iBLAST DATA BROADCASTING FIELD TESTS
A Study to Understand and Quantify Reception of the ATSC Signal

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EXECUTIVE SUMMARY

iBlast has recently completed its first series of field tests of reception of the Advanced Television Systems Committee (ATSC) digital television (DTV) signal in Los Angeles, Portland, San Diego, and San Jose. There was one station per city, each one a partner station in the iBlast network, and each one broadcasting their DTV signal in the ultrahigh frequency (UHF) portion of the spectrum. We measured characteristics of the over-the-air (OTA) broadcast signal at a variety of locations (a total of 202 sites), incorporating a range of distances from the broadcasting transmitter that would typically be relevant within a given market, as well as a variety of different terrain. We were particularly interested in, and measured reception characteristics at a number of indoor locations (a total of 73 sites). The goals of our testing efforts were to develop a basic understanding of reception of the iBlast signal and to correlate field measurements with software predictive models for the purpose of provisioning iBlast receivers.

While no rigorous statistical conclusions may be drawn from our current test results, we are encouraged for several reasons. First, the raw percentages of sites with successful reception, both indoor and outdoor, consistently exceeded 90%. Second, we observed marked improvement in the performance of current-generation receivers and antennas, as compared to units previously tested. Third, we were able to extract useful statistics such as the difference in signal strength between different receiving antenna heights, as well as the difference between outdoor and indoor signal strengths (reflecting actual wall attenuation coefficients). Fourth, our data presents a reasonable picture of the magnitude of the electric field strength required for successful VSB reception. Finally, while we have not yet developed sufficient quantitative evidence on the issue, we noticed during the course of testing that a modest preamplifier (of roughly 10 dB) between the antenna and receiver substantially increased both the chances for successful indoor reception, as well as the ease of maintaining indoor reception. Our experience suggested that most indoor reception problems that we encountered were due to insufficient field strength.

INTRODUCTION

iBlast has a substantial interest in understanding and quantifying the feasibility of reception of over-the-air broadcast of the ATSC digital television signal. We have constructed a network to accomplish data broadcasting with our nationwide local partner television stations using the unused portion of their terrestrial DTV broadcast signal. The benefit of our service is directly related to the number of households existing within contours of adequate signal strength and quality. We hoped, therefore, to find in our field tests an extremely high probability of reception throughout the geographic area of each market.

We are, however, pragmatic in our approach. We are well acquainted with the variety of factors that degrade both the strength and quality of the broadcast signal, resulting in less than 100 percent of any given region, or market, being able to receive the over-the-air signal. To prevent potential iBlast users from having unsatisfactory experiences when installing and using an iBlast receiver, we wish to predict with high accuracy that the iBlast signal can be robustly received at a given location.

Having established what our objectives were in our field test efforts, we believe it's important to state what our tests did not include. We were not interested in testing one modulation scheme against another, and made no effort to do so. The debate over which modulation standard is right for the United States is one that has been frequently rancorous, and we have no intention or desire to contribute to the debate. Equally, we do not seek to "improve" the vestigial sideband (VSB) modulation standard – although we certainly support and encourage the efforts of others to do so. Our tests were not designed to seek out areas of weakness in the ATSC standard. We seek to understand the reach of the ATSC signal as it stands, using the latest generation and highly-regarded demodulation devices, as well as several well-designed indoor antennas.

DESCRIPTION OF THE TESTS

We are currently reporting the results of tests of ATSC reception, as conducted in four west coast cities in approximately the last half-year. The cities are Los Angeles, where iBlast is located, San Diego, San Jose, and Portland. The stations whose signals we measured are listed in Table 1, all four of which are in the UHF. We chose to begin our testing in the UHF because a solid majority of our partners (approximately 90%) have their DTV channels in the UHF. We expect to incorporate VHF broadcasts into upcoming rounds of field tests.

	Call Letters	DTV Channel
Los Angeles	KTLA-DT	31
Portland	KOIN-DT	40
San Diego	KGTV-DT	25
San Jose	KICU-DT	52

Table 1: Television stations used for tests in each market

To varying degrees, we tested reception both outdoors and indoors; outdoor tests were conducted with the receiving antenna height at either eight or thirty feet above ground.

For the outdoor tests, we followed procedures established by the DTV Station Project (formerly known as the "Model HDTV Station Project"), which is a modification of the procedures used in the original FCC's Advisory Committee on Advanced Television Services (ACATS) field tests in Charlotte, N.C.[1] The tests were directed at quantifying both the strength and quality of the OTA signal.

To that end, we used a test vehicle modeled after the test van specified by the DTV Station Project,[2] which is shown in Figure 1.

