# ATSC Recommended Practice: Mobile Receiver Performance Guidelines

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The Advanced Television Systems Committee, Inc., is an international, non-profit organization developing voluntary standards for digital television. The ATSC member organizations represent the broadcast, broadcast equipment, motion picture, consumer electronics, computer, cable, satellite, and semiconductor industries.

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

ATSC was formed in 1982 by the member organizations of the Joint Committee on InterSociety Coordination (JCIC): the Electronic Industries Association (EIA), the Institute of Electrical and Electronic Engineers (IEEE), the National Association of Broadcasters (NAB), the National Cable Telecommunications Association (NCTA), and the Society of Motion Picture and Television Engineers (SMPTE). Currently, there are approximately 140 members representing the broadcast, broadcast equipment, motion picture, consumer electronics, computer, cable, satellite, and semiconductor industries.

ATSC Digital TV Standards include digital high definition television (HDTV), standard definition television (SDTV), data broadcasting, multichannel surround-sound audio, and satellite direct-to-home broadcasting.

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## 1. SCOPE AND DOCUMENTATION STRUCTURE

### 1.1 Forward

This document addresses the signal conditions that may be encountered with assessment of the potential impact upon the front-end portion of a receiver of A/153-based mobile digital television broadcasts. This document provides recommended performance guidelines that are intended to maximize reception. In general, the recommendations in this document build on those contained in A/74 (which applies to fixed terrestrial receivers), with the addition of new guidelines pertinent to mobile reception. Areas where the recommendations are new or different include: dynamic multipath, antenna configurations in mobile receivers, the effects of more limited power supplies, possible proximity to interfering signals, and presence of unlicensed devices radiating in the TV bands.

### 1.2 Scope

This document provides recommended performance guidelines for the portion of a mobile television receiver known as the “front-end,” which includes the antenna and all subsequent signal processing through demodulation, equalization, and error correction. The output of the receiver front-end is the input to the Transport (or Management) Layer decoder.

Specifically, the receiver elements whose performance contributes to meeting these guidelines are:

- Antenna and any antenna controls
- Tuner – including radio frequency (RF) amplifier(s), associated filtering, and the local oscillator(s) and mixer(s) required to bring the incoming RF channel frequency down to the frequency where demodulation occurs
- Selectivity and passband shaping, whether at baseband or an Intermediate Frequency (IF)
- Gain control and signal conditioning
- A/D or D/A converters at any point in the signal path
- Demodulation, equalization, error correction, and synchronization

### 1.3 Document Structure

The recommended performance guidelines for a mobile A/153 receiver front-end as described in this document include a general system overview, a list of reference documents, and the recommended performance guidelines for the front-end receiver elements. The performance guidelines are divided into five general categories:

- Sensitivity
- Multi-signal overload
- Selectivity
- Multipath
- Single-frequency and multiple-frequency networks

## 2. REFERENCES

At the time of publication, the editions indicated were valid. All referenced documents are subject to revision, and users of this RP are encouraged to investigate the possibility of applying the most recent edition of the referenced document.

### 2.1 Informative References

The following documents contain information that may be helpful in applying this document.

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

[2] CTIA: "CTIA Certification Test Plan for Mobile Station Over the Air Performance Method of Measurement for Radiated RF Power and Receiver Performance, V 3.1"

[3] IEC: "Mobile and Portable DVB-T/H Radio Access – Part 1: Interface Specification," Doc. IEC 62002-1, May 2008.

[4] Haslett, Christopher: *Essentials of Radio Wave Propagation*, Cambridge University Press, 2008.

[5] ETSI: "Technical Report Digital Video Broadcasting (DVB); DVB-H Implementation Guidelines," Doc. TR 102 377 V1.2.1 (2005-11).

[6] NTIA: "NTIA Report 02-390 Man-Made Noise Power Measurements at VHF and UHF Frequencies," Robert J. Achatz and Roger A. Dalke.

[7] ATSC: "Recommended Practice: Receiver Performance Guidelines," Doc. A/74, Advanced Television Systems Committee, Washington, D.C., 18 June 2004.

[8] ATSC: "ATSC Mobile/Handheld Digital Television Standard, Part 2 – RF/Transmission System Characteristics," Doc. A/153 Part 2:2009, Advanced Television Systems Committee, Washington, D.C., 15 October 2009.

## 3. DEFINITION OF TERMS

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

### 3.1 Compliance Notation

This section defines compliance terms for use by this document:

**should** – This word indicates that a certain course of action is preferred but not necessarily required.

**should not** – This phrase means a certain possibility or course of action is undesirable but not prohibited.

## 4. RECEIVER PERFORMANCE GUIDELINES

### 4.1 Sensitivity and Antenna Considerations

Sensitivity is typically defined as the minimum field strength required for reception. There are multiple potential use cases from the perspective of the receiver type and the reception condition. Each of these has a different sensitivity. The classes of device type are defined and sensitivity metrics are discussed. Two metrics for sensitivity are described. Recommended performance according to device class and reception condition is given.

#### 4.1.1 Typical Mobile Reception System

The overall sensitivity of a given system is determined by the combined performance of its receiver and antenna. A typical block diagram for a receive system is shown in Figure 4.1. The typical input noise figure for a practical receiver implementation is about 6 dB. This value is inclusive of the impacts of matching, the input filter loss, and the gain stages of the tuner.

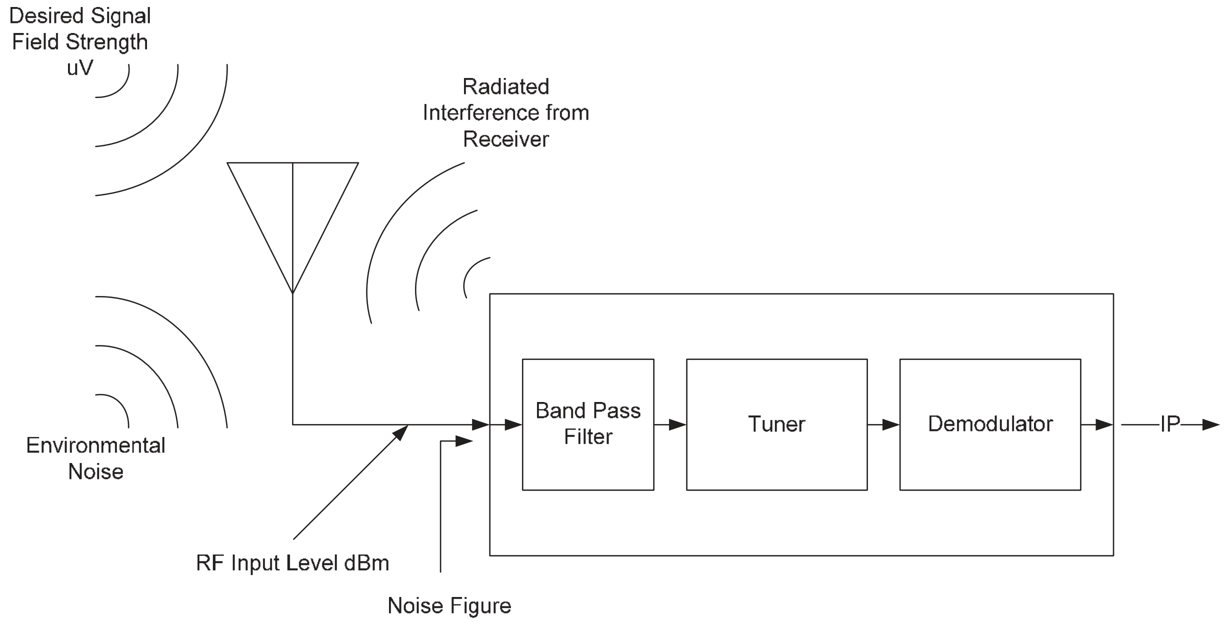

**Figure 4.1** Typical mobile reception system.

#### 4.1.2 Device Classes

There are multiple classes of devices suitable for mobile reception. These are defined by the physical constraints of the application. These classes are loosely defined for the purposes of this document as Outdoor Mobile, Portable Handheld, and Personal Player.

