offsets ranging from -200 to +200 kHz about the nominal local oscillator frequency. These frequencies were set with a 1 Hz precision and both the transmitter local oscillator and the Rig Local oscillator were externally locked to the same stable 10 MHz reference signal.

At each frequency offset the level of the Rig Drive level attenuation was decreased while monitoring the receiver error rate. When the receiver reached the error threshold the signal differential was recorded.

Frequency offsets were tried alternately above and below the nominal centre frequency so that any adaptive equalisation would have to readjust significantly if it was tracking the interfering DTTB signal.

As the points were measured they were plotted in Excel and further points measured to best approximate the interference level curve.

The measurement of non precision DTTB interferer was similar to the precision interferer described above except the Zenith 8-VSB modulator was used as the unwanted signal. This modulator was set to produce a scrambled zero data sequence so that the bit error rate meter could not lock onto the unwanted signal. Similar offsets from -200 to +200 kHz were measured.

The delay introduced by the different path lengths for the rig and transmitter signals was measured by observation of the received segment sync pulses on a CRO which was triggered from the modulator segment sync. Both the rig and transmitter signals were individually applied and the time difference measured on the CRO. The delay was determined to be 600 ns.

Figure 3.10.2 to 3.10.4 plot the results obtained from the measurement for both the Precision interferer and Different modulation cases. Figure 3.10.2 shows that for the precise co-channel condition there is a optimum point at zero offset and a ±9 Hz window allowing 8-9 dB co-channel protection. Beyond this offset the protection rises to around 20 dB with the different modulation interferer achieving the system C/N threshold of 14.6 dB around zero offset.

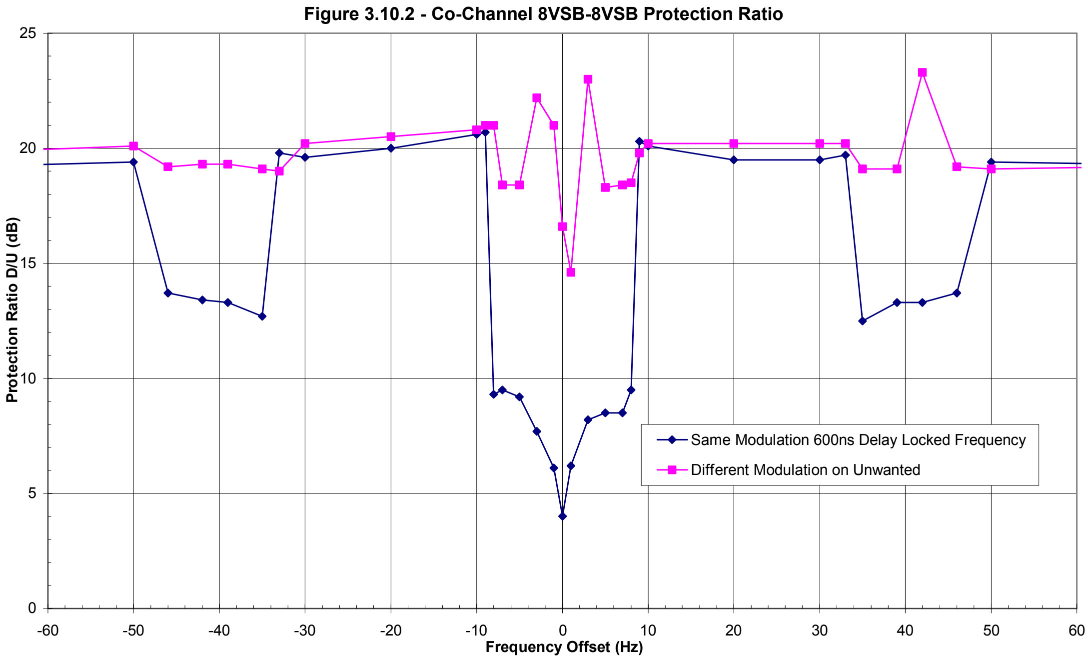


Figure 3.10.2 - 8-VSB into 8-VSB co-channel interference ±60 Hz

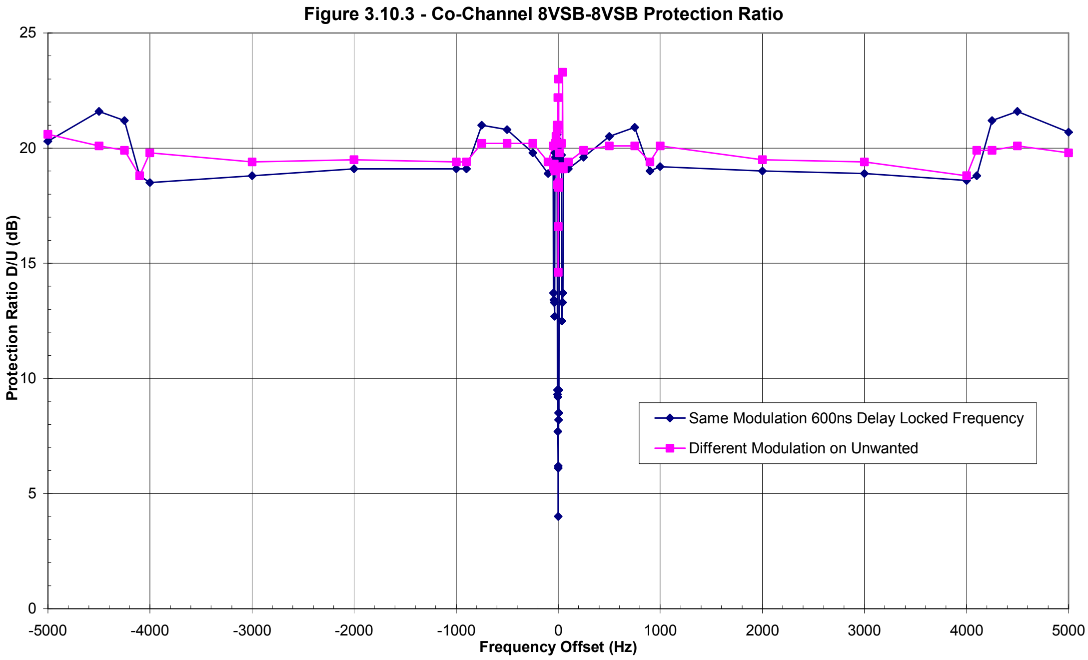


Figure 3.10.3 - 8-VSB into 8-VSB co-channel interference ±5 kHz

The Same modulation curve diverges from the different modulation curve at various spots probably due to standing wave aliases in the combined signal, and aliasing with the receiver equaliser tap steps. Figure 3.10.4 shows that beyond 35 kHz offset the two modulation modes asymptote to the system C/N threshold.

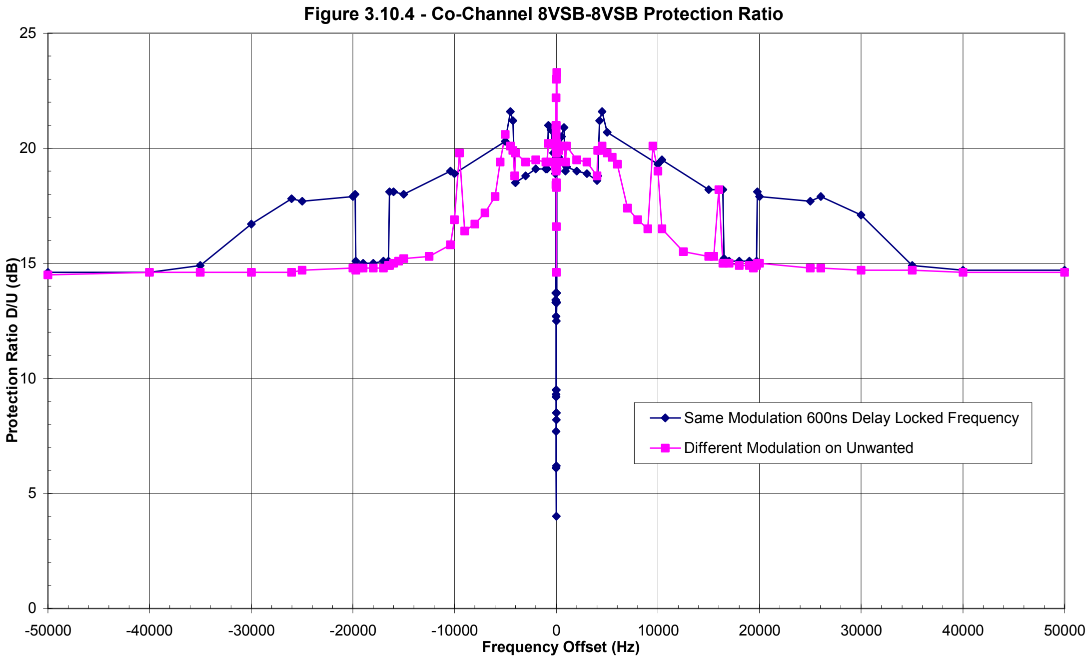


Figure 3.10.4 - 8-VSB into 8-VSB co-channel interference ±50 kHz

The co-channel performance of the two DTTB systems tested can be approximated to the system C/N threshold as each system when not synchronous appears as a white noise type interferer.

3.11Adjacent Channel DTTB

The adjacent channel performance was measured using the external transmitter signal as the wanted DTTB signal and the rig signal as the unwanted DTTB signal. For the COFDM measurement the same modulator was used as the signal source however with 8-VSB the Zenith modulator making a scrambled zero sequence was used as the unwanted adjacent channel signal. The measurement procedure was similar to the co-channel measurements described in section 3.10 above. The COFDM system was originally measured using the method described in section 3.10.1 however after the 8-VSB testing it was remeasured using the 8-VSB procedure described in section 3.10.2. In this case the signal through the transmitter was treated as the wanted signal and the main rig signal used as the unwanted adjacent channel interferer.

DTTB System	Lower Adjacent Channel	Upper Adjacent Channel
COFDM	-28.3 dB	-28.5 dB
8-VSB	-30.4 dB	-32.2 dB

Table 3.11.1 - DTTB-DTTB Adjacent Channel Protection (7 MHz)

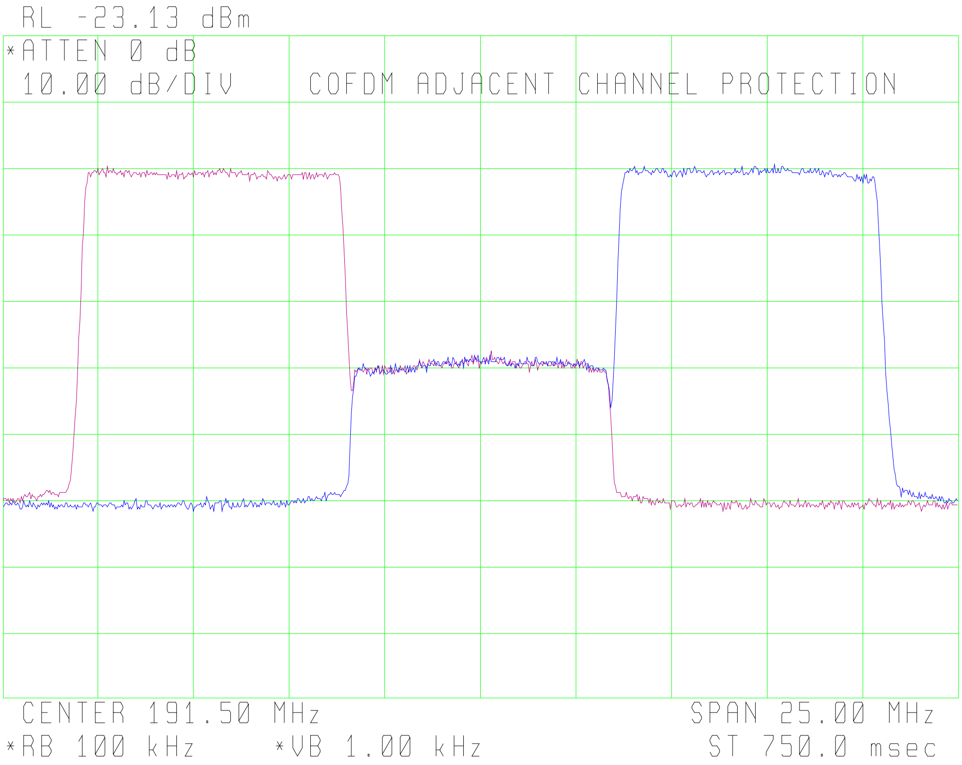


Figure 3.11.1 - COFDM Adjacent Channel Interference

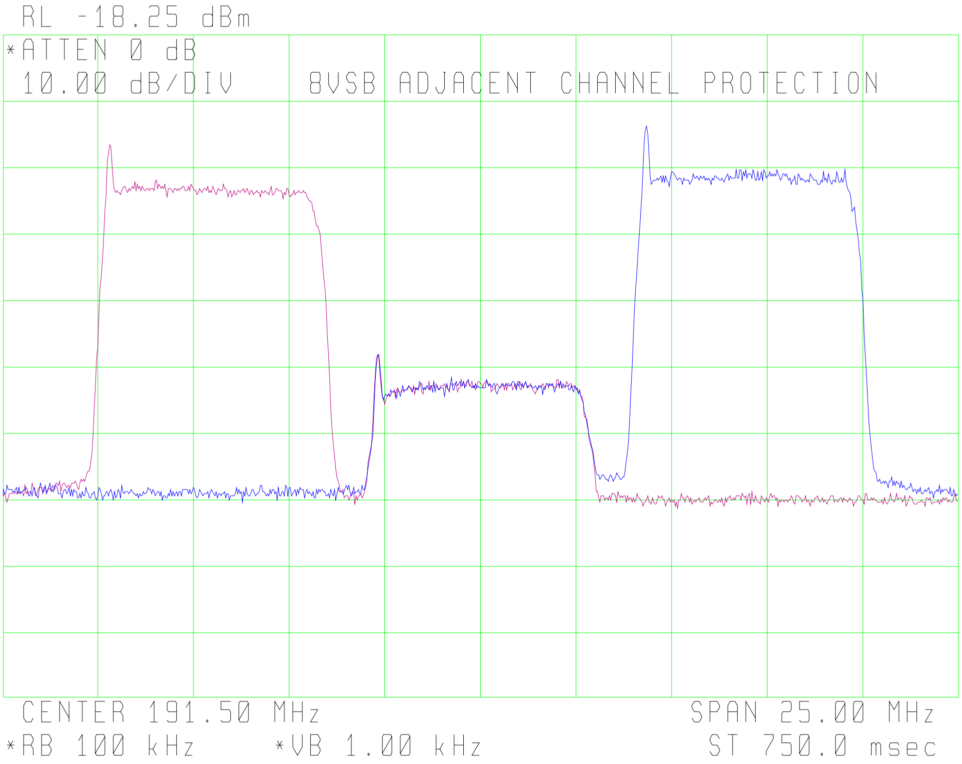


Figure 3.11.2 - 8-VSB Adjacent Channel Interference

Figure 3.11.1 and Figure 3.11.2 are each combined plots of the upper and lower adjacent channel power levels which caused system failure to occur for the COFDM and 8-VSB systems respectively. The wanted channel DTTB receiver input level was 50 dBuV. These measurements and plots of each adjacent channel were carried out individually. Table 3.11.1 details the adjacent channel protection. The COFDM figure is that obtained from the re-measurement.

3.11.1Lower Adjacent Channel

The DTTB rig filter was adjusted to the lower adjacent channel position and the rig local oscillator varied to move the rig generated DTTB signal into the lower adjacent channel area. The unwanted signal level was increased until failure point was observed.

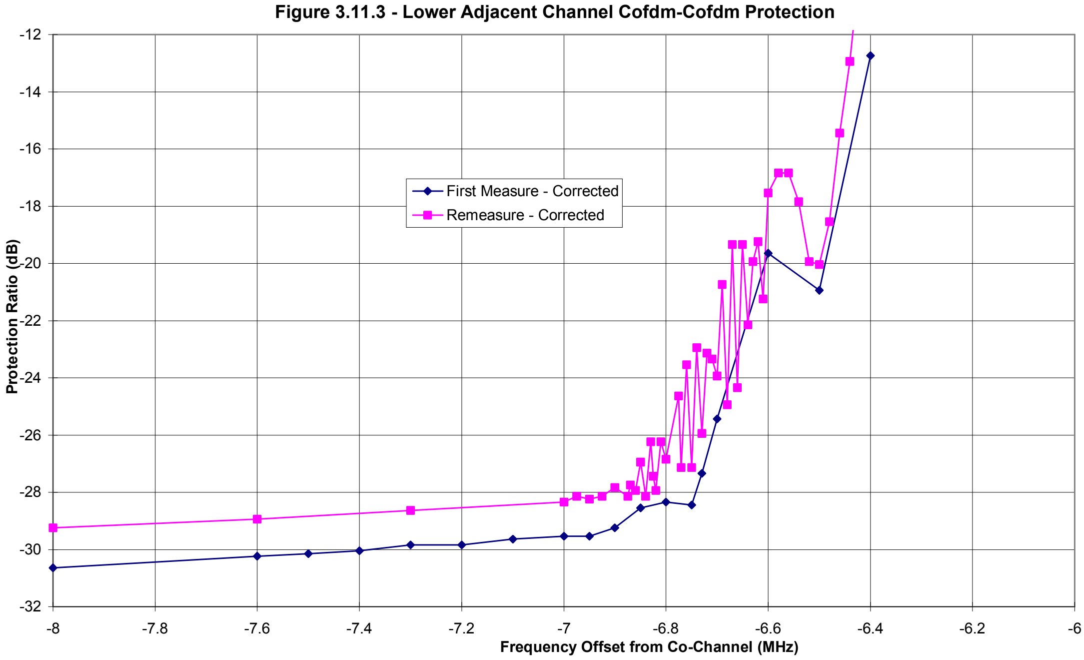


Figure 3.11.3 - COFDM into COFDM Lower Adjacent Channel Interference

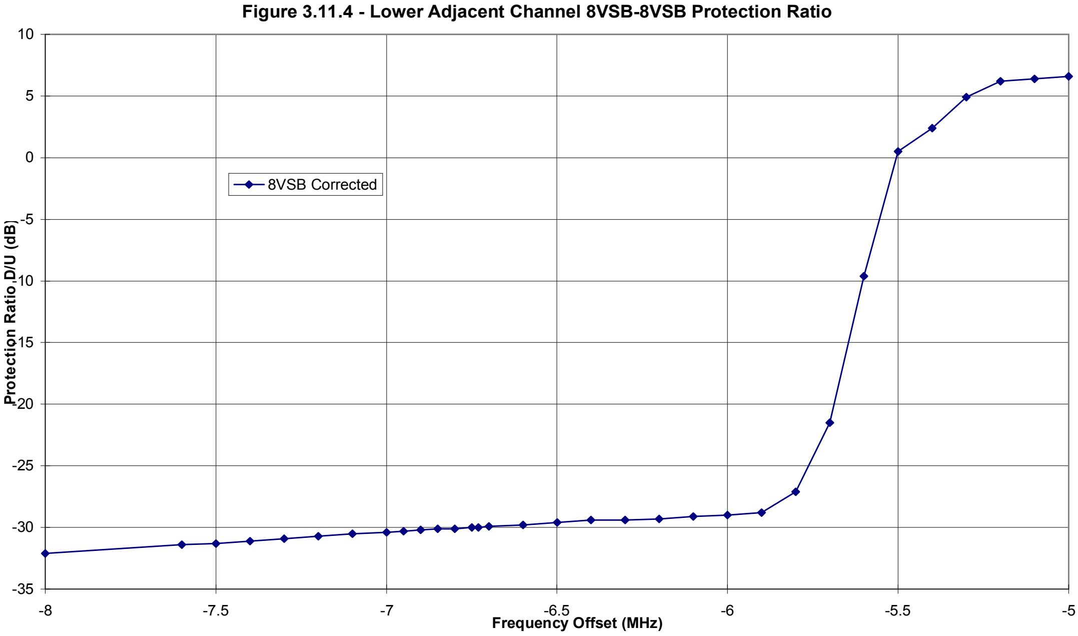


Figure 3.11.4 - 8-VSB into 8-VSB Lower Adjacent Channel Interference

Figure 3.11.3 and Figure 3.11.4 show the transition from the lower adjacent channel to the on channel protection ratio. Correction for the variation in signal power from the co channel to adjacent channel frequency offset has been factored into these plots.

During the remeasure of COFDM closer frequency offsets were tried to investigate the perturbation at -6.6 MHz . This revealed the fine oscillatory nature of this measurement which is attributed to the OFDM carriers interleaving as they drift past each other. There still appears to be a significant perturbation around -6.55 MHz.

The 8-VSB curve in figure 3.11.4 shows a smoother transition into the on channel region. The unwanted DTTB signal encountered the skirt of the wanted 8-VSB pilot at -5.7 MHz

3.11.2Upper Adjacent Channel

The DTTB rig filter was adjusted to the upper adjacent channel position and the rig local oscillator varied to move the rig generated DTTB signal into the upper adjacent channel area. The unwanted signal level was increased until failure point was observed.

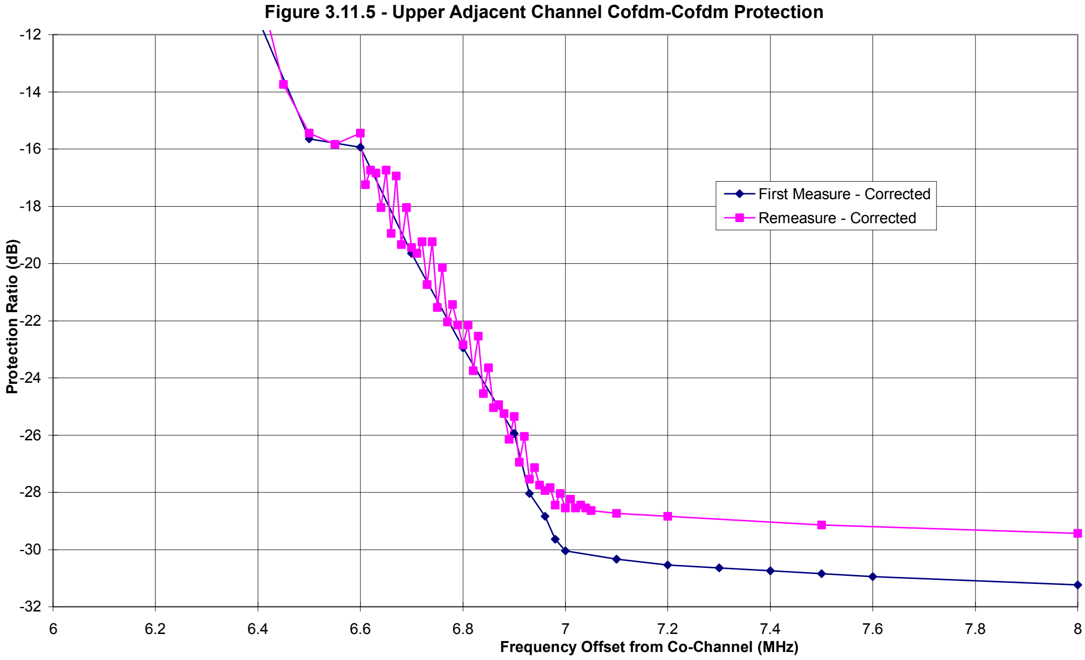


Figure 3.11.5 - COFDM into COFDM Upper Adjacent Channel Interference

Figure 3.11.5 and Figure 3.11.6 show the transition from the upper adjacent channel to the on channel protection ratio. Correction for the variation in signal power from the co channel to adjacent channel frequency offset has been factored into these plots.

Perturbations in the COFDM performance are still visible but of reduced impact in the remeasure. The upper adjacent channel for COFDM is very quick to degrade with any offset of the unwanted DTTB towards the on-channel position.

In both measurements the 8-VSB system has an extra 1 MHz of leeway due to the systems narrower bandwidth.

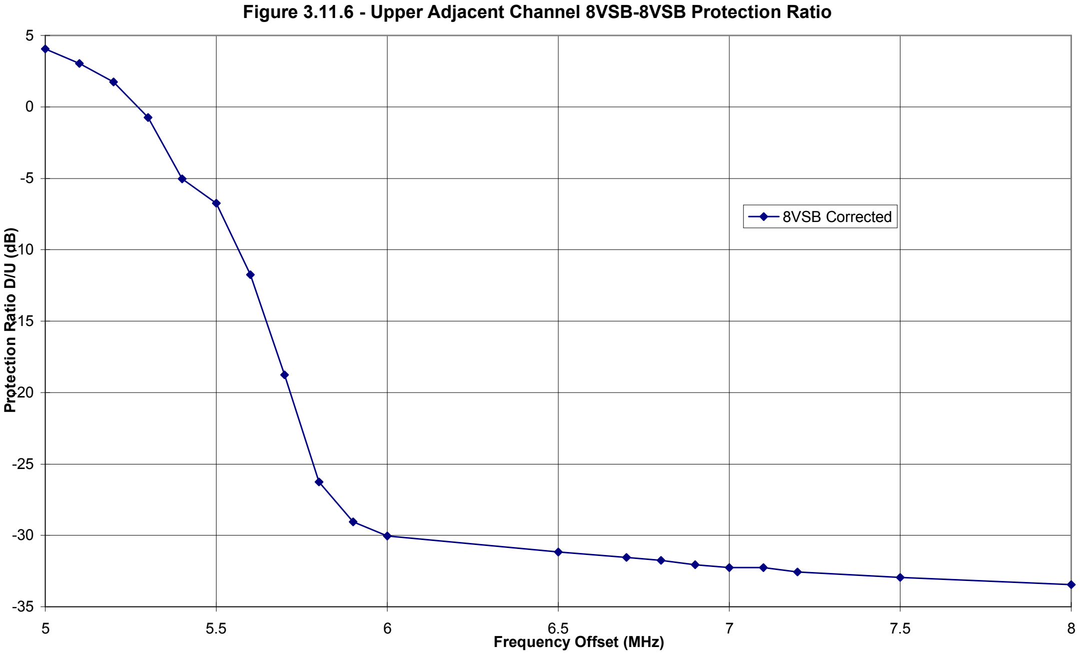


Figure 3.11.6 - 8-VSB into 8-VSB Upper Adjacent Channel Interference

3.12Impulse Noise Performance

Impulse noise is a common interference source in real installations, however it is difficult to characterise the effects of this type of interference. It was decided to measure the impulse noise performance by comparison with the existing PAL television system and direct comparison of the two DTTB systems. Figure 3.12.1 shows the changes to the D/U combiner test splitter area of the test rig required to implement this test.

An electric food mixer (Sunbeam Mixmaster Picture 23) was set up in the laboratory with an inductive power line clamp installed on the mains lead (30-1000 MHz). The machine was run at speed setting “10” out of 12 and the impulsive interference signal from the mains lead clamp fed to the test rig on 75Ω coax. The impulsive noise was fed via a 10 dB fixed attenuator to a ZSC-2-4 2 port hybrid combiner which was inserted after the D/U combiner but before the Test splitter.

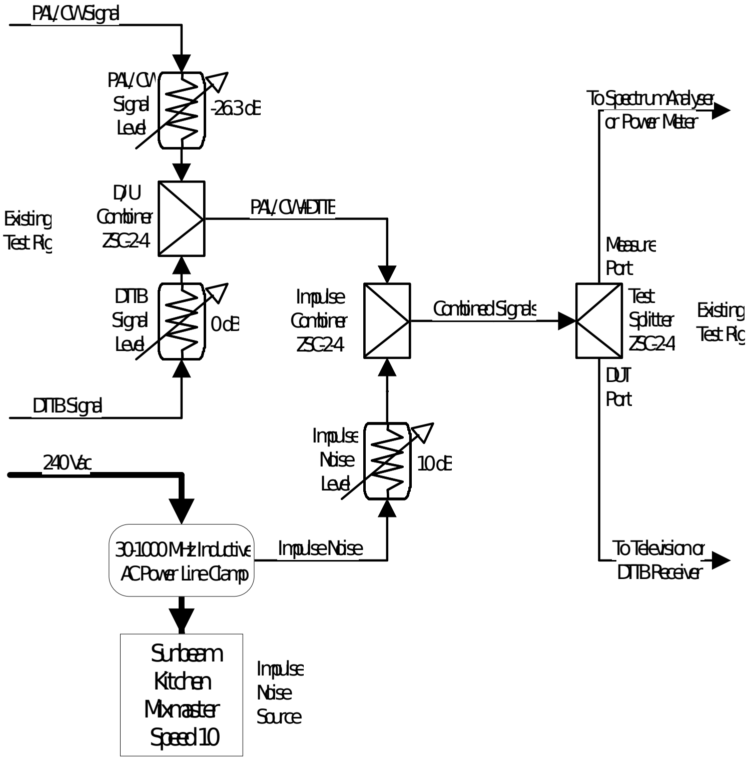


Figure 3.12.1 - Impulse Noise Test

Picture 23 - Sunbeam Mixmaster

In this way the impulsive noise could be added to either DTTB or PAL signals by selecting the appropriate signal source.