Figure 1: The iBlast test van in typical outdoor test configuration

The test procedures and equipment, as well as variations on them, have been used in most of the ATSC VSB testing conducted throughout the industry, including the Advanced Television Technology Center (ATTC) tests, the Association for Maximum Service Television (MSTV) and National Association of Broadcasters (NAB) tests, and the Federal Communications Commission (FCC) tests.

[1] "DTV Field Test Methodology and Results and Their Effect on VSB Receiver Design", Gary Sgrignoli, Zenith Electronics Corporation, IEEE Transactions on Consumer Electronics, Volume 45, Number 3, August 1999. Available at the DTV Station Project's web site at: http://whd-tv.com/Documents/GenFldTstPlan.pdf

[2] "ATSC Field Test Vehicle Design Information", Gary Sgrignoli, Zenith Electronics Corporation, available on the DTV Station Project's web site at: http://whd-tv.com/Documents/ftvan.pdf.

The test van was outfitted with a directional ultrahigh frequency (UHF) antenna manufactured by Scala mounted to a pneumatic mast which could be raised as high as thirty feet above ground level (AGL), and whose direction could be measured using an attached compass. The radio frequency (RF) electronics system used to deliver the received signal from the mast-mounted antenna to test and measurement equipment in the van was itself thoroughly measured to quantify the gains and losses in the system. An Agilent Vector Signal Analyzer was used to display and measure the spectrum of the relevant DTV channel and any pertinent nearby (in frequency) NTSC channels. Finally, a Zenith Pro Demodulator was employed to determine the quality of the signal in terms of signal-to-noise ratio (SNR), the segment error rate (SER), and the equalizer tap energy. We also sought to establish what “margin” existed at each site between the observed signal level and the signal level at the threshold of visibility (TOV). Again, the procedure was standard, employing a combination of variable attenuation and the controlled introduction of white Gaussian noise.

Figure 2: Typical indoor set-up, using an experimental antenna and Sencore AT-986

VSB diagnostics we examined included the Modulation Error Ratio (MER), pre- and post-forward error correction (FEC) estimates of the bit error rate (BER), and equalizer tap energies. To provide a secondary means of signal acquisition cross-check on those reported characteristics, we also outfitted a personal computer (PC) with a Broadlogic DTA-100 VSB receiver PCI card, which reports SNR and SER measurements.

For indoor testing, we employed a portable device from Sencore (model AT-986) equipped with a Broadcom BCM 3510 VSB demodulator, to quantify the strength of the signal, as well as to give us a variety of VSB diagnostic characteristics from the received signal. A typical setup for indoor testing is shown in Figure 2.

As a means of comparing signal strengths across measurement devices and receiving antennas, we felt it best to tabulate signal strengths in terms of the electric field strength in the RF energy, spectrally confined to the DTV channel of interest. To accomplish this, we measured the magnitude of the power or voltage delivered to the RF measurement device, and calculated the corresponding electric field strength in the arriving electromagnetic wave, in units of dB relative to one microvolt per meter (dBuV/m). The calculation accounts for the load impedance of the RF measurement device, the gain of the receiving antenna and the frequency of the DTV signal. The advantage of quoting signal strengths this way is that the effects of the receiving antenna and RF measurement device are normalized, leaving only the physical characteristic of the electromagnetic wave as it is presented to the receiving antenna. Ultimately, the electric field strength is the connection to theoretical physical models, such as classical Kirchoff diffraction theory, which may be used to predict signal strength on the basis of propagation path geometry.

We accomplished our indoor tests by manually rotating the antenna to peak the signal. Aside from the fact that the antenna was frequently mounted on a tripod, our test set-up and antenna adjustment procedure was very similar to what we expect a consumer would typically do to receive our signal. By this we mean that no "extraordinary means" (i.e. high gain antennas and/or fine angular adjustments) were taken to try to find the signal. We restricted our patience in trying to find the signal according to what we believe to be reasonable to expect a consumer to perform in an attempt to receive our service.

While we are pleased to have reception statistics based upon rather unsophisticated set-up and alignment (representative of what a typical consumer will do), we recognize that quantifying "ease-of-use" as it pertains to antenna positioning and rotation would be both interesting and useful information. At the current time, we have no such quantitative data, but we intend to incorporate ease-of-use measures into future tests.

ANTENNAS

Because we consider indoor reception a crucial issue, iBlast believes that well-designed indoor antennas are a key part of our network. As a result, we have developed relationships with several leading and antenna manufacturers in the hopes of accomplishing two goals. First, we seek to determine which currently available antenna designs perform best for indoor reception of the ATSC signal. Second, we hope to stimulate the development of novel designs which improve the chances for successful and reliable indoor reception of OTA digital broadcast.