##### 4.1.2.1 Outdoor Mobile

This class of reception is typified by a roof top or window mounted antenna on a consumer automobile or mini-van. The receiver electronics are mounted inside the vehicle. The antenna system is not integral to the receiver; however, the performance is determined by the combination of an antenna system and the receiver. The typical use case is vehicular reception in multiple environments, e.g., rural, suburban, and urban. The antenna typically has a gain that varies with angle of elevation (with the gain at zero elevation of greatest interest) but is considered non-varying or random vs. azimuth.

##### 4.1.2.2 Portable Handheld

This class of reception is typified by a "cellular phone" form factor. The device may be carried in a purse or pocket, and the antenna system is an integral component of the device. Typical operational use cases include indoor, outdoor, and in-vehicle reception. The antenna is considered to have a non-uniform pattern that is positioned with random orientation with respect to the signal.

#### 4.1.2.3 Personal Player

This class of device is assumed to be of dimensions comparable to a personal disk player. The display and antenna are incorporated into a single physical unit. The typical dimensions are greater than those of a Portable Handheld device. This type of device may include either an internal or deployable antenna. For the purpose of calculating performance, the signal is assumed to arrive from a random direction and the antenna usually is considered to be used with random orientation to that direction. Due to increased size and/or deployability, the efficiency of the antenna may be greater than that of a portable handheld device. The designer may also wish to consider whether a reliably useful increase of gain may be obtained with a deployable antenna (depending on user adjustment), in which case calculations could be based on gain (in dBi) rather than efficiency (in dB).

#### 4.1.2.4 Antenna Gain or Efficiency According to Device Class

The differences in physical dimensions according to device class have a direct impact on the realizable antenna gain. Table 4.1 summarizes typical gains according to device class. The outdoor mobile and portable handheld gains given as examples are patterned after reference [3]. The VHF internal antenna efficiency values given as examples are provided for purposes of illustrating calculation methods and are not representative of a particular device or devices.

**Table 4.1** Typical Antenna Gain by Device Class and Band

| **Device Class** | **Typical UHF Antenna Gain(dBi) or Efficiency (dB)** | **Typical High VHF[1] Antenna Gain(dBi) or Efficiency (dB)** | **Antenna Type** |
|---|---|---|---|
| Outdoor Mobile | 0 dBi | –3 dBi | Roof mount |
| Portable Handheld | –8.6 dB | –25 dB | Internal |
| Personal Player | –5.6 dB | –22 dB | Internal |

The antenna performance values provided for device classes that support an integral antenna are stated as antenna efficiency (i.e., space averaged antenna gain) in dB, which provides for calculations based on random antenna orientation.[2] Since all passive antennas dissipate some power, antenna efficiency is always less than 0 dB. Antenna efficiency is used for handheld devices, because the orientation of the antenna in the device is unspecified and the orientation of the device with respect to the strongest direction of arrival is essentially random.

Antenna efficiency and antenna gain in a preferred direction may be significantly higher for deployable or detachable antennas, as compared to an internal antenna. The performance of these types of antenna is not discussed in this document.

Antennas for the Outdoor Mobile use case are assumed to be omni-directional with the maximum gain oriented toward the horizon. For the Outdoor Mobile use case, performance

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[1] No data was submitted for low-VHF antennas.

[2] Due to reciprocity between transmitting and receiving antennas, receiving antenna efficiency, which is used in the calculations herein, is equal to transmitting efficiency, which is defined as the ratio of the total radiated power to the total input power when an antenna is used for transmitting. This value is also equal to the antenna power pattern integrated over $4\pi$ steradians; i.e., space averaged antenna gain.

values are specified as gain with respect to an isotropic antenna (dBi), which, it may be noted, is also the method typically used in calculations for fixed reception of TV signals.

#### 4.1.3 Sensitivity Metrics

The sensitivity of a given device as defined above is the minimum field strength required for reception. This definition, while generally accurate, does not address the issue of reception conditions nor does it indicate clearly the effects of the different types of antenna used in particular mobile applications.

The maximum sensitivity for a given device is defined as AWGN reception of the most robust mode available in the system.

##### 4.1.3.1 Sensitivity Equation

Minimum field strength values can be calculated with the following formula (see Reference [3]):

$$E = P - Gr + 20\log F + 77.2$$

Where

$E$ = field strength in dBμV per meter

$P$ = required receiver input power in dBm

$Gr$ = antenna efficiency (dB) or gain (dBi) according to the application

$F$ = frequency in MHz

The required input power, P, is calculated as follows.

$$P = \text{input-referred noise power in dBm + implementation margin + AWGN C/N for the chosen FEC code rate}$$

An additional margin is required under multipath and Doppler conditions, which additional margin depends on both the particular conditions and receiver design.

##### 4.1.3.2 Sensitivity Metrics and Example Calculations for Outdoor Mobile Antennas

The minimum field strength for Outdoor Mobile reception is shown in Table 4.2. Values in this table are exemplary, but not unrealistic. The 3 dB implementation loss for Outdoor Mobile includes the feed cable loss and device implementation loss.

**Table 4.2** Typical Minimum Field Strength Outdoor Mobile

| **Device Class and Band** | **Implementation Margin** | **Noise Figure** | **Antenna Gain** | **AWGN C/N for Rate 1/4** | **Minimum Field Strength** |
|---|---|---|---|---|---|
| Outdoor Mobile UHF 584 MHz | 3 dB | 6 dB | 0 dBi | 3 dB | 37.9 dBμV/m |
| Outdoor Mobile High VHF 195 MHz | 3 dB | 6 dB | –3 dBi | 3 dB | 31.4 dBμV/m |

##### 4.1.3.3 Sensitivity Metrics and Example Calculations for Personal Player Built-in Antennas

For small, built-in antennas, maximum sensitivity is called Total Isotropic Sensitivity (TIS) and a method for its measurement is detailed in “CTIA Test Plan for Mobile Station Over the Air Performance”[2]. This type of measurement captures the impact of device implementation loss including noise figure, the radiated self-interference from the device, and antenna efficiency. The loss in performance due to radiated self interference is commonly referred to as “desense”. Since the TIS measurements and calculations are only for AWGN, they do not reflect the impact of or required field strength for propagation impairments such as multipath, Doppler, and environmental noise.

The TIS can be calculated from conducted AWGN performance, implementation margin, antenna efficiency, and noise figure. Table 4.3 and Table 4.4 show the calculated TIS based on the previously defined typical device parameters. A total of 3 dB has been allocated to implementation margin, which includes the desense loss.

Note that estimates are not provided for possible improvements obtainable with a deployable antenna.

