ATSC Recommended Practice: Receiver Performance Guidelines

Document A/74:2010, 7 April 2010

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Specifically, ATSC is working to coordinate television standards among different communications media focusing on digital television, interactive systems, and broadband multimedia communications. ATSC is also developing digital television implementation strategies and presenting educational seminars on the ATSC standards.

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The revision history of this document is given below.

A/74 Revision History

A/74 approved	18 June 2004
Corrigendum No. 1	11 July 2007
Amendment No. 1	29 November 2007
A/74:2010 approved	7 April 2010

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ATSC Recommended Practice: Receiver Performance Guidelines

1 SCOPE AND DOCUMENT STRUCTURE

1.1 Foreword

This document addresses the front-end portion of a receiver of digital terrestrial television broadcasts. The recommended performance guidelines enumerated in this document are intended to assure that reliable reception will be achieved. Guidelines for interference rejection are based on the FCC planning factors that were used to analyze coverage and interference for the initial DTV channel allotments. Guidelines for sensitivity and multipath handling reflect field experience accumulated by testing undertaken by ATTC, MSTV, NAB, and receiver manufacturers.

1.2 Scope

This document provides recommended performance guidelines for the portion of a DTV receiver known as the "front-end," which includes all circuitry from the antenna through the process of Forward Error Correction (FEC) that is associated with recovery and demodulation of the 8-VSB signal. The output of the receiver front-end is the input to the Transport Layer decoder. Specifically, the circuits whose performance contributes to meeting these guidelines are:

- Antenna and antenna control interface (CEA-909).
- Tuner—including radio frequency (RF) amplifier(s), associated filtering, and the local oscillator (or pair of local oscillators in the case of double conversion tuners)—and mixer(s) required to bring the incoming RF channel frequency down to that of the intermediate frequency (IF) amplifier/filter.
- Intermediate frequency (IF) amplification (with automatic gain control) and filtering, including the major portion of pre-decoding gain, channel selectivity, and at least a portion of the desired-channel band-shaping.
- Digital demodulation, including in-band interference rejection, multipath cancellation, and signal recovery.
- Forward Error Correction (FEC), wherein errors in the demodulated digital stream caused by transmission impairments are detected and corrected for incoming signals with signal-to-impairment ratios above a threshold. Packets with uncorrectable errors are "flagged" for possible mitigation in the video and audio decoders.

This document does not discuss optional means by which receivers might attempt to conceal or otherwise mitigate the visible or audible consequences of uncorrected bit stream errors. Although most receivers include circuits that effect some degree of error concealment, the results are subjective and not quantified so easily as the performance of the circuits listed above.

1.3 Document Structure

The recommended performance guidelines for a DTV receiver front-end described in this document include a general system overview, a list of reference documents, and the recommended performance guidelines for the front-end circuit elements. The performance guidelines are divided into four general categories:

- Sensitivity
- Selectivity
- Interference rejection
- Multipath handling

2 REFERENCES

At the time of publication, the editions indicated below were valid. All standards are subject to revision, and parties to agreement based on this document are encouraged to investigate the possibility of applying the most recent editions of the documents listed below.

2.1 Informative References

[1] IEEE/ASTM SI 10-2002, "Use of the International Systems of Units (SI): The Modern Metric System", Institute of Electrical and Electronics Engineers, New York, N.Y.

[2] 47 CFR Part 73, FCC Rules, Federal Communications Commission, Washington, D.C.

[3] ATSC: "Digital Audio Compression (AC-3, E-AC3) Standard," Doc. A/52B, Advanced Television Systems Committee, Washington, D.C., 14 June 2005.

[4] ATSC: "ATSC Digital Television Standard," Doc. A/53 Parts 1 – 6, Advanced Television Systems Committee, Washington, D.C., 2007/2009.

[5] ATSC: "Program and System Information Protocol for Terrestrial Broadcast and Cable," Doc. A/65:2009, Advanced Television Systems Committee, Washington, D.C., 14 April 2009.

[6] ATSC: "Program and System Information Protocol Implementations Performance Guidelines for Broadcasters," Doc. A/69:2009, Advanced Television Systems Committee, Washington, D.C., 25 December 2009.

[7] CEA: "Recommended Practice for DTV Receiver 'Monitor' Mode Capability," Doc. CEA-CEB5-B, Consumer Electronics Association, Arlington, VA, May 2007.

[8] CEA: "Antenna Control Interface," Doc. CEA-909-A (ANSI), Consumer Electronics Association, Arlington, VA, December 2007.

[9] A. K. Y. Lai, A. L. Sinopoli, and W. D. Burnside: "A Novel Antenna for Ultra-Wideband Applications," IEEE T-AP, Institute of Electrical and Electronics Engineers, New York, N.Y., vol. 40, no. 7, pp. 755-760.

[10] J. J. Lee and S. Livingston: "Wideband Bunny-ear Radiating Elements", IEEE-APS Symposium Digest, Institute of Electrical and Electronics Engineers, New York, N.Y., vol. 3, pp.1604 – 1607, 1993.

3 DEFINITION OF TERMS

With respect to definition of terms, abbreviations, and units, the practice of the Institute of Electrical and Electronics Engineers (IEEE) as outlined in the Institute's published standards [1] are used.

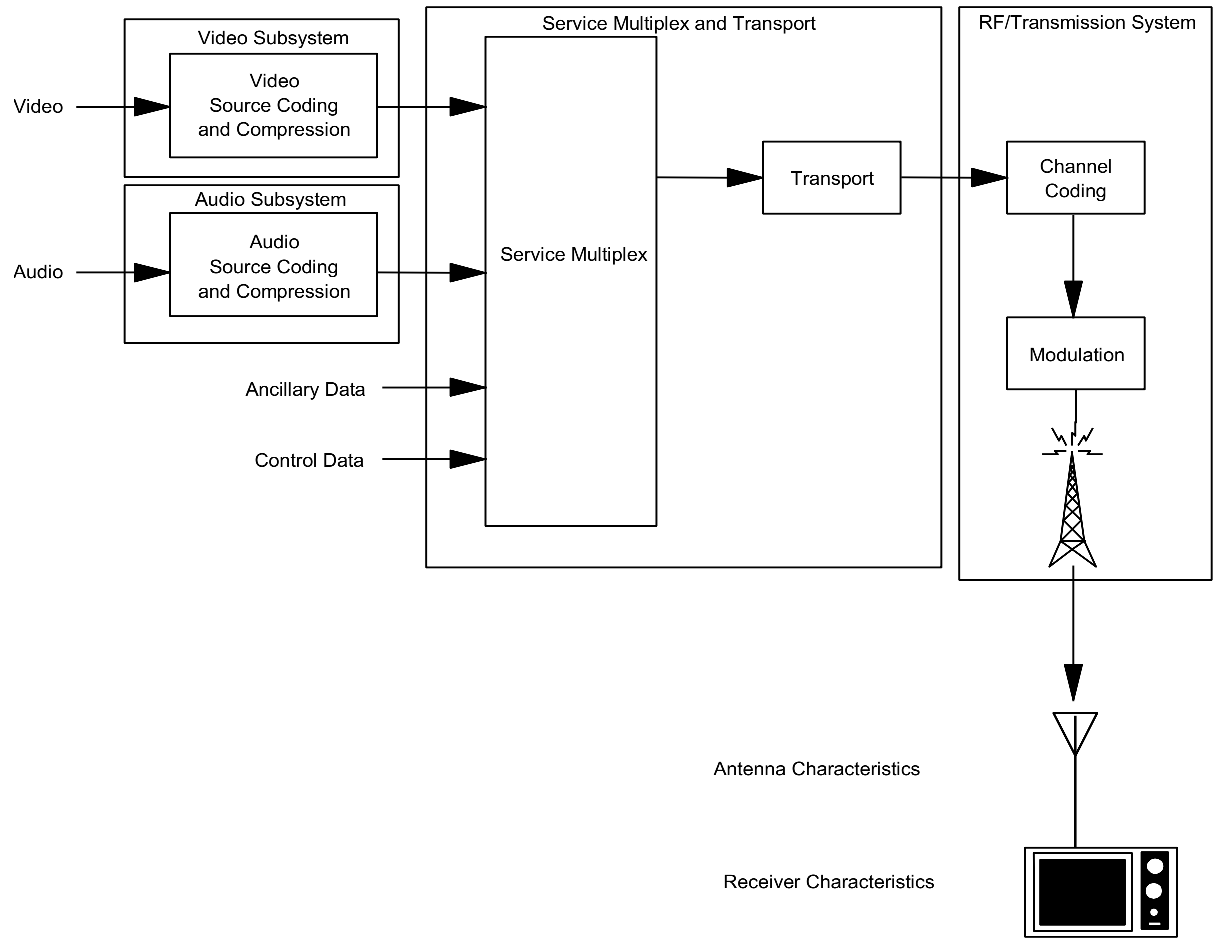

Figure 4.1 Overall block diagram of the digital terrestrial television broadcasting model.

3.1 Compliance Notation

Descriptions of ATSC document types can be found in the ATSC Bylaws (B/2). Definitions of acceptable conformance terminology can be found in the ATSC Procedures for Technology and Standards Group Operation (B/3).

4 SYSTEM OVERVIEW

4.1 Objective

The performance guidelines for digital television broadcast receivers describe a system designed to ensure reliable reception of digital television in the terrestrial environment.

4.2 System Block Diagrams

A basic block diagram representation of the digital terrestrial television broadcast system is shown in Figure 4.1. The video subsystem, the service multiplex and transport, and the RF/ transmission system are described in ATSC A/53 [4].

Figure 4.2 shows a block diagram of the front-end sub-system of a DTV receiver.

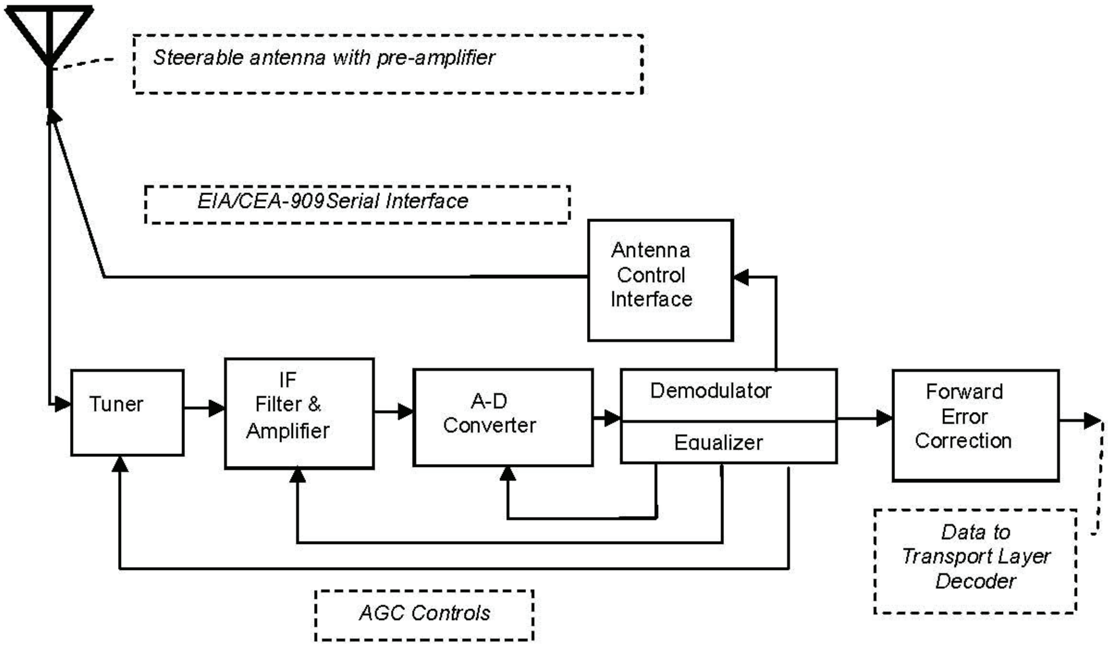

Figure 4.2 Digital television receiver front-end subsystem block diagram.

5 RECEIVER PERFORMANCE GUIDELINES

5.1 Sensitivity

A DTV receiver should achieve a bit error rate in the transport stream of no worse than $3x10^{-6}$ (i.e., the FCC Advisory Committee on Advanced Television Service, ACATS, Threshold of Visibility, TOV) for input RF signal levels directly to the tuner from –83 dBm to –5 dBm for both the VHF and UHF bands. These specific guideline levels are intended to apply to fixed-service (i.e., not mobile/handheld) broadcast receivers, and the guidelines describe the case of a single DTV signal with no noise and no multipath interference. This is an overall receiver guideline and is meant to include all receiver circuit effects, including any phase noise that is contributed by the tuner in that particular receiver. It is desirable to expand the dynamic range beyond these bounds when possible.

Some of the following sections of this document contain tables where a level of –68 dBm is designated as "weak." This –68 dBm level has never been intended to be the lower limit of received signals in consumers' homes. In contrast, the –68 dBm level has been used historically as a test point for relatively low-level NTSC signals, and its use has been continued as a convenient test point for DTV receivers.

5.2 Multi-Signal Overload

The DTV receiver should accommodate more than one undesired, high-level, NSTC or DTV signal at its input, received from transmission facilities that are in close proximity to one another. For purposes of this guideline, it should be assumed that multiple signals, each approaching –8 dBm, will exist at the input of the receiver. Such signals may be derived from either a high gain antenna used in a close-in reception environment or via a mast-mount amplifier/antenna combination, as utilized in a more distant environment.[1] Even an indoor antenna (or direct pickup) might deliver such levels if happenstance results in an unlicensed device physically close (such as through an apartment building wall) and/or operating such that it is effectively the same as one of the triplet channels. (See Annex G.) Because the mix of signal levels will vary by market, no attempt to provide specific channel testing guidance has been incorporated in this document. Rather, the receiver designer is directed to examples of channel allocation situations as illustrated in Annex D.[2]

5.3 Phase Noise

A DTV receiver should be able to tolerate phase noise levels at TOV of –80 dBc/Hz at a 20 kHz offset from the received signal source. This is not a measurement of the phase noise that exists internal to the receiver, but rather a measure of the receiver's ability to tolerate phase noise that has been introduced into the transmitted signal, for example, as a result of the signal passing through a translator with poor phase noise performance. For purposes of this performance recommendation, receivers are expected to tolerate phase noise that decays at a rate of 20 dB per decade of frequency offset over a range of at least 500 Hz to 100 KHz.

5.4 Selectivity

The values for adjacent channel and taboo channel rejection were developed based on available UHF data. With current technology, VHF performance is expected to exceed the UHF performance.

5.4.1 Co-Channel Rejection

The receiver should meet or exceed the following thresholds for rejection of co-channel interference at the following desired signal levels (Table 5.1).

1. An examination of typical mast-mount amplifiers and preamplifiers available in the fall of 2003 indicated that the capability to handle multiple signals was limited to approximately –8 dBm output per channel output before intermodulation products were internally generated.
2. No attempt has been made to project the channel allocations and operating power levels after the DTV transition. It is possible that, due to spectrum repacking, channel combinations after the DTV transition will be tighter than the examples provided in Annex D.

Table 5.1 Co-Channel Rejection Thresholds

Type of Interference	Co-Channel D/U[a] Ratio (dB)	
	Weak Desired (–68 dBm)	**Moderate Desired (–53 dBm)**
DTV interference into DTV	+15.5	+15.5
NTSC interference into DTV	+2.5	+2.5
Notes: NTSC split 75% color bars with pluge bars should be used for video source. All NTSC values are peak power; all DTV values are average power.		

a. Throughout this document, all signal power levels and the ratios of signal power levels are expressed logarithmically in decibels. Signal levels are expressed in dBm (decibels above a milliwatt).

$$P_{\text{dBm}} = 10 \log_{10} (P_{\text{milliwatts}})$$

Ratios of signal levels, such as Desired-to-Undesired (D/U) signal level ratios, are expressed in dB.

$$P_{\text{D/U}}\text{dB} = 10 \log_{10} (P_{\text{D}} / P_{\text{U}})$$

where P_D and P_U are in the same units of watts, milliwatts, microwatts, etc.

The reader should be careful to remember that when the power level of the Desired signal (in watts) is greater than the power level of the Undesired signal (in watts) the sign of the log of the power ratio (D/U in dB) will be positive; when the power level of the Desired signal is less than the power level of the Undesired signal, the sign of the log of the power ratio (D/U in dB) will be negative. For example, when the D/U ratio (in dB) is 25 dB, the power level of the Desired signal is 25 dB above the power level of the undesired signal; when the D/U ratio is –25 dB, the power level of the Desired signal is 25 dB below the power level of the Undesired signal.

While the co-channel interference between DTV stations (both co-channel and adjacent-channel contributions) was taken into account in the DTV channel allocations and power assignments, the additional co-channel signal energy due to all other sources that a given receiver may encounter was not a factor in FCC spectrum planning. In particular, unlicensed devices operating on nearby channels will increase the noise floor due to their out of band emissions. Unlike the planned locations of DTV emitters, these devices can be at any distance and in any direction, and their contributions become significant when they are close to a given receiver. Even co-channel energy from spread spectrum devices can reduce the SNR to below the DTV reception threshold, which can occur if such a device is within a few meters of a DTV receiver, as can occur in places like an apartment building. When the DTV signal is from one direction and weaker than can be detected by an unlicensed device in another dwelling unit (perhaps on the opposite side of the building, communicating with a host in a different direction) additional co-channel noise can overpower the desired DTV signal. While those DTV receivers that are near the interference-limited edge of coverage are perhaps most at risk, other reception in terrain-shielded areas also may be impacted by co-channel interference of this sort. When such interference sources are from a different direction than the desired signal (the predicted geometry for this case), then adjustment of the receiving antenna may offer a practical mitigation tool. See Section 5.6 for more information about automatic antenna adjustment technology.

5.4.2 Adjacent Channel Rejection

The receiver should meet or exceed the thresholds given in Table 5.2 for rejection of first adjacent-channel interference at the desired signal levels shown above the columns therein. The FCC Rules prohibit NTSC stations operating on the first upper and/or lower adjacent channels from locating their transmitters closer than 88.5 km apart from one another. Such a restriction limits receivers tuned to a desired station to exposure to first adjacent channel undesired signals only when the desired signal is at the weak signal level. The moderate and strong desired signal levels are included in the table because, in the development of the original DTV allotment table, the FCC Rules did not apply a mileage separation restriction to DTV stations operating on the first upper and/or lower adjacent channels. Allowing a first adjacent channel undesired station to be located anywhere within a desired station's service area, as made possible by the FCC Rules, will expose receivers tuned to that desired station to undesired signals when the desired signal also is at moderate and strong levels.[3]

Table 5.2 First Adjacent Channel Thresholds

Type of Interference	Adjacent Channel D/U Ratio (dB)		
	Weak Desired (–68 dBm)	**Moderate Desired (–53 dBm)**	**Strong Desired (–28 dBm)**
Lower DTV interference into DTV	–33[a]	–33[b]	–20
Upper DTV interference into DTV	–33	–33[b]	–20
Lower NTSC interference into DTV	–40	–35	–26
Upper NTSC interference into DTV	–40	–35	–26
Note: All NTSC values are peak power; all DTV values are average power.			

a. The FCC planning factors for DTV into DTV are –26 and –28 dB in “Reconsideration of the Sixth Report and Order” (FCC 98-24). These were based on asymmetric transmitter splatter in the first adjacent channel. For this document, –27 dB is used and a 6 dB margin is added to reach –33 dB D/U. Most test equipment will not generate the FCC-allowed splatter. By meeting the –33 dB guideline with lab generators that do not have sideband splatter, it is assured that the limiting interference in the field will be adjacent splatter rather than overload. The margin is added to allow for improvement in DTV transmitter technology.

b. The adjacent channel rejection ratio for DTV into moderate DTV is set equal to the ratio for DTV into weak DTV because of the incidence of predicted DTV into DTV interference at moderate levels. The rejection ratios for NTSC into weak DTV and NTSC into moderate DTV do not need to be equal, due to the use of either co-location or distant spacing of analog and digital transmitters. Practical receiver designs, however, may attain the same rejection at moderate level as at weak level.

For additional information, including the effects of tuner non-linearity, the reader is referred to Annex E on Adjacent Channel Interference.

5.4.3 Taboo Channel Rejection

The receiver should meet or exceed the following thresholds for rejection of taboo-channel interference at the desired signal levels (Table 5.3, 5.4)

3. Receiver designers should be aware that, in the U.S., there might be narrow-band transmissions operating on adjacent TV channels. For example, in some cities, vacant TV channels are used for public safety land mobile communications. In addition, the FCC has adopted an Order that allows unlicensed consumer devices to operate on unused TV channels (see ET docket 02-380).

Table 5.3 Taboo Channel Rejection Thresholds for DTV Interference into DTV

Channel	Taboo Channel D/U Ratio (dB)		
	Weak Desired (–68 dBm)	**Moderate Desired (–53 dBm)**	**Strong Desired (–28 dBm)**
N +/– 2	–44	–40	–20
N +/– 3	–48	–40	–20
N +/– 4	–52	–40	–20
N +/– 5	–56	–42	–20
N +/– 6 to N +/– 13	–57	–45	–20
N +/– 14 and 15	–50[a]	–45	–20

Notes:
These numbers are consistent with the maximum signal level in Section 5.1.
All DTV values are average power.

a. This value should not be interpreted as just a tuner image rejection value in that it applies to the entire receiver.

Table 5.4 Taboo Channel Rejection Thresholds for NTSC Interference into DTV

Channel	Taboo Channel D/U Ratio (dB)		
	Weak Desired (–68 dBm)	**Moderate Desired (–53 dBm)**	**Strong Desired (–28 dBm)**
N +/– 2	–44	–40	–20
N +/– 3	–48	–40	–20
N +/– 4	–52	–40	–20
N +/– 5	–56	–42	–20
N +/– 6 to N +/– 13	–57	–45	–20
N +/– 14 and 15	–50	–45	–20

Notes:
NTSC split 75% color bars with pluge bars should be used for video source.
All NTSC values are peak power; all DTV values are average power.

5.4.4 Interference from Two or More Undesired Signals

Two or more strong undesired signals can, in the presence of tuner non-linearity, generate spectra of cross-modulation and 3rd-order intermodulation that raise the effective noise floor of the desired signal. For two interfering signals at frequencies Fa and Fb, the intermodulation frequencies are

$$[2 * Fa +/– Fb] \text{ and } [2 * Fb +/– Fa]$$

For three or more interfering signals, the intermodulation frequencies are of the form

$$[Fa +/– (Fc – Fb)], [Fb +/– (Fc – Fa)], \text{ and } [Fc +/– (Fb – Fa)]$$

At best, the desired channel can be received only if these receiver-generated noise spectra are at least 15.2 dB below the level of the desired signal. Tuner selectivity and control of these distortion products at expected reception levels are the means to achieve this performance. These effects are explained in more detail and quantified with examples in Annex F for two undesired signals and Annex G for three undesired signals.

5.4.5 Burst Noise Performance

The receiver should tolerate a noise burst of at least 165 µs duration at a 10 Hz repetition rate without visible errors. The noise burst should be generated by gating a white noise source with average power –5 dB, measured in the 6 MHz channel under test, referenced to the average power of the DTV signal.

5.4.6 Interference from Strong Out-of-Band Transmitters

Receivers in consumer settings may be exposed to very strong signals from out-of-band transmitters. Examples of the sources of such signals are FM stations located in residential areas or along roadways and television transmitters in a band other than that to which a receiver is tuned located near residential areas. In cases of these sorts, for instance, reception can be affected by FM or VHF signals when a receiver is tuned to a UHF station, or reception of a VHF station can be affected by FM or UHF signals. Instances of such interference cases were reported as the causes of some reception failures following completion of the DTV transition in the US.

NTSC receivers frequently included traps prior to their first active components to reduce the levels of such out-of-band signals before they could affect the operation of the front-end portions of the receivers. Designers of future receivers and components are advised to consider the potential impact of strong out-of-band signals when establishing the architectures of their receiver front-end designs.

5.5 Multipath

5.5.1 Introduction

The aim of this section is to focus on real multipath propagation conditions found in the field and on the practical difficulties DTV demodulator designers may encounter. Equalizer design techniques are not addressed, as equalizer design is a topic that has been widely documented in specialized literature over the past years.

Field studies of DTV signal reception have demonstrated a wide range of varying multipath and noise conditions. It is generally admitted that there is no adequate model representing the diversity of conditions observed in the field. Past experience has proven that there is a clear benefit in gaining knowledge from the field environment to improve receiver performance.

This section provides information and recommendations regarding the multipath conditions that may be experienced in the field. The recommendations consist of two complementary parts, which are digitally captured signals obtained in actual field conditions and selected multipath ensembles created using laboratory test equipment.

In the first part of this section, a dataset of field ensembles (DTV captured signals) is furnished as an example of the various conditions that can be observed in the field. Most of the field ensembles contain data captured at sites where reception was difficult. The field ensembles are clearly not meant to represent the statistics of overall reception conditions but rather to serve as examples of difficulties that are commonly experienced in the field. A few mild ensembles are included in the data so that receiver design does not focus solely on new, difficult conditions, overlooking performance requirements shown to be necessary in the past.

In the second part of the section, recommendations on laboratory ensembles are proposed. The laboratory ensembles do not necessarily represent actual channel conditions, nor do they represent design criteria. The ensembles are intended to be supplementary diagnostic tools for testing designs in specific controlled conditions. Some element of variability of the relevant parameters was introduced in the laboratory ensembles to allow the diagnostics to operate with a wide set of characteristics. When possible, a bound on the variable parameters will be suggested to avoid an over-design of the receiver and to allow for proper trade-offs.

