Why are the ATSC-8VSB and M/H Standards Fundamentally Unsuitable for Next Generation Television Broadcasting and How to Painlessly Transit to ATSC/OFDM Network

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I. Introduction

Advances in wireless video transmission technologies have shown that handheld and mobile devices can now reliably receive high quality video transmitted at high data rates from television broadcast stations. These new technologies rely on OFDM-based[a] modulation, the most effective technology designed for multipath-prone wireless links typical of urban areas and for reception by handheld and mobile devices.

In Europe and Asia various private and government-supported groups have been establishing implementation guidelines for the next generation of handheld devices (NGH) using advanced OFDM technologies. In the U.S., the first generation M/H guidelines have recently been adopted by the ATSC but consumer adoption may be years away.

Not only is the U.S. lagging behind, the ATSC-8VSB and M/H standards are fundamentally unsuitable for point to multipoint DTV links.

One fundamental reason why the ATSC standards are inadequate for point to multipoint wireless DTV links is that each symbol uses the same carrier and the spectrum of each symbol occupies the entire channel bandwidth. Thus, two identical symbols, whether signal with echo or two signals in a single-frequency-network (SFN), can cancel each other and result in a null signal. There are other complications related to ATSC reception such as carrier recovery and equalization, but with low or no carrier power the issues related to recovery and equalization become moot.

In OFDM-based systems, each carrier out of thousands of closely spaced and orthogonal carriers is modulated by a different symbol. By uniquely pre-distorting the phase of each carrier, de-correlation is achieved between any two signals in SFN provided the inserted phase distortion is unique to each transmitter[1]. Then, a single carrier cancellation by another 0dB SFN signal will affect only a very narrow slice of the channel's bandwidth without significant reduction to the channel's carrier-noise ratio (CNR). Further, OFDM-based systems allow for the incorporation of an adjustable guard band interval, preceding the desired symbol, within which short-delayed echoes are added constructively with the signal, thus enhancing the channel's CNR. There are no such inherent capabilities in ATSC where received echoes always degrade the channel's CNR[b] and SNR[c].

The purpose of this paper is to provide a broader examination of the consequences of the ATSC 8VSB and M/H standards with respect to the future of wireless video transmission, and to argue that the future of DTV broadcasting in the U.S. would best be served by adoption of new OFDM-based technologies. Further, this paper shows how each ATSC-DTV station can add OFDM-SFN, with much higher throughput, without causing harmful interference to anyone. Indeed, within the current FCC inquiries regarding wireless innovation and spectrum sharing, only OFDM-based technologies are under consideration, albeit not for DTV broadcasting.