**Table 4.3** Typical TIS for UHF Devices with Self Contained Antenna Systems

| **Device Class** | **Implementation Margin** | **Noise Figure** | **Antenna Efficiency** | **AWGN C/N for Rate 1/4** | **TIS at 584 MHz** |
|---|---|---|---|---|---|
| Mobile Handheld | 3 dB | 6 dB | –8.6 dB | 3 dB | 46.5 dBμV/m |
| Personal Player | 3 dB | 6 dB | –5.6 dB | 3 dB | 43.5 dBμV/m |

**Table 4.4** Typical TIS for VHF Devices Self Contained Antenna Systems

| **Device Class** | **Implementation Margin** | **Noise Figure** | **Antenna Efficiency** | **AWGN C/N for Rate 1/4** | **TIS at 195 MHz** |
|---|---|---|---|---|---|
| Mobile Handheld | 3 dB | 6 dB | -25 dB | 3 dB | 53.4 dBμV/m |
| Personal Player | 3 dB | 6 dB | -22 dB | 3 dB | 50.4 dBμV/m |

#### 4.1.3.4 Operational Sensitivity

Operational sensitivity takes into account all factors affecting the required field strength for reception, including implementation losses for self-radiation (desense) and additional margin for multipath conditions.

The typical C/N for 5 percent errored time for a single instance of the specified multipath ensemble is a commonly applied metric for mobile multimedia, see reference [5] section 10.3.2.1. Table 4.5 below shows exemplary measurements of C/N required by a particular receiver for satisfactorily receiving a multipath ensemble commonly used in lab tests. These values should not be taken as necessarily typical of system performance in the field. Lab tests of this type should be used only as guides to the direction of progress during receiver development. Response to field captures of signals is more relevant to final achieved performance.

Figure 4.1 indicates the existence of environmental noise that increases the noise floor and thus increases the required field strength of the Desired signal. Environmental noise in the Table derives from sources such as man-made noise and galactic noise. Other noise sources such as in-band transmitters and "splatter" from adjacent channels that is permitted by the FCC transmission mask may have sufficient strength to impair reception. Overcoming these impairments may be a transmission system design issue or may be under control of the user. These degradations of reception are not considered in the calculation of TIS. A number of studies have been conducted with respect to the levels of this phenomenon, which is related to human activity. Figure 4.2 plots environmental noise levels as reported by the NTIA in reference [6]. The figure shows the individual contributions of each noise source. As shown, the level of environmental noise depends on the land use of the user's location.

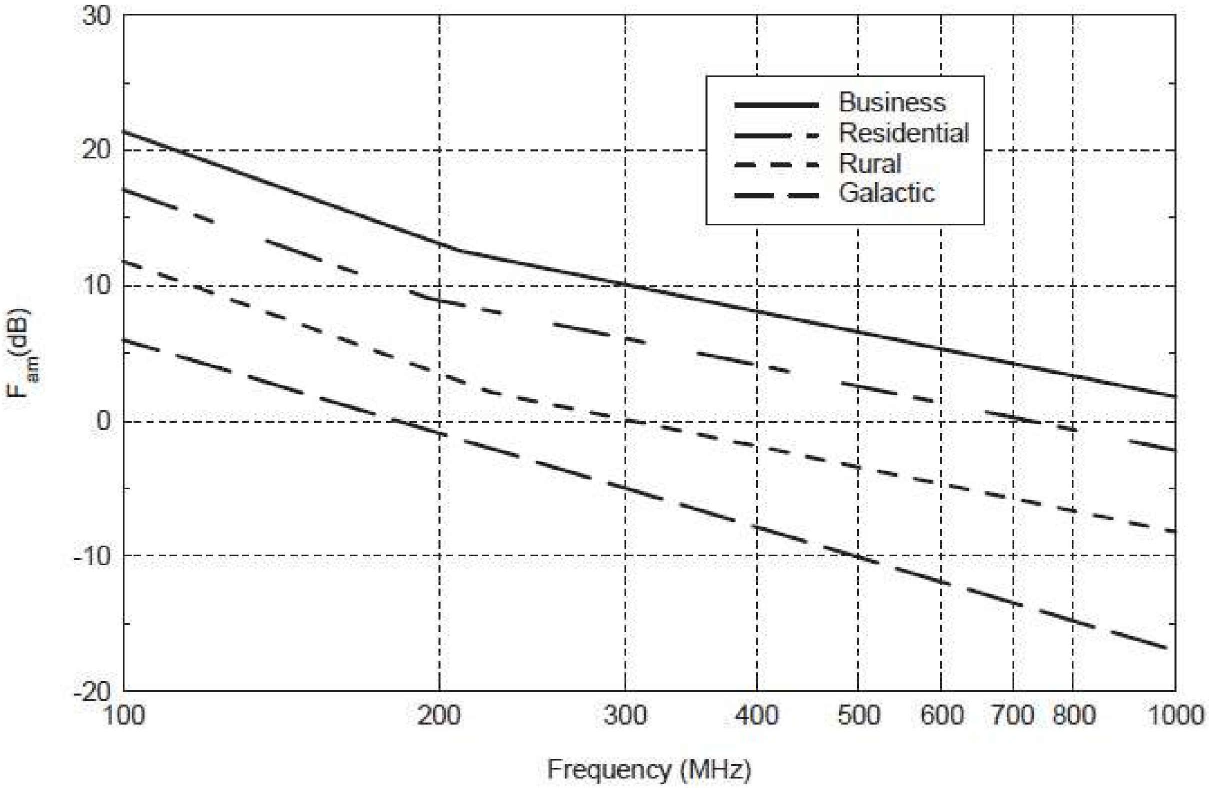

**Figure 4.2** Environmental noise relative to thermal noise from reference [6].

For example, the UHF operational field strength for single transmitter Portable Handheld can be calculated as

Operational Field Strength = Effective Input Noise Power + C/N for Desired Operational Mode – Antenna Efficiency + 20log $F$ + 77.2

Where:

Operational Field Strength is expected field strength for reception

Effective Input Noise Power is the equivalent input noise in dBm for combined effect of noise figure, implementation loss, and environmental noise

C/N for Desired Operational Noise is value from Table 4.5*b*

Antenna Efficiency is per Table 4.1

F is frequency in megahertz

An example calculation of Operational Field Strength for an Outside Mobile (vehicular) receiver (using Antenna Gain) is summarized in Table 4.5*a*.

**Table 4.5a** Example Operational Sensitivity Calculation for Outside Vehicular Antennas

| **Item** | **Personal Handheld 584 MHz** | **Personal Handheld 195 MHz** | **Units** |
|---|---|---|---|
| System Reference Temperature | 298.0 | 298.0 | K° |
| System Reference Temperature Noise Power | –106.5 | –106.5 | dBm |
| Device Noise Temperature (6 dB NF) | 1192.0 | 1192.0 | K° |
| Implementation Loss (self-radiation) (0 dB) | 0.0 | 0.0 | K° |
| Environmental Noise Temperature | 372.5 | 2384.0 | K° |
| Total System Input Noise Temperature | 1564.5 | 3576.0 | K° |
| Effective Input Noise Power | –99.3 | –95.7 | dBm |
| C/N for Mixed Rate and a TU-6 test ensemble[1] | 17.0 | 17.0 | dB |
| Required Receiver Input Power | –82.3 | –78.7 | dBm |
| Antenna Gain | 0.0 | –3.0 | dBi |
| Operational Field Strength | 50.2 | 47.3 | dBμV/m |
| **Note:**<br>1. See the sections on Effects of Multipath and Effects of Single Frequency Networks for detailed discussions. | | | |

An example calculation of Operational Field Strength for a portable/handheld or personal player unit (using Antenna Efficiency) is summarized in Table 4.5*b*.

