System Analysis and Planning Factors for Adjacent Channel Distributed Transmitters at UHF Frequencies

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***Abstract*—The interference between first adjacent channels N and N±1 in an environment of distributed on-channel transmitters is analyzed. Channel N uses a single transmitter and the adjacent channels N±1 use distributed on-channel transmitters. The conditions and planning factors that will permit reliable implementation of ACI-free areas across all applicable signal levels are presented. The effect of antenna gain, height and power relative to the physical separation between channels N and N±1 are analyzed and the regions of adjacent channel interference (ACI) are delineated.**

***Index Terms*—Distributed transmitters, adjacent channel interference, protection ratio.**

I. INTRODUCTION

Single frequency networks (SFN) for digital terrestrial television (DTTV) are being proposed as means of extending the service area of the main transmitter into areas of poor reception and as an alternative to a single, high-power transmitter[1]. In theory, SFN could provide the same service area as a single high-power transmitter at a much lower capital and operating expense. In reality, the ability to implement SFN without creating new cochannel self-interference depends on the modulation. In the case of COFDM modulation, where a guard band serves to minimize intersymbol interference, and where an equalizer with multiple taps is not required, wide-area SFN is possible. In the case of 8VSB modulation, where a guard band is unavailable and where an equalizer with multiple taps is required, implementation of SFN free of cochannel interference is presently possible only over a limited area[2,3]. This paper addresses the modulation-neutral interference created at the DTV receiver when adjacent channels are not collocated in distributed transmitters network. Although the analysis assumes the current planning factors in the U.S., it could be modified to accommodate any planning factors.

In markets where a first adjacent channel was assigned, the implementation of a practical SFN may be severely limited unless channels N and N±1 are multiplexed on all the distributed antennas[4]. If channels N and N±1 are not multiplexed on all the distributed antennas, then additional ACI, independent of the modulation format, will be introduced in some service areas.

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Unlike cochannel interference, which may be viewed as self-interference, ACI is hostile interference that degrades the signal-noise ratio (SNR) of the victimized channel. It is hard to measure and quantify the level of SNR degradation caused by ACI.

The relevant question to be discussed in this paper is whether a particular choice of antenna elevation pattern, radiated power, antenna height above average terrain (HAAT) and the physical separation (>0) between the towers of the N and N±1 channels would allow either wide or limited area SFN.

II. ANTENNA ELEVATION PATTERNS

Antennas for television broadcasting come with wide ranges of azimuth and elevation patterns. For UHF applications, the gain of an acceptable elevation pattern typically varies between 9 and 14dBd and the two patterns are shown in Figure 1. The higher the antenna gain (narrower beam width) the more desirable it is to synthesize a smooth pattern that would fit a *cosecantθ* function (θ being the angle below the horizontal) between the pointing angle at the peak power and 90^0 (tower base). Unless the antenna array is infinitely long and its current distribution continuous, a perfect *cosecantθ* pattern match is not possible. The patterns shown in Figure 1 represent practical compromises between the ideal patterns and the mechanical limit to the antenna's physical dimensions.

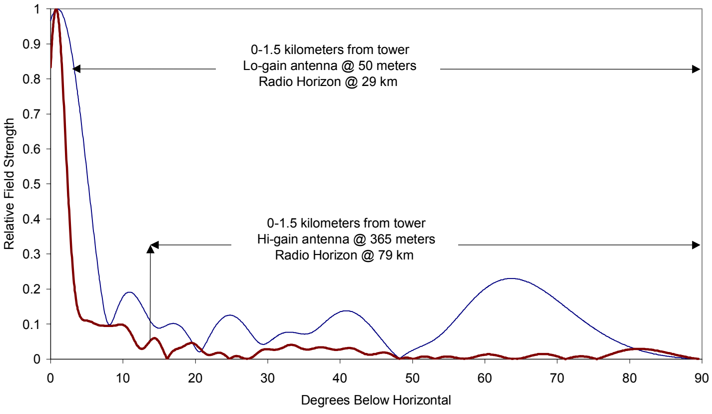

Figure 1: Elevation Patterns of the Two Antennas
Hi-gain=27 (14 dBd); Lo-gain=8 (9 dBd)