The examples documented in these sections and the accompanying Annexes are not necessarily the worst conditions that may be experienced. Examples of large (within a couple of dB of the main signal) and very long (approaching 100 microsecond) echoes have been found in the San Francisco Bay area using a whip antenna. The conditions causing these echoes are believed to be a strong reflector (e.g., the Golden Gate Bridge) at a height sufficient to cause its reflected signal to have little or no attenuation when it illuminates receivers. Mountains and buildings in other geographical regions may combine to create similar conditions.

It may be that sole reliance on an equalizer in the demodulator IC is not the best way to address these conditions. A directional antenna offers a means of mitigating this kind of multipath in some circumstances. This receiving system design option is discussed further in Section 5.6.

5.5.2 Field Ensembles

The data include different scenarios of field capture.

5.5.2.1 Capture Location

The field ensembles recommended in this document were recorded in the Washington, D.C., area and in New York City. The ensembles were chosen for their difficulty, considering past knowledge gained with various generations of DTV receivers and multiple field test campaigns.

The data includes outdoor and indoor captures in different types of environments, such as rural, residential, and suburban areas.

5.5.2.2 List of Recommended Field Ensembles

The list of the recommended field ensembles is provided in Annex A.

5.5.2.3 Field Ensemble Characterization

Each field ensemble is described by a series of labels that characterize the properties of the channel for the specific location in which the RF signal was recorded. The labels are categorized and summarized in Table 5.5. These labels describe the conditions at the time of the data capture and provide the channel characteristics. The receiver designer may use this information to gain insight regarding which areas of the receiver design may require specific care. For example, the dynamic nature of the channel, the distortion of the spectrum band-edge, and the cancellation of the pilot tone are elements that may affect the ability of the receiver to synchronize with the signal and, therefore, may contribute to a failure of the receiver. The design of the receiver could be adapted accordingly to mitigate the effects of these impairment classes.

Table 5.5 Field Ensemble Description

<table>
<tr><td colspan="4">Capture Description</td></tr>
<tr><td>Antenna Type
Log-periodic
Dipole
Double bow-tie</td><td colspan="2">Antenna Direction Optimization
Optimal
Random</td><td>Capture Parameters
AGC on/off
A/D precision
Others</td></tr>
<tr><td colspan="4">Site Description</td></tr>
<tr><td>Antenna Location
In-home
Outdoor, 30 feet</td><td>Neighborhood Description
Rural
Industrial park
Suburban
Others</td><td>Site Location
Distance from transmitter
Latitude/longitude of the site location</td><td>Miscellaneous
Channel name
Date of capture
Weather conditions
On site temperature
Construction type
Others</td></tr>
<tr><td colspan="4">Channel Description</td></tr>
<tr><td colspan="2">Upper/Lower Adjacent Channel
DTV
NTSC
None</td><td colspan="2">Channel Dominant Characteristics
Multiple echoes
Dynamic/static channel
In-band interference
Band-edge distortion
Pilot distortion
Others</td></tr>
</table>

A detailed description of all the labels is given in Annex A.

The labels associated with the ensembles listed in Annex A can be divided into three types of information representing a description of the site where the signal was recorded:

- The capture description
- The site description
- The channel description

The capture description is broken down into three categories:

- The type of antenna used to record the channel
- Optimization of the antenna direction
- Additional capture parameters, such as whether or not an AGC (Automatic Gain Control) was used during the capture of the channel, the analog-to-digital (A/D) converter precision, and so on

The site description specifies the context in which each field ensemble was recorded. This information is broken down into four categories:

- The antenna location
- The neighborhood description
- The site location
- Miscellaneous information, such as, the name of the file, the capture date, the recorded channel, the weather conditions during the capture of the signal, and so on

The channel description is broken down into two parts that specify the presence and type of upper and lower adjacent channels and a characterization of the nature of the captured channel. This characterization is intended to enable receiver designers better to assess the relative difficulty of each ensemble.

The channel characteristics have been extracted from observations of the channel spectrum over the entire period of the capture. The echo profiles of some captured channels have been explicitly identified and documented in Annex B, when the profile was felt to provide useful information in terms of channel diversity conditions. The impulse response estimate is produced by a correlation between the received signal and the PN511 binary training sequence embedded in the data field sync (see A/53 [4]). The impulse response produces a channel estimate with a maximum echo span of –23 µs (for pre-echo) and +23 µs (for post-echo) for every data field sync segment. A more detailed description of the channel estimation technique is given in Annex B.

5.5.2.4 Data Format

All field ensembles in Annex A represent a digital record having a maximum length of 25 seconds of 8-VSB DTV broadcast. The field ensembles were coded into a unique data format chosen for its compatibility with standard RF playback equipment.

The recorded DTV channels were sampled at 21.524476 Msamples/sec and down converted to a low central IF frequency of 5.38 MHz. The analog-to-digital conversion of the RF signal used a 10-bit or a 12-bit A/D. Each sample was encoded into a 2-byte word (signed int16 with a two's complement format). To encode a field ensemble of 25 seconds, 1.05 G Bytes were needed.

5.5.2.5 Recommended Physical Support for Field Ensemble Data Transfer

To play back the data on RF player equipment[4], two options are possible:

- The data can be transferred to an Integrated Device Electronics (IDE) hard drive or DVD-RW drive. A tape drive (Exabyte–compatible) can be used
- An external hard drive with a USB 2.0, Firewire, 10/100/1000 Ethernet, or Small Computer Systems Interface (SCSI) can be used.

The last option is recommended as it allows a flexible transfer of all the recommended field ensembles in a single transaction from the ensemble database repository.

The recommended field ensembles set is available by request to the ATSC.

5.5.3 Laboratory Ensembles

The emulation of realistic field conditions in a laboratory environment is considered to be difficult at best. The difficulty lies, in part, in the inability to create models for a wide range of multipath conditions and also, in part, in historical technical limitations of laboratory test equipment, which allows only borderline case tests.

Laboratory test ensembles are widely used, however, and are considered to be useful, in specific cases, for stressing the performance of DTV receivers within a controlled laboratory environment.

A minimal set of exemplary laboratory diagnostic ensembles is proposed, in the following sections, as a set of diagnostic tools for receiver design. The ensembles proposed in this section were selected or constructed based upon judgment of their utility by the members of the committee preparing this Recommended Practice. The ensembles have been selected for their ability to trigger specific failure mechanisms in receivers. When possible, a document reference

4. Suitable purpose-built RF players known to the ATSC include the Wavetech Services WS-2100 (http://www.wavetechservices.com) and the Sencore RFP 910 (http://www.sencore.com). There may be other devices available, and being listed here does not imply an ATSC endorsement.

stating the origin of a selected laboratory ensemble is furnished. To guarantee at least a minimal correlation with observations in the field, the laboratory diagnostic ensembles have been substantiated by a time domain analysis of field ensembles that were extracted from the field ensembles database Annex A (which were selected for their apparent difficulties and rough correlation with the laboratory ensembles). A summary of the analysis is furnished in Annex B. Finally, to allow for flexibility, the selected laboratory ensembles have been modified to allow for use of variable parameters.

The ensembles described in Section 5.5.3.2 are offered as a recommended tool for evaluating DTV receiver performance.

5.5.3.1 Channel Impulse Response Range

5.5.3.1.1 Typical Echo Range

The channel impulse response for a signal from a single DTV transmitter can be expected often to range from –30 µs (pre-echo) to +40 µs (post-echo), with amplitudes generally decreasing with displacement (see Table 5.6). This range is not to be taken as absolute but rather as what frequently has been observed in the field. Very large delays have been observed in certain environments, as discussed in Section 5.5.1. This Recommended Practice states the minimum echo range that the receiver might be expected to encounter in the field.

As is shown by the captured ensembles proposed in Annex C, it is clearly possible that there are channel impulse responses exhibiting echoes beyond this range. However, to the best of our knowledge, there is no data available to scientifically assess the probability of occurrence of any particular channel estimate for any particular time period.

A test for this capability should vary the echo offset over the range. The step size should not be the exact symbol time. A plot of single echo amplitude vs. displacement over this range (or greater) should aid in showing the performance of a design in this regard.

5.5.3.1.2 Single Static Echoes Amplitude / Equalizer Profile

Table 5.6 describes the magnitude of the channel impulse response profile for which the receiver should perform in a static or quasi-static condition.

Table 5.6 Recommended Target Performance for a Desired DTV Signal in the Presence of a Single Static Echo of Varying Delay

Echo Delay (µs)	Amplitude (dB)
–40.0	–15
–30.0	–7
–20.0	–7
–15.0	–5
–10.0	–3
–5.0	–0.5
5.0	–0.5
10.0	–1
15.0	–1
20.0	–2
30.0	–3
40.0	–4
50.0	–15

The receiver should be insensitive to the phase of a single echo, and so any test procedure should introduce a slow Doppler of 0.05 Hz (or the slowest Doppler rate above 0.05 Hz that is available). In the presence of a single echo, performance should be determined by TOV with a desired DTV signal power of –28 dBm to the limits defined by the profile.

It should be noted that some extant equalizer designs achieve performance better than that indicated in Table 5.6 over at least some portions of the time range (e.g., in at least one case, extending the TOV curve to –8dB at +/–70 µs). Creators of future designs are urged to consider bettering the performance indicated in Table 5.6, if doing so is consistent with other performance trade-offs such as dynamic multipath performance and performance in low S/N conditions.

Note that pure single echo conditions are seldom if ever expected to be encountered in the field. DTV receivers are expected to encounter multiple echoes in the field, including echoes with delays in between those points appearing in Table 5.6. Single echo performance is only one factor to consider in designing a DTV receiver. System designers should consider all factors, including the field ensembles in Annex A.

5.5.3.2 Single Dynamic Echoes

The ensembles proposed below (ATSC R.1[5]) attempt to create single echo scenarios where the echo path and the dominant path may reverse roles if the echo power is sufficiently strong. ATSC

5. ATSC R.1 is derived from the ATSC Group G.1.1 and G.1.2 (DTV Laboratory Test Plan, Revision 1.0, October 11, 2001).

R.1 ensembles allow for variability of the main parameters. The following table describes the ensemble test.

Table 5.7 ATSC Test Group R.1. Multiple Dynamic Echoes

ATSC Test Group	Test Impairment	Test Description	Desired Signal Level
Susceptibility to Dynamic Echoes in the Presence of Random Noise	R.1 Dynamic Alternating Pre- and Post-Echoes in the presence of noise	1. Variable Pre/Post 2. Delay, attenuation, and phase set per table below 3. Test with path 3 at variable Doppler; path 2 at 0.05 Hz 4. Increase echo power level of paths 2 and 3 together to determine TOV	Strong (–28 dBm)

The actual generation of the single dynamic echoes is achieved using the following path parameters in a six-channel simulator. Path 1 is the main path. Paths 2 and 3 have identical delays. The phase of path 3 is varied at specific Doppler rates. Consequently, the voltages of the two paths (2 and 3) add vectorially, constructively or destructively, according to the phase. The attenuation of echo paths 2 and 3 are varied such that the power of each echo is maintained at an equal level.

The path parameters are given below in Table 5.7.

Table 5.8 ATSC R.1 Ensembles

ATSC Ensemble	Channel Simulator Parameter	Path 1	Path 2	Path 3
ATSC R.1	Delay (µs)	0	Variable	Variable (Identical to Path #2)
	Attenuation (dB)	0	Variable	Variable (Identical to Path #2)
	Phase (deg.)	0	0.05 Hz Doppler	Variable (0 – 2Hz)

The relative time domain delay between the two signals (that of the main path and the resultant of the time varying combination of paths 2 and 3) should be variable. Note that the phase variations on each path will result in a time varying echo amplitude for each test point. It is recommended that the time delay range be from the smallest step supported by the test equipment up to 2 µs (the same setting for both path 2 and 3 for each test). It is recommended that the attenuation (the same setting for both path 2 and 3 for each test) should be varied from 7 dB to 0 dB. The echo delay range and other parameters suggested in this section were chosen to provide easily interpretable results to help receiver designers evaluate their designs, and are not to be construed as representing any knowledge of the frequency of occurrence of "bobbing" conditions (i.e., channels where the dominant signal path changes among two or more approximately equal echoes) in the field. The channel impulse response under field conditions generally will be more complex than the laboratory case and the delay between "bobbing" elements possibly may exceed the delay ranges suggested.

An example of such a multipath ensemble was observed in the ATTC outdoor signal capture WAS-311/48/01. It seems to indicate the presence of close-in alternating echoes with a span between echoes of about 300 ns. Another example of such a channel is shown in Figure B.11 with a span between echoes of 1.75 µs. The impulse response analysis of these two ensembles is furnished in Annex B. Note that these captures, while demonstrating the short time, large amplitude, varying echo condition, also contain multiple echoes at lower levels.

This test was chosen for its repeatability in laboratory conditions. Other models for alternating pre- and post-echoes can be proposed. For example, conditions such as Rayleigh fading attenuation could be investigated.

5.5.3.3 Multiple Dynamic Echo Ensembles

A series of multiple dynamic echo ensembles represented by the test ATSC R.2[6] is offered as a means to provide increasingly more difficult multipath conditions to a DTV receiver. These ensembles are described in Table 5.9.

Table 5.9 ATSC Test Group R.2. Multiple Static and Dynamic Echoes

ATSC Test Group	Test Impairment	Test Description	Desired Signal Level
Susceptibility to Dynamic Echoes in the Presence of Random Noise	R.2 Dynamic Echoes in the presence of noise	R.2.1. Dynamic Ensemble #1/ #2 / # 3 / #4 1. Test with path 5 at variable Doppler (0-5Hz) 2. Increase power of path 5 to determine TOV	Moderate (–53 dBm)
		R.2.2 Dynamic Ensemble # 1/ # 2 / # 3 1. Test at variable S/N levels 2. Test with path 5 variable Doppler (0 – 5Hz)	Moderate (–53 dBm)

The actual generation of the single dynamic echo for the ensemble ATSC R.2.1 is achieved using the path parameters defined in Table 5.10 in a six-path channel simulator. Path 1 is the main path.

Table 5.10 ATSC R2.1 Ensembles

Ensemble		Path 1	Path 2	Path 3	Path 4	Path 5	Path 6
Relative attenuation (dB)	#1	0	20	20	10	Varied to reach TOV	18
	#2	0	17	17	7		15
	#3	0	14	14	4		12
	#4	0	11	11	1		9
Delay (µsec)		0	–1.80	0.15	1.80	5.70	35.0
Phase or Doppler		0	125°	80°	45°	Variable (0 – 5 Hz)	90°

ATSC R2.1 includes a variable Doppler shift for the Path 5. The recommended range for the variable Doppler is 0 to 5Hz.

6. These ensembles were derived from a set of CRC (Communications Research Center, Canada) ensembles, which in turn were derived from an ensemble in “Grand Alliance System Test Procedures,” Advisory Committee on Advanced Television Service, Federal Communications Commission, SSWP2-1306, March 24, 1995.

Table 5.11 ATSC R2.2 Ensembles

Ensemble		**Path 1**	**Path 2**	**Path 3**	**Path 4**	**Path 5**	**Path 6**
Relative attenuation (dB)	#1	0	15	15	7	7	15
	#2	0	8	3	4	3	12
	#3	0	3	1	1	3	9
Delay (µsec)			–1.8	0.15	1.8	5.7	39.8
Phase or Doppler		0	125°	80°	45°	Variable (0 – 5 Hz)	90°
White Gaussian Noise		Variable					

The ATSC R.2.2 ensembles are created to explore the ability of a design to operate with increasing additive Gaussian noise in the presence of five echoes of various relative amplitudes (see Table 5.11). The proposed set explores equalizer performance in regions where Path 6 is at the boundary of the recommended range for the equalizer delay span. The ATSC R.2.2 modifications include the introduction of a variable level of Additive White Gaussian Noise (AWGN) and a displacement of the echo delay in Path 6 from 35 µs to 40 µs.

The power in Path 1 should be set at the practical limit[7] of the test bed, and white Gaussian noise should be added until the SNR is at least reduced to 18 dB. This minimal SNR value was recommended by the experts preparing this Recommended Practice for practical equalizer designs known in late 2003. The 18 dB SNR incorporates a 3dB margin over the theoretical ATSC 8-VSB SNR defined in the absence of multipath. The 3 dB margin takes into account the effects of noise enhancement introduced by the equalizer. Operation with lower SNRs is desirable and expected to approach the theoretical limit for a given architecture and under given multipath conditions as receiver designs become more mature. To avoid a variability of the SNR with respect to the delay of the estimated signal source, the signal power should be calculated for each test sequence by adding the absolute values of the power in all six paths. The noise power should be calculated over a 6 MHz bandwidth.

Threshold of operation is measured at a transport stream bit-error-rate (BER) of 3×10^{-6}.

5.5.3.4 Dynamic Multipath in the Presence of Doppler Frequency Shift and Airplane Flutter

The reception of the DTV signal in the presence of multipath may also be influenced by Doppler shift and airplane flutter if the reflecting object is moving. Doppler shift is an apparent change in frequency (or wavelength) due to the relative motion of the reflecting object with respect to the receiver. The exact analytical expression of the Doppler frequency shift (F_D) is related to the velocity of the reflecting object (V_R) relative to the signal path and the DTV channel frequency (F_{TV}) by the following equation:

$$F_D = V_R \text{ x } [\pm\cos(\theta_T) \pm \cos(\theta_R)] \text{ x } F_{TV} / c \qquad (1)$$

where c is the speed of light, and θ_T and θ_R are the angles between the velocity direction of the reflecting object and the paths between the reflecting object and the transmitter and receiver, respectively.

7. Note that total power, including the to-be-added noise, should be considered in determining what this starting level should be to avoid introducing distortions from the test bed.

Benson[8] reports that airplane flutter occurs at rates from 50 to 150 Hz. These rates have also been observed in DTV field signal captures. In particular, the indoor capture at site WAS-32/39/01[3] shows rates as high as 75 Hz in an 11 µs echo with amplitude of –25dB and rates in the order of 17 Hz with echo amplitude of –9dB with respect to the dominant signal path. This capture was taken in a single-family home approximately 19 miles from the transmitter and within several miles from IAD airport. A double bow-tie antenna with reflector was used and was aimed to optimize the signal spectrum. From equation (1) the relative object velocity for a 75 Hz Doppler at channel 39 (623 MHz) is 160 mph (assuming a positive Doppler frequency shift). This is a reasonable velocity if the echo is due to the presence of aircraft. The indoor capture at site WAS-49/36/01[3] shows Doppler rates that range between 17 Hz with a 1.75 µs echo with amplitude of echo of –5dB up to 150 Hz with echo amplitude between –20 dB and –30 dB. This site was a single-family home near the BWI airport. An aircraft was observed flying towards the receiver during the capture. Since these Doppler rates have been observed in the field, it is recommended that a limited number of laboratory test ensembles include variations in Doppler frequency from zero to 150 Hz..

Due to the limited amount of data, it was not possible to define a correlation between the echo profile and the Doppler shift.

5.6 Antenna Interface

A receiving system consists of an antenna and a receiver. It often may be the case that the antenna and receiver subsystems can work together more effectively if there is control of the antenna by the receiver. A vehicle for providing such control is the CEA-909-A antenna control interface.

The sections on multipath herein have described many signal conditions where reception is difficult. Furthermore, in the sections on sensitivity and overload, the authors of this document considered reception conditions made difficult by low received signal strength or by potential overload from large received signals. In some cases, reception can be improved with an antenna that has a more directional pattern than a dipole. Controlled amplification between the antenna and the tuner sometimes can be helpful.

Automatically controlled antenna- and pre-amplifier-based improvements in reception can be facilitated by including in the receiver the “Antenna Control Interface” described in the CEA-909 Standard [8]. CEA-909 defines a protocol and interfaces that can control an antenna’s directionality, polarization, pre-amplifier gain, and tuning optimization for a particular channel. The digital links use a common serial bit stream, with specified connectors and voltage levels. One interface is defined for a separate connector, and another interface is defined to share the coax connected to the antenna. The standard allows any controllable antenna to work with any receiver, as long as both support the same CEA-909 interface.

Modest directional performance can be achieved with antennas of consumer-friendly size, especially at UHF. With LVHF, the gain bits may be the more important, as pattern variation is not expected to be large in practical indoor antennas (and the gain is needed given the lower resultant aperture). Therefore this interface, together with a relatively simple antenna, may be able to mitigate the impact of large UHF echoes with large delays by null steering, which can reduce the amplitude of an echo outside the range of the equalizer to reduce or eliminate its impact on convergence. For example, calculations show that a 20-inch diameter 6 element circular plane

8. K. B. Benson, et. al.: “Television Reception Principles”, *Standard Handbook of Video and Television Engineering*, Chapter 17.1, McGraw-Hill, New York, N.Y., 2000.

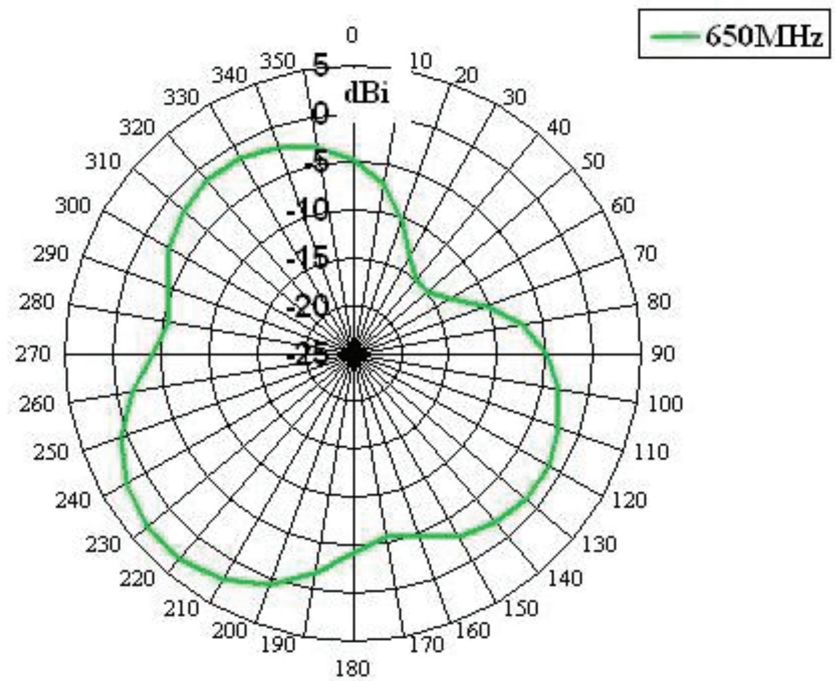

Figure 5.1 Theoretical gain for a ‘smart’ combination of 6 radial elements.

antenna can enable a steerable pattern approximating that shown in the Figure 5.1. Most directions have low gain but one has a significant null. Such a null placed in the direction of a significant echo would reduce its amplitude, perhaps to a level below the effective converged noise threshold, thereby enabling reception. See [8] and [9] for more on the antenna design technology. For a practical indoor antenna installation in proximity to unknown material, the effective pattern can be expected to vary significantly from theory and have less directivity at lower frequencies; significant nulls still can be expected.

The performance of the controllable antenna is not specified, nor is the receiver algorithm that optimizes the antenna configuration for a particular received signal. These are areas for competitive innovation. This lack of specificity, however, means that all data values should be varied by the receiver. The direction bits have no pre-assigned meaning, but the gain bits are defined. It is recommended to vary at least the two gain bits and the four coarse direction bits to obtain useful results. In particular, not changing the gain bits results in the antenna being set to either maximum attenuation or maximum gain; either condition is unlikely to be good for all channels. Sophisticated search algorithms can take advantage of the full CEA-909 bit stream specification. The dwell time on each combination is not specified since the settling and convergence times vary by receiving chip design; but all receivers should attempt to reach equalization stabilization for each combination, note the result (after a ‘long enough’ time if not stable) and then change the configuration. The best performing configuration should be stored for each channel.

It is expected that a controllable antenna will work in conjunction with a receiver’s equalizer, tuner, and demodulator to improve reception under conditions of multipath and unusually weak or strong signals. In some cases, an antenna with a directional pattern that gives only a few dB reduction of a specific multipath reflection can dramatically improve the equalizer's performance.

The CEA-909 interface describes fully automatic operation of the antenna and its control functions. It also allows the option for manual programming by the consumer. This manual mode might be entered when an antenna was moved, for example. During this mode the settings for antenna position/gain can be adjusted and/or optimized.

In addition to the initial set up scan, receivers should attempt to maximize consumer choice by performing 'off time' scans automatically. A reduction in the quality assessment values, as compared to the recorded values would indicate that something has changed and that re-optimization is desirable.

This antenna control capability also may improve reception in the presence of interfering sources, as the signal to noise ratio can be improved if the interfering signal is not in the same direction as the desired signal. If unlicensed devices become common, this capability may become essential to enable DTV reception with an indoor antenna.

Therefore, in addition to the other guidelines contained herein for the handling of signal conditions that are experienced in the field, implementation of antenna control, as enabled by CEA-909, is strongly recommended. Especially for receivers intended primarily for use with indoor antennas, offering an entire system including the controllable antenna may offer significantly improved performance.

5.7 Consumer Interface — Received Signal Quality Indicator

The capability to display received signal quality conditions on a quasi-real time basis is a feature that should be included in all digital broadcast receivers.

Unlike analog reception, transmission impairments such as echo, interference and noise do not manifest themselves in uniquely identifiable ways in a digital broadcast receiver's display. Reception and display of digital signals on a digital receiver is largely a "go-no go" experience for the consumer, and the received picture or audio by themselves offer little useful guidance as to the relative difficulty of the current reception conditions.

