A STUDY IN FIELD VERIFICATION OF 8-VSB COVERAGE

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Abstract

The new terrestrial transmission standard for Digital Television is known as 8-VSB. The DTV-M1 is used to take actual field measurements of a station's coverage area, allowing the user to compare these results with theoretical coverage predictions that are based upon mathematical models. This document describes the main concepts behind the design of the DTV-M1, a vehicle capable of performing such tasks. Equipment considerations, equations, algorithms, and measurement procedures used in this vehicle are explored.
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1 Introduction

1.1 The Need for Field Measurement

Current analog terrestrial television in the United States of America is known as NTSC. This television standard is currently being replaced by a new digital television standard known as ATSC. This standard allows for the transmission of digital video, audio and data in a 6 MHz bandwidth. As part of the requirements of the new television standard, present terrestrial coverage with NTSC will have to be maintained or improved upon. Coverage is based upon actual field strength measurements for a given transmission facility and is the primary reason for conducting field measurement tests. Other objectives for conducting field measurements test include:

- Comparison of actual digital transmission coverage to predicted coverage
- Comparison of digital transmission to analog transmission
- Comparison of one or more digital transmission systems
- Comparison different environmental conditions
- To provide sufficient data to statistically characterize digital transmission RF environment, thus creating better predicted coverage models

Coverage is characterized by grades of service, which is based upon particular signal strength. This characterization is detailed in the section on Measurement Theory. One test for coverage is at the end of the service area known as the fringe area. It is at these regions were transmission errors are more likely to occur. The transmitted signal has to be acquired by the demodulators (receivers) and remain locked to the signal under similar receive conditions presently encountered by NTSC receivers.
The coverage of the new transmission system can be estimated using theoretical techniques. Most propagation models do not take into consideration terrain and environmental conditions between the transmitting antenna and the receiving antenna. Complex terrain and environmental conditions involving multiple obstacles and reflecting objects are not considered in propagation models. Rather, they are lumped into one or two objects simulating propagation possibilities. These models also do not consider environmental clutter such as trees and buildings, which significantly affect the transmission of UHF and low VHF frequencies. These variances can have a gross effect on the actual transmission resulting in multi-path and other propagation phenomena. Based upon these variances there is a need to quantitatively verify the theoretical predictions with actual field measurements of the new transmission system. It is for this reason that the DTV-M1 pictured in Figure 1-1 was born. The completed design won an industry award from Television Broadcast at the National Association of Broadcasters trade show in 1999, for advancements in The Art and Science of Television Broadcast.

![Figure 1-1 Completed test measurement vehicle – DTV-M1](image)

1.2 Measurement Data Set

Title 47 of the Federal Communication Commissions (FCC) rules specifies the propagation model that must be used to determine coverage of the transmission system. The rules also contain procedures that must be followed for taking measurements and
analyzing the data for submittal to the FCC. The FCC has created a minimum data set that should be gathered due to the possibility of measurements being misinterpreted. This reduces the chance for misleading data as well as a consistent national database. It is upon an expansion of this recommended list that the DTV M1 is based. The data is automatically gathered and entered into the appropriate database field. The expanded data set will be submitted to the FCC as part of their request for proposal (RFP) for VSB Enhancements.

- Field strength (minimum, maximum, and median value) in dBuV/M
- Distance and bearing to the transmitter
- Ground elevation of test site
- Date, time of day, topography, and weather observations
- Azimuth orientation of receiving antenna for best reception
- Segment Error Rate (SER)
- Equalizer tap values and energy
- Noise floor
- Added noise
- Calculated margin to threshold

1.3 Organization of Thesis

The thesis is divided into six main sections, covering propagation theory to future product enhancements. Section 2, Propagation theory, covers propagation phenomenon

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such as reflection, diffraction, scattering, Fresnel zones, and large and small signal fading. Section 3, gives an overview of the Digital Television (DTV) modulation scheme eight vestigal sideband broadcast (8-VSB). This section gives details of the modulation standard and steps taken to protect the data against destructive propagation phenomena. Section 4 is an overview of the theory behind the different measurements used in evaluating the signal coverage, while Section 5 covers how the field test vehicle and automation software were designed to solve an industry problem. Section 6 helps with the interpretation of the collected data and Section 7 gives future software and hardware enhancements to the product. Section 8, the Appendix, contains a glossary, pictures of the construction of the vehicle, copy of the industry award given to the product, a satisfied customer article, and the manual for the written software.

\[2\text{ Measurement Sets, Request For Proposal for VSB Enhancements, Advanced Television Standards Committee, T3/S9, January 25, 2001.} \]
2 Propagation Theory

2.1 Free Space Propagation Model

In an ideal world a transmitted signal will propagate to a receiver without any obstructions in its path. This idealization is modeled using the free space propagation model. This model predicts the power decay to be a function of the transmitter-receiver (T-R) separation distance raised to some power.

With the knowledge of the transmitter power and antenna gain, receiver antenna gain, signal wavelength, losses in the transmission and reception system and the T-R separation, the theoretical power available at the receiver antenna can be calculated as expressed in the equation below. Assuming no losses in the transmission and reception systems (L=1), this is a rather straightforward calculation.

\[ P_r(d) = \frac{P_t G_t G_r \lambda^2}{4\pi^2 d^2 L} \]

The received E field in dBuV/m can be calculated by

\[ |E| = 120\log \sqrt{\frac{P_r(d)120\pi}{G_G \lambda^2/4\pi}} \]

However, in the real world the result of the above equation should not be used for purposes other than quick receive signal strength calculations. If one wants to get none detailed understanding, they are three basic forms of mechanisms that affect desired propagation performance. Reflection, diffraction and scattering that can have significant impact on the received power. Large-scale propagation and small-scale fading models take into consideration these mechanisms.
2.2 Basic Propagation Mechanisms

Reflection occurs when a propagating electromagnetic wave impinges upon objects such as buildings, walls and the earth’s surface, which have a large dimension when compared to the wavelength of the transmitted wave.\(^4\)

Diffraction is a result of the path between a transmitter and receiver being obstructed by a surface having sharp irregularities. The resulting secondary waves are present throughout and behind the obstacle, causing a bending of waves around the obstacle known as the shadowed region. This mechanism allows the propagation of radio waves to a receiver even when there is no line-of-sight path.\(^5\) The vector sum of the electric field component and the secondary waves make up the field strength in the shadowed region. This is demonstrated in Figure 2-1 below.

Figure 2-1 Diffraction at the edge of an obstacle

---

When the propagating wave impinges upon objects that are smaller in size than the wavelength and the number of these obstacles is large; scattering takes place. Scattered waves are produced by rough surfaces, small objects, or by other irregularities in the path of the propagating wave.\(^6\)

2.2.1 Reflections

For the purposes of this document only ground reflections using the 2-ray model will be examined. This model has been found to be reasonable accurate in predicting the large-scale signal strength\(\square\) over distances within the expected coverage contours of television stations. This model is based upon geometric optics and considers both direct line-of-sight (LOS) and ground reflected propagation paths between the transmitter and receiver.

The total electromagnetic field (\(E_{\text{TOT}}\)) is the addition of the LOS (\(E_{\text{LOS}}\)) and ground reflected (\(E_g\)) propagation paths. As the distance from the transmitter increases, the distance \(d'\) for line-of-sight and the distance \(d''\) for ground reflected signals becomes almost the same. Therefore, amplitudes between \(E_{\text{LOS}}\) and \(E_g\) are in essence equal and differ only in phase. This is so for distances greater than \(d\), where

\[
d > \frac{20 \pi h_r h_r}{3 \lambda}
\]

The received electromagnetic field (\(E_{\text{TOT}}\)) at that location is

\[
E_{\text{TOT}} = \frac{4 E_0 d_0 \pi h_r h_r}{d^2 \lambda}
\]

The received power at a distance \( d \) from the transmitter can be expressed as

\[
P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}
\]

Additionally, path loss becomes independent of frequency at large values of \( d \). The path loss can now be calculated as

\[
PL(dB) = 40\log(d) - \{10\log(G_t) + 10\log(G_r) + 20\log(h_t) + 20\log(h_r)\}
\]

The variables used are defined as:

- \( G_t \equiv \) gain of the transmitter
- \( G_r \equiv \) gain of the receiver
- \( h_t \equiv \) height of the transmitter
- \( h_r \equiv \) height of the receiver
- \( P_t \equiv \) power of transmitter
- \( P_r \equiv \) receiver power
- \( \lambda \equiv \) wavelength of specified frequency

#### 2.2.2 Diffraction

The phenomenon of diffraction can be explained by Huygen’s principle, which states that all points on a wavefront can be considered as point sources for the production of secondary wavelets, and that these wavelets combine to produce a new wavefront in the direction of propagation.\(^7\) As a result, diffraction allows the transmitted signal to propagate around curved surfaces, such as the earth, and behind obstructions.\(^8\)

---

Fresnel zones can explain diffraction losses as a function of the path difference around an obstruction. “Fresnel zones represent successive regions where secondary waves have a path length from the transmitter to receiver which are \( n \frac{\lambda}{2} \) greater than the total path length of a line-of-sight path.”\(^9\) This is commonly known as the excess path length \( \Delta \) and is obtained from the equation below where \( d_1 \) is the distance between the transmitter and the Fresnel zone, \( d_2 \) is the distance between the Fresnel zone and the receiver, and \( h \) is the height of the Fresnel zone.

\[
\Delta = \frac{h^2(d_1 + d_2)}{2d_1d_2}
\]

The phase difference \( \phi \) is given by

\[
\phi = \frac{2\pi \Delta}{\lambda}
\]

Fresnel zones indicate the regions in which diffracted signals alternately provide constructive or destructive interference to the total received signal. The equation for the \( n^{th} \) Fresnel zone circle is shown below.

\[
r_n = \sqrt[n]{\frac{\lambda d_1d_2}{d_1+d_2}}
\]

As a general rule, if the obstruction does not block the propagated waves at the first Fresnel zone (55% kept clear), losses attributed to diffraction will be minimal. In fact, further Fresnel zones will not significantly add to diffraction losses. \(^{10}\) The location of the first Fresnel zone between the transmitter and the receiver can be calculated by

---


\[ d = \left( \frac{4h_h}{\lambda} \right) \]

2.2.3 Scattering

Lampposts, trees and other vegetation, along with other such shaped and sized objects scatter transmitted signals in many directions. These objects perform this phenomenon due to their “rough” surfaces. Flat surfaces can also contribute to the scattering of signals by being rough in nature. Roughness is tested using the Rayleigh criterion which defines a critical height \( h_c \) of surface protuberances for a given angle of incidence \( \theta_i \). The surface is considered smooth if its minimum to maximum protuberance is less than \( h_c \):

\[ h_c = \frac{\lambda}{8 \sin \theta_i} \]

2.2.4 Fresnel-Kirchoff Knife-edge Model

The shadowing caused by a single object such as a hill or mountain results in attenuation due to diffraction. This diffraction can be estimated by treating the impeding object as a diffracting knife-edge. The electric field strength \( E_d \) of a knife-edge diffracted wave is

\[ \frac{E_d}{E_o} = F(\psi) = \frac{1+j}{2} \int_{\psi}^{\infty} \exp \left( -\frac{j\pi t^2}{2} \right) dt \]

Where \( E_o \) is the free space field strength in the absence of both the ground reflection and knife-edge, \( F(\psi) \) is the complex Fresnel integral; and \( \psi \), the dimensionless
Fresnel-Kirchoff diffraction parameter, is described by the equation below and commonly evaluated using tables or graphs.

\[ \psi = h \sqrt{\frac{2(d_1 + d_2)}{\lambda d_1 d_2}} \]

Plotting the integral in the complex plane results in a spiral as shown in Figure 2-2. In the curve (also known as Cornu’s Spiral), positive values of \( \psi \) appear in the first quadrant and negative values in the third quadrant. The spiral has the following properties:

- A vector drawn from the origin to any point on the curve represents the magnitude and phase of \( F(\psi) \).
- The length of arc along the curve when measured from the origin is equal to \( \psi \).

Figure 2-3 illustrates the geometry of knife-edge diffraction.

![Figure 2-3 Knife-edge diffraction geometry](image)

When compared to the free space E-field, there is a diffraction gain due to the knife-edge and is given by

\[ G_d(dB) = 20 \log |F(v)| \]

This equation is graphically represented in Figure 2-4, and as an approximate solution in provided by Lee in the equations below.\(^\text{13}\)

\[
\begin{align*}
G_d(dB) &= 0 & v \leq -1 \\
G_d(dB) &= 20 \log(0.5 - 0.62v) & -1 \leq v \leq 0 \\
G_d(dB) &= 20 \log(0.5 \exp(-0.95v)) & 0 \leq v \leq 1 \\
G_d &= 20 \log \left( 0.4 - \sqrt{0.1184 - (0.38 - 0.1v)^2} \right) & 1 \leq v \leq 2.4
\end{align*}
\]

\[ G_d(\text{dB}) = 20 \log(0.5 - 0.62 \nu) \quad \nu \geq 2.4 \]

Figure 2-4 Knife-edge diffraction gain \((G_d)\) as a function of Fresnel diffraction parameter \(\nu\)
2.3 Large Scale Fading

2.3.1 Longley-Rice Model

The Longley-Rice Model is based upon electromagnetic theory and on statistical analyses of both terrain features and radio measurements. The model predicts the local median attenuation of a radio signal as a function of distance in time and space.\textsuperscript{14} The median transmission loss is predicted with the use of path geometry of the terrain profile and the refractivity of the troposphere. The use of 2-ray ground reflection model is used to predict signal strengths within the radio horizon. While diffraction losses are estimated with Fresnel-Kirchoff knife-edge models. Scatter theory is used to predict troposcatter over long distances and Van der Pol-Bremmer method predicts far field diffraction losses in the double horizon paths.\textsuperscript{15}

The Longley-Rice model has been incorporated into a computer program. The source code and algorithm is available from the U.S. Department of Commerce National Telecommunications and Information Administration/Institute of Telecommunication Sciences website.\textsuperscript{16} The model can be used to calculate large-scale median transmission loss relative to free space loss over irregular terrain for frequencies between 20 MHz and 10 GHz includes the frequency bands for broadcast television. Antenna heights of 0.5 m to 3000 m, distance range of 1 km to 2000 km, and vertical or horizontal polarization are other system parameters of the Longley-Rice model.\textsuperscript{16}

They are two modes of operation to the Longley-Rice method. These are point-to-point mode and area mode. If detailed terrain path profile information is available, the

\textsuperscript{14} Hufford, George, Irregular Terrain Model (Longley-Rice), US Department of Commerce NTIA/ITS.
point-to-point mode can be used to determine path-specific parameters. Otherwise, if the terrain profile is not available, the area mode method is used to estimate path-specific parameters. Irrespective of the mode chosen input parameters include the distance between the transmitter and receiver, antenna structural height, minimum monthly mean surface refractivity, earth’s effective curvature, ground surface dielectric constant (transfer impedance), transmission frequency and climate. Terrain path profile information such as horizon distance of the antennas, angular trans-horizon distances, horizon elevation angle and terrain irregularity is needed for point-to-point mode calculations. Table 2-1 indicates values used in the Federal Communications Commission (FCC) implementation of the Longley-Rice model.

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<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative permittivity of ground (Farads per meter)</td>
<td>15.0</td>
</tr>
<tr>
<td>Ground conductivity (Siemens per meter)</td>
<td>0.005</td>
</tr>
<tr>
<td>Surface refractivity in N-units (parts per million)</td>
<td>301.0</td>
</tr>
<tr>
<td>Horizontal Polarization</td>
<td>0</td>
</tr>
<tr>
<td>Height of TV receiving antenna above ground (meters)</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 2-1 Parameter values used in FCC implementation of the Longley-Rice model

Since it’s original publication in 1968, there have been enhancements and corrections to the Longley-Rice model. An important modification deals with radio propagation in urban areas, which is of particular relevance to mobile radio and television. This modification termed the urban factor (UF) allows the addition of attenuation due to urban clutter close to the receiving antenna. This modification is of particular interest due to the request for proposal (RFP) from the Advanced Television Systems Committee (ATSC) Specialist Group on RF Transmission (T3S9). The goal of

---

the RFP is to identify potential specification enhancements that can be made to the existing Vestigal Sideband Broadcast (VSB) modulation that will facilitate mobile reception with a receiver moving at speeds up to 5 kilometers per hour.²⁰

2.3.2 Okumura Model

The urban factor that was added to the Longley-Rice model was obtained by comparing the predictions of the Longley-Rice model with measured data obtained by Okumura. Okumura’s model comprises of a set of curves giving the median attenuation relative to free space in an urban area. These curves were developed from extensive measurements using vertical omni-directional antennas. The model can be expressed as

\[ L_{50}(dB) = L_F + A_{mu}(f, d) - G(h_{te}) - G(h_{re}) - G_{AREA} \]

where \( L_{50} \) is the median value of propagation path loss, \( L_F \) is the free space propagation loss, \( A_{mu} \) is the median attenuation relative to free space, \( G(h_{te}) \) is the transmitter antenna height gain factor and \( G(h_{re}) \) is the mobile receive antenna height gain factor and \( G_{AREA} \) is the gain due to the type of environment.²¹ Refer to Figure 2-5 for \( A_{mu} \) values.

²⁰ ATSC Specialist Group on RF Transmission, Request for Proposal for Potential Revisions to ATSC
Further correction factors to allow for street orientation, suburban and rural area transmission and over irregular terrain, must be added or subtracted from the equation above as appropriate. The terrain-related parameters that form correction factors must be evaluated. Such factors include:

- Terrain undulation height ($\Delta h$) – defined as the height variation over a distance of 10 km from the receiver in a direction towards the transmitter.
- Isolated ridge height – defined as the relative height of a single obstructing mountain to the average ground level, between the receiver and the transmitter.
- Average slope – defined as the sloping angle $\theta$ (positive or negative), measured over 5 to 10 km.


- Mixed land-sea path parameter – defined as the percentage of the total path length covered with water.\footnote{22}

The Okumura model has a very slow response to rapid changes in terrain resulting in fairly accurate urban and suburban estimations, but poor in rural areas. It is also based entirely upon measured data and does not provide analytical explanation. Hata used this data to create an empirical formulation known as the Hata model.