As shown in Figure 1, if either antenna is at a height between 50 and 365 meters, the HAAT range for most television broadcast antennas, the service area within the first 1.5 kilometers from the base of the tower is subject to a potentially unsatisfactory signal level. That is so because practical designs with adequate and smooth null fill extend for only the first 15 degrees below the horizontal. Therefore, erratic reception due to large deviation in signal strength within 1.5 km of the antenna because of local reflections and low null fill is well known and accepted. In any case, it will be shown later in this paper that a lack of a smoother null fill structure beyond 15^0 does not change the system design principles developed here or the conclusions drawn.

III. MINIMUM PROTECTION RATIO

In 1998 the Federal Communications Commission (FCC) raised the adjacent channel protection ratio of channel N from interference by channel N-1 from –42dB to –28dB. That is, the power of the interfering channel could not be higher than that of its adjacent channel by more 28dB before the interference becomes visible. The ratio for interference by the N+1 channel was raised to –26dB from –43dB[a]. The revised protection ratio was still based on tests that excluded strong signals, sky noise and man-made noise. Sky and man-made noise levels are significant at lower VHF frequencies and that would negatively impact the establishment of distributed transmitters operating at the low VHF frequencies.

The ratios established by the FCC were helpful in creating the channel allocation table with the underlying assumption that all first adjacent channels would share a common antenna so that additional signal level variations at the receiver, local reflections for example, could be ignored. For real-world system analysis, particularly for distributed transmitter systems, the shared antenna assumption and the absence of strong signal assumption are invalid, as is ignoring significant external noise by codifying the same protection ratio for UHF and VHF frequencies.

Detailed analyses of the allowable Desired/Undesired ratio over the entire range of applicable signal levels, non-linear distortion at the receiver and at the transmitter including man-made and sky noise has been published[2]. In Tables V-VII (Ref. 2), the margins above the ACI Threshold of Visibility (TOV) are given for the expected range of signal levels at the input of a receiver whose 3rd order intercept (IP_3) is from 4 to 32dBm. Figure 2 shows the allowable level of the undesired adjacent channel at TOV over the dynamic range of the desired channel. Figure 2 is an adaptation of some of the data in Table V of (Ref. 2) from dBm to dBu so that the remainder of the analysis in this paper could be based on the commonly used dBu-based F(50,90) and F(50,10) propagation curves. The conversion from dBm into dBu assumed a gain of 10dBd for a receiver antenna 10 meters above ground[b].

Theoretically, the required dynamic range of the receiver would vary from 41dBu (–81dBm) to 115dBu (-5dBm) if the ACI is due to two first adjacent channels. The practical range is from 50dBu (-70dBm) to 100dBu (-20dBm). This range is realistic because a stronger signal can be attenuated and because 50dBu corresponds to the lowest signal level required for reliable reception by practical receivers[5] whereas the 41dBu level is the noise-limited contour assuming ideal receiver.

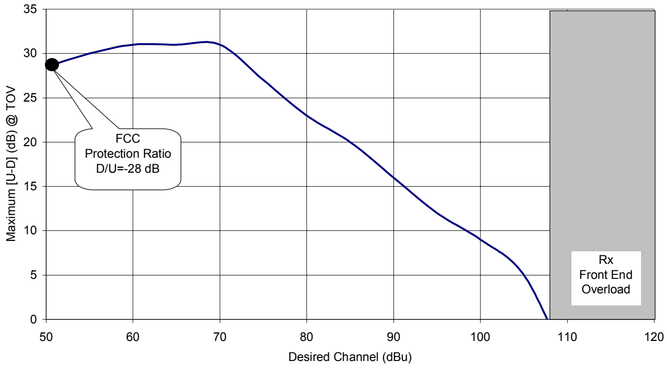

Figure 2: Maximum Allowable Undesired Channel Level Over Undesired Channel
Two Adjacent Channels on Shared Antenna