II. The Fundamental Issues

1 ATSC symbols have identical single-carrier and each symbol's spectrum occupies an entire channel's bandwidth

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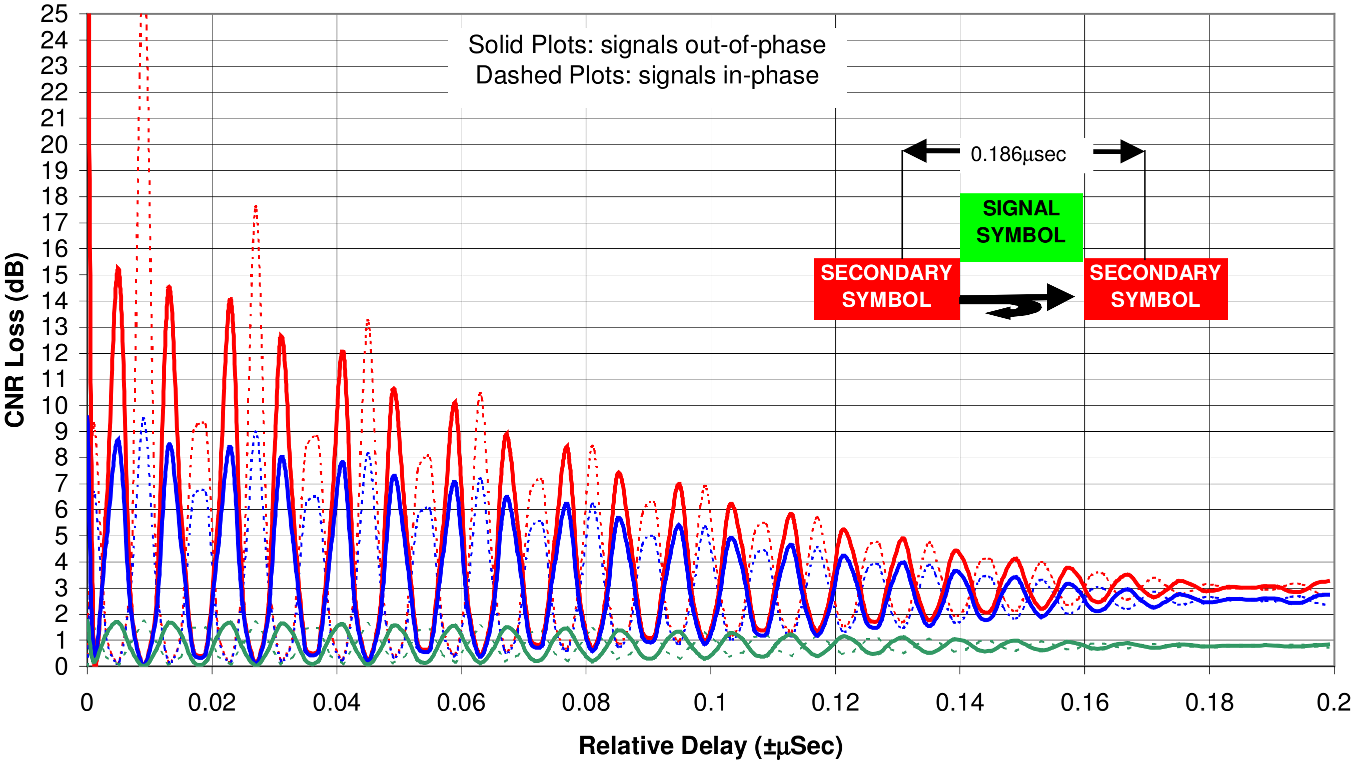
[a] OFDM (Orthogonal frequency Division Multiplexing) is a generic term that covers variety of modulation schemes. One version is COFDM used for DTV outside the U.S.A. COFDM is OFDM with forward error correction (FEC). It is presumed that any scheme used for DTV must include FEC.

[b] CNR==(average signal power at the terminals of the Rx antenna)/(total thermal noise at the terminals of the Rx antenna)

[c] SNR==(average demodulated symbols power post adaptive equalizer)/(total noise power at the output of the demodulator)

Figure 1: CNR Loss Due Autocorrelation of Two Identical ATSC Symbols

Carrier at 611 MHz
Rectangular Pulse 5.381MHz wide
Relative Signal Levels: 0dB, -6dB, -20dB



Consider two identical ATSC symbols arriving at the receive antenna without delay relative to each other. If their amplitudes are at 0dB relative to each other and out of phase, the combined signal is power null across the entire TV channel. If the two are in-phase, the combined signal power is four times that of each symbol. These are the extremes. What happens if the two are delayed relative to each other and their amplitudes not at 0dB is shown in Figure 1.

The details of the calculation plotted in Figure 1 can be found elsewhere[2]. When two symbols of equal amplitude combine constructively, the CNR loss is zero. During the autocorrelation period, two-symbol width duration (.186µsec), signals and their echoes combine as vectors, not as sum of powers. For relative delays longer than the autocorrelation period, the maximum CNR loss relative the available CNR of the two symbols is 3dB.