### 2.3.3 Hata Model

The Hata model presents the urban area propagation loss as a standard formula and provides correction equations for other applications. The standard formula used for local median path loss in urban areas is:

\[
L_{50(\text{urban})}(\text{dB}) = 69.55 + 26.165 \log(f_c) - 13.82 \log(h_{te}) - a(h_{re})
+ \{44.9 - 6.55 \log(h_{te})\}\log(d)
\]

where \(f_c\) is the frequency expressed in MHz, \(h_{te}\) is the effective transmitter antenna height, \(h_{re}\) is the effective receiver antenna height, \(d\) is the T-R separation distance in meters, and \(a(h_{re})\) is the correction factor for effective receive antenna height.\footnote{23} The receive correction factor for medium sized cities is given by

\[
a(h_{re}) = \{1.1\log(f_c) - 0.7\}h_{re} - \{1.56\log(f_c) - 0.8\} \text{ [dB]}
\]

and for a large city by

\[
a(h_{re}) = \{8.29\log(1.54 \times h_{re})\}^2 - 1.1 \text{ [dB]} \quad \text{for } f_c \leq 300 \text{ MHz}
\]

\[
a(h_{re}) = \{3.2\log(11.75 \times h_{re})\}^2 - 4.97 \text{ [dB]} \quad \text{for } f_c \geq 300 \text{ MHz}
\]

For path loss in suburban areas, the standard Hata formula is given as

\begin{footnotesize}
\end{footnotesize}
\[ L_{50(\text{suburban})}(\text{dB}) = L_{50(\text{urban})} - 2[\log(f_c/28)]^2 - 5.4 \]

and for rural areas as

\[ L_{50(\text{rural})}(\text{dB}) = L_{50(\text{urban})} - 4.78[\log(f_c)]^2 + 18.33[\log(f_c)]^2 - 40.94 \]

It is therefore recommended that the Hata model be used for coverage prediction in urban areas as an enhancement to the Longley-Rice model.

2.4 Small-Scale Fading

Small-scale fading is used to describe the rapid fluctuations of the amplitude of a radio signal over a short time period or traveled distance. This fading is due to two or more versions of the transmitted signal arriving at the receiver antenna at slightly different times, resulting in interference. This phenomenon is known as multipath.

2.4.1 Factors Influencing Small-Scale Fading

Multipath waves at the receiver antenna create a resultant signal that varies in amplitude and phase. The three most important effects are:

- Rapid changes in signal strength over a small travel distance or time interval.
- Random frequency modulation due to varying Doppler shifts on different multipath signals.
- Time dispersion caused by multipath propagation delays.\(^{24}\)

Fading in urban areas is a result of the height of the receiver antenna often being well below the height of surrounding structures. Therefore, there is no single line-of-sight path to the transmitter. Even if a direct line-of-sight exists, reflections from the
ground and other nearby objects create multiple copies of the signal that arrive at the receiver antenna at different times causing multipath propagation delays. If the receiver is mobile, the speed of the receiver, speed of surrounding objects and the transmission bandwidth of the signal are all factors that influence Small-Scale fading.

Small-scale fading will be discussed briefly in this document. Clustered measurements take into account the effects of small-scale. Taking the average of the results for an area in effect gets a good approximation for the receive signal for that location.

2.4.2 Types of Small-Scale Fading

2.4.2.1 Flat Fading

If the channel has a constant gain and linear phase response over a bandwidth that is greater than the bandwidth of the transmitted signal, then the received signal will undergo flat fading. These channels are also known as amplitude varying channels and referred to as narrowband channels, since the bandwidth of the signal is narrow when compared to the flat fading bandwidth of the channel.  

2.4.2.2 Frequency Selective Fading

If the channel has a constant gain and linear phase response over a bandwidth that is smaller than the bandwidth of the transmitted signal, then the channel creates frequency selective fading on the received signal. This means that multiple versions of the signal are received but attenuated and delayed in time and causes a distorted received

signal. Viewed in the time domain they are time dispersions of the transmitted symbols within the channel, thus causing inter-symbol interference (ISI). In the frequency domain, this is represented by certain received frequency components having greater gains than others.26

### 2.4.2.3 Fast Fading

If the channel impulse response changes rapidly within the symbol duration, the channel is referred to as a fast fading channel. This means, the coherence time of the channel is smaller than the symbol period of the transmitted signal that causes frequency dispersion resulting in signal distortion. Fast fading only deals with rate of change of the channel due to motion and in practice only occur for very low data rates.27

### 2.4.2.4 Slow Fading

If the channel impulse response changes much slower than the transmitted baseband signal s(t), the channel is referred to as a slow fading channel. The channel can be assumed to be static over one or more reciprocal bandwidth intervals.28

It should be made clear that the velocity of the mobile or velocity of objects within the channel, and the baseband signaling determines whether a signal undergoes fast or slow fading. It should also be noted that fast and slow fading deal with the relationship between time rate of change in the channel and the transmitted signal, and not with earlier discussed propagation path loss models.

---

3 Overview of 8-VSB

3.1 Choosing the 8-VSB Modulation Standard

The choice of the 8-VSB standard arose from a series of developments supported by private industry. This standard was chosen from over four different digital proposals and two analog system proposals. These systems were tested by the Advanced Television Test Center located in Alexandria, Virginia. One of the analog systems was withdrawn and the other was proven to have inferior performance when compared with the digital proposals. Overall performance of the digital systems had similar levels of performance. It was then recommended by the Advisory Committee on Advanced Television Service (ACATS), a panel of industry expert established by the Federal Communications Commission, to form a Grand Alliance to exploit the advantages of the different technologies. This alliance consisted of members from David Sarnoff Research Center, AT&T Corporation, Massachusetts Institute of Technology (MIT), Philips Consumer Electronics, Zenith Electronics Corporation, General Instrument Corporation, and Thomson Consumer Electronics. It was determined that quadrature amplitude modulation (AM-QAM) and vestigial sideband broadcast (VSB) modulation methods showed good performance in the system tests. Under further evaluation of the two systems conducted during the Charlotte North Carolina test in 1993, VSB showed better performance over QAM and was selected as the modulation standard for terrestrial broadcast.

---

The typical VSB transmission system is depicted in Figure 3-1 and consists of a Data Randomizer, Reed-Solomon encoder, data interleaver, trellis encoder, VSB modulator and an RF upconverter.

![Figure 3-1 Typical Vestigal Sideband Broadcast transmission system.](image)

### 3.1.1 Purpose of a Data Randomizer

The Data Randomizer XORs all incoming data bytes with a 16-bit maximum length pseudo random sequence that is initialized at the beginning of each data field. By doing this, the data randomizer guarantees a flat, noise-like spectrum, which permits the DTV receiver’s recovery loop to work optimally. This noise-like spectrum minimizes interference with NTSC signals by appearing as white noise to the NTSC receivers. The generator polynomial used is shown in Figure 3-2.

---

29 Sgrignoli, Gary, ATSC VSB Transmission System Tutorial, Zenith Corporation, p 29
Generator Polynomial \( G_{(16)} = X^{16} + X^{15} + X^{12} + X^{11} + X^7 + X^6 + X^3 + X + 1 \)

The initialization (pre load) occurs during the field sync interval

Inititalization to F180 hex (Load to 1)

\( X^{18} \ X^{15} \ X^{14} \ X^{13} \ X^{10} \ X^{8} \)

The generator is shifted with the Byte Clock and one 8 bit Byte of data is extracted per cycle.

Figure 3-2 Vestigal Sideband Broadcast Randomizer Generator Polynomial

3.1.2 Purpose of Reed-Solomon Coding

Reed-Solomon (RS) codes achieve the largest possible code minimum distance for any linear code having the same encode input and output block lengths\(^\text{30}\). Reed-Solomon codes are particularly useful for burst-error correction (channels having memory) and where the input symbols are large\(^\text{31}\). Reed-Solomon coding increases the space between transmitted bytes allowing for data recovery even after loosing some bytes. Using the generator polynomial in Figure 3-3, the VSB system adds 20 RS parity bytes for error correction bringing the total transmitted data block to 207 bytes up from 187 bytes.

\(^{30}\) Sklar, Bernard, Digital Communications Fundamentals and Applications, Prentice Hall, 1988, p 304

3.1.3 Purpose for using a Data Interleaver

Interleaving the coded message before transmission and de-interleaving after reception causes bursts of channel errors to be spread out in time and thus to be handled by the decoder as if they were random errors. Since channel memory decreases with time separation, the idea behind interleaving is to separate the codeword symbols in time. The interleaving times are similarly filled by the symbols of other codewords. Separating the symbols in time (time diversity) effectively transforms a channel with memory to a memoryless one, and thereby enables the random-error-correcting codes to be useful in a burst-noise channel. A typical convolutional interleaver is shown in Figure 3-4 below.

Figure 3-3  Reed-Solomon (207, 187) $t=10$ parity Generator Polynomial.

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3.1.4 Purpose of the Trellis Encoder

Trellis-coded modulation achieves coding gain without any bandwidth expansion. However, this benefit results in decoder complexity. The objective of Trellis coding is to increase the minimum distance between the signals that are the most likely to be confused, without increasing the average power. It accomplishes this feat by exploiting the repetitive structure of trellis diagrams. The block diagram for the 8-VSB trellis encoder is shown in Figure 3-5.

---

3.1.5 Purpose of the RF Upconverter

After the signal has left the trellis encoder, it is upconverted and the lower sideband removed for transmittal. Figure 3-6 shows graphical the procedure. The signal is split and sent to an I-channel and Q-channel filter. The I and Q channel filters prevent inter-symbol interference (ISI) from occurring. Each output of the filter is mixed with a cosine and sine signal then summed. At the output, a VSB spectrum results with the lower sideband removed. The absence of the lower sideband is a result of the difference in phase between the I and Q channels.
The terrestrial 8-VSB modulation has a net data rate of 19.29 Mbps and a transmission clock of 19.39 Mbps within a 6 MHz channel. As mentioned in the previous section, the data carried by the 8-VSB signal is divided into Data Frames consisting of two Data Fields, which are further divided into 313 Data Segments. Each Data Segment contains 187 bytes of data, a sync byte, and 20 Reed-Solomon parity bytes, adding up to 208 bytes and consisting of 832 symbols. Four symbols are used for segment synchronization leaving 828 symbols for data transmission as shown in Figure 3-7 below.

![Figure 3-6 Block diagram of RF upconverter showing lower sideband removal](image)

![Figure 3-7 VSB data frame](image)
These symbols are transmitted using the 8-VSB-modulation scheme. As a result of the 8-level signal, there are three bits per symbol. Doing the math, 828 x 3, yields 2484 bits of data in each Data segment. The exact symbol rate \( S_r \) of the system is calculated using the NTSC horizontal sweep frequency \( f_H \) and a 684 constant resulting as follows.

\[
S_r = f_H \times 684 = \frac{4.5}{286} \times 684 = 10.76223776\ldots (MHz)
\]

The chosen modulation, 8-VSB, consists of a 4-level AM vestigial sideband input signal with trellis coding that produces an 8-level output signal. As shown in Figure 3-8 below, the basic spectrum occupies a 6 MHz channel and is flat over most of the channel with roll-off regions on both spectrum edges where a nominal square root raised cosine response results in 620 KHz transition regions (310 KHz on either side). There is a small suppressed-carrier located 310 KHz from the lower band edge of the spectrum. The channel bandwidth of 6 MHz was chosen to match the existing bandwidth of NTSC channel as well as abide with Nyquist requirements. A Nyquist bandwidth of one-half the symbol rate is required to recover the transmitted data. This results in a passband (excluding sidebands) of

\[
\frac{S_r}{2} = 5.3811888\ldots MHz
\]

Excess bandwidth amounting to 6.000 – 5.381 = 0.619 MHz is required for data transmission beyond the Nyquist minimum. These frequency requirements are graphical demonstrated in Figure 3-8.

---

There are several features added to the 8-VSB signal to aid receivers in acquiring and locking to the signal in extreme propagation conditions. One such feature is the inclusion of the small pilot carrier at the edge of the band. This pilot is placed on the Nyquist slope of NTSC receivers, in order to effectively minimize co-channel interference between DTV and NTSC signals. This pilot can be acquired by the receiver to a signal-to-noise ratio of zero (0) dB.

### 3.2 Robustness

The 8-VSB system is designed to assure that demodulators will remain locked to the incoming signal under varying condition and allow receivers to recover the data. One measurement of system robustness is the amount of white noise (AWGN) that can be handled without the occurrence of data errors. This means that a signal will be error free up to a system threshold. For 8-VSB, the white noise threshold is 14.9 dB SNR and burst noise of 193 microseconds, which yields a $3 \times 10^{-6}$ bit error rate. Unlike its analog counterpart, the picture resulting from an 8-VSB signal does not degrade gradually as the

---

SNR decreases, but rather remains perfect up to the threshold. The steepness of the error probability curves shown in Figure 4-7, demonstrates what is commonly called the “cliff effect”. It is at this cliff or threshold at which bit errors occur, resulting in severe picture degradation.
4 Measurement Theory

4.1 Signal-to-Noise Ratio

Signal-to-Noise Ratio (SNR), or modulation error ratio (MER), is described as the ratio of the signal power to “noise” power, where noise includes any unintended noise source that causes a deviation of the received signal from an ideal state position. These sources include, but are not limited to, non-linear distortion, device noise, phase noise or any uncorrelated signals. SNR for 8-VSB is calculated at the sampling instance of the signal.

The SNR for an 8-VSB signal is described as

$$\text{SNR} = 10\log\left(\frac{\sum_{i} R_i^2}{\sum_{i} E_i^2}\right)$$

where:

- $R_i$ are real values of the reference vector at symbol “i”
- $E_i$ are real values of the error vector at symbol “i” calculated as $\text{Error} = I_{\text{REFERENCE}} - I_{\text{MEASURED}}$

A SNR ratio of at least 27-dB at the output of the transmitter is recommended by the ATSC to have minimal effect on a broadcast stations DTV coverage area. This 27-dB value provides a worse case for receiver threshold degradation between 15.0 to 15.3 dB, which has the effect of reducing the coverage area by roughly 0.3 miles for UHF frequencies. This Figure is calculated by converting the 27-dB transmitter SNR and the 15-dB receive SNR to an equivalent linear relative power, adding them together and converting them back to 0.28 dB increased noise power.
4.2 Phase Noise

Phase noise is a random modulation of the phase of the transmitted signal. This random modulation manifests itself in the time domain as jitter or uniform noise and as an angle between the measured and ideal signal in the frequency domain. When phase noise occurs, the entire constellation rotates around the origin as shown Figure 4-1.

![Figure 4-1 8-VSB I/Q constellation with phase noise rotation](image)

Along with the rotation of the constellation, a frequency shift of the carrier is noticed. This is best measured by examining the pilot spectrum closely without data modulation. The Carrier phase noise is currently defined at a 20 kHz frequency offset of the main pilot. The ATSC standard suggests a level, in dBC/Hz, no greater than –104 dBC/Hz @ a 20 kHz offset from the carrier frequency, which is shown in Figure 4-2 below.

---

The constellation of a received VSB signal has eight horizontal lines, each representing one of the 8-VSB I-channel data levels. Unlike the I-channel, the Q-channel is not discrete in nature but rather continuous due to the fixed relationship between I and Q signals caused by the VSB modulation. This relationship is a Hilbert transform (Figure 4-3) and is determined by the total channel characteristics (raised cosine transition regions).

![Figure 4-2. Phase noise measurement by measuring pilot offset](image)

![Figure 4-3 Hilbert Transform showing I and Q system impulse response.](image)

### 4.3 Error Vector Magnitude

Error Vector Magnitude (EVM) is the measure of the phase and magnitude difference between the ideal (reference) signal and the measured signal. Encoding the bit
information onto a RF carrier by varying the carrier’s magnitude and phase transmits a digital signal. The carrier can occupy any of several locations on the I versus Q plane (similar to x versus y). The location within the I/Q plane denotes a specific data symbol that consists of one or more data bits. The location of the ideal (reference) signal is determined generically by the modulation chosen. Additional information such as knowledge of the transmitted data stream, the symbol clock timing and baseband filtering parameters aid in locating the ideal signals. The measured signals magnitude and phase can be determined by the difference between the ideal signal phasor and measured signal phasor and calculated as shown in Figure 4-4. It is this difference that forms the basis for EVM measurements.

![Figure 4-4 Determining EVM from measured and reference signals](image)

4.3.1 Measuring EVM

A DSP based demodulator recovers the transmitted bitstream that has been converted from analog-to-digital. The recovered data bits are used to create a reference version of the input signal. This is accomplished by re-modulating the input signal with the use of the data symbol clock and the carrier of the input signal; creating a noise-free and highly accurate reference. This is demonstrated graphically in Figure 4-5.
Figure 4-5  Block diagram showing the calculation of EVM

Subtracting the actual incoming signal from the calculated ideal signal will yield the error vector. It should be noted that both waveforms are complex and consist of both I and Q channels. The Agilent (formerly Hewlett-Packard) 89441 Vector Signal analyzer is one instrument commonly used for this measurement and conveniently gives the result in a measurement table. It should be noted that the Tektronix RFA-300 could also be used for this measurement. There is a difference in the EVM values reported between these measurement devices. The Agilent 89441 calculates the EVM with both I- and Q-channel information, while the Tektronix only uses the I-channel. As a result, the EVM of the Agilent 89441 is \( \sqrt{2} \) (3 dB) greater than that of the Tektronix for an identical input signal.

EVM is calculated as follows:

\[
EVM[n] = \sqrt{I_{\text{error}}[n]^2 + Q_{\text{error}}[n]^2}
\]

where \([n]\) is the symbol index, \(I_{\text{error}}[n]\) is the I error at symbol \(n\), and \(Q_{\text{error}}[n]\) is the Q error at symbol \(n\).
By assuming equal probability of occurrence, EVM can be converted to SNR by first finding the RMS value of the normalized symbols for the I and Q channel using

\[
\sqrt{\frac{(-1)^2 + (-\frac{5}{7})^2 + (-\frac{3}{7})^2 + (-\frac{1}{7})^2 + (\frac{1}{7})^2 + (\frac{3}{7})^2 + (\frac{5}{7})^2 + (1)^2}{4}} = 0.92582
\]

resulting in

\[
EVM \; (%) = 92.582 \times 10^{-\frac{SNR}{20}}
\]

For receive signal-to-noise ratio (SNR) of 15 dB, using the above equation, the equivalent EVM_{\text{MAX}}(\%) is 16.46. Therefore, a receive site having an EVM of less than 16.46% will meet the required Federal Communication Commission receive threshold of 15 dB.

### 4.4 Impulse Noise

Impulse noise is RF interference generated by industrial equipment and home appliances. Some such devices include microwave ovens, fluorescent lights, hair-dryers, vacuum cleaners, high voltage power transmission lines, and transformers to name a few. Impulse noise usually affects VHF and low UHF television bands. It shows up as spurious waveforms on top of the desired signal. Due to its channel coding and interleaver implementation, digital television (DTV) signals are much more robust to impulse noise interference than traditional analog signals. Despite this design advantage, DTV can still succumb to the interference through carrier and synchronization loss limiting the system performance. A robust design in these circuits can help combat this
problem. I have conducted test to compare this robustness and have seen an analog signal un-watchable, while a DTV signal was unimpaired.

One way to measure impulse noise is to turn off the DTV transmitter and measure the band power of the 6 MHz television band. By subtracting the noise floor of the system from the measured band power, the impulse noise power can be determined. For purposes of this test, this method is adequate. Experiments are presently being conducted to attain better approximations of impulse noise using Cauchy models.

