WiFi-PLUS, Inc. July 23, 2004

White Paper: Antenna Design for Challenging Environments

Multi / Preferred Polarization, Multi / Preferred Path, Noise Reducing, LOS-Optimized and 'Obstruction-Penetrating' Multi-Faceted Antenna Designs

This white paper describes the inherent performance improvements in a new generation of "obstruction-penetrating" antennas and lists some circuitry innovations that can enable further benefits. It describes the inherent benefit of focusing on polarity and pattern above gain to solve connectivity issues.

Improvements in communications signal capture offer concomitant and dramatic improvements in the performance and usability of devises that capture, transmit, record and playback the voice, data and image signals that underpin communications across the widest range of applications. Antenna technology is central to effective, predictable, reliable wireless communications.

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1.0 Background – Wireless Communications

For years, wireless communications, including Wi-Fi WLAN and WWAN, cell phones, Land Mobile radio, aircraft radio, and satellite communications, have struggled with limitations of audio, video, and data transport, internet connectivity in obstructed (indoor and outdoor) and even in LOS (Line-Of-Sight) deployments. Communication needs are ever expanding and create new obstructed challenges with (EMS, RFID, laptops, hand-helds, monitoring devises, and digital signage. On average 3 -5 multi-path's can be created in a typical RF transmission. Site surveys can be used to cope with some of the problems created but what can be done when the wireless environment is under constant change. An application such as RF tagging will prove difficult in these multi-path obstructed environments that will constantly change as inventory can be moved and change the reflective nature of the transmission. Mobile and roaming use will present the same problems.

Antenna design changes needed to meet growing deployment challenges

The focus on gain, as well as circuitry solutions has significant limitations. Unresolved non-optimized leading edge technologies have often given way to 'bleeding edge' attempted resolutions. Unfortunately, all have fallen (somewhat) short of the desirable goals.

Presented here are novel, patented antenna design solutions with applications in and of themselves, as well as in combination with circuitry innovations, to benefit a myriad of wireless communications. These uniquely beneficial antenna designs are designed to incorporate Multi-Polarization, 'Geometric Spatial Capture of Signal' (built in spatial diversity), desirable Patterning, and Phase-shift Directives /DFDM ('Geometric Doppler Frequency Division Multiplexing').

2.0 Challenges – Environmental Radio Wave Alterations

While lower frequency radio waves benefit from an 'earth hugging' propagation advantage, higher frequencies inherently benefit from multi-reflection. However, with topographical changes (hills & valleys), obstructing objects (natural objects, such as trees, and man-made objects, such as buildings/walls), and with the resultant reflections, diffractions, refractions and scattering, maximum signal received may well be off-axis (non-direct path) and multi-path, resulting in partial cancellation of signals in null areas and weaker spots.

Obstruction penetration is key performance requirement

Also, some antennas may benefit from having gain at one elevation angle ('capturing' signals of some pathways), while other antennas have greater gain at another elevation angle, each type being insufficient where the other does well. In addition, the radio wave can have altered polarizations. And a very preferred (polarized) path often exists. Insufficient capture of signal can result.

3.0 Attempted Solutions – Diversity and Other Methods

Spatial diversity can be of distinct help with some of the null-spot issues. (V)OFDM technology (where allowed by the frequency and band) helps with some multi-path out-of-phase 'data clash' issues. Electronically steer-able antenna arrays alleviate some interference problems and provide a solution where multiple standard directional antenna/radio systems would otherwise be more difficult or clearly impractical. Dual slant polarization antenna/circuitry switching systems have shown much advantage over others in some obstructed environments.

4.0 Novel Antenna Design Solutions

As a "one antenna does all" solution, the ULTRA-M (patented) designs are uniquely beneficial, per the enclosed analyses.

Coined the Multi-Polarized Position-Independent Noise-Reducing Obstruction-Penetrating 'ULTRA-M Omni' and 'Ultra-M Beam' designs, these antennas are quite distinct from other antenna designs.

Beneficial properties include:

1. High Gain for their relatively small size.
2. Multi-Polarization - allowing utilization of altered polarized 'Preferred Path' signals (of all 6 electric and magnetic field polarization states).
3. Built-in Spatial Diversity ('Geometric Spatial Capture of Signal').
4. Phase-shift Directives/DFDM (coined by WIFI-PLUS as built-in 'Doppler Frequency Division Multiplexing').
5. Exceptional Patterning for Capture of the Signal from many changing directions.

