DTV Coverage and Service Prediction, Measurement and Performance Indices

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Abstract-- **It is now clear that methods used to predict the replication of NTSC service in the US were idealized and, for the most part, not validated. The need to review the methods and procedures now in use is highlighted by the various field tests conducted in the US and elsewhere.**

This paper outlines potential improvements in the modeling, methods and procedures now in use for prediction and measurement of DTV service.

Index Terms--**Coverage and service definitions, field test methodology, Longley-Rice propagation, Planning Factors, Effective Noise Figure, Signal-Noise ratio.**

I. INTRODUCTION

Early on, even before the 8-VSB standard was adopted, it was suggested that low-power HDTV transmission, as low as –12 dB average power relative to NTSC peak visual power, would provide for service replication to at least the Grade-B contour of NTSC stations.

It was generally thought that with incident field strength of 40.8dBu at 615 MHz, DTV receivers would be able to decode the signal and that higher field strength would not improve the reliability of reception.

Those predictions were based on an idealized receiver, a multipath-free propagation channel and coverage prediction software that uses only terrain elevation data, but not terrain clutter data [1]. Clutter data specify the land cover, such as forest, water etc. on top of the terrain elevation data. For these and other reasons, such as time availability statistics, it is now believed that the current predictions of DTV coverage and service will not be realized.

This paper outlines potential improvements in the modeling, methods and procedures now in use for prediction and measurement of DTV service.

II. SNR REQUIREMENT

The threshold Signal-Noise Ratio (SNR) of 15.2 dB, measured in the laboratories for an Additive White Gaussian Noise (AWGN) channel without multipath, is a benchmark only and that SNR should not be used for coverage prediction. Real world DTV channels with multipath distortion and/or interference will require much higher SNR values for reliable reception.

The FCC coverage prediction stipulates that a DTV receiver with a noise figure of 7 dB will be able to decode the signal when the received signal power is as low as –84 dBm, provided that the SNR ≥ 15.2 dB. Such capability has not been demonstrated even for an AWGN channel, much less for channels with real-world multipath. In fact, the noise floor of the test setups being used in field tests may have been higher than -84 dBm. The consumer-grade receiver minimum signal level is rated at -78 dBm.

An implementation margin is needed for realistic predictions of coverage and service for terrestrial DTV services. As will be shown shortly, the implementation margin should account for all undesired signals, both man-made and natural noise including Galactic or Cosmic noise.

III. PROPAGATION LOSS AND STATISTICS

Calculations show that for receivers with an outdoor antenna 30’ Height Above Ground (HAG), the Longley-Rice (L-R) model predicts coverage well beyond the Radio Horizon and well beyond the NTSC contours. This is borne out by calculations for TV stations in both flat and hilly terrain and for UHF and VHF channels as shown in Figures 1-4.

Figures 1 and 2 show the L-R coverage prediction in flat terrain around New Orleans, LA. Figure 1 is for a VHF-NTSC station with an Effective Radiated power (ERP) of 100 kW to which a UHF-DTV channel with an ERP = 1000 kW was assigned. Figure 2 is for a UHF-NTSC station with an ERP of 5000 kW to which a UHF-DTV channel with an ERP = 200 kW was assigned.

Figures 3 and 4 show the L-R coverage prediction in hilly terrain around Kansas City, MO. Figure 3 is for a VHF-NTSC station with an ERP of 100 kW to which a UHF-DTV channel with an ERP = 1000 kW was assigned. Figure 4 is for a UHF-NTSC station with an ERP of 5000

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kW to which a UHF-DTV channel with an ERP = 200 kW was assigned.

In Figures 1-4, the unshaded area around the station, at the center of the map, represents the area within the Radio Horizon. The Horizon is expected to be the edge of reliable DTV service. Coverage is predicted by L-R to the edge of the lightly shaded area, which extends 40 km beyond the Radio Horizon. The L-R coverage prediction also extends well beyond the FCC contours of the two stations. The outer edge of the dark shaded area , the area of no coverage, extends to 150 km.

Analysis of data collected in Washington DC (WHD) [2] and in New York (WCBS) [3] has confirmed the observation that the available signal within the predicted coverage area is significantly below that predicted by the L-R model.

Even less reliable prediction can be expected from the L-R model for an outdoor antenna 6’ HAG. The commonly assumed loss due to antenna height reduction is [4]:

$$\text{Loss (dB)}=(A/6)\ast 20\text{Log}_{10}(h/30) \qquad 1.5 \le h \le 40$$

Where h is in feet and A is given in Table 1.

Zone	**VHF (dB)**	**UHF (dB)**
Rural	A=4	A=4
Suburban	A=5	A=6
Urban	A=6	A=8

Table 1. Values of A for various areas.

For example, in urban areas and at UHF frequencies, the loss at 6' HAG would be -18.6 dB.

The L-R model allows for adjustable parameters such as ground clutter, percent confidence level and percentage of time/location availability. At present, ground clutter is not included, the confidence level was set at 50% and the location/time availability was set at 50/90. The values of these parameters could be adjusted as part of a validation process. The problem is that the model has not been validated for TV broadcasting: not for coverage or service, either inside the Radio Horizon or beyond the Radio Horizon.

As mentioned, that terrain clutter data was not taken into account in the L-R coverage prediction. Calculations performed at the Communications Research Centre Canada (CRC) for a DTV station near Ottawa show an average loss of 7.3 dB near the end of coverage when land cover is added to terrain height. The result of the calculations is shown in Table 2. Near the end of coverage the loss is higher and the distance to the radio Line-Of-Sight (LOS) becomes shorter.

The CRC's method of adding land cover data to L-R terrain data is a significant improvement over L-R calculation with only terrain elevation data. Even so, the gap between L-R and known measurements is higher than 7.3 dB as shown in Figures 1-4.

Site #	Distance (km)	Bearing (deg)	Signal Loss due to Added Land Cover (dB)
1	39	-146	11.7
2	32	-128	5.9
3	51	-130	8.2
4	65	-109	4.1
5	35	-98	6.5
6	53	-79	8.1
7	50	-65	8.1
8	43	-41	8.2
9	59	-31	9.8
10	53	-5	4.9
11	34	5	4.7
12	48	34	5.7
13	50	52	7.0
14	32	60	8.3
15	56	81	6.8
16	49	92	11.4
17	39	110	5.4
18	62	99	9.6
19	51	118	10.4
20	30	132	8.2
21	60	132	4.2
22	45	149	7.9
23	32	168	5.0
24	49	-170	5.8

Table 2. Results of calculations for 24 locations:
Average loss due to land cover = 7.3 dB
Standard deviation = 2.2 dB

IV. RECEIVER/ANTENNA MODEL FOR COVERAGE PLANNING

A realistic model would include the effect of impedance mismatches between the antenna and the input to the receiver and, for a fixed receiver, the additional loss incurred by any signal splitter to the VCR or second receiver. The impedance mismatches result in lower antenna gain, added signal loss, change in the receiver’s Noise Figure [5,6,11] and may result in added equalization loss.