4.5 8-Vestigal Sideband Broadcast (8-VSB) Eye Diagram

Separate eye diagrams show I and Q components changing over time by superimposing trajectory segments. The eye diagram customarily used in 8-VSB analyses only examines the I component. These segments are continuously retraced plotted amplitude versus time. The 8-VSB signal must attain one of eight possible levels at the sampling instance. As a result, multiple traces converge to give seven distinct “eyes” corresponding with the clock pulses of the receiver as shown in Figure 4-6. In the event of signal corruption due to impulse noise, signal fading or other propagation artifacts, the “eyes” will begin to close up and eventually disappear. At this point the receiver will not be able to distinguish the incoming symbols resulting in symbol and bit errors and eventual picture degradation (break-up). This phenomenon is paralleled in the constellation diagram discussed earlier as the symbols move further toward the center of the vertical symbol decision lines.
4.5.1 Bit Error and Segment Error Rates

The closing of the “eyes” in the eye-diagram mentioned above, results in ambiguity of the incoming signal to the receiver. This ambiguity is measured by bit errors and segment errors. Bit error is a measurement of the quality of the received signal at the bit level while its counterpart, segment error, is a measurement of the quality of the received signal at the segment level. Segments are a composition of bits; therefore, segment errors are derived from bit errors. The 8-VSB signal comprises of 832 segments per Data Field. Current professional receivers will calculate and report either SER or BER data. The acceptable bit error rate (BER) for ATSC is $3 \times 10^{-6}$ and is graphed in the Figure 4-7 below.

![Eye Diagram](image)

**Figure 4-6** Depiction of the distinct eyes of an 8-VSB signal

![Probability Graph](image)

**Figure 4-7** Probability of Error (SER) versus C/N Ratio for 8-VSB and 16-VSB
4.6 DTV Planning Factors

Planning factors are used to determine the minimum field strength for DTV reception. They are characterized as a function of the frequency and channel number in the VHF and UHF band. These values are assumed to characterize the equipment used for home reception. The values of the predicted field strength given in table 4-1 are calculated from these factors to achieve the equivalence to a grade B NTSC coverage area. The adjustment

\[ K_a = 20 \log \left( \frac{615}{\text{channel } \sim \text{ mid-frequency}} \right) \]

is added to the dipole factor (K_d) to account for field strength requirements for UHF channels above and below the geometric mean of 615 MHz.

<table>
<thead>
<tr>
<th>Planning Factor</th>
<th>Symbol</th>
<th>Low VHF</th>
<th>High VHF</th>
<th>UHF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric Mean Frequency</td>
<td>F</td>
<td>69</td>
<td>194</td>
<td>615</td>
</tr>
<tr>
<td>Dipole Factor (dBm-dBu)</td>
<td>K_d</td>
<td>-111.8</td>
<td>-120.8</td>
<td>-130.8</td>
</tr>
<tr>
<td>Dipole Factor Adjustment</td>
<td>K_a</td>
<td>None</td>
<td>None</td>
<td>K_a=...</td>
</tr>
<tr>
<td>Thermal noise (dBm)</td>
<td>N_t</td>
<td>-106.2</td>
<td>-106.2</td>
<td>-106.2</td>
</tr>
<tr>
<td>Antenna Gain (dB)</td>
<td>G</td>
<td>4</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Downlead Line Loss (dB)</td>
<td>L</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>System Noise Figure (dB)</td>
<td>N_s</td>
<td>10</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Required Carrier/Noise Ratio (dB)</td>
<td>C/N</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 4-1 Planning Factors for DTV Reception

The modified Grade B contour for analog stations is determined by using the values above. These values give the Grade B field strength of the DTV signal and are subject to Longley-Rice calculations for analog stations, and calculated by

\[ \text{Field Strength} = L + N_t + N_s + C/N - K_d - K_a - G \]

Which is tabulated below in table 4-2.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Defining Field Strength, dBu, to be predicted using F(50, 90) curves</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 – 6</td>
<td>28</td>
</tr>
<tr>
<td>7 – 13</td>
<td>36</td>
</tr>
<tr>
<td>14 – 69</td>
<td>41 – 20 log [615/(channel mid-frequency)]</td>
</tr>
</tbody>
</table>

Table 4-2  Field Strength defining the area subject to calculation for DTV stations.

---

5 Implementation

5.1 Overall System

The DTV-M1 has several components that work together to accomplish the tedious task of 8-VSB coverage verification. The main measurement is done using a Hewlett-Packard 89441V vector analyzer. However, this unit does not stand on its own. A spectrum analyzer, Ground Position System (GPS) receiver, a compass and weather station are a few of the devices that aid in acquiring the necessary data required.

![Preparing DTV-M1 test vehicle for measurement](image)

At the heart of all this equipment is the Harris Navigator Measurement Control System. This custom designed, software based control system automates and simplifies the test and measurement process by providing prompts throughout the entire measurement process. It captures signal information data from each test performed, including the location and actual waveforms from the vector and spectrum analyzers. The captured data is automatically logged into a Microsoft® Access™ database for each station being measured. The data can be compiled to provide a complete profile of the station’s coverage area.
Theoretical path loss predictions methods, such as Longley-Rice, are used to predict the coverage areas of the DTV signal. These predictions should take into consideration the terrain, transmitter power and transmission pattern of the transmit antennas. The DTV-M1 is used to verify these theoretical assumptions, proving that the television’s station continues to have the same or better coverage than its current National Television Standards Committee (NTSC) analog signal.

The DTV-M1 is designed around the measurement vehicle used for analog test measurements specified by the Federal Communication Commission. These specifications were enhanced and changed to meet the needs for a highly accurate Digital Television (DTV) field test measurement vehicle.

5.1.1 Choosing the Equipment

In system design, it is necessary to calculate the Radio Frequency (RF) energy that will finally be at the end of the cable entering the receiver. It was with this objective that the following system design and implementation was undertaken. Certain criterions were used to choose the devices and components used in the field test measurement vehicle. Overall criterions applicable to all components were weight, cost and physical size.

5.1.1.1 Receive Antennas

An appropriate receiving antenna that would provide a “flat” and consistent gain response across a group of frequencies within the 54 to 806 MHz band was needed. This is of great importance since it is not physically feasible to have an antenna for each of the
68 RF channels. The manufacture of this antenna would have to be able to provide actual frequency sweep test results of the antennas, depicting the gain response across the receive frequencies. Additionally, these antennas had to provide a gain significantly greater than the losses of the system before the amplification stage. However, mere frequency gain response was not enough. The antennas being provided had to able to be installed in a non-permanent fashion. Therefore, the antennas had to have easy mount and un-mount capabilities and be relatively lightweight. This requirement is necessary to enable fast connection and disconnection of the appropriate antenna during setup and tear down. Additional, a heavy antenna would create potential safety hazards to the person placing the antenna on the mast as well as the ability of the mast to support such weight. Upon these criteria, SCALA Antennas® was found to provide the best antennas. The specification sheets for the selected antennas are included in the Appendix.

![Scala channel 14-69 UHF receive antenna](image)

**5.1.1.2 Cable**

With a relatively low incoming signal level, a 50 Ω cable with a low signal loss over long lengths would be needed. The cable would have to have a relatively flat frequency response across the entire TV frequency spectrum (54 MHz – 806 MHz). This cable also needed to be lightweight since it had to go up the antenna mast. Belden
Cable® was the likely candidate for such and application, resulting in Belden 8267 being chosen to meet this requirement and shown in Figure 5-3. This cable has nominal attenuation in the desired frequency range below 8 dB per 100 feet. Other characteristics are detailed in table 5-1.

![Belden 8267, 50Ω RF cable](image)

**Figure 5-3**  Belden 8267, 50Ω RF cable

<table>
<thead>
<tr>
<th>Freq MHz</th>
<th>Nom. Attenuation (dB/100ft)</th>
<th>Nom. Attenuation (dB/100m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.18</td>
<td>0.59</td>
</tr>
<tr>
<td>10.0</td>
<td>0.62</td>
<td>2.03</td>
</tr>
<tr>
<td>50.0</td>
<td>1.5</td>
<td>4.92</td>
</tr>
<tr>
<td>100.0</td>
<td>2.1</td>
<td>6.9</td>
</tr>
<tr>
<td>200.0</td>
<td>3.0</td>
<td>9.8</td>
</tr>
<tr>
<td>400.0</td>
<td>4.8</td>
<td>15.7</td>
</tr>
<tr>
<td>700.0</td>
<td>6.5</td>
<td>21.3</td>
</tr>
<tr>
<td>900.0</td>
<td>7.6</td>
<td>24.9</td>
</tr>
<tr>
<td>1000.0</td>
<td>8.2</td>
<td>26.9</td>
</tr>
<tr>
<td>4000.0</td>
<td>21.5</td>
<td>70.5</td>
</tr>
</tbody>
</table>

Table 5-1  Belden 8267 Attenuation chart

---

5.1.1.3 Connectors

Due to the size of the Belden 8267 cable and the antenna connections available, N-type connectors had to be used. In addition, N-type connectors have relatively low insertion loss. The insertion loss typically ranges between 0.05 to 0.08 dB.

Figure 5-4  N-type connector used for RF connectivity

5.1.1.4 DTV Exciter

The un-board DTV exciter is needed in the event that the transmitter tower is inaccessible due to weather or terrain conditions. The exciter would need to have a SMPTE 310M (terrestrial broadcast transmission interface standard) input and a 50 Ω RF output. The RF output had to be accurate, stable and consistent. Having a width of 19-inches, allowing the unit to be rack mounted, light weight, and needing less than 200 watts of power would be advantageous. Harris Corporations DTV exciter pictured in Figure 5-5 had all the characteristics necessary to be included in the project, some of which are detailed in the table below. The specification sheet can be viewed at [http://www.harris.com/](http://www.harris.com/).

Figure 5-5  Harris CD 1A UHF and VHF DTV Exciter
Harris CD 1A DTV Exciter Specification

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF Load Impedance</td>
<td>50 ohms</td>
</tr>
<tr>
<td>Frequency Range</td>
<td>All VHF and UHF Channels (2 – 69)</td>
</tr>
<tr>
<td>Transport Stream Input</td>
<td>SMPTE-310M, 19.392658 Mb/s serial</td>
</tr>
<tr>
<td>Maximum Power Output</td>
<td>1 Watt peak, 250 mW average</td>
</tr>
<tr>
<td>Carrier Frequency Stability</td>
<td>± 200 Hz per month</td>
</tr>
<tr>
<td>Signal to Noise Ratio</td>
<td>≥ 27 dB</td>
</tr>
<tr>
<td>Physical Dimensions</td>
<td>19” wide, 25” deep, 7” high</td>
</tr>
<tr>
<td>Weight</td>
<td>36 pounds</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>150 watts typical</td>
</tr>
</tbody>
</table>

Table 5-2 Excerpt specifications for the Harris CD 1A UHF and VHF DTV exciter.

5.1.1.5 RF Switch

The design procedures necessitate the use of an RF switch located at the top of the mast to switch between the cable from the antenna and the *up lead* cable from the onboard DTV exciter or from the transmitter tap point used in “morning calibration” procedures. This RF switch needed to have low insertion loss and the ability to be controlled via a contact closure. Pictured in Figure 5-6, the Hewlett-Packard/Agilent® provides such a device that met these criteria and is described in the excerpts from the datasheet below.

“The Agilent 8761A is a single-pole, double-throw coaxial switch with excellent electrical and mechanical characteristics for 50 ohm transmission systems operating from DC to 18 GHz. It features broadband operation, long life, low SWR, excellent repeatability, and magnetic latching solenoids. The Agilent 8761A switch is small and lightweight, making it ideal for applications where space is limited. Because of its

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42 Harris CD 1A DTV Exciter specification sheet, Harris Corporation.
versatility and excellent electrical performance, it is well suited for automated testing and systems applications."43

RF Splitters

With a single RF input entering the system, distribution of RF signals to the receivers and measurement devices was of great necessity. The use of RF splitters having high quality 50-ohm input N-type connections, maximum 6-dB loss, along with low insertion loss specifications were desired. The RF splitters should also not change the incoming RF spectrum characteristic of the incoming signal. The pictured ZFRSC-2050 splitters from Mini-Circuits® met these requirements, shown in table 5-3 below, and were readily available for reasonable cost.

Figure 5-6  Agilent 8761A 50-ohm coaxial switch.

Figure 5-7  Mini-Circuits ZFRSC-2050 2-way RF splitter.

43 http://www.tm.agilent.com/classes/MasterServlet?view=productdatasheet&pro-
### 5.1.1.6 RF Combiner

The addition of Additive White Gaussian Noise (AWGN) is necessary to simulate noisy environments that will occur in the “real world”. It is for this reason that a RF combiner was needed to add AWGN to the received RF signal. The combiner had to have low coupling loss across all concerned frequencies and not alter the RF spectrum. The ZFDC-10 from Mini-Circuits® was the most feasible due to size, cost and technical specification. This combiner is pictured in the Figure below and its specifications tabulated below in Table 5-4 and 5-5.

![Figure 5-8 Mini-Circuits ZFDC-10-5 RF coupler](image-url)

#### Table 5-3  Mini-Circuits® ZFRSC-2050 2 Way-0° splitter RF characteristics

<table>
<thead>
<tr>
<th>Frequency MHz</th>
<th>Isolation, dB</th>
<th>Insertion Loss, dB Above 6.0dB</th>
<th>Phase Unbalance Degrees</th>
<th>Amplitude Unbalance, dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC-2000</td>
<td>6.20</td>
<td>6.60</td>
<td>7.00</td>
<td>0.10</td>
</tr>
<tr>
<td>L=low range (fL to 10fL) M=mid range (10fL to fU/2) U=upper range (fU/2 to fU)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.00 0.10 0.20 0.50 1.40 1.00 2.00 5.00 0.10 0.20 0.50
5.1.1.7 RF Amplifier

Essential components of the RF measurement vehicle are amplifiers. These devices had to provide maximum gain while not adversely increasing the noise floor of the overall system. A flat gain response across the interested RF spectrum and small packaging was also essential. The amplifier also needed to be capable of passing the incoming frequencies along with frequencies generated by the noise generator. This is essential for the avoidance of Inter-Symbol Interference. Mini-Circuits met the stringent amplifier specification with their ZFL series amplifiers, which are pictured in Figure 5-9 and described in table 5-6.
Figure 5-9  Mini-Circuits ZFL series 50-ohm amplifiers

<table>
<thead>
<tr>
<th>Frequency MHz</th>
<th>GAIN, dB</th>
<th>Maximum Power, dBm</th>
<th>Dynamic Range</th>
<th>VSWR</th>
<th>DC Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-1000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f_L - f_U</td>
<td>Min.</td>
<td>Max. Flatness</td>
<td>Output (1 dB Comp.)</td>
<td>Input (no damage)</td>
<td>NF dB Typ.</td>
</tr>
<tr>
<td>10-1000</td>
<td>20</td>
<td>±1.00</td>
<td>+25</td>
<td>+15</td>
<td>4.50</td>
</tr>
</tbody>
</table>

Lw=low range (f_L to f_U/2)  U=upper range (f_U/2 to f_U)

Table 5-6  Mini-Circuits® ZFL-1000V amplifier characteristics

<table>
<thead>
<tr>
<th>Frequency MHz</th>
<th>GAIN, dB</th>
<th>Maximum Power, dBm</th>
<th>Dynamic Range</th>
<th>VSWR</th>
<th>DC Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-1000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f_L - f_U</td>
<td>Min.</td>
<td>Max. Flatness</td>
<td>Output (1 dB Comp.)</td>
<td>Input (no damage)</td>
<td>NF dB Typ.</td>
</tr>
<tr>
<td>10-1000</td>
<td>28</td>
<td>±1.00</td>
<td>+20</td>
<td>+5.00</td>
<td>5.00</td>
</tr>
</tbody>
</table>

Lw=low range (f_L to f_U/2)  U=upper range (f_U/2 to f_U)

Table 5-7  Mini-Circuits® ZFL-1000VH amplifier characteristics

5.1.1.8  Noise Generator

The measurement procedure requires the determination of the noise threshold before picture and audio breakup. To determine this threshold, the addition of additive white noise (AWGN) was necessary. To provide a true white noise source was impractical for this application. However, since interest is only in a predetermined bandwidth, a band-limited white noise generator was adequate. The pertinent RF band is between 54 MHz to 806 MHz and the NC-6109 pictured in Figure 5.10 by Noise-Com® had an output bandwidth from 100 Hz to 1 GHz with an output power of +10 dBm,
making it perfectly suited for the task. More specification information of this product can be obtained from [http://www.noisecom.com/](http://www.noisecom.com/).

![NoiseCom NC-6109 all white gaussian noise generator (AWGN)](image)

**Figure 5-10** NoiseCom NC-6109 all white gaussian noise generator (AWGN)

### 5.1.1.9 Spectrum Analyzer

The spectrum analyzer was used to monitor fast changing frequency variations caused by multi-path and other interference. The interferences cannot be observed on the “averaging” Vector Signal Analyzer (VSA). Its use would include the azimuth peaking of the RF signal and provide spectrum information when moving measurements were being performed. This moving measurement consists of keeping track of the maximum and minimum points of the signal while the vehicle is driven for 100 feet. The analyzer would have to be able to “record” the change of the RF spectrum and output the maximum and minimum points at the conclusion of the tests. This also necessitates the analyzer to have a method of exporting the data to a computer. In addition to exporting the data, the analyzer would also need to be computer controllable through the same port. The RF input needed to be capable of receiving and displaying signals as low as –75 dB. This is due to the possibility of received signal levels being that low. The Hewlett-Packard/Agilent® 8591E pictured in Figure 5-11 met these requirements and was therefore chosen for the task. A brief overview of the spectrum analyzers specification is tabulated in table 5-8 below.
Figure 5-11 Agilent 8591E Spectrum Analyzer

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Range</td>
<td>9 kHz to 1.8 GHz</td>
</tr>
<tr>
<td>RBW Range</td>
<td>1 kHz to 3 MHz</td>
</tr>
<tr>
<td>DANL (1 GHz)</td>
<td>-130 dBm; -78 dBmV (with Opt. 001)</td>
</tr>
<tr>
<td>Second Harmonic Distortion (1 GHz)</td>
<td>&lt; -70 dBc</td>
</tr>
<tr>
<td>Third Order Intermodulation (1 GHz)</td>
<td>&lt; -70 dBc</td>
</tr>
<tr>
<td>Phase Noise (10 kHz offset)</td>
<td>≤ -90 dBc/Hz</td>
</tr>
<tr>
<td>Residual FM (30 Hz RBW, 30 Hz VBW)</td>
<td>≤ 30 Hz peak-peak in 300ms</td>
</tr>
<tr>
<td>Absolute Frequency Response</td>
<td>± 1.5 dB</td>
</tr>
<tr>
<td>Gain compression</td>
<td>≤ 0.5 dB</td>
</tr>
<tr>
<td>Sweep Time</td>
<td>20ms to 100s</td>
</tr>
</tbody>
</table>

Table 5-8 Key specifications for the Agilent 8591E Spectrum Analyzer

5.1.1.10 8-VSB Vector Signal Analyzer (VSA)

The main measurement capability lies within this box. The 8-VSB analyzer had to have a RF front-end capable of receiving off-air signals (-85 dBm and above) well above its internal noise floor. The unit needed to have a control port enabling it to export data to an external computer. The same control port would be used as a means to automate measurement procedures. The needed data included band power levels, RF

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data points, and spectrum screen shots of the measurement screen. Physical considerations could not be ignored. Power consumption, weight and physical space needed were of great concern. It turned out that these simple requirements were not as trivial as they seemed.