A digital broadcast receiver's digital signal quality indicator should be more than simply a signal strength meter, and should take into account the effects of multipath and interference impairments, as well as insufficient or excessive signal level. Moreover, the signal indicator should be easy to understand, intuitive to use and easy to access for a consumer in order to effectively position or aim an antenna, judge the need or effectiveness of additional front end amplification and/or aid in other user-controlled adjustments to optimize the receiver's configuration with respect to the current reception conditions.

Receiver manufacturers should consider two applications of indicator displays; setup displays and operational displays. Each application should provide some manner of signal level indication as well as indications of the effects of multipath and interference impairments. Setup displays should be persistent to facilitate the installer's achieving proper system alignment. Operational displays may be transient or under user control if desired. User options should be provided in both categories.

Means to achieve such signal quality indications should be left to the judgment of individual receiver manufacturers.

Annex A: Capture Labels and Descriptions

The recommended ATSC set of RF captured field ensembles is listed in Figure A.1 (see next page). A detailed description of the labels associated with each ensemble is given below.

Column	Description
Site Name	A unique identifier to label the ATSC capture data.
City	City where the data was collected.
State	State where the data was collected.
Date	The date when the data was collected.
Channel	The RF television channel of the capture data.
Type of capture	Location where data was collected (i.e., in-home, outdoor).
Length of capture	Length of the capture data in seconds.
Quality of Capture	Whether the data contains errors or gaps (i.e., symbol errors, drops, etc.).
Latitude	Geographic coordinates (latitude) of where the data was collected.
Longitude	Geographic coordinates (longitude) of where the data was collected.
Distance from transmitter	Distance in miles between the transmitter and the receiver (i.e., capture device).
Lower adjacent	Whether a first lower adjacent television station (NTSC or DTV) was operating when the capture was collected.
Upper adjacent	Whether a first upper adjacent television station (NTSC or DTV) was operating when the capture was collected.
Neighborhood description	Description of the surroundings where the data was collected.
Location type	Description of the location of the structure near or where the data was collected.
Antenna location	A more detailed description of the location of where the data was collected (i.e., bedroom, living room, outdoor).
Antenna height	Approximate height above ground of the receive antenna where the data was collected.
Antenna type	Type of antenna used during the data collection.
Antenna orientation	Orientation of the antenna (i.e., Optimal, Random). Optimal orientation was achieved when the waveform on the spectrum analyzer exhibited maximum amplitude and best flatness .
Construction type	The construction of the structure near or where the data was collected.
Siding	Exterior shell of the structure where data was collected.
Weather conditions	Weather conditions when the data was collected.
Temperature	Temperature in Fahrenheit when the data was collected.
Data captured by	Owner(s) of the captured data.
Data format	Resolution and format of the data.
AGC	Whether an AGC was used during the capture.
SAW	The bandwidth of the SAW filter used for the capture device.

Original data capture	Name of the file where the data was originally captured.
Demodulated by current receivers	This column states whether the data was demodulated by different generations of receivers. The information in this column is based on testing that was conducted by MSTV in December of 2003 and used three separate receiver generations. The latest prototype receiver is identified as a third generation receiver.
Capture comments	Special comments that were collected during the capture.
Single echo	Examination of the waveform on a spectrum analyzer to determine whether the waveform exhibited conditions that suggested the presence of a single predominant echo.
Close-in echoe(s)	Examination of the waveform on a spectrum analyzer to determine whether the waveform exhibited conditions that suggested the presence of a close-in echoe(s).
Multiple echoes	Examination of the waveform on a spectrum analyzer to determine whether the waveform exhibited conditions that suggested the presence of a multiple echoes.
Deep notche(s)	Examination of the waveform on a spectrum analyzer to determine whether the waveform exhibited conditions that suggested the presence of deep and narrow notches in the order of 10 dB or more during the capture. When this entry is filled in along with the next entry (wide notches) it means that the notches are deep (greater than 10 dB) and wide (100 KHz or more).
Wide notche(s)	Examination of the waveform on a spectrum analyzer to determine whether the waveform exhibited conditions that suggested the presence of wide notches, in the order of 100 KHz or more.
Flat fading	Examination of the waveform on a spectrum analyzer to determine whether the waveform is generally flat within the 6 MHz bandwidth and changing in amplitude.
Band-edge distortion	Examination of the waveform on a spectrum analyzer to determine whether the waveform exhibited conditions that suggested the presence of distortion at the edge of the 6 MHz bandwidth, such as a tilt (more than 8 dB) or deep notch during the capture.
Pilot notch	Examination of the waveform on a spectrum analyzer to determine whether the waveform exhibited conditions that suggested the loss or severe notching of the pilot during the capture.
Static	Examination of the waveform on a spectrum analyzer to determine whether the waveform exhibited only static conditions during the capture.
Slow dynamic	Examination of the waveform on a spectrum analyzer to determine whether the waveform exhibited slowly varying dynamic conditions during the capture.
Moderate dynamic	Examination of the waveform on a spectrum analyzer to determine whether the waveform exhibited moderately varying dynamic conditions during the capture.
Fast dynamic	Examination of the waveform on a spectrum analyzer to determine whether the waveform exhibited fast-moving dynamic conditions during the capture.
Irregular dynamic	Examination of the waveform on a spectrum analyzer to determine whether the waveform exhibited dynamic conditions that changed from fast to slow to moderate or vice versa during the capture.
Regular dynamic	Examination of the waveform on a spectrum analyzer to determine whether the waveform exhibited dynamic conditions that did not change during the capture.
In-band interference	Examination of the waveform on a spectrum analyzer to determine the presence of other factors outside the 6 MHz bandwidth of the signal (i.e., contribution of adjacent channel, etc.).

Figure A.1 RF capture spreadsheet (next 9 pages).
Note: an electronic version of this Microsoft Excel document is available from ATSC; use the following link:
http://www.atsc.org/refs/a74/Annex-A-Revised-Figure-A1.xls.

	A	B	C	D	E	F	G
1	Site Name	City	State	Date	Channel	Type of Capture	Length of Capture (sec)
2	NYC/209/44/01	NYC	NY	10/27/2000	44	in-home	23
3	NYC/202/44/01	NYC	NY	10/27/2000	44	in-home	23
4	NYC/200/44/01	NYC	NY	10/27/2000	44	in-home	23
5	NYC/208/44/01	NYC	NY	10/27/2000	44	in-home	23
6	NYC/205/44/01	NYC	NY	10/27/2000	44	in-home	23
7	NYC/206/44/01	NYC	NY	10/27/2000	44	in-home	23
8	NYC/204/44/01	NYC	NY	10/27/2000	44	in-home	23
9	NYC/207/44/01	NYC	NY	10/27/2000	44	in-home	23
10	NYC/217/56/01	NYC	NY	10/27/2000	56	in-home	23
11	NYC/215/56/01	NYC	NY	10/27/2000	56	in-home	23
12	NYC/212/56/01	NYC	NY	10/27/2000	56	in-home	23
13	NYC/211/56/01	NYC	NY	10/27/2000	56	in-home	23
14	NYC/216/56/01	NYC	NY	10/27/2000	56	in-home	23
15	NYC/218/56/01	NYC	NY	10/27/2000	56	in-home	23
16	NYC/210/56/01	NYC	NY	10/27/2000	56	in-home	23
17	NYC/213/56/01	NYC	NY	10/27/2000	56	in-home	23
18	NYC/219/56/01	NYC	NY	10/27/2000	56	in-home	23
19	WAS-006/34/01	Washington	DC	6/9/2000	34	Outdoor-30 feet	25
20	WAS-023/34/01	Washington	DC	6/7/2000	34	in-home	25
21	WAS-023/48/01	Washington	DC	6/7/2000	48	in-home	25
22	WAS-003/27/01	Washington	DC	6/2/2000	27	Outdoor-30 feet	25
23	WAS-003/35/01	Washington	DC	6/2/2000	35	Outdoor-30 feet	25
24	WAS-311/34/01	Washington	DC	6/5/2000	34	in-home	25
25	WAS-311/35/01	Washington	DC	6/5/2000	35	Outdoor-30 feet	25
26	WAS-311/36/01	Washington	DC	6/5/2000	36	Outdoor-30 feet	25
27	WAS-311/39/01	Washington	DC	6/5/2000	39	in-home	25
28	WAS-311/48/01	Washington	DC	6/5/2000	48	Outdoor-30 feet	25
29	WAS-032/48/01	Washington	DC	6/1/2000	48	in-home	25
30	WAS-034/27/01	Washington	DC	6/8/2000	27	in-home	25
31	WAS-034/35/01	Washington	DC	6/8/2000	35	in-home	25
32	WAS-034/48/01	Washington	DC	6/8/2000	48	in-home	25
33	WAS-038/34/01	Washington	DC	5/31/2000	34	in-home	25
34	WAS-038/34/01	Washington	DC	5/31/2000	34	Outdoor-30 feet	25
35	WAS-038/36/01	Washington	DC	5/31/2000	36	in-home	25
36	WAS-047/48/01	Washington	DC	6/13/2000	48	in-home	25
37	WAS-049/34/01	Washington	DC	6/14/2000	34	in-home	25
38	WAS-049/39/01	Washington	DC	6/14/2000	39	in-home	25
39	WAS-051/35/01	Washington	DC	5/24/2000	35	Outdoor-30 feet	25
40	WAS-063/34/01	Washington	DC	6/21/2000	34	in-home	25
41	WAS-068/36/01	Washington	DC	5/23/2000	36	Outdoor-30 feet	25
42	WAS-075/35/01	Washington	DC	6/16/2000	35	in-home	25
43	WAS-075/36/01	Washington	DC	6/16/2000	36	in-home	25
44	WAS-075/39/01	Washington	DC	6/16/2000	39	in-home	25
45	WAS-080/35/01	Washington	DC	6/15/2000	35	in-home	25
46	WAS-081/36/01	Washington	DC	6/19/2000	36	in-home	25
47	WAS-082/35/01	Washington	DC	6/20/2000	35	in-home	25
48	WAS-083/36/01	Washington	DC	6/22/2000	36	in-home	25
49	WAS-083/39/01	Washington	DC	6/22/2000	39	in-home	25
50	WAS-086/36/01	Washington	DC	7/12/2000	36	in-home	25
51	WAS-086/48/01	Washington	DC	7/12/2000	48	Outdoor-30 feet	25
52							
53							
54							
55	**Due to imperfections in the recording device, these vectors, where strong adjacent channel signal						

	H	I	J	K	L	M
1	Quality of Capture	Latitude	Longitude	Distance from Transmitter (M)	lower adjacent (n-1)	Upper Adjacent (n+1)
2	good/no error	40-46-35	73-58-39	2.00		
3	good/no error	40-46-35	73-58-39	2.00		
4	good/no error	40-46-35	73-58-39	2.00		
5	good/no error	40-46-35	73-58-39	2.00		
6	good/no error	40-46-35	73-58-39	2.00		
7	good/no error	40-46-35	73-58-39	2.00		
8	good/no error	40-46-35	73-58-39	2.00		
9	good/no error	40-46-35	73-58-39	2.00		
10	good/no error	40-46-35	73-58-39	2.00		
11	good/no error	40-46-35	73-58-39	2.00		
12	good/no error	40-46-35	73-58-39	2.00		
13	good/no error	40-46-35	73-58-39	2.00		
14	good/no error	40-46-35	73-58-39	2.00		
15	good/no error	40-46-35	73-58-39	2.00		
16	good/no error	40-46-35	73-58-39	2.00		
17	good/no error	40-46-35	73-58-39	2.00		
18	good/no error	40-46-35	73-58-39	2.00		
19	good/no error	38-55-1	77-16-27	10.76	none	DTV
20	good/no error	38-49-23	77-20-32	16.71	none	DTV
21	good/no error	38-49-23	77-20-32	15.49	none	none
22	good/no error	38-11-46	77-11-31	48.41	NTSC	none
23	no video and sound	38-11-46	77-11-31	51.91	DTV	DTV
24	good/no error**	38-53-17	77-4-21	4.34	none	DTV
25	no video and sound	38-53-17	77-4-21	3.86	DTV	DTV
26	see capture comments	38-53-17	77-4-21	4.74	DTV	none
27	good/no error	38-53-17	77-4-21	4.34	none	none
28	see capture comments	38-53-17	77-4-21	3.86	none	none
29	good/no error**	38-52-48	77-25-6	17.80	none	none
30	good/no error	38-48-35	77-2-27	7.53	NTSC	none
31	good/no error**	38-48-35	77-2-27	9.57	DTV	DTV
32	good/no error	38-48-35	77-2-27	9.57	none	none
33	48 symbols dropped@14.9905 sec	39-2-50	76-50-44	14.32	none	DTV
34	48 symbols dropped@15.07375 sec	39-2-50	76-50-44	14.32	none	DTV
35	48 symbols dropped@22.2029 sec	39-2-50	76-50-44	14.28	DTV	none
36	48 symbols dropped@13.773 sec	38-47-33	77-14-53	13.07	none	none
37	48 symbols dropped@10.2250 sec	39-10-58	76-51-23	20.15	none	DTV
38	48 symbols dropped@24.855 sec	39-10-58	76-51-23	20.15	none	none
39	good/no error	38-55-44	76-43-22	20.29	DTV	DTV
40	48 symbols dropped@19.5019 sec	38-46-10	77-6-38	12.66	none	DTV
41	good/no error**	38-44-34	76-54-8	17.72	DTV	none
42	good/no error	38-47-58	77-3-32	9.99	DTV	DTV
43	good/no error**	38-47-58	77-3-32	10.93	DTV	none
44	good/no error	38-47-58	77-3-32	10.53	none	none
45	no video and sound	38-47-52	77-6-24	9.88	DTV	DTV
46	good/no error	38-50-32	77-11-6	9.64	DTV	none
47	48 symbols dropped@17.1644 sec	38-50-51	77-11-38	8.25	DTV	DTV
48	48 symbols dropped@14.8805 sec	38-54-36	77-3-26	3.46	DTV	none
49	48 symbols dropped@12.1696 sec	38-54-36	77-3-26	3.05	none	none
50	good/no error	39-5-2	76-29-18	33.27	DTV	none
51	good/no error	39-5-2	76-29-18	34.38	none	none
52						
53						
54						
55	s were present, may be affected by non linear phenomena					

	N	O
1	Neighborhood Description	Location Type
2	Urban apartments	High rises
3	Urban apartments	High rises
4	Urban apartments	High rises
5	Urban apartments	High rises
6	Urban apartments	High rises
7	Urban apartments	High rises
8	Urban apartments	High rises
9	Urban apartments	High rises
10	Urban apartments	High rises
11	Urban apartments	High rises
12	Urban apartments	High rises
13	Urban apartments	High rises
14	Urban apartments	High rises
15	Urban apartments	High rises
16	Urban apartments	High rises
17	Urban apartments	High rises
18	Urban apartments	High rises
19	Suburban - Cul de Sac - Some Trees	Single Family Home
20	Suburban almost rural with lots of trees	Single Family Home
21	Suburban almost rural with lots of trees	Single Family Home
22	Suburban	Single Family Home
23	Suburban	Single Family Home
24	Apartment Buildings, Single Family Homes	Apartment (High-Rise)
25	Apartment Buildings, Single Family Homes	Apartment (High-Rise)
26	Apartment Buildings, Single Family Homes	Apartment (High-Rise)
27	Apartment Buildings, Single Family Homes	Apartment (High-Rise)
28	Apartment Buildings, Single Family Homes	Apartment (High-Rise)
29	Suburban	Single Family Home
30	Metal Roof	Town House
31	Metal Roof	Town House
32	Metal Roof	Town House
33	Townhouse community Near B-W Parkway	Town House
34	Townhouse community Near B-W Parkway	Town House
35	Townhouse community Near B-W Parkway	Town House
36	Single Family homes. Small rolling hills	Single Family Home
37	Single Family homes. Mostly flat terrain. Flight path of BWI airport (landing path).	Single Family Home
38	Single Family homes. Mostly flat terrain. Flight path of BWI airport (landing path).	Single Family Home
39	Suburban	Single Family Home
40	Suburban Alexandria mix of single and two floor homes	Single Family Home
41	Residential	Single Family Home
42	Suburban	Single Family Home
43	Suburban	Single Family Home
44	Suburban	Single Family Home
45	Suburban hills and lots of trees	Town House
46	Suburban, Hilly Terrain, Trees	Single Family Home
47	Suburban Inside Beltway, very hilly	Single Family Home
48	Upscale Urban townhomes, Georgetown, Hilly	Town House
49	Upscale Urban townhomes, Georgetown, Hilly	Town House
50	Rural, Large separate lots	Single Family Home
51	Rural, Large separate lots	Single Family Home
52		
53		
54		
55		

	P	Q	R	S	T	U	V	W
1	Antenna Location	Antenna height	Antenna Type	Antenna Orientation	Construction Type	Siding	Weather Conditions	Temperature
2	Bedroom	6	Double Bow-Tie	Optimal	Wood	Brick	Cloudy	50
3	Bedroom	6	Loop	Optimal	Wood	Brick	Cloudy	50
4	Bedroom	6	MegaWave	Optimal	Wood	Brick	Cloudy	50
5	Bedroom	6	Rabits Ears	Optimal	Wood	Brick	Cloudy	50
6	Bedroom	6	Silver Sensor (V)	Optimal	Wood	Brick	Cloudy	50
7	Bedroom	6	Silver Sensor (H)	Optimal	Wood	Brick	Cloudy	50
8	Bedroom	6	Silver Sensor (H)	Optimal	Wood	Brick	Cloudy	50
9	Bedroom	6	Yagi	Optimal	Wood	Brick	Cloudy	50
10	Bedroom	6	Bow-Tie	Optimal	Wood	Brick	Cloudy	50
11	Bedroom	6	Double Bow-Tie	Optimal	Wood	Brick	Cloudy	50
12	Bedroom	6	Dual Silver Sensor	Optimal	Wood	Brick	Cloudy	50
13	Bedroom	6	Dual Silver Sensor	Optimal	Wood	Brick	Cloudy	50
14	Bedroom	6	Loop	Optimal	Wood	Brick	Cloudy	50
15	Bedroom	6	MegaWave	Optimal	Wood	Brick	Cloudy	50
16	Bedroom	6	Rabbit Ears	Optimal	Wood	Brick	Cloudy	50
17	Bedroom	6	Silver Sensor(H)	Optimal	Wood	Brick	Cloudy	50
18	Bedroom	6	Yagi	Optimal	Wood	Brick	Cloudy	50
19	outdoor	30	Log Periodic	Optimal	Wood	Concrete	Partly Cloudy	94
20	Living Room	6	Double Bow-Tie	Optimal	Brick	Brick	Sunny	74
21	Living Room	6	Double Bow-Tie	Optimal	Brick	Brick	Sunny	76
22	outdoor	30	Log Periodic	Optimal	Wood	Vinyl	Sunny	91
23	outdoor	30	Log Periodic	Optimal	Wood	Vinyl	Sunny	93
24	Living Room	6	Double Bow-Tie	Optimal	Wood	Brick	Cloudy	70
25	outdoor	30	Log Periodic	Optimal	Wood	Brick	Cloudy	70
26	outdoor	30	Log Periodic	Optimal	Wood	Brick	Cloudy	70
27	Living Room	6	Double Bow-Tie	Optimal	Wood	Brick	Cloudy	70
28	outdoor	30	Log Periodic	Optimal	Wood	Brick	Cloudy	70
29	Living Room	6	Double Bow-Tie	Optimal	Wood	Brick	Cloudy	86
30	Living Room	6	Double Bow-Tie	Optimal	Metal	Brick	Sunny	77
31	Living Room	6	Double Bow-Tie	Optimal	Metal	Brick	Partly Cloudy	81
32	Living Room	6	Double Bow-Tie	Optimal	Metal	Brick	Partly Sunny	82
33	Rec Room	6	Double Bow-Tie	Optimal	Wood	Aluminum	Sunny	70
34	outdoor	30	Log Periodic	Optimal	Wood	Aluminum	Sunny	75
35	Rec Room	6	Double Bow-Tie	Optimal	Wood	Aluminum	Sunny	70
36	Family Room	6	Double Bow-Tie	Optimal	Wood	Wood	Cloudy	70
37	Living Room	6	Double Bow-Tie	Optimal	Wood	Vinyl	Cloudy	70
38	Living Room	6	Double Bow-Tie	Optimal	Wood	Vinyl	Cloudy	70
39	outdoor	30	Log Periodic	Optimal	Brick	Brick	Sunny	83
40	Living Room	6	Double Bow-Tie	Optimal	Wood	Brick	Cloudy	75
41	outdoor	30	Log Periodic	Optimal	Wood	Brick	Cloudy	65
42	Living Room	6	Double Bow-Tie	Optimal	Wood	Vinyl	Cloudy	88
43	Living Room	6	Double Bow-Tie	Optimal	Wood	Vinyl	Partly Cloudy	85
44	Living Room	6	Double Bow-Tie	Optimal	Wood	Vinyl	Partly Cloudy	86
45	Living Room	6	Double Bow-Tie	Optimal	Brick	Aluminum	Cloudy	76
46	Living Room	6	Double Bow-Tie	Optimal	Concrete	Brick	Cloudy	71
47	Living Room	6	Double Bow-Tie	Optimal	Brick	Brick	Sunny	N/A
48	Living Room	6	Double Bow-Tie	Optimal	Brick	Brick	Cloudy	78
49	Living Room	6	Double Bow-Tie	Optimal	Brick	Brick	Cloudy	77
50	Living Room	6	Double Bow-Tie	Optimal	Wood	Wood	Sunny	80
51	outdoor	30	Log Periodic	Optimal	Wood	Wood	Sunny	90
52								
53								
54								
55								

	X	Y	Z	AA	AB
1	Data Captured by	Data Format	AGC	SAW	Original data capture filename
2	ATTC	12 bits as 2-Byte Signed Integer	n	8Mhz	NYC_200_44_10272000_DBT1
3	ATTC	12 bits as 2-Byte Signed Integer	n	8Mhz	NYC_200_44_10272000_LOOP1
4	ATTC	12 bits as 2-Byte Signed Integer	n	8Mhz	NYC_200_44_10272000_MEGA1
5	ATTC	12 bits as 2-Byte Signed Integer	n	8Mhz	NYC_200_44_10272000_RAB1
6	ATTC	12 bits as 2-Byte Signed Integer	n	8Mhz	NYC_200_44_10272000_SSEN1
7	ATTC	12 bits as 2-Byte Signed Integer	n	8Mhz	NYC_200_44_10272000_SSEN2
8	ATTC	12 bits as 2-Byte Signed Integer	n	8Mhz	NYC_200_44_10272000_SSEN3
9	ATTC	12 bits as 2-Byte Signed Integer	n	8Mhz	NYC_200_44_10272000_YAGI1
10	ATTC	12 bits as 2-Byte Signed Integer	n	8Mhz	NYC_200_56_10272000_BWT1
11	ATTC	12 bits as 2-Byte Signed Integer	n	8Mhz	NYC_200_56_10272000_DBT2
12	ATTC	12 bits as 2-Byte Signed Integer	n	8Mhz	NYC_200_56_10272000_DSEN1
13	ATTC	12 bits as 2-Byte Signed Integer	n	8Mhz	NYC_200_56_10272000_DSEN2
14	ATTC	12 bits as 2-Byte Signed Integer	n	8Mhz	NYC_200_56_10272000_LOOP1
15	ATTC	12 bits as 2-Byte Signed Integer	n	8Mhz	NYC_200_56_10272000_MEGA1
16	ATTC	12 bits as 2-Byte Signed Integer	n	8Mhz	NYC_200_56_10272000_RAB1
17	ATTC	12 bits as 2-Byte Signed Integer	n	8Mhz	NYC_200_56_10272000_SSEN1
18	ATTC	12 bits as 2-Byte Signed Integer	n	8Mhz	NYC_200_56_10272000_YAG1
19	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_06_34_06092000_REF
20	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_23_34_06072000_OPT
21	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_23_48_06072000_OPT
22	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_3_27_06022000_REF
23	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_3_35_06022000_REF
24	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_311_34_06052000_OPT
25	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_311_35_06052000_REF
26	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_311_36_06052000_REF
27	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_311_39_06052000_OPT
28	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_311_48_06052000_REF
29	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_32_48_06012000_OPT
30	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_34_27_06082000_OPT
31	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_34_35_06082000_OPT
32	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_34_48_06082000_OPT
33	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_38_34_05312000_OPT
34	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_38_34_05312000_REF
35	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_38_36_05312000_OPT
36	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_47_48_06132000_OPT
37	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_49_34_06142000_OPT
38	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_49_39_06142000_OPT
39	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_51_35_05242000_REF
40	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_63_34_06212000_OPT
41	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_68_36_05232000_REF
42	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_75_35_06162000_OPT
43	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_75_36_06162000_OPT
44	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_75_39_06162000_OPT
45	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_80_35_06152000_OPT
46	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_81_36_06192000_OPT
47	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_82_35_06202000_OPT
48	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_83_36_06222000_OPT
49	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_83_39_06222000_OPT
50	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_86_36_07122000_OPT
51	ATTC/MSTV	12 bits as 2-Byte Signed Integer	n	8Mhz	WAS_86_48_07122000_REF
52					
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	AC
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	AD	AE
1	Capture comments	Single dominant echo
2		
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15		
16		
17		
18		
19		y
20		
21		
22		
23		
24		
25		
26	-17 dBu V/mPro Demod - constant SER 12860Many aircraft above and in front of location	
27	Signal path in air traffic flight path - frequent fades and flutter-54.5 dBu V/m	
28	pro demod would not lock during capture. Possible hits	
29		
30		
31		
32		
33		
34		
35	Pro demod would not lock.	
36		
37		
38		
39		
40	Very Poor Signal Level	
41		
42	Wind gusts of up to 15 mph	
43	Wind comes and goes.Very dynamic signalAttempted capture several times	
44	Windy	
45		
46		
47		
48		
49		
50		
51		
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55		

	AF	AG	AH	AI	AJ	AK	AL	AM	AN
1	Close-in echoe(s)	Multiple echoes	Deep notche(s)	Wide notche(s)	Flat fading	Band-edge distortion	Pilot notch	Static	Slow dynamic
2	y	y			y				y
3	y	y			y		y		y
4		y			y				y
5		y		y	y		y		y
6		y			y		y		y
7	y	y			y				y
8	y	y			y				y
9		y			y				y
10		y			y				y
11		y			y				y
12		y			y				y
13		y			y				y
14		y			y				y
15		y			y				y
16		y			y				y
17		y			y				y
18		y			y				y
19								y	
20		y	y	y		y			
21		y	y	y					
22		y	y				y		y
23									
24		y			y				
25		y			y				y
26		y	y	y				y	y
27		y			y				y
28		y	y	y					
29		y	y	y					y
30	y				y				y
31					y		y		
32		y							
33		y	y						
34									
35									
36		y			y				y
37		y	y		y	y			y
38		y	y						y
39					y			y	
40					y			y	
41					y			y	
42		y	y	y		y			
43		y	y	y		y	y		
44		y	y	y		y			
45								y	
46									
47		y			y	y		y	
48		y			y	y	y		
49		y			y				y
50									
51									
52									
53									
54									
55									

	AO	AP	AQ	AR	AS
1	Moderate dynamics	Fast dynamic	Irregular dynamic	Regular dynamic	In-band interference
2					weak lower
3					weak lower
4					none
5					weak lower
6					weak lower
7					weak lower
8					weak lower
9					weak lower
10					none
11					none
12					none
13				y	weak lower
14				y	weak lower
15				y	none
16					weak lower
17				y	none
18				y	none
19					moderate upper
20	y		y		upper adjacent
21	y		y		none
22				y	inband l. adj. Audio
23					strong upper & lower
24					inband upper & lower
25					moderate lower & strong upper adj
26				y	inbandlower
27					none
28					none
29					none
30					strong lower
31					weak lower & strong upper
32		y			none
33					Inband RFI
34					none
35					Inband RFI
36				y	none
37					none
38					strong lower
39					Strong Upper& lower adj.
40					upper adj.visual
41					lower adjacent ch.
42	y		y		Upper & lower adj.
43		y	y		Inband RFI
44	y			y	none
45					strong upper and lower adj
46					Inband RFI
47					Strong Upper Adj.
48					moderate lower adj
49					none
50					Inband RFI
51					weak lower adj
52					
53					
54					
55					

Annex B: Impulse Response Analysis

B.1 SCOPE

This annex provides a detailed impulse response analysis for a selection of captured field ensembles. The field ensembles were selected to give examples of the richness of multipath conditions in the field. The ensembles, however, do not necessarily represent limits on field conditions that may be experienced.