**Table 4.5b** Example Operational Sensitivity Calculation for Small Built-in Antennas

| **Item** | **Personal Handheld 584 MHz** | **Personal Handheld 195 MHz** | **Units** |
|---|---|---|---|
| System Reference Temperature | 298.0 | 298.0 | K° |
| System Reference Temperature Noise Power | –106.5 | –106.5 | dBm |
| Device Noise Temperature (6 dB NF) | 1192.0 | 1192.0 | K° |
| Implementation Loss (self-radiation) (3 dB) | 1192.0 | 1192.0 | K° |
| Environmental Noise Temperature | 372.5 | 2384.0 | K° |
| Total System Input Noise Temperature | 2756.5 | 4768.0 | K° |
| Effective Input Noise Power | –96.9 | –94.5 | dBm |
| C/N for Mixed Rate and a TU-6 test ensemble[1] | 17.0 | 17.0 | dB |
| Required Receiver Input Power | –79.9 | –77.5 | dBm |
| Antenna Efficiency | –8.6 | –25.0 | dB |
| Operational Field Strength | 61.3 | 80.0 | dBμV/m |
| **Note:**<br>1 See the sections on Effects of Multipath and Effects of Single Frequency Networks for detailed discussions. | | | |

### 4.2 Multi-Signal Overload

A mobile DTV receiving device should be designed to tolerate more than one high-level, undesired signal at its input and still operate properly. These undesired signals may be DTV signals from transmission facilities that are close to the receiver and/or transmissions from nearby Part 15 unlicensed devices. For purposes of this guideline, it should be assumed that multiple undesired signals, each approaching 120 dBμV/m or greater, could be present.[3]

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[3] Value is referenced to a dipole.

Transmissions from unlicensed devices very near the mobile DTV device can present some of the highest levels of undesired signals.[4]

Unlicensed devices can transmit on TV channels that are not being used for licensed TV operations. For example, an unlicensed personal/portable device operating at UHF on the first adjacent channel with the maximum allowable EIRP of 40 milliwatt will produce an undesired field of about 120 dBμV/m one meter away. The same device operating on non-first adjacent TV channels with the maximum allowable EIRP of 100 milliwatt will also produce an undesired field of about 125 dBμV/m at the same distance. Multiple signals from multiple unlicensed devices are not considered.

Additional discussion of the potential overload effects of multiple received signals is found in ATSC Recommended Practice A/74, which contains performance guidelines for fixed-location receivers. A/74 Annex F describes conditions observed in a laboratory with two interfering signals. A/74 Annex G describes conditions observed in a laboratory with three interfering signals. Under some conditions, these analyses may pertain to mobile receivers as well as fixed receivers. A/74 Annex E, although written to describe the particulars of adjacent channel interference, also discusses tuner nonlinearities that are relevant to multiple signal overload.

Designers of mobile receivers should recognize that the mobile signal environment may impact the degradations described in A/74. In particular:

- Mobile antennas may have lower gain than fixed antennas
- Power constraints on mobile receivers may lead to greater difficulties in controlling tuner nonlinearities
- A portable device can be located very close to an unlicensed transmitter

### 4.3 Selectivity

Receiver selectivity design issues are described in Section 5.4 of ATSC Recommended Practice A/74. The signal conditions described therein also pertain to the mobile reception case. Designers should note that mobile receivers, for reasons of location and antenna directivity, may face weaker desired signals and stronger undesired signals than typical fixed receivers.

### 4.4 Effects of Multipath

In a typical application, the performance of a mobile device is related to the reception conditions with respect to multipath. There are typically differences in multipath according to surroundings and these have been documented in numerous channel models, e.g., Typical Urban 6 (TU-6), Pedestrian Outdoor (PO), or Pedestrian Indoor (PI), as defined in reference [3]. These models define a single cluster of arrivals generally related to the statistical properties of the particular modeled multipath environment and a rate of change generally referred to as Doppler rate, which

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[4] Under FCC rules, unlicensed devices can operate on TV channels at locations where the TV channel is not being used for broadcast television service. Two classes of unlicensed devices are defined: 1) fixed devices that are permitted to operate with a maximum EIRP of up to 4 Watts; and, 2) personal/portable devices that are permitted to operate with a maximum EIRP of 100 mW (40 mW on adjacent channels). Interfering signal levels in this section are calculated with the assumptions of free space propagation and that the unlicensed device is operating at maximum permitted power. Multiple signals from multiple unlicensed devices are not considered.

is specified for simulation as a Doppler frequency or the equivalent receiver velocity at a given carrier frequency. The performance of devices in the presence of such channel profiles can indicate *operational* sensitivity, according to the operational mode.

The performance of mobile multimedia systems has been defined utilizing TU-6 and 5 percent errored time [4]. For ATSC M/H, a 5 percent RS-Frame Error Rate is equivalent to 5 percent errored time.

Performance with respect to two Doppler rates is of particular significance. These Doppler rates are $Fd_{3dB}$, the frequency at which C/N threshold is degraded by 3 dB due to Doppler effects and the frequency at a 3 km/hr pedestrian speed. $Fd_{3dB}$ represents the upper limit of Doppler rate that is receivable with the specified channel model. The performance at pedestrian Doppler rate and below may show effects of long-duration fades that are not fully alleviated by data interleaving. The intermediate rates are typically less stringent. These concepts are illustrated in Figure 4.3.

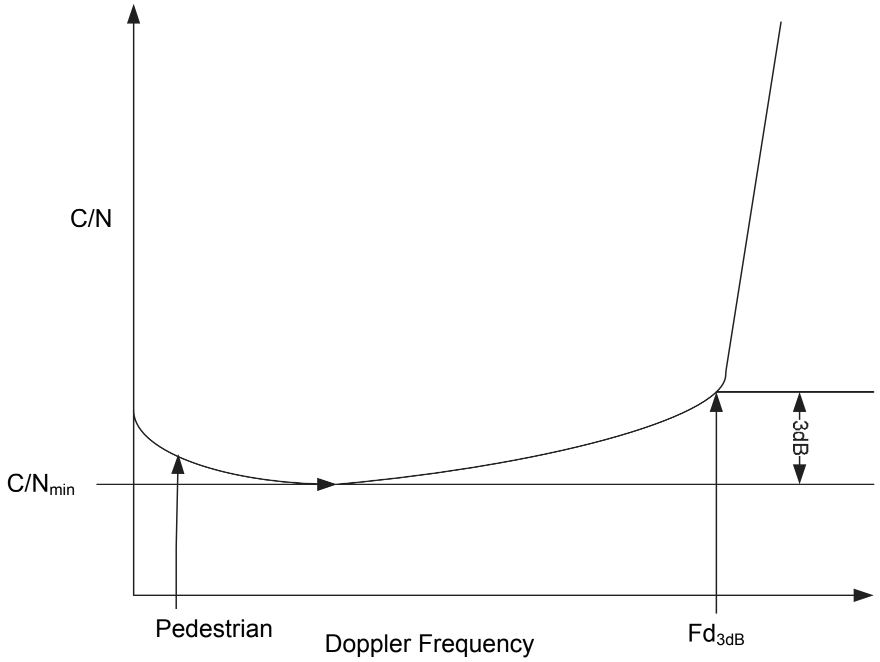

**Figure 4.3** Typical receiver performance characteristic vs. Doppler.

By use of a single-path Rayleigh fading signal (flat fading), the effects of fade rate and duration may be separated from the over-all performance, which includes Doppler phase/frequency shifts. This test may be useful to the receiver designer in the hardware development process.

Table 4.6 illustrates C/N threshold performance measured in two early ATSC Mobile DTV receivers for the single-path Rayleigh channel. The receivers were characterized by the performance at pedestrian and urban street traffic speeds that were of interest in this case. Determination of $Fd_{3dB}$ under these conditions also may be useful to the designer.