Toward the first of these two goals, we have obtained a variety of compact indoor antennas from a wide variety of innovative antenna manufacturers. We have been highly encouraged by the performance of several of these antennas, the manufacturers of which include, but are not limited to, Antiference, Arc Wireless, Radio Shack, RDI Electronics, Skycross, and Terk.

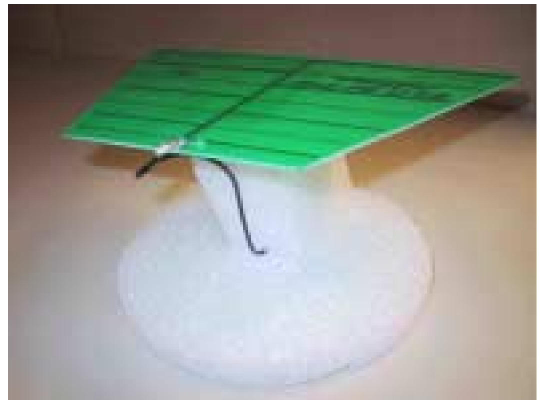

Figure 3: One of the prototype antennas used for indoor testing.

We should make clear that some of the antennas used in our tests were made specifically for iBlast, and are not yet commercially available. One such antenna, provided by RDI Electronics, is shown in Figure 3.

In order to better understand how best to improve the chances for indoor reception, we have subjected these antennas to characterization in the controlled environment of an anechoic chamber, which is shown in Figure 4. We collected radiation patterns in both azimuth and elevation for both principal- and cross-polarization. We have taken a variety of them with us in our field tests to see how their performance in isolation relates to performance in "the real world". We have also included antennas with modest amounts of pre-amplification in order to understand how the presence of such amplification might affect the rate of successful indoor reception.

The antennas used in our field tests possessed a sufficiently wide angular range of reception to facilitate manual setup. An important consideration for iBlast is the ease of use and setup for the consumer. If we were to employ antennas of high forward gain, we would correspondingly increase the

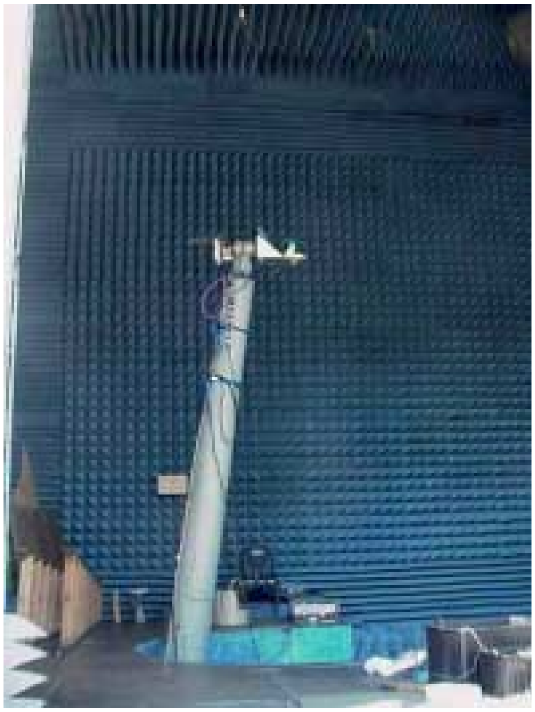

Figure 4: iBlast antenna evaluation included gain and pattern testing in an anechoic chamber. This served to establish a "baseline" prior to field work.

difficulty for the consumer to point the antenna in the correct direction to receive the signal. We, therefore, have restricted our selection of antennas to ones with angular tolerances on the order of 60 to 120 degrees. We were able to quantify the angular reception pattern for each of our field test antennas during our laboratory tests in the anechoic chamber. The result is that the consumer does not have to finely adjust the antenna orientation in order to catch the incoming signal.

Toward the second of the above goals, we have made modest progress as well. Our initial impression of commercial indoor antenna technology for the UHF band was that technological advancement in the field had largely been dormant for many years. The ever-increasing ubiquity of cable delivery services had nearly eliminated interest in developing novel indoor UHF antennas.

Considerable advances, however, have been made in antenna technology for military communications and cellular communications. Therefore iBlast approached antenna vendors in these industries to develop antenna designs specifically to solve reception problems in the UHF band. Several manufacturers have come forward with interesting and promising ideas on how to apply formerly classified technologies to the problem of indoor reception. Over the coming months, we expect to intensify this effort with the goal of bringing novel products to the market.