After the impulse noise combiner was added, the test rig calibration level changed by 3.5 dB to
-27.26 dBm at the measurement point. This changed the 0 dB calibration level at the DTTB receiver to approximately -31 dBm.

So as to not change the loading or character of the impulse noise a fixed 10 dB was used for the injection attenuator. Since the effect of impulse noise is different to that of white noise the COFDM system was also placed in picture mode and degradation of the picture observed. Four separate measurements of the impulse noise behaviour were performed with a wide spread observed in the 8-VSB failure level. The v1.0 equaliser in the COFDM receiver was used during this test.

The Table 3.12.1 below summarises the performance of the DTTB systems. The values indicate the attenuation of the wanted signal below the calibration level where failure was observed for a constant interference level.

System	**Test 1**	**Test 2**	**Test 3**	**Test 4**
8-VSB BER	31-35 dB	28 dB	30 dB	27-34 dB
COFDM BER	24 dB	20-21 dB	22 dB	22 dB
COFDM Picture	20 dB			19 dB

Table 3.12.1 - Impulse Performance of DTTB systems

During Test 2 two additional tests were performed.

1. A 6 and 10 dB pad were separately placed in line with the combined signal being measured to see if the differing noise figure of the two DTTB tuner systems may be the cause of the disparity in impulse noise performance.
2. A 7 MHz Telonic filter tuned to channel 8 (191.5 MHz) was placed in series with the impulsive noise to band-limit it to channel 8.

No significant change in the relative levels that had been measured were noted during these additional tests. Changes of less than 1 dB were observed but it is estimated that the experimental error with the impulse noise measurement may be in excess of 2 dB. The measurement indicates that the differing noise figures of the systems are not contributing to the difference and that out of band impulse noise was not contributing to front end overload in the tuner.

To document the impulse noise a digital CRO was used to show the impulsive levels being applied to the receiver. The screen dump in Figure 3.12.2 was taken as a single shot directly from the measurement port. Figure 3.12.3 shows the effect of placing a 7 MHz channel 8 filter in line. This gives an indication of the level that the DTTB receivers IF and demodulation stages would be dealing with. Typical impulse peaks before the filter were 180 mV peak to peak and after the filter 4-5 mV peak to peak.

The 8-VSB system was subjected to the impulse noise and achieved it's BER output failure point when the signal level was reduced by a minimum of 27 dB and up to 35 dB below the calibration level. The level seemed to vary over an 8 dB range from test to test as the adaptive equaliser made differing judgements of how to handle the impulsive impairment.

The COFDM system operating at 64QAM 2/3 FEC 1/8 Guard interval was subjected to the impulse interference and exceeded it's BER error threshold at a signal level between 20 and 24 dB below the rig calibration level. Additionally the COFDM system was put into picture mode so that output errors with all error correction systems operating could be observed. Onset of picture freezes occurred at 19-20 dB below calibration level and by 24 dB regular impairment at least every 2 seconds was occurring. The COFDM demodulator alarm light did not illuminate between 19 and 24 dB signal level.

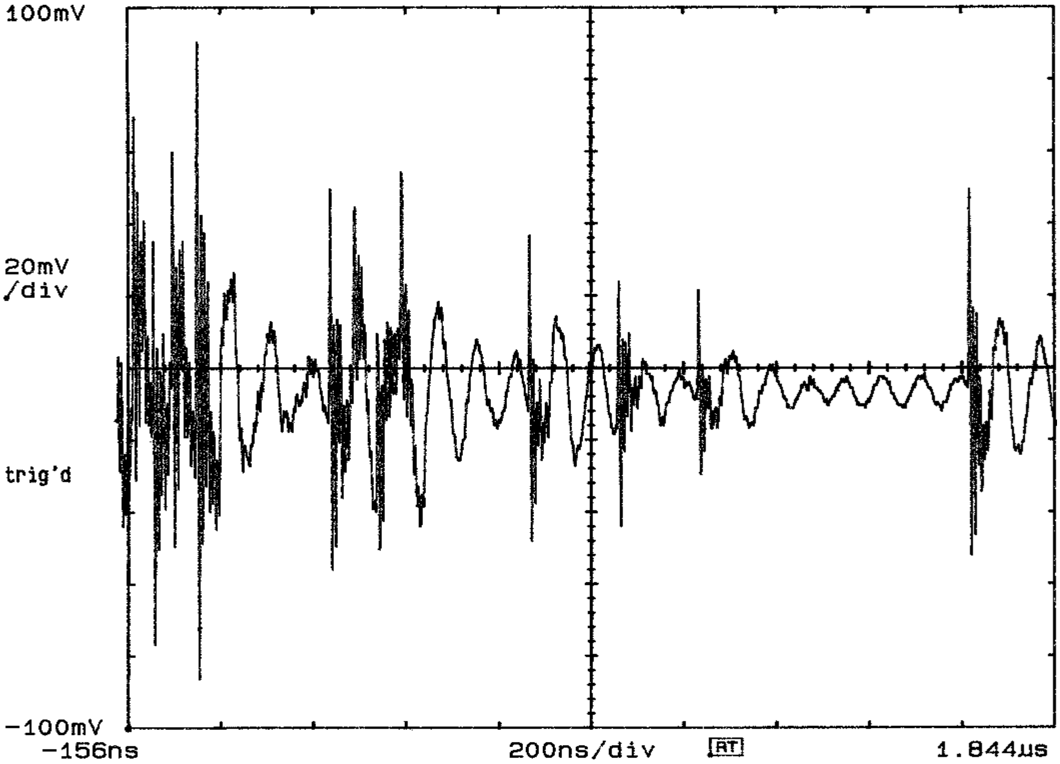


Figure 3.12.2 - Typical Impulse Noise - No Filter

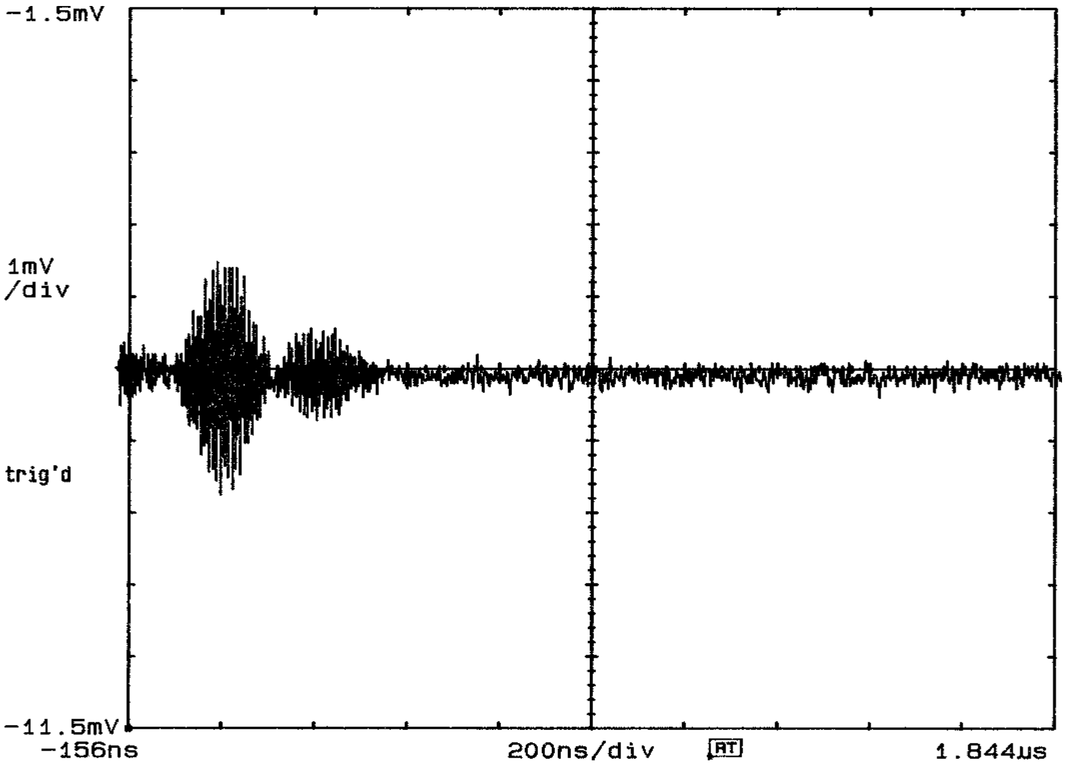


Figure 3.12.3 - Typical Impulse Noise through 7 MHz Channel 8 Filter

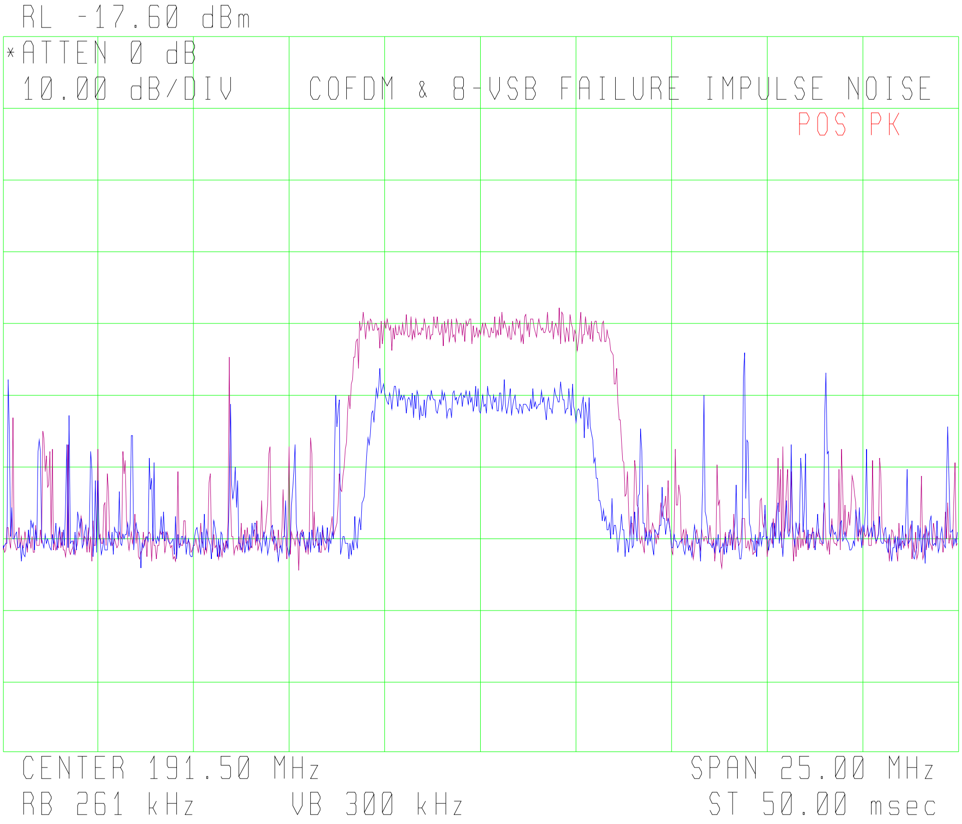


Figure 3.12.4 - Impulse noise optimum failure point for COFDM & 8-VSB

Figure 3.12.4 is a channel 7 to 9 spectrum plot of both COFDM (violet) and 8-VSB (blue) at their best immunity levels (24 & 35 dB) giving some indication of the relative level of the adjacent impulse noise peaks.

The reaction of the COFDM system to the impulsive noise was much more repeatable than the 8-VSB system. This may be due to the different equalisation techniques being used (frequency domain for COFDM and time domain for 8-VSB).

Level	Description
0 dB	At the calibration level (11 mV) there were occasional white impulse noise dots visible on the picture. This was judged to be the just perceptible point.
10 dB	At this lower signal level the impulse noise began to affect all areas of the picture, although still mainly confined to dots and small dashes. Some viewers may complain at this level if they knew that it was interference that could be fixed. This was judged to be slightly annoying and a grade 4 picture.
20 dB	At this signal level the impulse noise disturbed the majority of the picture area with a small level of 100 Hz banding evident. Some of the impulsive noise strikes extended up to a line length and this interference level was judged to be annoying to a level where a viewer was being distracted from the program and would be very likely to complain to the relevant authorities. This was judged to be a Grade 3 picture
25 dB	This signal level produced clicks on the stereo sound with impulsive noise present over the entire picture.

Table 3.12.2 - Description of Impulse Interference on PAL Receiver

The NEC television receiver was used to observe the affect of the impulse interference on a normal television set. As impulsive noise does not photograph well a description of the impairment is given in Table 3.12.2.

It would also appear that PAL is up to 10 dB more sensitive to impulsive interference than COFDM. The 8-VSB system shows the least sensitivity to impulsive interference.

3.13On Channel Doppler effect

The on channel doppler effect was measured using the 1500 metre coaxial delay producing a 7.5 us echo of the original signal. The NEC transmitter was run at approximately 150 watts into the coaxial delay.

The returned echo was fed via a 20 dB pad into the link receive path and down-converted to a 36 MHz IF. The signal was then re-mixed back to the normal channel 8 frequency using a signal generator within the main test rig under control of the test computer.

The frequency of the final up conversion from 36 MHz was varied in 1 Hz steps to doppler shift the returned echo signal. Both signal generators were locked to the same 10 MHz GPS reference signal.

The shifted echo and the direct signal from the transmitter were combined through attenuators and the resulting combination fed to the receiver and a power meter through the normal test rig.

The power meter was used to compare the echo signal to the direct signal and adjust the direct signal calibration attenuator to achieve a 0 dB relative echo level.

During manual measurements the 0 dB calibration was checked and adjusted if necessary before each measurement. During automatic measurements the calibration level was checked every 5 echo measurements.

Measurements of the echo level to achieve system failure for each doppler frequency offset were carried out first for the post echo case (direct signal at 0 dB echo signal varies) and then for the pre echo case (echo signal at 0 dB direct signal varies)

The doppler performance was plotted for frequencies out to the point where the echo became white noise like at a coarse resolution. A fine resolution of 1 Hz was used below 100 Hz doppler shift as this would seem to be the probable limit for a real doppler situation (53 Hz ~ 300 km/hr).

Figure 3.13.1 shows the pre and post echo performance of the COFDM system in the presence of a single fixed doppler echo with variation of the system guard interval. The result is very similar to that obtained for the co-channel DTTB interference tests in section 3.10.1 except that the zero doppler echo levels are higher. This is because the echo was not degraded by the link system. The 8 us guard interval shows the low doppler system performance degrading as the edge of the guard interval is approached. Figure 3.13.2 is a magnified zoom of the doppler performance which shows a relatively flat response with little effect for ±80 Hz shift. For a 3 dB degradation in echo performance a doppler shift of ±140 Hz can be tolerated.

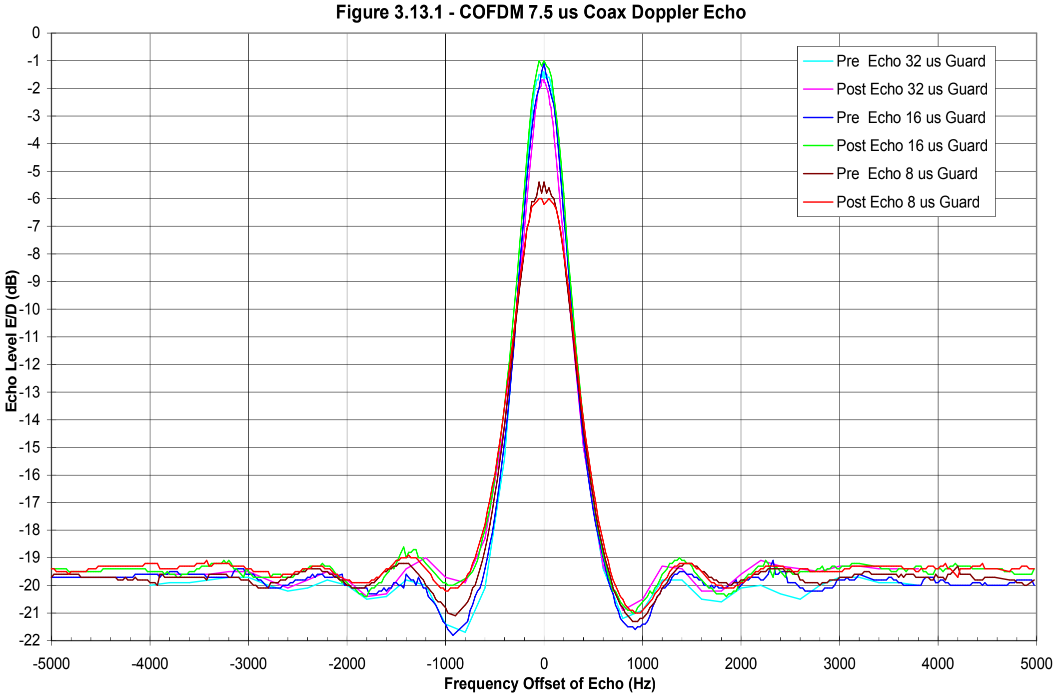


Figure 3.13.1 - COFDM Doppler Echo Performance

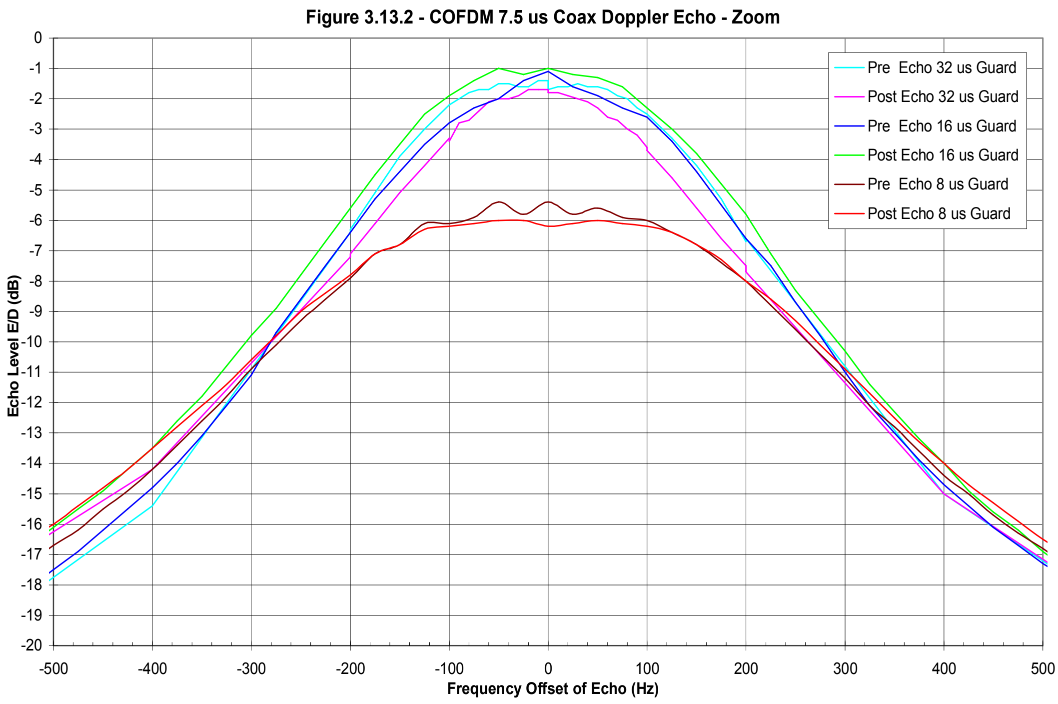


Figure 3.13.2 - COFDM Doppler Echo Performance ±500 Hz

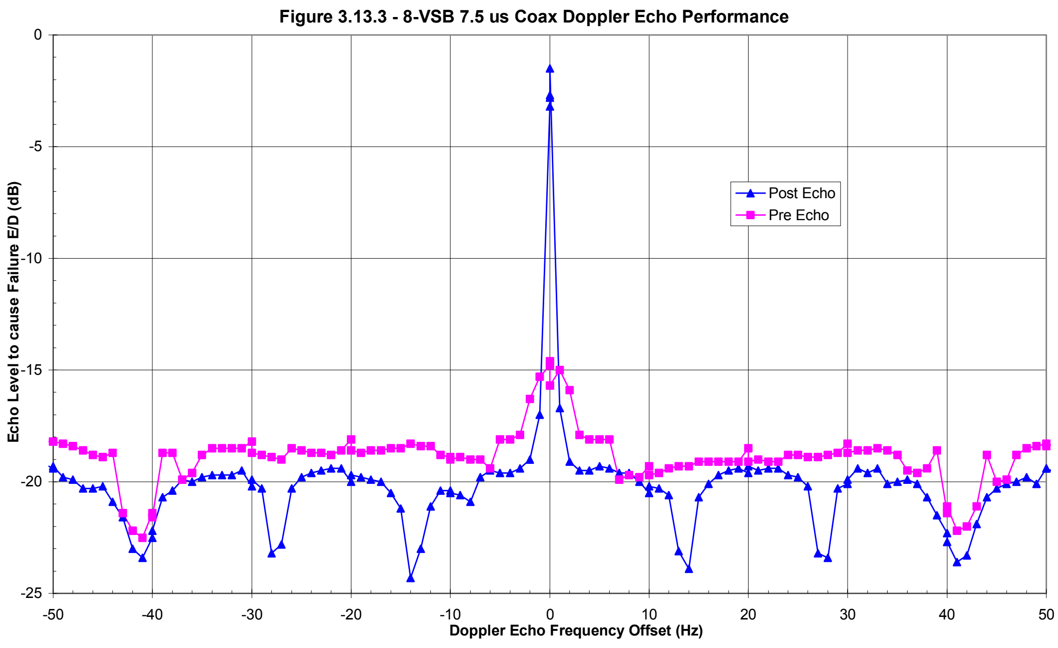


Figure 3.13.3 - 8-VSB Doppler Echo Performance ±50 Hz

Figure 3.13.3 is a plot of the close in 8-VSB doppler performance for both pre and post echo signals. The 8-VSB system cannot handle pre echoes beyond 3 us so the best doppler performance for this situation is the system C/N threshold, however the doppler performance is less than ±1 Hz with a zero doppler echo level of 2-4 dB being achieved. The cyclic dips in the doppler echo level correspond to critical frequencies which are interacting with the receiver equaliser tap size.

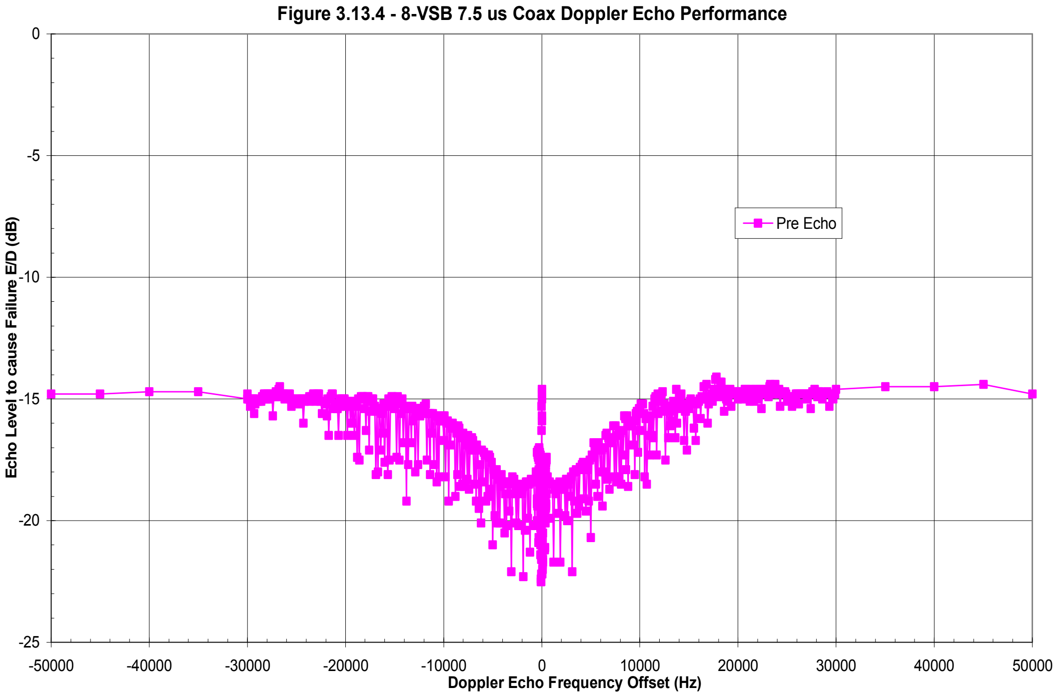


Figure 3.13.4 - 8-VSB Doppler Pre Echo Performance

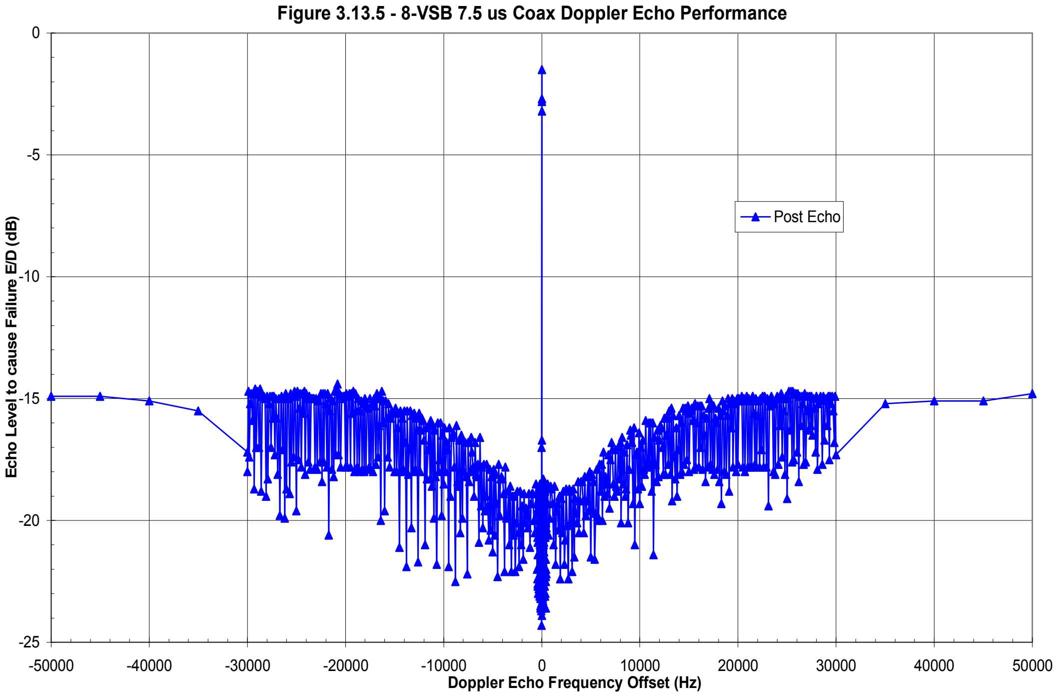


Figure 3.13.5 - 8-VSB Doppler Post Echo Performance

Figure 3.13.4 and Figure 3.13.5 individually show the wider frequency doppler echo performance with the echo level asymptoting to the system C/N threshold between 20 and 30 kHz.

It was found that, when measuring the 8VSB system in the area of 1 Hz offset, as the measurement changed from a post echo to a pre echo the

8VSB receiver would not respond to even a perfect unimpaired signal. It was as if the receiver had locked into a specific equalisation point. The only way to free the receiver from this condition was to remove the input signal entirely, causing the receiver to begin it’s AFC range scan, and then reapply the DTTB signal. Consultation with Zenith indicates that the equaliser may be entering a “blind” mode during these conditions.

3.14Transmitter Compression Performance

The transmitter compression performance is a measurement of the receiver's reaction to compression and non linear intermodulation in a high power PA operated beyond its normal power level. This measurement is useful in determining the ability of an amplifier to increase the range of a digital signal through increased power output and to determine what the maximum useful power level is.

A point is reached where the increase in intermodulation for a given increase in power does not improve the carrier to noise for a receiver located at the edge of the service area. This sets an operational limit for the particular amplifier. Precorrection can be applied to extend the performance beyond the limit set by the intermodulation distortion, however this measurement was intended to characterise a typical transmitter without elaborate correction.

The compression performance is measured by measuring the minimum received signal level of the receiver at various levels of transmitter overdrive.

A maximum safe operating power level was determined for the transmitter and then the transmitter was driven to this level into a dummy load with the AGC off. The test sample signal was fed into the measurement rig and calibrated to 27.6 dBm at the receiver by adjusting the direct signal level calibration attenuator.

The transmitter drive level was then reduced by 20 dB and the minimum signal level measured. The transmitter drive was increased in progressively smaller steps until the previously calibrated maximum power level was reached. Care was taken not to run the transmitter over normal power for any extended time and immediately after the test completed the computer reduced the power level to 5 dB below maximum.