The first column of Table 4.6 indicates the coding mode used. Q indicates ¼-rate SCCC coding and H indicates ½-rate coding. The sequence of four letters (e.g., HQQQ) indicates the coding in Regions A, B, C, D of the signal. The second part of the entry in column 1 is the number of Reed-Solomon parity bytes in the RS Frame coding. In this test, all modes used the maximum of 48 bytes.

**Table 4.6** C/N Threshold with Single Path Rayleigh Fading

| **Transmission modes** | **Doppler Frequency, Hz** | **Receiver 1 C/N** | **Receiver 2 C/N** |
|---|---|---|---|
| Quarter (QQQQ)<br>48 bytes | 2 | 17 dB | 17 dB |
| | 30 | 16 dB | 16 dB |
| | 75 | 16dB | 16 dB |
| Half (HHHH)<br>48 bytes | 2 | 23 dB | 23 dB |
| | 30 | 23 dB | 23 dB |
| | 75 | 23 dB | 23 dB |
| Mixed (HQQQ)<br>48 bytes | 2 | 19 dB | 19 dB |
| | 30 | 18 dB | 18 dB |
| | 75 | 18 dB | 18 dB |

Table 4.7 illustrates measured C/N threshold on two early receivers for the TU-6 ("Typical Urban," 6 paths) model. Note that:

- C/N in Table 4.6 and Table 4.7 is calculated from total signal power including all paths. C/N calculated from only the main path will be lower. Depending on the multipath generator and signal measuring protocol used in practical measurements, it may be necessary to convert between main-path referenced C/N and total-power referenced C/N.
- C/N threshold performance was better with TU-6 conditions than with single path Rayleigh fading.

**Table 4.7** C/N Threshold with TU-6 Doppler channel

| **Transmission Modes** | **Doppler Frequency, Hz** | **C/N (dB @ 5% error time or less)** | |
|---|---|---|---|
| | | **M/H Receiver 1** | **M/H Receiver 2** |
| Quarter only<br>48 bytes | 0.5 | 14 | 13 |
| | 2 | 14 | 13 |
| | 30 | 13 | 13 |
| | 75 | 13 | 13 |
| Quarter only<br>24 bytes | 0.5 | 16 | 15 |
| | 2 | 15 | 15 |
| | 30 | 15 | 14 |
| | 75 | 14 | 13 |
| Half only<br>48 bytes | 0.5 | 23 | 19 |
| | 2 | 20 | 19 |
| | 30 | 20 | 19 |
| | 75 | > 5% error time* | > 5% error time* |
| Half only<br>24 bytes | 0.5 | 23 | 21 |
| | 2 | 21 | 20 |
| | 30 | 21 | 19 |
| | 75 | > 5% error time* | > 5% error time* |
| **Note:**<br>*The measured failure points of these early receivers should not be interpreted as a system characteristic. | | | |

Table 4.8 illustrates the range of results obtained with two early receivers and six different multipath models. The small range indicates that the commonly used TU-6 multipath model generally should be sufficient for frequent reference during receiver development, while measurement with a wide range of models may be reserved for less frequent verification of design progress and final results.

**Table 4.8** Receiver 2 C/N Ranges for Six Different Multipath Models at Various Doppler Speeds

| Transmission Modes | RS bytes | C/N range for Receiver 2 (5% error time or less) |
|---|---|---|
| Quarter only (QQQQ) | 48 bytes | 13 to 14 dB |
| | 24 bytes | 13 to 15 dB<br>(1 to 2 dB degradation vs. 48 bytes) |
| Mixed (HQQQ) | 48 bytes | 16 to 18 dB |
| | 24 bytes | 19 to 21 dB<br>(1 to 2 dB degradation vs. 48 bytes) |

The multipath models used for generating Table 4.8 were:

- Typical Urban, 6 paths
- Typical Urban, 12 paths
- Rural Area, 6 paths
- Hilly Terrain, 12 paths
- Outdoor Urban High-Rise Area – Low Antenna, 10 paths
- Outdoor Urban Low-Rise Area – Low Antenna, 10 paths

The data in Tables 4.6, 4.7, and 4.8 were generated using RF channel 44, center frequency 653 MHz. Table 4.9 shows the conversion from Doppler speed to Doppler frequency for channel 44.

**Table 4.9** Doppler Speed vs. Doppler Frequency for Channel 44 (653 MHz)

| Doppler Frequency, Hz | Doppler Speed, km/h |
|---|---|
| 0.3 | 0.5 |
| 1.8 | 3 |
| 30 | 50 |
| 73 | 120 |

### 4.5 Considerations Regarding Single-Frequency and Multiple-Frequency Networks (SFNs and MFNs)

Network type can impact overall receiver performance. A network may be classified as single transmitter, single-frequency network (SFN), or multi-frequency network (MFN). MFNs operate as a group of single transmitters carrying the same or very closely related content at the same time on different channels. MFNs, in particular, are anticipated in A/153. The Cell Information Table (CIT) is transmitted to facilitate switching between MFN transmitters by Mobile receivers, which may change channels when transitioning between coverage areas of individual transmitters, as appropriate to optimize reception.

In reception from SFNs, multiple transmitters share the same channel, and their signals coexist in certain locations. SFNs depend upon receiver adaptive equalizers to treat the signals from the several transmitters as echoes of one another and to recover the data from the more complex echo ensemble that results. In SFNs, it is common to see multiple echo clusters originating from the separate transmitters. It also is possible to see multiple echo clusters in single transmitter applications due to strong reflections, especially when the direct path from the transmitter is obstructed. This is not a typical behavior, although it does occur relatively frequently in certain types of environments.

For SFNs, the principal network characteristics that are likely to impact receivers are the relative amplitudes of the signals from the several transmitters (along with their related multipath clusters) and the time offsets of signal arrival from the respective transmitters. At any given location, the impact of these characteristics will depend upon network design choices and will be primarily upon operation of the adaptive equalizer and symbol synchronization in the receiver. With multiple transmitters in a network, it also is likely that there will be more echoes (both network-created and naturally occurring) than might exist in a single-transmitter operation. Moreover, echoes may vary more rapidly than with single transmitters. For example, receivers may move behind or out from behind buildings that differently obstruct the signals from the different transmitters.

In areas where the signal from a particular transmitter is stronger than all other transmitters in the SFN by the amount of the noise-limited threshold for the particular mode of operation (plus an amount related to the noise enhancement that results from operation of the adaptive equalizer), the signal from that transmitter will be dominant. Accordingly, reception will be essentially the same as that from just a single transmitter at the same location and having the same characteristics. In areas where the signals from multiple transmitters are closer to equal in signal strength, the capability of the adaptive equalizer (and symbol synchronizer) to process the resulting combined echo ensemble and, consequently, of the receiver to recover the transmitted data, will depend upon the capability of the receiver to process the number of echoes present and the total time displacement between the earliest and latest arriving echoes.

It is important to note that, while naturally-occurring echoes usually tend to have energy displaced more to the trailing side of the strongest impulse received than to the leading side, this is not true in single-frequency networks. In SFNs, echoes of any strength can appear either leading or trailing the strongest received impulse, displaced by any time offset that results from the combination of transmitter spacing and relative receiver location. Thus, the use of equalizers able to deal with such echo conditions is of great importance in an SFN environment. Furthermore, due to the economics of transmitter implementation, transmitters in SFNs tend to be spaced more widely than would be typical for the cells in a PCS or similar telephonic network, and, consequently, the lengths of the equalizers employed must be correspondingly long to permit reliable reception. It also should be noted that the need for more reliable reception by receivers in motion is likely to drive increased use of SFNs and MFNs (when adequate spectrum is available) over time.