A complete analysis of the overall effects of the impedance mismatches between the antenna and the tuner is presented in the Appendix. The results indicate a significant and previously unaccounted-for loss in the SNR margin in every TV band. For example, the effects of a typical impedance mismatch between the antenna and tuner on the added loss and group delay are shown for VHF and UHF frequencies in Figures 5-7. For channel 2-6, the added loss may be 3.5 dB and the Group Delay ±15 nsec. For channel 7-13, the added loss may be 3.3 dB and the Group Delay ±12 nsec. For UHF channels, the added loss may be 2.8 dB and the Group Delay ±5 nsec.

The factory specified Noise Figure is based on measurement with a noise source whose input resistance is constant, either 50Ω or 75Ω. The actual Noise Figure of a TV receiver depends on the impedance of the signal source, which is typically the antenna.

Two examples of how the antenna VSWR affects the noise figure will be presented here. For a log-periodic set-top antenna, the worst VSWR (2.9) occurs at about 752 MHz (Channel 61) and the minimum VSWR (1.466) occurs at about 480 MHz (Channel 15). For the double bow-tie antenna with a screen and a balun, the worst VSWR (9) occurs at about 470 MHz (Channel 14) and the minimum VSWR (1.446) occurs at about 652 MHz (Channel 44). Using this data together with the results of Tables A1 and A2 and equations A11-A12 in the Appendix, we can readily estimate the range of noise figure degradation caused by these antennas. For the range of all possible $|\Gamma_{opt}|$, which is the magnitude of the complex source reflection coefficient corresponding to the minimum noise figure, the results are shown in Table 3. The extreme values of $|\Gamma_{opt}|$ in Table 3 (i.e. 0.05 and 0.9) are shown mainly for illustration purposes as it is quite unlikely for the optimum reflection coefficient of actual tuners to be so far away from (or so close to) 75 Ω. Excluding these extreme values of $|\Gamma_{opt}|$ in Table 3, the estimated degradation to the factory noise figure could reach 20 dB and is about 6 to 7 dB higher with the double bow-tie antenna.

$\|\Gamma_{opt}\|$	**Min-Max Noise Figure Degradation for Log-periodic Antenna (dB)**	**Min-Max Noise Figure Degradation for Double Bow-Tie Antenna (dB)**
0.05	**3-17**	**3-25**
0.1	**0-13**	**0-20**
0.2	**0-10**	**0-17**
0.3	**0-10**	**0-16**
0.4	**0-10**	**0-16**
0.5	**0-11**	**0-17**
0.6	**0-12**	**0-18**
0.7	**0-14**	**0-20**
0.8	**0-18**	**0-24**
0.9	**0-24**	**0-30**

Table 3. Estimated noise figure degradation for the range of possible $|\Gamma_{opt}|$ and F_{75} = 6-9 dB. See Tables A1 and A2.

The two examples shown are based on a short length of cable between the antenna and tuner. The effect of arbitrary length is treated in Section III of the Appendix.

A realistic receiver model should be based on proper characterization of the total noise level. The power levels of these sources have been quantified [7] and the results, modified for US channel width, are shown in Figure 8. With outdoor antennas, and especially in the Low-VHF range, Man-made and Galactic sources are the predominant contributors of noise and far exceed the noise power generated within the receiver.

At present, the only assumed source of noise power is thermal noise at room temperature. What Figure 8 shows is that the combination of Man-made and Galactic noise power may easily account for a loss of 10-20 dB of SNR margin at Low-VHF frequencies.

Although setting the ideal receiver's performance in an AWGN channel is a valuable benchmark, such benchmarking is of limited use for practical service planning. With a realistic model, the SNR requirement will exceed 15.2 dB and the minimum detectable signal will be significantly higher than the –84 dBm implied by the current FCC's planning factors [1].

It is of interest to note that complete characterization and calibration of receivers for real-world operation has not been made available. For example, the Effective Noise Figure is unknown and the SNR requirement at input levels below –68 dBm is unknown. The field test method now in use to determine coverage and service is based on an equipment setup that does not simulate the receiver called-for by the FCC or any available consumer-grade receivers.

Clearly the practical modeling of receivers for outdoor, indoor, pedestrian, and mobile applications is desirable.

V. MINIMUM SIGNAL LEVEL

Recent reports on field testing in the US [8, 9] and Brazil [10] have demonstrated that the minimum decodable signal levels are well above those assumed in the planning factors. In the UHF band, that field strength level is near 50 dBu compared with the specified value of 41 dBu. For VHF channel 2, the minimum field strength at which the DTV signal is decodable, is at least 40 dBu compared with the specified value of 28 dBu.

Field strength is defined and measured at a single wavelength and the usage of this term for wide-band signals is misleading. To emphasize this point, quotation marks will be applied in this paper henceforth to this term.

The discrepancy between the expected and actual signal level at which the DTV signal is decodable has not been explained. In the UHF band the discrepancy is probably due to a combination of incorrect SNR requirement, impedance mismatches between the antenna and the receiver's input, incorrect factory noise figure, and error in predicting the "field strength." In the Low VHF band, the missing Galactic, Impulse and Man-made noise margins would be additional and dominant elements in the cited discrepancy.

VI. FIELD TEST SAMPLING STATISTICS

Proper statistical sampling is a prerequisite if the data are to be validly projected as representative of the area in question. For coverage estimation, the sample should be representative of the predicted service contour area. For service estimation, the sample should be representative of the population inside the F (50,90) contour.

For example, testing at 10 indoor locations in downtown NYC, with successful (100%) reception, is of little value to broadcasters. Similarly, testing at 100 outdoor locations in the suburbs with successful (100%) reception cannot serve as a basis for coverage or service determination.

For coverage estimation, the sample must be weighted for (separate) areas inside and beyond the Radio Horizon bounded by the predicted service contour.

Service estimation may require more extensive testing than heretofore was deemed sufficient. The sample must be weighted for (separate) populations inside and (separate) beyond the Radio Horizon. At least inside the Radio Horizon, the sample should be representative of (separate) metropolitan, suburban and rural populations.

VII. FIELD TEST SETUP

In all documented measurements to date, the "White Noise Added" technique was used. This technique masks the effect of the impedance mismatch between the antenna and tuner and entirely masks the receiver's Noise Figure. This technique would also mask the Galactic, Man-made and Impulse Noise present at VHF.

The AWGN noise injected at all locations to determine the SNR margin is not representative of real-world propagation channels (Ricean and Rayleigh). For example, injecting AWGN during indoor testing where reception is subject to movement by people and vehicles, tree sway etc. would not provide a realistic SNR margin for the environment being tested. The difference could be significant. Places where SNR margin ≥ 0 dB would be classified as locations with good reception. This methodology masks the problems in consumer-grade equipment, such as impedance mismatches and real noise figure, and makes the margin look better than it really is.