The FCC's single point "Desired" to "Undesired" protection ratio of –28dB is marked in Figure 2. It shows that as long as the interfering signal does not exceed 78dBu, the sum of the minimum decodable level of 50dBu and the FCC protection ratio of U/D=28dB, the desired channel would be decoded throughout the dynamic range of 50 to 108dBu with at least 0dB margin relative to TOV. However, it is unrealistic to expect that the signal level of the interfering channel remain below 78dBu throughout the service area of the desired channel. As we are about see, even with power as low as 1kW the field strength reaches above 90dBu in the area near the tower.

As the level of the desired channel increases over 70dBu, the increase in the nonlinear distortion at the receiver limits the allowable level of the adjacent channel. The 28dB margin allowed by the FCC drops to zero when the desired level reaches 108dBu. Above 108dBu the front end of the receiver overloads without the presence of ACI. Fortunately, a 10-20dB attenuator could be automatically inserted ahead of the receiver's front end when the desired signal is very strong.

If the omnidirectional antenna of each adjacent channel is on a separate tower, the allowable level of the undesired channel must be reduced by a by at least 14dB. This margin is the sum of three components: ±1.5dB for daily fading of either channel (Ref. 3), ±4dB for field variation due to local reflections and ±1.5dB to account for the relative difference in azimuth pattern of the two antennas. If the azimuth pattern of either antenna is directional rather than omnidirectional, the margin required will become a function of the differential power in

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[a] The difference was most likely due to an experimental error that should have been averaged out rather than by the asymmetrical pilot.

[b] FCC planning factors.

the azimuth plane. Henceforth, omnidirectional antennas are assumed without loss of generality.

IV. PRINCIPLES OF ACI PROTECTION PLANNING

From the analysis in Section III, the principles that must be followed to protect adjacent channels from interfering with each other’s reception are:

1. Where either of the adjacent channels is greater than –15dBm≈105dBu, attenuation of 10-20dB should be added ahead of the front end of the receiver so as to reduce the level of non-linear distortion. This would prevent a receiver overload and would permit a higher level ACI without breaching TOV.
2. If each of the adjacent channels is on a separate tower, the allowable Desired/Undesired ratio at TOV that is shown in Figure 2 must be reduced by a “separation allowance” for local signal variation at the receiver. The minimum “separation allowance is 14dB. For example, if the protection ratio for adjacent channels on a shared antenna is D/U=-28dB, then it must be raised (higher Desired or lower Undesired) to a minimum of D/U=-14dB if the adjacent channels do not share an antenna. Absent antenna sharing, the D/U=-14dB is the minimum protection ratio for distributed transmitters on adjacent channels.
3. The protection ratio applies to the difference between F(50,10) for the undesired channel and F(50,90) for the desired channel Where the tower height does not exceed 50m or the undesired signal is very strong, F(50,90)≈F(50,10) and the ratio could be applied to the difference between F(50,90) field strength of each channel.

In Sections V and VI these principles will be applied to collocated and non-collocated antennas.

V. COLLOCATED ANTENNAS

Consider the case of channel N with a high-gain antenna at a height of 365m HAAT and radiating 1,000kW. It is collocated on the same tower with an adjacent channel N±1 radiating 1kW from a low-gain antenna at a height of 50m HAAT. The elevation patterns of these two omnidirectional antennas are shown in Figure 1. Figure 3 shows the field strength of each channel from the base of the tower to the horizon.