Signal capture in new electronic form factor in X-Y-Z axis.

It is important to emphasize that, although the most superior results of this antenna technology are seen by using it at both ends of the wireless link, PCMCIA cards with built-in dual diversity polarization properties approximate the performance of the 'ULTRA-M Link', when communicating with ULTRA-M antennas presented as HUB antennas. Also, as can be deduced by analysis of the physical properties presented, sufficient survey studies reveal that utilizing the presented technology at the other end of even a singularly polarized antenna systems still provides overall improvement in the wireless link.

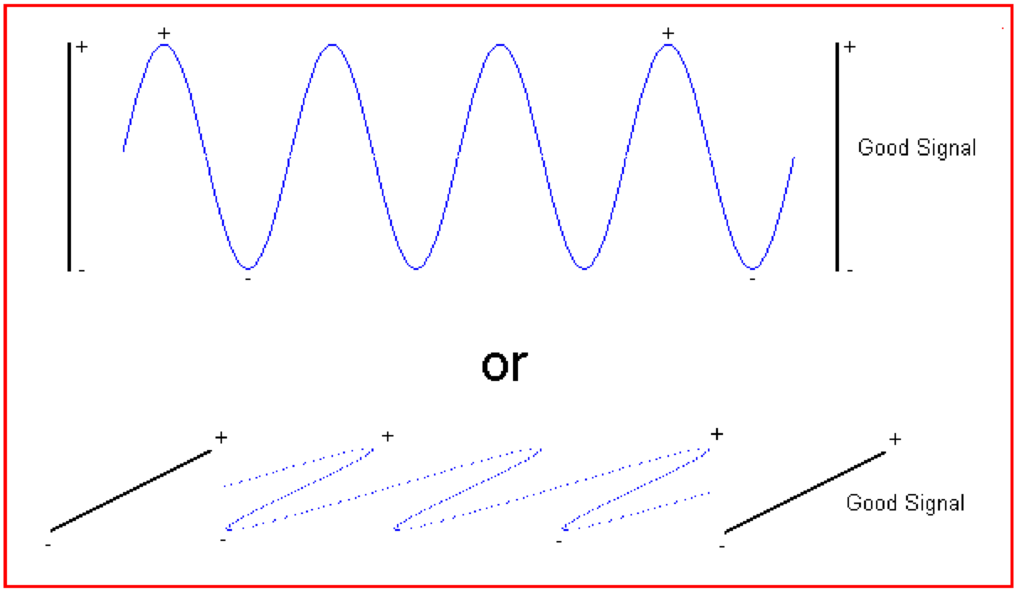
This is indeed a different way of looking at things, even about the issue of polarization. Rather than switching (electronically) between differently polarized antennas, the presented concept is about producing and receiving all polarizations such that the very most Prominent (Preferred) Pathway signal is utilized, in its polarization state - frequently, one slant polarization or another. All X-Y-Z axes are produced and received with these novel antenna designs, and the maximum signal in the obstructed environment is the more direct path (point A to point B), with the same-phase other-polarization-state waves along the same path added. This is especially (but not exclusively) the case with man-made, vertically & horizontally shaped/edged structures.