One of the technologies developed for military use, and of interest to iBlast, is the adaptive phased array. If such technology could be transferred to commercial applications, such as terrestrial datacast reception, we anticipate benefits in a variety of forms. One of the most obvious benefits comes from the potential for the antenna to steer itself to find a desired channel. The result for the consumer is a substantial and compelling improvement in the ease-of-use of an OTA broadcast. For our purposes, it may also provide a means of automatically changing channels to receive datacasts that have been programmed to occur on different channels at different times. It enables our service to allow a consumer to request data from multiple stations in a single market, without having to worry about repositioning his antenna.

SITE SELECTION PROCESS

In order to properly appreciate the results of our tests, we first must describe how we arrived at our choice of test sites. Ideally, one would design a set of test sites in some quantitatively "even" distribution. By even, we mean, for example, that one could choose the sites so that they lie equidistant from one another in either a Cartesian or radial coordinate system. One might also choose sites to quantitatively follow population distribution. Either way, the result would be that, with a sufficient number of test sites, one could then rigorously develop a statistically and quantitatively accurate projection of signal availability across an entire market area. Due to time and cost constraints on our first pass of testing, we did neither. We want to clearly state that we do not yet have sufficient data to statistically validate whether or not the results of the 202 test sites reflect what will happen when ATSC receivers are ubiquitous in the coming years. Further testing with more refined site selection is required to reach such a conclusion.

While we did not rigorously develop a geographically or demographically even distribution of test sites, we *did* make a conscious and deliberate attempt to sample a variety of areas in each market. We attempted to include sites at a variety of distances and at a variety of compass headings from the relevant transmitter. We attempted to incorporate a variety of terrain between transmitter and test site. With only a few exceptions, however, we did not seek to "push the envelope" of the reception area. By this, we mean that a solid majority of our testing was done within what we considered to be a reasonable distance from the transmitter. That usually worked out to be a range of approximately forty to fifty miles.

Our indoor site selection, as is true for most studies of indoor reception, was constrained by the availability of sites to our test engineer. Our ground rule was that we tested where we were allowed in the door. As a result, both the number and geographic variety of indoor sites is significantly less than with our outdoor tests. Our indoor test sites were predominantly either urban or suburban. Amongst the urban sites, however, only a small number are either dense urban or "urban canyon" where skyscrapers predominate.

We did make a deliberate attempt to select sites incorporating a diversity of construction types and locations representative of expected typical users of the iBlast service in the respective markets. Bearing these objectives and constraints in mind, we were able to accumulate a modest sample of indoor sites which we believe is worthy of note.

SUMMARY STATISTICS

Our tests were conducted on the ATSC signals from one station per market. The basic characteristics of those signals and their transmitters are shown in Table 2. Success or failure in reception was determined according to the standard Threshold of Visibility (TOV), which is defined as 2.5 segment errors per second.

The duration of the tests was short, typically lasting approximately five to ten minutes. As such, our results represent a "snapshot" of each of the test sites, and do not reveal anything of the long-term behavior of reception at the various sites. In the near future, iBlast expects to position "drone" receivers at many sites for purposes of monitoring signal strengths and VSB diagnostics over significantly longer periods of time. The combination of short-term observations and longer-term logs and statistics should prove a valuable tool in understanding the reach and reliability of our service.

	Center Freq (MHz)	ERP (kW)	HAAT (m)	HAMSL (m)
KTLA-DT Los Angeles	575	310	954	1854
KOIN-DT Portland	629	806	530	615
KGTV-DT San Diego	539	316	205	285
KICU-DT San Jose	701	251	668	900

Table 2: Television stations and their transmitter characteristics

The characteristics listed in Table 2 are the center frequency, in units of megahertz (MHz), of the DTV channel, the effective radiated power (ERP) of the transmitter, in units of kilowatts (kW), the height of the transmitting antenna above average surrounding terrain (HAAT), in units of meters (m), and the height above mean sea level (HAMSL) of the transmitting antenna, in units of meters. The range of distances from transmitter to test site is shown by city in Table 3.

	Minimum Distance (miles)	Maximum Distance (miles)
Los Angeles	12.8	61.8
Portland	2	46
San Diego	2	44
San Jose	2.8	49

Table 3: Range of test sites from each transmission tower.

Broken down by city, and further broken down by outdoor versus indoor reception, the summary of successful versus unsuccessful reception is given in Table 4.

		Outdoor 30 foot	Outdoor 8 foot	Indoor	Total
Los Angeles	Successful	68	20	14	102
	Unsuccessful	2	5	3	10
	Total	70	25	17	112
	Percentage	97	80	82	91
Portland	Successful	25	33	17	75
	Unsuccessful	0	3	1	4
	Total	25	36	18	79
	Percentage	100	91	94	95
San Diego	Successful	43	0	13	56
	Unsuccessful	0	0	1	1
	Total	43	0	14	57
	Percentage	100	NA	93	98
San Jose	Successful	44	32	19	95
	Unsuccessful	3	2	1	6
	Total	47	34	20	101
	Percentage	93	94	95	94

Table 4 Summary of Results for Each of the Four Test Cities

The cumulative result for all four cities is shown in Table 5.