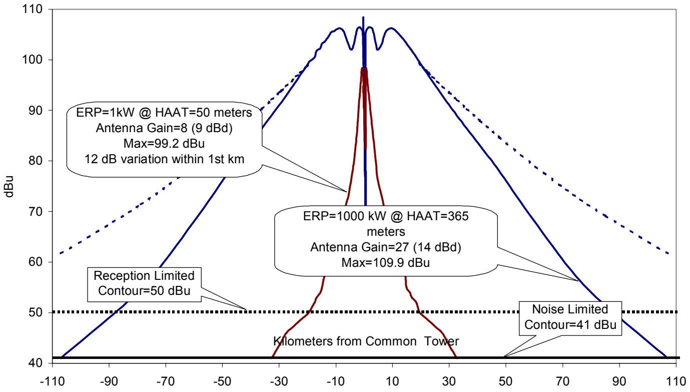


Figure 3: Field Strength vs. Distance from Antenna
F(50,90) ———
F(50,10) ············

Within 1.5 kilometers of the tower, the field strength of either channel swings widely, 38dB for channel N and 12dB for channel N±1. This range is shown in Figure 1 as spanning a wide angular sector from just below the horizontal down to the base of the tower. As explained earlier, the field strength in that sector cannot be relied on for DTTV reception even in the absence of ACI. Beyond the first 1.5km, the differential field strength between the two channels exceeds both the 14dB and 28dB margins in all locations. Thus ACI into the N±1 channel can be expected everywhere.

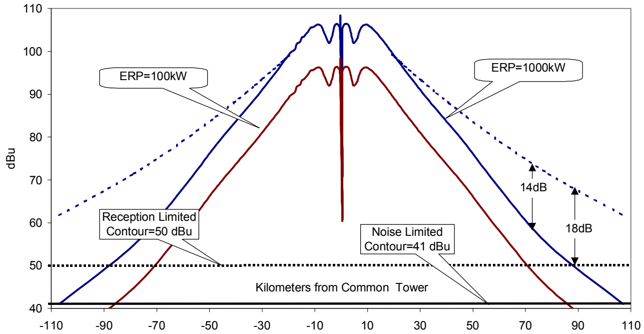


Figure 4: Field Strength vs. Distance from Antenna
Shared Antenna vs. Two Stacked Identical Antennas @ 365 +/- 6 meters
F(50,90) ———
F(50,10) ············

Figure 4 shows two cases of collocated adjacent channels with identical high-gain elevation pattern. If the two adjacent channels share an antenna at 365m HAAT and each radiates 1,000kW, then at the edge of the 50dBu reception contour the differential between the undesired at F(50,10) and the desired at F(50,90) would not exceed 18 dB, keeping well below the 28dB permissible for a shared antenna. In this case the desired channel could lower its power to 100kW and still keep its service area ACI-free. If the two channels are collocated on the same tower but do not share an antenna, then the applicable Desired/Undesired protection ratio increases to –14dB. For example, if the two antennas are identical and stacked over each other, then even if each channel radiates 1,000kW, ACI above TOV might be present occasionally between 72 km away and the edge of the reception contour at 90km.

It follows that ACI-free service areas of adjacent channels on a common tower can be accomplished through one of two implementations:

(a) Multiplex all adjacent channels on one antenna limiting the radiated power differential to a maximum of 10dB.
(b) Collocate two antennas with similar patterns on one tower and limit the differential field strength at the desired receiver to a maximum of 14dBwith the reception contour of the desired channel.

Either solution applies as long as neither channel uses distributed antennas or both channels share all distributed antennas. Systems where the antennas are not shared and are on separate towers will be addressed in section VI.

The accuracy of the propagation algorithms is critical to reliable system implementation. Of the two algorithms used in the U.S., the Longley-Rice algorithm ignores ground cover and uses a low 50% confidence factor. Its coverage prediction significantly exceeds that of the F(50,90) contours[6]. The F(50,90) contours are also inadequate because the underlying data is representative of average terrain, not specific to any location, and the 90% time availability for DTTV is inadequate[c]. Nevertheless, the F(50,90) is acceptable to the FCC and it can be used to study initial feasibility, augmented later by a more accurate algorithm for system planning.