Figure 2: Channel Distortion by Two Identical ATSC Symbols

When the Echo is Doppler shifted the shown distortion crawls
When the Echo is static the distortion is static

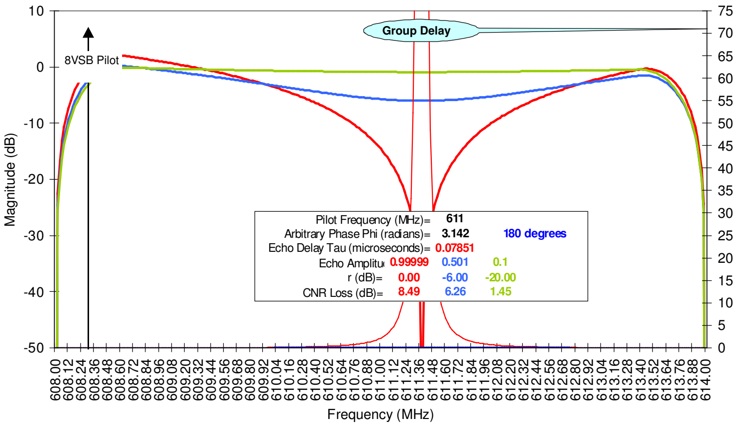


Figure 1 shows how strong, short-delayed, and especially dynamic echoes[d], relative to the desired signal or relative to each other, result in severe loss of CNR and SNR. This autocorrelation period between identical ATSC symbols is a major and unavoidable cause of degradation in the reception of indoor and mobile ATSC signals.

The corresponding spectral distortion due to the autocorrelation of two identical ATSC symbols is shown in Figure 2 for the same three relative signal levels as in Figure 1 and for a relative delay of .07851µsec between the two symbols, each .093µsec

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[d] Effectively shifting the display of Figure 1.

wide. The CNR loss was calculated by numerical integration and the result agrees with that shown in Figure 1 for that same delay. Also added to Figure 2 is the group delay distortion. Figure 2 has been confirmed experimentally[2].

Each M/H symbol also occupies the entire channel bandwidth and may suffer the same loss of CNR. M/H receivers, due to their lower antenna height and higher antenna gain loss, may incur additional loss of CNR. On the other hand, the measured M/H receiver's[e] threshold SNR is between 3dB and 13dB, depending on payload and Doppler shift whereas the measured 8VSB receiver threshold SNR for static is ≈15dB.

2 Fresnel Zone provides inadequate clearance for ATSC links to rooftop antennas

The prediction model for 8VSB coverage explicitly excluded from the link budget the loss of CNR and the added SNR noise due to multipath. This omission implied a LOS (Line-of-Sight) path to rooftop antennas, as was the case for the analog NTSC standard. This implicit LOS model formed the basis for the claim of comparable DTV and analog TV coverage and service because multipath as a parameter in the transmitter to receiver LOS DTV link's planning factors could be ignored. In the real world of the 21st century, LOS to rooftop antennas is available to few consumers in urban and suburban areas, and multipath is a major limitation to DTV reception.

But what defines LOS for ATSC 8VSB and M/H signals?

For narrow-band, essentially single-carrier signals such as NTSC, LOS path is presumed to exist if the 1st Fresnel Zone radius is cleared of obstructions throughout the path between the transmitting and receiving antennas.

The first Fresnel Zone is a spheroid around the LOS whose radius along the LOS is given by (see Appendix A):

$$R=\sqrt{\frac{d_1 d_2}{D}\lambda} \qquad (1)$$

where d_1 and d_2 are segments along the path whose length is $D=d_1+d_2$ and λ is the wavelength. The minimum radius R is required to prevent up to 1/2 wavelength-delayed reflections causing destructive interference at the point of reception.

Path clearance is presumed if no obstacles are within 60% of R. Such clearance along the path permits the characterization of the LOS path as "free-space," which implies that the path is free of multipath such as reflections, scattering and diffraction.

Figure 3 shows the required clearance radius along a 21km path, first for NTSC signals in the three bands. The clearance radius is independent of the antennas' height.