Cumulative	Outdoor 30 foot	Outdoor 8 foot	Indoor	Total
Successful	180	85	63	328
Unsuccessful	5	9	6	20
Total	185	94	69	348
Percentage	97	90	91	94

Table 5 Aggregate summary of results across all sites

The discrepancy from city to city in the numbers of outdoor tests conducted at 30 feet and those at 8 feet is the result of an evolution in our test procedure. We began our tests with only 30 foot measurements, but later incorporated the 8 foot measurements to give us a richer picture of how antenna positioning might affect our customers' reception. Our plan is to continue testing at both heights.

PORTLAND AS A SAMPLE MARKET

Our results from Portland provide a good example of important information learned in our testing process. The first thing worth noting comes from comparing field strength measurements at different antenna heights in our outdoor measurements. It is well-accepted in the engineering community that higher receiving antennas experience stronger signals, and therefore provide stronger and more reliable reception. When the analog standard for terrestrial television broadcast was established by the National Television Systems Committee (NTSC) more than a generation ago, the expectation for antenna location was outside the home at a height of 30 feet above ground.

Due to likely consumer resistance, and neighborhood prohibitions against such high outdoor antennas, it is doubtful that a majority of the population will be willing to install outdoor antennas at 30 feet in order to receive DTV. It is more practical to consider lower antenna heights, surfacing the question of the relative performance of such antenna placement outside a home. Somewhat arbitrarily, we chose to examine outdoor signal strengths at eight feet above ground, and the results obtained are of some interest quantitatively.

In Portland, our measurements of signal strength at thirty and eight feet are shown in Figure 5, where the data points have been sorted by the electric field strength at thirty feet. What emerges is that the field strengths at lower antenna height are, as expected, lower than those seen at thirty feet with some non-negligible scatter in difference. The average loss in signal strength from thirty feet to eight feet is approximately 6.7 dB, with a standard deviation of 7.9 dB. Results of similar magnitude were obtained in Los Angeles and San Jose, where the differences were 9.0 dB and 6.9 dB, respectively. We made no such comparison in San Diego, where testing was completed before we incorporated the 8 foot test in our procedure.

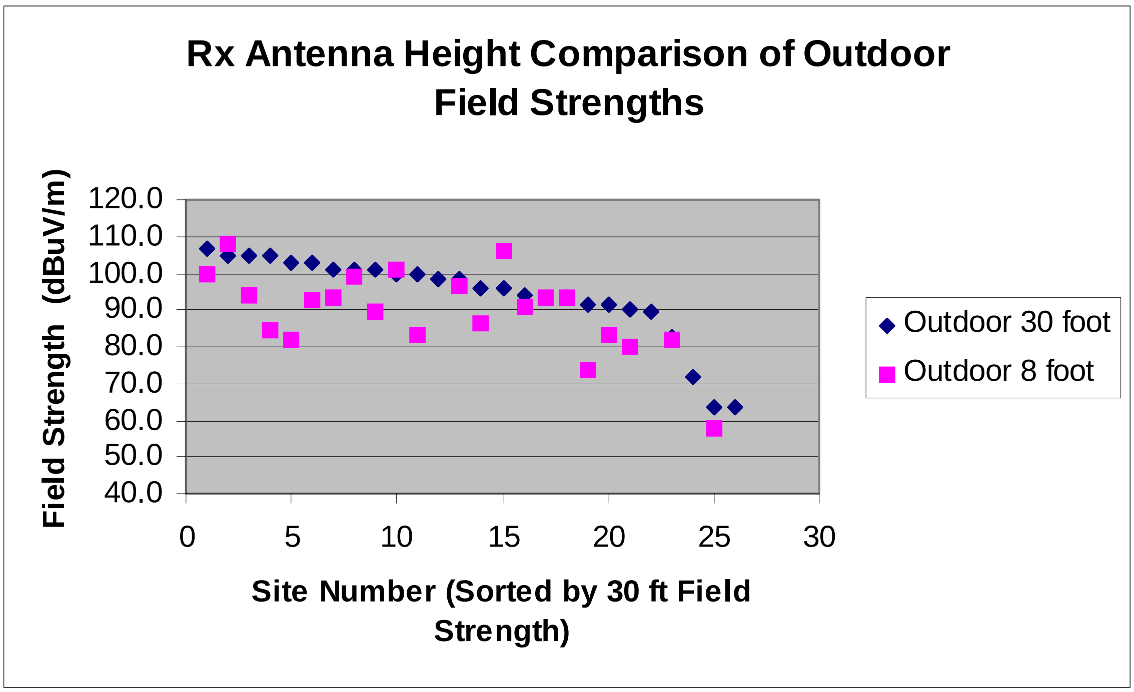

Figure 5 The variation in outdoor field strength at 8-foot and 30-foot antenna heights