Knowledge of the radii of the noise-limited and reception contours versus antenna height and radiated power (ERP) is essential in planning a distributed transmitter system. Figure 5 shows that increasing the contour radius can be accomplished by either doubling the height above average terrain or by increasing the radiated power by an order of magnitude. Clearly, height is golden.

ERP* kW	Contour dB	HeightAbove Average Terrain-meters				
		50	100	150	200	400
1	41	30	40	45	50	60
	50	20	30	35	40	50
10	41	40	50	55	60	70
	50	30	40	45	50	60
100	41	55	65	70	75	90
	50	40	55	60	65	70
300	41	65	75	80	85	95
	50	50	60	65	70	80
1000	41	75	85	90	95	105
	50	60	70	75	80	90

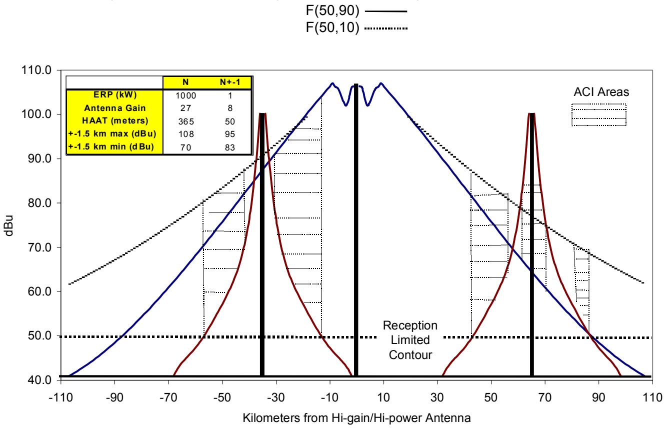
*Antenna gain 8-27 (9dBd-14dBd)

Figure 5: Rounded Distance in km to F(50,90) Contours

VI. NON-COLLOCATED ANTENNAS

In this section it will be demonstrated that, absent terrain shielding, if the distributed antennas of all adjacent channels are not collocated on all towers, ACI can generally be expected in some of the service areas.

Figure 6: Non-collocated Hi-gain/Hi-power and Lo-gain/Lo-power Antennas



Consider a single channel N transmitting the maximum allowable power of 1,000 kW using a high-gain, smooth-pattern antenna (Fig.1) at HAAT=365m. The distributed transmitters are on an adjacent N±1 channel radiating 1kW using a low-gain antenna at HAAT=50m. In one of two examples shown in Figure 6, the tower of the adjacent channel is 35km away from the tower of channel N, and in the second example it is 65km away. The field strength is unpredictable and highly variable within the first ±1.5km from each tower. The ±1.5km areas are shown as black stripes centered at the tower location.

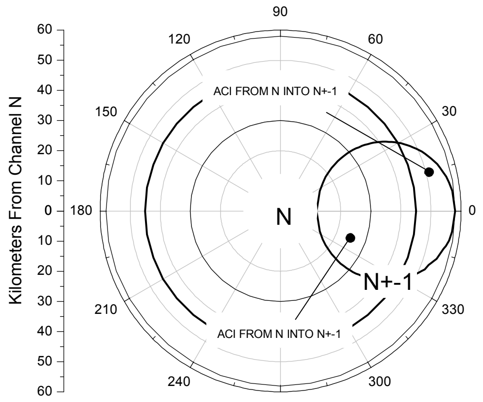


Figure 7a: Areas of Interference Between Adjacent Channels
N+-1 35 miles from N (Fig. 6)

When the adjacent N±1 channel is located 35km away from the N channel, its ACI-free area will be between 30km and 42km. This is the region in which the field strength of channel N±1 does not exceed the 14dB margin. In the remaining area, bounded by the minimum 50dBu reception contour of the N±1 channel, ACI from channel N into channel N±1 will be present. The ACI contours of this example are shown in Figure 7a.