After the test was completed the transmitter pre-correction was switched off and the measurement completed again.

The minimum signal level that had been measured for the rig was used as the baseline for the minimum signal level measurement and all values were plotted relative to this value. Ideally at maximum transmitter output the plot should intersect with the X axis of the plot.

Figure 3.14.1 and Figure 3.14.2 show the results of this measurement operating with each of the test transmitters for each DTTB modulation type. Where the curves begin to deviate from a linear progression is the point where the receiver is starting to be affected by on channel intermodulation products. The Harris transmitter curve for COFDM modulation in Figure 3.14.1 shows that operating this transmitter above 28 dBW will not further assist the receiver which is at the edge of the service area, and only waste power. The measurements documented in Figure 3.14.1 were conducted in April and do not show an optimum pre-corrector alignment which was subsequently done by Harris during the 8-VSB testing. Figure 3.14.2 shows the extension in performance that can be gained when the pre-corrector is correctly aligned.

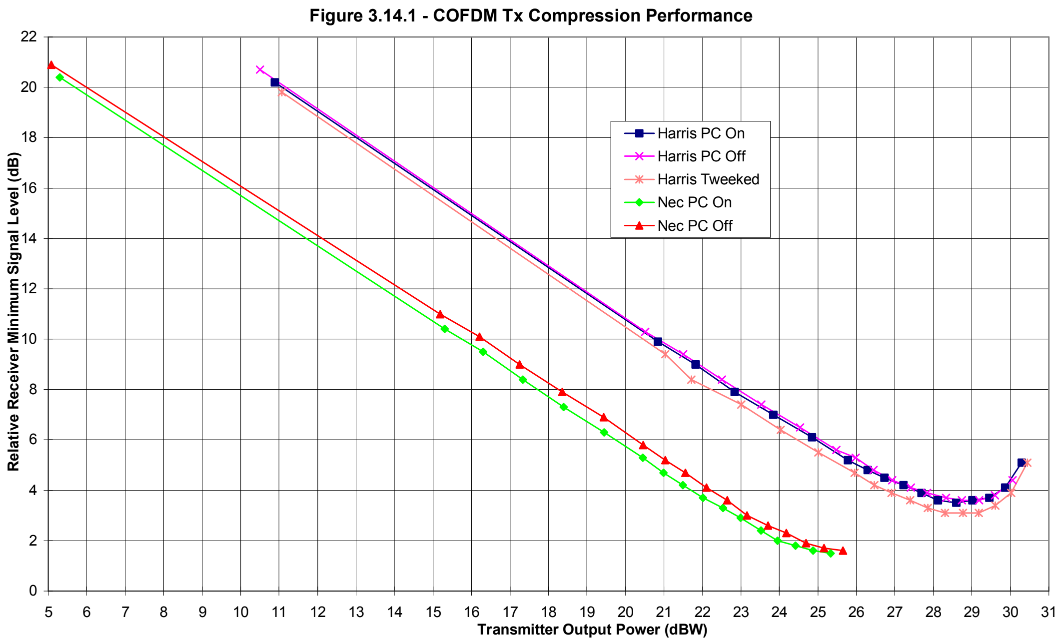


Figure 3.14.1 - COFDM Transmitter Compression Performance

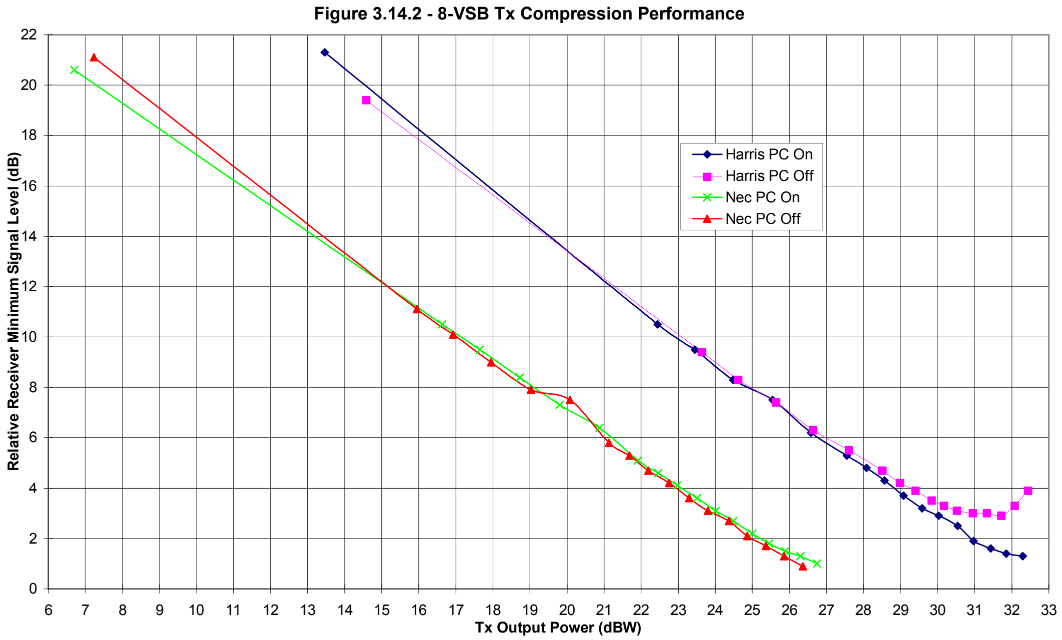


Figure 3.14.2 -8-VSB Transmitter Compression Performance

DTTB System	NEC 200 W Tx	Harris 1 kW Tx
COFDM	24.5 dBW = 280 W	27.8 dBW = 605 W
8-VSB	26.5 dBW = 450 W	30.5 dBW = 1125 W

Table 3.14.1 - Maximum DTTB Power with no correction

For the two transmitters tested with the correction off Table 3.14.1 indicates the maximum power level for each modulation type.

Note the Harris transmitter was rated for 8-VSB operation and the NEC transmitter was rated for ODFM operation.

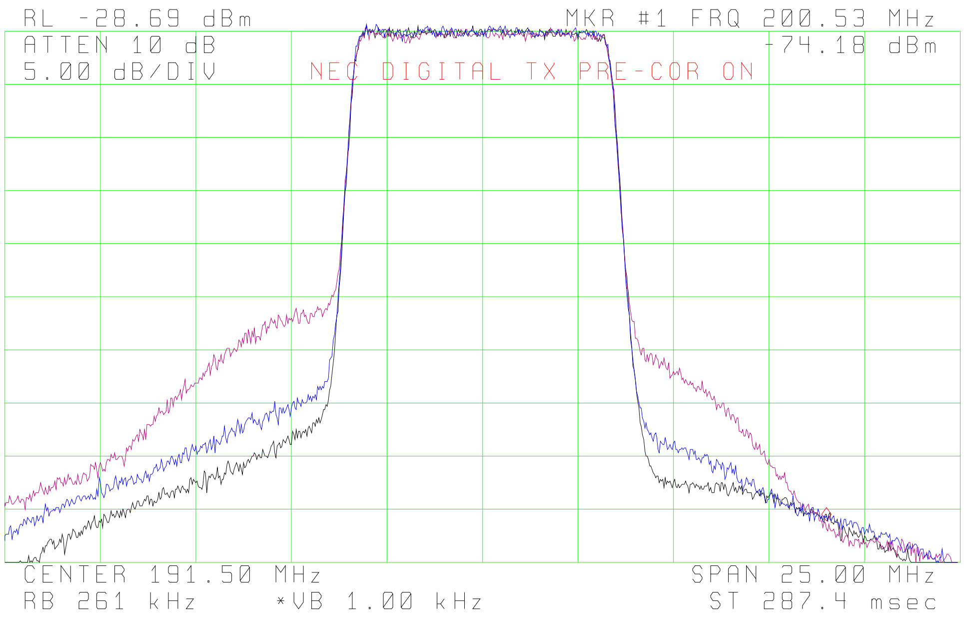


Figure 3.14.3 - COFDM NEC Tx @ 200 W ±3 dB

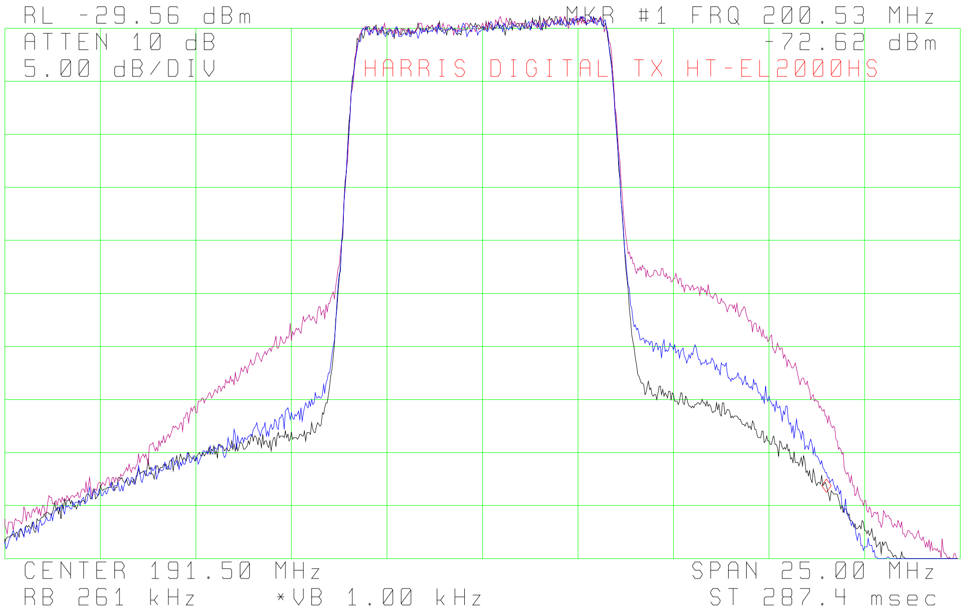


Figure 3.14.4 - COFDM Harris Tx @ 500 W ±3 dB

Figure 3.14.3 and Figure 3.14.4 show the NEC and Harris transmitters COFDM spectrum when operated 3 dB above (violet) and below (black) their nominal power with the pre-correction active. The nominal power for the Harris transmitter was reduced to 500 W as it is obvious from the compression curve that the 1 kW nameplate rating refers to 8-VSB operation. The shoulders immediately outside the channel give some indication of the on channel intermodulation products. Generally when the shoulders were less than 30 dB the digital signal was starting to be impaired.

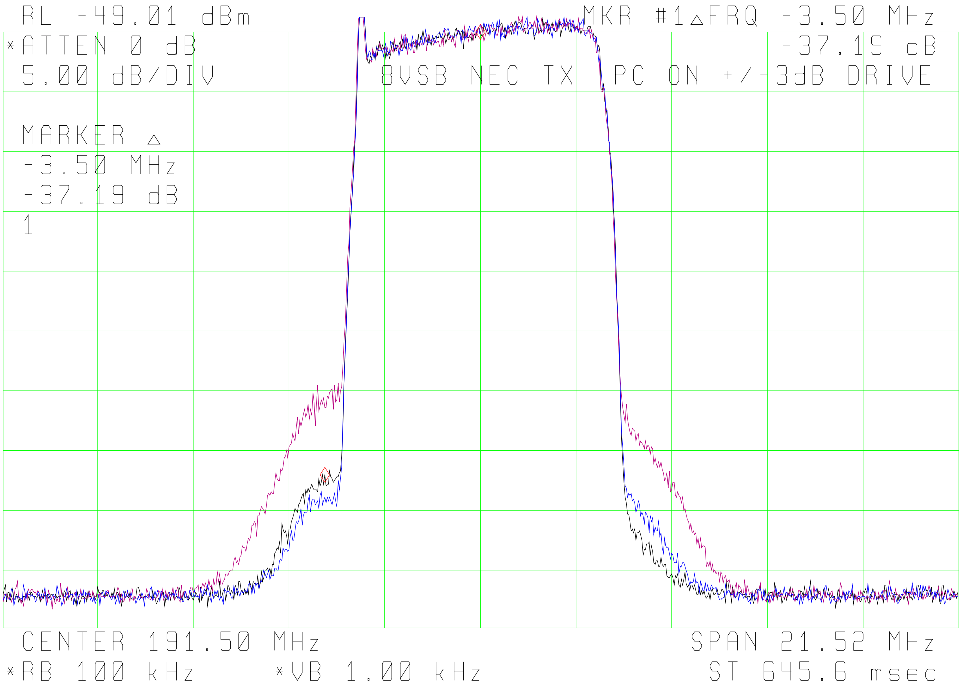


Figure 3.14.5 - 8-VSB NEC Tx @ 200 W ±3 dB

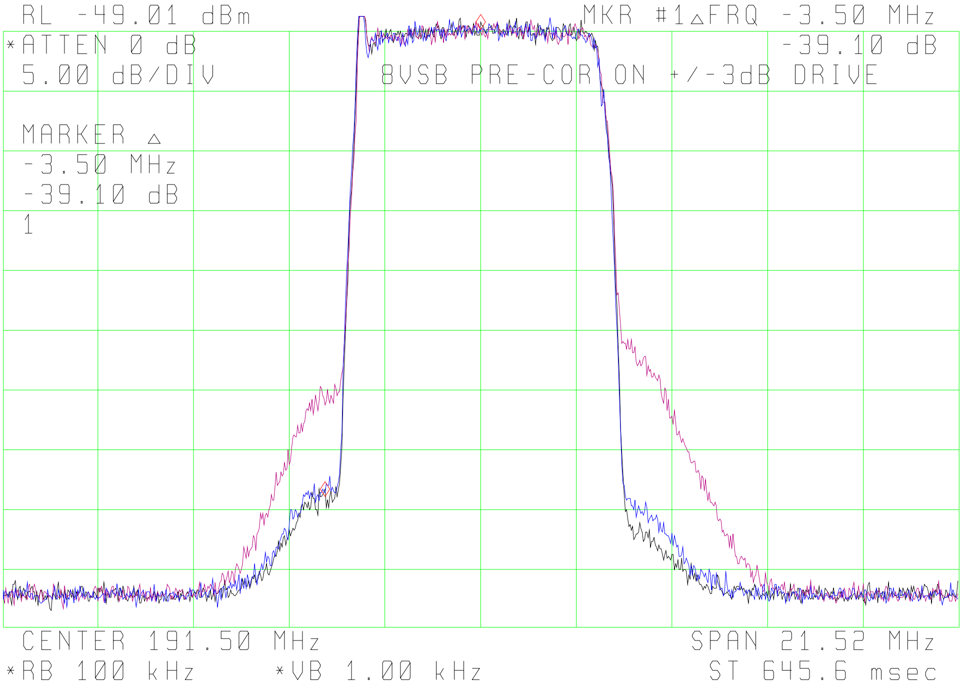


Figure 3.14.6 - 8-VSB Harris Tx @ 900 W ±3 dB

Figure 3.14.5 and Figure 3.14.6 show the NEC and Harris transmitters 8-VSB spectrum when operated 3 dB above (violet) and 3 dB below (black) their nominal power with the pre-correction active.

It is interesting to note that at the 3 dB lower power level the NEC lower shoulder was 2 dB worse than at nominal power.

The out of band shoulder levels for 8-VSB are reduced in comparison with those measured for COFDM as shown in Figure 3.14.3 and Figure 3.14.4.

This is to be expected as there is only a single carrier with modulation at any instant, giving significantly less scope for the generation of IMD products.

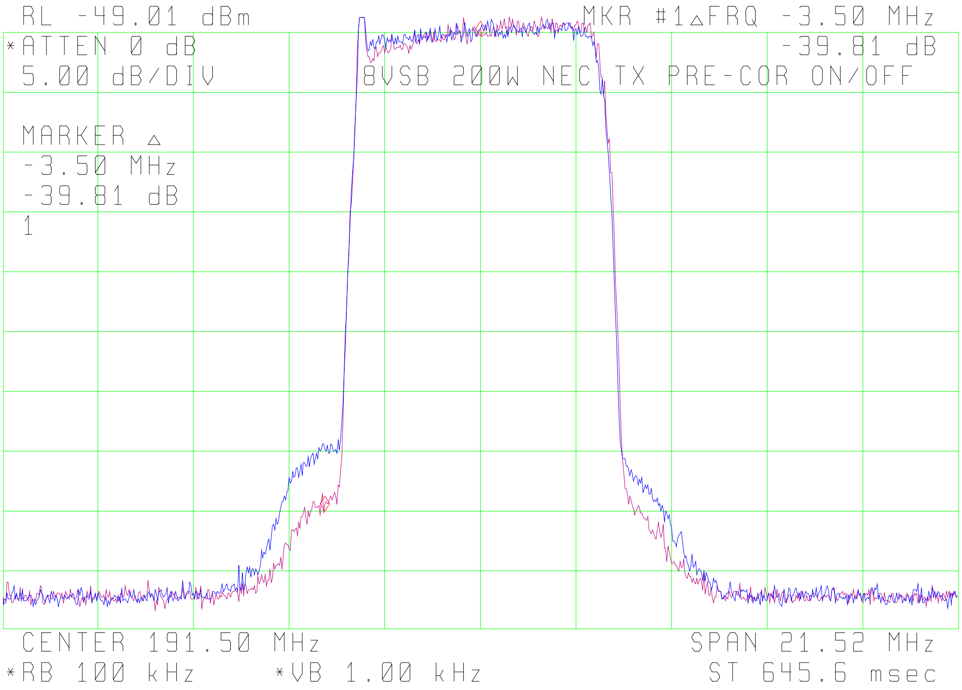


Figure 3.14.7 - 8-VSB NEC Tx @ 200 W Pre Corrector On/Off

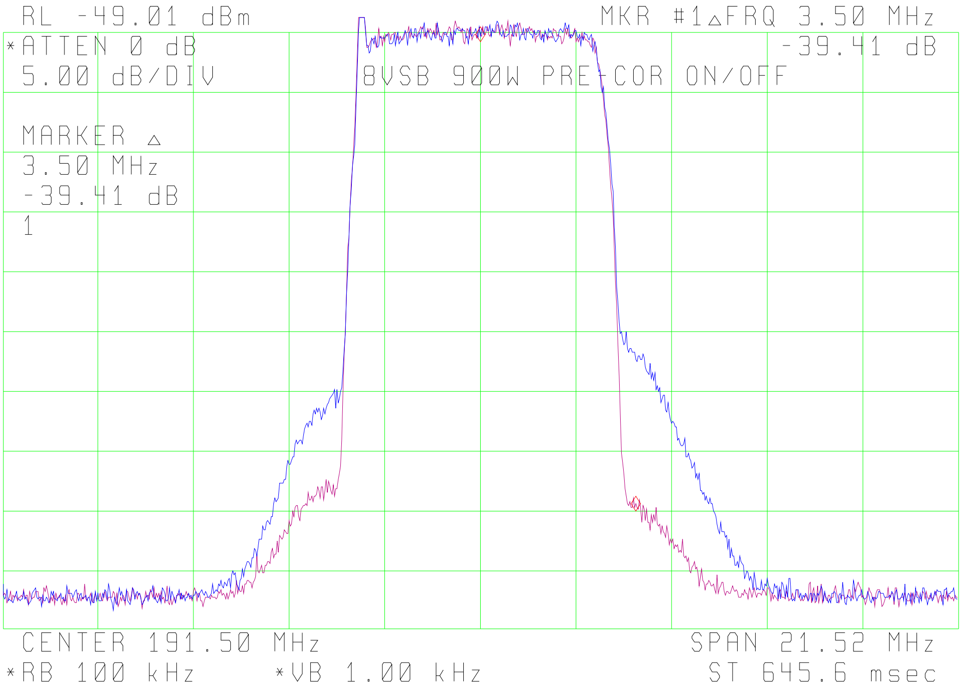


Figure 3.14.8 - 8-VSB Harris Tx @ 900 W Pre Corrector On/Off

Figure 3.14.7 and Figure 3.14.8 show the effect of the transmitter pre-correction with 8-VSB at nominal power for each transmitter. The blue curves show the pre-correction bypassed while the violet curve shows the normal pre-corrector. The Harris pre-corrector is obviously working much harder than the NEC corrector. Regretfully these same plots were not measured during the COFDM compression test.

3.15Transmitter Output Power Calibration

A DTTB signal was applied to the transmitter IF along with the appropriate local oscillator level to achieve operation at the centre of channel 8. A 30 dB 500 W resistive pad was installed on the output of the transmitter and the transmitter drive level backed off 20 dB below the normal power level. A HP436A 30 W Bolometer power head was connected to the load and the transmitter run.

The indicated forward power meter on the transmitter was observed and the Tx drive level attenuator adjusted in 0.1 dB steps to achieve a unit of 10 power level and/or to align the meter needle with a scale marking. The output power indicated on the HP436A was then recorded along with the Forward power. The transmitter was calibrated over the full range of it's indicated power meter.

The calibration was performed separately with AGC both on and off.

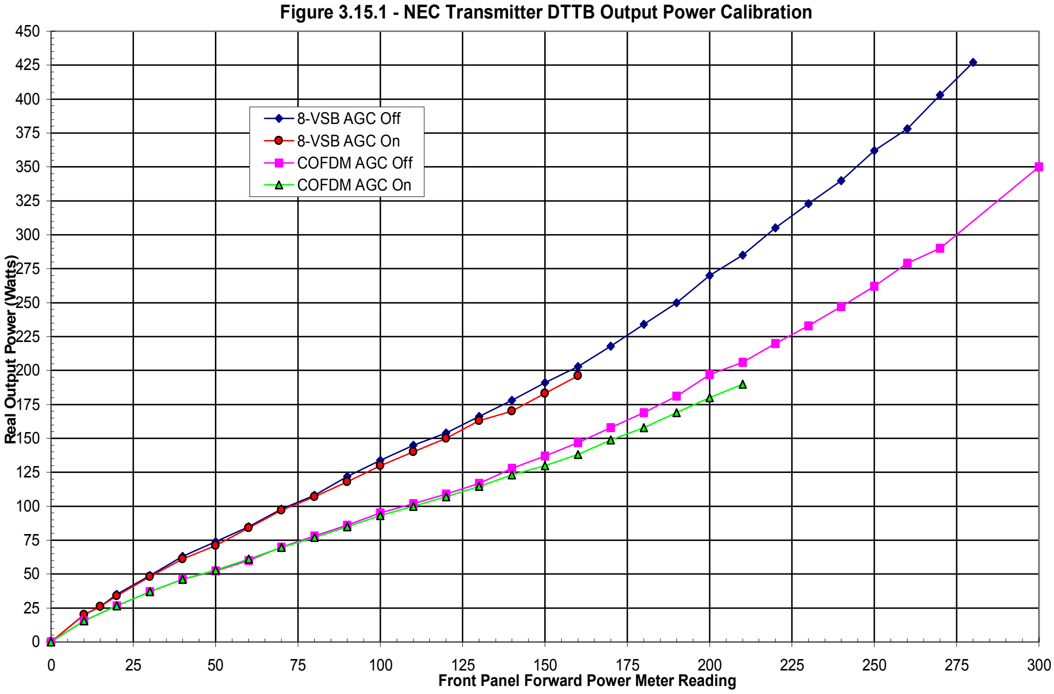


Figure 3.15.1 - NEC Transmitter Power Calibration Curve

Figure 3.15.1 is the calibration curve for the NEC transmitter. Note that the calibration varies dependent on the AGC operation.

Figure 3.15.2 is the calibration curve for the Harris transmitter. Due to the higher power of this transmitter, extended operation above 500 W was not possible into the 500 W 30 dB pad. The transmitter was run for a short period at full power and a calibration of the test port using the HP power meter found that for 1000W digital out (+60 dBm) there is a coupling loss of 40.5 dB. So +19.5 dBm at the test port is equivalent to +60 dBm at the output.

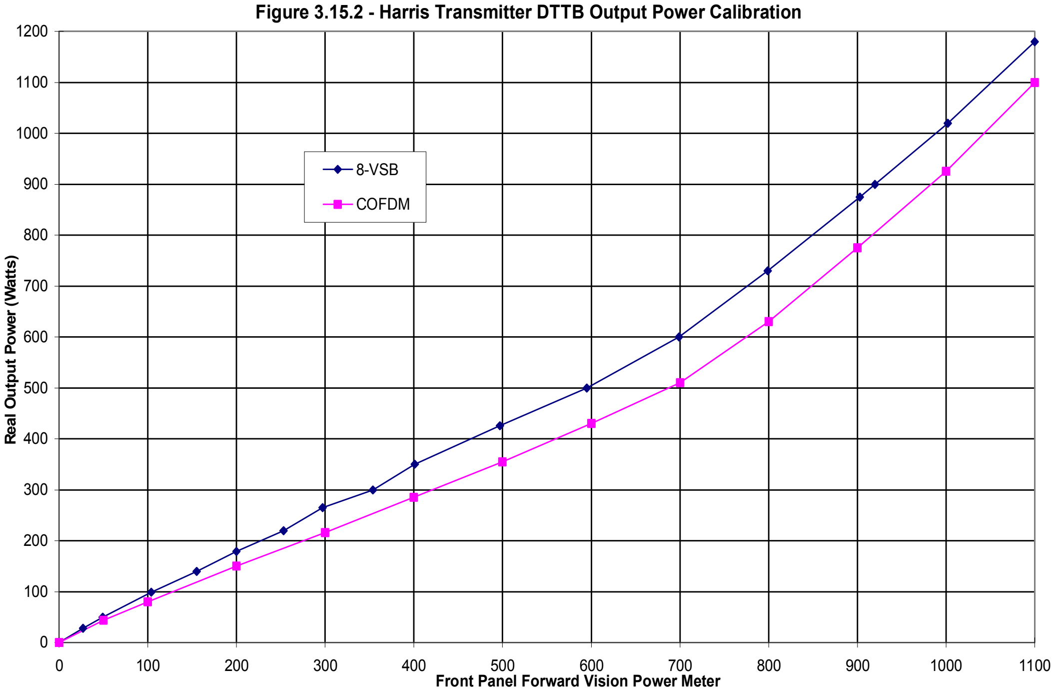


Figure 3.15.2 - Harris Transmitter Power Calibration Curve

3.16Transmitter Shoulder performance

The shoulder performance of the two transmitters was measured running similar power levels on both transmitters. This provided an indicative shoulder performance and out of band emissions of real on-air operation during the field testing phase.

The transmitter was run with a COFDM signal at the nominal power level indicated on the forward power meter into a dummy load. A HP-70000 spectrum analyser was connected to the test port to observe the channel 8 RF signal with a span of 25 MHz so that the upper and lower adjacent channel space was visible. The video bandwidth of the spectrum analyser was set to 3 kHz to provide an averaged noise spectrum and the reference level set so that the centre of the Digital signal was aligned with the top graticule. The scale was adjusted to 5 dB/div and a delta marker used to indicate the centre channel and upper channel limit positions corresponding to the shoulder measurement.

The spectrum analyser trace was stored in memory and spectrum traces repeated for drive levels of ±3 dB about the nominal output level. The attenuation between the test port and spectrum analyser was adjusted in each case to keep the centre of the digital signal co-incident with the top graticule providing a common reference point for the spectrum comparisons. When all three spectrum plots had been stored they were all simultaneously displayed and plotted. The shoulder was measured as the smallest step from the centre channel level to the highest edge of channel position to the nearest dB.

Figure 3.16.1 and Figure 3.16.2 show the shoulder performance of each of the DTTB systems (violet COFDM & blue 8-VSB) operating at 200 W through each transmitter. These measurements were taken with a 4% bandwidth tunable telonic filter on the transmitter output. This filter was used to simulate adjacent channel filtering that would be applied to normal Australian transmission sites. Figure 3.16.3 through Figure 3.16.6 show individual transmitters and modulation types with (blue) and without (black) this filter. Table 3.16.1 details the measurement of these shoulder levels. It is obvious that without the output filter there are out of band emissions extending into the adjacent channels which may cause problems for adjacent services in some situations.

DTTB System	NEC Tx Lower	NEC Tx Upper	Harris Tx Lower	Harris Tx Upper
COFDM	34 dB	36 dB	39 dB	44 dB
8-VSB	39 dB	40 dB	41 dB	43 dB

Table 3.16.1 - DTTB Shoulder Levels @ 200 W for a 7 MHz channel

Note the Harris transmitter is operating over 4 dB below its normal power level during this measurement.