B.2 CHANNEL IMPULSE RESPONSE ANALYSIS

B.2.1 Data Analysis Using Real Versus Complex Demodulators/Equalizers

The channel impulse response analyses in this annex were obtained by performing a cross correlation of the PN511 sequence in the captured signal's field sync with a PN511 reference signal. Some comments may be helpful on the use of a real only demodulator/equalizer versus a complex demodulator/equalizer. These comments are not a recommendation of one receiver architecture versus another but are intended to provide information regarding analyzing channel impulse response via cross correlation.

By way of example, in a real-only equalizer/demodulator, the magnitude of the echo is dependent upon the carrier phase relationship between signals received from the echo and dominant paths (assuming receiver carrier recovery is predominantly influenced by the dominant path). So, if one takes the case of an echo that is in phase quadrature with the main path, the output of a real demodulator will, theoretically, be zero for a static echo and will be maximum only when the relative phase of the carrier reference is zero or 180 degrees. So, there exists a chance of losing cross correlation information with a real-only demodulator/equalizer. With a complex demodulator, the correct magnitude of the echo can be obtained from the *I* and *Q* output data under all relative phase conditions.

Also, the correlation power of the echo path will naturally fall off as the delay limits of the PN sequence are approached, as mentioned above.

B.2.2 Channel Estimations Using 511 Pseudo-Random Sequence

Channel estimations may be obtained from RF captures using the 511 pseudo-random number sequence located in the 8-VSB field sync. The field sync and its PN511 sequence is repeated every 24.2 milliseconds. Consequently, over 1000 channel estimations may be computed during each 25-second capture.

The channel estimation is calculated using a symbol-by-symbol cross-correlation of the recovered 8-VSB symbol stream. The PN511 symbol sequence is located within the synchronization segment of the captured RF signal. This recovered PN511 sequence is correlated with three ideal PN511 sequences, as illustrated in Figure B.1. As the recovered PN511 sequence is incremented across the ideal sequences, the main path and echoes are revealed in the results of the correlation.

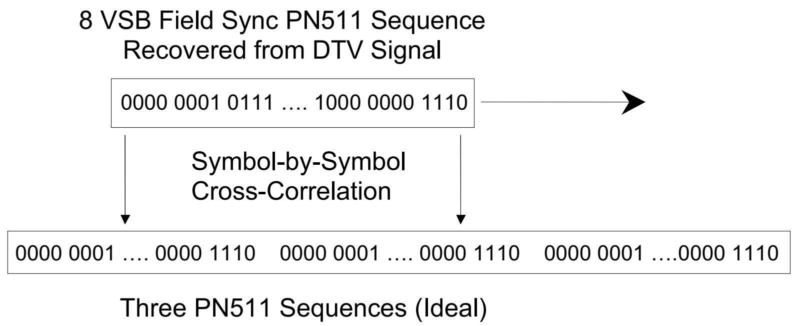

Figure B.1 Method of channel estimation using the PN511 pseudo-random number sequence in the 8-VSB field sync involves a cross correlation with three ideal PN511 sequences.

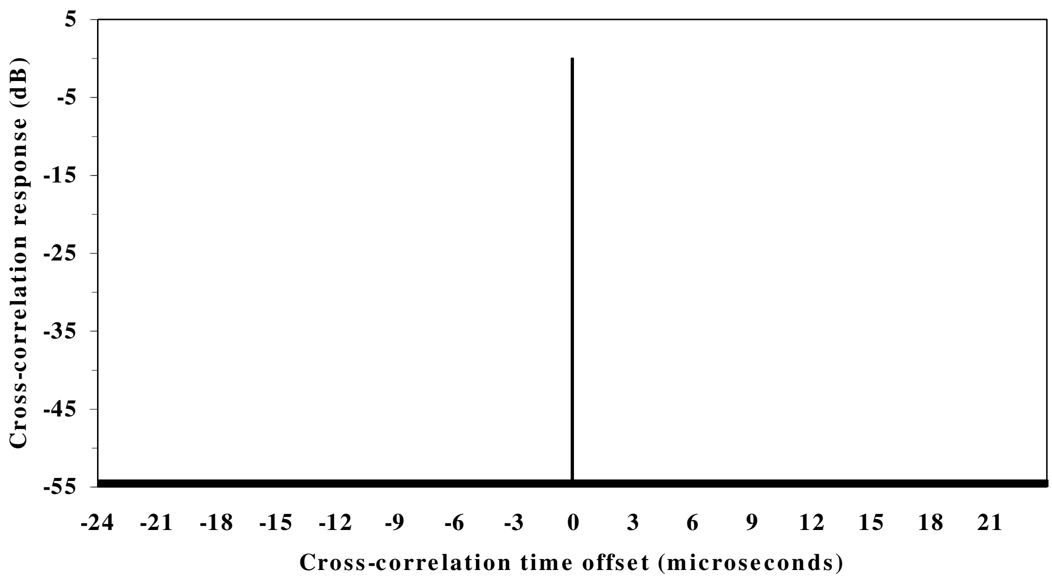

Figure B.2 Cross-correlation of an ideal 8-VSB PN511 sequence showing a single main path at zero microseconds.

Figure B.2 illustrates the correlation of an ideal 8-VSB signal. A single response is observed at zero microseconds. Otherwise, there is no correlation from –23.69 µs to +23.69 µs (±255 symbols).

In contrast, Figure B.3 shows the channel estimation for a single 10 µs echo captured in the laboratory with a power 6 dB below the main path. In addition to the main path at zero microseconds, the echo is observed at 10 µs. However, the echo appears to have a power lower than the main path by more than 6 dB.

The apparent decrease in echo power is the result of a correlation with only part of the PN511 sequence of the echo. As the delay of the echo moves away from either side of zero, that portion of the echo PN511 sequence included in the correlation diminishes. Consequently, the apparent power in the echo diminishes. In order to obtain the true echo power, the apparent power must be compensated. Figure B.4 illustrates the compensation factor required to obtain the actual echo

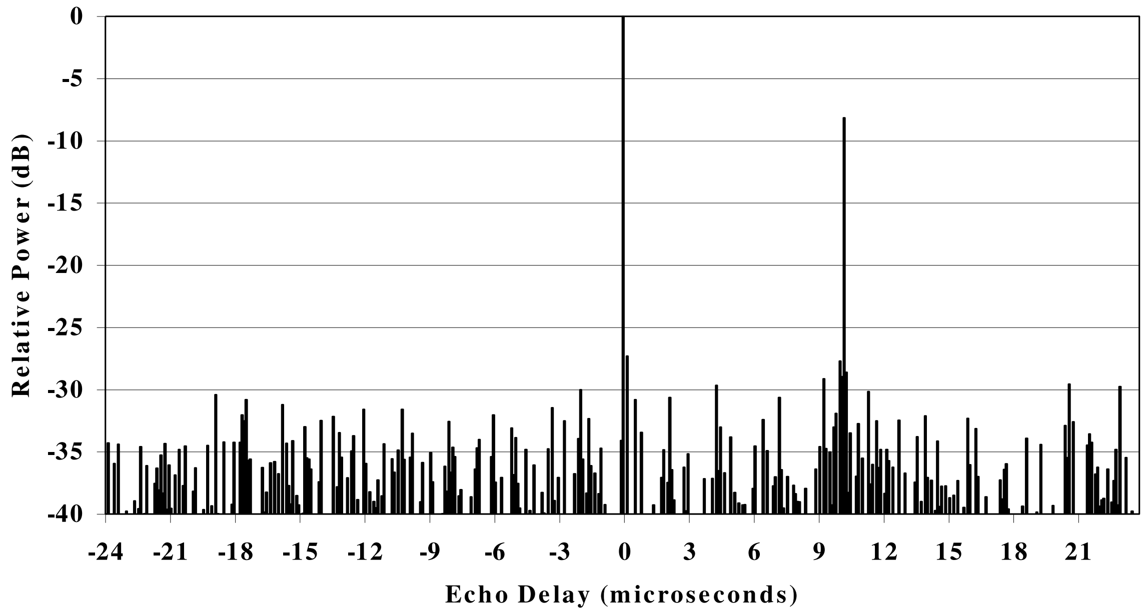

Figure B.3 Channel estimation of an 8-VSB signal capture in the laboratory in the presence of a 10 µs echo that is 6 dB lower in power than the main path.

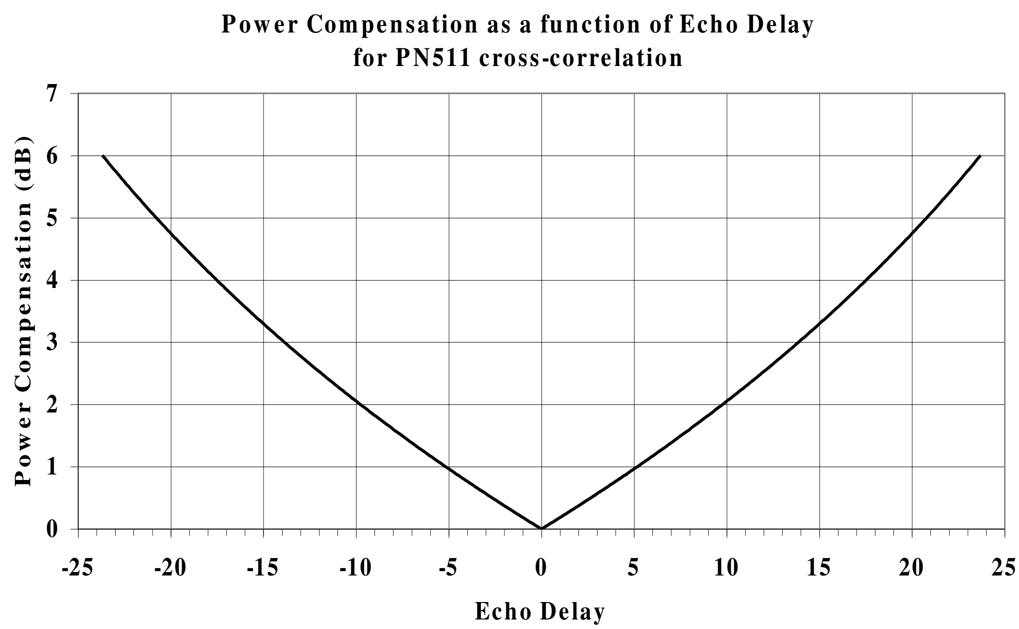

Figure B.4 Power compensation function required to obtain the actual echo power from channel estimations using the 8-VSB PN511 sequence.

power. In the example shown in Figure B.3, the 10 µs echo is actually 2 dB higher than the echo power measured by the cross-correlation.

B.2.3 Doppler Frequency Estimate

B.2.3.1 Comments on Doppler Analysis

When one considers evaluating multipath echoes with Doppler in an ATSC receiver (or other digital receiver), it should be remembered that the absolute transmit carrier frequency or phase is unknown because there is no direct carrier reference available in the receiver, as there would be, for example, in a radar system. The radar receiver has the advantage of receiving a direct carrier reference from the transmitter. So, at the radar receiver, it can be discerned which targets (echoes) are moving.

In the case of a DTV receiver, one has no knowledge of the absolute transmit frequency and phase. A relative carrier reference is reconstructed in the receiver that could be the vector sum of the individual multipath components, or perhaps just the dominant path, depending on how carrier recovery is implemented. For example, when it is inferred that a 10 µs post echo has a Doppler rate of say, 3 Hz, the 10 µs echo could, in fact, be perfectly stationary while the dominant path is the one with the Doppler component. One can only speak of "relative" Doppler shifts between the multipath signals and cannot determine for certain the absolute rates of the individual components.

As another example, if a pre-echo is present (not the dominant path signal), it is clear that the dominant path signal is not coming directly from the transmitter site, but is a reflection, as would be any post echo. If the "pre-echo" in such a case were the direct path signal from the transmitter, one would expect it to exhibit very little Doppler (except, perhaps, for tower sway). Consequently the receiver designer should not assume that the dominant signal is stationary in frequency or phase.

B.2.3.2 Methodology for Doppler Frequency Estimate

Doppler frequencies were computed by observing the amplitude of the real part of the echo from the impulse response of the channel. Since the echo under consideration is isolated (not combined with any other echo), it is similar to observing the real part of a complex phasor over time. The real part of a phasor goes to minimum value at 180 degrees and 360 degrees, and, therefore, has two minimums (or maximums) in a single cycle. By calculating the reciprocal of the time between two minimums of the amplitude of the real part of the echo, the Doppler frequency at which the echo is rotating is obtained. The computation of Doppler frequency has been verified by simulating a synthetic channel with a software modulator and comparing the echo amplitude and Doppler frequency at multiple locations.

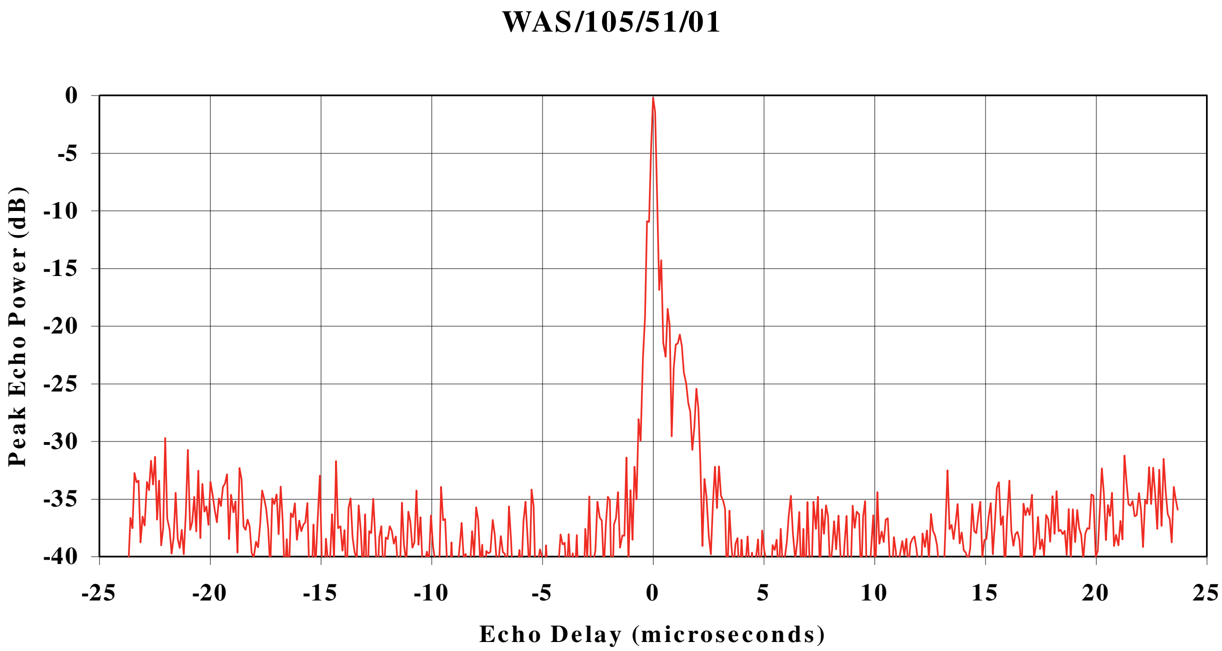

Figure B.5 Peak echo power as a function of echo delay observed for the duration of the RF capture at site WAS-105/51/01.

B.3 ANALYSIS OF RF CAPTURED DTV SIGNAL

B.3.1 Captured Channel WAS-105/51/01[9]

Figure B.5 illustrates the maximum main path power and echo power observed at any given instance within the outdoor signal capture WAS-105/51/01. The signal was recorded with a 6-foot dipole antenna in presence of pedestrian traffic. The antenna direction was not optimized for this capture. Although it appears that there is a significant spread in energy around the main path, the multipath conditions remain rather mild, as it was reported that the channel was demodulated by receivers of different generations.

9. Although interesting from the multipath point of view, this channel has not been included in the recommended set of field ensembles, as it has been determined that the channel may be affected by capture equipment artifacts.

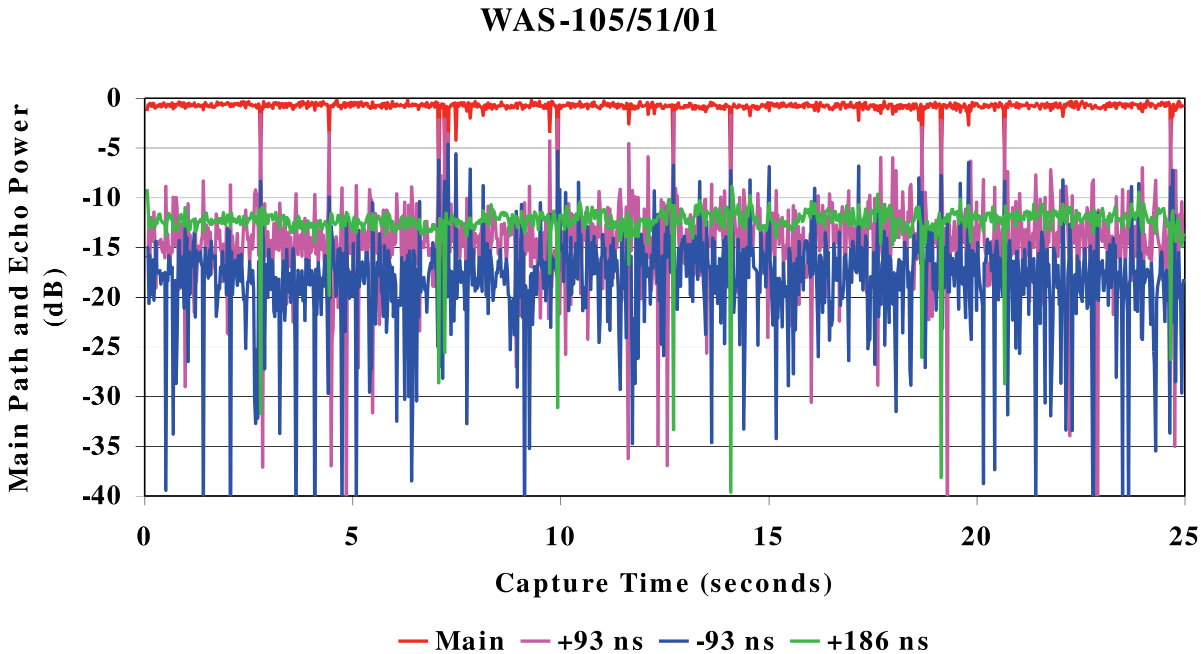

Figure B.6 Power of the main path in addition to the greatest "echoes" shows considerable variation over the duration of the RF capture for site WAS-105/51/01.

Figure B.6 illustrates the main power in addition to the echo power for the three greatest "echoes" (+93 ns, –93 ns, and +186 ns) during the RF signal capture WAS-105/51/01, showing the dynamic nature around the main path.

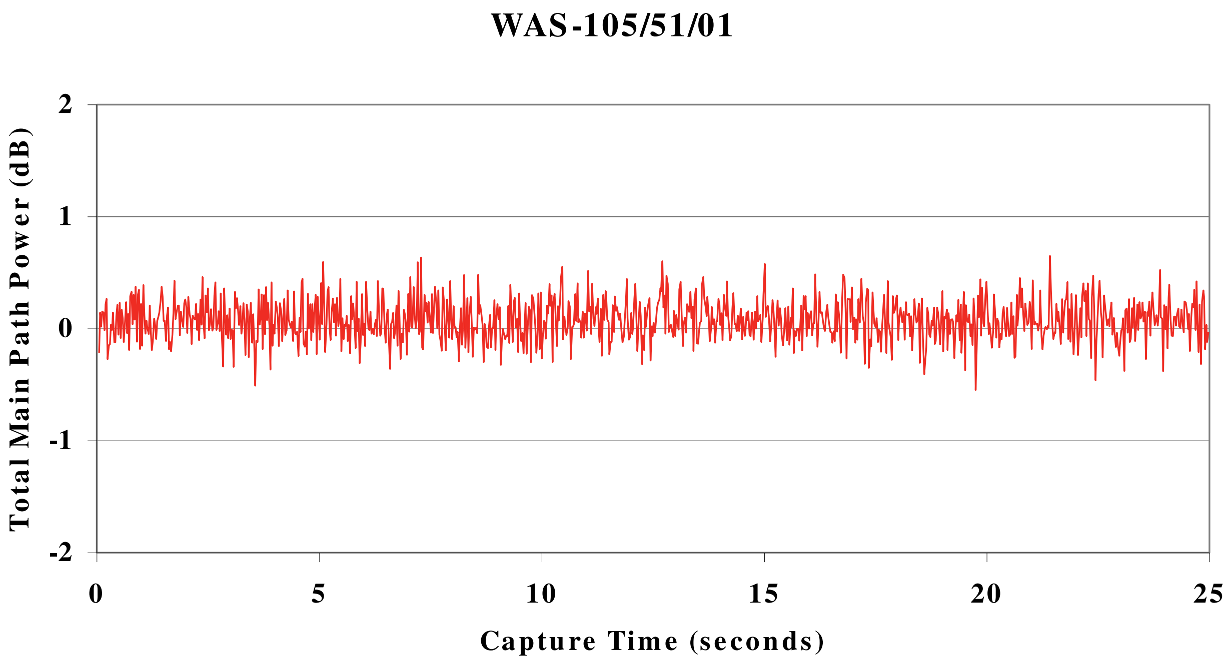

Figure B.7 Total power of the main path and ±3 "echoes" about the main path illustrating the power is constant even though the main path is dynamic.

Figure B.7 demonstrates that it is likely that the main path signal itself is dynamic. This figure illustrates the total energy of the main path plus six adjacent "echoes" (± 93 ns, ± 186 ns, and ± 279 ns). Note that, even though the main path and the adjacent echoes vary considerably, the total power fluctuation is less than 1 dB.