Further, the Pass/Fail approach used to-date does not answer the question of why is there a failure. For example, the most recent MSTV/NAB [8] test shows that 60% of the failed sites with outdoor antenna at 30' HAG met the minimum SNR. Why then did they fail?

VIII. SNR AND "FIELD STRENGTH" MEASUREMENT VIA SPECTRUM INTEGRATION

For DTV signals with 8-VSB modulation, a definition of SNR, which is mathematically founded, intuitively acceptable to engineers and measurable in the laboratory and in field tests, is unavailable.

Intuitively, Signal = Desirable Power and Noise = Undesirable Power. At the transmitter room, a Vector Analyzer has been used to measure the power of desired symbols and the power of error vector around the desired symbols. But in the field, where heavy multipath is common, it is not at all clear whether part or all of the multipath should be treated as Signal or as Noise. In other words, under what conditions does multipath increases the SNR and under what condition does multipath increase the Inter Symbol Interference (ISI)?

Defining the Signal as the total received power and the Noise as AWGN leads to the conclusion that the SNR at the input to the receiver increases with increased multipath. In urban and indoor situations, there may not even be a main signal, only reflections, some of which are of equal magnitude. If all multipath signals are part of the signal power, then the SNR margin may not be an indicative figure of merit of reception robustness. In any case, even accurate measurement of the total received power may not be trivial.

When the received power is measured by integrating the power spectrum curve (or segments thereof) as displayed on a spectrum analyzer, the result may contain an error of unknown magnitude.

The integrated signal power is not just the Desired Signal power. It includes, Man-made, Galactic, and thermal noises and residual transmitter generated in-band noise. It also includes some but not necessarily all multipath signals. For example, pairs of identical and asymmetric echoes, one of positive amplitude and positive delay relative to the main signal and one of negative amplitude and negative delay relative to the main signal, will cause only a second-order distortion of the displayed power spectrum. They will create group delay. Thus, in a multipath channel, a pair of such echoes would measure high SNR when using the spectrum integration technique whereas in reality, the true SNR would be much lower. There may be other combinations of echoes that would yield essentially flat spectrum display.

One approach that may help identify and rectify the multipath problem cited, is to apply an appropriate form of diversity reception to the spectrum integration method.

The integration method is relatively inexpensive. Whether it compares favorably, in most environments, with more sophisticated instrumentation has not, to the writers' knowledge, been determined. Even if the spectrum integration technique were improved with diversity reception, the measured SNR would still have an error of unknown magnitude. That is so because SNR degradation in multipath channels is due to two separate components: Amplitude distortion and pulse broadening ("dispersion fading") [13,14]. Only amplitude distortion will be seen on the spectrum analyzer's display.

In the spectrum integration method, the “field strength” is derived from the measured total received power including multipath, noise etc. and assuming the gain of the antenna is known. Calibration of the antenna’s gain by comparing it to a “tuned” reference dipole is another source of error as the antenna gain may be affected by its local surroundings. How the receive antenna could be tuned and its gain and directivity at the measured frequency be determined except when measured on a calibrated range, has not been explained in any of the test procedures. In fact, the outdoor characteristics of the test and reference antennas do not apply to indoor environments.

IX. DEFINITIONS

A. Coverage

Coverage describes the statistical availability of the signal power to the receiver within the station’s F(50,90) contour.

> ***Coverage Index*** = % of sampled locations with incident “field strength” (or power flux density) ≥ minimum “field strength” (or power density) required for reception at 30’ HAG.

The minimum “field strengths” are specified by the FCC as 41 dBu for UHF channels, 36 dBu for channels 7-13 and 28 dBu for channels 2-6.

The measurement of coverage is subject to proper sampling (Section VI) and the calculation is subject to the FCC’s choice of propagation model. The Coverage Index assumes an AWGN channel and Log-normal distribution. The median signal and standard deviation should be specified.

Locations subject to heavy multipath and/or interference should be avoided as the would-be errors in the statistical distribution and the measurement itself may be hard to quantify.

B. Service

Fixed Outdoor Service describes the statistical availability of reliable DTV reception anywhere and anytime within the station’s F (50,90) contour using a consumer-grade receiver connected to a directional outdoor antenna through a coaxial cable.

Fixed Indoor Service describes the statistical availability of reliable DTV reception anywhere and anytime within the station’s F (50,90) contour using a consumer-grade receiver directly connected to a portable indoor antenna through a short cable. This includes electronically controlled "smart" antennas.

> ***Fixed Service Index*** = % of sampled locations where reception without impairments for ≥ X minutes has been possible.

The measurement of service is subject to proper sampling (Section VI).

It is important to emphasize that service measurements must be made from the point of view of the consumer. Therefore, the location and rotation of antenna must be limited. The height and gain of the antennas may be arbitrary, but must be specified. The choice of receiver manufacturer is also arbitrary, so long as the receiver is compliant with certain performance parameter values, which are either specified or implied in the FCC Planning Process for DTV.

C. System Performance

System performance describes the expected rather than actual service at the sampled locations where the incident “field strength” (or power flux density) ≥ minimum required “field strength” (or power flux density) specified for reception at 30’ AG.

> ***System Performance Index*** = % of sampled locations where the minimum “field strength” (or power flux density) required for reception at 30’ AG was met and reception, indoor and (separate) outdoor without impairments for ≥ X minutes has been possible.

The system performance index is calculated from coverage and service measurements. It can be assigned to both indoor and outdoor reception.

SNR should not be substituted for the “field strength” because in many locations with adequate "field strength" the SNR may be below threshold due to noise, interference and multipath.

X. CONCLUSIONS

The present planning factors, prediction and measurement of DTV coverage and service are not adequate. They could and should be significantly improved.

A definition of SNR, which is mathematically founded, intuitively acceptable to engineers and which is measurable in the laboratory and in field tests, would be very helpful.

The planning factors should be based on real-world noise figure and real-world noise sources and real-world threshold SNR. The planning factors should include the option of using a Low Noise Amplifier (LNA) where appropriate.

The L-R propagation algorithm should be modified and validated for reasonable prediction of signal level at various heights above ground. Modifications may include ground clutter and improved probabilities for time, location and confidence factors.

The current field testing methodology should be changed. Coverage and service measurements should be revised to minimize potential errors. The receiver used in the measurements should be well characterized and allowed to operate at the lowest signal level as prescribed by the planning factors.

A significant improvement in system performance can be expected if the receive antenna is electronically integrated with the receiver. Such "smart" antenna would include electronically controlled LNA and impedance matching and AGC control circuitry. Space diversity reception and directional pattern steering could be also added.

APPENDIX

The factory-specified Noise Figure is based on a matched source-generator measurement. The Effective Noise Figure, accounting for the mismatch at the antenna and at the receiver's front-end, may be higher than the 7 dB for UHF channels used in the FCC's Planning Factors. The Effective Noise Figure may be defined as:

$$F(\text{dB}) = 10*\text{Log}_{10}(F_{75}+\Delta F) - 10*\text{Log}_{10}(\Delta L) + 10*\text{Log}_{10}(EQ)$$

Where:

F_{75}=Factory noise figure measured with matched impedance noise source.