4.1 Gain vs. Polarization and Gain vs. Pattern

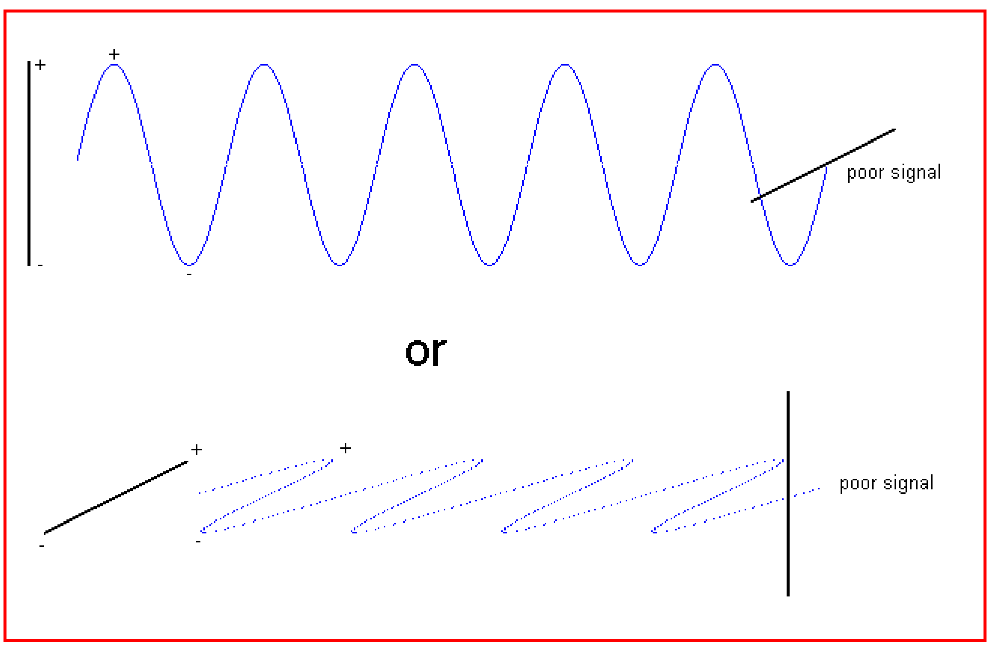
Certainly, gain (the increased ability to send and receive signals in a particular direction) is important. However, if the polarization of the signal and antenna are not matched, poor performance results…

If the transmitting antenna is vertical, then vertical (up-and-down) polarization results. If the receiving antenna is also vertical, then they are matched for wireless communications. This is similarly true for horizontal antennas with horizontal signal coupling.

This is conceptually illustrated in the diagrams as follows.



But if one antenna is horizontal like a regular TV antenna, horizontally (side-to-side) polarized, and the other antenna is vertically polarized, the signal received will be reduced due to mismatch of polarizations, by 20+ dB (being ≤1/100th the signal of a matched polarization scenario).



Therefore, a 21 dBi gain, vertically polarized antenna attempting to receive a (nearly) horizontally polarized signal, is essentially a ~1 (or even negative) dBi gain product at that time. Gain is important, but to be effective, must be in the proper polarization.

Example Scenario Solution: CELL/PCS PHONE

Maximum signal amplitude used

A vertically polarized signal from a Cell/PCS phone transmission tower will be received more poorly as the Cell/PCS phone is held/placed more sideways (horizontally). The nearly spherically pattern multi-polarized 'MP-BULLET' antenna in this application functions well in any position.

A 45 degree tilted antenna will receive vertically and horizontally polarized signals, but at 3+ dB down (≤½ power). However, if the signal intended to be received is also at a 45-degree tilt, but perpendicular to the 45-degree tilt receive antenna, the signal is again reduced to 1/100th.

Now, if a transmitting antenna produced all polarizations in all planes and all X-Y-Z axes (the axially side-to-side plane - like circularly polarized antennas - but also forward-backward tilt) and the receiving antenna captured all polarizations, the Significantly Greatest Preferred (Polarization) Path and maximum signal amplitude would be utilized.