When the adjacent N±1 is located 65km away from the N channel, its ACI-free areas will be between 56km and 62km and between 71 and 80km. These are the regions in which the field strength of channel N does not exceed the 14dB margin. In the remaining areas bounded by the minimum 50dBu reception contour of the N±1 channel, ACI from channel N into channel N±1 and from channel N±1 into channel N will be present. The ACI contours of this example are shown in Figure 7b.

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[c] In Europe, "acceptable" DTTV reception requires (75,99) percentages for (location,time) probabilities. For "good" reception the corresponding probabilities are (95,99).

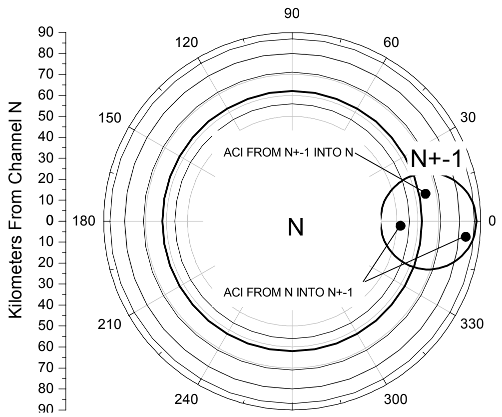

Figure 7b: Areas of Interference Between Adjacent Channels
N+-1 65 miles from N (Fig. 6)

Raising the power of the N±1 or relocating it would not eliminate the ACI into one of the two adjacent channels. Would changing the elevation pattern of the N±1 channel antenna from a low-gain to a high-gain, almost *cosecantθ* shaped pattern of the N channel make a difference? Figure 8 shows the difference, once for the N±1 channel located 48km and once for 72km located away from the N channel. In either case ACI is present within some regions.

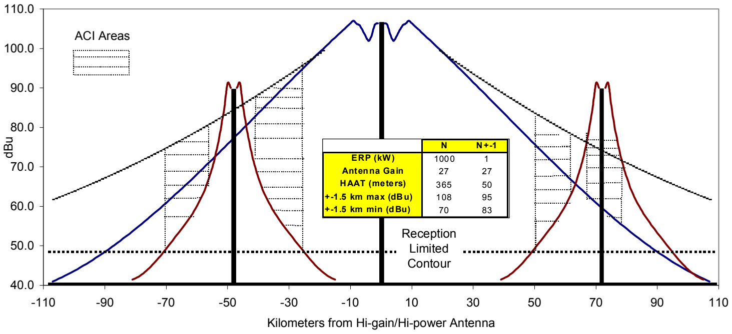

Figure 8: Hi-gain/Hi-power and Hi-gain/Lo-power Antennas Separated
F(50,90) ——— F(50,10) ………

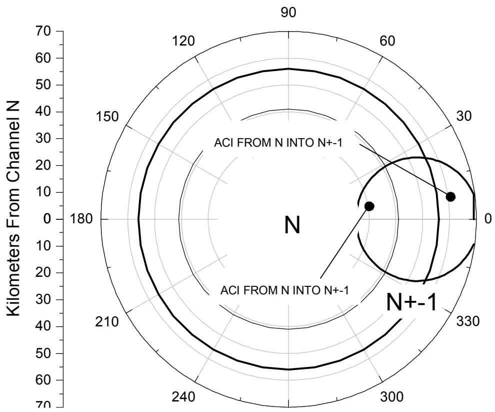

Figure 9a: Areas of Interference Between Adjacent Channels
N+-1 48 miles from N (Fig. 8)

When the adjacent channel N±1 is 48km away from the N channel, the only ACI-free area inside the reception contour of the N±1 channel is between 41km and 56km. This is the region where the N±1 channel exceeds the maximum 14dB differential. The ACI contours of this example are shown in Figure 9a.