Some test results for laboratory-generated multipath are presented in Tables 4.10 and 4.11. Results for single-transmitter and SFN cases are presented. These examples indicate performance observed for the particular hardware implementations available at the time, and they are not necessarily expected or recommended receiver performance. All modes described utilize RS(187,235).

**Table 4.10** Operational C/N for 5 Percent Errored Time Single Transmitter

| **Multipath Ensemble** | **SCCC Mode** | **C/N for Pedestrian 1 Hz Doppler Rate** | **C/N for Mobile ≥3 Hz Doppler Rate** |
|---|---|---|---|
| TU-6* | Rate 1/4 | 15 | 14 |
| TU-6* | Mixed | 18 | 17 |
| TU-6* | Rate 1/2 | 21 | 20 |
| Note:<br>* The worst case of the ensembles tested. Only small variations were observed between different types of ensembles. | | | |

**Table 4.11** Operational C/N for 5 Percent Errored Time SFN Operation

| **Multipath Ensemble** | **SCCC Mode** | **Typical C/N for Pedestrian 1 Hz Doppler Rate** | **Typical C/N for Mobile ≥3 Hz Doppler Rate** |
|---|---|---|---|
| Single path Rayleigh* | Rate 1/4 | 17 | 16 |
| Single path Rayleigh* | Mixed | 19 | 18 |
| Single path Rayleigh* | Rate 1/2 | 23 | 23 |
| Note:<br>* Note: Single path Rayleigh is shown as it produced the worst case performance in the receivers tested. Various SFN conditions were simulated in the lab, and the results were better than or equal to those for a single path Rayleigh channel, except when the relative time offset of signal arrival from multiple transmitters was greater than the range of the receiver's equalizer. | | | |

# Annex A: Relative Performance of Available Mobile Modes

## 1. INTRODUCTION

This Annex presents field measurements of various operating modes described in A/153. It is intended to compare the utility of different modes in various signal environments. This material is expected to be of utility to broadcasters as well as receiver designers.

## 2. PARAMETERS

There are four parameters that control the level of robustness for the mobile transmission:

- SCCC[1] (Serial Concatenated Convolutional Code) outer code rate
- RS (Reed-Solomon) Code Mode
- RS Frame Mode
- SCCC Block Mode

### 2.1 SCCC Code Rates

The SCCC Outer Code rate is set on a data Region basis. As defined in the A/153 Standard, there are four Regions (A, B, C, D) in a Group of mobile data. Each Region can be individually set to ½ or ¼ rate.

### 2.2 Parity Bytes

The RS Code can be set for 24, 36 or 48 bytes of parity.

### 2.3 RS Frame Mode

The RS Frame can be set to carry one (Primary) Ensemble of data, or two (Primary and Secondary) independent Ensembles of data (“dual Frame” mode).

### 2.4 SCCC Block Mode

The SCCC Block Mode configures the system to encode either an individual data block or two combined data blocks (Paired mode).

### 2.5 Tested Modes

There are over 100 different configurations possible for the mobile system. Selected modes that represent the endpoints and some middle points on that configuration spectrum were studied. Results with the other modes are expected to be between the end points tested.

### 2.6 Code Rates

Four different SCCC Outer Code Rate sets were selected to be measured:

- 2222
- 2244
- 2444
- 4444

The non-mixed rate modes used Paired SCCC Block Mode. Unless otherwise indicated, the tests used 48 byte parity and one RS Frame.

### 2.7 Parity Bytes

All modes were tested with 48 byte parity. Additionally, the two most common modes (2444 mixed rate and full ¼ rate) were tested with 24-byte parity.

### 2.8 RS Frame Mode

In addition to the single RS Frame mode, the performance of the independent Primary and Secondary RS Frames at both ½ rate and ¼ rate were tested. Forty-eight byte parity was used for dual RS Frame cases.

## 3. TEST ROUTE

Figure A.1 shows the route taken in the Chicago area. The test route was chosen to represent a few particularly challenging conditions and is not representative of a general coverage test. The route was divided into sections representing four different reception conditions.

- Heavily ghosted, strong signal
- Highway
- Suburban
- Weak Signal

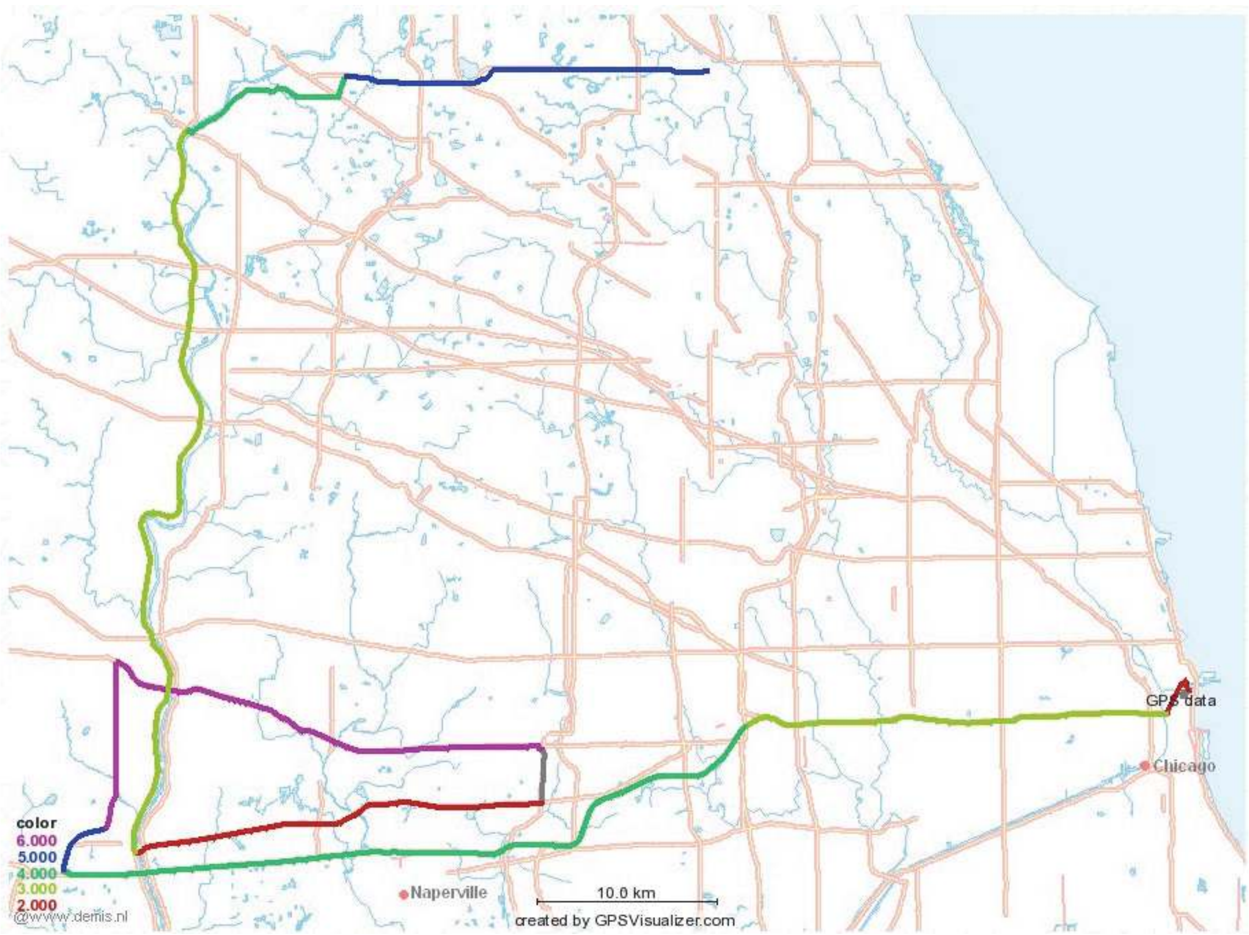

**Figure A.1** Route used to provide multiple reception conditions.

A few notes on the route segments are helpful: The transmitter is near the downtown start of the route (at the lower right part of the map). Emission was on channel 51 at 1000 kW ERP from an antenna at 523 m HAAT (station WPWR). Lower Wacker Drive is a part of the downtown portion that is completely covered above by Upper Wacker Drive, with occasional visibility to the adjoining river on one side. There is no direct line-of-sight to the transmitter. I290 and I88 are 8 lane expressways. The eastern portion of I290 is depressed below grade level, but is generally within direct sight of the transmitter. Route 31 is a rural road following along a river in the river valley. Algonquin is a section of road on the far side of a hill with complete obstruction of the direct signal.