In the same vein as signal degradation due to a lower receiving antenna is the issue of signal degradation through the walls of a house or apartment. To understand the issue of indoor reception, we sought to quantify the difference between the RF electric field strength outside versus inside a test site. Our data from Portland is shown in Fig. 6, where we have plotted the outdoor field strength at eight feet above ground and the field strength indoors, sorted by the outdoor field strength.

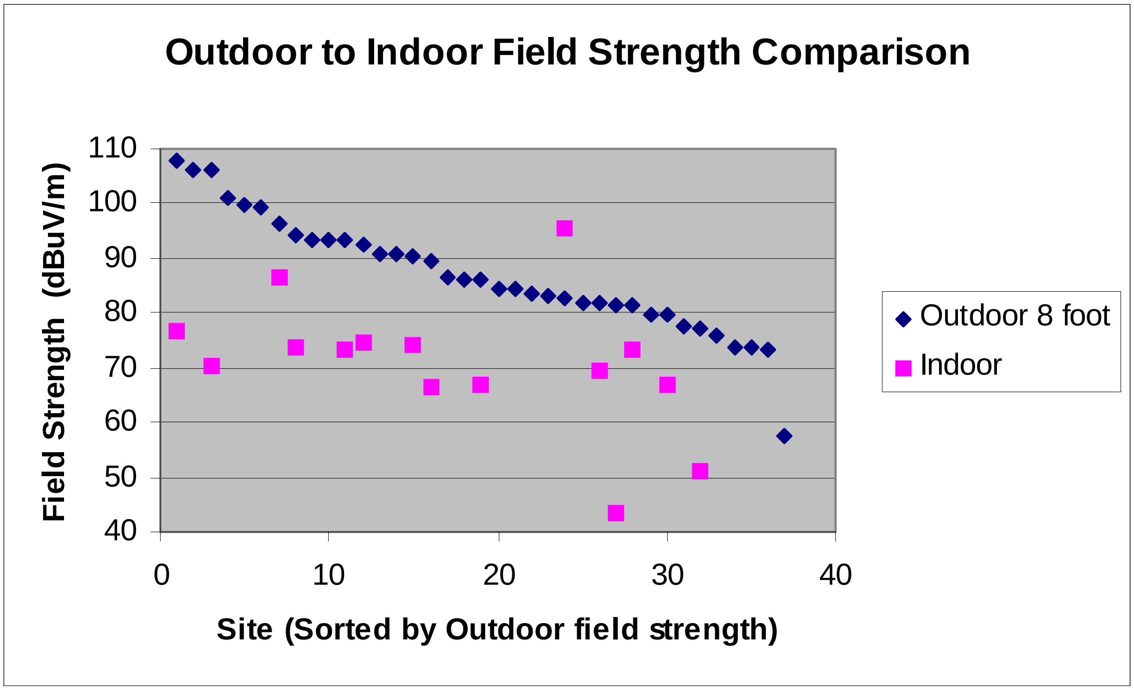

Figure 6 Outdoor to indoor variation in field strength, caused by wall attenuation

Two items can be seen from the results of Figure 6. First is that indoor strengths, with only rare exceptions, are significantly lower than outdoor field strengths, exactly as one would expect. The average outdoor-to-indoor loss for the Portland area was approximately 18.5 dB, with a standard deviation of 12.4 dB. The corresponding loss for San Jose was 21.5 dB. We do not have sufficient quantitative information to derive comparable results for Los Angeles or San Diego because we added appropriate measurement equipment for indoor testing after most (or all) of the testing for those two cities was complete. The second item of note from Fig. 6 is that there is substantial scatter in the indoor field strength data.

One somewhat less obvious item worth noting is that the field strengths observed indoors hover at or around the strengths (seen in Figure 7) where drop-out of reliable reception begins to occur, approximately in the mid-seventy dBuV/m range. We are persuaded that this is consistent with our as-yet-unquantified observation that antennas equipped with modest preamplifiers significantly improve the chances for successful indoor reception. If, in fact, one is operating in an environment where field strengths are above the absolute threshold for reception, but at or below the point where sporadic drop-out occurs, then it is not unreasonable to expect modest preamplification to be significant in improving indoor reception rates. Since our current test results are not complete enough to quantitatively verify or refute such a hypothesis, we expect to design future tests to increase our understanding of this issue.