ΔF=Change in F_{75} due to the antenna impedance mismatch. See equation (A6).

ΔL=Increase in the power transfer loss due to the antenna impedance mismatch.

EQ=Power penalty by the equalizer. The equalizer penalty is a nonlinear function and must be determined experimentally.

For a straight section of line with length x and a propagation constant $\gamma=\alpha+j\beta$, the added power loss, ΔL, due to mismatched impedance is:

$$\Delta L = \frac{\left(1-|\Gamma_A|^2\right)\left(1-|\Gamma_R|^2\right)}{\left|1-e^{-2\gamma x}\Gamma_A\Gamma_R\right|^2} \tag{A1}$$

Where Γ_A and Γ_R are, respectively, the reflection coefficients of the antenna and the receiver, and $\gamma=\alpha+j\beta$.

The real part of the propagation constant, α, is the attenuation and the imaginary part of the propagation constant is $\beta=2\pi/\lambda g$ where λg is the wavelength in the propagation medium. The added loss is in addition to the loss without mismatches, which is given by $e^{-2\alpha x}$.

The total group delay variation due to the impedance mismatch between the antenna and the front-end of the receiver is given by:

$$\frac{d\Phi}{d\omega} = \frac{x}{v}\left[1-2|\Gamma_A||\Gamma_R|e^{-2\alpha x}\,\frac{|\Gamma_A||\Gamma_R|e^{-2\alpha x} - Cos(-2\beta x+\Psi)}{1+|\Gamma_A|^2|\Gamma_R|^2 e^{-4\alpha x} - 2|\Gamma_A||\Gamma_R|e^{-2\alpha x}Cos(-2\beta x+\Psi)}\right] \tag{A2}$$

Where v = phase velocity and $\Gamma_A\Gamma_R = |\Gamma_A||\Gamma_R|e^{j\Psi}$

The relationship between the noise figure of the DTV receiver and the *complex* reflection coefficient of the antenna with the downlead cable, Γ_s, is [11]:

$$F = F_{opt} + \frac{4\,r_n\left|\Gamma_s-\Gamma_{opt}\right|^2}{\left(1-|\Gamma_s|^2\right)\left|1+\Gamma_{opt}\right|^2} \tag{A3}$$

Where F_{opt} is the minimum (optimum) noise figure, Γ_{opt} is the complex source reflection coefficient corresponding to the minimum noise figure, and r_n is the normalized equivalent input noise resistance of the tuner (i.e. $r_n = R_N/Z_o$ with Z_o = 75 Ω, usually).

Let the F_{75} be the tuner noise figure when the source is *matched* to 75 Ω, i.e. when $\Gamma_s = 0$ in eq. (A3):

$$F_{75} = F_{opt} + \frac{4\,r_n\left|\Gamma_{opt}\right|^2}{\left|1+\Gamma_{opt}\right|^2} \tag{A4}$$

F_{75} can also be called the *factory noise figure* measured with a matched source of 75 Ω. Solving eq. (A4) for r_n yields:

$$r_n = \left(F_{75} - F_{opt}\right)\frac{\left|1+\Gamma_{opt}\right|^2}{4\left|\Gamma_{opt}\right|^2} \tag{A5}$$

The noise figure degradation can readily be found by subtracting eq. (A4) from (A3):

$$\Delta F = F - F_{75} = \frac{4\, r_n}{\left|1+\Gamma_{opt}\right|^2}\left[\frac{\left|\Gamma_s - \Gamma_{opt}\right|^2}{\left(1-\left|\Gamma_s\right|^2\right)} - \left|\Gamma_{opt}\right|^2\right] \qquad \text{(A6)}$$

Clearly, all the above parameters are *frequency-dependent.* Moreover, all the complex reflection coefficients have a magnitude *smaller than one* since all these impedances have a *positive* real part:

$$\left|\Gamma_s\right| < 1 \, and \left|\Gamma_{opt}\right| < 1 \qquad \text{(A7)}$$

At the time of writing, only Γ_s is known accurately from measurements made on typical set-top indoor antennas across the UHF band. However, it is known that for DTV tuners, the factory noise figure F_{75} is typically around 4 (6 dB) but can be as high as 7.94 (9 dB) on some UHF channels. In light of these figures, let us assume that the optimum noise figure F_{opt} cannot typically be much lower than 5 dB (3.2) for the “good” channels and around 7.5 dB (5.62) on those “bad” UHF channels.

As mentioned earlier, r_n and Γ_{opt} are routinely measured for microwave transistors, but are not usually supplied by tuner manufacturers. It is nonetheless possible to give *bounds* for r_n with the help of (A7) without knowing the phase of Γ_{opt}. Given the triangle inequality

$$|\, a \,| - |\, b \,| \leq |\, a \pm b \,| \leq |\, a \,| + |\, b \,| \qquad \text{(A8)}$$

where a and b are complex numbers, the following inequality holds:

$$\left(1-\left|\Gamma_{opt}\right|\right)^2 \leq \left|\,1+\Gamma_{opt}\,\right|^2 \leq \left(1+\left|\Gamma_{opt}\right|\right)^2 \qquad \text{(A9)}$$

Using eq. (A9), eq. (A5) now becomes:

$$\left(F_{75} - F_{opt}\right)\frac{\left(1-\left|\Gamma_{opt}\right|\right)^2}{4\left|\Gamma_{opt}\right|^2} \leq r_n \leq \left(F_{75} - F_{opt}\right)\frac{\left(1+\left|\Gamma_{opt}\right|\right)^2}{4\left|\Gamma_{opt}\right|^2} \qquad \text{(A10)}$$

Using (A10) and the above values for F_{75} and F_{opt}, we can put bounds on r_n for different values of $|\Gamma_{opt}|$ for a typical “good” UHF channel:

$\|\Gamma_{opt}\|$	$r_{n\ min\ good\ ch}$	$r_{n\ max\ good\ ch}$
0.05	72.2	88.2
0.1	16.2	24.2
0.2	3.2	7.2
0.3	1.09	3.76
0.4	0.45	2.45
0.5	0.2	1.8
0.6	0.089	1.42
0.7	0.0367	1.18
0.8	0.0125	1.01
0.9	0.00247	0.891

Table A1. Bounds for $r_{n\ good\ ch}$ for the range of possible values of $|\Gamma_{opt}|$ for a typical “good” UHF channel for the tuner assuming that F_{75} is 6 dB (4) and that the minimum noise figure F_{opt} is 5 dB (3.2).