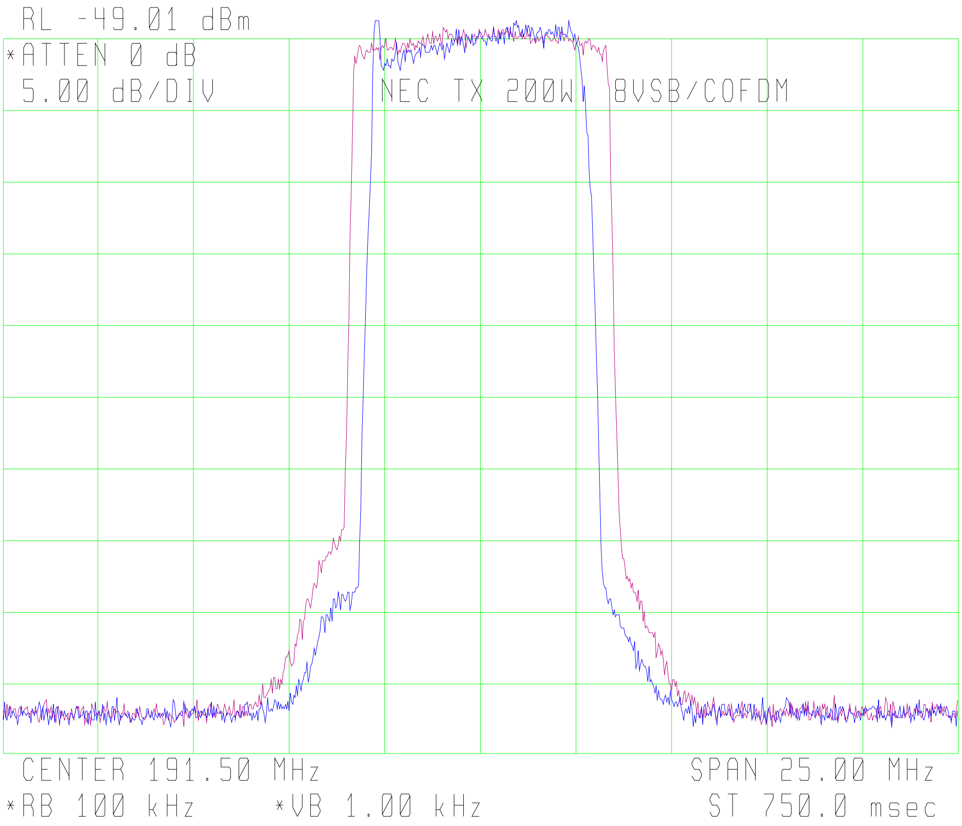


Figure 3.16.1 - Shoulder Plots for 200 W DTTB through NEC Tx

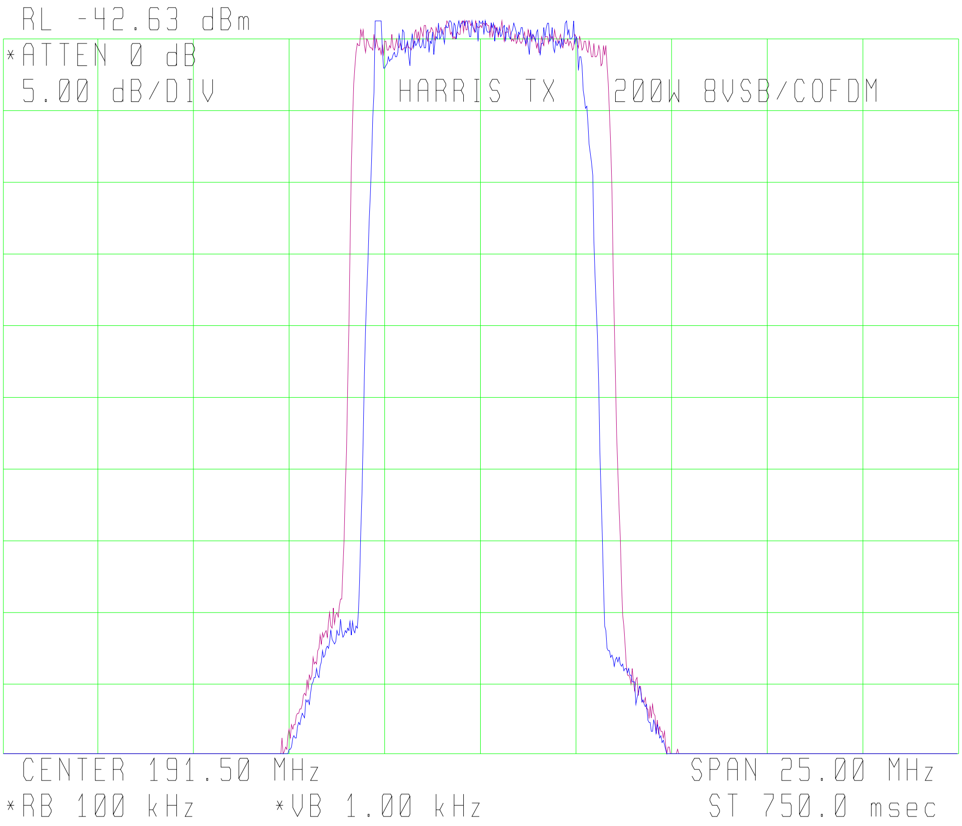


Figure 3.16.2 - Shoulder Plots for 200 W DTTB through Harris Tx

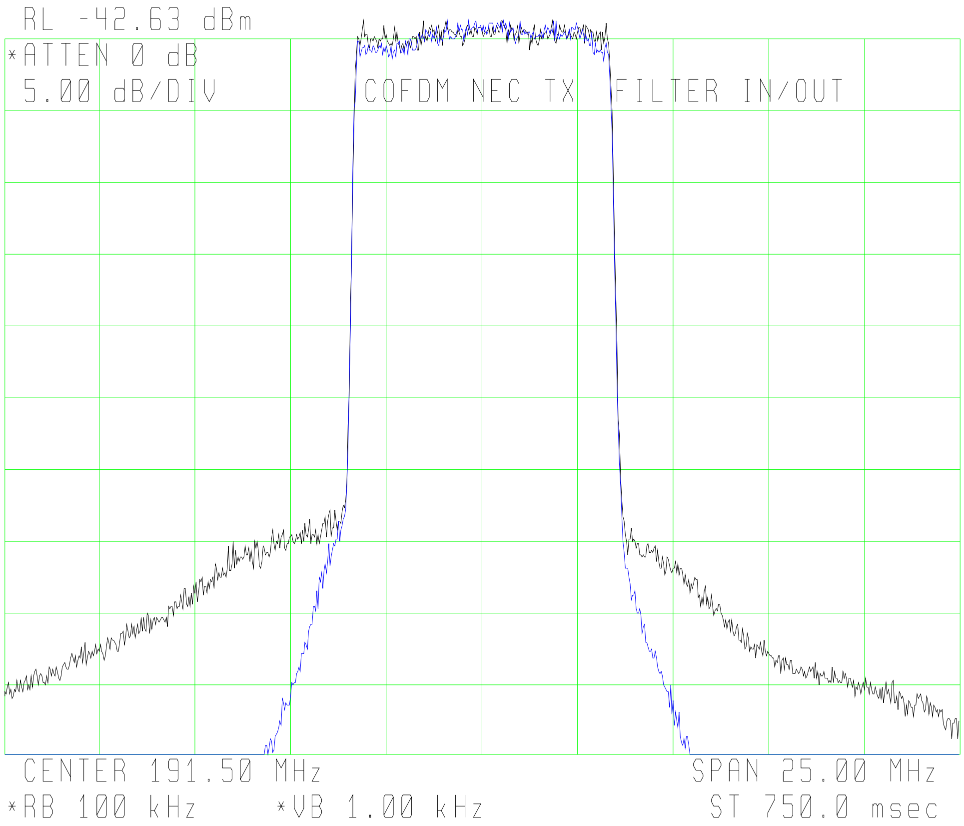


Figure 3.16.3 - Effect of Output Filter on COFDM thru NEC Tx @ 200 W

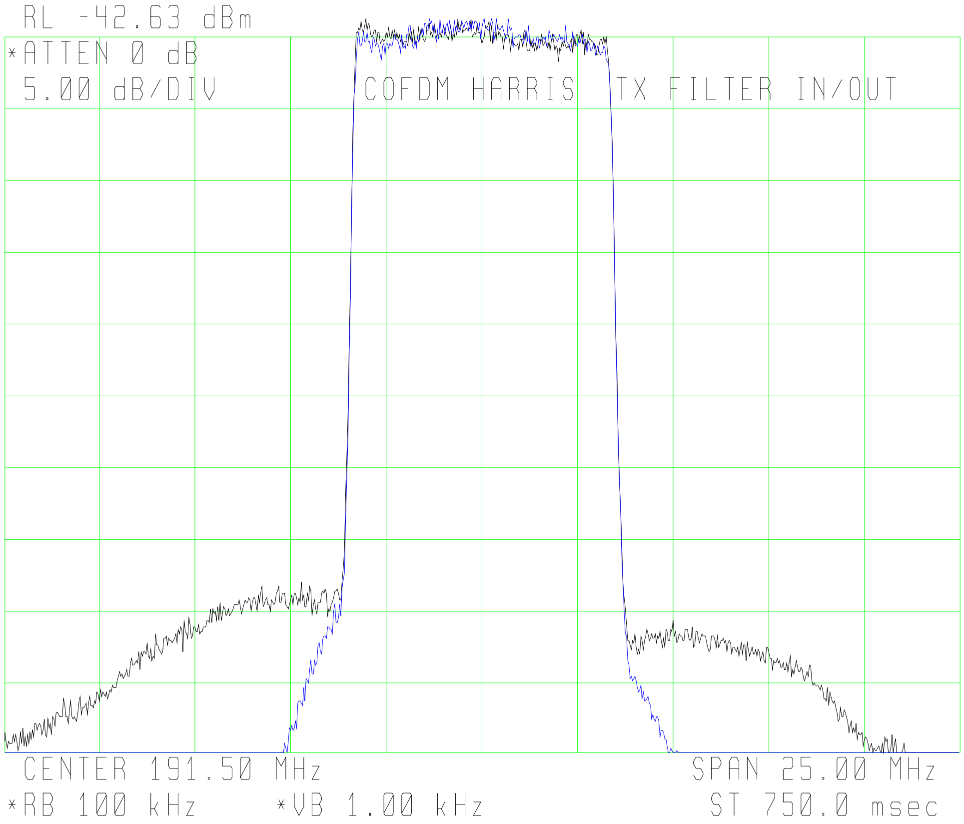


Figure 3.16.4 - Effect of Output Filter on COFDM thru Harris Tx @ 200 W

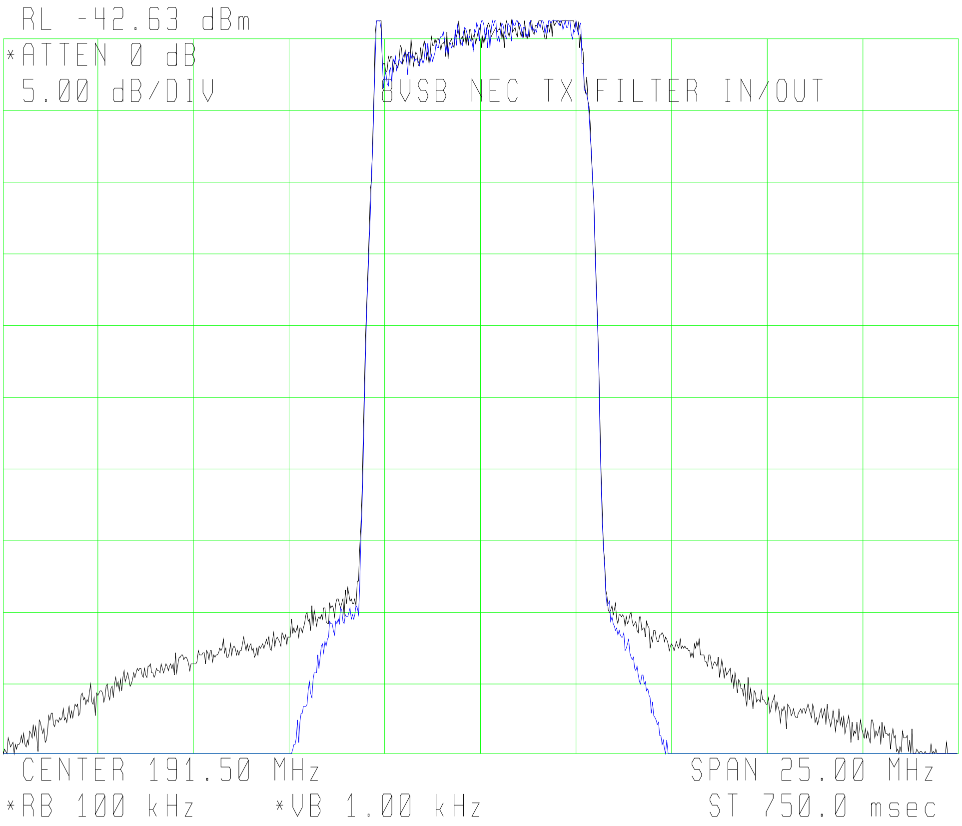


Figure 3.16.5 - Effect of Output Filter on 8-VSB thru NEC Tx @ 200 W

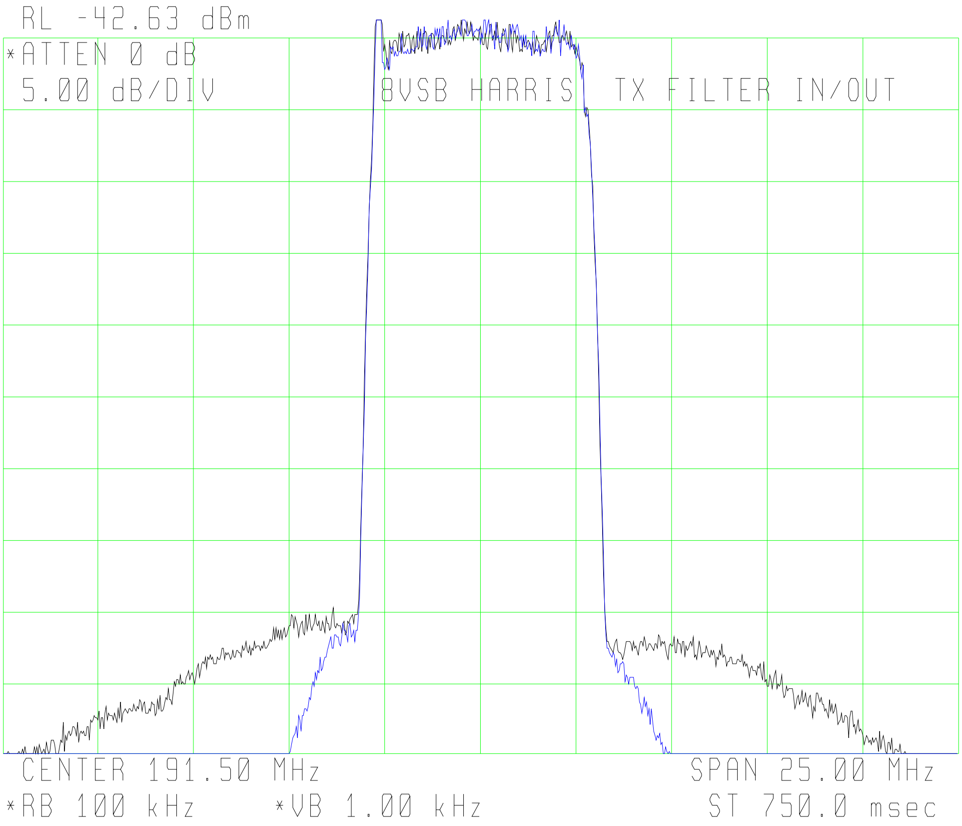


Figure 3.16.6 - Effect of Output Filter on 8-VSB thru Harris Tx @ 200 W

3.17BER vs Signal Level

A measurement of the BER vs minimum signal level characteristic was performed using the following procedure for both DTTB systems. As outlined in section 3.18 the curves for the two systems are not directly comparable and separate parameters were used during the measurement to allow for the differing system error measurement points.

The measurement was performed as follows:

1. The DTTB receiver had its signal supplied from the test rig.
2. A Minimum signal level measurement (Section 3.6) was made to determine the threshold error level due to signal level.
3. The signal level was then decreased below the threshold level by:
   5.0 dB for COFDM and 2.0 dB for 8-VSB
4. The Bit Error Rate was measured in 10^9 data samples for accuracy.
5. The signal level was increased in the following increments.
   0.5 dB for COFDM and 0.1 dB for 8-VSB
6. The measurement was repeated (steps 4-6) until the signal level exceeded the original minimum signal threshold by:
   5.0 dB for COFDM and 0.5 dB for 8-VSB.
7. The data was then plotted.

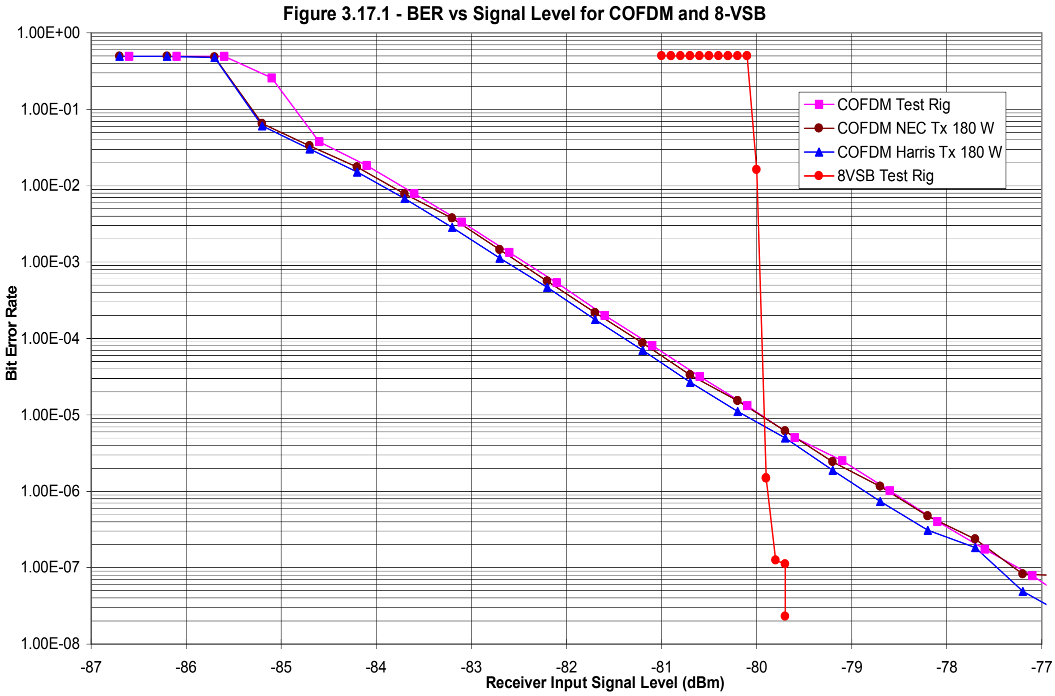


Figure 3.17.1 - BER vs Receiver Signal Level for DTTB

Figure 3.17.1 shows the performance of the DTTB systems with the rig and both transmitters around the 180 W output level.

These plots are typical of the normal performance measured. During the course of the laboratory testing the COFDM VHF receiver had some variation in it's minimum signal performance which was isolated to the tuner input section. Some additional chassis earthing around the tuner was installed and it is also suspected there may be an intermittent RF input cable. The variation observed caused a degradation of up to 2 dB in tuners front end performance.

Figure 3.17.1 also shows the cliff edge output performance of the DTTB systems. This is demonstrated in the 8-VSB plot but will be similar for both systems data output.

The failure point of the 8-VSB system occurred at around 2 dB higher signal level than the COFDM system.

3.18BER vs Carrier to Noise

The BER for varying C/N threshold levels was plotted for both DTTB systems operating through the test rig transmitters and the link. The plots obtained from this measurement give a visual representation of the error failure characteristic of each of the digital systems.

Due to the different error rate measurement methods in the DTTB systems, we cannot make a direct comparison of the curves. The COFDM BER curve is measured before the reed solomon error correction. If it had been possible to do this test after RS error correction a steeper slope similar to 8-VSB would have resulted. Because of this difference, distinct measurement parameters were required for the two modulation systems during this test.

The measurement was performed as follows:

1. The DTTB receiver had its signal supplied from the test rig.
2. A Threshold Carrier to Noise level measurement (Section 3.5) was made to determine the threshold error level due to white noise.
3. The noise level was then increased above the threshold level by:
   5.0 dB for COFDM and 3.0 dB for 8-VSB
4. The Bit Error Rate was measured in 10^9 data samples for accuracy.
5. The noise level was decreased in the following increments.
   0.5 dB for COFDM and 0.1 dB for 8-VSB
6. The measurement was repeated (steps 4-6) until the noise level was reduced to the following levels below the original threshold.
   5.0 dB for COFDM and 0.5 dB for 8-VSB.
7. The data was then plotted.

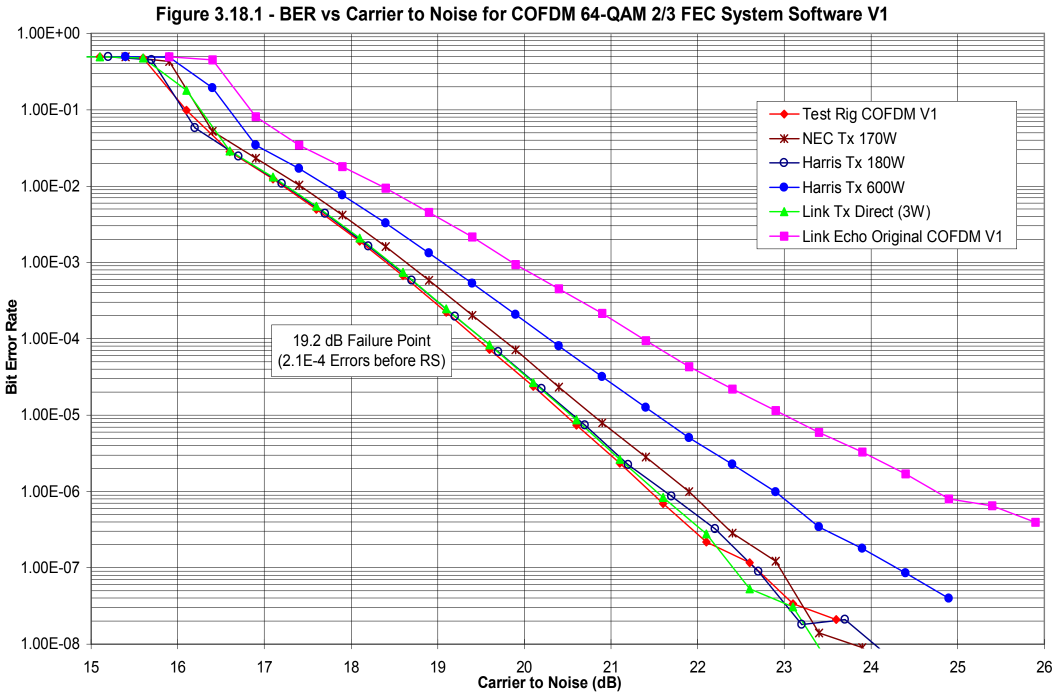


Figure 3.18.1 - BER vs System C/N Threshold for COFDM V1 Software

Figure 3.18.1 shows the performance of the COFDM system with the various devices tested during the main COFDM laboratory testing phase in April. The Harris and NEC transmitter performance is close to that of the test rig alone. The 600W Harris curve shows some degradation in performance which is probably due to the pre-correction not being optimum at this power level. The link echo signal shows a significant C/N penalty. Variation of the guard interval was found to have no effect on the curves measured. The NEC transmitter operating at low power was used as the source for both the Coax (75W) and Link (3W) echo systems.

In May an upgrade to the system software was supplied by NDS to fix an interleaver problem. The system equalisation was left at version 1.0 however a 0.3 dB increase in the system C/N level was observed.

Figure 3.18.2 shows measurements of the BER vs C/N which were conducted after this upgrade. The original test rig curve is provided for reference. A 0.4 dB change in C/N at the failure point is observed for the coax system direct path, which ideally should match the original test rig measurement. It is noted that when the mixer intermodulation, at the link translator, was fixed the COFDM BER performance degraded slightly. It is thought that this result may be experimental error due to the long period which elapsed between these two measurements and the change in system software.

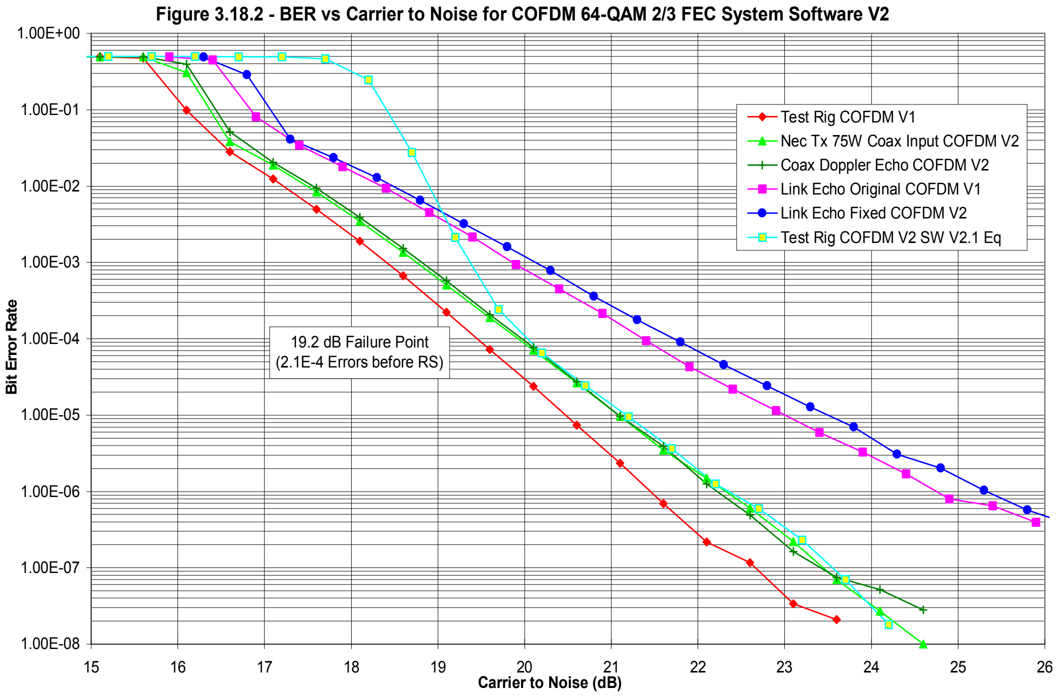


Figure 3.18.2 - BER vs System C/N Threshold for COFDM V2 Software

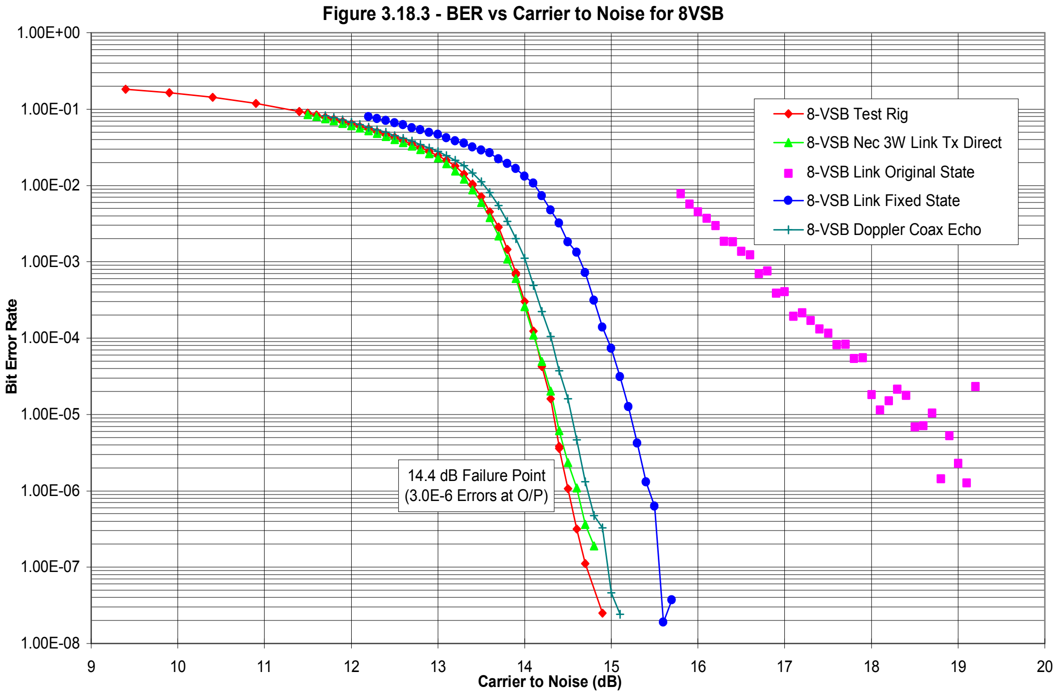


Figure 3.18.3 - BER vs System C/N Threshold for 8-VSB

Figure 3.18.3 shows the performance of the 8-VSB system with the various system configurations. A slight degradation in the performance is observed through the coax delay while the degradation due to the link in it’s early state (mixer intermodulation present) is very significant. Once the link system was improved the link shows a similar slope to the transmitted signal with an additional 1 dB C/N margin.