Yet another item which became clear was the issue of how much field strength is necessary to successfully receive the ATSC signal. It is commonly accepted that reception of the digital 8-VSB signal with its incorporated forward error correction is nearly a threshold process. In more common terminology, this is known as the "digital cliff", where reception is perfect until the signal is degraded sufficiently to overwhelm the forward error correction, at which point reception fails completely. The CNR at the threshold is at, or slightly above, 15 dB. We sought to determine in our outdoor testing how much margin existed between the received signal and the threshold at which reception fails. Our process for doing so was described above in the section entitled "Description of the

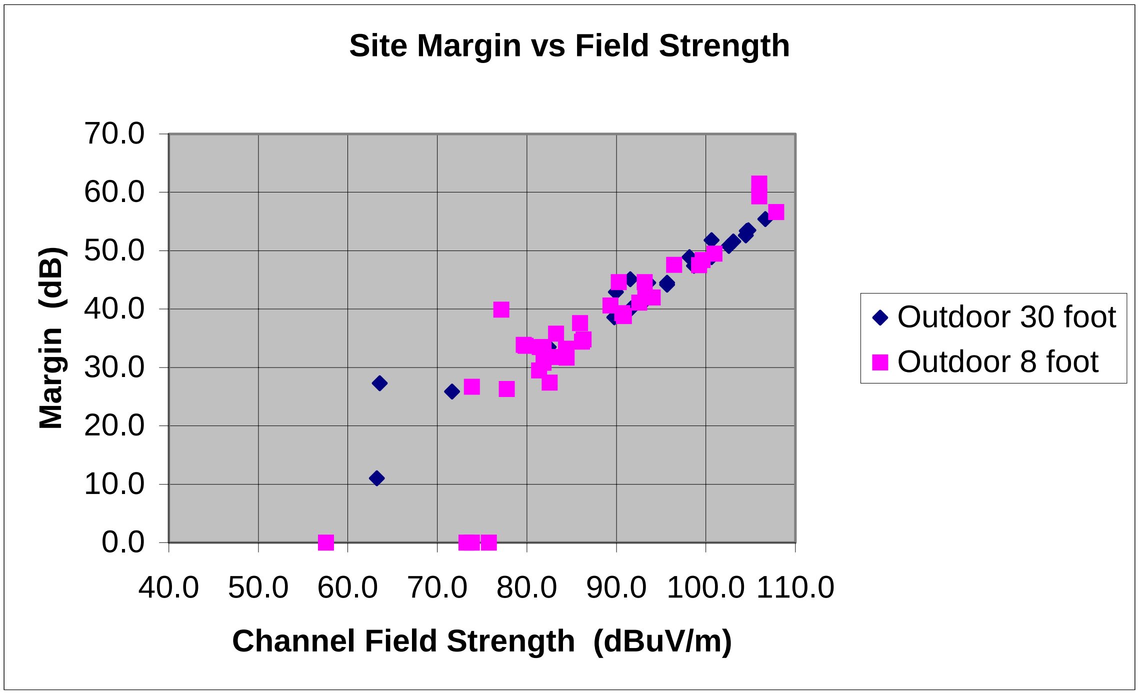

Figure 7 The measured variation between reception margin and field strength

Tests", and the results for Portland are presented in Figure 7. The margin shown on the vertical axis of Figure 7 is how much degradation in the form of attenuation or added white Gaussian noise can be introduced at a given site before the reception fails. Qualitatively speaking, a higher margin should be a strong indicator of easier and more reliable reception. The margin is plotted against the dependent variable of electric field strength in the RF channel at the site.

Two results present themselves here. First, failed reception (sites where margin is quoted as 0 dB) occurs rarely for field strengths above 80 dBuV/m, with drop-outs beginning in the high- to mid- seventies. Second, extrapolation to lower field strengths strongly suggests an absolute minimum field strength for any reception of approximately mid-fifties dBuV/m. While results for the threshold in other cities varied slightly from this number, the differences were not substantial enough to merit attention. What does seem to vary substantially from city to city is the field strength at which drop-out begins to occur above threshold. This is almost certainly attributable to differences in terrain, ground clutter, transmitting antenna height, all of which contribute to multipath corruption of the signal.

OBSERVATIONS

We were able to make several key observations during our tests. The first is that we believe it is clear from the results that reception is a threshold process (as is widely accepted) and that the threshold for successful reception for the stations we tested in the UHF, in terms of electric field strength, lies somewhere in the low- to mid-fifty dBuV/m range.

Another key issue which came to our attention during the current round of testing is that one's chances of achieving successful indoor reception was substantially improved by incorporating even a modest amplification at the antenna. By modest, we mean on the order of 10 dB, something achievable with extremely simple and inexpensive electronics. We do not have statistics yet on how to quantify the effect of a 10 dB preamp on the "batting average" for indoor reception, but developing such data is likely to be a goal of subsequent rounds of tests.