Most measurement devices available were designed for installation at transmitter sites, where a direct RF tap from the transmission line could be connected to the input of the device. These high RF levels were not available in the field. Some units were smaller than others, but did not provide the necessary functionality or RF input response necessary. A technical compromise would have to be made to fulfill the primary objective of the system, that being RF measurement. The Hewlett-Packard/Agilent® 89441V was chosen not for it’s size or weight, but rather its RF spectral abilities. It also had some other features that could be used in future enhancements to the product. Some of its abilities are listed and tabulated below, with further details available at http://www.agilent.com/

- Constellation, eye, and error magnitude analysis for QAM, VSB, and DVB modulation formats
- Adaptive equalization
- Peak-to-average power measurements
- Dynamic power measurements, including: peak, average, band-integrated, and adjacent channel
- Waveform capture and analysis
- Carrier phase noise measurements to -116 dBc/Hz
- Scalar, vector analysis modes and video demodulation
5.1.1.11 Ground Position Satellite (GPS) Receiver

The GPS receiver needed to be small, accurate and provide compatible with street mapping software over its RS-232 data port. The Garmin GPS36 TracPak was able to provide this functionality in a package no larger than a computer mouse. The Garmin GPS36 was housed in a water-resistant case equipped with internal memory backup. The unit provides information such as GPS coordinates, satellite orbital parameters, last known position, date, and time.
5.1.1.12 Electronic Compass

An electronic compass was needed to provide the heading of the vehicle. This data was used in the algorithms to determine the direction of the vehicle and thus direct the receive antennas towards the transmitter site. An RS-232 interface was necessary to allow the data to be retrieved and processed. Magnetic immunity built into the unit was also of interest. A seemingly easy shoe to fit was difficult to find. Although expensive, the KVH-1000 electronic compass was found that had the correct feature set. The unit was small and had built in compensations for magnetic variances. The unit was also used in military applications.

5.1.1.13 Antenna Mast

According to the test vehicle specifications provided by the ATSC, the height from the ground to the top of the antenna should be 30 ft (approximately 9.1 meters). Standard masts used on electronic newsgathering (ENG) vehicles do not meet this requirement. It was therefore necessary to request a custom mast built for this application. Will-Burt® was able to provide the desired mast that was still raised and

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45 Agilent 89441V Vector Signal Analyzer specification sheet, Appendix
lowered compressed air. A segment of the mast with mounted antenna is shown in Figure 5-14 and the general specifications tabulated in table 5-10.

![Wil-Burt custom masts with mounted antenna](image)

Figure 5-14  Wil-Burt custom masts with mounted antenna

<table>
<thead>
<tr>
<th>Wil-Burt Heavy Duty Non-Locking Mast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload capacity</td>
</tr>
<tr>
<td>Extended height</td>
</tr>
<tr>
<td>Mast weight</td>
</tr>
<tr>
<td>Number of sections</td>
</tr>
<tr>
<td>Tube diameter range</td>
</tr>
<tr>
<td>Average wall thickness</td>
</tr>
<tr>
<td>Mast displacement</td>
</tr>
<tr>
<td>Collar type</td>
</tr>
<tr>
<td>Maximum operating pressure</td>
</tr>
<tr>
<td>Wind speed</td>
</tr>
<tr>
<td>Magnetic extension warning light included</td>
</tr>
</tbody>
</table>

Table 5-10  Specifications for Wil-Burt custom heavy-duty non-locking mast.
5.1.1.14 Mast Camera

A color mast camera was placed on the top of the antenna mount to allow the test operator to look in the direction that the antennas were pointed. This allows the user to document any visible obstructions between the antenna and the transmitter tower.

5.1.1.15 Antenna Mount with Controller

An antenna mount capable of motion in the horizontal and vertical planes was necessary to facilitate the peaking of the incoming RF signal. Since this unit was going to be used on an automated measurement vehicle, it would also have to have a data port and the ability to being controlled to degree accuracy. Weight would also be an important choice criterion, in that the antenna mount would have to be placed at the top of the mast with the mounted antennas, where a weight limit of the air operated mast exists. After extensive research, an antenna mounting system commonly used for Amateur Radio (HAM) was chosen to meet the requirement. The YAESU® G-5500 shown in Figure 5-15 could be used without major modifications. The specifications are detailed in table 5-11 below.

![YAESU® G-5500 mount with controller](image)
<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Supply Voltage:</td>
<td>117 VAC, 50-60 Hz</td>
</tr>
<tr>
<td>Power Requirements</td>
<td>120 VA</td>
</tr>
<tr>
<td>Rotor Voltage:</td>
<td>24 VAC</td>
</tr>
<tr>
<td>Rotation Time (Non Loaded):</td>
<td>Elevation: 80 sec at 50 Hz, 67 sec at 60 Hz</td>
</tr>
<tr>
<td></td>
<td>Azimuth: 70 sec at 50 Hz, 58 sec at 60 Hz</td>
</tr>
<tr>
<td>Rotation Range:</td>
<td>Elevation: 180°</td>
</tr>
<tr>
<td></td>
<td>Azimuth: 450°</td>
</tr>
<tr>
<td>Rotation Torque:</td>
<td>Elevation: 1,400 kgf-cm</td>
</tr>
<tr>
<td></td>
<td>Azimuth: 600 kgf-cm</td>
</tr>
<tr>
<td>Braking Torque:</td>
<td>Elevation: 4,000 kgf-cm</td>
</tr>
<tr>
<td></td>
<td>Azimuth: 4,000 kgf-cm</td>
</tr>
<tr>
<td>Maximum Vertical Load:</td>
<td>Elevation: 30 kg or less</td>
</tr>
<tr>
<td></td>
<td>Azimuth: 200 kg or less</td>
</tr>
<tr>
<td>Mast Outside Diameter:</td>
<td>Ø 38 to Ø 63</td>
</tr>
<tr>
<td>Boom Outside Diameter:</td>
<td>Ø 32 to Ø 43</td>
</tr>
<tr>
<td>Braking Type:</td>
<td>Mechanical and Electrical stoppers</td>
</tr>
<tr>
<td>Wind Loading Area:</td>
<td>1.0 m2 or less</td>
</tr>
<tr>
<td>Maximum Continuous Duty:</td>
<td>5 minutes</td>
</tr>
<tr>
<td>Operating Temperature Range:</td>
<td>0°C to +40°C (Controller)</td>
</tr>
<tr>
<td></td>
<td>-20°C to +40°C (Rotator)</td>
</tr>
<tr>
<td>Rotator Dimension:</td>
<td>Elevation: 254 _ 190 _ 129 mm</td>
</tr>
<tr>
<td></td>
<td>Azimuth: Ø186 _ 150 mm</td>
</tr>
<tr>
<td>Rotator Weight:</td>
<td>Approx. 9 kg</td>
</tr>
<tr>
<td>Controller Dimension (WHD):</td>
<td>200 _ 130 _ 193 mm</td>
</tr>
<tr>
<td>Controller Weight:</td>
<td>Approx. 3 kg</td>
</tr>
</tbody>
</table>

Table 5-11 Specifications for the YAESU® G-5500 antenna mount
5.1.1.16 ATSC Receiver

A professional ATSC receiver capable of being remotely controlled by a computer and providing equalizer tap coefficients, bit error rate (BER) and receiver signal-to-noise ratio (SNR) was necessary. The Harris® ARX-H200 professional receiver was appropriate. The receiver was small in size, low in power consumption and was capable of providing the necessary data through an RS-232 port. The receiver also provided a High Definition (HD) video output that would be used to determine visual impairments and a balanced AC-3 digital audio output to facilitate listening for audio impairments. Other specifications of the pictured receiver (Figure 5-16) are detailed on the product specifications located at the Harris website (http://www.harris.com).

![Harris ARX-H200 ATSC professional receiver](image)

Figure 5-16 Harris ARX-H200 ATSC professional receiver

5.1.1.17 NTSC Receiver

A professional NTSC receiver, capable of being remotely controlled by a computer and providing channel information was required. The Videotek® DM-192 NTSC receiver was appropriate for the task. The unit provided remote functionality and channel control. Some of the Videotek DM-192 features are listed below.

- 192 channels (including cable channels)
- Envelop or synchronous detection
- Full time Stereo, SAP, PRO, 4.5 MHz and composite audio outputs
- User selectable RS-232/RS-422 port
5.1.1.18 Video Monitoring

To determine when signal degradation had occurred for both NTSC and ATSC tests, appropriate video monitoring equipment that provided reference type picture quality and met the physical requirements were needed. For NTSC verification, the Ikegami TM-9 monitor pictured in Figure 5-18 was used, while for ATSC verification the Ikegami HTM-2003 monitor pictured in Figure 5-19. The data sheets for both monitors are included in the Appendix and tables 5-12 and 5-13 list some of their specifications.

<table>
<thead>
<tr>
<th><strong>Ikegami TM-9 Specifications</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
</tr>
<tr>
<td><strong>Color System</strong></td>
</tr>
<tr>
<td><strong>CRT</strong></td>
</tr>
<tr>
<td><strong>Scanning Frequency</strong></td>
</tr>
</tbody>
</table>
**Rated Power**
120V AC, 60Hz under UL
12V DC (18V to 10.8V acceptable battery range)

**Horizontal Resolution**
More than 300TV Lines

**Power Consumption**
0.57A

**Color Temperature**
6500'K

**Input Terminals**
1) Input A:
Composite Video
Auto-termination, BNCx2, bridged output possible
1.0V(p-p), 75ohms, negative sync.

2) Input B:
Composite Video
Y/C
Auto-termination, BNCx2, bridged output possible
Y: 1.0V(p-p), 75ohms, negative sync
C: 0.286V(p-p), 75ohms(NTSC), 0.3V(p-p), 75ohms(PAL)

(Y/C Input Priority)
Auto-termination, S-4pin x2, bridged output possible

3) External Sync:
Composite sync, 1.0 - 4.0V(p-p)
BNC x2, bridged output possible

**Audio Terminals**
RCA pinx4 for input A & B, bridged output possible

**Audio Speaker**
3.5inch (8cm) round, 1W output

**Tally/Remote**
DIN 8-pin

**External Dimensions**
8-3/4" x 9-5/16" x 12-1/2"
(222mm x 236mmm x 317mm)

---

Table 5-12  Ikegami TM-9 NTSC reference monitor.

Figure 5-19  Ikegami HTM-2003 high definition reference monitor.

---

**Ikegami HTM-2003 Specifications**

<table>
<thead>
<tr>
<th>Input</th>
<th>Signal</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scanning Lines</td>
<td>1125</td>
<td>525/1050</td>
</tr>
<tr>
<td>Frames per Second</td>
<td>30</td>
<td>60/30</td>
</tr>
<tr>
<td>Interlace Ratio</td>
<td>2:1</td>
<td>Non-interlace/2:1</td>
</tr>
</tbody>
</table>

---

68
5.1.1.19 Audio Monitoring

Similar to video monitoring, audio degradation observations were also needed for the measurements. Size was the biggest criteria for the analog audio amplifier that was used with the NTSC receiver. A 1.75” high Wohler AMP-1A amplifier with specifications shown in table 5-14 (pictured in Figure 5-20) fit the job perfectly. The ATSC amplifier requirements were not as straightforward as the NTSC counterpart. The ATSC audio amplifier had to be able to decode an AC-3 digital audio stream and physically fit in tight quarters. Wohler had a unit that was just 3.5” in height and met the ATSC audio decoding requirements. The Wohler ATSC-3 is pictured in Figure 5-21 and the specifications tabulated in table 5-15.
### Wohler AMP-1A Analog Audio Monitor

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input Impedance</strong></td>
<td>100 k ohms balanced; 10 k ohms unbalanced</td>
</tr>
<tr>
<td><strong>Minimum Input level for maximum output (max volume)</strong></td>
<td>0 dBv bal. / -12dB unbalanced</td>
</tr>
<tr>
<td><strong>Input overload</strong></td>
<td>+26 dBv balanced +14 dBv unbalanced</td>
</tr>
<tr>
<td><strong>Peak acoustic output (@ 2 ft.)</strong></td>
<td>98 dB SPL</td>
</tr>
<tr>
<td><strong>Response, sixth octave (@ 2 ft.)</strong></td>
<td>80 Hz - 16 kHz (+/-7dB) (-10 dB @ 50Hz, 22kHz)</td>
</tr>
<tr>
<td><strong>Power output RMS each side (4 OHMS)</strong></td>
<td>18W transient/10W continuous</td>
</tr>
<tr>
<td><strong>Power output RMS center bass (4 OHMS)</strong></td>
<td>32W transient/18W continuous</td>
</tr>
<tr>
<td><strong>Distortion, electrical</strong></td>
<td>Less than 0.15% at any level below limit threshold</td>
</tr>
<tr>
<td><strong>Distortion, acoustical</strong></td>
<td>8% or less at worst case frequencies above 180 Hz</td>
</tr>
<tr>
<td></td>
<td>Including cabinet resonance; typically less than 2%</td>
</tr>
<tr>
<td><strong>Hum and noise</strong></td>
<td>Better than -65 dB below full output</td>
</tr>
<tr>
<td><strong>Magnetic shielding</strong></td>
<td>Less than 1 Gauss any adjacent surface</td>
</tr>
<tr>
<td><strong>Input connectors</strong></td>
<td>Balanced: loop-through XLR; Unbalanced; RCA phono</td>
</tr>
<tr>
<td><strong>1/4” Headphone jack</strong></td>
<td>Headphone amplifier mutes speakers</td>
</tr>
<tr>
<td><strong>Power Consumption (avg. max.)</strong></td>
<td>35 W</td>
</tr>
<tr>
<td><strong>Dimensions (avg. max.)</strong></td>
<td>(H x W x D) 1.75 x 19 x 12 inches 44.5x 483 x 298 mm</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>14 lbs. (6.4 kg) including power transformer</td>
</tr>
<tr>
<td><strong>UL approved / CE compliant power supply</strong></td>
<td>Versions available: 110/100/230 V 50/60 Hz</td>
</tr>
</tbody>
</table>

Table 5-14  Wohler AMP-1A audio specifications.
### Wohler ATSC-3 Audio Monitor

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input impedance</td>
<td>110 ohms balanced; 75 ohms unbalanced</td>
</tr>
<tr>
<td>Minimum Input level for maximum output (max volume)</td>
<td>0 dBv bal. / -12dB unbalanced</td>
</tr>
<tr>
<td>Input overload</td>
<td>+26 dBv balanced +14 dBv unbalanced</td>
</tr>
<tr>
<td>Peak acoustic output (@ 2 ft.)</td>
<td>104 dB SPL</td>
</tr>
<tr>
<td>Response, sixth octave (@ 2 ft.)</td>
<td>80 Hz - 16 kHz (+/-5dB) (-10 dB @ 40Hz, 20kHz)</td>
</tr>
<tr>
<td>Power output RMS each side (4 OHMS)</td>
<td>20W transient/11W continuous</td>
</tr>
<tr>
<td>Power output RMS center bass (4 OHMS)</td>
<td>20W transient/11W continuous</td>
</tr>
<tr>
<td>Distortion, electrical</td>
<td>Less than 0.1% at any level below limit threshold</td>
</tr>
<tr>
<td>Distortion, acoustical</td>
<td>6% or less at worst case frequencies above 140 Hz</td>
</tr>
<tr>
<td>Including cabinet resonance; typically less than 1.5%</td>
<td></td>
</tr>
<tr>
<td>Hum and noise</td>
<td>Better than -68 dB below full output</td>
</tr>
<tr>
<td>Magnetic shielding</td>
<td>Less than 0.8 Gauss any adjacent surface</td>
</tr>
<tr>
<td>Input connectors</td>
<td>Balanced: loop-through XLR; Unbalanced; RCA phono</td>
</tr>
<tr>
<td>1/4” Headphone jack</td>
<td>Headphone amplifier mutes speakers</td>
</tr>
<tr>
<td>Power Consumption (avg. max.)</td>
<td>50W</td>
</tr>
<tr>
<td>Dimensions (avg. max.)</td>
<td>(H x W x D) 3.5 x 19 x 10 inches 89 x 483 x 254 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>18 lbs. (8.2 kg) including power transformer</td>
</tr>
<tr>
<td>UL approved power supply</td>
<td>Versions available: 110/100/230 V 50/60 Hz</td>
</tr>
</tbody>
</table>

Table 5-15 Specifications for the Wohler ATSC-3 AC-3 (Dolby Digital) audio monitor.
5.1.1.20 Vehicle

A vehicle capable of accommodating all the necessary equipment and test personnel needed to be located. The vehicle had to have adequate power, size, weight, and cooling capabilities. There was no better solution than to use the already proven ENG type vehicles that were designed to handle similar requirements. These vehicles had “beefed up” suspensions, on-board power generators, and battery backup power using true sine wave inverters, four equipment racks and space for storing hazard cones, antennas, and any other necessary measurement items. Since Harris Corporation already built these vehicles; modifying one to fit this application was not an issue. A description of the major elements of the vehicle is detailed below:

- 3 – equipment racks (48” high x 19” wide)
- Rotating Captain’s chair for the operator seat
- Duo-Therm 13,500 BTU, integrated roof-top air conditioner and 5000 BTU heater
- Recessed Power Control for electrical circuits of the vehicle
- External 30 amp AC connector
- Onboard 5 kW Onan Generator
- Safety Equipment
  - Backup (reverse) alarm
  - Fire extinguisher
  - Carbon Monoxide detector
  - 4 orange warning cones
- Non-skid 5’ x 8’ roof platform with access ladder

The layout of the test vehicle is pictured in Figure 5-22 and details of the placement of the equipment are discussed in the Equipment Layout section.
Figure 5-22  Test vehicle with some of the key components pictured
5.1.2 Equipment Layout

The placement of the equipment was crucial to the comfort of the test operators. It was therefore necessary to layout the vehicle where the most frequently used equipment was placed close to the operator. Considerations also had to be made for one or more persons conducting the test and operate comfortable. There were a few iterations on paper before reaching the equipment layout shown below in Figure 5-23.

The Agilent® 89441V vector signal analyzer was placed in the center rack located in front of the test operator. This was done since this is the primary test equipment used. Viewing monitors were placed on either side of the vector signal analyzer. The RF test panel on which the variable system attenuator was mounted was
placed just above the counter close to the computer keyboard and mouse to allow for
convenient access. During the measurement procedure, the attenuator, keyboard and
mouse are used frequently. The other support equipment was placed in the remaining
accessible portions of the racks.
5.1.3 System Block Diagram

The main components of the system comprises of receiving antennas, onboard DTV exciter (small transmitter), system attenuator, white noise generator, Radio Frequency (RF) amplification stage, NTSC (analog signal) receiver, ATSC (DTV – digital signal) receiver, spectrum analyzer, vector signal analyzer, weather monitoring station, antenna controller, GPS receiver, electronic compass and a computer to control it all.