For wide-band signals the minimum clearance depends on modulation. The Fresnel radius does not apply to ATSC-8VSB and M/H because the required equivalent clearance must be such as to essentially prevent, or at least minimize, the autocorrelation of identical symbols shown in Figure 1.

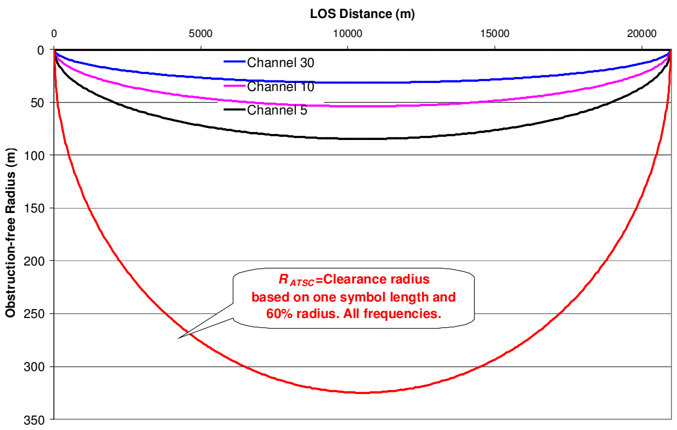
The equivalent formula for the minimum clearance radius, free of obstructions, for ATSC symbols is derived in Appendix A:

$$R_{ATSC}=.6\sqrt{\frac{d_1 d_2}{D}2L_A} \qquad (2)$$

where L_A=27.9m is the autocorrelation length of one symbol period and d_1 is the distance from the transmitter to the point on the LOS path where the clearance radius R_{ATSC} is desired.

Figure 3 also shows the clearance radius for ATSC for the same 21km path between equal-height transmitter and receiver. Thus, the required clearance radius for ATSC is a far larger than that required for NTSC. For the shown path, the maximum clearance radius for UHF-NTSC would be 32m whereas the related clearance for ATSC would be 325m.

Figure 3: NTSC 60% Fresnel Zone Clearance Radii vs ATSC Clearance Radius



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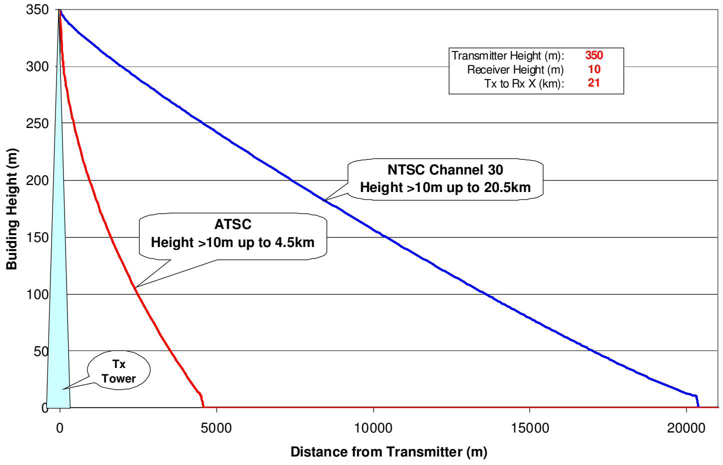
[e] Receive antenna degradations such as impedance mismatch and group delay not included.

The clearance radius for ATSC severely limits the height of buildings to which LOS path to the receiver is desired. The analysis of the permissible height as a function of distance from the transmitter tower is for ATSC and NTSC is presented in Appendix B and the result shown in Figure 4.

Figure 4 shows that, assuming a tall tower 350m above ground for the transmitter and a rooftop antenna 10m above ground for the receiver, the LOS extends only to 4.5km for ATSC compared with 20.5km for UHF-NTSC. Thus, the assumption that comparable LOS reception with rooftop antennas would be possible for NTSC and ATSC is shown to be incorrect.