3.19C/N Threshold vs Signal Level

The C/N margin for varying signal levels was plotted for all COFDM modulation modes as well as 8-VSB. The plots obtained from this measurement give a visual representation of the C/N and noise figure performance of each of the digital receivers.

The measurement was performed as follows:

1. The DTTB receiver had its signal supplied from the test rig.
2. A minimum signal level measurement (Section 3.6) was made to determine the threshold error level due to low signal level.
3. The minimum signal level was then applied and noise injected using the C/N test set.
4. The additional noise level was adjusted to find the error threshold with a resolution of 0.1 dB.
5. The C/N level was recorded and then the signal level was increased by 0.5 dB for COFDM and 0.1 dB for 8VSB.
6. The measurement was repeated (steps 4-6) until the signal level reached normal operating levels. As the signal level was increased above the minimum signal level the step size of each increment increased up to a maximum of 10 dB steps.
7. The data was then plotted.

The bit error rates for this measurement were measured using 10^7 data samples for the initial noise level searches increasing to 10^9 data samples when within 0.2 dB of the final result for accuracy.

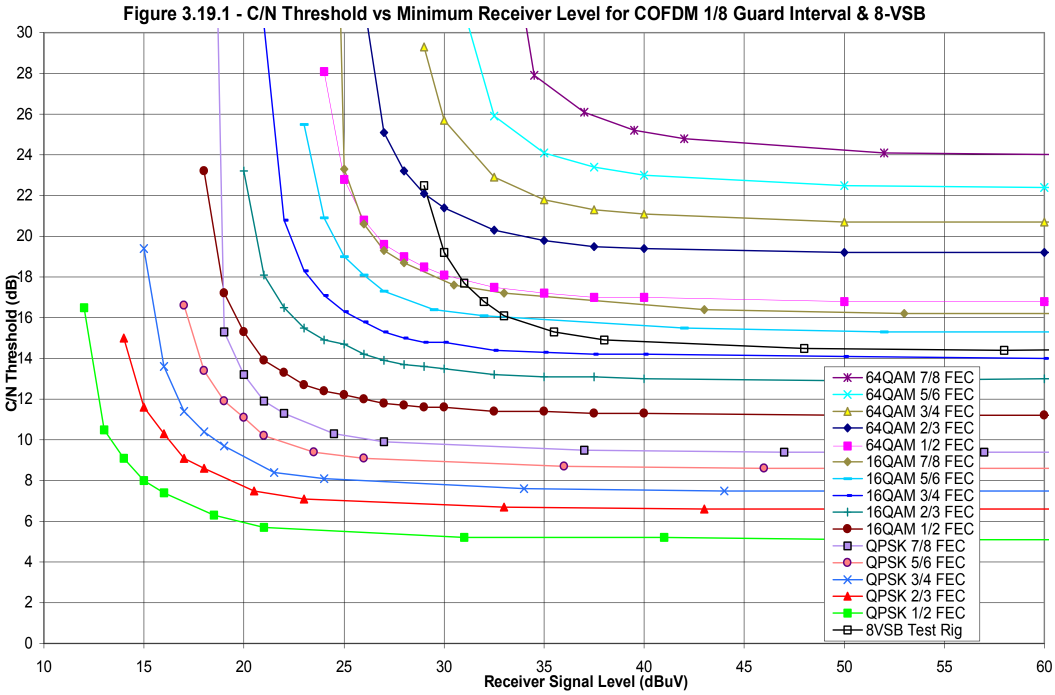


Figure 3.19.1 - DTTB Noise Figure Plot - C/N vs Min Receiver Level

Figure 3.19.1 details the results of this measurement for all the various modulation types. It can be seen that the 8-VSB system performs around the level of COFDM 16QAM 3/4 & 5/6 FEC rates at signal levels above 37 dBuV however below this level 8-VSB degrades around 6 dB earlier than the 16 QAM rates which have comparable C/N thresholds.

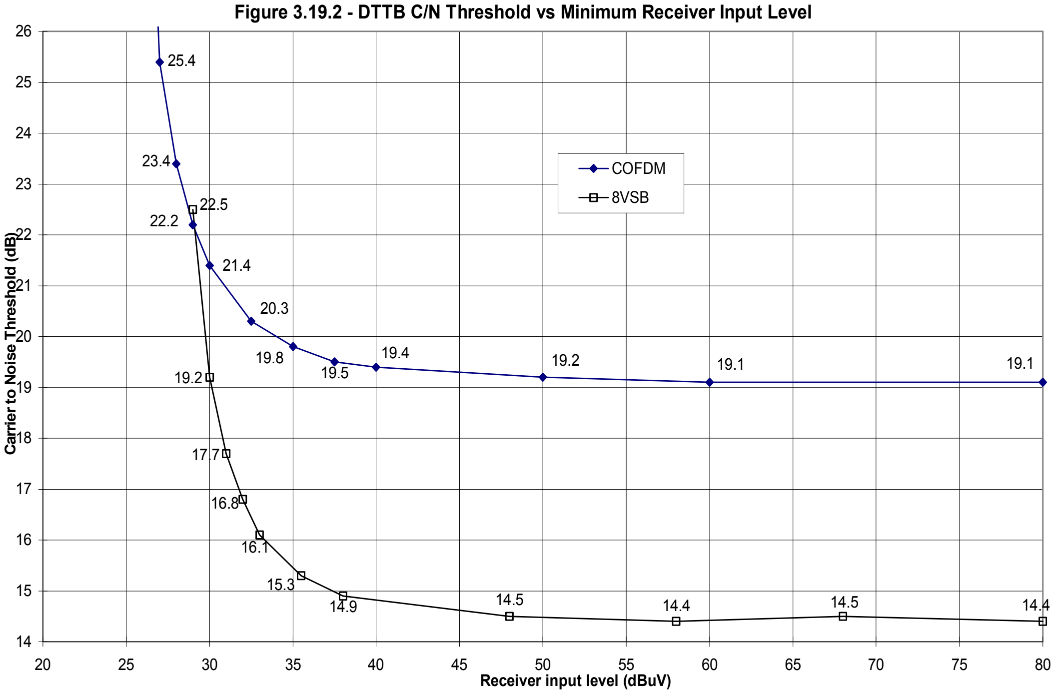


Figure 3.19.2 - DTTB Noise Figure Plot

Figure 3.19.2 shows the plots for COFDM 2/3 FEC and 8-VSB annotated with C/N threshold levels for the measurement points. Both systems have a similar degradation with signal level to the 1 dB excess C/N margin point with 8-VSB achieving 35 dBuV and COFDM achieving 34 dBuV. The 8-VSB system degrades with a steeper slope from this point, this is due to it's higher noise figure. Curves were plotted for varying COFDM guard intervals, however no variation was in performance was observed.

Although the 8-VSB system has a better system C/N against the COFDM system being evaluated the higher noise figure of the 8-VSB receiver offsets this performance gain in the low signal performance area.

3.20Loss of Lock measurement

The error indicators on the DTTB receiver were observed as the white noise level applied to the receiver was increased. Changes in locking condition were noted as they occurred.

Regrettably this measurement was not able to be performed with the 8-VSB equipment.

The DMV receiver has a total of 6 red LEDs on the rear panel whose functions are indicated in Table 3.20.1. The output error LED followed the operation of the front panel alarm indicator, however this test focused on LEDs 2-5. As the C/N during the test was below 19 dB LED 1 indicated output errors were present for all values measured in the test.

LED 1	Output Error
LED 2	TPS - Transmission Parameter Signalling
LED 3	AGC - Automatic Gain Control
LED 4	AFC - Automatic Frequency Control
LED 5	TREC - Timing Recovery (Clock)
LED 6	Reset

Table 3.20.1 - Functions of COFDM Demodulator Error LEDs

It was found that the loss of lock occurred around 4 dB C/N. Measurements were made to 1 dB C/N. Noise levels beyond 0.5 dB C/N were not available without modification to the test rig. LED 3 indicated the AGC remained locked for the entire test. The status of the three remaining LEDs 2,4 & 5 is graphically represented in Figure 3.20.1

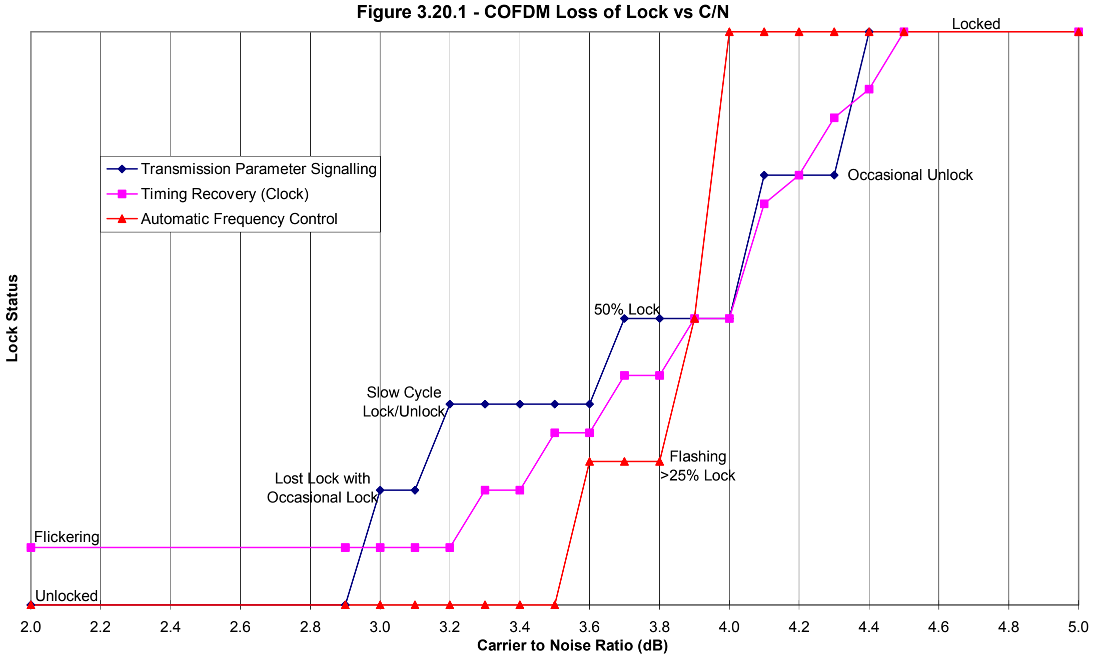


Figure 3.20.1 - COFDM Loss of Lock vs C/N

The flickering of the timing recovery LED below 3.2 dB indicated the clock PLL was scanning trying to lock to this point. Solid lock did not occur until 4.5 dB C/N. The AFC starts to acquire lock at 3.5 dB and is locked at 4 dB C/N. The TPS is transmitted on selected highly protected pilot carriers within the COFDM system. As TPS indicates the modulation type and FEC parameters for the system it is arranged to be more robust than the most rugged system mode (QPSK 1/2 FEC). TPS lock starts at around 3 dB and is solidly locked at 4.4 dB C/N.

3.21Variation of basic parameters with software upgrade

In May 1997 a later version of the COFDM software was provided to achieve full DVB compliance. The system software change from Version 1 to Version 2 involved changes to the interleaver algorithm. A new receiver equaliser v2.0 was also suppled and a re-measure of the basic system parameters was carried out as the various segments of this software were installed. The basic performance parameters measured were Carrier to Noise, Minimum signal level & echo performance. The receiver minimum signal level was found to be very sensitive to earthing around the receiver area, so some variation in minimum signal level was noted, even without a software change being effected. Table 3.21.1 details the measured parameters for the VHF receiver. The version 2.0 equaliser software has caused the system C/N threshold to increase by around 0.8 dB. There is a 4.5 dB change in the co-channel interference performance and maybe a 1 dB change in the echo performance however it was judged that the degradation in C/N performance was a high penalty to pay for this. As the field trials were unlikely to encounter significant co-channel interference it was decided to leave the version 1.0 equaliser installed in the receiver for the field tests.

Encoder and Receiver Software	V1	V1	V2	V2
Receiver Equaliser Software	V1.0	V2.0	V2.0	V1.0
Minimum Signal Level (dBm)	-80.8	-79.8	-80.2	-81.9
Minimum Signal Level (dBuV 50 Ohms)	26.2	27.2	26.8	25.1
System C/N Threshold (dB)	19.1	19.9	19.9	19.3
Calculated Rx Noise Figure (dB)	5.6	5.8	5.4	4.3
Lower Adjacent Ch (dB)	-35.0	-35.7	-36.7	-36.4
Pal/Cofdm Co Chan Max (dB)	3.7	-3.1	-4.4	2.6
Pal/Cofdm Co Chan Centre (dB)	1.2	-3.1	-3.9	0.6
Upper Adjacent Ch (dB)	-37.6	-38.0	-39.1	-38.5
17.2 us Post Echo (dB)	8.5	10.5	9	8.2
17.2 us Pre Echo (dB)	2.8	2.6	2.4	3

Table 3.21.1 - Effect of Software on VHF Rx System Parameters

While these measurements were being made the field vehicle was being set up and the VHF receiver was required for testing in the field vehicle. During this period the UHF receiver was measured with the software as it was upgraded. Unfortunately as the rig was set up for VHF operation, CCI and echo measurements were not available. Table 3.21.2 details the results of the UHF receiver's basic parameters and their variation with the new software. A 0.5 dB increase in the C/N threshold was also observed with the UHF receiver.

Encoder and Receiver Software	V1	V1	V2	V2
Receiver Equaliser Software	V1.0	V2.0	V2.0	V1.0
Minimum Signal Level (dBm)	-76.7	-76.3	-77.2	-78
Minimum Signal Level (dBuV 50 Ohms)	30.3	30.7	29.8	29.0
System C/N Threshold (dB)	20.2	20.7	20.6	20.2
Calculated Rx Noise Figure (dB)	8.6	8.5	7.7	7.3

Table 3.21.2 - Effect of Software change on UHF Rx System Parameters

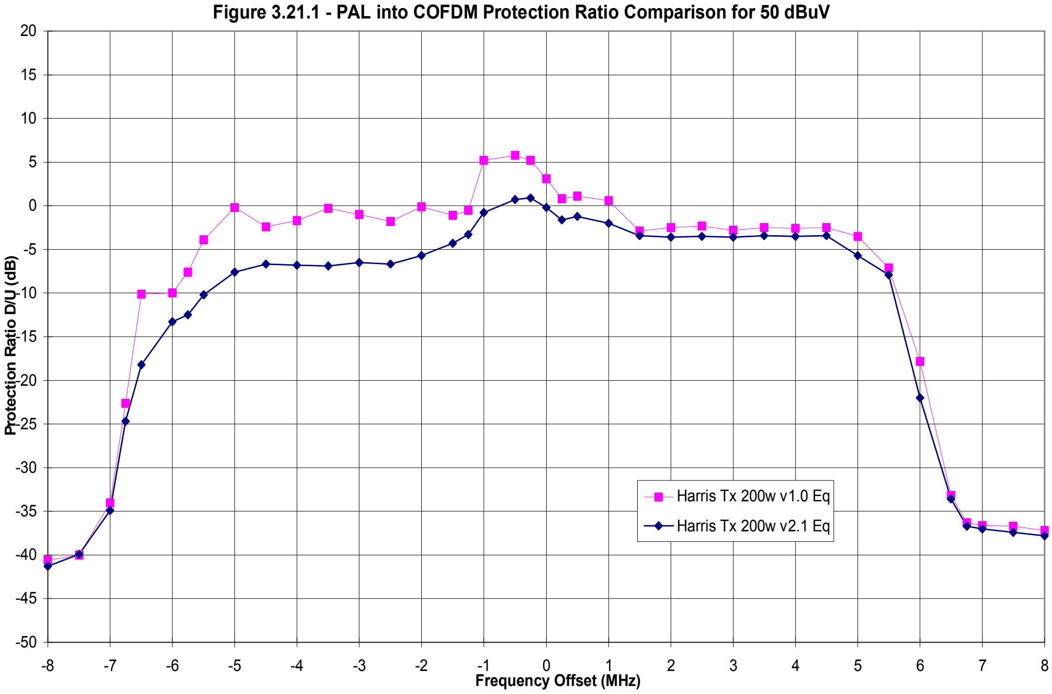


Figure 3.21.1 - PAL into COFDM protection for different software equalisers

Figure 3.21.1 shows a PAL into COFDM interference protection plot through the Harris Tx at 200W with the version 1.0 and version 2.1 equalisers. Co-channel performance improves by 3 dB while adjacent channel performance remains the same. The system responds to the PAL sound carriers much better however this is not a major factor in a real system implementation.

Figure 3.21.2 below shows the CW into COFDM performance for the similar comparison. No significant difference in performance is observed in this plot.

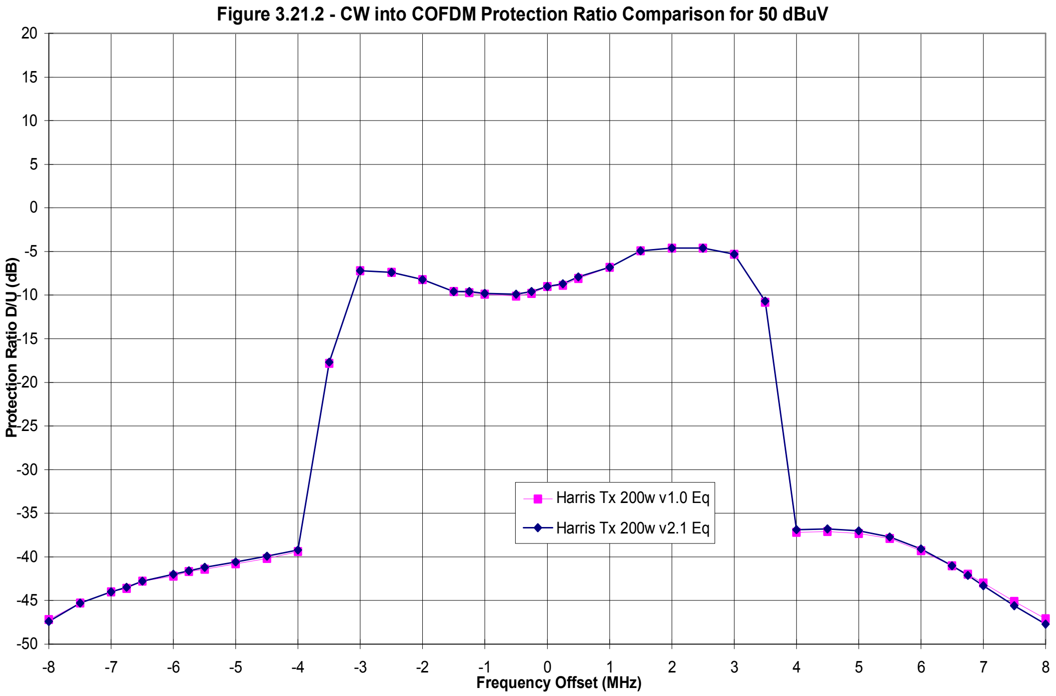


Figure 3.21.2 - CW into COFDM protection for different software equalisers

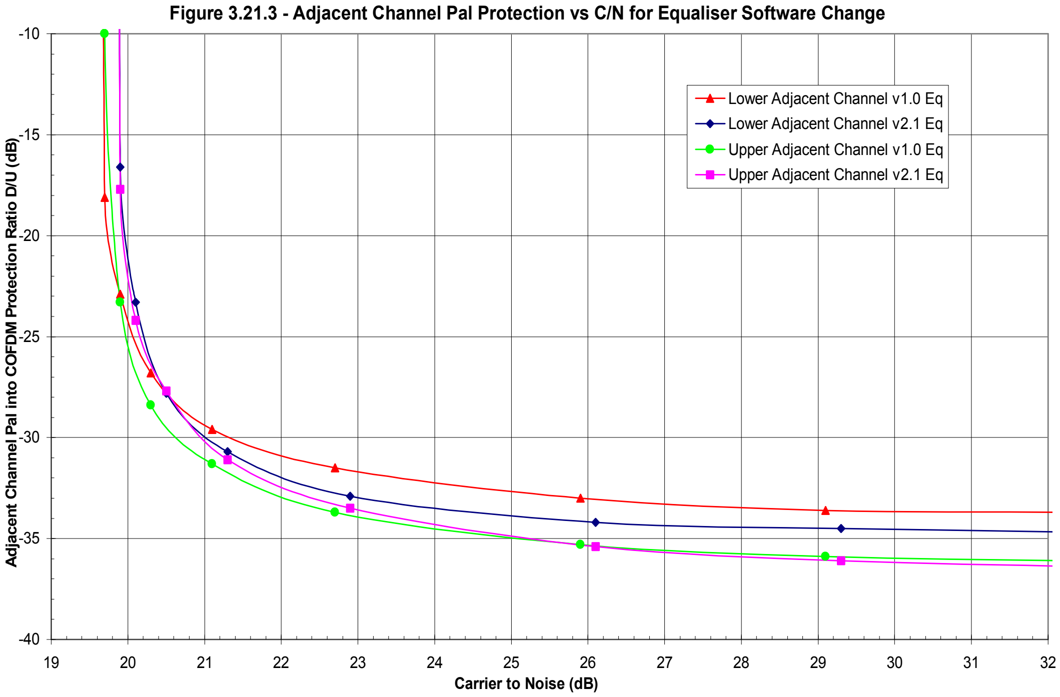


Figure 3.21.3 - Adjacent Channel Protection vs C/N for Equaliser Software Change

Figure 3.21.3 shows the COFDM system sensitivity to adjacent channel PAL interference in the presence of a low C/N. It would appear that the version 1.0 equaliser is around 1 dB better in the lower adjacent channel.

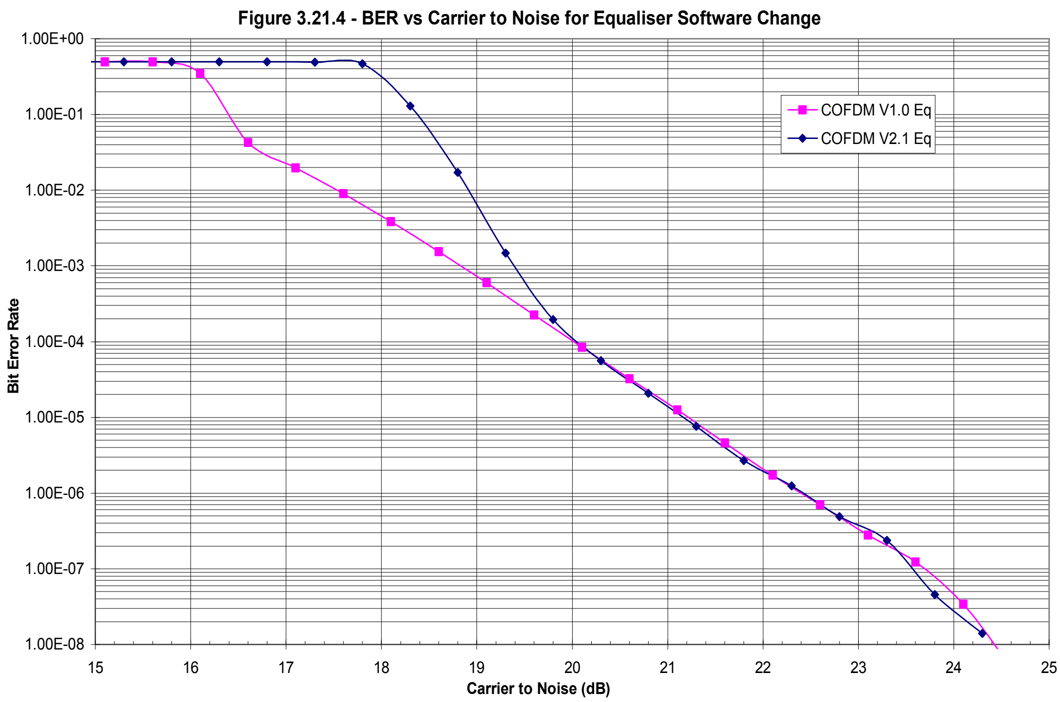


Figure 3.21.4 - BER vs C/N for Equaliser Software Change

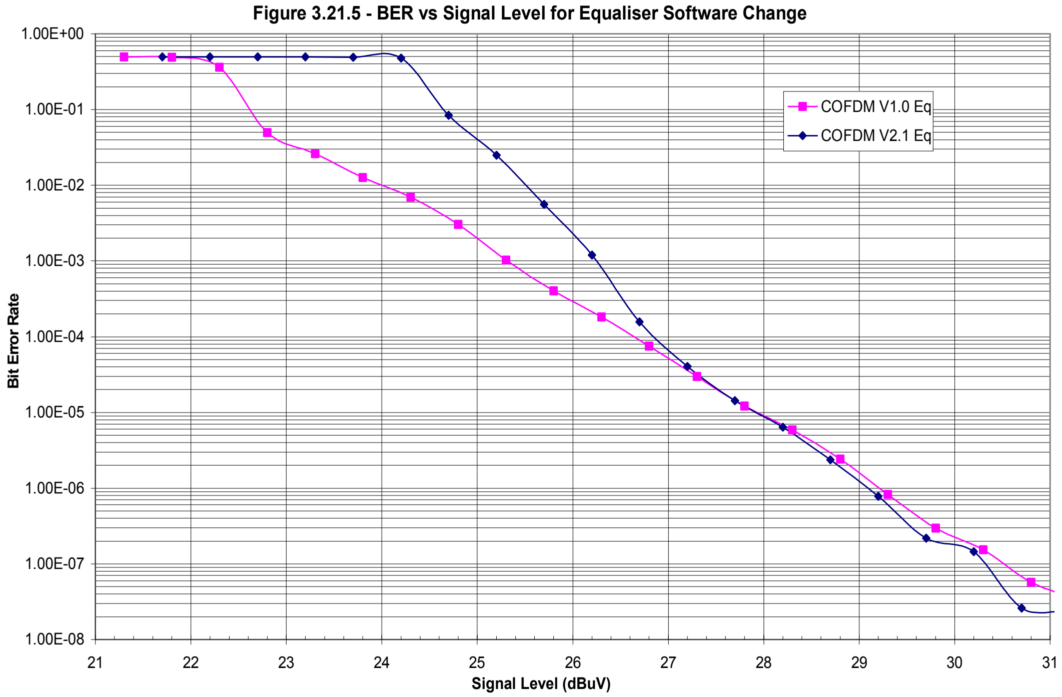


Figure 3.21.5 - BER vs Signal Level for Equaliser Software Change

Figure 3.21.4 and Figure 3.21.5 show the difference in BER characteristic between the new and old equalisers. The crash rate of the system in the high error rate area, below the system failure point, has been increased to improve the overall system performance.

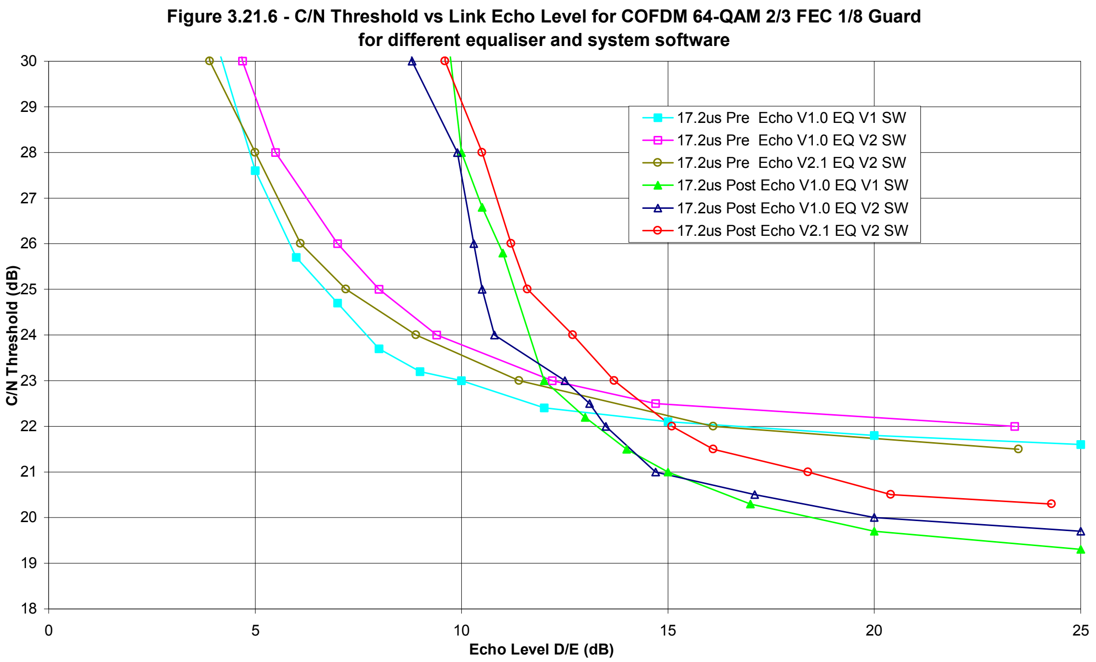


Figure 3.21.6 - COFDM C/N vs Link Echo Level for Software Upgrade

Figure 3.21.6 compares the C/N vs Echo level on the link for the Software changes. The overall echo performance of the new equaliser is about the same with the post echo not as good at low C/N levels.