When the adjacent N±1 is 72km away from the N channel, the only ACI-free areas inside the reception contour of the N±1 channel will be between 62km and 67km and between 78km and 95km. These are the regions in which the 14dB margin is maintained. In the remaining areas, bounded by the minimum 50dBu reception contour of the N±1 channel, ACI from channel N into channel N±1and from channel N±1 into channel N will be present. Clearly, changing the pattern of the distributed channel antenna to replicate the pattern of the channel N antenna has only shifted the ACI areas at a substantial increase of the antenna's cost. The ACI contours of this example are shown in Figure 9b.

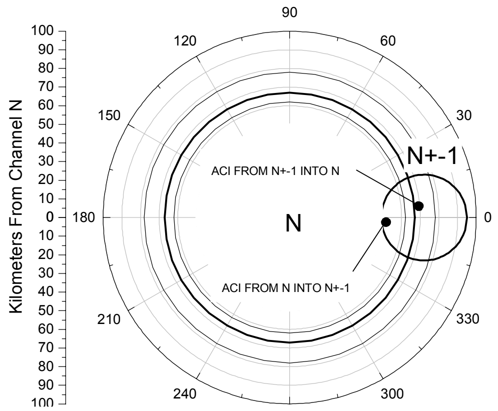

Figure 9b: Areas of Interference Between Adjacent Channels
N+-1 72 miles from N (Fig. 8)

It is possible, albeit impractical, to implement an ACI-free, extremely low power distributed transmitter system, near the edge of the reception of a moderate power transmitter. Figure 10 shows an example of such a system. Here, the non-distributed channel is operating at a power of 100kW from an antenna 365m HAAT. Depending on the chosen antenna

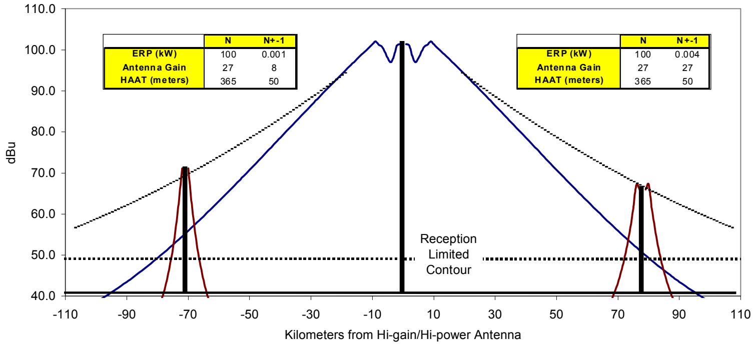

Figure 10: ACI-free With Etremely Low Power Distributed Transmitters
F(50,90) ——— F(50,10) ………

pattern, the distributed channel must be 70-80km away and operate at 1-4 Watts from a tower 50m HAAT.

VII. CONCLUSION

The FCC's -27±1dB "Desired/Undesired" ratio should not be used as an indicator of protection from adjacent channel interference in non-collocated distributed transmitter systems. That ratio was devised for shared antenna systems and is rooted in experiments that excluded man-made, sky and equalizer noises. Worse, the maximum allowed undesired level during those experiments was –38 to –40dBm, almost 35dB below the expected maximum levels. The maximum expected interference level at the receiver level is –8dBm for a single high-power adjacent channel and –5dBm for two adjacent high-power channels. As Table V in Reference 2 shows, the margin relative to TOV becomes negative for "Desired/Undesired" ratios far higher than -27±1dB for strong signals ≥ -15dBm.

In the absence of terrain shielding, the only practical way to have ACI-free service areas for all adjacent channels is to build a joint distributed transmitter system. This can be accomplished in one of two ways. One option is to combine all adjacent channels, preferably with equal power on shared distributed antennas. Another option is collocation of all the individual antennas on each of the distributed towers in a way that would limit the differential field strength at the receiver to a maximum of 14dB everywhere in the designated service area.

With terrain shielding and directional antennas, some distribution of transmitters, gap-filler for example, is possible without creating ACI to adjacent channels that are not collocated or share an antenna with the distributed channel.

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