Both the receiving antenna and the onboard DTV exciter are connected to a RF relay. The RF signal from the optional onboard DTV exciter and the incoming RF from the antennas are switched with a RF relay. The outgoing signal passes through a system attenuator where incoming signals to the system can be blocked, allowing system noise floor measurements. After passing through the system attenuator, the signal is combined with the white noise generator that is used for signal threshold determination. This signal is amplified through a two-stage amplification process. They are two-stages in the amplification process to ensure adequate signal levels to the test and measurement equipment downstream. A 3 dB attenuator is placed between the amplifiers to decouple them, preventing ringing and other anomalies. The amplified signal is divided with RF splitters and the signal fed to the RF inputs of the test and measurement equipment. All these RF connections are done with Belden 8267 50 Ω cable.
Equipment having network interfaces are connected to the control PC via a computer network. The vector signal analyzer was the only test equipment that had a network interface. All other devices were connected using an RS-232 data interface. The basic block diagram of the system is shown in Figure 5-24.

Figure 5-24  Block diagram of DTV test vehicle.
5.1.4 Safety Considerations

It is of great importance that care be taken to keep both test personnel and equipment safe from harm. Seemingly common sense, the FCC has stipulated some safety precautions for a test vehicle.

“The measurement platform, antenna, mast and coaxial feed line represents potential safety hazards from electric shock and/or falling objects.” “Accordingly, all measurement sites must be free of overhead power lines, steeply sloped terrain, wet surfaces, high winds, thunderstorms, and other natural or man made obstructions or conditions which could threaten the safety of persons or property.”

To enforce and enhance the safety procedures mentioned above, the automation software prompts the user to check for this criterion. Check boxes have to be marked before the user can proceed with the measurements. Other safety prompts such as ensuring that no one is on the antenna platform before initiating system calibration, since the software will automatically un-stow antenna and rotate it into the position necessary to mount the appropriate antenna. Added physical features such as locating the switch to raise the mast on the outside of the vehicle, forces the user to be outside of the vehicle to ensure that the mast will not hit overhead obstructions.

5.2 Automation Software and Flow Charts

The need for automation software to gather the measurement data was inevitable. The software would have to prompt the user to acquire some information and

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46 Draft, Recommended Practice On DTV Field Testing, Advanced Television Standards Committee
automatically configure and interrogate test equipment and other devices for measurement information. The following sections give the flowcharts of the major portions of the software that was coded to accomplish this task.

5.2.1 Programming Language

A user-friendly graphical user interface (GUI) providing intuitive field measurement screens was needed. With three months to create, develop and build the product, a programming environment that allowed fast and versatile GUI development as well as the ability to perform mathematical calculations was essential. Microsoft’s Visual Basic® version 5.0 was chosen. Visual Basic® had exceptional GUI ability that could be harnessed quickly and efficiently. It also was capable of performing some math functions, with the ability of linking to more powerful programming languages such as C++ through dynamic link libraries (DLL) if necessary.

5.2.2 Database

A portable database with a standard interface was chosen to facilitate the exporting of the recorded data to statistical packages, math analysis packages, graphing packages, simple spreadsheets enabling measurement evaluation or generate reports. These packages would be used to examine the received measurement data and compare it to the results of predicted models. Additionally, coverage area maps based upon actual measurements could be created and seasonal coverage changes graphed. Microsoft Access® database was chosen due to its wide use in industry and its ability to export to other data formats that cannot directly port an Access® database. It also allows for
additional fields to be appended to an existing table and new tables to the database structure. Furthermore, the main automation program was coded in Visual Basic®, and Microsoft™ Access® is capable of direct programming in Visual Basic®.

5.2.3 New Station Information

Information regarding the station to be measured is recorded with the aid of the New Station graphical screen. The software prompts the user to enter pertinent information, as bulleted below, about the station. The software then creates a unique software station identification (station_id) based upon the station name and channel number. This station_id is used as the primary key in the database. A database file (<filename.mdb>) is created for the new station. All measurements taken pertaining to this station is recorded in the appropriate tables in the database. The first database is for the station information just entered and contains the following fields.

- Station Name
- Channel
- Station Identification
- Address
- City
- State
- Zip Code
- Country
- Transmitter Coordinates
- Transmitter Effective Radiated Power (ERP)
- Transmitter Tower Height Above Average Terrain (HAAT)

The flow of software procedures necessary to perform the above functions is shown in the flow charts of Figures 5-25 to 5-28.
New Station

Figure 5-25  Flow chart showing software steps that have to be taken to save station information in a database (1 of 3)
New Station

1

Enter station state

Enter station zip code

Enter station latitude

Enter station longitude

Enter station Effective Radiated Power (ERP)

2

Figure 5-26 Flow chart showing software steps that have to be taken to save station information in a database (2 of 3)
New Station

Figure 5-27  Flow chart showing software steps that have to be taken to save station information in a database (3 of 3)
5.2.4 Recall Station

After the original information for a station has been entered, there is no reason to re-enter it every time a new measurement is to be made. The Recall Station user screen allows the user to recall a previously created database and edit the saved information if necessary. It is necessary to load the database for the station being tested. In the event that multiple stations are being tested at the same location, at the conclusion of the test for station A, the database for station B has to be loaded. No additional tables or fields are added at this point. The flow of software procedures necessary to perform the above functions is shown in the flow charts of Figures 5-30 through 5-32.
Recall Station

Choose Database from list

Available Databases

Next Operation

Recall Information

Edit Information Operation

Load station name into global variable

System Database

Save/Create Database file

Save

3

Cancel Operation

End

Load channel number into global variable

1

Figure 5-28  Flow chart showing software steps that have to be taken to recall saved station databases (1 of 3)
Recall Station

Figure 5-29 Flow chart showing software steps that have to be taken to recall saved station databases (1 of 3)
Recall Station

Figure 5-30  Flow chart showing software steps that have to be taken to recall saved station databases (1 of 3)
5.2.5 System Calibration

After the addition of a new station or recalling an existing station, it is necessary to conduct a system warm-up and calibration sequence. The software prompts the user through manual procedures while warning of potentially hazardous procedures, and conduct automatic calibration of the test equipment. Equipment calibration is performed based upon the specifications of the manufacture. The main test equipment, namely the Vector Signal Analyzer and the Spectrum analyzer, is allowed to warm up for 30 minutes before testing can begin. The software does not sit and wait for this to happen. Rather, it tests the communication between itself and equipment such as the electronic compass, GPS, antenna controller and weather monitoring station. As different devices come online, the appropriate status box changes from red to green on the GUI. In the event a device does not come to life after a predetermined number of attempts, the user is prompted to check the port assignments for the device and restart the system calibration. The software warns against raising the mast from stow position (antenna mast down with antenna removed and mount down) to mount position (antenna mast down with antenna removed and mount up) without first checking for the presence of other personnel on the antenna platform or the presence of power lines. Although fully automated, the equipment in the test vehicle can be operated in a manual fashion. A detailed flow of events to accomplish this task is shown in the software flow charts of Figures 5-33 through 5-35.
System Calibration

Figure 5-31 Flow chart showing software steps that have to be taken to conduct equipment calibration procedures (1 of 5)
System Calibration

Figure 5-32  Flow chart showing software steps that have to be taken to conduct equipment calibration procedures (2 of 5)
Figure 5-33  Flow chart showing software steps that have to be taken to conduct equipment calibration procedures (3 of 5)
System Calibration

Figure 5-34  Flow chart showing software steps that have to be taken to conduct equipment calibration procedures (4 of 5)
System Calibration

Figure 5-35  Flow chart showing software steps that have to be taken to conduct equipment calibration procedures (5 of 5)
5.2.6 Morning Calibration

After the system has warmed up and all devices are operational, the morning calibration is next inline. The purpose of the Morning Calibration is to ascertain the characteristics of the transmitter at the transmitter site and the characteristics of the field test vehicle. A direct RF connection from the transmission line is fed into the field test vehicle and losses in the RF cabling for the antenna calculated. The overall RF gain of the vehicle, as well as its noise floor is calculated and stored. The tap energy (described under ATSC tests) is also computed from either the Professional Receiver or the Vector Signal Analyzer. The result is essentially an ideal number, since there should not be any impairment in the path. The software flow of this procedure is described below and in the flow chart diagram of Figure 5-36. Calculations used in for morning calibration is also detailed below.
Morning Calibration

Figure 5-36 Flow chart showing software steps that have to be taken to conduct the morning calibration procedure
5.2.6.1 Measurement Procedure

5.2.6.1.1 System Characteristics

- Check incoming Signal Level of Transmitter RF Tap
  - Connect RF Tap feed from TX directly to the Vector Signal Analyzer
  - Ensure RF Tap level is between 0 dBm and 20 dBm
  - Make a note of the Channel Band Power

- Measure Cable Output Loss
  - Connect RF TAP cable to up-lead cable
  - Connect down-lead cable from antenna to Vector Analyzer
  - Ensure that RF relay is in the position that connects the up-lead to the down-lead cable
  - Note channel band power on VSA.

RF Attenuator Level

- Adjust *variable attenuator* until the band power of the signal on the VSA reaches –30 dB.
- Note the value of the *variable attenuator* level.

Measure System Gain

- Connect down-lead cable to the input of the RF amplifier stage.
- Connect the output of the amplifier stage to the input of the VSA.
- Note the channel band power on the VSA

Measure Noise Floor

- Adjust the *variable attenuator* to 100 dB and wait until signal level on the VSA reaches the noise floor
Note the channel band power on the VSA

5.2.6.2 Receiver Characteristic

With the same physical RF connections as above, it is necessary to document a benchmark for the receiver data each morning. The following data should be received and documented from the ATSC receiver being used.

Tap Energy

- Using the white noise generator, add white noise (AWGN) until picture impairments are noted. These impairments include picture breakup or audio popping. When this is noted, remove 1 dB of added noise. This will indicate the threshold of the system and should correspond close to theoretical 15-dB Signal to Noise (SNR) level specified by the FCC.
- The receiver equalizer tap coefficients should be used to calculate the tap energy of the system and noted.
- Add the three- (3) attenuator values on the AWGN generator. This will indicate the total noise added to the system at the threshold.
- Connect the Noise Generator's output to the input of the HP Vector Signal Analyzer to record the amount of noise added to the system.
Signal to Noise Ratio

- Record the input SNR indicated by the receiver. This should be 15 dB or close to it.
  
  This value is the theoretical SNR for 8-VSB modulation.

- Record the output SNR indicated by the receiver. This should be greater than the input SNR previously indicated.

Noise Threshold

- Add AWGN to the signal until the picture starts to break up.

- Record the input SNR indicated by the receiver.

- Record the output SNR indicated by the receiver
  
  *(These values indicate the receive threshold of the system)*

- Connect output of AWGN generator to the input of the VSA and record the band power level. This indicates the level of noise added to the system.

- Add the values of the attenuators on the AWGN generator and note said values.

5.2.6.3 Stored Data

- Station Identification
- Channel
- Date
- Time
- Transmitter Tap Power
- Downlead cable loss
- RF Attenuator setting to achieve –30 dBm
- RF Gain of test vehicle
- Noise Floor
- Receiver SNR In (pre equalizer)
- Receiver SNR Out (post equalizer)
- Tap Energy data points
- Tap Energy
- Added Noise to achieve threshold
- Receiver SNR at noise threshold
5.2.6.4 Morning Calibration Equations

Transmitter Tap Power – measured RF output level coming from transmitter’s tap port.

Down Lead Cable Loss – the signal level lost in the cable running from the top to the bottom of the antenna mast.

Up Lead Cable Loss – the signal level lost in the cable running from the bottom to the top of the antenna mast.

RF Attenuator – the value of the variable attenuator when the measurements are taken.

Cable Output Signal – measured RF level at the output of the equal length up lead and down lead cable with the transmitter tap signal connected to the input.

\[
\text{Down Lead Cable Loss} = \frac{(\text{Transmitter Tap Power} - \text{Cable Output Signal} - \text{RF Attenuator})}{2}
\]

System Output Level – the measured signal level at the output of the system. This output is measured after the amplifiers and splitters in the system.

RF System Gain – the calculated gain of the system in units of dBm.

\[
\text{RF System Gain} = \text{System Output Level} - \text{Transmitter Tap Power} + \text{RF Attenuator} + (\text{Down Lead Cable Loss} \times 2)
\]

Noise Figure – the ratio of the total noise power unit bandwidth at the output of a system to the portion of the noise power that is due to the input termination at the standard noise temperature of 290 K expressed in decibels (dB).\textsuperscript{48}

\text{Thermal Noise Constant} = -106.2

\text{Noise Figure} = \text{Noise Floor} - \text{Thermal Noise Constant} + \text{RF System Gain} + \text{Down Lead Cable Loss}

5.2.7 New Site Location

At the conclusion of the system calibration, morning calibration and the connection of the appropriate antenna for the stations channel, a suitable test site can be chosen to begin the field test procedure. Dependent upon the measurements being conducted, radial, arc or grid points are chosen as test sites. The Federal Communications Commission (FCC) stipulates a minimum of 15 test locations and approximately one-half the population of the test area, if the result is greater than 15.\textsuperscript{50}

The software flow of this procedure is described below and in the flow chart diagram of Figure 5-37 to 5-39.


New Site

Figure 5-37  Flow chart showing software steps that have to be taken to set up a site for DTV testing (1 of 3)

New Site

Get Current GPS Position

Convert present GPS Longitude (DMS) to degrees

Convert present GPS Latitude (DMS) to degrees

Convert transmitter Longitude (DMS) to degrees

Convert transmitter Latitude (DMS) to degrees

Calculate Horizontal distance using Longitude data (x)

Calculate Vertical distance using Latitude data (y)

Calculate distance to transmitter using vertical data, horizontal data and mapscale \(\sqrt{x^2 + y^2}\)

Calculate direction to transmitter

Figure 5-38  Flow chart showing software steps that have to be taken to set up a site for DTV testing (2 of 3)
New Site

Get Current Truck Heading from Compass

Truck Heading < Direction to Transmitter (TX)

heading = TX direction - vehicle heading

heading >= 0 and heading <= 270

heading = 360 - vehicle heading + TX direction

heading > 270 and heading < 360

heading > 0 and heading <= 270

Antenna dir = 180 + (heading/1.5)

Antenna dir = (heading -270)/1.5

Send heading to Antenna Controller

Figure 5-39 Flow chart showing software steps that have to be taken to set up a site for DTV testing (3 of 3)
5.2.7.1 Radial Test Points

Radial test points allow for measuring the terrain-effects as a function of distance away from the transmitter, as it affects the strength of the received signal. These points are selected along a radial starting at 10 miles from the transmitter, with subsequent points at 5-mile intervals. If the terrain is very irregular, smaller point spacing of 2 or 3 miles can be used. The radials should be directed towards specific populated areas for which coverage is desired or across variable terrain. The use of topographic maps of the area should be employed and points chosen that intersect with roads. This allows for accessibility, which is needed for cluster and 100-foot measurements.

5.2.7.2 Arc Test Points

Unlike Radial test points, Arc test points widen the measurement data field by covering an area at a constant distance from the transmitter. This new coverage area may have greater terrain variations that would affect propagation. This method of point selection allows a more accurate characterization of the test area. Points are selected along the first arc approximately 15-20 miles away from the transmitter. The second and third arc locations are approximately 25-35 miles and 40-60 miles away from the transmitter. These distances correspond one-third divisions of a typical coverage area that has a radius of 50 miles. Points on the first arc should be approximately 8 miles apart, equating to roughly 24 degree spacing along the arc, to meet the FCC requirement. On the subsequent arcs points $2\pi r/15$, where $r$ is the radius of the arc, yield separation distances of 14 and 25 miles respectively.
Radial and Arc test points correspond more closely to Longley-Rice propagation models. In that, these test locations do not adequately account for urban clutter. Grid test points and clustering measurements techniques take up the slack and their results more closely mimic the prediction models of Okumura and Hata.

5.2.7.3 Grid Test Points

Grid test points allow measurement of urban and sub-urban areas where reflection and diffraction abound. These measurement points characterize empirically the test location. The use of one mile grid spacing in the area in question with the grid further sub-divided with four diagonal and four vertical lines. The intersection of the sub-dividing lines creates 16 distinct points. These points should be used as test points. If the test points are not accessible, points as close to the ones calculated should be noted and used. The quantity of points needed is based upon the total population of the area being examined, which can be calculated as previously mentioned. Roughly four grids dispersed in the urban area with sixteen points per grid are sufficient to characterize the area. However, further data points can be taken if deemed necessary. Figure 5-40 shows the division of an urban area and Figure 5-41 shows the subdivision of a 1 x 1 mile block and the selection of grid test points.
Figure 5-40  Layout of grid for an urban area
Figure 3.11  Detail of cell measurement locations for an urban area.

5.2.7.4  Cluster Measurements

Cluster measurements are used to enhance the data measured at Radial or Arc test points. Clustered points allow for variations due to multipath at a particular test location. The results of the cluster measurements should be averaged and treated as a single test point. A minimum of five evenly distributed test points should be chosen as demonstrated in Figure 5-41 below.
5.2.7.5 Seasonal Measurements

The effects of seasonal variations are seen in all propagation models. To account for these variations industry experts advice repeating one-fourth of the original measurements taken at their respective locations six months after the initial measurements. The data points are chosen arbitrarily. However, accounting for non-line-of-sight locations and high vegetated areas should be included as part of the seasonal measurements.

The software automatically calculates the distance and direction to the transmitter based upon the transmitter and test sites ground position system (GPS) location and the
direction the test vehicle is facing. It then automatically aims the antenna towards the transmitter, regardless of truck orientation. Current temperature, humidity and wind speed is also recorded and all data is time and date stamped.

The database table should include the fields indicated below, with the indexed items as options.