3.22Off Air Channel 7 & 9 PAL into Channel 8 COFDM

As VHF channel 7 and 9 are transmitting in the vicinity of the Communications laboratory, where the test program was conducted, these off air signals were used to interfere with the DTTB systems to measure their adjacent channel protection in the presence of concurrent upper and lower adjacent PAL transmissions.

The following test procedure was adopted:

1. Off air signals from a VHF yagi on the lab roof were directly connected to the PAL/CW level attenuator in place of the normal interferers and the attenuation set to zero.
2. The Vision carrier levels of both Channel 7 & 9 were measured on the spectrum analyser before and after the DTTB protection level measurements.
3. A channel 8 DTTB signal from the rig was then mixed with the off air signals and attenuated until the DTTB receiver reached the appropriate error rate failure point.
4. The attenuation was recorded and protection to each of the Off air PAL channel vision carriers recorded.
5. The offset of the DTTB receiver was then changed, the rig LO adjusted to match the new DTTB centre frequency and the measurement repeated.
6. When a complete scan of the offset range was complete, 3 channel spectrum plots were recorded at the DTTB failure point.

In this manner the DTTB receiver was scanned across its offset range overlapping the off air PAL transmissions. From these measurements Figure 3.22.1 of adjacent channel protection with offset frequency was obtained. Note that the channel 7 signal only has a single monophonic sound carrier 10 dB below the vision carrier rather than the normal stereo pair 13 & 20 dB down. Also note that these measurements were done using normal off air program material on channels 7 and 9.

It is obvious from this plot that COFDM cannot move down in frequency without quickly incurring a significant degradation in protection. The unused spectrum around the 6 MHz 8-VSB signal provides a degree of latitude in the exact frequency assigned to the 8-VSB signal.

The zero offset adjacent channel protection data is given in Table 3.22.1 below. The COFDM signal peaks at the centre channel position with a 2 dB higher protection than the 8-VSB signal.

Mod Type	Vision Ch 7	Vision Ch 9	DTTB Failure	Prot D/U Ch 7	Prot D/U Ch 9	Average Prot D/U
COFDM	-27.2 dBm	-30.2 dBm	-64.0 dBm	-37.8 dB	-34.8 dB	-36.3 dB
8-VSB	-33.5 dBm	-36.2 dBm	-69.2 dBm	-35.7 dB	-33.0 dB	-34.4 dB

Table 3.22.1 - DTTB Adjacent Channel Off Air PAL Protection

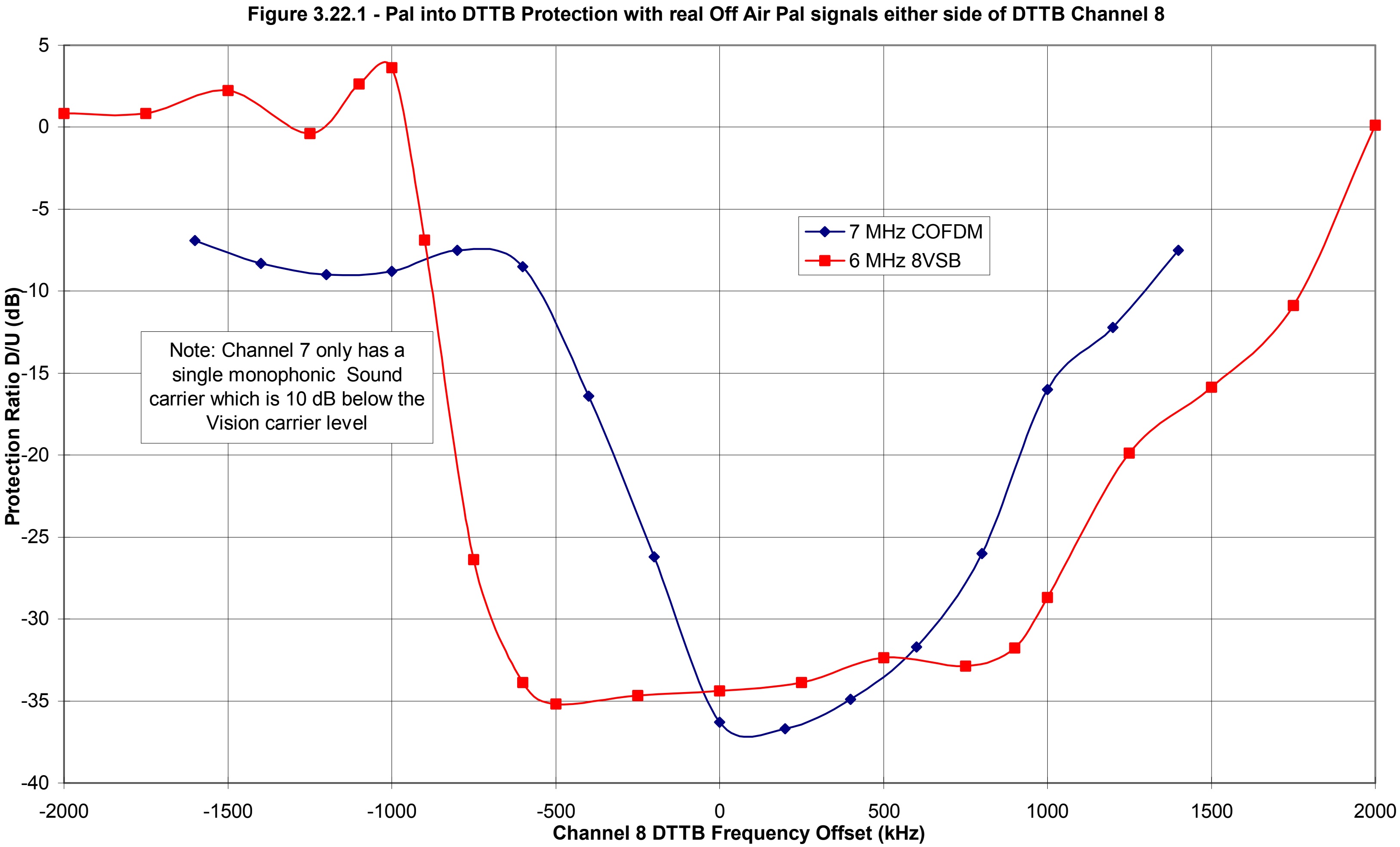


Figure 3.22.1 - Off Air PAL into DTTB Protection

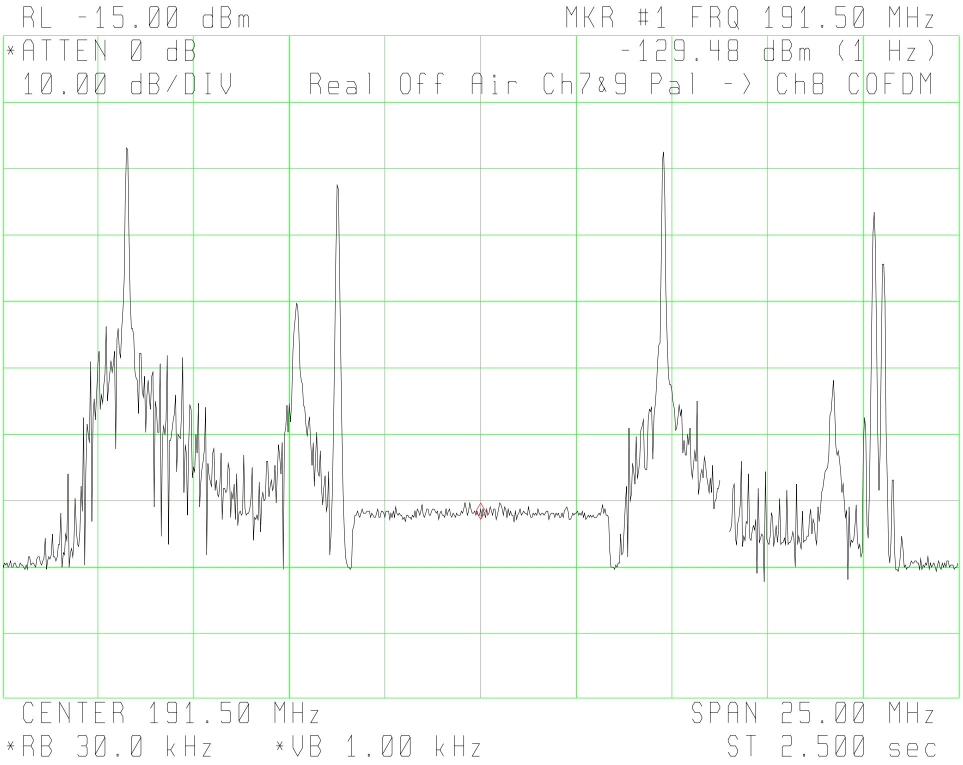


Figure 3.22.2 - COFDM Adjacent Channel PAL Failure Spectrum

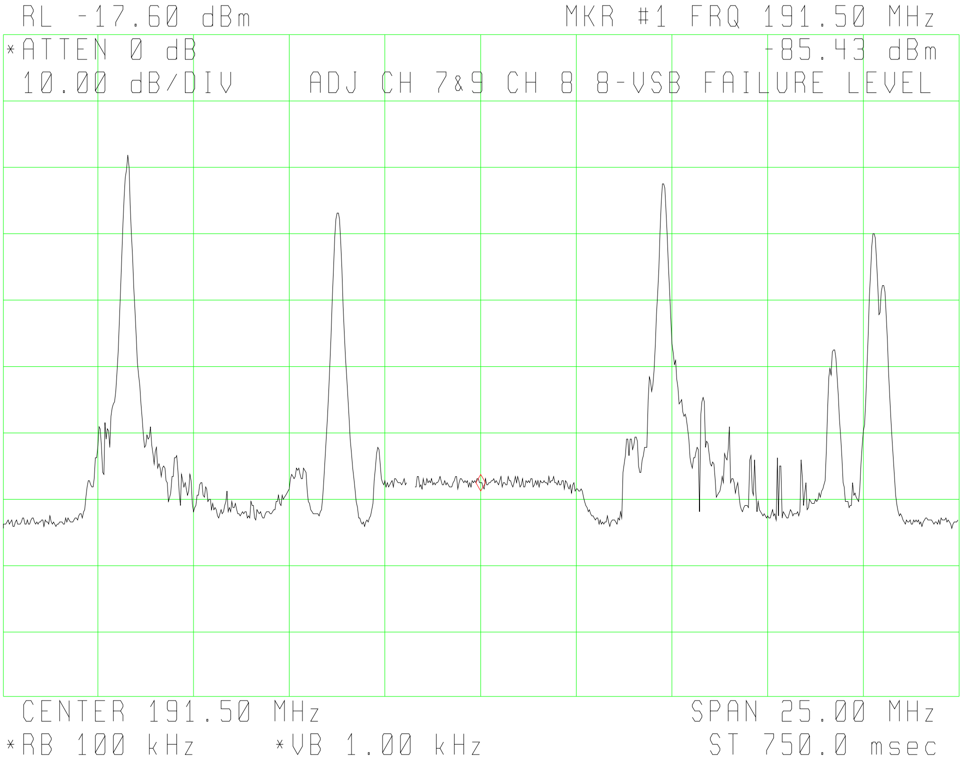


Figure 3.22.3 - 8-VSB Adjacent Channel PAL Failure Spectrum

Figure 3.22.2 and Figure 3.22.3 are the spectrum plots for the COFDM and 8-VSB systems at their channel 8 adjacent channel PAL failure point.

Examination of the lower adjacent channel area of Figure 3.21.1 shows the ingress of the monophonic sound carrier from the off air channel 7 into the channel 8 DTTB signal as it's frequency is moved about. This observation has been used to estimate the IF bandwidth of each DTTB receiver.

A 10 dB change in the DTTB protection performance was estimated to be a good measure of the noise bandwidth of the IF filters. Taking a 10 dB increase in the protection from the zero offset measurement, the COFDM system is found to have 200 kHz headroom while the 8-VSB system has around 750 kHz headroom. Since the channel 7 sound carrier is 250 kHz below the upper edge of the 7 MHz channel this is subtracted from these figures giving a difference of -50 kHz for COFDM and +500 kHz for 8-VSB from the nominal 7 MHz channel for the lower adjacent channel edge. If we assume the same performance for the upper edge of the signals then the estimated IF bandwidth of COFDM is 7.1 MHz and 8-VSB is 6 MHz.

3.23AFC Range

The Automatic Frequency Control (AFC) range was determined for each DTTB receiver while operating from the test rig on VHF channel 8 at a receiver input level of 27.6 dBm.

1. The frequency of the Modulator LO generator was increased in 1 kHz or less increments from the nominal LO centre frequency until the receiver lost lock or exceeded its error rate failure point.
2. When the (Unlock) limit was reached the frequency was slowly decreased until the receiver regained lock (Relock).
3. The Unlock & Relock values for the upper side were noted then the matching points were re-measured using a negative frequency offset to determine the lower side values. The difference gives the AFC range.

Table 3.23.1 shows the result of the AFC range measurement for both DTTB systems tested.

AFC Range	**COFDM Unlock**	**COFDM Relock**	**8-VSB Unlock**	**8-VSB Relock**	**Units**
Low Side	5.29	5.26	327	69	kHz
High Side	6.91	6.23	291	290	kHz
Total Range	12.2	11.5	618	359	kHz

Table 3.23.1- AFC Range of DTTB Receivers

3.24Offset Steps

Marginally different techniques were used for the COFDM and 8-VSB systems to measure the receiver tuning offset step size.

3.24.1COFDM

1. The COFDM receiver was instructed to change frequency up one offset step.
2. The Rig LO frequency was then adjusted in 1 kHz steps to find the centre of the frequency relock range.

The COFDM receiver was found to have a 200 kHz offset step with a total of 8 steps available. 3 of these were above the centre frequency while 4 were below the centre frequency.

It is noted that the offset step size exceeds the AFC lock range by around 20 times for the COFDM equipment. This means that the offset function would be no use for correcting a mis-tuned receiver unless the required frequency fell very close to one of the offset step increments.

3.24.28-VSB

1. The 8-VSB receiver the RF input cable was directly connected to the spectrum analyser and the LO frequency determined by its leakage out the antenna RF port.
2. As the 8-VSB offset was varied the steps in the LO frequency were noted.

   The 8-VSB receiver was determined to have a first IF of 921.0 MHz. The LO was found at 1.1125 GHz for VHF channel 8 (191.5 MHz). A total of 16 250 kHz frequency steps are available with the 8-VSB receiver 7 above the centre and 8 below giving a tuning range of -2 to +1.75 MHz about the channel centre.

   The 8-VSB receiver offset steps are smaller than the AFC range allowing a broader set of frequencies to be received.

3.25Mast Head Amplifiers

Performance of 8-VSB through mast head amplifiers. Two mast head amplifiers, 10 dB and 30 dB unit, were inserted into the rig before the test splitter during the off air PAL protection test (Section 3.22). It was found that no significant degradation or improvement in the C/N performance of the DTTB signal was observed when the mast head amplifiers were operated in their linear range. When the 30 dB amplifier had over 65 dBuV applied to it’s input significant intermodulation across the entire VHF spectrum resulted affecting both PAL and DTTB signal reception.

When there was no additional visible degradation of the PAL signal through the mast head amplifier the 8-VSB system performed nominally.

Regretfully this measurement was not performed on the COFDM system.

3.26Translator Link Performance

Much effort was expended trying to understand why the link performed significantly worse than the coaxial delay. Observation of the 8-VSB system found that the link used up much of its equaliser before any significant ghosts were applied. Tests of the link equipment showed that there was a non-linear effect occurring and after much investigation the mixer at the translator is suspected of having too large an input signal applied. This mixer was feeding directly a reactive band-pass filter leading to intermodulation and non-linear effects on the transmission chain. Amplification around the mixer was rearranged and extra amplification added to the receive end of the link. This improved the 8-VSB equaliser performance such that an 8-VSB output S/N of 25 dB was achieved. This improvement in performance allowed the link echo measurements which were previously in excess of 20 dB to improve to 16.2 and 8.9 dB for pre and post echoes respectively. Re-measurement of the COFDM echo performance on the link after its improvement did not yield any significant change in the echo performance level.

3.27Correlation of Picture Impairment

The system failure point was quantified for different impairments by a comparison of the picture and BER failure points observed at the receiver. This comparison is necessary to verify the selection of the QEF BER failure point (2.1×10^{-4}) that was used during most of the laboratory testing. The QEF point has been determined for the system based on white noise impairment and the QEF error measurement is done without the reed solomon code active. There may be variation in the ability of the reed solomon code to correct errors induced by non gaussian noise impairments such as multipath, bursts or impulse noise.

During the picture impairment testing the COFDM system was set for picture mode operating with two 4-8 Mb/s MPEG streams. The lower the bit-rate of the stream the more damage individual errors caused on the output picture.

1. The monitor on the DTTB receiver video output was observed while the impairment level was varied around the previously measured BER failure point until picture failure was observed.
2. When Picture failure was observed the impairment level was decreased in 0.1 dB increments until no further picture impairment was noted using cyclically repeated moving picture sequences.
3. The level where impairment failed to be noticed in a 2 minute picture cycle was recorded.

Table 3.27.1 gives the results of the correlation of COFDM output errors to the QEF BER performance using the version 1.0 equaliser software. The difference column shows the margin between error rate and picture failure. A positive number in this column indicates that the picture failed at a higher impairment level. Most measurements were made using 1/8 Guard interval.

Measurement / Impairment Type for COFDM 64-QAM 2/3 FEC	Alarm Light	QEF BER Failure	Picture Failure	BER-Pic Difference

C/N Threshold Test Rig at 0.11 mV	20.2 dB	19.2 dB	18.2 dB	1.0 dB
C/N Threshold NEC Tx Direct	21.0 dB	19.6 dB	18.7 dB	0.9 dB
C/N Threshold Coax Delayed Signal	21.2 dB	19.7 dB	18.7 dB	1.0 dB
C/N Threshold Link Delayed Signal		21.9 dB	20.1 dB	1.8 dB
Impulse Noise - Wanted Signal Level	Not Lit	21-24 dB	19-20 dB	~-3 dB
Co-Channel CW Protection Ratio	8.9 dB	8.8 dB	9.0 dB	-0.2 dB
Co-Channel PAL Protection Ratio	2.4-3.0 dB	2.6 dB	-0.5 dB	3.1 dB
Upper Adj Ch PAL Protection Ratio	-37.1 dB	-37.9 dB	-37.3 dB	-0.6 dB
Lower Adj Ch PAL Protection Ratio	-35.3 dB	-34.2 dB	-34.5 dB	0.3 dB
Doppler Coax Post Echo @ 1/32	-6.2 dB	-6.1 dB	-4.5 dB	1.6 dB
Doppler Coax Post Echo @ 1/8	-1.4 dB	-1.5 dB	-0.8 dB	0.7 dB
Link Pre Echo Level @ 1/8	-4.2 dB	-3.7 dB	-2.6 dB	1.1 dB
Link Post Echo Level @ 1/8	-10.5	-8.4	-8.4	0 dB

Table 3.27.1 - Comparison of COFDM Picture and QEF BER failure point

These results show that for most of the protection and multipath measurements undertaken during the laboratory testing the picture fails at a level similar to that measured by the QEF error rate. In most cases the impairment needs to be around 1 dB higher to cause picture impairment except for the signals which traversed the link and for the impulse noise case.

It is obvious that the channel 8/44 translator link causes some degradation in the digital signal, and is combining real variable transmission path effects with the laboratory measurement. This introduces an extra level of uncertainty into the measurement which may account for the higher deviation.

The Impulse noise behaviour of the COFDM system is documented in section 3.12 and is probably due to the burst nature of this interference which completely destroys data recovery for short periods with the intervening periods characterised by error free performance.

The design of the viterbi decoder and the length of interleaving used within the COFDM system will dictate the performance for this type of impairment. It is noted that much of the development effort for COFDM system within Europe has been centred on the use of the UHF television band where Impulse noise has a much lower impact than the Low VHF bands.

3.28PAL/COFDM Time Delay

As the 8-VSB equipment was not supplied with video coders and decoders it was not possible to measure the video latency through this system.

The PAL interference source was modulated at VHF channel 9 with the same video that was being fed to the COFDM DTTB equipment. A PAL television receiver was placed next to the DTTB receiver and an equal 3 dB split of a combined 27.6 dBm signal containing COFDM at channel 8 and PAL at Channel 9 fed to the receivers operating in picture mode.

The output of both receivers were observed with the same program playing from the digital Betacam. A stop-watch was used to record the time between cuts in the PAL and Digital pictures. The stopwatch measurement averaged out to 1.4 seconds latency for a 8 Mb/s program stream.

During a subsequent demonstration of COFDM and PAL side by side at Parliament house (see Report 97/5[v]) a video delay of 36 frames was required to be inserted in the PAL transmission chain to compensate for the delay introduced by the complete digital transmission chain. When an external LVDS transport stream decoder was used the latency increased by a further frame to 37 frames.

The latency which will be introduced by any DTTB system may impact on real time applications where synchronisation or commercial activities are involved.

Typical examples are:

Outside broadcast / Studio interviews
Network Synchronisation especially with cascading
Online betting.

3.29Spectrum Plots

Spectrums of the baseband IF signals of both DTTB systems were taken.

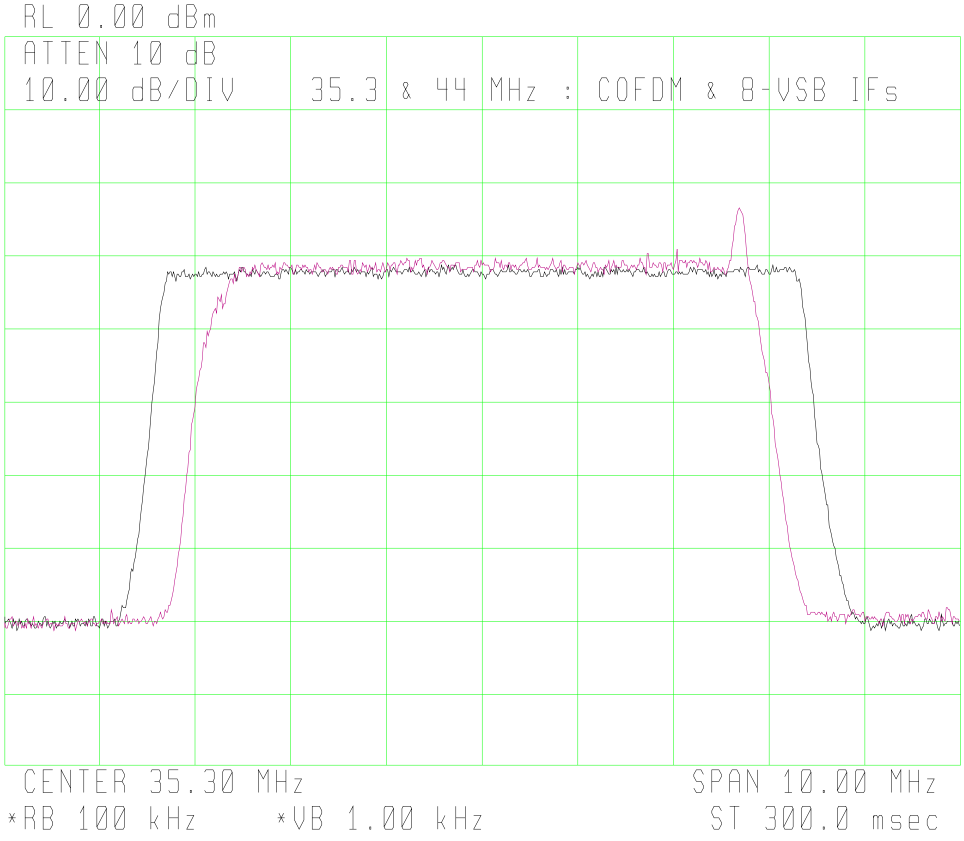


Figure 3.29.1 - DTTB IF Spectrums

Figure 3.29.1 shows the final IF signals for COFDM (black) and 8-VSB (violet). The two spectrums have been overlaid with the 8-VSB signal being measured and stored with a centre frequency of 44 MHz and then the COFDM signal was stored at it’s centre frequency of 35.3 MHz. Both IF signals are inverted requiring mixing up to the final channel using high side injection. The shoulder level at IF appears around 48 dB. Measurement of the plot in Figure 3.29.1 gives an IF bandwidth for COFDM of 6.7 MHz and for 8-VSB, 5.5 MHz.

Figure 3.29.2 shows the 10.7 MHz baseband IF of the 8-VSB system which is the frequency where the signal is modulated and VSB filtered. Note that the shoulder level is around 55 dB in this case.

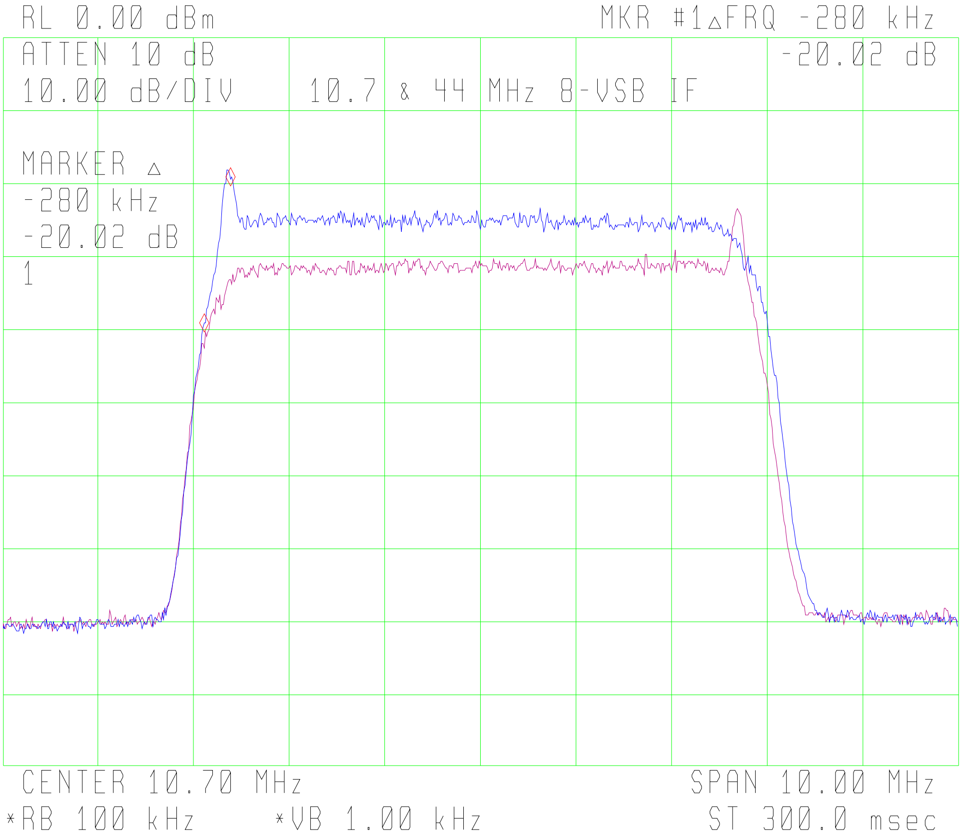


Figure 3.29.2 - 8-VSB 10.7 MHz & 44 MHz IF

Figure 3.29.3 and Figure 3.29.4 were an attempt to quantify the peak to average power ratios of the two DTTB systems. The Blue curve is a 100 sample average of the DTTB signal while the black curve is a positive peak hold which was accumulated over a 10 minute period.

From these traces it appears that COFDM has a peak to average ratio of around 11.5 dB and for 8-VSB it is around 10 dB. These numbers do not agree with the theory so there is probably a measurement error using this simple technique.