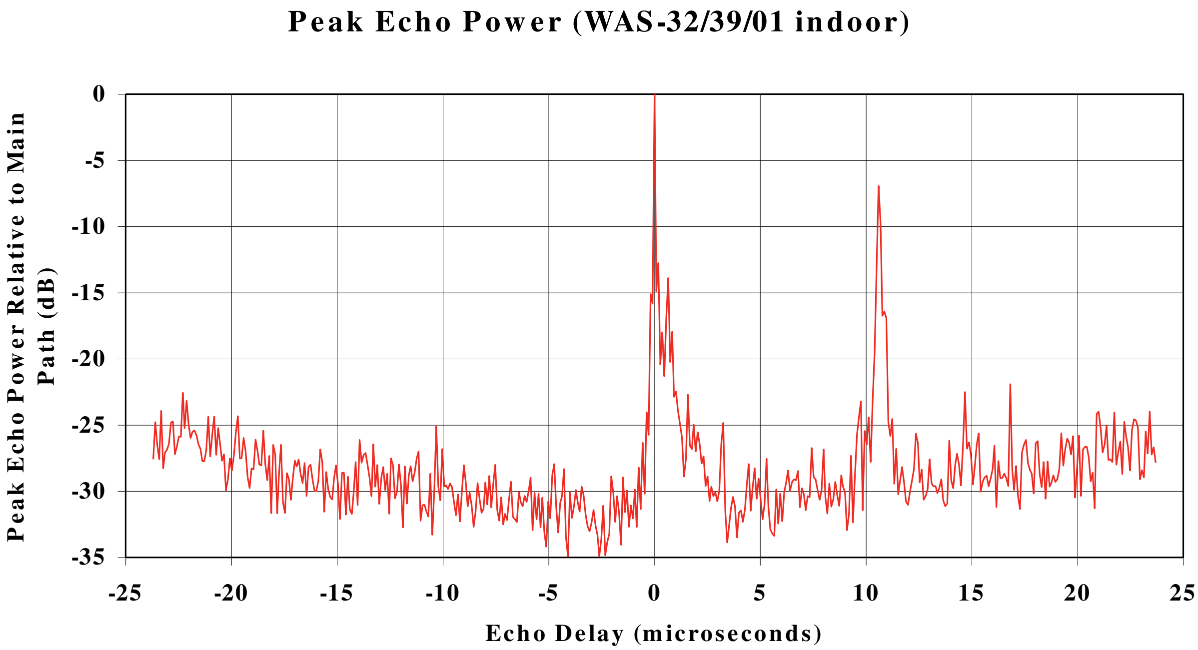

Figure B.8 Peak echo power as a function of echo delay observed for the duration of the RF capture at indoor site WAS-32/39/01.

B.3.2 Captured Channel WAS-032/39/01 (Indoor)

Figure B.8 shows the maximum echo powers during the indoor RF signal capture for site WAS-032/39/01. In addition to the spread of energy localized around the main path, the impulse response clearly shows the presence of a post echo around 11 μs with an amplitude relative to the main path of –7 dB maximum.

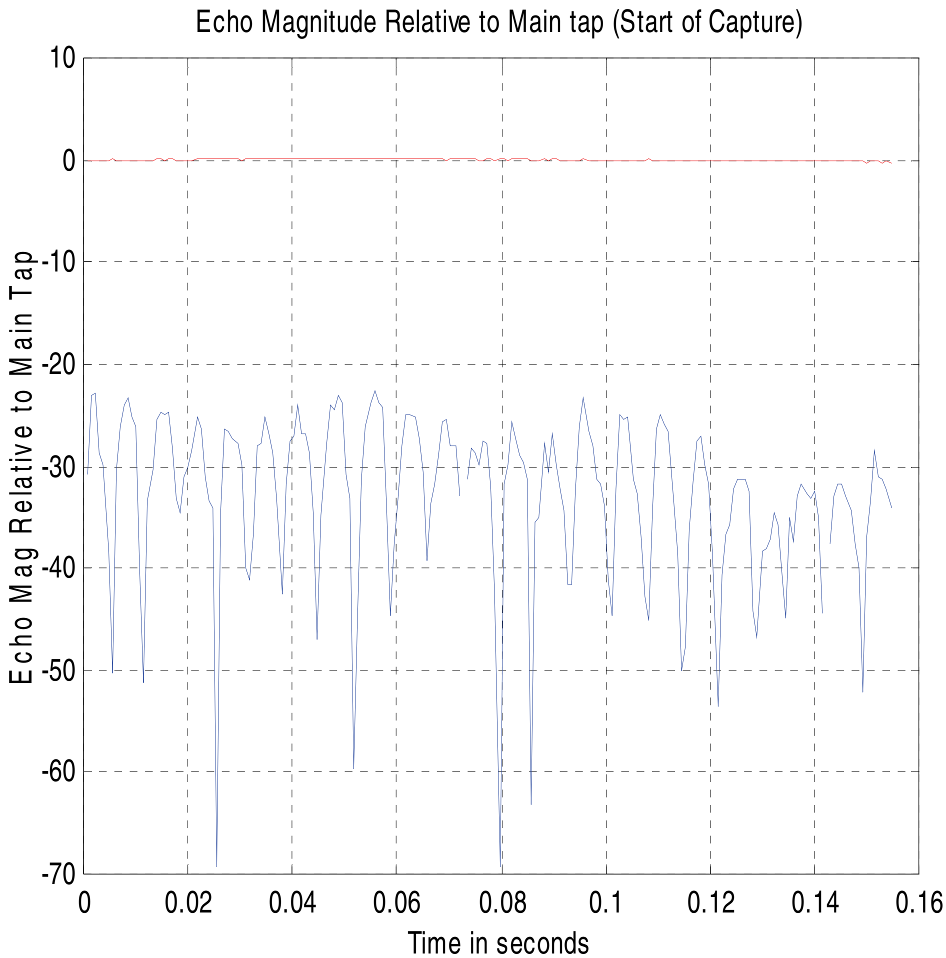

Figure B.9 The 11 µs echo magnitude at the beginning of the capture at indoor site WAS-32/39/01. Doppler frequency is 75 Hz.

Figure B.9 shows the magnitude of the post-echo located at +11 µs echo relative to the main path during the start of the capture. This echo is dynamic. The dynamic nature of the echo is interpreted as induced by a Doppler frequency shift with a frequency around 75 Hz (one cycle is completed in approximately 13 ms). For comparison, a line showing the amplitude of the main path is added to the plot.

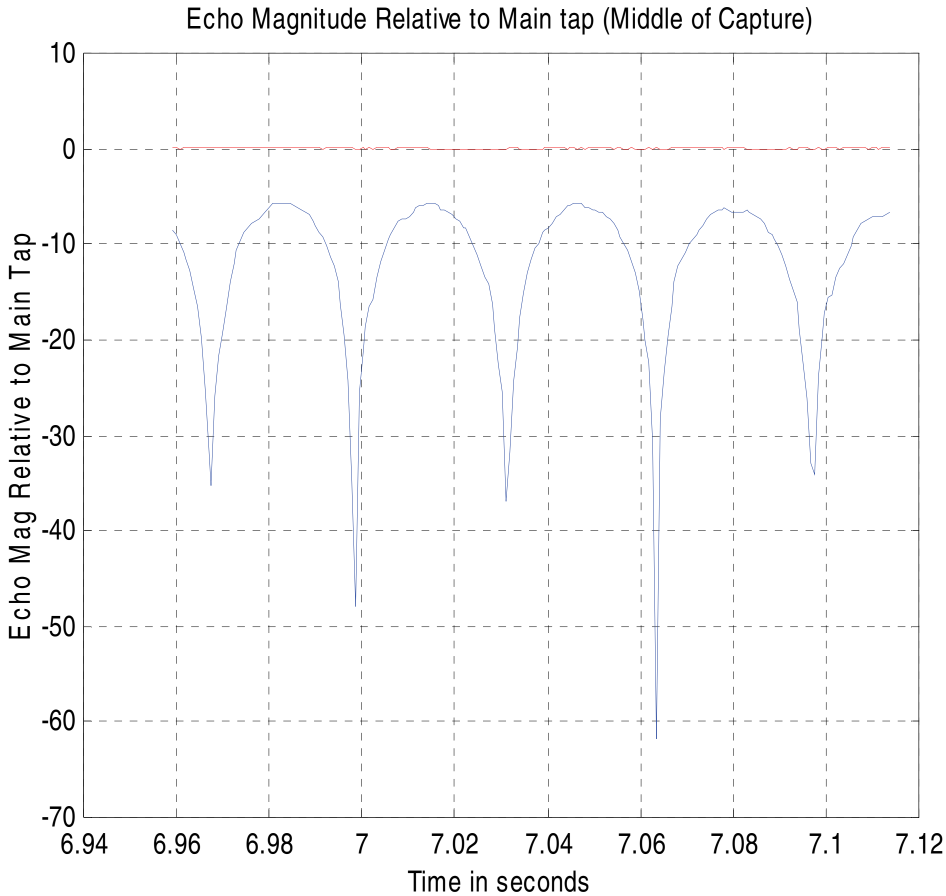

Figure B.10 The 11 µs echo magnitude 6.9 seconds into the capture at indoor site WAS-32/39/01. Doppler frequency is 17 Hz.

Figure B.10 shows the magnitude of the 11 µs echo relative to the main path at around 6.7 seconds from the beginning of the capture. We notice that the echo strength is now 15 dB higher than before. The maximum of the echo reaches about –9 dB, which confirms the results furnished in Figure B.8. Notice that the Doppler frequency is significantly lower. The cycle time is now around 0.06 seconds, which indicates a Doppler frequency of 17 Hz.

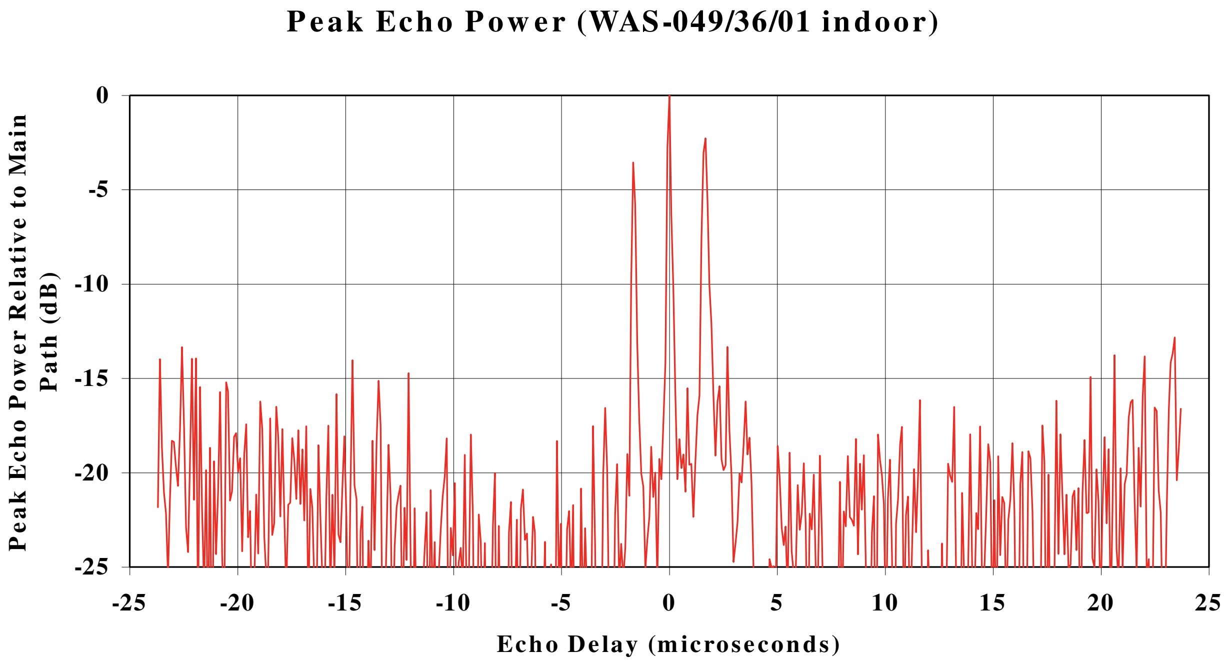

Figure B.11 Peak echo power as a function of echo delay observed for the duration of the RF capture at indoor site WAS-49/36/01. The evenly spaced echoes peaked at ± 1.67 µs indicate that the main path and the echo alternate—a "bobbing" channel.

B.3.3 Captured Channel WAS-049/36/01

Figure B.11 shows the maximum echo power over the entire RF signal capture period. Note that there are equally spaced pre- and post-echoes, as would be expected for the "bobbing channel" (the dominant path swapping between main and post-echo positions). A channel estimate at the beginning of this capture shows that there is a distinct main path and one or more close in echoes. The post echo of principal interest is 1.75 µs from the main path and has a rotating phase, as illustrated in the subsequent Figures B.12 through B.18.

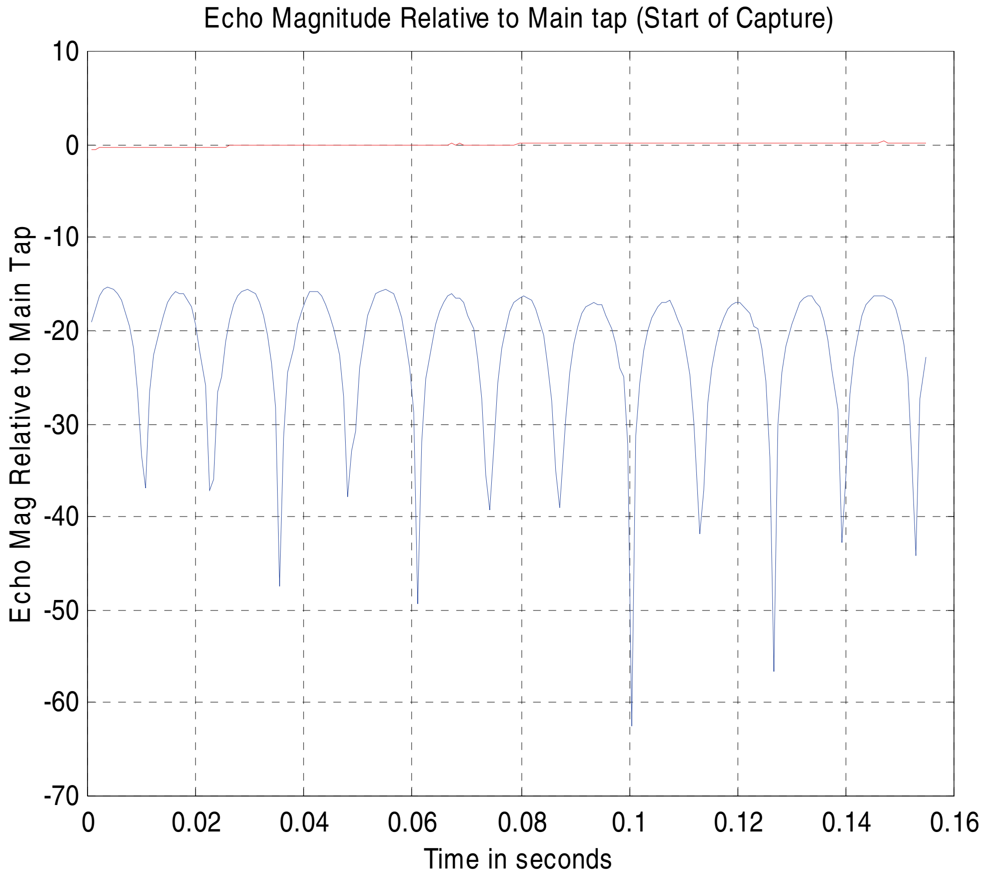

Figure B.12 Echo Magnitude for the 1.75 µs echo relative to the main path at the beginning of the capture at indoor site WAS-49/36/01. The echo magnitude is –15 dB relative to the main path. The Doppler frequency is 40 Hz.

Figure B.12 shows the magnitude of the 1.75 µs echo relative to the main path over a period of about 0.16 seconds at the beginning of the capture. Notice that the main path amplitude is constant, whereas the echo has variable amplitude. The cycle time for this echo at this time is around 25 ms, which gives a Doppler frequency of about 40 Hz. The echo magnitude is aproximately –15 dB relative to the main path.

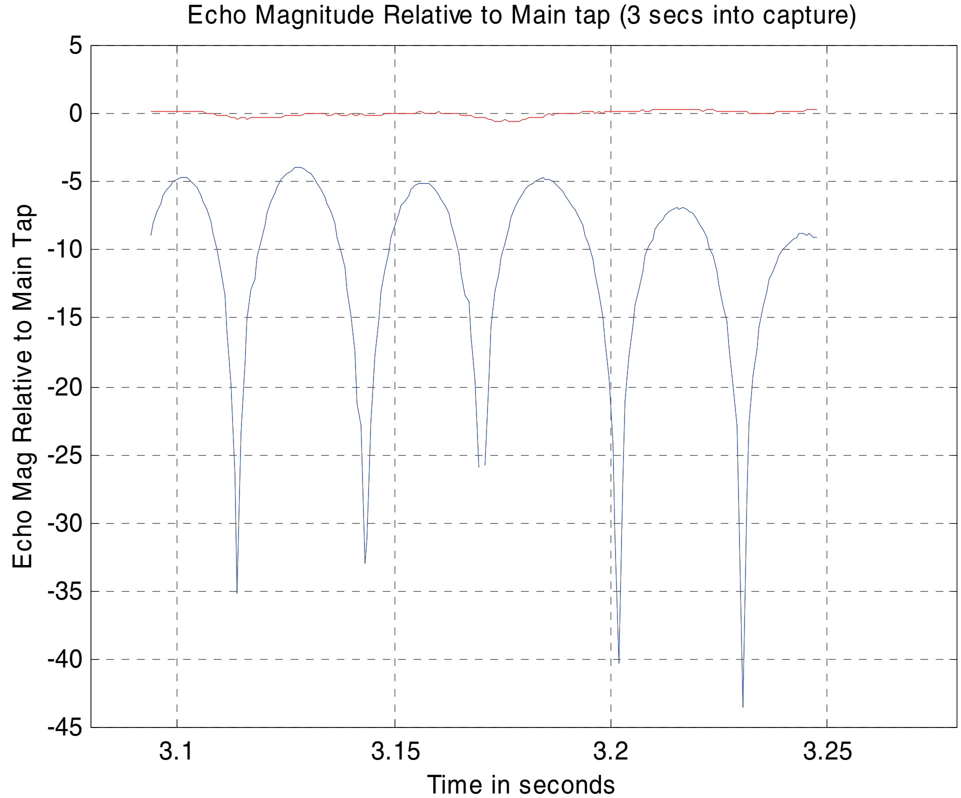

Figure B.13 Echo magnitude for the 1.75 µs echo relative to the main path, 3 seconds into the capture at indoor site WAS-49/36/01. The echo magnitude is –5 dB relative to the main path and has a Doppler frequency of 17 Hz.

Figure B.13 shows the magnitude of the 1.75 µs echo relative to the main path, 3 seconds into the capture. Notice that the main path amplitude is constant, whereas the echo has variable amplitude due to the Doppler phase rotation. The cycle time for this echo at this time is around 59 ms, which gives a Doppler frequency of about 17 Hz. The echo magnitude is about –5 dB relative to the main path.

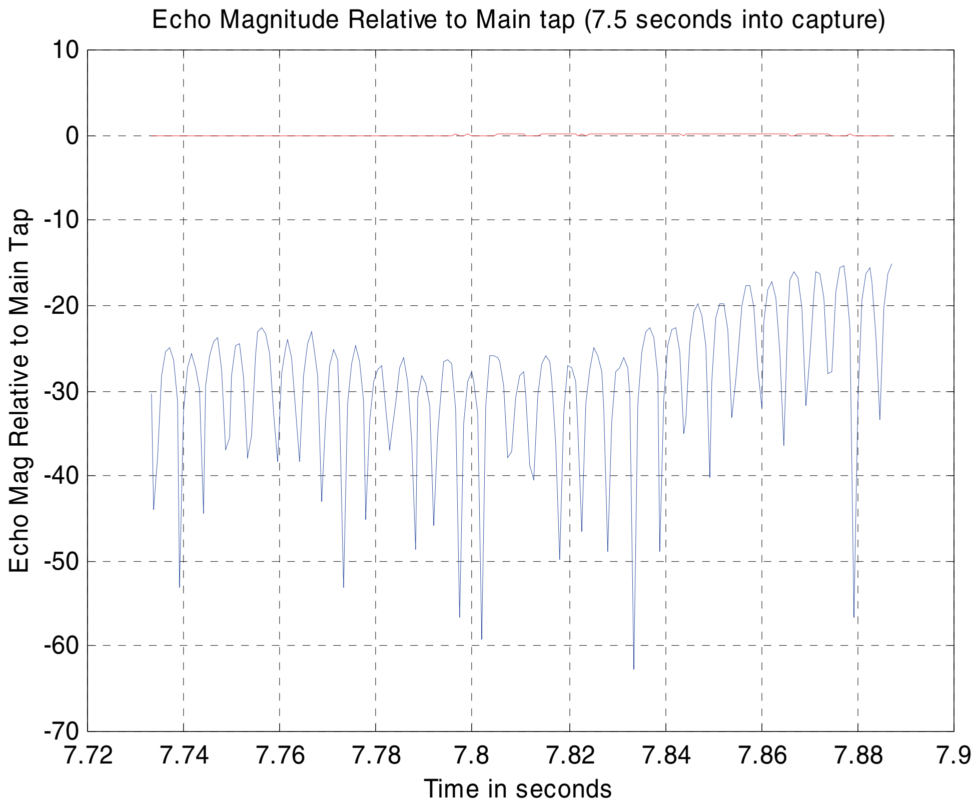

Figure B.14 Echo magnitude for the 1.75 µs echo relative to the main path, 7.5 seconds into the capture at indoor site WAS-49/36/01. The echo magnitude is –25 dB to –15 dB relative to the main path and has a Doppler frequency of 80Hz.

Figure B.14 shows the magnitude of the 1.75 µs echo relative to the main path, 7.5 seconds into the capture. Notice that the main path amplitude is constant, whereas the echo has variable amplitude due to the Doppler phase rotation. The cycle time for this echo, at this time, is around 11.5 ms, which gives a Doppler frequency of about 80 Hz. The echo magnitude is about –25 dB to –15 dB relative to the main path.

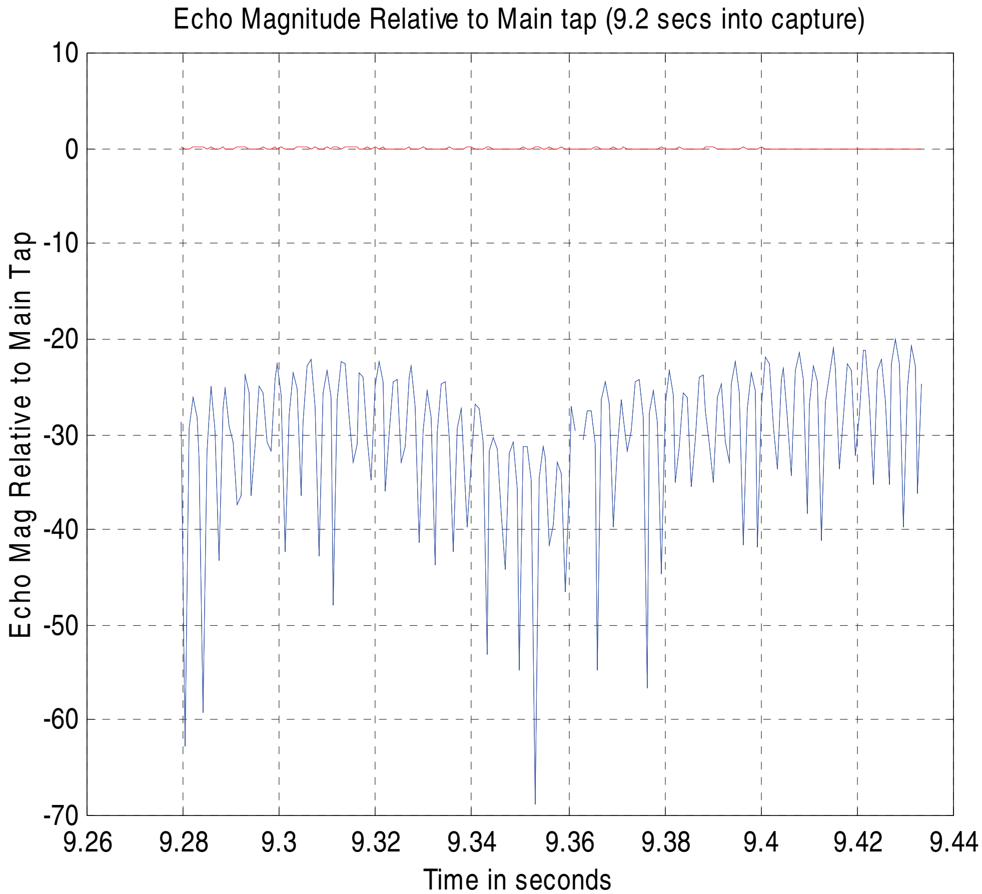

Figure B.15 Echo Magnitude for the 1.75 μs echo relative to the main path, 9.2 seconds into the capture at indoor site WAS-49/36/01. The echo magnitude is –25 dB to –20 dB relative to the main path and has a Doppler frequency of 150 Hz.

Figure B.15 shows the magnitude of the 1.75 μs echo relative to the main path, 9.2 seconds into the capture. Notice that the main path amplitude is constant, whereas the echo has variable amplitude due to the Doppler phase rotation. The cycle time for this echo, at this time, is around 6.5 ms, which gives a Doppler frequency of about 150 Hz. The echo magnitude is about –25 dB to –20 dB relative to the main path.