The total route takes approximately four hours to drive, affording about 15,000 data sets per run. Each run used two to four mobile DTV Receiver Development Kits capable of recording performance data.

## 4. RELATIVE PERFORMANCE

A total of twelve runs collected data representing ten different configurations. The results are categorized in the following figures. In these figures, the horizontal axis shows each of the test modes (the two rightmost modes have reduced, 24 byte parity) and the vertical axis is the error rate as a fraction of the total route time. The absence of a bar indicates zero or insignificant errors.

### 4.1 Heavily Ghosted, Strong Signal

Figure A.2 includes the Downtown and Lower Wacker segments of the route. It can be seen that almost any mode works in strong signal conditions, even if there are very strong echoes present. Note that 2444 and 4444 results appear twice in this and later analyses. This is because the data was gathered on two different runs.

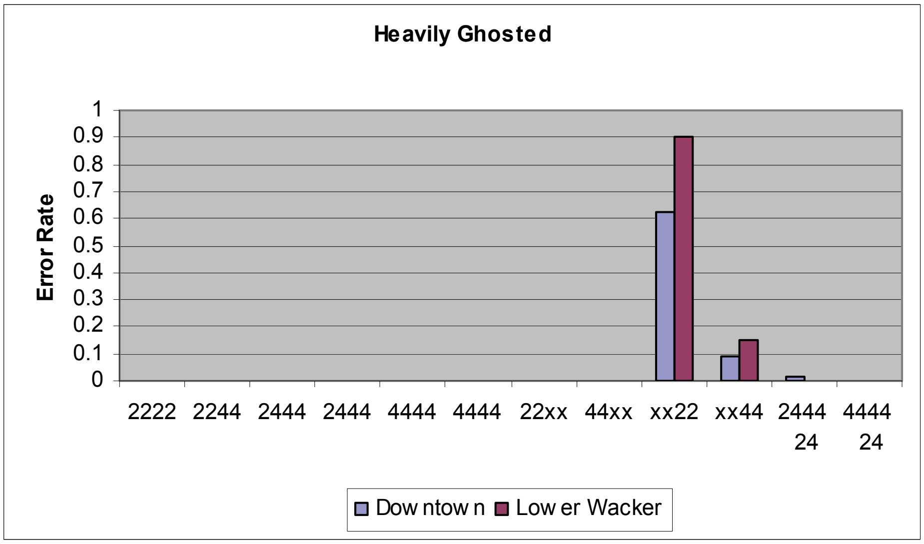

**Figure A.2** Segments with severe multipath distortion.

### 4.2 Highway

Figure A.3 includes the I290 and I88 segments of the route. The far end of the I88 segment reaches into the Fox River Valley where the signal level decreases. Highway conditions begin to show a sensitivity to the higher data rate codes (i.e., more Regions having half rate coding), but this sensitivity is small in comparison to the signal level sensitivity

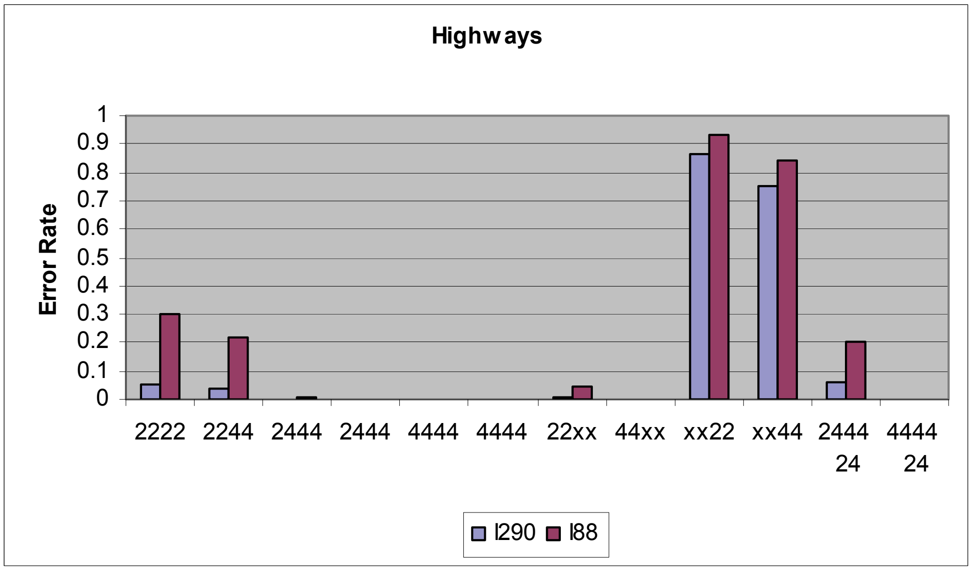

**Figure A.3** Segments with high speeds and traffic.

### 4.3 Suburban

Suburban areas (Figure A.4) show a very minor correlation to the amount of higher data rate code in use. Pure quarter rate is always best, even with reduced parity

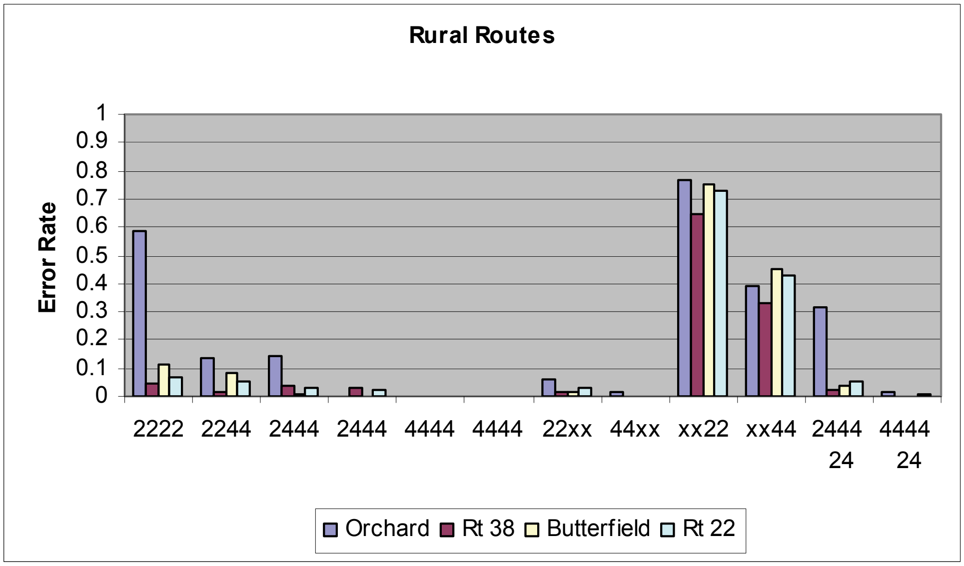

**Figure A.4** Segments in a suburban setting.

### 4.4 Weak Signal

The weak signal routes (Figure A.5) included areas with signal levels well below the threshold of reception. Along these routes, there is no obvious correlation to a varying amount of higher data rate codes. This is not surprising since the white noise threshold is similar for any mode including a Region of half rate coding. The largest change is noticed when quarter rate code is used in all Regions