For a “bad” UHF channel assuming that F_{75} equals 7.94 (9 dB) and that F_{opt} equals 7.5 dB (5.62), (8) yields:

$\|\Gamma_{opt}\|$	$r_{n\ min\ bad\ ch}$	$r_{n\ max\ bad\ ch}$
0.05	209.38	255.78
0.1	46.98	70.18
0.2	9.28	20.88
0.3	3.16	10.89
0.4	1.31	7.11
0.5	0.58	5.22
0.6	0.258	4.12
0.7	0.107	3.42
0.8	0.036	2.94
0.9	0.0072	2.59

Table A2. Bounds for $r_{n\ bad\ ch}$ for the range of values of possible $|\Gamma_{opt}|$ for a typical “bad” UHF channel for the tuner assuming that F_{75} is 9 dB (7.94) and that the minimum noise figure F_{opt} is 7.5 dB (5.62).

I. ESTIMATED WORST NOISE FIGURE DEGRADATION FOR “BAD” UHF CHANNELS FOR THE TUNER AND THE WORST ANTENNA VSWR

Using the upper part of the triangle inequality (eq. (A8)) with eq. (A6), the worst noise figure degradation for “bad” UHF channels can be estimated by:

$$\Delta F_{\max bad\ ch} = \frac{4\, r_{n\ \max bad\ ch}}{\left(1-\left|\Gamma_{opt}\right|\right)^2}\left[\frac{\left(\left|\Gamma_{s\max}\right| + \left|\Gamma_{opt}\right|\right)^2}{\left(1-\left|\Gamma_{s\max}\right|^2\right)} - \left|\Gamma_{opt}\right|^2\right] \qquad \text{(A11)}$$

where $|\Gamma_{s\ max}|$ is the magnitude of the *worst* reflection coefficient of the antenna and its downlead cable in the band of operation.

II. ESTIMATED MINIMUM NOISE FIGURE DEGRADATION FOR “GOOD” UHF CHANNELS FOR THE TUNER AND THE BEST ANTENNA VSWR

Using the triangle inequality (eq. (A8)) with eq. (A6), the *minimum* noise figure degradation for “good” UHF channels can be estimated by:

$$\Delta F_{\min\, good\ ch} = \frac{4\, r_{n\,\min\, good\ ch}}{\left(1+\left|\Gamma_{opt}\right|\right)^2}\left[\frac{\left(\left|\Gamma_{s\,\min}\right|-\left|\Gamma_{opt}\right|\right)^2}{\left(1-\left|\Gamma_{s\,\min}\right|^2\right)} - \left|\Gamma_{opt}\right|^2\right] \tag{A12}$$

where $|\Gamma_{s\ min}|$ is the magnitude of the *lowest* reflection coefficient of the antenna and its downlead cable in the band of operation.

The dependence of the effective noise figure on the mismatch is not bounded by an upper limit. Increased mismatch would result in increased noise figure and eventually cause a loss of service. This effect is of particular importance when Hi-Q antennas such as loops and monopoles are combined with tuners that exhibit high mismatch relative to the designed input impedance of 75 ohms.

III. THE EFFECT OF A LONG DOWNLEAD CABLE

The estimates in Table 3 assumed that the tuner was connected directly or through a short piece of coaxial cable to a set-top antenna. For an arbitrary length of cable, the cable's attenuation must be taken into account either at the input to the tuner or at the input to the antenna.

Let Γ_A be the complex antenna reflection coefficient measured at the plane of its connector. Then Γ_s at the input of the tuner, i.e. at a distance x from the plane of the antenna’s connector, is given by [12]:

$$\Gamma_s = \Gamma_A\, e^{-2j\beta x - 2\alpha x} \tag{A13}$$

where x is the length of the downlead cable. In terms of the magnitude of these reflection coefficients, (A13) can be rewritten as:

$$|\Gamma_s| = |\Gamma_A|\, e^{-2\alpha x} \tag{A14}$$

For 50' of RG-59 coaxial cable, the exponential term amounts to 1 dB for channels 2-6, 2 dB for channels 7-13 and 4 dB at UHF.

Thus, at the input plane of the DTV receiver, a long downlead cable decreases the antenna VSWR. For practical lengths of cable, the added attenuation would reduce somewhat the range of ΔF in Table 3.

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Figure Captions

Fig. 1. Longley-Rice (L-R) DTV coverage in flat terrain: VHF-NTSC to UHF-DTV @ 1000 kW. Radio horizon @ 84 km, L-R coverage fringe @ 125 km. Inner contour: F(50,90) of UHF-DTV; outer contour: F(50, 50) of VHF-NTSC.

Fig. 2. Longley-Rice DTV coverage in flat terrain: UHF-NTSC to UHF-DTV @ 200 kW. Radio horizon @ 84 km, L-R coverage fringe @ 110 km. Contours of F(50,90) of DTVand F(50, 50) of NTSC overlap.

Fig. 3. Longley-Rice DTV coverage in hilly terrain: VHF-NTSC to UHF-DTV. Radio horizon @ 60-80 km, L-R coverage fringe @ 100-125 km. Inner contour: F(50,90) of UHF-DTV; outer contour: F(50, 50) of VHF-NTSC.

Fig. 4. Longley-Rice DTV coverage in hilly terrain: UHF-NTSC to UHF-DTV. Radio horizon @ 60-80 km, L-R coverage fringe @ 100-125 km. Contours of F(50,90) of DTVand F(50, 50) of NTSC overlap.

Fig. 5. Added loss and group delay due to antenna/tuner impedance mismatch for Channels 2-4. Antenna VSWR: 3 and tuner VSWR: 3.

Fig. 6. Added loss and group delay due to antenna/tuner impedance mismatch for Channels 7-9. Antenna VSWR: 3 and tuner VSWR: 3.

Fig. 7. Added loss and group delay due to antenna/tuner impedance mismatch for UHF channels. Antenna VSWR: 3 and tuner VSWR: 3.

Fig. 8. Median values of man-made and galactic noise power relative to kTB according to Recommendation ITU-R PI.372.-6.

Table Captions

Table 1. Values of A for various areas.

Table 2. Results of calculations for 24 locations: average loss due to land cover = 7.3 dB and standard deviation = 2.2 dB.

Table 3. Estimated noise figure degradation for the range of possible $|\Gamma_{opt}|$ and F_{75} = 6-9 dB. See Tables A1 and A2.

Table A1. Bounds for $r_{n\ good\ ch}$ for the range of possible values of $|\Gamma_{opt}|$ for a typical “good” UHF channel for the tuner assuming that F_{75} is 6 dB (4) and that the minimum noise figure F_{opt} is 5 dB (3.2).

Table A2. Bounds for $r_{nbad\ ch}$ for the range of values of possible $|\Gamma_{opt}|$ for a typical “bad” UHF channel for the tuner assuming that F_{75} is 9 dB (7.94) and that the minimum noise figure F_{opt} is 7.5 dB (5.62).