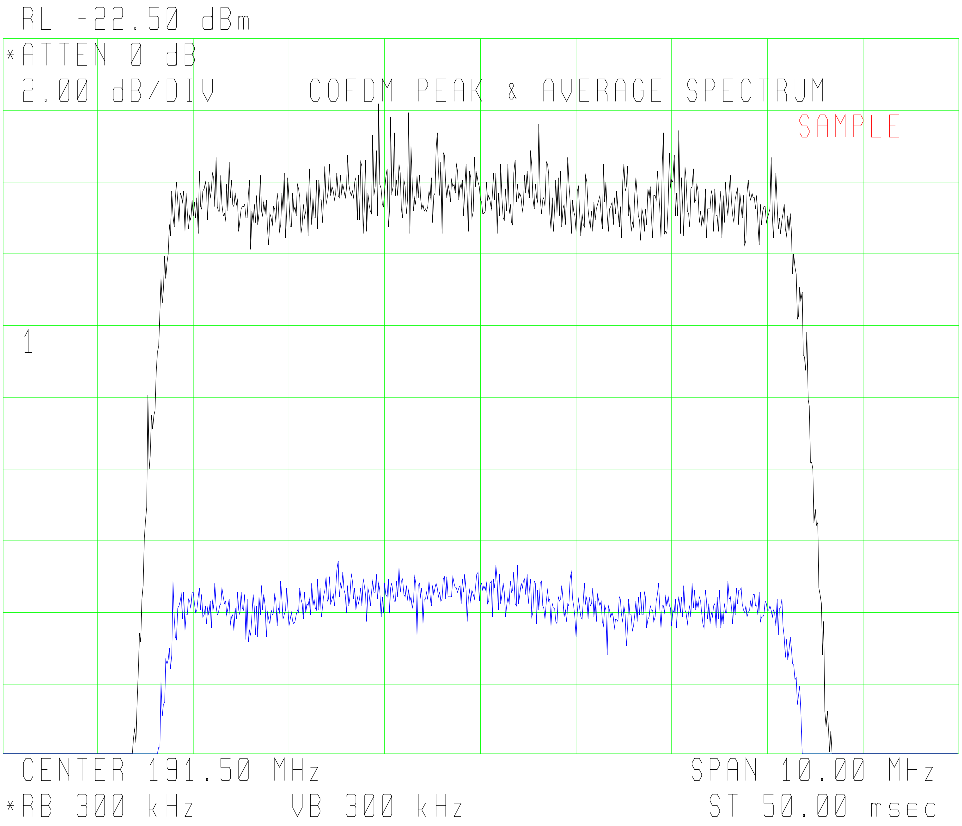


Figure 3.29.3 - COFDM Peak & Average Spectrum

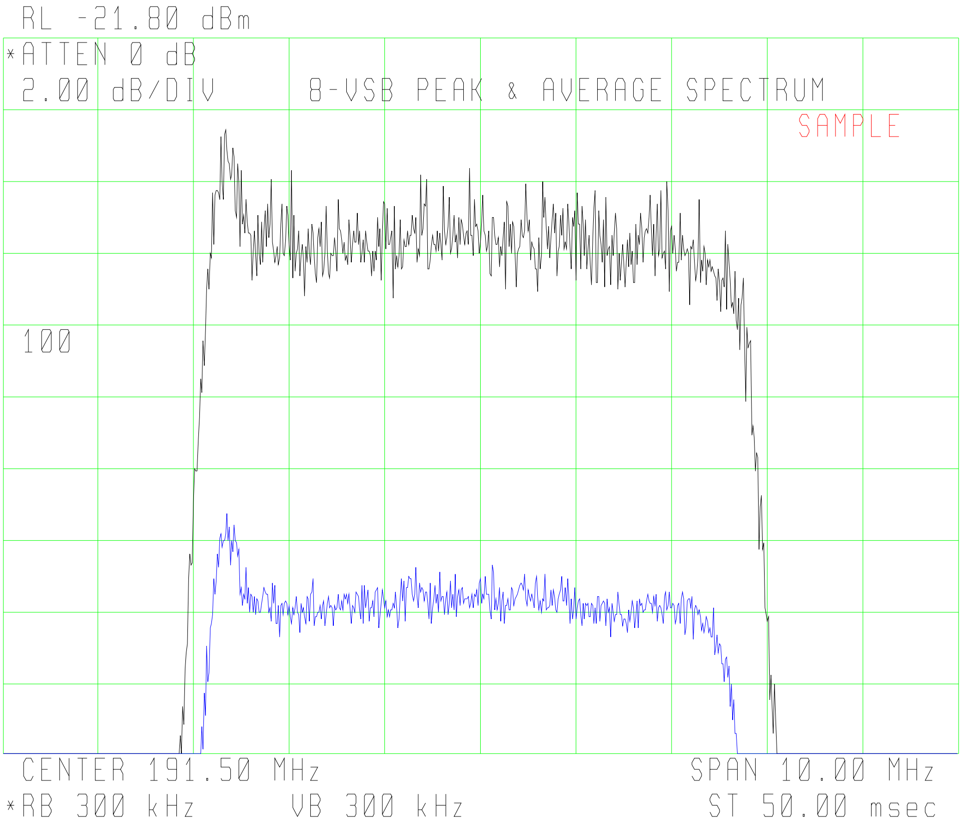


Figure 3.29.4 - 8-VSB Peak & Average Spectrum

4Result Summary

is a summary of the main numerical results obtained in the tests:

Parameter	COFDM	8-VSB	Section
C/N Threshold in Native System Bandwidth	19.1 dB	15.1 dB	3.5
C/N Threshold Measured as 7 MHz a Channel	19.1 dB	14.3 dB	3.5
Minimum Receiver Signal Level	25.1 dBuV	27.2 dBuV	3.6
Calculated Apparent Noise Figure	4.6 dB	11.3 dB	3.7
Payload Data Capacity	19.35 Mb/s	19.39 Mb/s	3.7
DTTB into PAL Co-Channel Protection LOP	50.5 dB	51.2 dB	3.2
DTTB into PAL Co-Channel Protection SCM40	41.1 dB	45.4 dB	3.2
DTTB into PAL Co-Channel Protection SCM30	35.8 dB	38.7 dB	3.2
DTTB into PAL Lower Adjacent Channel Protection LOP	3.5 dB	4.6 dB	3.2
DTTB into PAL Lower Adjacent Channel Protection SCM40	-5.3 dB	-1.5 dB	3.2
DTTB into PAL Lower Adjacent Channel Protection SCM30	-9.5 dB	-7.7 dB	3.2
DTTB into PAL Upper Adjacent Channel Protection LOP	5.5 dB	5.0 dB	3.2
DTTB into PAL Upper Adjacent Channel Protection SCM40	-6.4 dB	-0.9 dB	3.2
DTTB into PAL Upper Adjacent Channel Protection SCM30	-10.6 dB	-7.8 dB	3.2
PAL into DTTB Co-Channel Interference	1.4 dB	9.1 dB	3.3,3.7
PAL into DTTB Lower Adjacent Channel Interference	-35.4 dB	-38.6 dB	3.3,3.7
PAL into DTTB Upper Adjacent Channel Interference	-37.5 dB	-38.7 dB	3.3,3.7
CW into DTTB in channel interference range	+6 to -11 dB	+14 to +7 dB	3.4
DTTB into DTTB Co-Channel Hostile Interference	20.4 dB	14.6 dB	3.10
DTTB into DTTB Lower Adjacent Channel Interference	-28.3 dB	-30.4 dB	3.11.1
DTTB into DTTB Upper Adjacent Channel Interference	-28.5 dB	-32.2 dB	3.11.2
Impulse Noise Performance (Differential to PAL Grade 4)	9-14 dB	17-25 dB	3.12
7.5 us Coax Static Post Echo Level	0 dB	-2.2 dB	3.8.1
7.5 us Coax Static Pre Echo Level	0 dB	-13.5 dB	3.8.1
17.2 us Link Static Post Echo Level	-8 dB	-8.4	3.8.2
17.2 us Link Static Pre Echo Level	-3 dB	-16.2	3.8.2
Sensitivity to IF Translator Performance	Low	High	3.8.2,3.26
Echo Level for 1 dB change in C/N Threshold - Coax	-11 dB	-12 dB	3.9
Echo Level for 1 dB change in C/N Threshold - Link	-17 dB	-14 dB	3.9
Static Doppler Post Echo Performance (-3 dB about peak)	±140 Hz	±1 Hz	3.13
Typical DTTB Shoulder Level for 200 W Transmitter	34-39 dB	39-41 dB	3.16
Receiver Signal Level where C/N Threshold Degrades 1 dB	34 dBuV	35 dBuV	3.19
Off Air PAL Ch 7 & 9 into DTTB protection	-36.3 dB	-34.4 dB	3.22
Estimated Receiver IF Bandwidth	7.1 MHz	6.0 MHz	3.22
AFC relock range	11.5 kHz	359 kHz	3.23
Tuning Offset Steps	8 x 200 kHz	16 x 250 kHz	3.24
Modulation IF Frequency	35.3 MHz	44.0 MHz	3.29
Modulated IF Bandwidth	6.7 MHz	5.5 MHz	3.29

Table 4.1.1 - Main Numerical Result Summary

CAUTION: When interpreting these results caution should be exercised. Individual parameter values contained in Table 4.1.1 relate to measurements taken using the specific implementations of pre-production (DVB) and prototype (8-VSB) receivers used. Use of any value in isolation from it’s related context should be avoided.

Note: In all cases the COFDM system values reported in Table 4.1.1 are for (2k) 64QAM 2/3 FEC 1/8 Guard 7 MHz variant.

5Conclusion

The test results presented in this report provide a good indication of the 7 MHz performance of future DTTB receivers in the VHF band, however the receivers tested are early pre-production devices. Once the domestic level receivers based on a small highly integrated chip set are available, it would be wise to verify the performance of these units.

The laboratory tests have provided data which quantifies the static performance of the DTTB systems. Field trials of the DTTB systems will provide data on the dynamic performance in a real complex, variable transmission environments.

UHF implementation will also play an important part in the implementation of DTTB in Australia. UHF performance has not been addressed in this test program.

Any evaluation of these results will need to be based on the specifications and requirements of the particular user. The laboratory tests have shown some performance differences between the systems however the laboratory tests by themselves do not provide sufficient basis to choose between the DTTB modulation technologies.

6Acknowledgments

I would like to thank the following people and organisations who assisted with the testing associated with the DTTB modulation systems.

Ian Waters, Ian Anderson & Keith Malcolm, DCA Comms Lab
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David Johnson, NDS Australia
Rich Citta & Steve Heinz, Zenith USA
Peter Gough & Ian Clifford, WIN TV
FACTS & FACTS Engineering Specialists Group
Communications Laboratory Staff
DVB Project, ATSC
News Data Systems
COMSYST Australia & Harris Corp
NEC Australia
Hewlett Packard, Tektronix, Rhode & Schwarz
Australian Broadcasting Authority
National Transmission Authority
University of Canberra

7Annex

7.1DVB Comments

The following comments were received from DVB on the 31st of March 1998. Corrections have been made to the report to reflect the errors highlighted.

31-MAR.'98(MAR) 21:43 DVB-PROJECT-OFFICE TEL:41 22 7172727

**Digital Video
Broadcasting**

DVB Comments on Australian Lab Tests and Field trial results

Comments compiled for DVB by Jeff Gledhill (NDS)
with assistance from Chris Nokes (BBC) and Lis Grete Muller (Tele Danmark A/S)
31/3/98

FACTS and the communications Labs are to be congratulated on the thorough and professional organisation of both the field trial and the laboratory measurements. These tests must be among the most complete investigations of digital transmission systems made anywhere in the world.

1 Scope of the tests and choice of DVB-T system parameters

An important difference between the DVB-T and ATSC systems is that ATSC allows only one bit-rate (excluding the 16-VSB mode intended for cable) whereas DVB-T has several adjustable parameters, which allow a trade off between robustness and bit rate. The lab tests and field trial concentrated largely on tests of one mode. The mode chosen was 64 QAM with a rate 2/3 code and a 1/8 guard interval - primarily to give a similar bit rate as ATSC. Consideration was given to using 16 QAM with a 1/32 guard interval, but this was rejected on advice from NDS. This mode actually has a 2.5 dB better AWGN performance, but has significantly worse performance in non-Gaussian channels. In fact it is likely that this mode would replicate the performance of ATSC quite closely.

Because at the time equipment was only available working to the 2K variant of DVB-T, the 8K modes could not be tested. It is also worth noting that for the same absolute guard interval, the 8K variant of DVB-T delivers nearly 2 Mbit/s extra bit rate using the some modulation and coding. Alternatively, for exactly the same bit rate, four times the echo performance is possible.

1.1 Performance of DVB-T receivers

It is important to understand that there is no prescription for the implementation of a DVB-T receiver. There are a number of trade-offs that can be made - for example Doppler performance against AWGN performance. There are also cost/complexity trade-offs. Therefore in these tests "DVB-T" Is not being compared with "ATSC", but one implementation of each system is being tested.

1.2 The equipment

An important difference between the ATSC and DVB-T receivers was that the ATSC receiver appeared to be a laboratory demonstrator, whereas the DVB-T equipment was designed to be as close an emulation of a consumer unit as possible at the time. Thus the DVB-T receiver from NOS was much smaller than that from ATSC, and included a MPEG decoder (based an a PACE board from a domestic receiver). The DVB-T tuners were an "off-the-shelf" domestic design, apart from the substitution of a frequency synthesiser chip to improve phase noise (note that these tuners were manufactured by Philips, not ALPS as stated in the report on the laboratory measurements). On the other hand the ATSC receiver included no video decoding. and its tuner was believed to be a dual conversion design based on professional components.

Considerable pressure was applied by FACTS to deliver equipment as early as possible. The COFDM modulator was delivered in late 1996 followed by two receivers in February 1997. It had been expected that the ATSC would deliver a complete system before this, but as things transpired, the ATSC receiver was not actually delivered until some months after the DVB equipment.

It is not claimed that the equipment supplied by NDS was as mature as that from the ATSC - it had only been working for a short time and was not fully optimised. In fact, as originally supplied there was an error in the implementation of one of the interleavers (and corresponding de-interleaver). This was discovered as the result of inter-operability tests with a BBC modem, and fortunately was fixable with a firmware upgrade (it is not believed that this error would have significantly affected test results even if it had not been corrected). A further significant factor was that the tuners used in the receivers (one VHF and one UHF) were far from optimum. These were PAL tuners hastily substituted for the one normally used, to allow operation in 7 MHz channels. The resulting tuner / IF board was not as well screened as the original 8 MHz version resulting in significant 'self interference' from the digital circuitry inside the receiver. Although the communications labs made excellent efforts to improve the earthing arrangements inside the receiver, variations in the noise performance of around 1 dB were seen In the tests, probably mainly because of this effect.

Subsequently, the NDS DVB-T receiver design has been optimised in a number of ways. Important optimisations include:

- An improved channel state CCI detection algorithm
- A longer channel estimation filter
- Modifications to the UHF tuner to improve adjacent channel performance
- Use of a professional MPEG decoder with better error performance

The first of those required only a PROM to be changed, and this was supplied for the tests in Australia. Unfortunately, used alone, this does slightly worsen the noise performance, so it was not used for most of the tests. In fact a further optimisation of the values in this PROM allows the same CCI performance with negligible noise penalty. This is independently supported by tests on an entirely different DVB-T receiver, as reported in reference 3.

The second modification results in much better performance with strong echoes, but could not be supplied since it required the replacement of a 120 pin programmable gate array, soldered to the motherboard. The third and fourth modifications also would have required the return of the receiver to NDS in the U.K.

There was also a difference in the conduct of the tests, in that ATSC insisted on being present during the laboratory tests, and made adjustments to the equipment between tests, whereas DVB or NDS representatives were in general not present.

2· Observations on the Laboratory measurements

2.1 Note on failure criteria BER measurements (Report section 3.1, page 19)

ATSC and DVB-T have used different system failure criteria, which were carried through into the lab measurements. The ATSC definition of failure is a Bit Error Ratio of 3 x 10^{-4} at the final modern output. ATSC claim that this corresponds to 'Threshold Of Visibility (TOV)' on decoded pictures. Since no video decoder was provided, it was not possible to check this, however it must be said that without sophisticated concealment. This would normally correspond to a severely impaired MPEG stream. Strictly DVB does not define a failure criterion at all, but instead prefers to define a performance criterion where the system is still working, since it is this criterion which must be used for service planning. In analogue television terms, this corresponds to the difference between planning for Grade 4 services and Grade 1 services. The DVB-T limiting criterion of 2 x 10^{-4} at the output of the Viterbi decoder before the Read Solomon decoder corresponds to a 'Quasi Error Free (QEF)' condition - a BER of the order of 10^{-11}, at the final modem output, or around one visible picture artefact per hour.

The results based on these measurements will thus be slightly skewed in favour of ATSC. Fortunately, the difference between QEF and TOV will generally not be large, - probably around 1.5 dB, but when burst errors occur - e.g. due to impulse noise - the difference may be greater. Similarly for co-channel interference, the difference may be over 4 dB.

2.2 Digital interference into PAL (Report section 3.2, pages 20 ... 26)

Since both the ATSC and DVB-T signals approximate to white noise, they would be expected to cause similar levels of interference into PAL. Some differences might be expected because of the slightly wider DVB-T spectrum. DVB-T would be more likely to cause interference to the sound in both co- and adjacent channel cases, but would concentrate less power in the critical parts of the vision spectrum when acting as a co-channel interferer. In fact, the measurements seemed consistently to show a small advantage for DVB-T. This is difficult to understand, but may be due to the fact that COFDM is a better approximation to Gaussian noise than 8-VSB.

2.3 PAL / CW Interference into Digital (Report section 3.3 / 3.4, page 27)

Co channel

Essentially two sets of measurements were made on the DVB-T receiver, one based on an early and one based on an upgraded channel state estimation PROM. The latter resulted in an improvement in the DVB-T performance, but in either case DVB-T Significantly outperformed the ATSC system. In the case of the upgraded system this amounted to an 11 dB advantage at the channel centre. This must be a very significant result for any circumstances where Digital Transmissions must co-exist with PAL.

With a CW Interferer, and using the upgraded channel state estimation, the differences are even more dramatic. With an advantage for DVB-T of at minimum 12 dB, and at exact channel centre a massive 23 dB.

Adjacent channel

Adjacent channel results are heavily dependent on tuner performance, so care should be taken in reading too much into the results presented here. As it happens the performance of the DVB-T and ATSC receivers are rather similar, both having very large protection ratios better them -35 dB. Figure 3.3.1 shows a small advantage (-3 dB) for the ATSC receiver in the lower adjacent channel, and a very small advantage for (-1 dB) for the DVB-T receiver in the upper adjacent.

2.4 Additive White Gaussian Noise performance (Report section 3.5 p35)

Measurements of the AWGN performance of the ATSC and DVB-T receivers, working in the 64 QAM rate 2/3 mode, showed approximately a 4 dB advantage for the ATSC system, and ATSC have made much of this. However, this advantage is not as significant as it seems and it is important to understand where it comes from.

Firstly, being essentially laboratory test equipment, the ATSC receiver has a very low implementation margin compared to the theoretical 8-VSB performance. The DVB-T equipment on the other hand loses about 1 dB of performance, primarily due to the use of a domestic, PAL tuner. Further, there is a trade off in the channel estimation algorithm between Doppler performance and static AWGN performance. As implemented, the NDS receiver uses a wide bandwidth temporal channel estimation filter which, according to simulation, results in good Doppler performance but loses 1.6 dB AWGN performance. By reducing the Doppler performance to a few Hz (still better than ATSC - see section 2.10) most of this 1.6 dB can be reclaimed. Thus on a fair comparison, and also taking into account the different BER criterion used in the measurements, the ATSC advantage shrinks to less than 1 dB, for this DVB-T mode.

In fact the choice of this particular mode is rather arbitrary. It is interesting to compare two other DVB-T modes - an 8K system using 64 QAM, rate 2/3 code with a 1/32 guard interval, and 16 QAM, rate 7/8 code and a 1/32 guard interval. The first of these variants would replicate the 2K variant used in most of the tests except for the Doppler performance. However, it would deliver nearly 2 Mbit/s extra data rate for the same noise performance. The 16 QAM rate 7/8 system delivers just under 1 Mbit/s less data, but theoretically has 1 dB better performance than ATSC In Gaussian channels. Of course the use of this mode would lose a lot of the advantages of DVB-T over ATSC in ability to handle strong echoes, CCI, etc.

Even if all the previous comments about differences in system performance are ignored for a moment, the minimum signal levels, exactly as measured, are extremely revealing. Table 3.5.1 shows that when the performance of the system matters most, that is at the minimum input signal level, COFDM outperforms 8-VSB by about 2 - 2.5 dB. This somewhat surprising result leads to an effective noise figure measured in Table 3.7.1 of 3 - 6 dB worse for 8-VSB. One possible explanation for this is that any self-interference (for example, from harmonics of digital signals) will be most noticeable at low signal levels. The 8-VSB system has been shown to be poor at combating CW Interference, so this could explain the relatively poor effective noise figure.

It is also important to remember that unlike ATSC, DVB-T has many modes of operation so performance can be traded for bit rate. Thus operation is possible down to signal / noise ratios of under 5 dB, or bit rates of up to 27 Mbit/s.

2.5 Echo Performance (report section 3.8 p40)

Because of the lack of a channel simulator, a delayed signal was generated using either using a length of cable, or by sending the signal down a microwave link. It is probable that results using the link are somewhat pessimistic, because of various imperfections in the signal path.

Echo performance was probably the aspect of the DVB-T equipment that suffered most as a result of the equipment being an early prototype. As supplied, and in the 64 QAM rate 2/3 mode, the receiver was only just able to work with Short (7.5 us) 0 dB post echoes, showing an SNR loss of around 20 dB. With a longer (17 us) 0 dB echo the system was not able to work at all, although those results may have been in part due to degradation on the microwave link. With updated interpolation filters, NDS receivers now show a S/N degradation of around 6 dB due to 0 dB echoes over most of the guard interval. Similar results are quoted in reference 3.

With weak echoes the ATSC system shows a slight advantage over the DVB-T system, but this is really just a reflection of the somewhat better Gaussian noise performance with this implementation of the DVB-T receiver (see 2.4 above).

However, as supplied, the DVB-T equipment was still able to show The ability of COFDM to function with very strong echoes in a way that the 8-VSB system cannot. 8-VSB is unable to deal with 0 dB echoes under any circumstances. For post echoes, the best-achieved figure was -3 dB with an echo length of 4.2 us. Pre-echo performance was very poor, with a maximum tolerable echo of -13.8 dB with an echo as short as 4.2 us. To be fair, this could probably be improved with more complex equalisation filters.

Curiously, the DVB-T equipment actually worked better with pre-echoes than post echoes (it should be completely symmetrical). This may have in part been due to the performance of the microwave link, but was probably mainly attributable to the early version of the firmware used in these tests.

Comment regarding notches in the spectrum

The note on page 42 stating that only short 0 dB echoes produced severe notches, is describing an artefact of the bandwidth setting of the spectrum analyser. Even with long echoes the notches are still deep in reality.

2.6 Co-and adjacent channel interference from digital (report 3.10 p53)

Co - channel Since only one DVB-T modulator was available, DVB-T measurements were conducted with a delayed and frequency-shifted version of the COFDM signal. As the report points out, this is roughly equivalent to a measurement of Doppler performance. This explains the greatly superior performance of the DVB-T system with a small frequency offset with this measurement (see section 2.10). With un-correlated interferers both ATSC and DVB-T interference would be expected to act more or less as Gaussian noise, and this is confirmed by the 8-VSB measurement in figure 3.10.4, and has been confirmed for DVB-T in measurements elsewhere.

One interesting observation is that the measurements made using the microwave link as delay, and with a large frequency offset (report figures 3.10.1 and 3.10.3), both systems show some degradation compared to interference with an unimpaired DTTB signal - presumably due to imperfections in the link. In the case of DVB-T, this impairment amounts to around 2 dB, but ATSC shows 5 - 7 dB loss of performance. This is perhaps a reflection of the ability of the two signals to handle 'real world' impairments.

Note: In table 4, the final summary, there appears to be an error in the PAL into 8-VSB co-channel protection ratio. On the basis of figures 3.3.1 to 3.3.4, this should be 9 dB at channel centre, not 2.4 dB.

Adjacent channel In this case, the use of a frequency-shifted version of the DVB-T signal rather than independent signals would not be expected to significantly affect the result. As with the PAL interference, this measurement reflects the quality of the tuner more than the digital systems. The ATSC receiver shows an advantage of 2-4 dB, but since this is in the context of protection ratios - in the order of 30 dB, this is not a significant difference.

2.9 Impulse interference (report 3.12 page 62)

Impulse interference is the one case where ATSC may have an advantage over the 64 QAM rate 2/3 2K mode of DVB-T. However, even this needs some qualification:

Firstly the difference between the systems may not be as large as the tests seem to indicate (an average of around 8 dB). This is because the BER measurements are inevitably averaged over a long period. Even if a mean BER of $3x10^{-6}$ Is accepted as the failure point for MPEG with randomly distributed errors, with bursts of errors the failure point will be significantly lower.

Secondly, the results are likely to vary depending on the nature of the interference. The interference used, a food mixer, consisted of high amplitude spikes of short duration, and a relatively infrequent repetition rate. Consequently, the ATSC error correction sees short bursts of errors, and deals with them by interleaving, which converts a short burst of errors into a larger number of even shorter bursts. The ATSC Reed Solomon outer code inherently performs well given this sort of error pattern. So long as the error bursts remain short in duration, above a certain threshold performance will be nearly independent of pulse amplitude. The interference simply erases a number of bits - this number being related primarily to pulse duration not amplitude.

DVB-T also spreads the interference, but in a different way. In this case the energy in an interference pulse is spread by the receiver FFT over a complete symbol - many thousands of bits, a much larger number than the ATSC interleaving. This energy approximates to noise the amount of noise becoming worse as the pulse amplitude increases. If the effective SNR in a symbol becomes greater than the system failure threshold, a burst of hundreds or thousands of errors may result.

However, some length of interference bursts will exceed the combined burst error correction capability of the ATSC interleaving and error correction. The amplitude of interference the system can deal with will be much reduced. In this case, the way that the DVB-T spreads the interference becomes an advantage, so for longer pulses the DVB-T system may outperform the ATSC system. This remains to be confirmed.

Thirdly, the 8K variant of DVB-T spreads the energy in an impulse over a symbol four times longer than the 2K variant. For interference pulse repetition rates significantly less than the symbol repetition rate (1 kHz) and pulse durations significantly less than a symbol (1 ms) the 8K system should have a 6 dB better performance than the 2K variant - i.e. similar to ATSC.

Having said this, the field trial results did indicate a greater sensitivity to 'real world' impulse interference for at least the 2K DVB-T mode tested compared to ATSC.

2.10 Doppler Performance (report section 3.13)

The Doppler tests were conducted using a single frequency-shifted echo. Although in the real world multiple echoes are the norm, this test gives quite a good indication of the system performance.

The Doppler tests show the most dramatic variation between the systems of all the tests. As indicated earlier, the COFDM system was optimised for mobile reception, at slight expense to the AWGN performance. The system was found to be still able to operate with strong echoes (-3 dB) with Doppler shifts of around 100 Hz. On the other hand, the ATSC system failed at around 1 Hz.

Although the ATSC system was not designed for mobile reception, there must be a worry that its Doppler performance is so poor that even portable, reception may be unreliable due to slow dynamic multipath, e.g because of people walking around the room. Even fixed reception may be affected by objects moving in the wind, or reflections off vehicles.

2.11 AFC performance (Table 3.23.1)

Note that the narrow lock range of the DTTB receiver is a consequence of the use of a voltage-controlled crystal oscillator in the IF Stages, it is not fundamental. Chip-based implementations of the specification have a lock range of at least ± 70 kHz.

3 Comments on the Field trial

Both NDS (DVB) and Zenith (ATSC) representatives were present as equipment was installed for the field trial. As stated in the field trial report, great care had been taken to ensure the accuracy and reliability of the measurements. This can be seen in the consistency of the results, few of which are anomalous or difficult to explain.

Although the field trial represented a very thorough trial of DTTB, the limited time available and the restriction of measurements to Sydney mean that some caution must be used in interpreting the results. In particular, the reception sites chosen were not randomly distributed, but were deliberately biased to be interesting (i.e. likely to be difficult for DTTB). This affects the percentage of sites unserved. Sydney is also in many respects quite a difficult reception environment, with multipath from tall buildings and interference from overhead power distribution. There is one exception to this, however, the absence of co-channel interference. From the laboratory measurements, CCI would be expected to disadvantage ATSC much more than DVB-T, and this could be an important factor in other locations (e.g. Melbourne) where significant interference is expected.

Comments on the results summarised in the Field Trial Data Presentation follow.

3.2 Measurements of the analogue transmissions (Presentation 13.2.4..14)

These measurements are broadly as would be expected, and represent a useful confidence check on the measurement procedures.

3.3 DTTB Field Strengths (13.2.15..21)

In general the ATSC field strength seems to be slightly higher (typically 0.5 - 1 dB) than DVB-T. In principle this would give a slight unfair advantage to 8-VSB in terms of number of sites covered. In practice the difference is probably not significant.

3.4 Threshold C/N (13.2.2I..24)

These results tie up fairly well with the lab test results - under good reception conditions the DVB-T system showing a C/N failure point of around 19 dB, the ATSC showing around 15 dB. There are some slight differences in results depending on the use of a spectrum analyser or a HP Vector Signal Analyser, and system noise or noise Injection methods. The combination of VSA and noise injection methods seem to give least spread, perhaps indicating that these are the most reliable, but given the difficult measurement conditions in a field trial, all the methods are surprisingly consistent.