Figure 4: Maximum Buiding Height for LOS Path

LOS = Path free of destructive self-interference



The maximum building height profile is of particular importance for future DTV broadcasting where some form of SFN using relatively low height transmitting towers is expected to be part of the dominant transmission infrastructure.

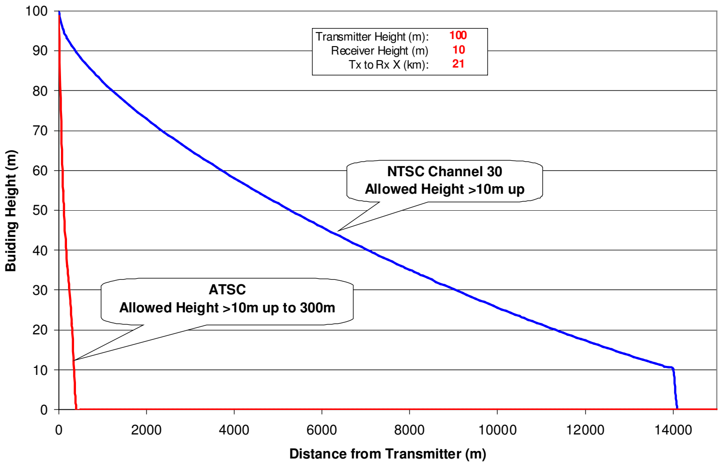
3 SFN is impractical for ATSC-8VSB and ATSC-M/H

It has been shown that SFN for ATSC-8VSB is impractical except perhaps for sites with rooftop antennas and with LOS to the transmitter and accepting approximately 25% loss of coverage and much higher loss of service (relative to single stick) [2].

Now, based on the analysis of Section II-2, it is possible to address the feasibility of SFN for ATSC with LOS ("multipath-free") path to receivers equipped with directional rooftop antennas. The result is shown in Figure 5: ATSC LOS from a 100m tower to a directional antenna, 10m above ground, can be established only if obstructions beyond 300m from the tower do not exceed 10m above ground. Within 300m of the tower, the obstruction height must be inside the shown profile. This profile is based on the criterion of minimum self-interference created by autocorrelation of identical symbols as described in Appendix B.

Figure 5: Maximum Buiding Height for LOS Path

LOS = Path free of destructive self-interference



Another complication is the inability to simultaneously provide continuous M/H SFN service without severe penalties to 8VSB service. This situation is depicted in Figure 6.

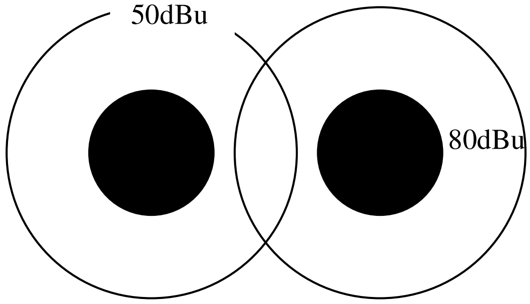


Figure 6: Continuous M/H Service Requires Heavy Overlap of 8VSb Coverage Areas

The black-shaded circles in Figure 6 represent the ~80 to 90dBu-coverage[f] contour for mobile and hand-held devices. It is always smaller than ~50dBu-coverage contour available to rooftop antennas because of the poor transfer function of in-situ small antennas, their lower height above ground and the higher building penetration loss incurred by receivers that are used outdoors. If the assumed tall tower reliable service radius for M/H were 15km for a minimum required signal of 80dBu at 10m above

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[f] Measured at 30 feet above ground and taking into account the lower threshold SNR of ATSC-M/H.

ground, the related radius for 8VSB would be closer to 45km for a required minimum signal of >50dBu and a directional rooftop antenna at 10m above ground.

It is apparent from Figure 6 that geographically continuous ATSC M/H service requires an increase in the area covered by overlapped 0dB signals, essentially a trading off "good" 8VSB service area in order to provide continuous M/H service.