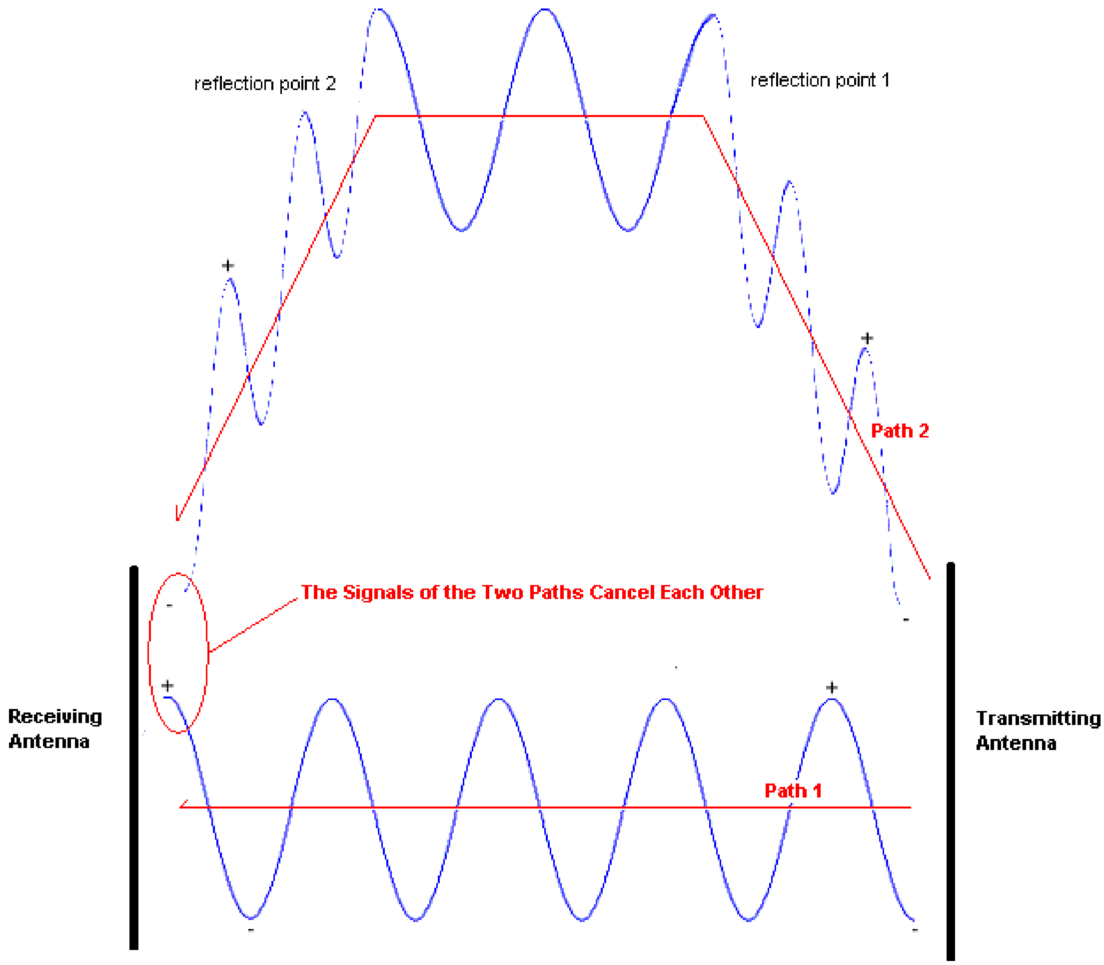
The ULTRA-M Omni has an effective dual-polarized lobe, but in ALL azimuth (360 degree) directions, and therefore, by nature of its construct and design is ALL-Polarized.

The ULTRA-M Beam is, simply stated, a MULTI-ALL-Polarized Beam.

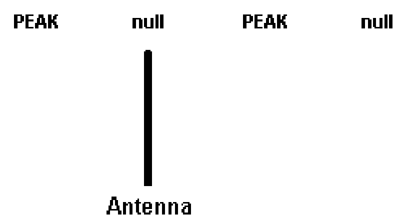
Furthermore, due to unique electromagnetic interaction theorems utilized in their design, they exhibit surprisingly high gain and in a small package. With their Multi-Polarization qualities, their high gain is useable.

4.2 Multi-Path Wave Cancellation

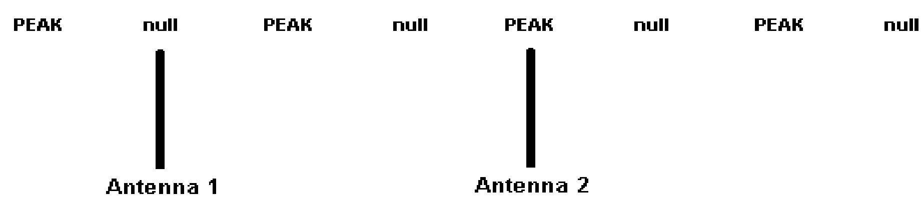
Some (data) radio equipment comes equipped with two antenna, spatial diversity connections. One intent of this diversity is to reduce the null spot problems of a singular antenna. Simply stated, due to multi-path, a single antenna may receive different/out-of phase signals from different paths.