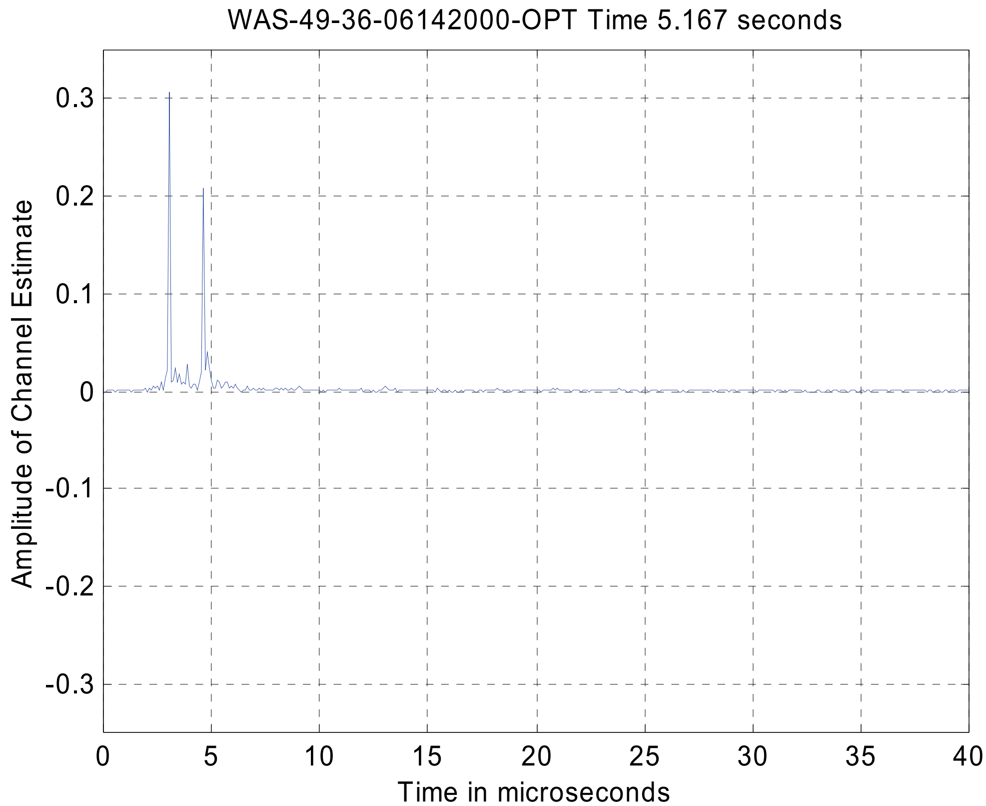

Figure B.16 Channel estimate (absolute value) for the RF capture at indoor site WAS-49/36/01, showing the main path and 1.75 μs echo.

Taking another intermediate look at capture WAS-49/36/01, we can see a bobbing channel appear. Figures B.16, B.17, and B.18, occurring at 5.167, 5.227, and 5.279 seconds into the capture, depict the main path and the post-echo exchanging positions. This confirms the plot furnished in Figure B.11.

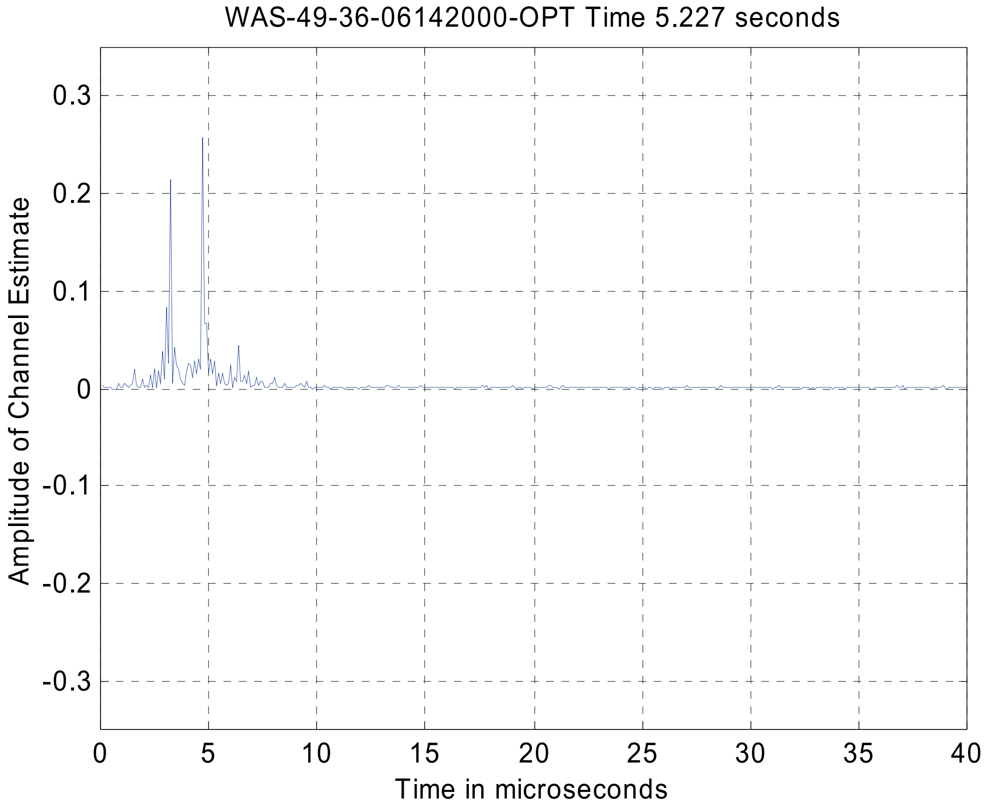

Figure B.17 Channel estimate (absolute value) for the RF capture at indoor site WAS-49/36/01, showing the main path and 1.75 μs echo. The 1.75 μs echo has increased in magnitude with respect to the main path.

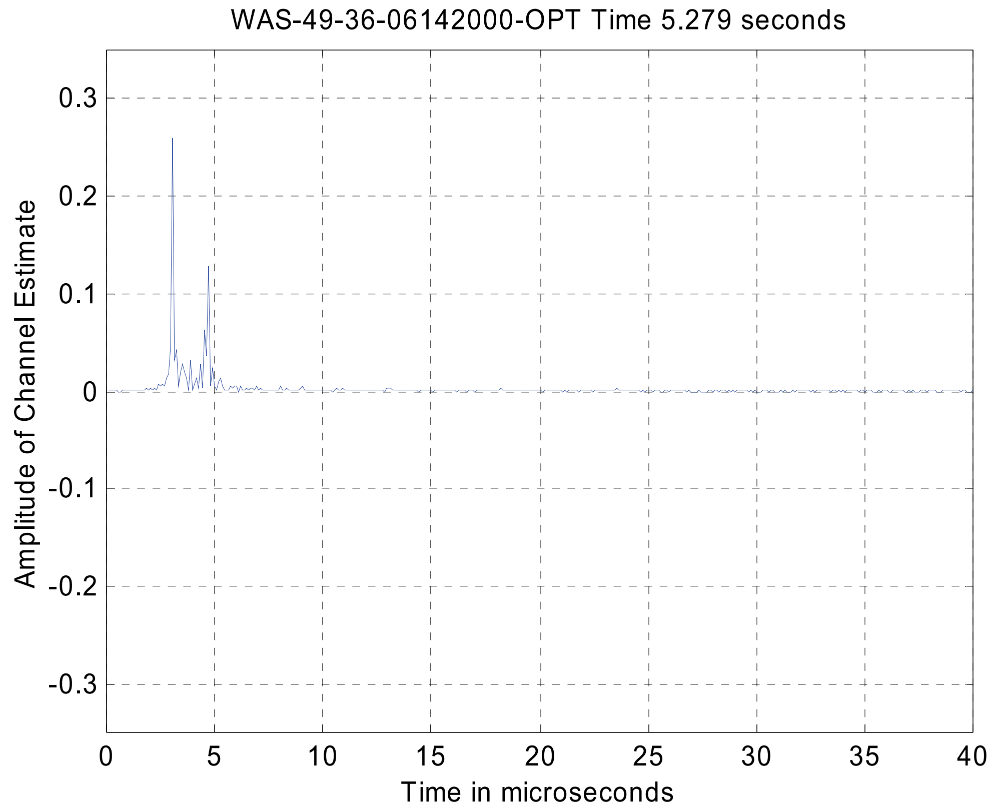

Figure B.18 Channel estimate (absolute value) for the RF capture at indoor site WAS-49/36/01, showing the main path and 1.75 µs echo. The 1.75 µs echo is now a post echo with respect to the main path.

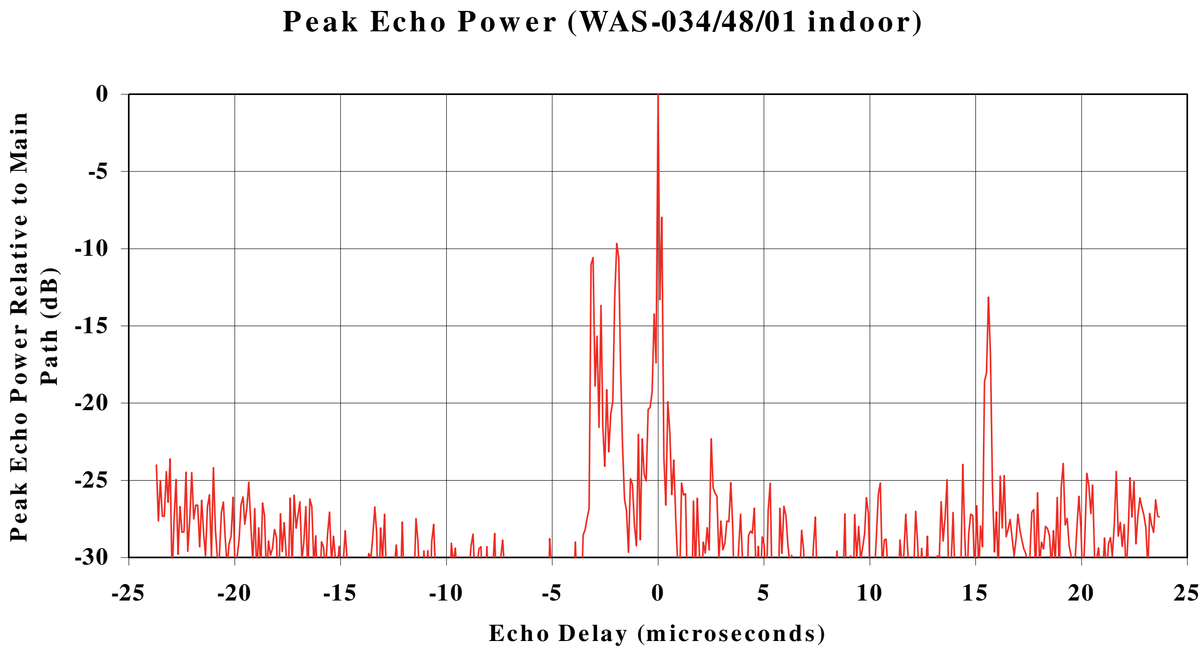

Figure B.19 Peak echo power as a function of echo delay observed for the duration of the RF capture at indoor site WAS-034/48/01.

B.3.4 Captured Channel WAS-034/48/01

Figure B.19 illustrates the peak echo power relative to the main power throughout a 25-second RF capture for the indoor capture WAS-34/48/01. The capture has a dynamic main path as well as strong dynamic pre-echoes at –1.95 µs and –3.07 µs and a post-echo at +15.6 µs. Site WAS-034/48/01 is a town house located 9.6 miles from the transmitter.

It is instructive to note that, by observing the channel estimates of WAS-034/48/01 and WAS-034/36/01, it appears that the post-echo in the channel 36 capture is the main path in the channel 48 capture, and the main path in the channel 36 capture is the pre-echo in the channel 48 capture. That is, the echo and the main path have exchanged positions. The echo amplitudes are relatively constant over time in each capture, however, and can therefore be characterized as static. Both channels have a weak echo at 18.5 µs.

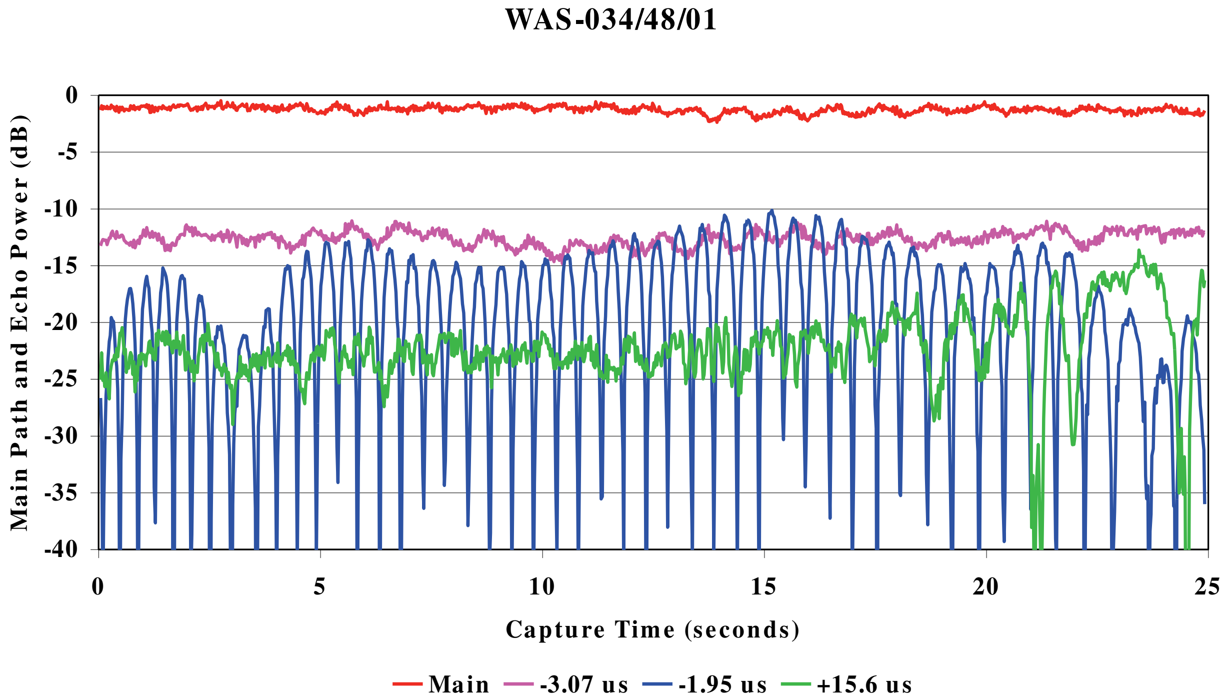

Figure B.20 Power of the main path and three main echoes illustrates the dynamic nature of echoes for indoor site WAS-034/48/01.

Figure B.20 illustrates the echo power over the 25-second capture. Notice the presence of a slow Doppler affecting the three main paths.

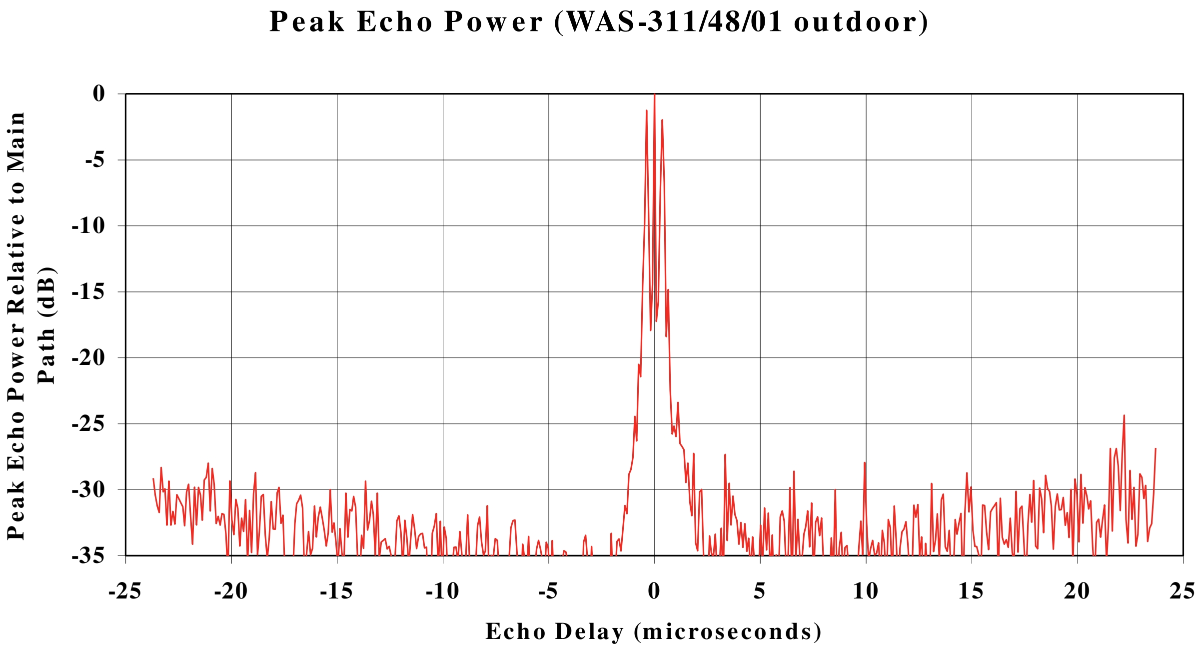

Figure B.21 Peak echo power as a function of echo delay observed for the duration of the RF capture at outdoor site WAS-311/48/01. The evenly spaced close-in echoes peaked at ± 372 ns indicate that the main path and the echo alternate—a "bobbing" channel.

B.3.5 Captured Channel WAS-311/48/01

Another example of a "bobbing" channel is provided with the outdoor capture WAS-311/48/01. This outdoor field capture involved no direct transmission path, even though the receive antenna was only 3.9 miles from the transmit antenna. Figure B.21 illustrates the maximum main path power and echo power observed at any given instance within the capture. The evenly spaced, close-in echoes, peaked at ± 372 ns, indicate that the "main" and "echo" paths alternate.

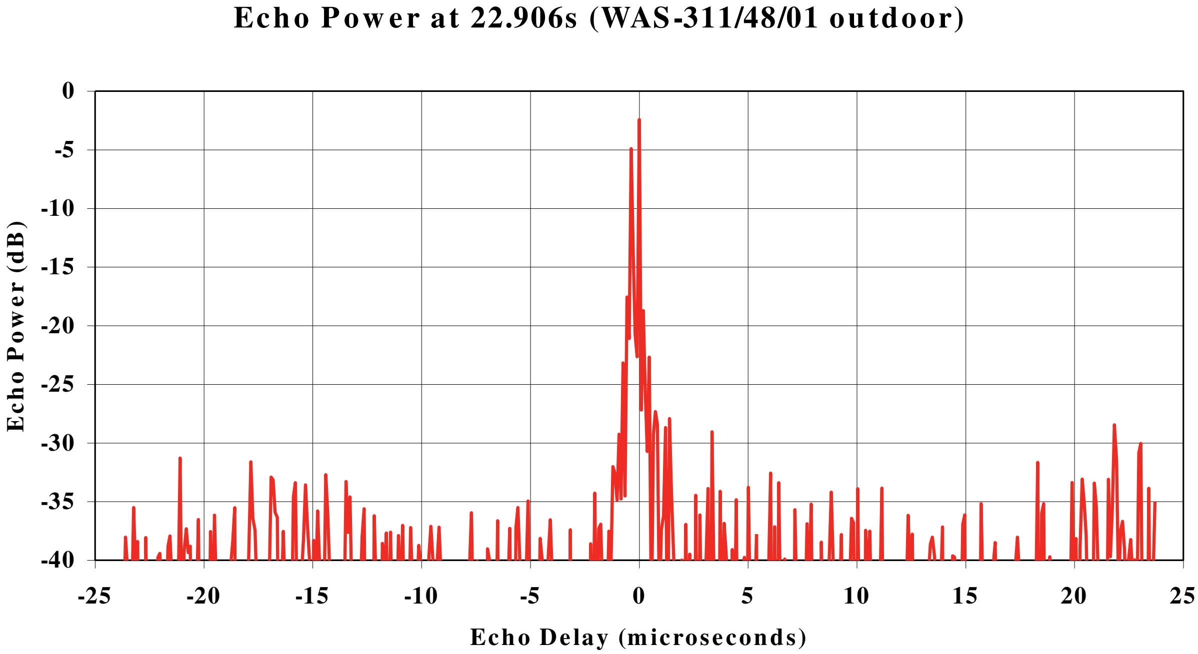

Figure B.22 Echo power as a function of echo delay observed at 22.906 seconds into the RF capture of outdoor site WAS-311/48/01. A strong pre-echo is present at –372 ns.

The “bobbing” nature of the echoes is evident in Figures B.22 and B.23. At 22.906 seconds into the capture, a strong 372 ns pre-echo is present, as illustrated in Figure B.22.

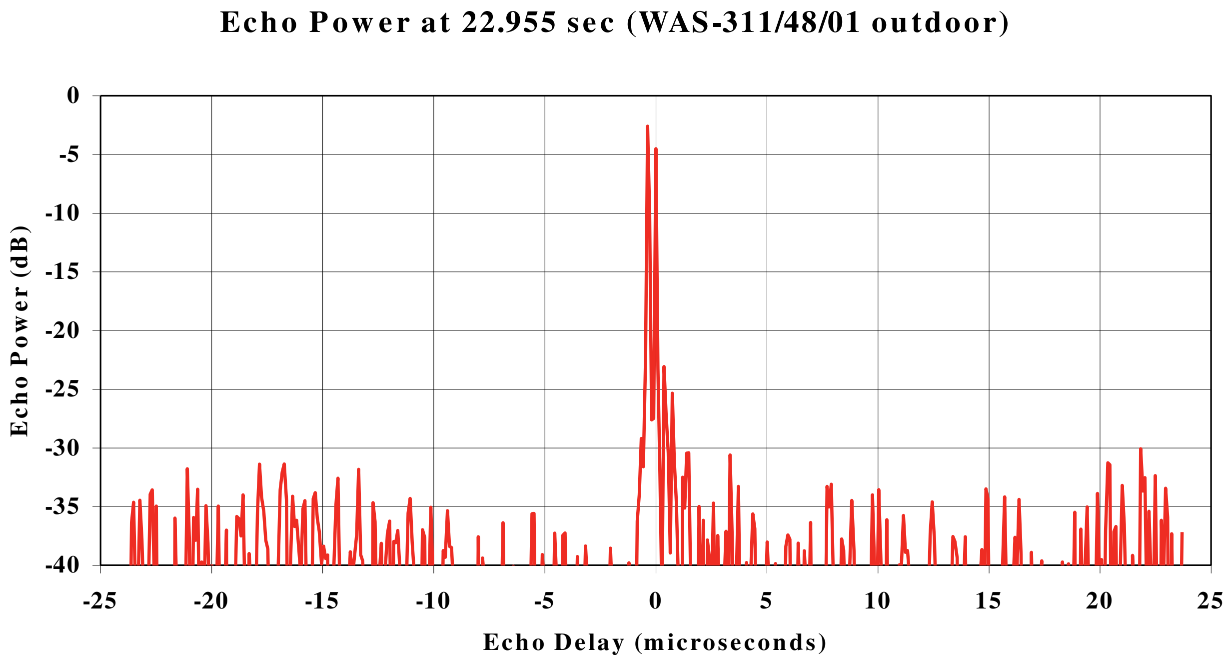

Figure B.23 Echo power as a function of echo delay observed at 22.955 seconds into the RF capture of outdoor site WAS-311/48/01. After two additional field syncs in time, the 372 ns pre-echo is now the dominant path.

Two field syncs later in time (at 22.955 seconds), the formerly pre-echo path now exceeds the main path, as illustrated in Figure B.23. The original echo has become the dominant path. It is clear that signal conditions do exist where, although the receive antenna is directional and 30 feet high, strong echoes can be present and may even exceed the dominant path in signal level.

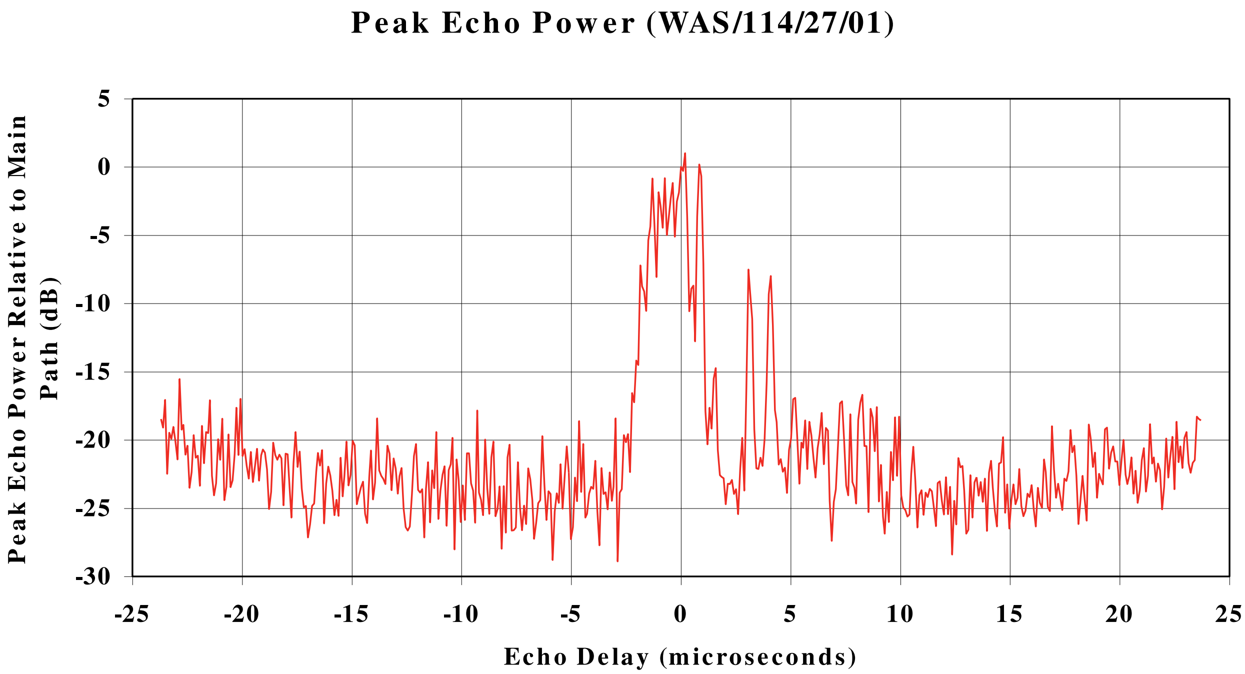

Figure B.24 Peak echo power observed in RF capture WAS/114/27/01.