- Date
- Time
- Receive Site Longitude Location
  - Degrees
  - Minutes
  - Seconds
- Receive Site Latitude Location
  - Degrees
  - Minutes
  - Seconds
- Distance to Transmitter (miles)
- Direction to Transmitter (degrees)
- Location Address
- Location Description
- Visible Obstructions
- Nature of Power Lines
- Test Personnel (Allow for 3-4)
- Temperature
- Humidity
- Wind speed
- Terrain
  - Flat
  - Rolling
  - Rough
  - Hills
  - Mountains
- Foliage
  - None
  - Light Trees
  - Medium Trees
  - Heavy Forest
- Weather
  - Clear
  - Partly Cloudy
  - Cloudy/Overcast
  - Light Rain
- Heavy Rain
- Snow/Sleet
- Heavy Sleet

- Urbanization
  - Rural
  - Suburban (1-2 Story)
  - Suburban (3-4 Story)
  - Urban (4-10 Story)
  - Urban (Tall Bldg)
  - Light Industrial
  - Heavy Industrial

- Population of Area

- TV Antenna Present
  - None
  - 10%
  - 20%
  - 30%
  - 40%
  - 50%
  - 60%
  - 70%
  - 80%
  - 90%
  - 100%

- Satellite Dishes Present
  - None
  - 10%
  - 20%
  - 30%
  - 40%
  - 50%
  - 60%
  - 70%
  - 80%
  - 90%
  - 100%

- Additional Comments
5.2.8 ATSC Tests

At the heart of the coverage verification process is the measurement of the received 8-VSB characteristics. The test locations chosen based upon Radial, Arc, or Cluster criterions are tested for adequate signal reception. Several categories of tests are performed at this time. The first test involves acquiring present reception conditions without the addition of controlled noise. The second test involves testing the thresholds of the 8-VSB system with the addition of controlled white noise. The White Noise test calculates the amount of additional noise that the signal at this location can endure before signal degradation. This in turns indicates the amount of headroom there is in the system. The impulse noise test is a measure of existing impulses that can affect the reception of the signal. This test was described previously in Section 4.4. The software flow chart is presented in Figure below.
ATSC Test

Start

Range input of Vector Signal Analyzer as close to -30 dBm

Measure 6 MHz Band Power from Vector Signal Analyzer VSA (Channel Power)

Find Pilot of 8-VSB signal, 0.31 MHz from left band edge

Enter Attenuator Setting

Calculate DTV Field Strength

Calculate DTV Signal-to-Noise Ratio

Without Noise

With Noise

Impulse Noise

100 foot run

Tilt Plot

Stopband Plot

Spectrum Plot

Figure 5-42  Software flow chart showing the main portion of the ATSC measurement test
5.2.8.1 Without White Noise Measurements

After the field test unit has been setup as described in the ATSC test setup procedures, the equalizer tap values are retrieved from either the professional receiver or the Vector Signal Analyzer (VSA). The tap energy is then calculated using the equations presented in section 6.3. The error vector magnitude calculated by the Vector Signal Analyzer is retrieved and stored for future analysis. A graphic file of the spectrum is captured from the analyzer, labeled and stored on the local hard drive. The functional procedure is described in the software flow chart of Figure 5-43.
Figure 5-43  Flow chart of ATSC test conducted without adding white noise (AWGN)
5.2.8.2 With White Noise Measurements

Similar to the previous test, the signal is peaked on the VSA and gaussian white noise is added to the system to determine the amount of noise headroom available at this test location before reaching the 15 dB receiver threshold. When a picture breakup is noticed by viewing the un-board high definition monitor, reduce the added noise by 1 dB. This will indicate the threshold before the digital cliff edge. As before, the equalizer tap values are retrieved from either the professional receiver or the Vector Signal Analyzer (VSA). The tap energy is then calculated using the equations presented in section 6.3. The error vector magnitude calculated by the Vector Signal Analyzer is retrieved and stored for future analysis. A graphic file of the spectrum is captured from the analyzer, labeled and stored on the local hard drive. This procedure is described in Figure 5-44.
Add AWGN to system until picture begins to break-up

Measure added AWGN

Retrieve DTV receiver equalizer taps

Calculate Tap Energy

Retrieve Segment Error Rate from receiver

Retrieve Error Vector Magnitude from VSA

Save Database file

System Database

END

Figure 5-44  Flow chart of ATSC test conducted without adding white noise (AWGN)
5.2.8.3 Impulse Noise

As described under Measurement Theory, impulse noise affects signal reception particularly in VHF and low UHF channels. Turning off the transmitter and measuring the band power of the 6 MHz channel, yields the band noise of the channel. Measuring the noise floor of the test vehicle and subtracting the two results yield the impulse noise. Although impulse noise is sporadic, in areas where this noise is a problem the occurrence will be sufficiently often to characterize the noise level. This procedural software flow is described in Figure 5-45.

ATSC - Impulse Noise

![Flow chart of procedure to measure the band power of the impulse noise of the channel](image)

Figure 5-45  Flow chart of procedure to measure the band power of the impulse noise of the channel
5.2.8.4  100-Foot Run

The entire test thus far has been done in a fixed mode of operation. To better characterize the channel, a moving measurement of 100 feet at speeds not exceeding 5 KPH (3 MPH) with the antenna still elevated at 9.1 meters and pointing towards the transmitter. The purpose of the test is to average the effects of multipath and nearby objects that could affect the received signal. However, before conducting this test ensure that it is possible to conduct a 100-foot straight run without the antenna encountering any obstructions at its extended 9.1-meter height. If a location close to the selected test site is not appropriate, find one as close as possible. Place orange traffic cones in the roadway to warn passing motorist. At one end of the run area, with extended mast peak the signal by rotating the antenna for maximum signal strength. Start the automation software that in turn will start the Vector Signal Analyzer peak tracking. The maximum and minimum band power levels are retrieved and stored. The core software procedure is demonstrated in the software flow chart in Figure 5-46.
ATSC - 100 Foot Run

Figure 5-46 Flow chart showing software procedures used to implement the “100-foot” run test
5.2.8.5 ATSC Graphs

The ability to capture the actual spectrums for the test described is executed in three distinct fashions. These spectral widths are a 20 MHz and 10 MHz plot with 10 dB per division y-axis, and a 10 MHz plot with a 1 dB per division y-axis. These plots provide insight to the spectral conditions when the tests were performed. A Tag Image Format (TIF) file and raw x and y data points are saved. Allowing the recreation of the spectrum and overlay of several test locations. This software function for all three types of plots is described in Figure 5-47.
ATSC Graphs

Figure 5-47  Flow chart showing software steps in saving spectrum graph data points and screen captures
5.2.8.6 Data Storage

They are several measurement data that should be stored in the database. A subset of what was implemented is indicated in the February 13, 2001 draft of the ATSC Recommended Practice on DTV Field Testing. The additional fields will be recommended for inclusion in the final ATSC document. Listed below is a list of the fields that were implemented and that will be recommended to the ATSC.

- Station Id
- Test Id
- Date
- Time
- Direction of Antenna
- Antenna Gain
- Receive Antenna type
- Noise Floor
- RF Attenuator
- DTV Signal Power
- DTV Pilot Power
- DTV Field Strength
- DTV Signal-to-Noise Ratio
- Impulse Noise
- Segment Error Rate
- Equalizer Tap Values
- Equalizer Tap Energy
- Added Noise

---

5.2.9 ATSC Calculations

The ½ - wave dipole defining output voltage equation

\[ V = E \frac{\lambda}{(2 \pi)} = E \frac{c}{2 \pi F} \]

Where

- \( V \) = dipole output voltage in volts (V) into 75 \( \Omega \)
- \( E \) = electric field strength in V/m
- \( c \) = speed of light \((3 \times 10^8 \text{ m/s})\)
- \( F \) = center frequency of channel in Hz
- \( \lambda \) = Wavelength in meters \((c/F)\)

\( K_{\text{ve}} \) – is the conversion factor from field strength to voltage for median frequencies of specified channels. This factor is calculated by the equation:

\[ K_{\text{ve}} = 20 \times \log (K'_{\text{ve}}) \text{ where } K'_{\text{ve}} = \frac{c}{2 \pi} \]

\( K_{\text{pv}} \) – Conversion constant for converting voltage to power in a 75 \( \Omega \) system

\[ P = \frac{V^2}{R} \]

\[ K_{\text{pv}} = 10 \times \log \left[ \frac{(1 \mu V)^2}{0.075 \Omega \cdot W} \right] = 108.75 \text{ dBm-dB\muV} \]

Antenna Gain – The manufactures published gain of the antenna being used in dBm.

Field Strength Constant – used to consolidate values comprising of the dipole factors \( K_{\text{ve}}, K_{\text{pv}}, \) and Antenna Gain.

\[ \text{Field Strength Constant} = K_{\text{ve}} + K_{\text{pv}} - \text{Antenna Gain} \]
ATSC Signal Power – measured value of channel band power in dBm using values recorded by the Vector Signal Analyzer

RF System Gain – measured system gain, which considers amplifier gains and system losses. This measurement includes losses due to cables and attenuator’s in the system as well as RF amplification.

ATSC Attenuator Level – setting of variable attenuator to achieve –30-dBm measurement levels.

Down Lead Loss – measured losses in RF antenna cable.

Field Strength – adjusted field strength of the incoming signal that takes into consideration losses and gains of the RF system.

\[
\text{Field Strength} = \text{ATSC Signal Power} - \text{RF System Gain} + \text{ATSC Attenuator Level} + \text{Down Lead Loss} + \text{FS Constant}
\]

Noise Floor – the measured noise of the RF system (without an input). This value indicates the lower receiving threshold of the system.

Nominal S/N – indicates the calculated signal to noise ratio of the system. Based upon the ATSC standard, this value should be equal or greater than 15 dBm.

\[
\text{Nominal S/N} = \text{ATSC Signal Power} - \text{Noise Floor} + \text{ATSC Attenuator Level}
\]

Total Added AWGN – the signal power of the AWGN added to the system to reach the noise threshold. Connecting the output of the noise generator to the input of the Vector Signal Analyzer and measuring the 6 MHz band power results in this value.
DTV Margin – is a measure of how far a signal can drop before picture and sound are lost. This value is ascertained at the end of the *With White Noise* measurement procedure. The white noise threshold of errors is about 15 dB.

\[
\text{DTV Margin} = \text{RF System Gain} - \text{Total Added AWGN}
\]
6 Interpreting the Results

The sample test results included in this section will demonstrate how one should interpret the data received. Field measurement tests were conducted along an arc five miles from the transmitter site and eight test points identified. The Longley-Rice predictions were not available. However, ball park predictions can be made by using the equations in section 2 of this document along with the information in table 6.1.

<table>
<thead>
<tr>
<th>Transmitter Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter Power and Antenna Gain (watts)</td>
</tr>
<tr>
<td>Transmitter height above average terrain (feet)</td>
</tr>
<tr>
<td>Receive antenna gain (dBi)</td>
</tr>
<tr>
<td>Receive antenna height (feet)</td>
</tr>
<tr>
<td>Center frequency (MHz)</td>
</tr>
</tbody>
</table>

Receive site 1

| Distance to transmitter (miles) | 4.63 |
| Bearing to transmitter (degrees) | 2 |
| Weather | Cloudy/Overcast |
| Wind (mph) | 10 |
| Temperature (°F) | 40.5 |
| Relative Humidity | 53 |
| Power Lines | None |
| Terrain | Flat |
| Folliage | Light Trees |
| Urbanization | Suburban (1-2 Story) |
| DTV Field Strength (dBuV/m) | 125.16 |
| Impulse Noise (dBm) | Not measured |

Receive site 2

<p>| Distance to transmitter (miles) | 5.08 |
| Bearing to transmitter (degrees) | 50 |
| Weather | Cloudy/Overcast |</p>
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind (mph)</td>
<td>0</td>
</tr>
<tr>
<td>Temperature (°F)</td>
<td>39.8</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>55</td>
</tr>
<tr>
<td>Power Lines</td>
<td>None</td>
</tr>
<tr>
<td>Terrain</td>
<td>Rolling</td>
</tr>
<tr>
<td>Folliage</td>
<td>Medium Trees</td>
</tr>
<tr>
<td>Urbanization</td>
<td>Rural</td>
</tr>
<tr>
<td>DTV Field Strength (dBuV/m)</td>
<td>105.65</td>
</tr>
<tr>
<td>Impulse Noise</td>
<td>Not measured</td>
</tr>
</tbody>
</table>

**Receive site 3**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to transmitter (miles)</td>
<td>5.32</td>
</tr>
<tr>
<td>Bearing to transmitter (degrees)</td>
<td>94</td>
</tr>
<tr>
<td>Weather</td>
<td>Cloudy/Overcast</td>
</tr>
<tr>
<td>Wind (mph)</td>
<td>2</td>
</tr>
<tr>
<td>Temperature (°F)</td>
<td>39.6</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>57</td>
</tr>
<tr>
<td>Power Lines</td>
<td>None</td>
</tr>
<tr>
<td>Terrain</td>
<td>Flat</td>
</tr>
<tr>
<td>Folliage</td>
<td>Medium Trees</td>
</tr>
<tr>
<td>Urbanization</td>
<td>Suburban (1-2 Story)</td>
</tr>
<tr>
<td>DTV Field Strength (dBuV/m)</td>
<td>112.52</td>
</tr>
<tr>
<td>Impulse Noise</td>
<td>Not measured</td>
</tr>
</tbody>
</table>

**Receive site 4**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to transmitter (miles)</td>
<td>5.25</td>
</tr>
<tr>
<td>Bearing to transmitter (degrees)</td>
<td>128</td>
</tr>
<tr>
<td>Weather</td>
<td>Cloudy/Overcast</td>
</tr>
<tr>
<td>Wind (mph)</td>
<td>1</td>
</tr>
<tr>
<td>Temperature (°F)</td>
<td>39</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>57</td>
</tr>
<tr>
<td>Power Lines</td>
<td>None</td>
</tr>
<tr>
<td>Terrain</td>
<td>Flat</td>
</tr>
<tr>
<td>Folliage</td>
<td>Light Trees</td>
</tr>
<tr>
<td>Urbanization</td>
<td>Suburban (3-4 Story)</td>
</tr>
<tr>
<td>Parameter</td>
<td>Value</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>DTV Field Strength (dBuV/m)</td>
<td>119.68</td>
</tr>
<tr>
<td>Impulse Noise</td>
<td>Not measured</td>
</tr>
<tr>
<td><strong>Receive site 5</strong></td>
<td></td>
</tr>
<tr>
<td>Distance to transmitter (miles)</td>
<td>4.95</td>
</tr>
<tr>
<td>Bearing to transmitter (degrees)</td>
<td>221</td>
</tr>
<tr>
<td>Weather</td>
<td>Cloudy/Overcast</td>
</tr>
<tr>
<td>Wind (mph)</td>
<td>2</td>
</tr>
<tr>
<td>Temperature (°F)</td>
<td>41.5</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>50</td>
</tr>
<tr>
<td>Power Lines</td>
<td>None</td>
</tr>
<tr>
<td>Terrain</td>
<td>Flat</td>
</tr>
<tr>
<td>Folliage</td>
<td>Medium Trees</td>
</tr>
<tr>
<td>Urbanization</td>
<td>Suburban (1-2 Story)</td>
</tr>
<tr>
<td>DTV Field Strength (dBuV/m)</td>
<td>115.87</td>
</tr>
<tr>
<td>Impulse Noise</td>
<td>Not measured</td>
</tr>
<tr>
<td><strong>Receive site 6</strong></td>
<td></td>
</tr>
<tr>
<td>Distance to transmitter (miles)</td>
<td>4.82</td>
</tr>
<tr>
<td>Bearing to transmitter (degrees)</td>
<td>272</td>
</tr>
<tr>
<td>Weather</td>
<td>Cloudy/Overcast</td>
</tr>
<tr>
<td>Wind (mph)</td>
<td>1</td>
</tr>
<tr>
<td>Temperature (°F)</td>
<td>41.5</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>53</td>
</tr>
<tr>
<td>Power Lines</td>
<td>None</td>
</tr>
<tr>
<td>Terrain</td>
<td>Flat</td>
</tr>
<tr>
<td>Folliage</td>
<td>Medium Trees</td>
</tr>
<tr>
<td>Urbanization</td>
<td>Suburban (1-2 Story)</td>
</tr>
<tr>
<td>DTV Field Strength (dBuV/m)</td>
<td>115.52</td>
</tr>
<tr>
<td>Impulse Noise</td>
<td>Not measured</td>
</tr>
<tr>
<td>Weather</td>
<td>Cloudy/Overcast</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Wind (mph)</td>
<td>1</td>
</tr>
<tr>
<td>Temperature (°F)</td>
<td>41.5</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>53</td>
</tr>
<tr>
<td>Power Lines</td>
<td>None</td>
</tr>
<tr>
<td>Terrain</td>
<td>Hills</td>
</tr>
<tr>
<td>Folliage</td>
<td>Medium Trees</td>
</tr>
<tr>
<td>Urbanization</td>
<td>Suburban (1-2 Story)</td>
</tr>
<tr>
<td>DTV Field Strength (dBuV/m)</td>
<td>115.87</td>
</tr>
<tr>
<td>Impulse Noise</td>
<td>Not measured</td>
</tr>
</tbody>
</table>

**Receive site 7**

| Distance to transmitter (miles) | 4.50 |
| Bear to transmitter (degrees)   | 305  |
| Weather                        | Cloudy/Overcast |
| Wind (mph)                     | 0    |
| Temperature (°F)               | 40.5 |
| Relative Humidity              | 57   |
| Power Lines                    | None |
| Terrain                        | Flat |
| Folliage                       | Medium Trees |
| Urbanization                   | Suburban (1-2 Story) |
| DTV Field Strength (dBuV/m)    | 114.89 |
| Impulse Noise                  | Not measured |

**Receive site 8**

<p>| Distance to transmitter (miles) | 4.79 |
| Bear to transmitter (degrees)   | 176  |
| Weather                        | Cloudy/Overcast |
| Wind (mph)                     | 2    |
| Temperature (°F)               | 42.5 |
| Relative Humidity              | 44   |
| Power Lines                    | None |
| Terrain                        | Flat |
| Folliage                       | Light Trees |</p>
<table>
<thead>
<tr>
<th>Urbanization</th>
<th>Suburban (1-2 Story)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DTV Field Strength (dBuV/m)</td>
<td>115.46</td>
</tr>
<tr>
<td>Impulse Noise</td>
<td>Not measured</td>
</tr>
</tbody>
</table>

**Receive site 9**

| Distance to transmitter (miles) | 47.23 |
| Bearing to transmitter (degrees) | 40    |
| Weather                         | Clear |
| Wind (mph)                      | 15    |
| Temperature (°F)                | 43.2  |
| Relative Humidity               | 27    |
| Power Lines                     | Transformers within 30 feet |
| Terrain                         | Flat  |
| Folliage                        | Medium Trees |
| Urbanization                    | Rural |
| DTV Field Strength (dBuV/m)     | 68.91 |
| Impulse Noise                   | Not measured |

**Receive site 10**

| Distance to transmitter (miles) | 47.20 |
| Bearing to transmitter (degrees) | 40    |
| Weather                         | Clear |
| Wind (mph)                      | 0     |
| Temperature (°F)                | 42.4  |
| Relative Humidity               | 30    |
| Power Lines                     | Transformers within 30 feet |
| Terrain                         | Flat  |
| Folliage                        | Medium Trees |
| Urbanization                    | Rural |
| DTV Field Strength (dBuV/m)     | 69.98 |
| Impulse Noise                   | 16.45 |

Table 6-1  Test results for station on UHF channel 2
6.1 Field Strength

The first thing that is needed to be done is to calculate $\lambda$ from the equation $\lambda = \frac{c}{f_c}$ which gives $\lambda = 3\times10^8/57\times10^6 = 5.5556$. Using the path attenuation model equation and assuming no path loss ($L=1$)

$$P_r(d) = \frac{P_c G_c G \lambda^2}{4\pi^2 d^2 L}$$

$$P_r = 10 \log \left[\frac{(7000 \times 8.2 \times (5.5556)^2)/(4\pi)^2 \times (4.63 \text{ miles} \times 1.6093 \times 1000)^2}{4.63 \text{ miles} \times 1.6093 \times 1000}\right]$$

$$= -66.94 \text{ dBm}$$

The predicted received E-field is given by

$$|E| = 120\log \left[\frac{P_r(d)120\pi}{G_c \lambda^2 / 4\pi}\right]$$

where $P_r$ is in watts. This yields $E = -145.33 \text{ dBuV/m}$. The received signal of -125.16 dBuV/m is greater than was predicted. However, the terrain and foliage between the receive site and the transmitter, along with the climatic conditions were not taken into consideration. The same can be done for the other test sites. This will be left as an exercise for the reader.