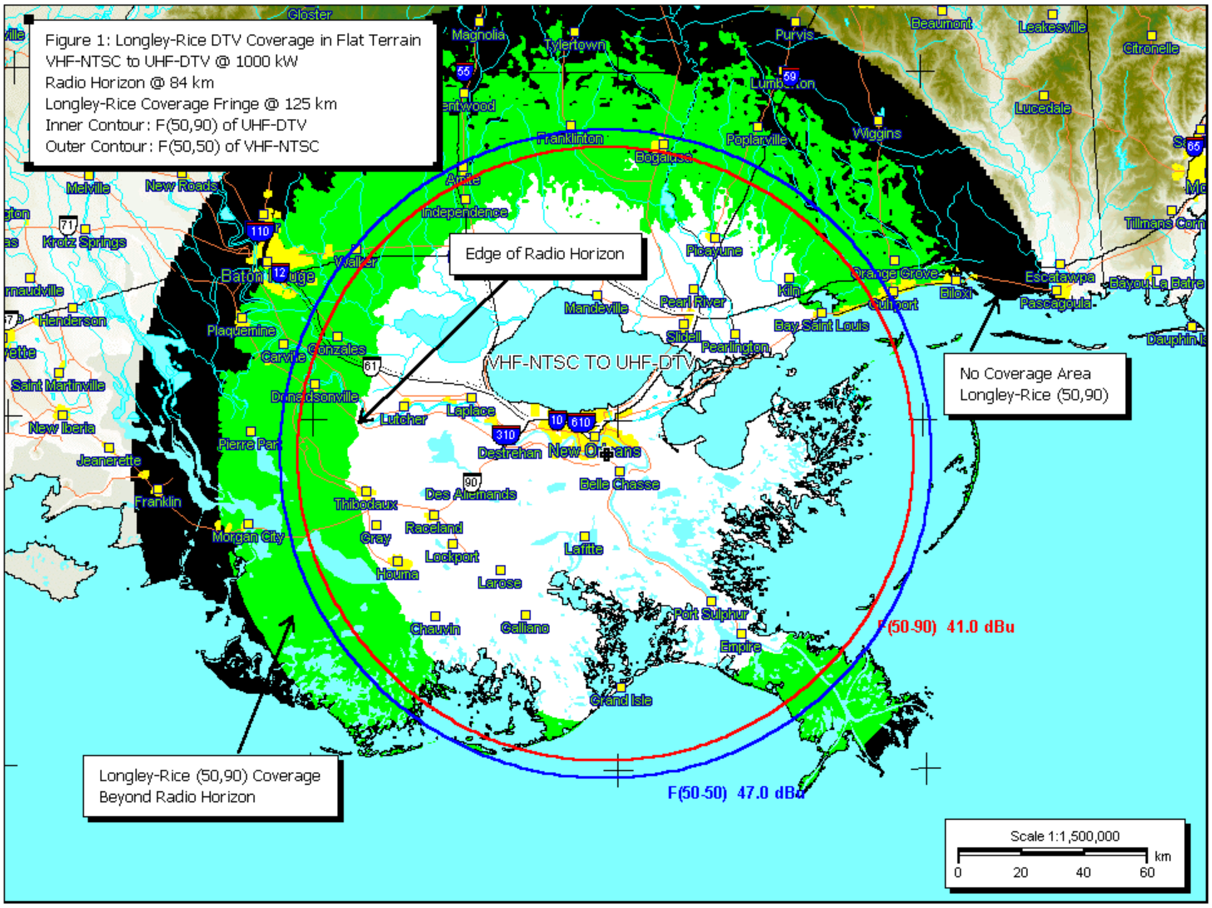


Figure 1: Longley-Rice DTV Coverage in Flat Terrain
VHF-NTSC to UHF-DTV @ 1000 kW
Radio Horizon @ 84 km
Longley-Rice Coverage Fringe @ 125 km
Inner Contour: F(50,90) of UHF-DTV
Outer Contour: F(50,50) of VHF-NTSC

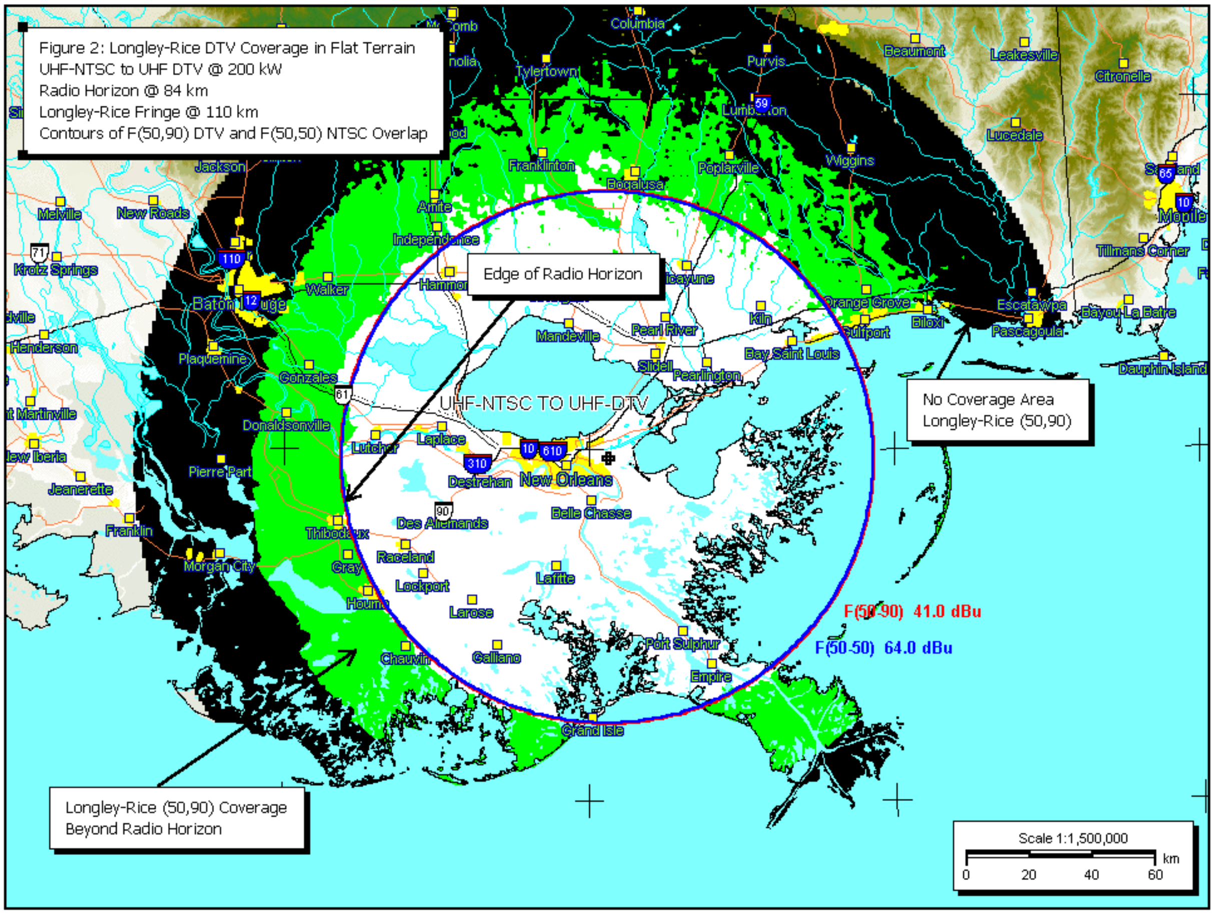


Figure 2: Longley-Rice DTV Coverage in Flat Terrain
UHF-NTSC to UHF DTV @ 200 kW
Radio Horizon @ 84 km
Longley-Rice Fringe @ 110 km
Contours of F(50,90) DTV and F(50,50) NTSC Overlap