B.3.6 Captured Channel WAS-114/27/01

Figure B.24 illustrates the peak echo power of RF outdoor capture WAS-114/27/01. The figure demonstrates the presence of strong pre- and post-echoes that are close in delay to the main path.

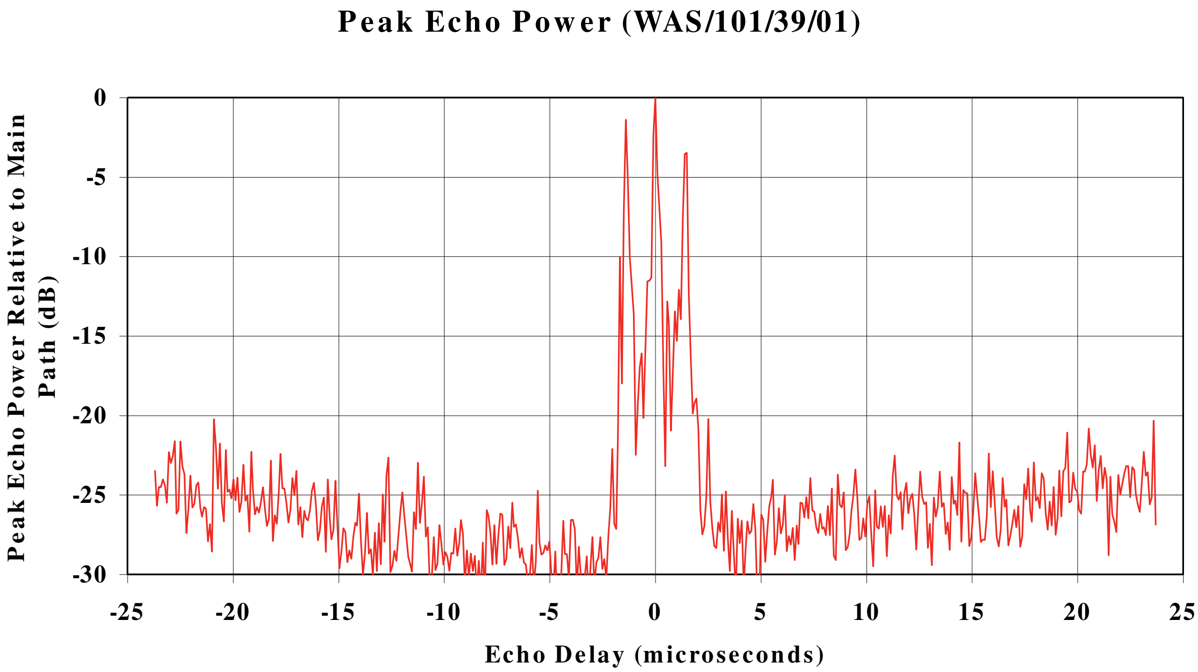

Figure B.25 Peak echo power observed in RF capture WAS/101/39/01.

B.3.7 Captured Channel WAS-101/39/01

Figure B.25 illustrates the peak echo power of RF outdoor capture WAS-101/39/01. This channel has a pattern characteristic of a close-in “bobbing channel”.

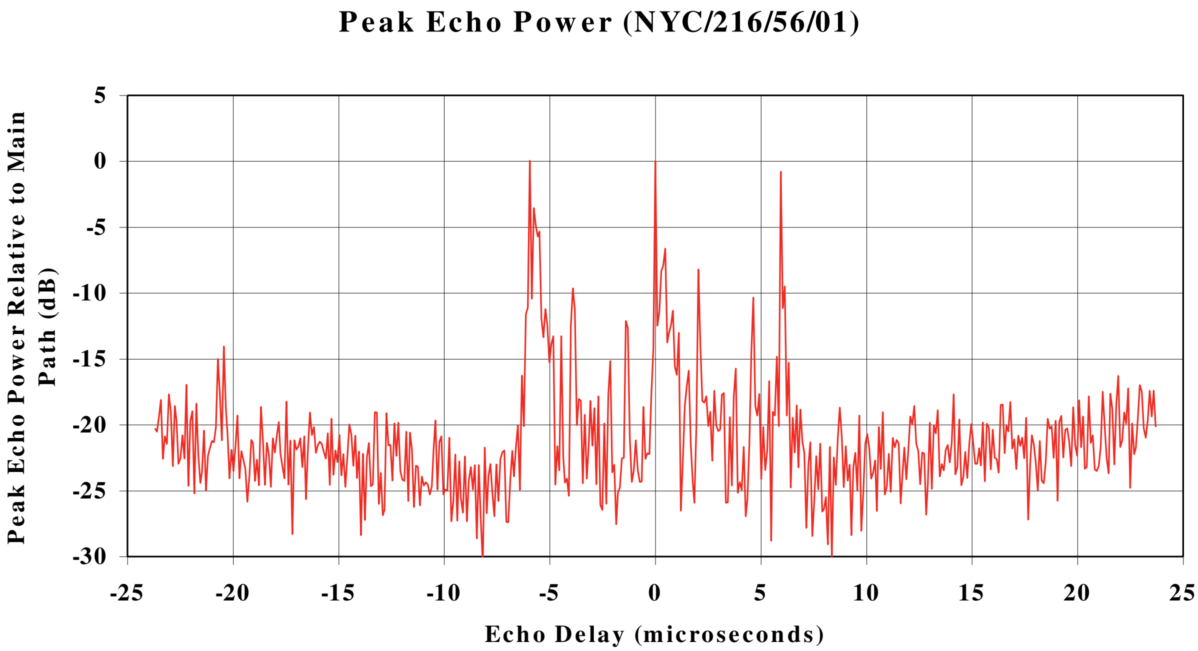

Figure B.26 Peak echo power observed in RF capture NYC/216/56/01 using a loop-type antenna in a fourth-floor urban apartment.

B.3.8 Captured Channel NYC-216/56/01

Figure B.26 shows the peak echo power of indoor channel NYC/216/56/01 captured with a loop-type antenna six feet above floor level. The figure demonstrates the presence of both strong pre- and post-echoes. The capture location was a fourth-floor urban apartment constructed of wood with brick siding. The room had windows on two adjacent walls.

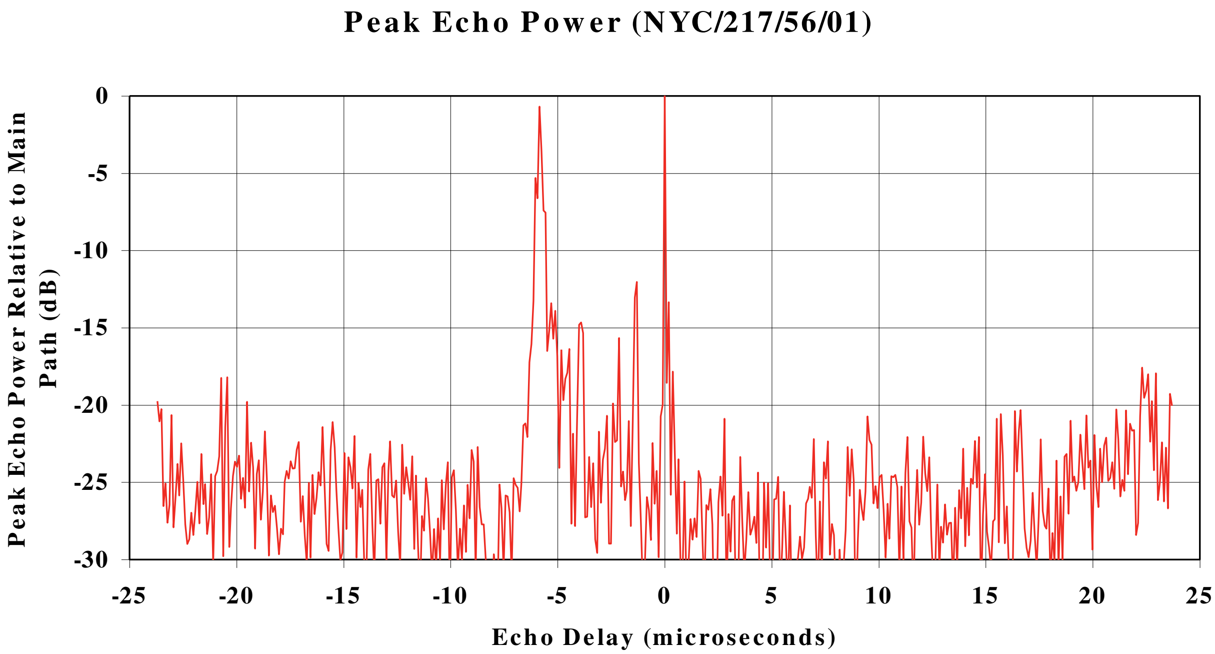

Figure B.27 Peak echo power observed in RF capture NYC/217/56/01 using a single bowtie-type antenna in a fourth-floor urban apartment.

B.3.9 Captured Channel NYC-217/56/01

Figure B.27 shows the peak echo power of indoor channel NYC/217/56/01 captured at the same location as NYC/216/56/01, using a bowtie-type antenna at a 6-foot height above floor level.

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Advanced Television Systems Committee

Annex C: Example of Channel Impulse Response with Moderate Pre and Post-Echo

C.1 SCOPE

Some examples of captured channels with moderately long pre and post echoes are shown below as an illustration of field conditions with possible long RF delay spread.[10]

C.1.1 Far Pre-Echo[11]

The channel in Figure C.1 represents the amplitude of the impulse response estimate of a channel capture in the Portland, OR, area. The impulse response estimate shows the presence of a pre-echo at approximately –14 µs with a relative amplitude to the main signal of about –10 dB.

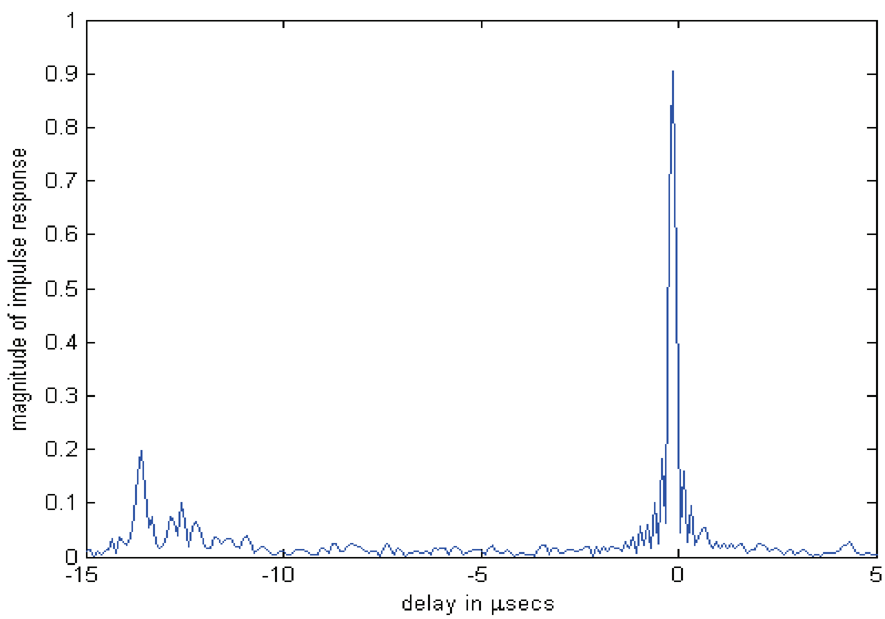


Figure C.1 Channel impulse response with pre echo at –14 µs.

C.1.2 Far Post-Echo

The channel in Figure C.2 represents the amplitude of the impulse response estimate of a channel captured on the roof of a 3-story building in the Philadelphia, PA area. The impulse response

10. It should be noted that the estimates of channel impulse responses in these examples were obtained without use of the PN511 sequence embedded in the field sync data segment (see A/53 [4]).
11. Although interesting from the multipath point of view, this channel has not been included in the recommended set of field ensembles, as it has been determined that the channel may be affected by capture equipment artifacts.

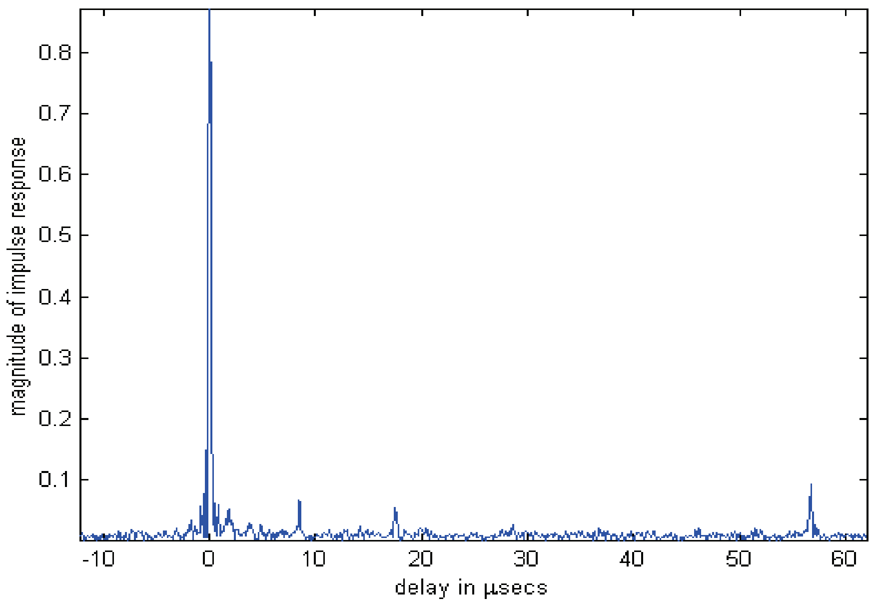


Figure C.2 Channel impulse response with post echo at 57 µs.

estimate shows the presence of a post-echo at approximately +57 µs with a relative amplitude to the main signal of about –19 dB.

Annex D:
Analysis of Received Power for a Sample Receiver

The calculations in Annex D are an analysis of the received power for a sample receiver located in Hollywood, FL, 33021. The receiving antenna was assumed to be the FCC standard antenna with a 10 dBd (12 dBi) gain and a 14 dB front to back ratio. The receiver line loss was assumed to be 4 dB. There was no consideration of balun loss, mismatch loss, etc. The receiving antenna was assumed to be pointed to the WBZL-DT transmitting facility.

All nearby transmitting facilities were identified that would have significant signals at the Hollywood location. The transmitting facilities' azimuth and elevation patterns were employed to estimate the received signal level. The FCC standard receiving antenna azimuth pattern was employed. There was no consideration of receiving antenna elevation pattern effects, which were assumed to be negligible for the location under study.

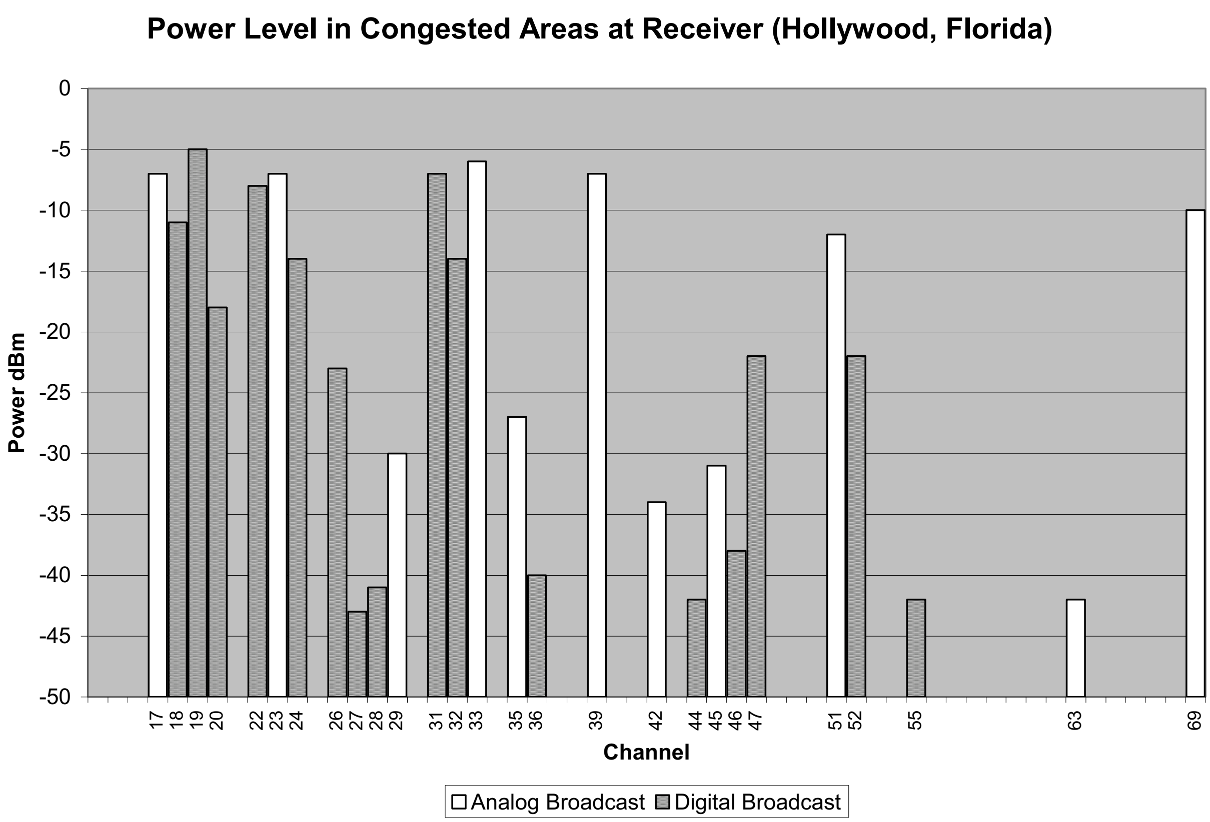


Figure D.1 Power level at specified receiver.

Table D.1 TV/DTV Received Power Analysis; Location: Hollywood, Fla.

TV Ch.	Station Call Sign	Mode	Distance (km)	Compass Direction from Receiver (deg.)	Maximum ERP (kW)	Antenna Height Above MSL (m)	Calculated RF Power at Receiver (dBm)
17	WLRN-TV	Analog	6.8	193	2820	311	–7
18	WPBT-DT	Digital	6.8	193	1000	311	–11
19	WBZL-DT	Digital	6.1	204	1000	254	–5
20	WLRN-TV	Digital	4.3	179	625	303	–18
22	WFOR-TV	Digital	6.1	204	1000	300	–8
23	WLTV(TV)	Analog	6.1	204	4470	299	–7
24	WLTV-DT	Digital	6.1	204	500	259	–14
26	WPXM-DT	Digital	3.7	174	200	284	–23
27	WXEL-DT	Digital	62	356	400	444	–43
28	WFLX-DT	Digital	62	356	630	462	–41
29	WFLX(TV)	Analog	62	356	5000	462	–30
31	WTVJ-DT	Digital	6.1	204	1000	314	–7
32	WBFS-DT	Digital	5.8	192	1000	263	–14
33	WBFS-TV	Analog	5.8	192	5000	286	–6
35	WPXM(TV)	Analog	38.8	198	3420	103	–27
36	WPXP-DT	Digital	63.2	359	1000	390	–40
39	WBZL(TV)	Analog	6.1	204	5000	278	–7
42	WXEL(TV)	Analog	52	356	2140	444	–34
44	WPPB-DT	Digital	3.7	141	565	311	–42

Annex E: Adjacent Channel Interference (ACI)

DTV transmitters generate a significant amount of sideband splatter—3rd- and 5th-order distortion products that fall in the adjacent channels. The FCC limits this splatter into adjacent channels by means of an RF Mask. The maximum power radiated in each adjacent channel is required to be at least 44.7 dB below the radiated power within the allocated channel. DTV receivers tuned to either of these adjacent channels were found to attenuate this splatter by 1.8 dB (to –46.5 dB down)[12] [13] For example: if the undesired signal is 31.3 dB stronger than the desired signal (D/U = –31.3 dB), the signal-to-noise power ratio in the desired channel through a perfectly linear receiver would be 46.5 – 31.3 = 15.2 dB, which is the threshold SNR of the ATSC signal at which reception fails.

In order to allow for a practical degree of receiver non-linearity, the FCC limits the D/U ratio for adjacent channels. Within the predicted noise-limited contour of each station, the FCC Rules permit the DTV signal power of an undesired adjacent channel station to reach a Desired-to-Undesired (D/U) signal ratio of –26 dB on the lower adjacent channel, and –28 dB on the upper adjacent channel, anywhere within the coverage area of the desired station (i.e., the undesired signal is stronger than the desired signal by the specified amount). The undesired signal power is permitted to exceed the specified D/U ratios in a proportion of cases that is limited by the population impacted by the interference that exceeds the specified D/U ratios. For brevity, this document will use the mean D/U of –27 dB.

As an example, where the desired signal is received at –35 dBm and an undesired signal on either adjacent channel is received at –8 dBm, the D/U = –27 dB.

Third-order distortion products can generate additional in-channel noise in the receiver's tuner. Example 1 below shows a calculation in which the maximum in-channel noise, including receiver-generated 3rd-order distortion products, will be below –52.2 dBm. Example 2 below shows the same calculation for a larger desired level. Note that the IM3 that the receiver is allowed to generate from this U signal is more restricted in the case where D = –35 dBm than is the case where D = –28 dBm.

12. Bendov, Oded: "Interference to DTTV Reception by First Adjacent Channels", *IEEE Transactions on Broadcasting*, Institute of Electrical and Electronics Engineers, New York, N.Y., vol. 51, no. 1, pg. 30, May 2005.
13. Rhodes C. W., and Sgrignoli, G. J.: "Interference Mitigation for Improved DTV Reception," *IEEE Transactions on Consumer Electronics*, Institute of Electrical and Electronics Engineers, New York, N.Y., vol. 51, no. 2, pg. 465, May 2005.

Example 1

When:

D = –35.0 dBm U = –8 dBm

SNR = 15.2 dB Received splatter = –8 dBm – 46.5 dB = –54.5 dBm

In-channel noise = –50.2 dBm = 0.000 009 550 mw

Received sideband splatter = –54.5 dBm = 0.000 003 548 mw

Maximum additional noise = 0.000 006 002 mw = –52.2 dBm

Example 2

When:

D = –28.0 dBm U = –8 dBm

Threshold SNR = 15.2 dB Received splatter = –8 dBm – 46.5 dB = –54.5 dBm

In-channel noise = –43.2 dBm = 0.000 047 863 mw

Received sideband splatter = –54.5 dBm = 0.000 003 548 mw

Maximum allowable additional noise (IM3) = 0.000 044 315 mw = –43.5 dBm

Any additional noise in the desired channel would cause reception to fail. To the extent that the undesired signal on an adjacent channel is less than –8 dBm, some additional noise can be tolerated. It should be noted that if there are signals on both adjacent channels of equal power, their received power must be below –11 dBm each for reception to be possible. There are communities in which both adjacent channels (N – 1 and N + 1) are allocated. A DTV signal on channel N can only be received at locations where the D/U ratios are at least 3 dB lower than the FCC planning factors so that their total power is less than –8 dBm. It should be noted that regulatory planning factors currently are based on consideration of only two signals at a time. The reception environment in the field is more complex and receivers will need to deal with multiple-interferer cases.

Additional "noise" may be 3rd-order intermodulation products (IM3) falling in the desired channel, which are generated in the tuner of the affected receiver when overloaded by the stronger (U) signal(s). A summary of allowable in-channel noise at various input signal conditions is given in Table E.1.

Table E.1 Allowable Levels of In-Channel Noise for Different D/U Conditions

Desired level (dBm)	–28	–35	–53	–68	–81
Undesired level (dBm)	–8	–8	–26	–41	–54
Maximum allowed in-channel noise, including IM3 (dBm)	–43.5	–52.2	–70.2	–85.2	–85.2 (including Rx noise @ –99.2 dBm)

Wideband RF AGC systems will attenuate the D signal and U signals whose frequency components are at the input to the RF AGC detector. This changes the U level at the mixer (generally the stage that is non-linear), reducing the power of the IM3 generated in the receiver by 3 dB per each 1 dB decrease in the U signal power at the mixer input. Near and inside the edge of the noise-limited coverage, the D signal power is marginal. If the Undesired signal on N+/–1 forces a significant reduction in the gain of the RF amplifier, the desired signal (also attenuated) may arrive at the mixer less than 15.2 dB above the receiver generated noise (referred to the mixer input) in which case reception fails. At such marginal locations no receiver topology can work with adjacent channel D/U ratios at or near their FCC upper limits. Nevertheless, wideband RF AGC does mitigate interference throughout most of the noise-limited coverage area of stations, and is widely used.

Use of a directional antenna may mitigate adjacent channel interference by discriminating against the undesired signal (and its sideband splatter) if the angle between the ray paths of the desired and undesired signals provides discrimination against the undesired signal. The FCC assumed that a highly directional antenna will be used in devising the table of DTV channel allotments. The maximum discrimination factor used is 14 dB for relative bearing angles > +/– 48 degrees.