Due to the different lengths of these signal paths, and resultant variations in phase, the combination of these signals may result in partial or even complete wave cancellation, with an end result of decreased, or even no usable, signal. Therefore, peak ('hot') & null spots occur.

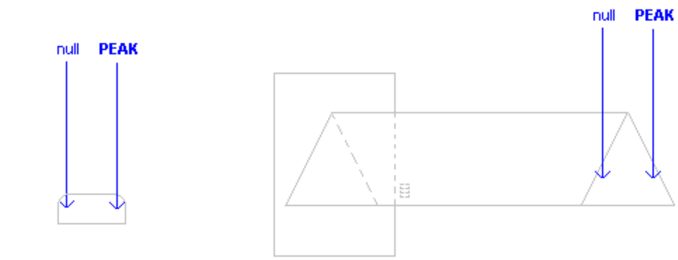


By incorporating receive diversity, whereby the radio switches between two antennas, chances are more likely that one of the two antennas will be in a peak ('hot') spot than if only one antenna is used.



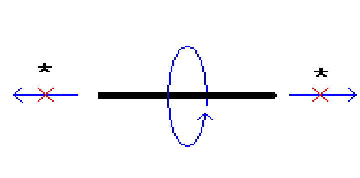
However, not all data radios (AP's, bridges, PCI/PCMCIA cards, and USB devices) come equipped with (spatial) diversity.

The ULTRA-M (OMNI and BEAM models) antennas have Geometric Spatial Capture of Signal (built-in spatial diversity) design. If a portion of the antenna is in a null spot, another portion of the antenna is likely to be in a peak ('hot') spot.



4.3 Polarization and Diversity

A specific beneficial utilization of spatial diversity is to have antenna 1 (positioned) for capturing vertically polarized signals and antenna 2 (positioned) for capturing horizontally polarized signals.



Unfortunately, the horizontally positioned antenna 2 (rubber duck, etc.) loses its omni-directional capabilities. Again, the ULTRA-M antenna has the advantage.

The ULTRA-M OMNI antenna has, in addition to Geometric Spatial Capture of Signal, the quality of exhibiting all (vertical/horizontal/and all in-between) polarizations at the same time in an OMNI-DIRECTIONAL pattern, from the horizon to straight up (and from the horizon to straight down when ceiling mounted).

The ULTRA-M BULLET antenna is essentially spherical in pattern, in addition to exhibiting 'Geometric Spatial Capture of Signal' for null reduction and Multi-Polarization, the latter two also being beneficial properties of the high gain, low wind-load, ULTRA-M BEAM antennas.

Multi-Polarized antennas show superior performance

In repeat, thorough testing and analysis, with gains matched, the ULTRA-M Multi-Polarized antennas outperformed all the others, even circularly polarized designs. And frequently, the Multi-Polarized ULTRA-M designs even also exceeded the performance of higher gain antennas.

It has become clear that determining real-life performance of antennas in changing positions and obstructed environments requires more than anechoic chamber testing with equipment like a network analyzer. Simulated changes in the environment can be rather reflectively conclusive. In vivo real-life testing and evaluation requires many repeat trials in various scenarios and is laborious, but the statistical analysis is what determines the overall validity of new design concepts as they relates to actual consumer usage.

For this T&E report, in that it had previously been clearly determined that circular polarization was significantly better than either vertical, horizontal, or a diversity combination of the two, testing was performed comparing the subject multi-polarized antennas with the circularly polarized antennas, in terms of SNR, packet loss, and the radio bit rate. Testing here was performed in the 2.4 GHz radio frequency band.

Tests were done in which one end of the link had two of the multi-polarized omni antennas in a diversity configuration (the second antenna was receive-only). The other end of the link had either one (or two) of the 18" directional multi-polarized antennas.

The directional antenna was placed outside, and the omni end was moved within another building so that there were from 10 to 20 walls between the two endpoints. Signal and noise levels were recorded at both ends, as well as video packet loss, and the bit rate of the radio (the radio automatically switches between 11Mbps, 5Mbps, 2Mbps, and 1Mbps depending on the quality of the signal). The same test was run 3 to 5 times (each test lasted about a minute), with 3 different antenna configurations:

1) Multi-polarized antennas (omni diversity at one end and a single directional antenna at the other end).
2) Multi-polarized antennas (omni diversity at one end and directional diversity at the other end).
3) Circular polarized antennas (omni diversity at one end and a single directional antenna at the other end).