Finally, and rather generally, we were pleasantly surprised at the rate and the ease with which we were able to achieve successful indoor reception at the sites we visited. There has been a great deal of gloom and skepticism surrounding the issue of indoor reception for DTV, however our experiences simply did not support the many dreary projections. Our field test experience has left us with no doubt that indoor reception is a serious issue worthy of attention and study, but we remain optimistic regarding its ultimate feasibility.

Furthermore, we are encouraged that our results are similar to other test results. In particular, the accumulated results published recently by the ATSC from a wide variety of field tests conducted by many groups show successful indoor reception in high percentages of sites in most of the markets tested. The notable exception is Washington, D.C. That accumulated experience is depicted below in Figure 8. It is worth noting that what is being quoted in Figure 8 is the System Performance Index (SPI) for the ATSC signal (used for evaluation of the VSB modulation standard), which is different from the raw batting averages we are quoting in our field test results. We also tested in cities with qualitatively different terrain than those represented by the ATSC results. On the other hand, the rates of success, understanding that there is a quantitative difference in the definition of "success", are not terribly inconsistent with our own results.

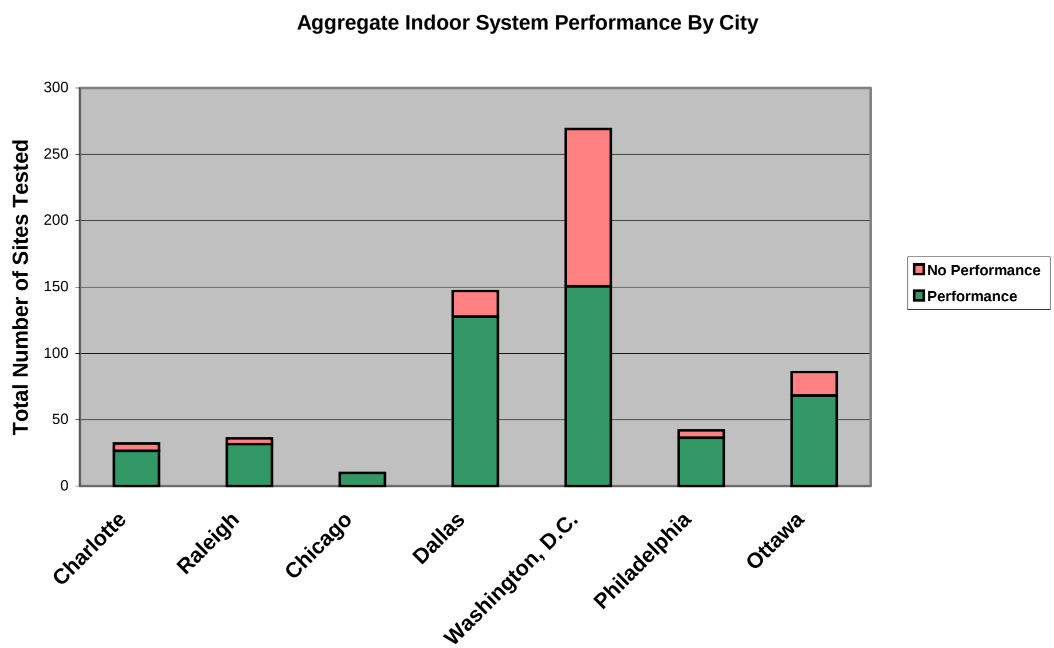

Figure 8 The ATSC's compilation of previous measurements in seven cities[3]

[3] ("Performance Assessment of the ATSC Transmission System, Equipment and Future Directions", Report of the ATSC Task Force on RF System Performance, April 12, 2001, available on the ATSC web site at http://www.atsc.org/papers/Performance_Assessment.pdf)

CONCLUSIONS AND FUTURE PLANS

Our results indicate that indoor reception of the ATSC signal is feasible at a large number of locations, using the latest VSB demodulator chips and new, amplified antenna designs matched to the receiver. A key parameter for indoor reception is sufficient RF signal level. Although we have so far collected a limited number of field test results, we are encouraged by the results. We are also encouraged by continuing developments to improve the basic VSB demodulator technology and believe we have only scratched the surface in efforts to develop better antennas. The recent efforts of television broadcasters to maximize effective radiated power will further improve reception. We plan to continue field testing to develop a larger database that will represent a more statistically valid sample and that will enable us to develop a predictive coverage model correlated to the test results. iBlast will work with VSB demodulator and antenna vendors to incorporate technology improvements in these tests as they are developed.