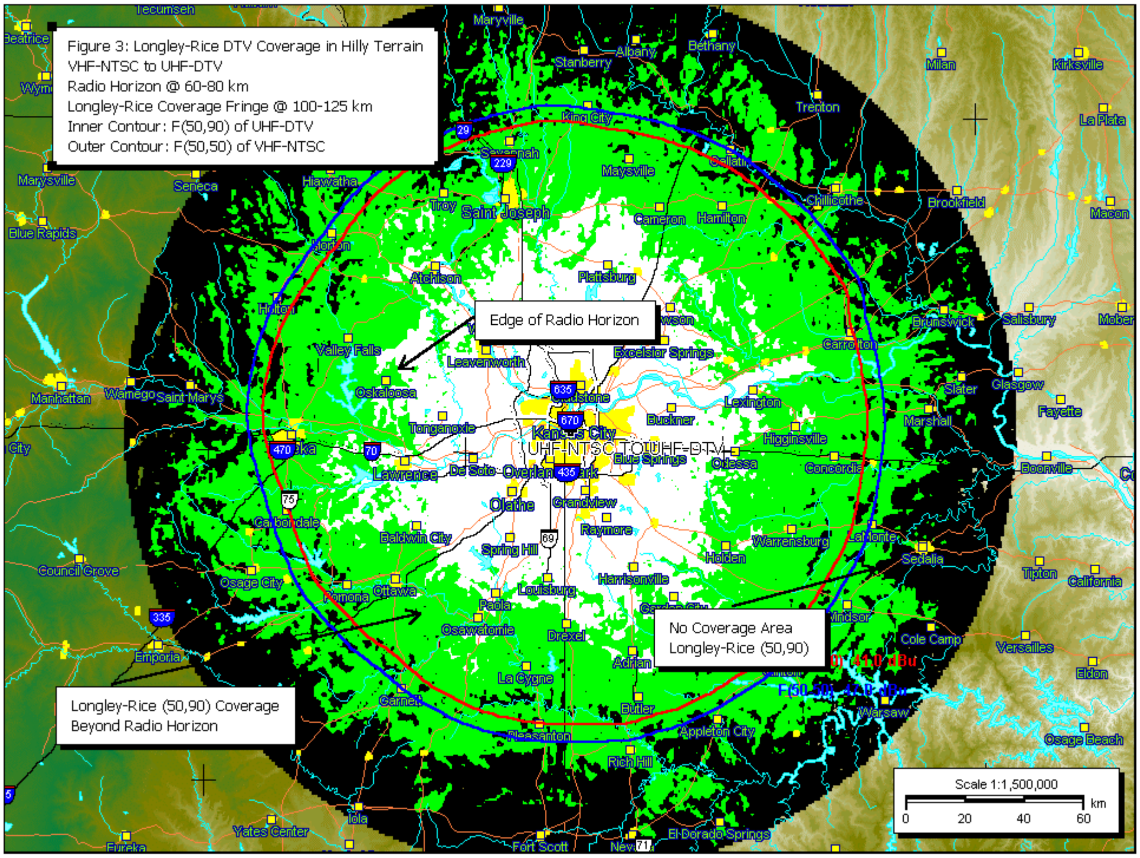


Figure 3: Longley-Rice DTV Coverage in Hilly Terrain
VHF-NTSC to UHF-DTV
Radio Horizon @ 60-80 km
Longley-Rice Coverage Fringe @ 100-125 km
Inner Contour: F(50,90) of UHF-DTV
Outer Contour: F(50,50) of VHF-NTSC

Edge of Radio Horizon

No Coverage Area
Longley-Rice (50,90)