In contrast, OFDM-based SFN is designed to constructively add strong, short-delay echoes, and multiple 0dB signals and these OFDM characteristics are mandatory for SFN that provides geographically continuous and reliable service.

III. Gradual Transition to OFDM SFN

Because overlap of 0dB signals is compatible with OFDM-based SFN, geographically continuous service for mobile and static receivers is possible. Further, the new SFN could be implemented without interference to ATSC reception.

The gradual development of SFN for OFDM assumes that two DTV stations in adjacent markets do not object to reuse their frequencies by each other provided no new interference is created, unless mutually acceptable. In many markets, additional unoccupied channels would also be available.

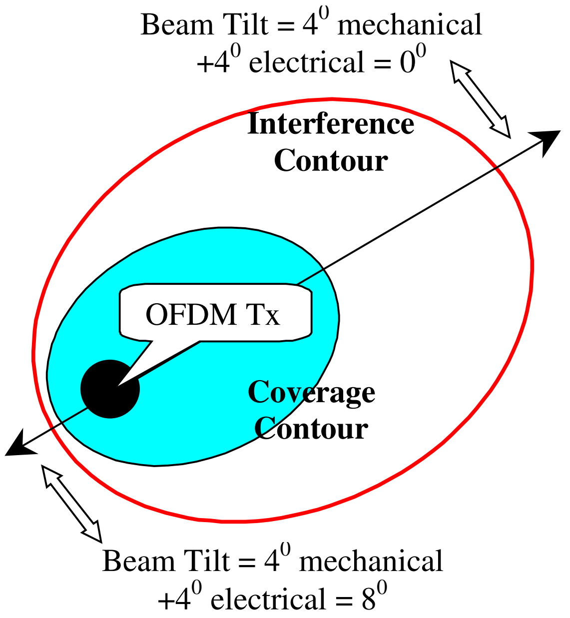


Figure 7: Coverage and Interference Footprint of Mechanically Tilted Antenna with Electrical Beam Tilt

Figure 7 shows one of three building blocks of the proposed new SFN. The illustrated F(50,90) coverage and F(50,10) interference footprints are not circular relative to the OFDM transmitter. Such footprints are achieved by mechanically tilting the antenna relative to the supporting tower. As shown in Figure 7, if the antenna is tilted mechanically 4^0 toward SW and it has a built-in electrical beam tilt of 4^0, then the total tilt would be 8^0 toward SW and 0^0 toward NE.

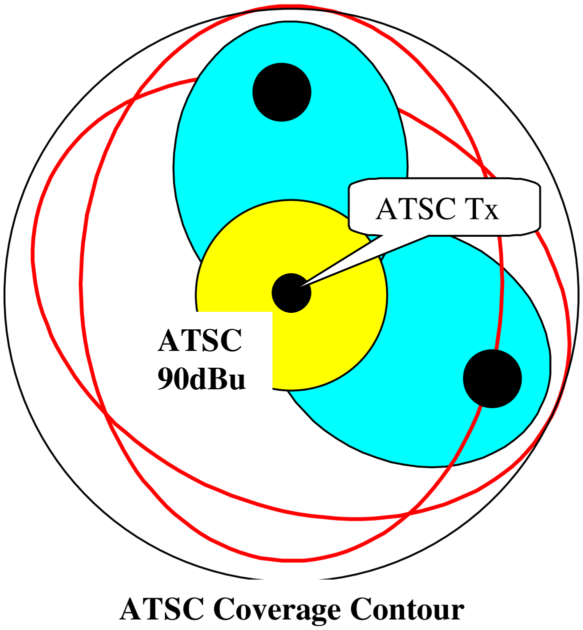


Figure 8: Gradual Implementation of SFN OFDM on Channel A with a Single Tower ATSC on Channel B

As shown in Figure 8, the new SFN can be built around the existing ATSC transmission facility one low-height OFDM transmission tower at a time, and thus provide geographically continuous service to hand-held and mobile devices without interfering with ATSC reception. The new SFN can use the best available compression and a software-based receiver that will demodulate both ATSC and OFDM signals.