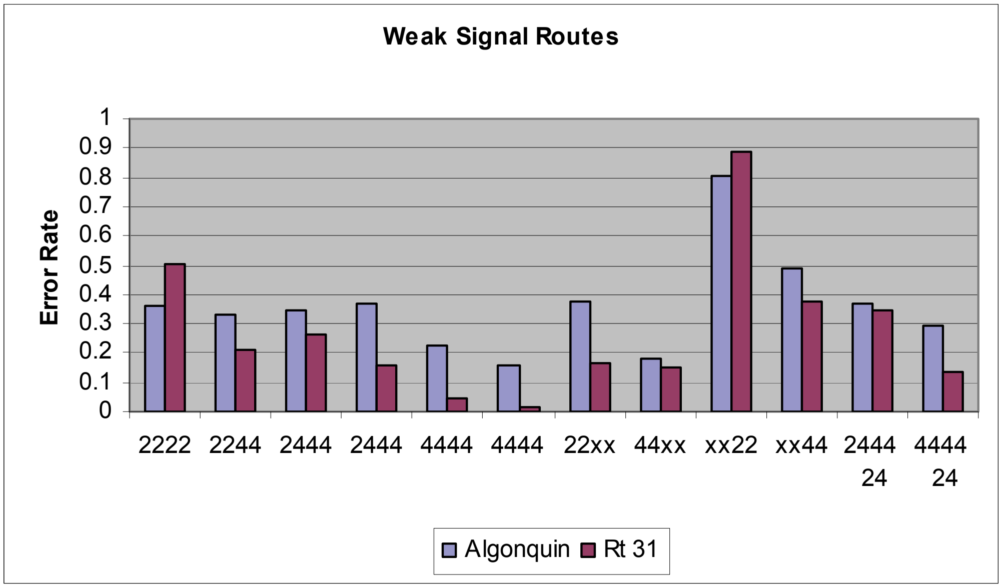

**Figure A.5** Segments including very weak signals.

### 4.5 Overall

Throughout all of the graphs above, it becomes obvious that the Secondary RS Block performance (modes xxNN) is severely reduced. Again, signal strength is the most important attribute identifiable from this study with regard to system performance for the tested modes.

A summary of the performance of all modes tested is shown in Figure A.6. Here, a visual indication of the amount of data transmitted vs. the fraction of data recovered over the entire route is shown. A recovery value of 1 is perfect reception.

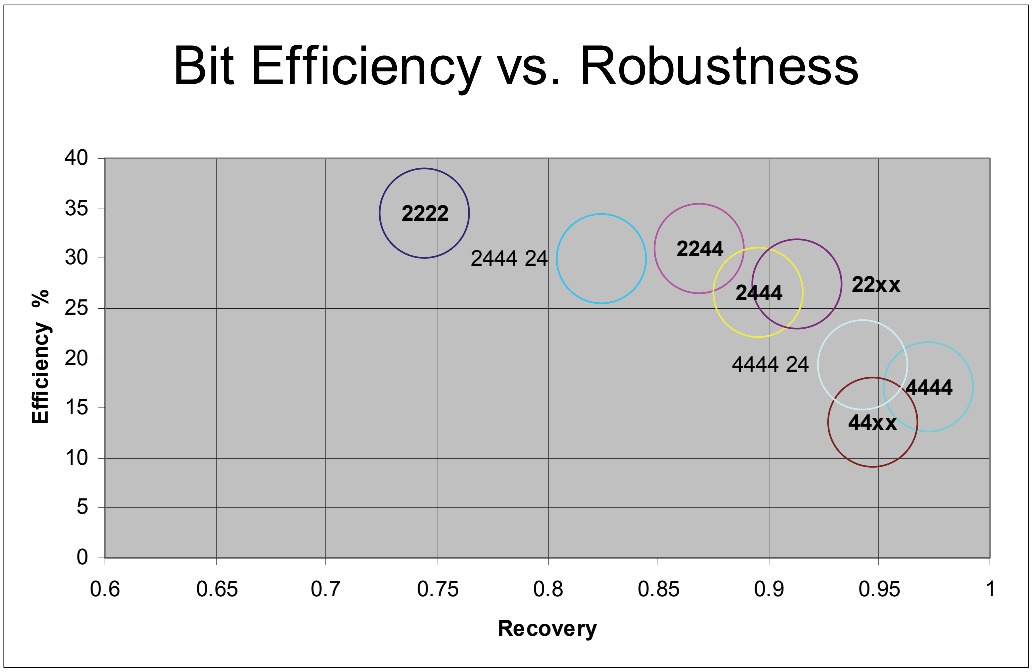

**Figure A.6** Full route performance.

The data points are represented by large circles. This is meant to be representative of the uncertainty of the results from only a single run. The overlaps are meant to indicate that different modes are not guaranteed to perform in a fixed hierarchy. Still, the general trend is obvious, that higher data payloads tend to higher error rates.

Table A.1 presents the error rates for all the tests. Note that the various route segments have vastly different lengths, were selected to represent interesting and difficult cases, and do not represent individually or in total the expected over-all error statistics for the entire urban area.

**Table A.1** Summary of Measured Error Rates (fraction of data lost)

| | **Error Rate** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2222** | **2244** | **2444** | **2444** | **4444** | **4444** | **22xx** | **44xx** | **xx22** | **xx44** | **2444 24** | **4444 24** | **Minutes Duration** |
| Downtown | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0.63 | 0.09 | 0.02 | 0. | 6 |
| Lower Wacker | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0.9 | 0.15 | 0. | 0. | 4 |
| I290 | 0.05 | 0.04 | 0. | 0. | 0. | 0. | 0.01 | 0. | 0.86 | 0.75 | 0.06 | 0. | 20 |
| I88 | 0.3 | 0.22 | 0.01 | 0. | 0. | 0. | 0.05 | 0. | 0.93 | 0.84 | 0.21 | 0. | 27 |
| Orchard | 0.59 | 0.14 | 0.15 | 0. | 0. | 0. | 0.06 | 0.02 | 0.77 | 0.39 | 0.31 | 0.01 | 14 |
| Rt 38 | 0.04 | 0.02 | 0.04 | 0.03 | 0. | 0. | 0.01 | 0. | 0.65 | 0.33 | 0.03 | 0. | 38 |
| Rt 53 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0.84 | 0.43 | 0. | 0. | 3 |
| Butterfield | 0.12 | 0.08 | 0.01 | 0. | 0. | 0. | 0.01 | 0. | 0.75 | 0.45 | 0.03 | 0. | 28 |
| Rt 31 | 0.5 | 0.21 | 0.26 | 0.16 | 0.05 | 0.01 | 0.17 | 0.15 | 0.89 | 0.37 | 0.34 | 0.13 | 63 |
| Algonquin | 0.36 | 0.33 | 0.34 | 0.37 | 0.23 | 0.16 | 0.38 | 0.18 | 0.81 | 0.49 | 0.37 | 0.29 | 17 |
| Rt 22 | 0.07 | 0.05 | 0.03 | 0.02 | 0. | 0. | 0.03 | 0. | 0.73 | 0.43 | 0.05 | 0.01 | 22 |