Longley-Rice (50,90) Coverage
Beyond Radio Horizon

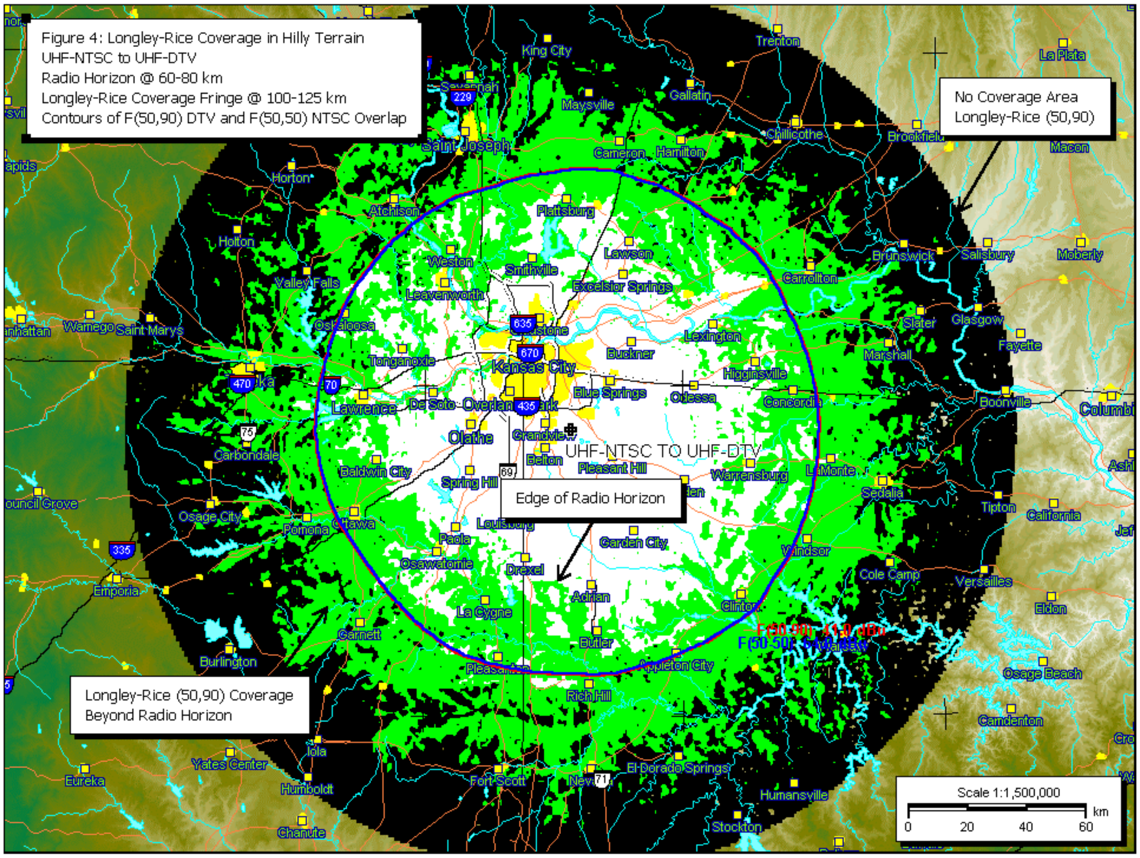


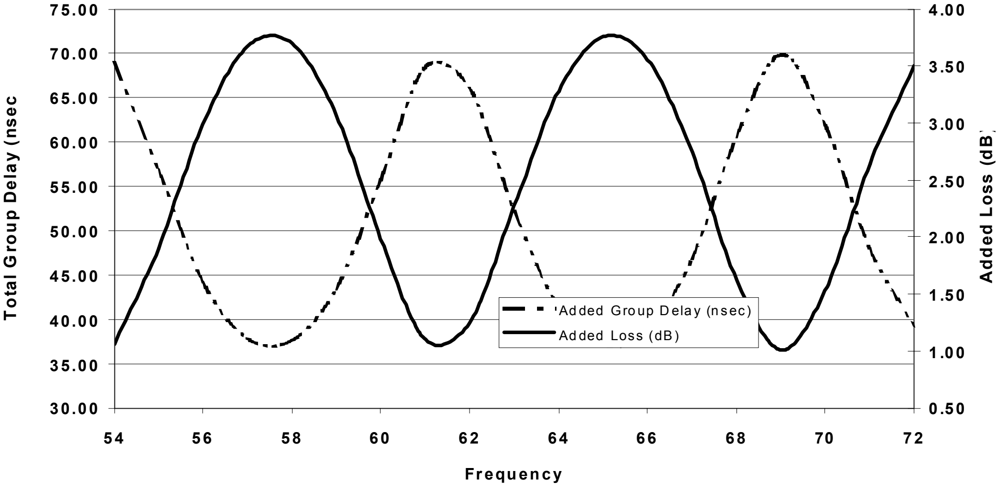
Figure 4: Longley-Rice Coverage in Hilly Terrain
UHF-NTSC to UHF-DTV
Radio Horizon @ 60-80 km
Longley-Rice Coverage Fringe @ 100-125 km
Contours of F(50,90) DTV and F(50,50) NTSC Overlap

No Coverage Area
Longley-Rice (50,90)

Edge of Radio Horizon

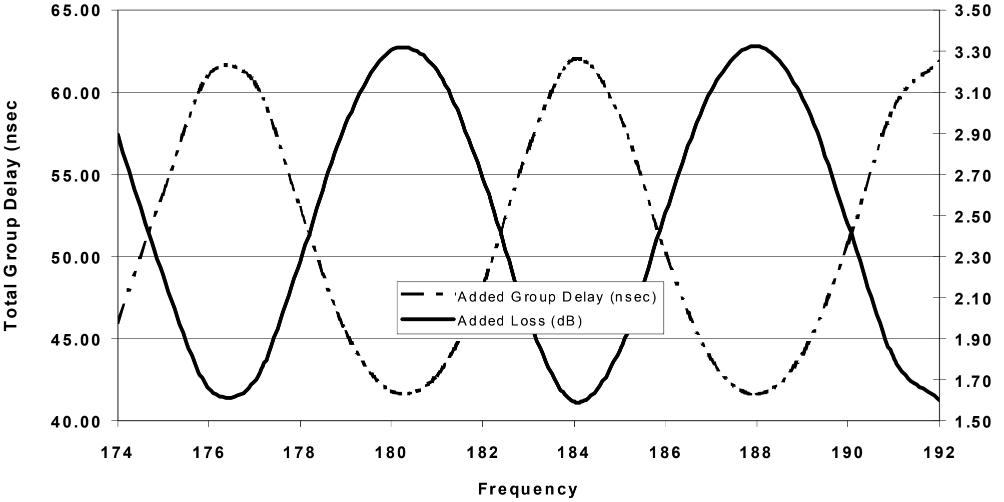
Longley-Rice (50,90) Coverage
Beyond Radio Horizon

Figure 5: Added Loss and Group Delay due to Antenna/Tuner Impedance Mismatch
Channels 2-4
Antenna VSWR=3 Tuner VSWR=3



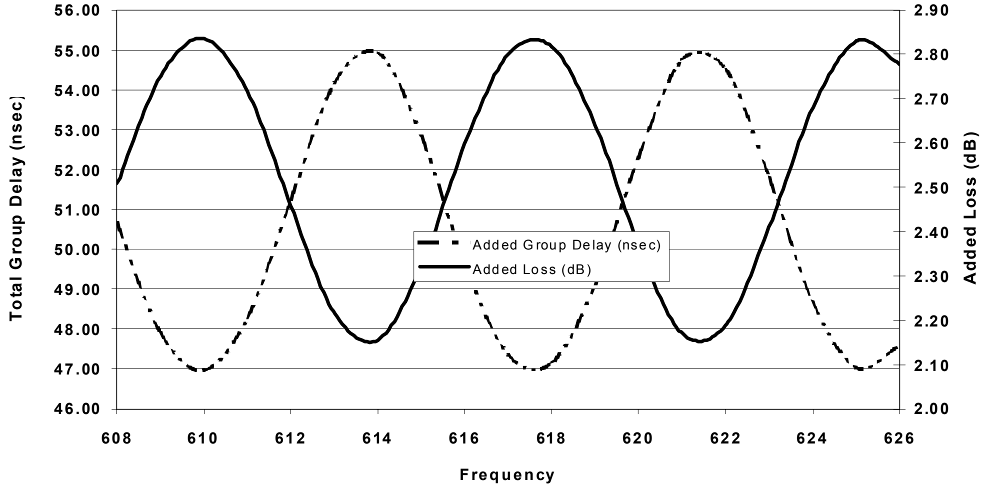
Antenna/Tuner Downlead Parameters		
Nominal Attenuation:	2.00	dB/100'
Relative Velocity of Propagation:	0.78	to the speed of light
Length of Downlead:	50.00	Feet

Figure 6: Added Loss and Group Delay due to Antenna/Tuner Impedance Mismatch
Channels 7-9
Antenna VSWR=3 Tuner VSWR=3



Antenna/Tuner Downlead Parameters		
Nominal Attenuation:	4.00	dB/100'
Relative Velocity of Propagation:	0.78	to the speed of light
Length of Downlead:	50.00	Feet

Figure 7: Added Loss and Group Delay due to Antenna/Tuner Impedance Mismatch
UHF
Antenna VSWR=3 Tuner VSWR=3



	Antenna/Tuner Downlead Parameters	
Nominal Attenuation:	8.00	dB/100'
Relative Velocity of Propagation:	0.78	to the speed of light
Length of Downlead:	50.00	Feet

Figure 8: Median Values of Man-made and Galactic Noise Power Relative to kTB
[Recommendation ITU-R PI.372.-6]
Thermal noise=kTB=-106.2 dBm @ T=290 deg K