Since each transmitter in the OFDM network will have its own unique ID, the network would be capable to download on demand video and data from cellular telephone or from the Internet, in addition to broadcasting regular programs.

A critical element of the proposed SFN is the combined mechanical and electrical tilt, which can best be achieved with antennas having high gain in the elevation plane. Such UHF antennas are used by full power stations and are very heavy and very expensive. They require an inner conductor made of copper and a steel shell.

In contrast, the proposed antenna for the new OFDM SFN would have an outer shell made of aluminum slotted pipe, say 6” in diameter, possibly 30’ high. An inner core made of steel would support the aluminum pipe. The inner core and outer shell will be bolted to the tower structure’s top plate. A steel inner core is possible because the transmission power would be low. Such antenna, shown in Figure 9, would be very inexpensive and present relatively low wind load to the tower even with 4^0 mechanical tilt.

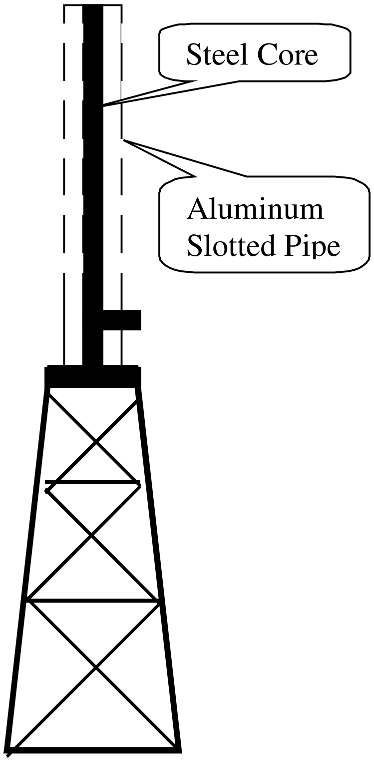


Figure 9: Circularly Polarized Inexpensive Antenna for OFDM SFN

IV. Conclusions

A sustainable future for OTA DTV broadcasting requires robust, high throughput and continuous reception over a wide area by hand-held and mobile devices, not just by static receivers tethered to rooftop antennas.

A robust and geographically continuous reception by hand-held and mobile devices over a wide area mandates that OFDM-based SFN be deployed. No other known modulation scheme has the capabilities of OFDM in the harsh environment characterizing consumer reception.

This paper shows how such network can be built and tested at a relatively low cost and, because another channel from an adjacent market can be reused, the new OFDM SFN will not interfere with the existing ATSC service in any market.

The new SFN could be built gradually and use H.264/265 coding. That would increase the broadcast throughput to the equivalent of two new HDTV channels in addition to the existing ATSC channel. Later, as software-based receivers proliferate, the ATSC channel can be converted to OFDM and even more efficient compression could be deployed.

Appendix A: The ATSC Clearance Radius for LOS Path

The traditional first Fresnel Zone clearance radius is the minimum radius, fee of obstructions, along the direct transmitter to receiver path. Obstructions inside this radius may cause severe destructive interference by reflections whose path length is $\leq \lambda/2$. The derivation of the Fresnel radius is aided with reference to Figure A1.

The path difference between the direct and reflected ray is:

$$\Delta = \sqrt{d_1^2 + R^2} + \sqrt{d_2^2 + R^2} - D$$

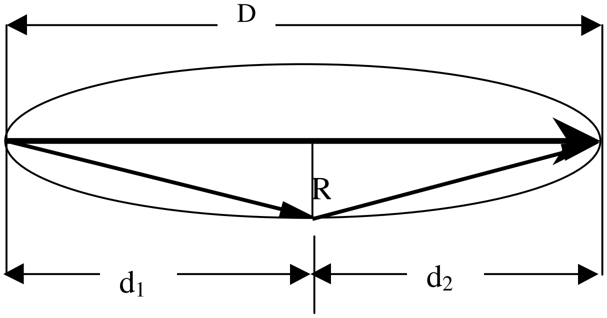
$$\Delta \cong d_1 + \frac{R^2}{2d_1} + d_2 + \frac{R^2}{2d_2} - D \quad \text{(A1)}$$

and solving for R:

$$R = \sqrt{2\Delta \frac{d_1 d_2}{D}} \quad \text{(A2)}$$

With $\Delta = \lambda/2$ the Fresnel clearance radius is defined for narrow-band single carrier signals.