Annex F: DTV-DTV Interference from Two Received Undesired Signals

Two undesired signals can, in the presence of receiver non-linearity, generate intermodulation that can produce an elevated noise spectrum that can occupy three contiguous channels. Depending on desired and undesired signal levels, reception may be impaired. This Annex quantifies and explains these effects.

Intermodulation between two undesired signals Fa and Fb (Fa being the lower of the two frequencies) results in new undesired frequencies: 2 * Fa – Fb, which lies below Fa, and 2 * Fb – Fa, which is above Fb. Fa and Fb may be sidebands of the same signal, or sidebands of different signals in the case of multiple undesired signals. These 3rd-order distortion products fall in the same band as the overloading signals as shown in Figure F.1. New frequencies produced by the sums 2 Fa+ Fb and/or 2 * Fb + Fa do not fall within the same band as the overloading signals, but

Fa \ Fb	IM3 (MHz)					
	57 MHz Ch. 2	63 MHz Ch. 3	69 MHz Ch. 4	79 MHz Ch. 5	85 MHz Ch. 6	98 MHz FM band
- 2 +		69 MHz	81 MHz			
- 3 +			57 MHz 75 MHz			
- 4 +				59 MHz 89 MHz	53 MHz	
- 5 +					73 MHz	60 MHz
- 6 +						72 MHz

Figure F.1: IM3, 2 Fa – Fb and 2 Fb – Fa from either: a) two low VHF transmitters, or b) a low VHF signal plus an FM signal, where the product falls in a low VHF channel.

Notes:

1) Each IM3 product occupies three (3) consecutive channels
2) The frequency of the center of the center channel is shown in MHz
3) Spectrum of each IM product extends +/–9 MHz from the center frequency

Fa \ Fb		IM3 (MHz)					
		57 MHz Ch. 2	63 MHz Ch. 3	69 MHz Ch. 4	79 MHz Ch. 5	85 MHz Ch. 6	98 MHz FM band
2	- +		177 MHz 183 MHz	183 MHz 195 MHz	193 MHz 215 MHz	199 MHz	212 MHz
3	- +			195 MHz 201 MHz	193 MHz	211 MHz	
4	- +				217 MHz		
5	- +						
6	- +						

Figure F.2 Third-order IM products, 2 Fa + Fb and 2 Fb + Fa, generated by two low VHF band signals that fall in high VHF band TV channels.

Notes:

1) Each IM3 product occupies three (3) consecutive channels
2) The frequency of the center of the center channel is shown in MHz
3) Spectrum of each IM product extends +/–9 MHz from the center frequency

in some cases fall in the high VHF band as shown in detail in Figure F.2; or, in the case of two undesired signals in the high VHF band, some IM3 frequencies fall in the UHF band, as shown in Figure F.3

In the case of DTV signals on either the high VHF band or the UHF band, it is convenient to work with their channel numbers. For example, see Figure F.4, where DTV signals on channels 30 and 33 generate 3rd-order IM (IM3) falling in channels 27 and 36. This particular example is of a pair of (undesired) signals of the form N + K and N + 2 K, where K is an integer. Two signals on channels N + K and N + 2 K create IM3 in channels N and N + 3 K. Receivers tuned to either channel N or N + 3 K may suffer interference from this pair of undesired signals. The spectrum of 3rd-order IM generated by pairs of DTV signals is 3 channels wide. Therefore, but to a lesser extent (6dB), channels adjacent to channel N and N + 3 K may also be subject to interference.

In 2007, the FCC published a report of tests[14] that it conducted of interference rejection by consumer DTV receivers in which there were two undesired DTV signals on channels N + K, and

14. FCC/OET 07-TR-1003, "Interference Rejection Thresholds of Consumer Digital Television Receivers Available in 2005 and 2006," Tables A-9 and A-10, 30 March 2007, http://www.fcc.gov/oet/info/documents/reports/DTV_Interference_Rejection_Thresholds-03-30-07.doc

Fa \ Fb	IM3 (MHz)						
	(177 MHz) Ch. 7	(183 MHz) Ch. 8	(189 MHz) Ch. 9	(195 MHz) Ch. 10	(201 MHz) Ch. 11	(207 MHz) Ch. 12	(213 MHz) Ch. 13
Ch. 7		537	543	549	555	561	567
Ch. 8	543		555	561	567	573	579
Ch. 9	555	561		573	579	585	591
Ch. 10	567	573	579		591	597	603
Ch. 11	579	585	591	597		603	615
Ch. 12	591	597	603	609	615		627
Ch. 13	603	609	615	621	627	633	

Figure F.3 Third-order IM products 2 Fa + Fb and 2 Fb + Fa generated by two (2) high VHF band signals Fa and Fb.

Notes:

1) Each IM3 product occupies three (3) consecutive channels
2) The frequency of the center of the center channel is shown in MHz
3) Spectrum of each IM product extends +/–9 MHz from the center frequency

N + 2 K where K, the offset between undesired channels, varied from 1 to 5 inclusive. These tests demonstrated that receiver thresholds are substantially lower when there are two signals in such a pair, than the thresholds with any of the individual signals alone.

Usually, distortion products above 3rd-order are negligible. Third-order distortion products are the principal cause of DTV-DTV interference, as these may fall in the desired channel, where they generate a form of co-channel interference. This increases at the rate of 3 dB per 1 dB increase in the undesired signal received power. Third order distortion products such as 2 * Fa + Fb (or if there are three undesired signals Fa, Fb, and Fc, products such as Fa + Fb + Fc) may fall in or very near the desired channel. For example, three signals on channels 8, 10, and 12, whose center frequencies are 183 MHz, 195 MHz, and 207 MHz, can produce a third-order distortion product centered at 585 MHz within the UHF band (channel 33).

Receivers generally have been designed with sufficient RF selectivity between the antenna terminals of the receiver and its mixer so that out-of-band signals are attenuated sufficiently to avoid such interference. However it is worth drawing attention to this problem as we enter the era of digital TV broadcasting with reduced RF spectrum available for broadcasting, which results in denser packing of DTV signals within the remaining spectrum. For example, third order distortion of two UHF channels of the form 2 Fa – Fb or 2 Fb – Fa generally falls in other UHF TV channels.

The spectrum of 3rd-order distortion products, when the undesired signals are DTV signals, always extends over three channels. In the example cited the spectrum of the IM3 extends ± 9 MHz from 585 MHz — from 576 MHz (channel 31) to 594 MHz (channel 34). If a receiver lacks sufficient RF selectivity, 3rd-order distortion of the 2 *Fa + Fb or 2 * Fb + Fa form could involve pairs of the high VHF band channels interfering with reception of a signal in a portion of the UHF band, as shown in Figure F.3.

In the case of reception of signals broadcast in the UHF band, the undesired signal may be very close to the desired signal. For example the desired signal may be on channel 34 and undesired signals may be on channels 32 or 36. The RF selectivity problem is acute in the UHF band as the desired signal may be centered on 593 MHz and the undesired signals can be as close as 581 MHz and 605 MHz. Practical tracking filters cannot reject UHF signals near the desired channel. Therefore signals on channels N+/– 2, 3, 4, 5 and to a lesser extent other undesired signals even further offset from the desired channel may reach the mixer at a power level at which the mixer suffers overloading and therefore generates 3rd-order distortion products.

The third order distortion effects for one undesired signal is:

Cross-modulation (which includes compression of the desired signal) and 3rd-order intermodulation (IM3) products in both adjacent channels.

The third order distortion effects for two undesired signals are:

Cross-modulation (which include compression of the desired signal) and 3rd-order intermodulation (IM3): 2 * Fa +/–Fb and 2 * Fb +/–Fa.

The third order distortion effects for three or more undesired signals are:

Triple beat cross-modulation: Fa +/– (Fc – Fb), Fb +/– (Fc – Fa) and Fc +/– (Fb – Fa)

Cross modulation of the desired signal by a stronger undesired DTV signal results in noise being added to the desired signal, lowering its SNR. One strong DTV signal can cross-modulate all weaker signals, causing interference if this undesired signal can overload the mixer because it has not been sufficiently attenuated by the filtering ahead of the mixer.

Third-order intermodulation products also are generated by all DTV transmitters and some products are radiated in adjacent channels as described above. Third-order IM may also be generated in a DTV receiver when undesired signal(s) in either adjacent channel overload the receiver. Some of them fall in the desired channel reducing the SNR also described above. This is the principal interference mechanism for adjacent channel interference in DTV receivers.

Consider two undesired signals on channels 30 (569 MHz) and 33 (587 MHz), as shown in Figure F.4 for some arbitrary amount of tuner non-linearity. The 3rd-order distortion products will fall principally in channels 27 and 36. For example

2 * 581 MHz – 569 MHz = 593 MHz — channel 36 (the desired channel)

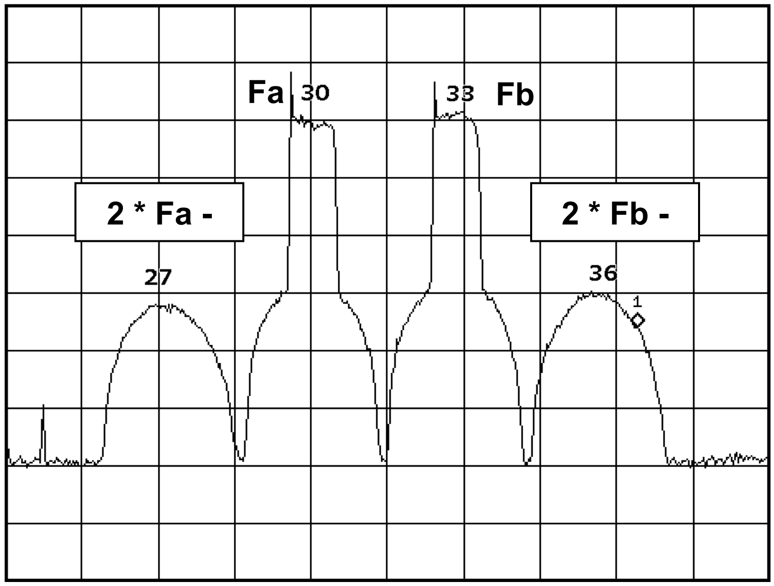


Figure F.4 Distortion products for two undesired signals on channels 30 (569 MHz) and 33 (587 MHz).

The undesired signal on channel 30 is called Fa, and the other on channel 33 is called Fb. Third-order intermodulation products always occupy 3 contiguous channels. The center channels of these are

2 * Fa – Fb and 2 * Fb – Fa

In Figure F.4, Fa = 569 MHz and Fb = 587 MHz;

2 * 569 – 587 = 551 MHz (center of channel 27)

The IM3 spectra occupy channels 26, 27, and 28; and channels 35, 36, and 37. Figure F.4 shows these IM3 spectra, which resemble "beehives" centered on channels 27 and 36. The noise power in each of their side-channels (26, 28 and 35, 37) has 6 dB less noise than the center channels 27 and 36. A simpler way to make such calculations for high VHF band and UHF channels is to use the channel numbers. For example

2 * Fa – Fb (2 * 30 – 33) = 27 and 2 * Fb – Fa (2 * 33 – 30) = 36

It follows that if the signal received on channel 30 or 33 is not more that 15.2 dB above the receiver generated IM3 in those channels, reception will fail. Reception of signals on channels 26, 28 or 35, 37 will fail if the desired signal is not 15.2 dB or more above the co-channel noise due to receiver generated IM3. Designers should control tuner selectivity and non-linearity so that S/N ratios exceed these fundamental thresholds for the expected range of signal levels of received channels.

More generally, a desired signal on channel N or N + 3 K may suffer interference from undesired signals on channels N + K and N + 2 K, where K is any integer, positive or negative. In

Figure F.4, K = 3. Desired signals on channel N +/–1 and channel N + 3 K +/–1 are also subject to interference, but to a lesser extent, by 6 dB, as is shown in Figure F.4.

Annex G: DTV-TV Interference from a Triplet of Undesired Signals

For a triplet of undesired signals, for example channels 33, 35, and 37, there will be two IM3 "beehives" below this triplet, and two more above it as shown in Figure G.1. The center channels of the outer "beehives" are channels 29 and 41. The center channels of the inner pair of 'beehives" are channels 31 and 39.

With triplets of undesired signals, there are other 3rd-order intermodulation products generated. For example, there are:

2 * Fa – Fb: 66 – 35 = 31	2 * Fb – Fc: 70 – 37 = 33	2 * Fc – Fa: 74 – 33 = 41
2 * Fb – Fa: 70 – 33 = 37	2 * Fc – Fb: 74 – 35 = 29	2 * Fa – Fc: 66 – 37 = 29

and there are also triple-beat cross-modulation products:

Fa +/– (Fc – Fb)	= 33 +/– 2	= 31 and 35
Fb +/– (Fc – Fa)	= 35 +/– 4	= 31 and 39
Fc +/– (Fb – Fa)	= 37 +/– 2	= 35 and 39

The triplet of Figure G.1 is a symmetrical triplet. There are 42 symmetrical triplets in the Table of Permanent FCC Channel Allotments.

There are 161 asymmetrical triplets in this Table of Permanent Channel Allotments. Most of these occur in major markets.

In many communities, all DTV transmitters are co-sited so that the received power of all DTV signals in that community are roughly equal at most sites. Co-siting reduces the possibility of large differences in received signal power and the possibility of third-order distortion products causing loss of reception.

At sites between large communities, viewers may receive signals from one community at much lower powers than those from the other community (especially if the antenna is aimed towards one group of transmitters and away from the others) in which case, interference due to third-order distortion products may be encountered. The use of antenna rotators or steerable antennas such as is envisioned in the CEA-909 Interface Standard may mitigate such interference.

With symmetrical triplets, a number of distortion products fall in a single channel (as shown in Figure G.1), where they are masked by a stronger signal. With asymmetrical triplets such as shown in Figure G.2, the distortion products generally do not fall in a single channel. Asymmetrical triplets such as in Figure G.2 have a more uniform spectrum of third-order distortion products, meaning that many channels are affected by the high noise floor extending over a large range of channels as can be seen by comparing the spectra in Figure G.1 (symmetrical) and Figure G.2 (asymmetrical) triplets.

The implications of this are that a large number of stations are subject to interference from one or more asymmetrical triplets, which are the more numerous kind. For example, the spectrum of

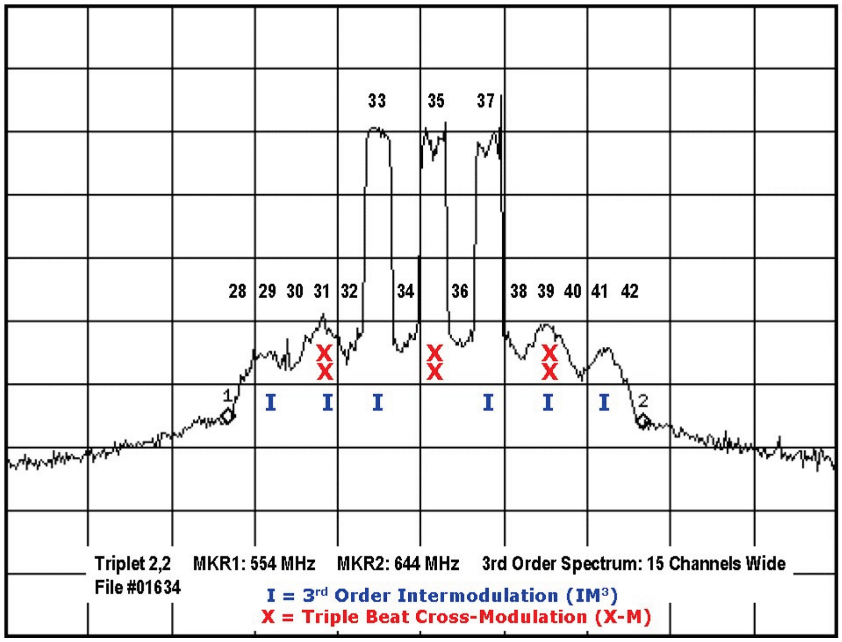


Figure G.1 Symmetrical triplet of undesired signals.

Notes:

1) Two of the triple-beat cross-modulation products fall in the same channel, increasing the power of this noise by 3 dB in each case.
2) In some channels, a triple beat and IM3 may both be present.

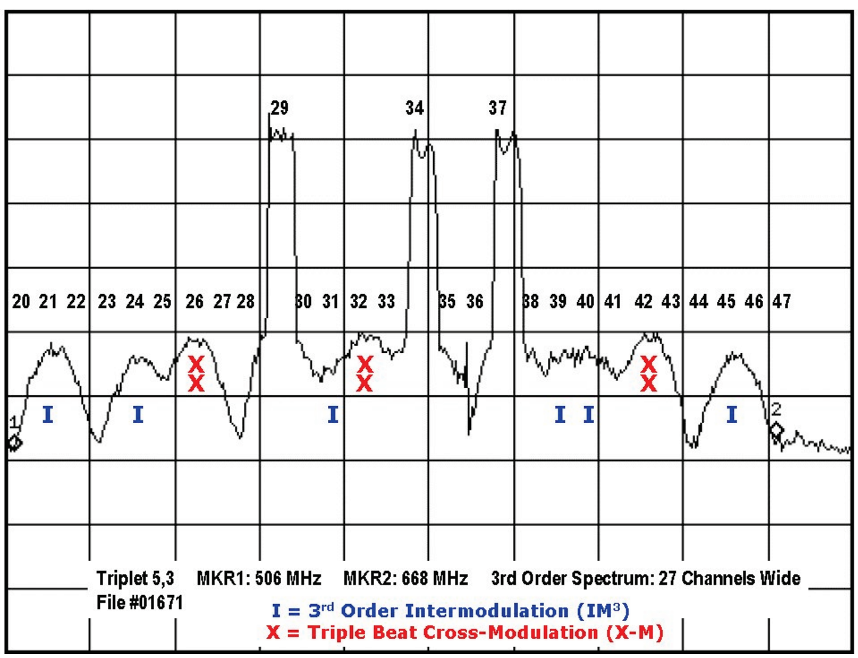


Figure G.2 Asymmetrical triplet of undesired DTV signals.

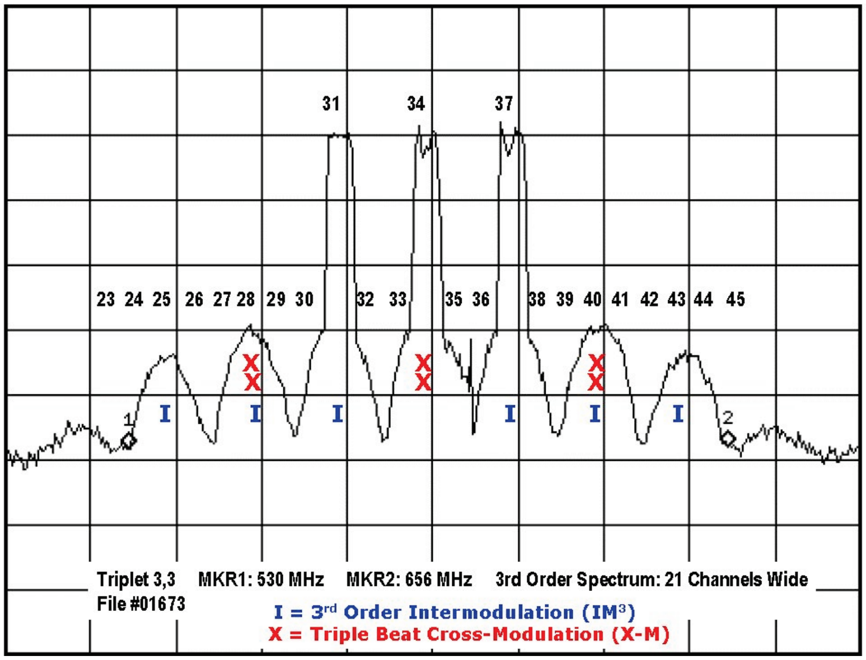
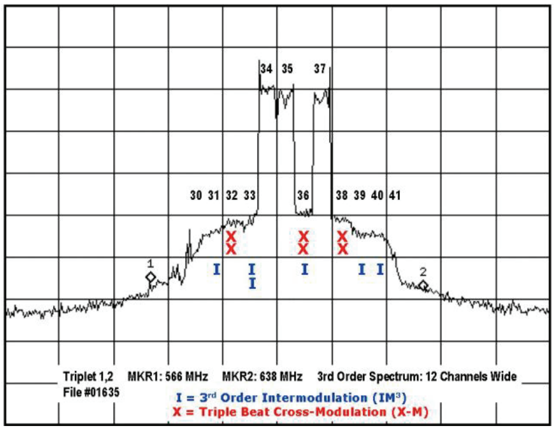


Figure G.3 Symmetrical triplet example (triplet 3,3).

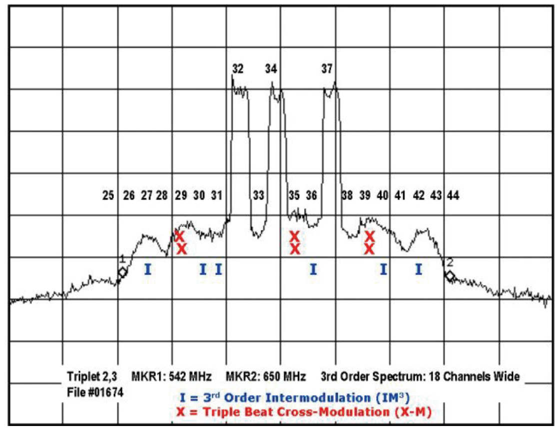
3rd-order distortion products in Figure G.1, a symmetrical triplet, extends from channel 28 to channel 42. The IM3 spectrum of the asymmetrical triplet shown in Figure G.2 extends from channel 20 to channel 47. Two channels, 27 and 44, are not loaded with IM3. The number of channels in which receiver generated IM3 appears due to a triplet depends on the offset of the signals which comprise the triplet.

Offsets of 1 to 5 channels are found in 111 of the triplets found in the FCC Table while there are 203 offsets of 1 – 9 channels in that Table of Allotments. Thus, most triplets are closely spaced in the frequency domain. This has the unfortunate consequence that RF selectivity of receivers will have a minimal benefit in rejecting interference from these closely spaced triplets.

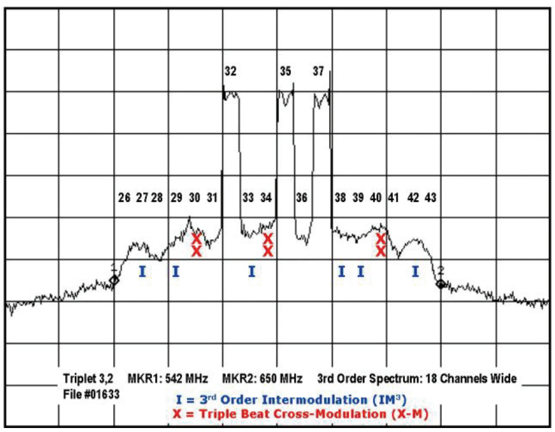
The following examples of triplets have been generated to illustrate potential undesired signal products (Figures G.3 and G.4).



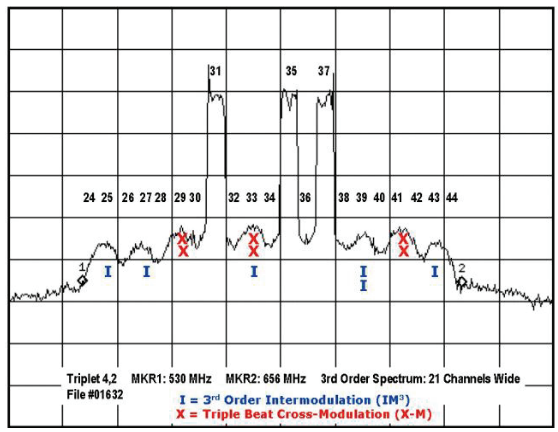
Triplet 1,2



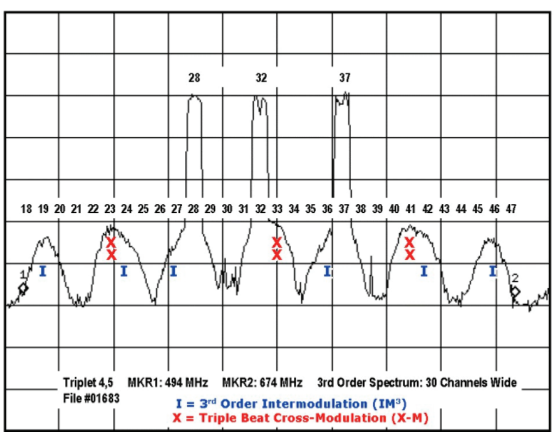
Triplet 2,3



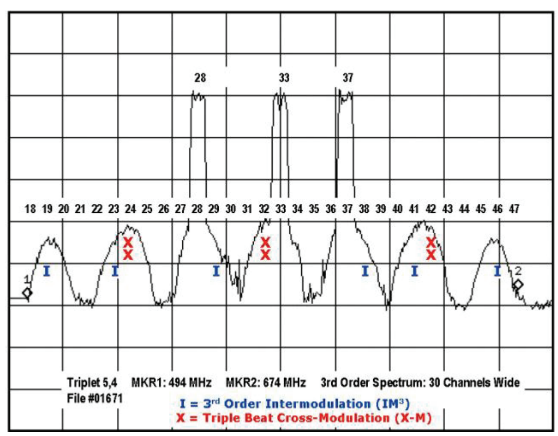
Triplet 3,3



Triplet 4,2



Triplet 4,5



Triplet 5,4

Figure G.4 Asymmetrical triplet examples.

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