3.5 COFDM and 8-VSB threshold C/N (13.25..31)

These show the threshold C/Ns with both ATSC and DVB-T measurements on the same figure, using the different measurement techniques. Some care should be taken in interpreting these figures. At first sight the DVB-T system seems to have more anomalously poor results. However, many of these correspond to sites where the ATSC receiver did not work at all, consequently there is no ATSC measurement on the figure.

3.6 Decoder NF (13.32)

These results show that the DVB-T had suffered a change in noise figure from 4.6 dB to 10.7 dB between the lab measurements and the field trial. It has subsequently been found on other copies of the equipment that the 75 ohm input socket can be damaged by connection to 50 ohm connectors, leading to a loss of receiver sensitivity. This is a possible explanation. Owing to the use of a mast head amplifier, this should not have in general affected the measurement results.

3.7 COFDM v 8-VSB noise threshold (13.33..38)

These show directly the difference in SNR performances shown in figures 21..31 - the same comments apply.

3.8 Service availability and Dynamic Threshold effects (13.39..44)

Figure 13.41 is one of the most significant diagrams in the report, since it shows the most important result to the consumer - whether the service is viewable. As expected, with this transmitter power, neither system fully replicates PAL coverage. Despite a slightly worse SNR performance, the DVB-T receiver was able to decode a signal at more sites than the ATSC, although the difference (2% of sites) is not large enough to be statistically significant. For this DVB-T mode, and this transmitter power, the receiver performances are in practice the same.

However, the reasons for the failure are important (figure 13.42). A major cause for both systems is multipath. Since the equipment was supplied, the DVB-T receiver's multipath performance has been substantially improved. The option also exists of using one of the 8K DVB-T modes which would allow echoes of four times the duration to be tolerated for no loss of SNR performance or bit rate.

The other major causes of failure were impulse noise, which mainly affected DVB-T, and flutter which affected ATSC. There is an important difference between the two in that a simple increase in signal strength would help with impulse interference, but not necessarily with flutter. This partly accounts for the effects seen in 43, where most of the DVB-T failures occurred in areas of low signal strength, whereas there are significant 8-VSB failures at high signal strength. This implies that if an increase in transmitter power was possible, DVB-T coverage may significantly improve, but ATSC may not.

System failure comparisons with PAL S/N (13.2.46..48)

These results are generally consistent with previous noise measurements, and reiterate the point that some degree of PAL viewing may be possible when DTTB is not.

4 Conclusion

For the laboratory measurements, a good summary is the table in section 4 of the report (page 103). For the majority of measurements, the systems as supplied actually have quite similar performance, in the DVB-T mode chosen. However, the DVB-T equipment does have a very significant advantage for co-channel interference (PAL and CW) and Doppler. On the other hand the ATSC equipment has a better ability to cope with some types of impulse noise.

An important result of the field trial is that given the transmission power used, DTTB does not fully replicate PAL coverage. However, the field trial results have shown that the DVB-T system achieves very slightly better coverage than ATSC, and confirms the better ability of DVB-T to handle time-varying channels. The ATSC advantage with impulse noise was also confirmed.

On the basis of these results alone, the DVB-T system appears to have the overall advantage. However there are at least three reasons to believe that the advantage for DVB-T is even greater than indicated by the results:

1. There is reason to believe that there is more room for improvement in the DVB-T system than for the ATSC system. Some improvements (e.g. better echo performance) have already been demonstrated.
2. At most field trial locations where DVB-T was unable to decode a signal, a simple increase in power would be sufficient to make the system work. However, because of its sensitivity to flutter, this is not the case for ATSC. There are therefore an irreducible number of unserved sites, even after, for example, the PAL services are switched off and DTTB powers can be increased substantially.
3. The DVB-T system has much greater flexibility than ATSC. The ability to use other modes of the system, and also the existence of Hierarchical modes and the ability to work in Single Frequency Networks means that implementing a real transmission system is a much more practicable proposition than with ATSC. Thus some of the coverage deficiencies found in the field trial could be remedied with low-cost on-channel repeaters with DVB-T; this is unlikely to be possible with the ATSC system.

5 References

[1] Laboratory Report 98/01 - Laboratory testing of DTTB Modulation Systems - Neil Pickford, Communications LAB.

[2] Field Trial Data Presentation - Report. FACTS specialist Group Advanced Transmission.

[3] Evaluation of a DVB-T Compliant Digital Terrestrial Transmission System - C.R. Nokes, I.R. Pullen, J.E. Salter, BBC R&D. IBC conference report 1997 pp 331-336 (IEE publication).

7.2ATSC Comments

ADVANCED
TELEVISION
SYSTEMS
COMMITTEE

VIA FAX & PRIORITY MAIL

April 24, 1998

Mr. Bruce Robertson
Chairman, FACTS Engineering Committee
NINE NETWORK AUSTRALIA
24 Artarmon Road
Willoughby, NSW, Australia 2068

Dear Mr. Robertson:

The Advanced Television Systems committee (ATSC) is very pleased to have the opportunity to have its 8-VSB transmission subsystem tested by the FACTS as a candidate for possible adoption and use in Australia. In addition to the independent review of our system, which has already been adopted in the United States, Canada, and South Korea, your testing provides the -world's first direct comparison of the ATSC system and the system supported by the DVB.

Moreover, we appreciate the opportunity to review, ask questions and make comments about the test results prior to your evaluation process and public release of the data and your recommendations.

The ATSC has formed a small working group of people who have been intimately involved in the U.S. testing processes. Members of that working group are listed in Appendix A for your information. Keeping our group small has enabled us to maintain the confidentiality you requested.

Your testing groups are to be congratulated on the methodology and thoroughness of both the laboratory and field trials. The sheer volume of the summary and detailed data (more than one foot thick when stacked!) attests to the efforts of those doing the testing and data compilation. In fact, it is that sheer volume of data that has caused our review to take longer than any of us had anticipated -- for which we apologize and appreciate your patience.

Overall, we are very pleased with the performance of the 8-VSB transmission system. We believe that the Australian field trial data is supportive of the ever increasing data base in the U.S. Moreover, now that independent data exists on the COFDM system, we believe that our assertions of substantially better overall performance with 8-VSB are backed up by data from an apples-to-apples testing process.

We have very few comments or questions on the Laboratory Trials. We will, therefore, concentrate our comments on the data from the Field Trials.

In establishing a new digital service in the environment of existing analog service, the two most important transmission factors are: (1) the capability of the new digital service to cover as much area as possible (nominally equal to the existing analog service area) without causing interference into the existing analog service; and (2) the capability of the new digital service (at substantially lower power than the analog service) to be immune to all types of interference -- be it from existing analog services, white noise, non-white or burst noise, or self-caused reflections (multipath).

<u>Carrier-to-noise ratio (C/N) threshold.</u> As we anticipated based on our own extensive testing in the U.S. and the results reported from Europe, the carrier-to-noise ratio (C/N) threshold was found to be slightly more than 4 dB better (lower) for VSB. Thus, the 4 dB difference determined in the testing program is extremely significant. For coverage area equal to that of 8-VSB, a COFDM signal would have to be transmitted at 4 dB greater power. This would result in either 4 dB greater transmitter power or 4 dB greater antenna gain or some combination thereof - all costly solutions. Moreover, the interference generated into PAL would be 4 dB more than that resulting from 8-VSB transmission. This is especially significant with COFDM, because it uses the entire 7 MHz channel with resultant high fields in the 0.5 MHz spectrum immediately adjacent to the upper and lower adjacent channel analog services. For a 6 MHz system, the 8VSB signal, of course, is centered in the allocated 7 MHz channel. (If a 7 MHz 8-VSB system is implemented, the 0.5 MHz guard bands would be sacrificed in favor of a 17% higher data rate.)

<u>Burst noise.</u> Unlike white noise with its flat passband spectrum, burst noise is much more random in frequency, amplitude and duration. Your field testing plan was designed to evaluate the effect of burst noise on both systems. The data shows that COFDM did not function at a total of 14 sites, six of which were lost due to burst noise. The 8-VSB system performed successfully at all of these six sites Burst noise is also extremely important for indoor reception, which is discussed in Appendix B.

<u>Multipath.</u> Many sites were chosen to explore large amplitude multipath performance. There were only two sites (three tests) at which the 8-VSB system did not function properly due to large ghosts (tests 2, 3 and 10) but at which COFDM did function properly. Site 10 failed because the receiving antenna was aimed at a ghost, resulting in a long pre-ghost outside the range of the equalizer. [At site 1, 8-VSB had data errors greater than zero, although all of the diagnostics showed no reason for such errors.]

For completeness, there were eight sites where neither system performed successfully. This is most likely the result of very low signal strengths as well as noise.

Interference into PAL. The COFDM signal "caused up to 0.5 dB more impact" than 8-VSB. This may have been the result of COFDM using the entire 7 MHz channel.

The significant VSB to COFDM data comparison is summarized in the red/green charts of the report in two distinct ways. First, for those sites where zero errors were achieved, the carrier-to-noise ratio (C/N) threshold is plotted for each test. A good example is Chart 25, where a calculation of average C/N can readily be made. The average was shown to be about 4.0 dB. Second, at sites in which system failures actually occurred, since it is not possible to record C/N values, the failures were noted, as a function of assumed cause, for each failed test. The best example is Chart 41. [As explained in Appendix C, Chart 41 has mistakes resulting from the incorrect transfer of the raw data.] It is possible to combine the data as a function of C/N if histograms are used. Histograms, from which median and other percentiles can be obtained, have the additional advantage of smoothing the effects of a few outlying points (as occurred on the C/N threshold for both systems -- see Chart 25).

Figure 1 shows a histogram of the measured static carrier-to-noise ratio thresholds and the percentage of tests that were below that number. The entire data set is used, including failed sites. Failed sites have thresholds greater than 26 dB, and therefore show up at the top right comer of the histogram. The median (50 percentile) threshold for 8-VSB is 15.75 dB. The median for COFDM is 20.1 dB. Both numbers are within 1 dB of the measured white noise threshold in the laboratory tests. By design, the test sites were not statistically selected on the basis of population served or land area covered, but they were specifically aimed at sites where reception was expected to be difficult. Nevertheless, the median threshold is dominated by a single impairment -- white noise. Therefore, the difference between the performance of the two systems is slightly greater than 4 dB. To evaluate the performance of the systems under multiple impairments, the threshold for 90% or 95% of the sites would normally be used for a statistically based trial. Since this evaluation is closer to a worst-case situation, a more reasonable threshold number would be 75%. For 75% of the sites, the threshold for 8-VSB is 17.5 dB and for COFDM is it 22.75 dB. (Or read another way, at signal levels where 75% of the trial sites would be successfully received by 8-VSB, no sites would be received by COFDM.) In the case of multiple impairments (multipath and/or impulse noise in addition to white noise), an approximate 2 dB increase in threshold is required for both systems.

Figure 2 is a similar histogram of the dynamic C/N threshold. The dynamic threshold is a much more difficult case. The criteria for successful reception is zero errors for an unspecified period of time. It includes such long-term burst affects as airplane flutter and the non-stationary characteristic of impulse noise. The median thresholds for both systems have deteriorated approximately 1 dB. The difference between the two systems at both the 50 and 75 percentiles, is still slightly greater than 4 dB. There are now more sites with very large thresholds. For COFDM these represent mainly time-varying impulse noise, and for 8-VSB these sites are primarily related to airplane flutter.

The prototype VSB test-rack that was used in the trial had two modes of equalizer operation. The first, based solely on the training signal, is very accurate, but slow. The second, a blind-equalizer mode, is a data decision-directed mode which is considerably faster. There is an automatic algorithm to switch between them. Due to hardware limitations in the prototype tested, the blind-mode only operates on the feed-forward section of the equalizer, approximately the first four n-microseconds. This mode was not seen in the laboratory trials because the only dynamic ghost tested had a delay of 7.18 microseconds. To achieve zero errors during moderate-to-strong airplane flutter, the system would have had to be forced into the blind-mode, because relying on the automatic mode switching was too slow and errors occurred before the switching occurred. [For production receivers, the chipsets which have been developed by both LG Electronics and Lucent Technologies update all equalizer taps in one cycle so they are inherently much faster than the prototype used in the trials. Both chipsets also have training-signal and blind-equalizer modes controlled by the system microprocessor.]

Figure 3 is a worst-case C/N threshold histogram. It covers the entire test suite. At each site the higher (poorer) of dynamic or static threshold is used. The median threshold for 8-VSB is now 16.4 dB and the median threshold for COFDM is now 20.8 dB. The difference between systems at both the median point and the multiple impairment point of 75% is still in excess of 4 dB.

CONCLUSIONS

Although we have made a variety of comments and raised a number of questions, the overarching nature of the trials and the data collection/presentation is very well done.

We believe the results of the trials clearly prove the superiority of the 8-VSB system and substantiate our assertions relative to the attributes of 8-VSB compared to those of COFDM:

- The most significant difference is 8-VSB's superior C/N threshold, in excess of 4 dB
    - 4 dB less transmitter power required with 8-VSB for equal service area, and
    - 4 dB less interference into PAL services with 8-VSB for equal service area
- Superior immunity to burst or impulse noise emanating from electric motors, vehicle ignition systems, lighting systems, power line radiation and the like
    - important with outdoor reception
    - critical with indoor reception because of much lower signal strength and the presence of many electrically noisy appliances

- Comparable real world ghost performance between the two systems (performance with severe airplane flutter has been improved in second generation pre-production 8-VSB receivers using VLSI ICs)

- Higher data rate capability with 8-VSB
  - While the 8-VSB data rate used in the trials was only slightly greater, it was achieved with a 6 MHz bandwidth compared to 7 MHz for COFDM
  - 8-VSB provides more guard band(0.5 MHz on both sides, if a 6 MHz VSB system is used
  - Opportunity for a 17% increase in data rate, if a 7 MHz VSB system is used

Again, we appreciate the opportunity to provide our comments prior to the preparation of your full report, It is hoped that you will be able to provide some answers to the questions we have raised, and we look forward to continued dialog relative to the transmission system trials.

On behalf of the ATSC, its members, and the members of the ATSC Review Committee, we offer our sincere appreciation and best regards.

Sincerely,

WAYNE C. LUPLOW,
ATSC Executive Committee
Head, ATSC Australian Test Results Review Committee

WCL/e
Distribution: Bruce Robertson (4)
Robert Graves
Craig Tanner
Members of the ATSC Review Committee

Figure 1 - Static C/N

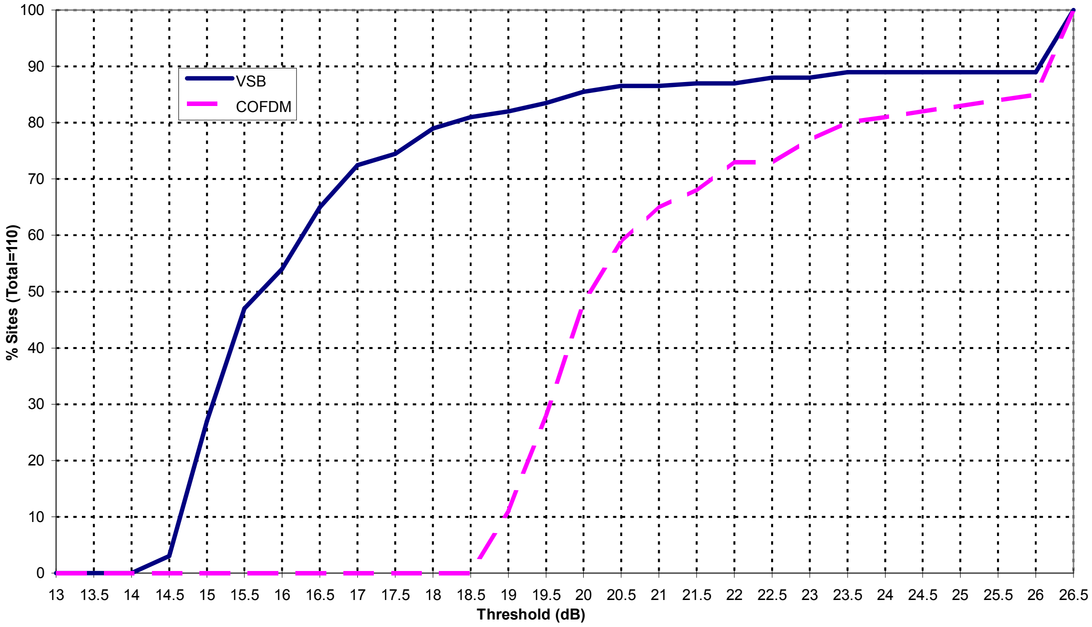


Figure 2 - Dynamic C/N

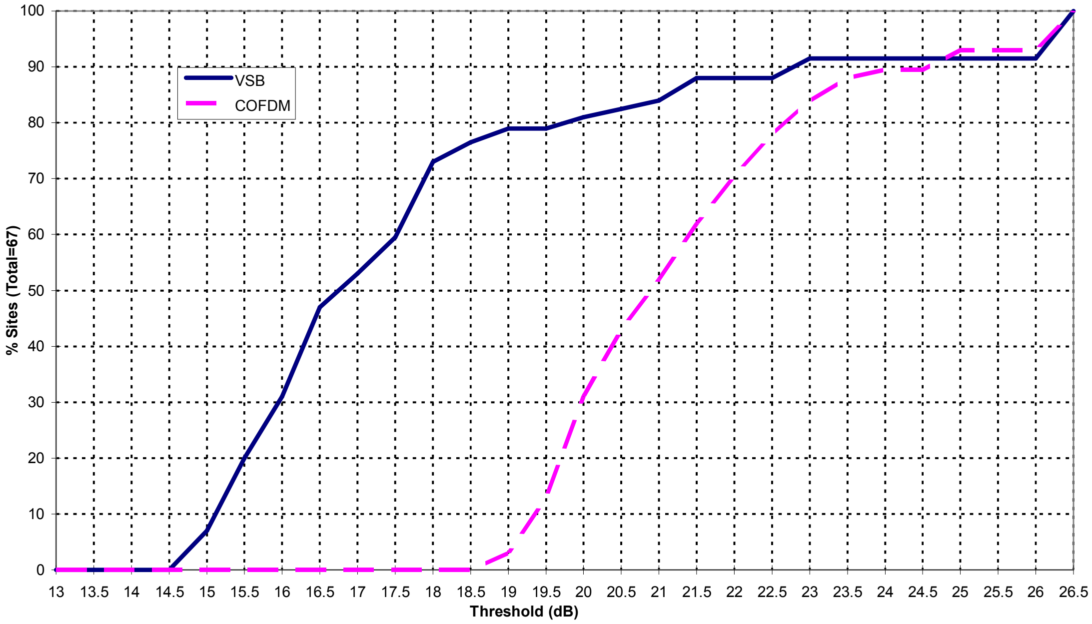
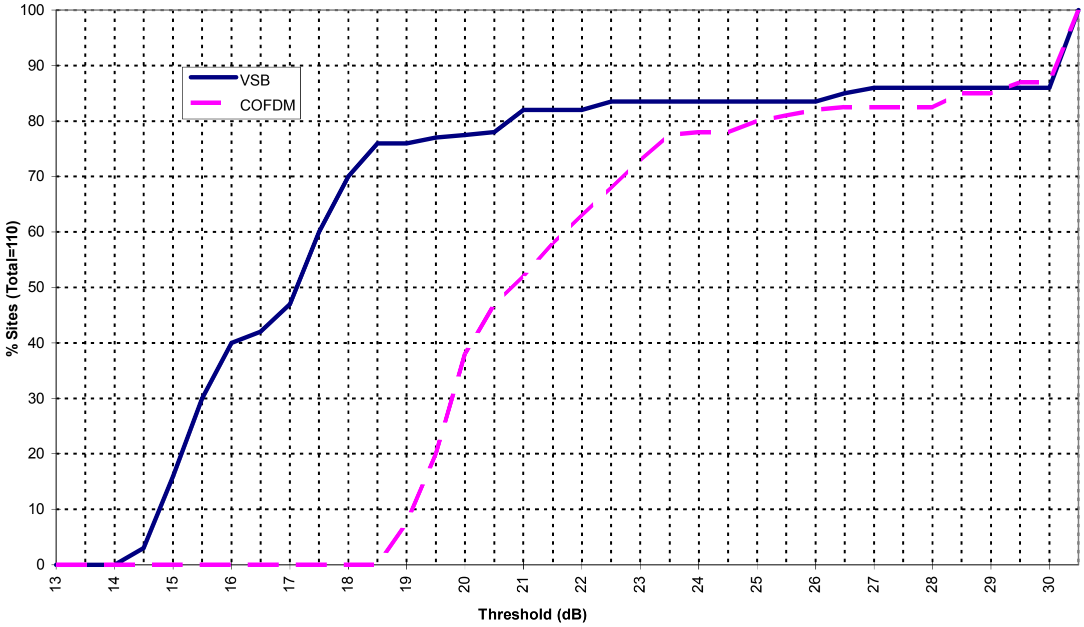


Figure 3 - Worst Case (Static or Dynamic) C/N



APPENDIX A

ATSC REVIEW COMMITTEE

John Henderson	Hitachi America
Robert Plonka	Harris Corporation
Victor Tawil	Maximum Service Television (MSTV)
Rich Citta	Zenith Electronics Corporation
Wayne Luplow	Zenith Electronics Corporation

APPENDIX B: INDOOR RECEPTION

While not a stated objective of the Australian field trials, considerable interest was voiced at the recent FACTS/ATSC meeting in Las Vegas about indoor reception. Thus, a few comments on this topic are included below.

In the U.S., indoor reception was an integral part of the Advisory Committee's field tests in Charlotte, North Carolina. More recently, extensive field testing has been done (and is continuing) at WRAL in Raleigh, North Carolina. The current report on this testing is attached as part of this letter. Furthermore, indoor testing is also part of the tests now under way in Washington, D.C. A report on these tests is expected to be completed by late June and we will mail a copy to you as soon as it is available.

The reception of an analog or digital signal indoors is significantly more difficult than outside reception. The transmission path parameters are all impacted in a negative way:

- Receiving Antenna Height -- has been lowered from 30 meters to 5 meters or less
- Building Penetration Loss -- has increased by a widely varying amount (from 5 to 30 dB, depending on the building construction, with an approximate median of 15 dB; worst-case is aluminum siding)
- Antenna Gain -- has been changed from a moderate-gain outside antenna to a lowgain rabbit ear or bow tie antenna for indoor reception
- Multipath -- has increased due to the loss of directionality of the antenna, and in a worst-case building, the signal only enters through multiple windows
- Impulse Noise -- has increased significantly due to the lower signal level and the many noise sources inside common residences (including microwave ovens, light dimmers, high efficiency RF light sources, and universal motors, such as mixers, vacuum cleaners and computers)

The Australian field trial directly addressed only one of these parameters -- antenna height. Many of the tests (38%) were conducted at a low antenna height of approximately 5 meters. These sites did show average field strength lower and an increase in multipath impairments. There was also an increase in impulse noise impairments, most likely due to the proximity of automobiles. The resulting thresholds for these sites were higher, but the differences from the overall field results are not statistically significant. It is expected that a comparative test of the two systems in an indoor environment would yield results similar to the present field test. Of course, the overall service availability would be lower for both systems.

Improvements in indoor antennas are desirable, and activities are under way in the U.S. to design active antennas that can be electronically steered.

8Glossary

As a significant number of acronyms are defined and used throughout this document here is a list of the major terms associated with digital television.

Digital television glossary

A/D	Analog to Digital
ABA	Australian Broadcasting Authority
AC-3	5.1 Channel Digital Audio Compression System
ACA	Australian Communications Authority
ACATS	Advisory Committee on Advanced Television Systems (USA)
ACI	Adjacent Channel Interference
AFC	Automatic Frequency Control
AGC	Automatic Gain Control
ATSC	Advanced Television Systems Committee (USA)
ATV	Advanced Television
AWGN	Additive White Gaussian Noise
B-pictures	Bidirectionally predictive pictures (motion) compensation
BAT	Bouquet Association Table (part of SI)
BER	Bit Error Rate
BRR	Bit Reduction Rate.
BST-OFDM	Band Segmented Transmission - Orthogonal Frequency Division Multiplex
C/I	Carrier to Interference
C/N	Carrier to Noise
CA	Conditional Access
CAT	Conditional-Access Table (part of SI)
CCI	Co Channel Interference
CD	Compact Disk
CIF	Common Image Format
COFDM	Coded Orthogonal Frequency Division Multiplexing
CPE	Common Phase Error
CRO	Cathode Ray Oscilloscope
CW	Continuous Wave
D/A	Digital to Analog
D/U	Desired to Undesired
DAB	Digital Audio Broadcasting
dB	Decibel
DBPSK	Differential Binary Phase Shift Keying.
DBS	Direct Broadcast Satellite
DCA	Department of Communications and the Arts
DCT	Discrete Cosine Transform
DMV	Digital Media Vision (company now called NDS broadcast)
DPCM	Differential Pulse Code Modulation
DSP	Digital Signal Processor
DTB	Digital Television Broadcasting
DTT	Digital Terrestrial Television
DTTB	Digital Terrestrial Television Broadcasting
DTV	Digital Television
DVB	Digital Video Broadcasting, suffixed

	S for satellite, C for cable, T for terrestrial, CS for SMATV, TXT for fixed-format teletext and MS for MMDS.
DVC	Digital Video Cassette
DVD	Digital Video Disk
EBU	European Broadcasting Union
EDTV	Enhanced Definition Television
EIT	Event Information Table (part of SI)
ELG	European Launching Group
EPG	Electronic Programme Guide
EPROM	Erasable Programmable Read Only Memory
ETS	European Telecommunication Standard
ETSI	European Telecommunication Standards Institute
FACTS	Federation of Australian Commercial Television Stations
FCC	Federal Communications Commission
FEC	Forward Error Correction
FFT	Fast Fourier Transform
GA	Grand Alliance
GOP	Group Of Pictures (motion compensation)
GPS	Global Positioning System
HD	High Definition
HDTV	High Definition Television Broadcasting
HFC	Hybrid Fibre Coax
HP	Hewlett Packard
I-pictures	Intra pictures (motion compensation)
IBC	International Broadcasting Conference
ICI	Inter-Carrier Interference
IDCT	Inverse Discrete Cosine Transform
IEC	International Electrotechnical Commission
IF	Intermediate Frequency
IFFT	Inverse fast Fourier transform
IMD	Inter-Modulation Distortion
IR	Infra Red
IRD	Integrated Receiver Decoder
ISDB	Integrated Services Digital Broadcasting
ISO	International Standardisation Organisation
ITU	International Telecommunication Union
LDTV	Low Definition Television
LED	Light Emitting Diode
LO	Local Oscillator
LOP	Limit of Perceptibility
MAC	Multiplexed Analog Components
MATV	Master Antenna Television
MCC	Multiplex Control Computer
MMDS	Multichannel, Multipoint Distribution System, or, multipoint microwave distribution system
MPEG	Video bit-rate reduction systems determined by the Moving Picture Experts Group
NDS	News Data Systems (company previously called DMV)
NIT	Network Information Table (part of SI)
NTA	National Transmission Authority

OFDM	Orthogonal Frequency Division Multiplexing
P-pictures	Predictive pictures
PA	Power Amplifier
PAL	Phase Alternate Line Television System
PAT	Programme Association Table (part of SI)
PMT	Programme Map Table (part of SI)
PPV	Pay Per View
PRBS	Pseudo Random Binary Sequence
PROM	Programmable Read Only Memory
PSI	Programme Specific Information (part of SI)
PSP	Programme Service Provider
QAM	Quadrature Amplitude Modulation
QEF	Quasi Error Free
QPSK	Quadrature Phase-Shift Keying
R&S	Rhode and Schwarz
RF	Radio Frequency
RLC	Run Length Coding
RS	Reed Solomon error protection
RST	Running Status Table (part of SI)
Rx	Receiver
S/N	Signal to Noise
SCM	Subjective Comparison Method
SCPC	Single Carrier Per Channel
SDH	Synchronous Digital Hierarchy
SDT	Service Description Table (part of SI)
SFN	Single Frequency Network
SI	Service Information, or housekeeping details added on to the video, audio and/or multi-media data stream
SIF	Simple Image Format
SMATV	Satellite Master Antenna Television
SMS	Subscriber Management System
ST	Stuffing Table (part of SI)
TDT	Time and Date Table (part of SI)
Tek	Tektronix
TOT	Time Offset Table (part of SI)
TOV	Threshold Of Visibility
TPS	Transmission Parameter Signalling
TREC	Timing Recovery
TS	Transport Stream
TSG	Test Signal Generator
TTL	Transistor Transistor Logic
Tx	Transmitter
UHF	Ultra High Frequency 300-1000 MHz
VHF	Very High Frequency 50-300 MHz
VLC	Variable Length Coding
VSB	Vestigial Side Band modulation system, prefixed by, 8 for 8 level terrestrial or 16 for 16 level cable version

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