Figure A1: Fresnel Ellipsoid Radius



Derivation (A2) does not apply near the end point of the path. Near the end points

$$R \approx \Delta\sqrt{1+\frac{2d_2}{\Delta}} \quad for\ d_2 \to 0$$

$$R \approx \Delta\sqrt{1+\frac{2d_1}{\Delta}} \quad for\ d_1 \to 0 \qquad (A3)$$

For ATSC signals, the same destructive interference depends on the autocorrelation period of identical symbols. As shown in Section II, the autocorrelation extends over two symbol periods, each .93μsec or 27.9m. Choosing conservatively only one symbol period and the same 60% of radius factor usually applied to Fresnel zone,

$$R_{ATSC} = .6\sqrt{\frac{d_1 d_2}{D}55.8} \qquad (A4)$$

Appendix B: Maximum Building Height for LOS

Referring to Figure B1, the maximum allowable building height, H(x), for LOS path D between a transmitter at height h_t and a receiver at height h_r separated by X can be derived as follows:

For $0<d_1<D$,

$$\theta = \tan^{-1}\frac{h_t - h_r}{X} \qquad \phi = \tan^{-1}\frac{R}{d_1} \qquad (B1)$$

$$x = d_1 Cos\theta \qquad (B2)$$

$$H(x) = h_t - \sqrt{d_1^2 + R^2}\,Sin(\phi+\theta)$$
$$for \quad H(X) \ge h_r \qquad (B3)$$

$$R = .6\sqrt{2\Delta\frac{d_1 d_2}{D}} \qquad (B4)$$

where $D=X/Cos\theta$

and $\Delta=\lambda/2$ for NTSC and 27.9m for ATSC

References

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[1] J. Robert, “Improved Robustness and Transmitter Identification for Multi-Antenna Systems.”

[2] O. Bendov, “Why Single Frequency Networks Using ATSC-8VSB Modulation Cannot Provide DTV Service Comparable with that of a Single Antenna on a Tall Tower.” www.tvantenna.tv

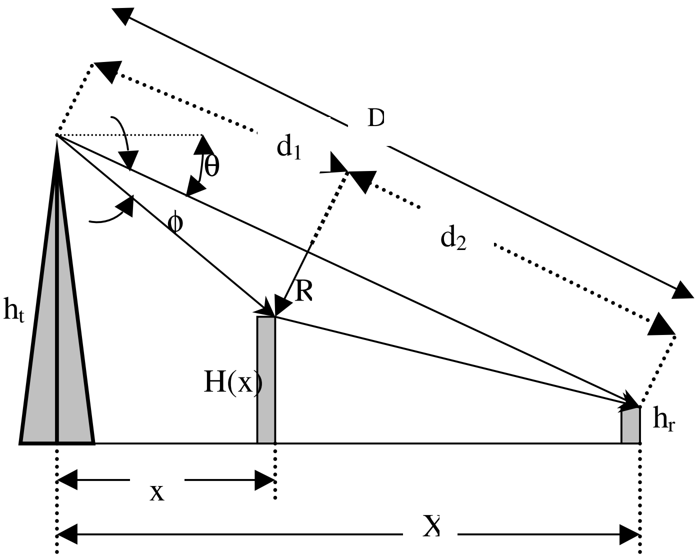

Figure B1: Geometry for Maximum Building Height H(x) for ATSC LOS to Receiver