Coverage is based upon predetermined field strength resulting in a grade of service for that area. The FCC has stipulated that the current Grade B coverage area for NTSC signals be matched with DTV field strengths as shown in table 6-2. $F(50, 90)$ indicates 50% coverage, 90% of the time.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Defining Field Strength, dBu, to be predicted using $F(50, 90)$ curves</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 – 6</td>
<td>28</td>
</tr>
<tr>
<td>7 – 13</td>
<td>36</td>
</tr>
<tr>
<td>14 – 69</td>
<td>$41 - 20 \log \left[615/(\text{channel mid-frequency})\right]$</td>
</tr>
</tbody>
</table>

Table 6-2 DTV Field strength definitions.
6.2 Tilt Plot

The tilt plot shows gives a close up of the top of the spectrum. This view shows any multipath, group delay or other propagation artifacts affecting the signal. Figure 6-2 is a close up view of a spectrum that was received by the control software. It shows the tilt of the spectrum due to multipath and group delay. Due to the design of the 8-VSB system, DTV receivers are able to recover the information without error. The tilt is compensated for with the FIR filters in the receivers. The values of filter tap coefficients yields what is known as Tap Energy.

![Figure 6-1 Tilt plot of 6 MHz DTV channel](image)

6.3 Tap Energy

Without going into the details of FIR filters, tap energy is a general indication of how hard the receiver’s equalizer is working. High tap energy generally means that there are a lot of propagation anomalies that are being corrected, while low tap energy means that the equalizer is not as busy. Tap energy should not be used as the only means of determining equalizer activity. It is possible for one to have a high tap energy value although the equalizer is not busy. This can happen if there is a delay in the signal that causes the taps other than the center tap to increase in value. Tap energy is calculated in reference to the center tap as shown in the equation below
\[ E_{TAP} = 10 \log \left[ \sum \left( \frac{C_i}{C_o} \right)^2 \right] \]

where \( C_o \) is the center tap and \( C_i \) are all remaining tap coefficients.

### 6.4 Statistics

It is helpful to find statistical interpretations of the data received. These interpretations include the mean and standard deviation. The mean is simple the measure of central tendency and is calculated by summing all fields strengths and dividing by the number of test points.

\[
u = \frac{\text{sum of data}}{\text{number of pieces data}}
\]

Standard deviation is defined as the deviation from the mean and is calculated by

\[
s = \frac{\sum (u - \bar{u})^2}{n-1}
\]

where \( u \) is the received field strength value, \( \bar{u} \) is the mean of the values, and \( n \) is the number of data points. The standard deviation is particular interest for cluster measurement data sets and can give a good indication of the amount propagation variations.

### 6.5 Spectrum Plots

The 10 MHz and 20 MHz spectrum plots should be used to view the 6 MHz channel and the adjacent channels. These plots will highlight any interference from
adjacent channels. The Figures below show typical 10 MHz and 20 MHz spectrum plots. Figure 6.3 shows a 10 MHz spectrum plot with the visual carrier of an NTSC channel. Figure 6.4 shows a 20 MHz spectrum plot with the complete adjacent NTSC channel. As seen in either Figure, neither signal is interfering with each other.

![Figure 6-2 10 MHz spectrum plot](image1)

![Figure 6-3 20 MHz spectrum plot showing adjacent channels](image2)

### 6.6 Error Vector Magnitude (EVM)

Error vector magnitude indicates the offset of spurious signals from the carrier. Traditionally, constellation diagrams are used to show symbol scattering. However, it is
possible to have scattering that will not show up in constellation diagrams but the vector signal analyzer can calculate the scattering and display in the form of an EVM percentage. The relationship between EVM and SNR is given by

\[ EVM(\%) = 92.582 \times 10^{-\frac{SNR}{20}} \]

For receive signal-to-noise ratio (SNR) of 15 dB, using the above equation, the equivalent EVM_{\text{MAX}}(\%) is 16.46. Therefore, a receive site having an EVM of less than 16.46% will meet the required Federal Communication Commission receive threshold of 15 dB.

6.7 Constellation and Eye-diagrams

As mentioned above, constellation diagram shown in Figure 6-5 is used to see symbol scattering. This is indicated as dots drifting away from the vertical decision lines. As the symbols drift to the center of two decision lines, the closing of the eyes begin to occur in the eye-diagram. The wider the “eyes”, the closer the symbols are to the decision lines as shown in Figure 6-6.
Figure 6-4  Constellation diagram showing symbols around the 8 decision points in 8-VSB

Figure 6-5  Eye-diagram of 8-VSB signal showing the 7 distinctive “eyes” and the 8 decision points.
7 Future Product Enhancements

The addition of the following items would further increase the flexibility of the DTV M-1 measurement vehicle. These additions consists of both hardware and software features.

7.1 Hardware Enhancements

*Bit-Stream Analyzer*

A device used to examine SMPTE 310M bitstream is known as a bit-stream analyzer. The presence of the analyzer will enable the user to verify the reception of a bitstream and that all the pertinent components of the bitstream are present. The bitstream in question, carries the Digital Television (DTV) data to the receivers.

*Bit-Stream Recorder*

The ability to record bitstreams in the field and store them for future analysis and archiving would be of great benefit. Having the recorded bit-stream would allow the Engineer to playback exact artifacts experienced in the field. Signal breakup at threshold is an example of such an artifact.

*Recording of RF data*

The ability to record 30 seconds of data at a test site location to allow analysis of the signal that was received at a later date. The analysis of group delays, echo lengths, phase, amplitude impulse response of the channel and other channel characteristics could
be determined and linked to errors seen in the recorded bitstream. This could be accomplished with an upgrade in the Vector Signal Analyzer.

7.2 Software Enhancements

*Report Generation*

The ability to produce varying type of graphical and text based reports within the control software or as a separate add-on would increase the usability of the recorded data. Presently, the recorded data can be manipulated by the user in software packages such as Microsoft® Excell™ and Access™.

*Multiple Test Site Analysis*

The ability to compare multiple test sites based upon defined criteria would allow the user to view anomalies from test site to test site for a particular station. This comparison could reveal coverage defects, lack of adequate field strength, and other similar test site comparisons.

*Link between Theoretical Prediction and Measured Results*

A software link between the theoretical predicted coverage with predicted signal strengths with actual measured results could demonstrate how accurate the theoretical predictions for the coverage area is and give some level of confidence of coverage for unmeasured areas.
Capturing Picture of test Area

With the color camera mounted at the same height and pointing in the same direction as the antenna, a picture of the “view” the antenna has to the transmitter and of the surrounding areas will enable visual placement of the test location during data analysis. This could be accomplished with the use of a video capture board in the automation computer.
8.1 Glossary

FCC – Abbreviation for Federal Communications Commission. An U.S. federal agency, the FCC was formed as a result of the Communications Act of 193 to regulate broadcasting and telecommunications. The FCC oversees about 11,000 radio stations and approximately 1,600 television stations.52

NTSC – An abbreviation for National Television Standards Committee, the American TV transmission standard which uses an interlaced 525-line, 30-frames-per-second picture.53

ATSC – An abbreviation for Advanced Television Standards Committee, the new American digital transmission standard. The standard consists of several picture resolution formats, having either a 4:3 or 16:9 aspect ratios.

Signal to Noise Ratio (SNR) – An electrical measure of the strength of the desired signal as compared to the noise.54

Carrier-to-Noise Ratio (CNR) – The ratio of the magnitude of the carrier to that of the noise after selection and before any nonlinear process such as amplitude limiting and detection.55

Transmitter Tap Power – measured RF output level coming from transmitter’s tap port.

Down Lead Cable Loss – the signal level lost in the cable running from the top to the bottom of the antenna mast.

Up Lead Cable Loss – the signal level lost in the cable running from the bottom to the top of the antenna mast.

52 The Complete Guide to Digital TV, Harris Corporation, 1997, p 26
53 The Complete Guide to Digital TV, Harris Corporation, 1997, p 38
54 The Complete Guide to Digital TV, Harris Corporation, 1997, p 42
RF Attenuator – the value that the variable attenuator is set at when the measurements are taken.

Cable Output Signal – measured RF level at the output of the equal length up lead and down lead cable with the transmitter tap signal connected to the input.

System Output Level – the measured signal level at the output of the system. This output is measured after the amplifiers and splitters in the system.

RF System Gain – the calculated gain of the system in units of dBm.

Thermal Noise – electric noise produced by thermal agitation of electrons in conductors and semiconductors. This is random motion of free electrons increases with temperature.\(^\text{56}\)

Noise Figure – the ratio of the total noise power unit bandwidth at the output of a system to the portion of the noise power that is due to the input termination at the standard noise temperature of 290 K expressed in decibels (dB).\(^\text{57}\)

Multi-path – is the multiple paths a received signal can take resulting in a signal consisting of the original signal and delayed replica.

Insertion Loss – the loss of signal strength when measured at the input and re-measured at the output.


Additive White Gaussian Noise (AWGN) – a band limited signal consisting of equal amount of energy for all frequencies within that band.

Channel Band Power – The average power of a 6 MHz television channel.

Noise Floor – The level of electrical noise in the system. Expressed in decibels with respect to a specified reference level. The value of the noise is integrated over a specified frequency range.

Inter-Symbol Interference – The overlap between two or more pulses gives rise to interchannel cross talk.

AC-3 – Terrestrial broadcast audio standard consisting of five full bandwidth channels and one low frequency channel.

Radio Frequency – A frequency at which a coherent electromagnetic radiation of energy is useful for communication.

DTV Margin – is a measure of how far a signal can drop before picture and sound are lost. This value is ascertained at the end of the With White Noise measurement procedure. The white noise threshold of errors is about 15 dB.

61 ATSC Field Test Results, Gary Sgignoli, Zenith Corporation, March 1997, p 6.
8.2 Test Vehicle Development Pictures

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Figure 8-2  Construction of rooftop platform
Figure 8-3  Construction of rotary antenna mount with color camera

Figure 8-4  Installation of audio, video, and RF test equipment inside of test vehicle
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Figure 8-7  RF test vehicle at test site in far field (fringe area) rural area beside transformers
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Figure 8-9  Inside finished DTV-M1 RF test vehicle with both analog (left) and digital (right) signals being monitored
8.3 Customer Article

Figure 8-10 Customer article from South Carolina Education Television on the DTV M1
8.4 Industry Award

Figure 8-11 Editors Pick Award given at the National Association of Broadcasters (NAB) trade show in Las Vegas, Nevada on April 1999, for the advancement in the art and science of television broadcast.

Figure 8-12 Mark Henry, DTV-M1 designer, with Editors Pick Award at NAB 1999.
8.5 Software Manual
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Exiting the Software
Introduction

The DTVM-1 Navigator is automation software that allows the user to attain RF characteristics of an NTSC and ATSC signal. This data is used to characterize the nature of the RF signal in designated areas of interest. The data is essential to ensure similar RF coverage of the present transmission signal with that of the new. These characteristics are saved in a Microsoft™ Access file that can be read using Microsoft™ Access 97 software or exported to Microsoft™ Excel.

The software gathers environmental and location data pertaining to the test site, and RF characteristics of the signal you are measuring. These characteristics include signal strength, field strength, impulse noise, and pilot power. The software gathers information from various onboard equipment; with insignificant user intervention.

DATA DISPLAYED IN THE GRAPHICS ARE FOR DEMONSTRATION PURPOSES ONLY.
What's on the CD

The following files are included on the CD-ROM:

- Setup.exe and associated files
- DTVM-1.exe
- Manual.pdf
- ReadMe.txt
Installing the DTVM-1 Navigator Software

The enclosed Compact Disc (CD) contains a self-extracting setup executable that will automatically install the Navigator software and setup the working directory.

The setup executable can be started by any of the means indicated below.

- **Method One – Using Windows Explorer**
  
  - Start *Windows Explorer*
  - Double click on the drive associated with your CD-ROM
  - Double click on the file called “setup.exe”
  - Follow the directions of the install wizard

- **Method Two – Using the Run Command**
  
  - Click on the **START** icon located on your Windows task bar
  - Click on **RUN**
  - Click on the **BROWSE** button
  - Select the drive associated with your CD-ROM
  - Double click on the file called “setup.exe”
  - Follow the directions of the install wizard
Setting the IP-address for the Vector Signal Analyzer

On the HP VSA:

- Press the **Local Setup** button
- Press the **F5** button corresponding to **LAN Setup**
- Press the **F2** button corresponding to **LAN Port Setup**
- Press the **F2** button corresponding to **IP Address**
- Set this to **15.8.184.114** using the keypad and press **F1** button to save the data
- Press the **F4** button corresponding to **Gateway IP**
- Set this to **0.0.0.0** using the keypad and press **F1** button to save the data
- Press the **F5** button corresponding to **Subnet Mask**
- Set this to **255.0.0.0** using the keypad and press **F1** button to save the data
- **Data Location**
  Data is stored in `E:\DTVM1\data\`. This location is hard coded into the software and cannot be changed.

- **Changing the ATSC receiver**
  The software is presently designed to communicate only with the Harris ARX-H200. Latter releases of software will provide communication with other professional broadcast receivers. When this is the case, select the receiver that is installed in your test vehicle.

### Port Assignments

The Control PC is equipped with a standard serial port and eight (8) high-speed serial ports. The standard port is not used by default but rather left for the user to use as they feel fit. The remaining eight ports are used for the controlled devices. The software allows dynamic changing of the serial ports. However, it is advised to keep the devices connected to their default ports.

#### Default Port Assignments
- Port 1 – User defined
- Port 2 – ATSC receiver
- Port 3 – Ground Positioning System (GPS)
- Port 5 – NTSC Receiver
- Port 6 – Spectrum Analyzer
- Port 9 – Not Used

### Screen Capture

This option is used to save whatever screen is presently displayed on the VSA.
- **To capture a screen:**
  Enter the filename you wish the screen to be saved as. 
  Press the CAPTURE button on the form.

Help

The DTVM-1 Navigator software gives a step by step walk through the test procedure. At present there is no online help. At the bottom of each screen there is a status bar that informs the user as to what is happening.

The **ABOUT** screen gives information regarding the software and how to contact **HARRIS CORPORATION**.
System Calibration

This screen steps the user through the setup procedure of the truck, checks status and initiates calibration of the test equipment. As the user clicks on the check marks as they complete them, the software will prompt them for other activities. It is best to click on the check marks to ensure that you have completed all the necessary procedures.

**WARNING**

**DO NOT RAISE MAST UNDER TREES, POWERLINES OR OTHER OBJECTS THAT MAY CAUSE DAMAGE EITHER TO YOU OR TO THE EQUIPMENT.**
Adding a New Station

Before any test can be performed, it is necessary to add a NEW STATION. This procedure creates the necessary directory and database files needed to record the test data.

Follow the directions below to add a NEW STATION

*Note:* None optional entries *must* be entered.

- Click on the NEW STATION button
- Enter STATION NAME
- Select the CHANNEL NUMBER
- The STATION ID is automatically created
- Enter the station’s ADDRESS – optional
- Enter the station’s CITY – optional
- Select the station’s STATE – optional
- Enter the station’s ZIP CODE – optional
- Enter the stations LONGITUDE information (hours, minutes, seconds)
- Enter the stations LATITUDE information (hours, minutes, seconds)
- Enter the station’s EFFECTIVE RADIATED POWER (ERP) – optional
- Enter the station’s HEIGHT ABOVE AVERAGE TERRAIN (HAAT) – optional
Recalling a Station

If you have already entered information regarding the station(s) that you are conducting tests on; there is no need to add them again. To recall these previously added station follow the steps outlined below.

- Click on the **RECALL STATION** button
- Select desired station from *pull down list*. The station will only be in this list if the *mdb* file associated with the station is located in the `DTVM1\data\` directory.
- Click on the **RECALL** button
- The station information should appear on the screen
- If there is a need to change any of the data appearing there click on the **EDIT INFORMATION** button
- Make the necessary changes and click on the **SAVE INFORMATION** button
- To use the selected station, click on the **NEXT** button. This will close the Recall station screen and use the selected station in the tests.
- To abort this screen, click on the **EXIT** button. By doing this, no station has been selected and testing cannot continue.
Morning Calibration

It is necessary to conduct a calibration of the equipment each morning before heading out to conduct field tests. This calibration is conducted at the transmitter site if the optional DTV exciter is not installed. If the exciter is installed, there is no need to travel to the transmitter site. This becomes advantageous if the transmitter is inaccessible to the test vehicle.

To conduct a Morning Calibration, follow the steps below

- Click on the GET RF CHARACTERISTICS button. This will initiate the test procedure. Follow the directions given by the software.

- Clicking on their respective buttons can capture the TILT, STOP BAND, AND SPECTRUM BAND plots.
Tilt Plot – a look at the 10 MHz band centered at the center frequency of the present channel with a 1 dB per division Y-axis. This allows the user to see how “flat” their signal is.

Spectrum Plot – a look at the 10 MHz band centered at the center frequency of the present channel with a 10 dB per division Y-axis. This allows the user to view present channel with a 3 MHz sideband outside of the 6 MHz band.

Stop Band Plot – a look at the 20 MHz band centered at the center frequency of the present channel with a 10 dB per division Y-axis. This allows the user to view upper and lower adjacent channels.

- Click on the Get DTV RX CHARACTERISTICS. This will initiate the test procedure used to acquire the S/N ratio and Tap energy of the receiver. Follow the test directions as prompted by the software.
New Test Location

For every test conducted, it is necessary to enter this screen. This screen will setup and store the necessary site information. If more than one test is conducted at the same location, it is necessary to re-enter this screen after completing the previous test. This is so because each test is assigned a different TEST ID. This TEST ID is essential for tracking data with the appropriate test conducted.

Based on the Latitude and Longitude information entered for the station, and on your present location, the software will automatically calculate the distance and direction to the Transmitter and rotate the antenna in the general direction of the transmitter site. The DTVM-1 Navigator automatically acquires humidity, temperature, wind speed, and GPS location information. It is necessary for you to enter other environmental conditions, observations, comments, and personnel present in the appropriate boxes.
**ATSC Tests**

These tests allow the characterization of an ATSC DTV RF signal. The software prompts the user during the various stages of the test, simplifying the test procedure. To start the ATSC TEST measurements ensure that a new test location has already been established within the software and that a TEST ID has been assigned. *(See New Location for more information)*

**ATSC Tests** – Click on the ATSC Tests button on the main screen. This will initiate the ATSC TESTS. Follow the onscreen prompts to complete the tests.

**Impulse Noise** – Click on the Impulse Noise button and follow the onscreen prompts to acquire the channel’s impulse noise. It will be necessary to turn off the transmitter for this test.
Graphic Screens

After the initial tests have been completed various graphic screens need to be retrieved from the VSA and saved on your local hard drive. There are two different methods used to store these screens. The first stores the a.tif graphic file on the local hard drive with a filename associated with the station name, channel, the type of graph (e.g. tilt), and TEST ID. The second method stores the actual raw data points in the Microsoft™ Access file under the table relating to the graph (e.g. Tilt Plot). Each data point is time and date stamped as well as having the STATION ID and TEST ID. An advantage of having the actual data points is it allows the user to overlay several graph data onto one graph to note the variations in signal based on location.

- Clicking on their respective buttons can capture the TILT, STOP BAND, AND SPECTRUM BAND plots.

  **Tilt Plot** – a look at the 10 MHz band centered at the center frequency of the present channel with a 1 dB per division Y-axis. This allows the user to view and save how “flat” the signal is.

  **Stop Band Plot** – a look at the 20 MHz band centered at the center frequency of the present channel with a 10 dB per division Y-axis. This allows the user to view and save upper and lower adjacent channels.

  **Spectrum Plot** – a look at the 10 MHz band centered at the center frequency of the present channel with a 10 dB per division Y-axis. This allows the user to view and save present channel with a 3 MHz sideband outside of the 6 MHz band.
- **Without Noise Test** – This test is used to analyze how a receiver under present reception conditions. Other receiver characteristics are also noted.

  - Clicking on their respective buttons can view the signals **Constellation**, **Eye Pattern**, **Spectrum** and a **Multiple (Quad) Display** of the signal.

    - **Constellation** – This graph displays how well the 8-VSB signals data matches up with the expected points

    - **Eye Pattern** – A graphical view of the Eye Diagram of the signal

    - **Spectrum** – a look at the 10 MHz band centered at the center frequency of the present channel with a 10 dB per division Y-axis. This allows the user to view present channel with a 3 MHz sideband outside of the 6 MHz band.

    - **Quad Display** – a combination of the Constellation, Eye Pattern and other data, displayed on the screen of the VSA simultaneously.
- **With Noise Test** – This test is used to analyze how a receiver will respond when Added White Gaussian Noise (AWGN) is injected into the signal to reach the 15 dB threshold. The amount of AWGN added is roughly the headroom for that signal at that test site. Other receiver characteristics are also noted.

- Clicking on their respective buttons can view the signals **Constellation**, **Eye Pattern**, **Spectrum** and a **Multiple (Quad) Display** of the signal.

  - **Constellation** – This graph displays how well the 8-VSB signals data matches up with the expected points.

  - **Eye Pattern** – A graphical view of the Eye Diagram of the signal.

  - **Spectrum** – A look at the 10 MHz band centered at the center frequency of the present channel with a 10 dB per division Y-axis. This allows the user to view the present channel with a 3 MHz sideband outside of the 6 MHz band.

  - **Quad Display** – a combination of the Constellation, Eye Pattern and other data, displayed on the screen of the VSA simultaneously.
100 Foot Run Test – This test is used to record the variations that the DTV signal may have over a 100 foot run. These variations are mostly due to multi-path.

Subjective Test – This test is used to note visual and aural qualities of the digital signal. There are two typical test used. The Texas Dude – a video clip with a lot of motion, and a 10-Minute video segment that includes a variety of motion speeds and content. This test are used to evaluate what the picture and sound are like when received.

- Click the appropriate circle to indicate which test is being conducted. Enter and/or check the boxes that apply.
NTSC Tests

These tests are used to establish the present coverage area of your existing transmission system. The software prompts the user during the various stages of the test, simplifying the test procedure. To start the NTSC TEST measurements ensure that a new test location has already been established within the software and that a TEST ID has been assigned. (See New Location for more information)

**NTSC Tests** – Click on the **NTSC Tests** button on the main screen. This will initiate the NTSC TESTS.
**Fixed Position Tests** – Click on the **Fixed Position Tests** to conduct testing on a NTSC RF signal. Follow the directions and prompts displayed onscreen.

**Impulse Noise** – Click on the **Impulse Noise** button and follow the onscreen prompts to acquire the channel’s impulse noise. There will be need to turn off the transmitter for this test.
Graphic Screens

After the initial tests have been completed various graphic screens need to be retrieved from the VSA and saved on your local hard drive. There are two different methods used to store these screens. The first stores the a tif graphic file on the local hard drive with a filename associated with the station name, channel, the type of graph (e.g. tilt), and TEST ID. The second method stores the actual raw data points in the Microsoft Access file under the table relating to the graph (e.g. Tilt Plot). Each data point is time and date stamped as well as having the STATION ID and TEST ID. An advantage of having the actual data points is it allows the user to overlay several graph data onto one graph to note the variations in signal based on location.

- Clicking on their respective buttons can capture the Tilt, Stop Band, and Spectrum Band plots.

**Stop Band Plot** – a look at the 20 MHz band centered at the center frequency of the present channel with a 10 dB per division Y-axis. This allows the user to view and save upper and lower adjacent channels.

**Spectrum Plot** – a look at the 10 MHz band centered at the center frequency of the present channel with a 10 dB per division Y-axis. This allows the user to view and save present channel with a 3 MHz sideband outside of the 6 MHz band.

**Subjective Test** – This test is used to note visual and aural qualities of the analog signal. Check the boxes that apply to your observations.
100 Foot Run Test – This test is used to record the variations that the analog signal may have over a 100 foot run. These variations are mostly due to multi-path.

- Click on START button to begin 100 foot test
- Click on STOP button to end 100 foot test
Exiting the Software

To exit the DTVM-1 Navigator software

- On the main screen click on **EXIT DTV CONTROL**
- Click on **YES** to confirm choice
8.6 DTV-M1 Specification Sheet
**Systems Integration Products**

**DTVM-1**

ATSC Field Measurement System

*next level solutions*
You’re spending an incredible amount of time and money to convert your plant to ATSC. So protect your investment with the Harris DTVM-1 ATSC Field Measurement System. Based on the rugged and dependable Harris M-1 Mobile System, the DTVM-1 is specifically designed to help broadcasters verify signal coverage within their FCC-allocated coverage areas, as well as to identify ATSC signal quality issues such as multipath interference, noise areas, shadowing, reflections and weak signals.

The DTVM-1 is capable of ATSC and NTSC signal analysis and comes equipped with an integrated transmission monitoring system that includes the Harris ARX-H200 professional ATSC receiver for off-air signal monitoring, a Hewlett-Packard 89441V 8-VSB signal analyzer, a telescopic antenna mast with an automated pan and tilt unit and standard measurement antennas, and an integrated RF system that includes noise calibration equipment.

The heart of the DTVM-1, the Harris Navigator Measurement Control System, simplifies and automates the test and measurement process.

Harris Navigator Measurement Control System

At the heart of the DTVM-1 is the Harris Navigator Measurement Control System. This custom-designed, software-based control system automates and simplifies the test and measurement process, capturing signal information data from each test performed, including the location and actual waveforms from the spectrum analyzer and RF signal analyzer. Captured information is then automatically logged into a database and can be compiled to provide a complete profile of your station’s coverage area. The Navigator performs a standard set of field tests in accordance with the field measurement practices recommended by WHD, the United States’ model DTV station. And the Navigator user interface is clean and straightforward, offering user prompts throughout the entire process to further simplify testing.

The DTVM-1’s ability to take fast, consistent measurements at all points within your entire coverage area will help you provide better service to your viewers, which means you have a better product to sell your advertisers.
The DTVM-1 is configured on a Ford E-350 Supervan one-ton chassis, equipped with all heavy-duty options and with a GVWR of 9,400 pounds, for years of dependable service. The interior layout of the DTVM-1 is both efficient and comfortable, with insulated and carpeted ceiling and walls, three equipment racks, a custom operator’s console and storage cabinet, plus extra storage in the rear compartment of the vehicle.

**Electrical Systems**

A 6.5 kW generator and 3.0 kW true sinewave inverter/charger provide on-board power to the DTVM-1, along with three deep-cycle auxiliary batteries. The power control panel is located next to the curbside doors for easy operation from outside the DTVM-1, and full analog metering is mounted in the bulkhead to free-up valuable rack space.

**Complete Test and Monitoring Equipment**

The DTVM-1 is equipped with a custom pneumatic 30-foot high mast system (measured ground to antenna, per ATSC recommendation), an automated pan and tilt unit with computer interface, and an antenna boresight camera for visual aiming, as well as a non-slip rooftop service platform.
**System Components**

Log-Periodic Reference Antennas
- Ch 2-4 (54-72 MHz) Model CL-24/HCM/50N
- Ch 2-6 (66-88 MHz) Model CL-46/HCM/50N
- Ch 7-13 (174-216 MHz) Model CL-713/HCM/50N
- Ch 14-69 (470-862 MHz) Model CL-1469/HCM/50N

RF Test Equipment
- Harris ARX-H200 ATSC Broadcast Receiver
- Videotek DM-192 NTSC Broadcast Receiver
- NoiseCom NC6110 AWGN Noise Generator
- Harris CD 1A Exciter (optional)
- HP8591E Spectrum Analyzer
- HP89441V VSB/QAM Signal Analyzer
  - 89441V Trace and Table Formats
    - Constellation
    - Vector Diagram
    - Eye Diagrams
    - Trellis Diagrams
    - Detected Symbol Table
    - Continuous Error Vector Magnitude vs. Time
    - Modulation Quality Summary
    - Continuous I or Q Vs Time
  - 89441V Analysis Types
    - Error Vector Magnitude
    - Phase Error
    - Amplitude Droop
    - Carrier Frequency Error
    - IQ Offset
    - Error Vector Spectrum
    - Measured IQ Spectrum

Audio/Video Monitoring
- One 20" Color HDTV Monitor
- Dual 9" Color NTSC Monitors
- Stereo Analog Audio Monitoring
- Harris AMP2-ATSC/AC3 Audio Monitor

Harris Navigator Measurement Control System
- High-speed CPU with 15" Flat Panel VGA Display
- Internal Tape Drive
- Internal Removable Media Drive
- High-resolution Color Ink-Jet Printer
- Windows®-based Graphical User Interface
- Microsoft Office Professional Software
- Harris Navigator Control Software
- Delorme Street USA® Software
- EDX™ Coverage Mapping Software
8.7 Scala Antenna Specification Sheet
The Kathrein Scala Division CL-24 is a ruggedly built, horizontally polarized log-periodic antenna, designed for professional VHF-TV transmit and receive applications.

Like all Kathrein Scala Division antennas, the CL-24 is made of the finest materials using state of the art electrical and mechanical designs, resulting in superior performance and long service life.

The CL-24 may be used stand alone or in arrays for higher gain, increased side-lobe suppression, or custom azimuth patterns.

**Specifications:**

- **Frequency range**: 54–72 MHz (broadband)
- **Gain**: 8.2 dBi
- **Impedance**: 50 or 75 ohms
- **VSWR**: < 1.5:1
- **Polarization**: Horizontal
- **Front-to-back ratio**: >25 dB
- **Maximum input power**: 250 watts, type “N” 75 ohm connector
  500 watts, type “N” 50 ohm connector
- **Azimuth pattern**: 54 degrees (half-power)
- **Elevation pattern**: 76 degrees (half-power)
- **Connector**: N female (50Ω or 75Ω), F female (for 75Ω Rx only)
- **Wind survival rating**: 120 mph (200 kph)
- **Mounting**: For masts of 2.375 inches (60 mm) OD.

See reverse for order information.

**CL-24/HCM** Center-mount
**CL-24/HRM** Rear-mount

*Mechanical design is based on environmental conditions as stipulated in EIA-222-F (June 1996) and/or ETS 300 019-1-4 which include the static mechanical load imposed on an antenna by wind at maximum velocity. See the Engineering Section of the catalog for further details.
The Kathrein Scala Division CL-46 is a ruggedly built, horizontally polarized log-periodic antenna, designed for professional VHF-TV transmit and receive applications.

Like all Kathrein Scala Division antennas, the CL-46 is made of the finest materials using state of the art electrical and mechanical designs, resulting in superior performance and long service life.

The CL-46 may be used stand alone or in arrays for higher gain, increased side-lobe suppression, or custom azimuth patterns.

Specifications:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency range</td>
<td>66–88 MHz (broadband)</td>
</tr>
<tr>
<td>Gain</td>
<td>8.2 dBi</td>
</tr>
<tr>
<td>Impedance</td>
<td>50 or 75 ohms</td>
</tr>
<tr>
<td>VSWR</td>
<td>&lt; 1.5:1</td>
</tr>
<tr>
<td>Polarization</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Front-to-back ratio</td>
<td>&gt;25 dB</td>
</tr>
<tr>
<td>Maximum input power</td>
<td>250 watts, type &quot;N&quot; 75 ohm connector</td>
</tr>
<tr>
<td></td>
<td>500 watts, type &quot;N&quot; 50 ohm connector</td>
</tr>
<tr>
<td>Azimuth pattern</td>
<td>54 degrees (half-power)</td>
</tr>
<tr>
<td>Elevation pattern</td>
<td>76 degrees (half-power)</td>
</tr>
<tr>
<td>Connector</td>
<td>N female (50Ω or 75Ω)</td>
</tr>
<tr>
<td></td>
<td>F female (for 75Ω Rx only)</td>
</tr>
<tr>
<td>Wind survival rating*</td>
<td>120 mph (200 kph)</td>
</tr>
<tr>
<td>Mounting</td>
<td>For masts of 2.375 inches (60 mm) OD.</td>
</tr>
<tr>
<td>CL-46/HCM</td>
<td>Center-mount</td>
</tr>
<tr>
<td>CL-46/HRM</td>
<td>Rear-mount</td>
</tr>
</tbody>
</table>

See reverse for order information.

<table>
<thead>
<tr>
<th>CL-46/HCM</th>
<th>CL-46/HRM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>29 lb (13.2 kg)</td>
</tr>
<tr>
<td></td>
<td>35 lb (15.9 kg)</td>
</tr>
<tr>
<td>Dimensions</td>
<td>93 x 68.2 x 9.9 inches (2363 x 1733 x 252 mm)</td>
</tr>
<tr>
<td></td>
<td>93 x 88.2 x 37 inches (2363 x 2241 x 940 mm)</td>
</tr>
<tr>
<td>Equivalent flat plate area</td>
<td>4.5 ft² (0.418 m²)</td>
</tr>
<tr>
<td></td>
<td>5.23 ft² (0.486 m²)</td>
</tr>
<tr>
<td>Shipping dimensions</td>
<td>84 x 10 x 6 inches (2134 x 254 x 153 mm)</td>
</tr>
<tr>
<td></td>
<td>99 x 14 x 6 inches (2315 x 356 x 153 mm)</td>
</tr>
<tr>
<td>Shipping weight</td>
<td>36 lb (16.3 kg)</td>
</tr>
<tr>
<td></td>
<td>72 lb (32.7 kg)</td>
</tr>
</tbody>
</table>

Azimuth pattern (E-plane)

Elevation pattern (H-plane)

* Mechanical design is based on environmental conditions as stipulated in EIA-222-F (June 1996) and/or ETS 300 019-1-4 which include the static mechanical load imposed on an antenna by wind at maximum velocity. See the Engineering Section of the catalog for further details.
The Kathrein Scala Division CL-713 is a ruggedly built, horizontally polarized log-periodic antenna, designed for professional VHF-TV transmit and receive applications.

Like all Kathrein Scala Division antennas, the CL-713 is made of the finest materials using state of the art electrical and mechanical designs, resulting in superior performance and long service life.

The CL-713 may be used stand alone or in arrays for higher gains, increased side-lobe suppression or custom azimuth patterns.

**Specifications:**

- **Frequency range:** 174–216 MHz (broadband)
- **Gain:** 9 dBi
- **Impedance:** 50 or 75 ohms
- **VSWR:** < 1.5:1
- **Polarization:** Horizontal
- **Front-to-back ratio:** > 25 dB
- **Maximum input power:** 250 watts (higher power rating optional)
- **Azimuth pattern:** 50 degrees (half-power)
- **Elevation pattern:** 62 degrees (half-power)
- **Connector:** N female (50Ω or 75Ω), F female (for 75Ω Rx only)
- **Wind survival rating:** 120 mph (200 kph)
- **Mounting:** For masts of 2.375 inches (60 mm) OD.

**Specifications: CL-713/HCM**

- **Weight:** 28.5 lb (12.9 kg)
- **Dimensions:** 89.2 x 33.9 x 9.9 inches (2266 x 862 x 252 mm)
- **Equivalent flat plate area:** 2.76 ft² (0.257 m²)
- **Shipping dimensions:** 95 x 10 x 6 inches (2413 x 254 x 153 mm)
- **Shipping weight:** 42 lb (19.1 kg)

**Specifications: CL-713/HRM**

- **Weight:** 40 lb (18.2 kg)
- **Dimensions:** 104 x 38.5 x 33.9 inches (2642 x 978 x 862 mm)
- **Equivalent flat plate area:** 3.03 ft² (0.282 m²)
- **Shipping dimensions:** 112 x 14 x 6 inches (2845 x 356 x 153 mm)
- **Shipping weight:** 79 lb (35.9 kg)

* Mechanical design is based on environmental conditions as stipulated in EIA-222-F (June 1996) and/or ETS 300 019-1-4 which include the static mechanical load imposed on an antenna by wind at maximum velocity. See the Engineering Section of the catalog for further details.
The Kathrein Scala Division CL-1469 is a ruggedly built, linearly polarized log-periodic antenna designed for professional UHF-TV transmit and receive applications.

Like all Kathrein Scala Division antennas, the CL-1469 is made of the finest materials using state of the art electrical and mechanical designs resulting in superior performance and long service life. The rugged fiberglass radome protects the antenna from icing and assures stable pattern and gain performance under adverse environmental conditions.

The CL-1469 may be used stand alone or in arrays for higher gain, increased side-lobe suppression, or custom azimuth patterns.

*The CL-1469 covers all 6, 7, and 8 MHz UHF-TV channels worldwide (bands IV/V).

**Specifications:**

- Frequency range: 470–862 MHz (broadband)*
- Gain: 8 dBi
- Impedance: 50 or 75 ohms
- VSWR: < 1.5:1
- Polarization: Horizontal or vertical
- Front-to-back ratio: >35 dB
- Maximum input power: 100 watts, type "N" 75 ohm connector; 250 watts, type "N" 50 ohm connector
- Azimuth pattern: 52 degrees (half-power)
- Elevation pattern: 72 degrees (half-power)
- Connector: N female (50 or 75 ohms)
- Weight: 22 lb (10 kg)
- Dimensions: 29 x 17 x 12 inches (737 x 432 x 305 mm)
- Equivalent flat plate area: 2.78 ft² (.258 m²)
- Wind survival rating*: 100 mph (160 kph)
- Shipping dimensions: 31 x 20 x 14.5 inches (787 x 508 x 368 mm)
- Shipping weight: 28.0 lb (12.7 kg)
- Mounting: Mounting kits available for masts of 2.375 to 4.5 inch (60 to 114 mm) OD.

* Mechanical design is based on environmental conditions as stipulated in EIA-222-F (June 1996) and/or ETS 300 019-1-4 which include the static mechanical load imposed on an antenna by wind at maximum velocity. See the Engineering Section of the catalog for further details.