The following table summarizes the results:

		Multi-Polarized With diversity at both endpoints	Multi-polarized with diversity only at the omni endpoint	Circular polarized with diversity only at the omni endpoint
Omni endpoint	Average Signal	-65.0 dBi	-63.6 dBi	-70.0 dBi
	Average Noise	-86.0 dBi	-87.2 dBi	-87.0 dBi
	Average SNR	20.8 dB	21.6 dB	16.7 dB
	Average Radio Bit Rate*	8.7 Mbps	9.0 Mbps	7.8 Mbps
Directional endpoint	Average Signal	-64.0 dBi	-64.8 dBi	-74.0 dBi
	Average Noise	-86.8 dBi	-88.6 dBi	-87.3 dBi
	Average SNR	22.0 dB	23.4 dB	13.0 dB
	Average Radio Bit Rate*	5.5 Mbps	5.2 Mbps	2.9 Mbps
Video Packet Loss	Average % packet loss	29%	24%	46%

* The 802.11b radio switches automatically between 11, 5, 2, and 1 Mbps, depending upon the signal quality. The Average Radio Bit Rate that was measured is the average of the radio's reported bit rate setting sampled at 1 sec. intervals.

In summary, the multi-polarized antennas consistently performed better than the circular polarized antennas, in terms of SNR, packet loss, and the radio bit rate. Subjectively, the video quality was perceptibly improved with the multi-polarized antennas.

With an application of streaming live video and audio at up to 4 Mbps, the multi-polarized antennas consistently performed better than horizontal, vertical, or circular polarization.

Test result: Multi-Polarization almost doubles antenna performance

In conclusion, the multi-polarized antennas provided almost twice the performance overall of circular polarized antennas, previously the best antenna design for difficult multi-path environments.

So, with outdoor and indoor obstructions come reflections, diffractions, refractions, and scattering of radio waves, and with that, much higher amplitude signal of a particular polarization in the more direct pathway (sometimes the primary end-result signal), and partial or complete changes of polarization in general.

The revolutionary multi/all-polarized antennas do well in this environment, being 'obstruction-penetrating' by producing all polarizations and capturing the (changing) Highly Preferred Polarization Path, holding the communication, where standard antennas fall short.

Furthermore, undesirable RF noise (either out-of-phase multi-path of the desired produced signal, or signal from other sources), with its inherent polarization will wreak havoc on similarly polarized wireless communications links; choosing polarization yields much less than 100% deployment success in attempting to polarize-select-block noise of varying polarizations from place to place.

On the other hand, success is had with multi-polarized links even with LOS in that only some of the desired transmission and reception is of the same polarization as the 'noise'. Signals of all polarizations are produced and these LOS multiple signals are all received, and per geometric antenna design, added beneficially in phase, the singularly polarized noise therefore accounting for but a small part of the total.

A stimulating reconsideration of multi-polarization utilization…

Clarification with LOS/NLOS scenarios:

LOS 1: Singularly polarized transmit and receive results in decreased /loss of signal when the laptop position changes, the wireless PDA, or phone, is held sideways or partially sideways.

Applicable to all obstructed environments; urban,rural, commercial, harsh atmospheres

With Multi-Polarization, especially if at both ends of the wireless path, signal strength is much better maintained with position independency, and with production/reception of all polarizations in phase, even greater stability is seen.

LOS 2: Diffractions with surrounding vertical/horizontally constructed man-made structures causes detrimental out-of-phase multi-path signals; less is seen with slant polarization - overall greater SNR.

LOS 3: QRM as industrial vertically polarized noise wreaks havoc on vertically polarized systems; less so with multi-polarized systems where clearly only one component is vertical (overall greater SNR again).

NLOS 1: Tree obstruction, for example, causing reduced signal but the major magnitude signal is still the direct path point A to B. Some multi-path same-polarization out-of-phase cancellation - such as benefited by (V)OFDM, with or without Multi-Polarized antenna technology. The best SNR may be with vertical or horizontal, or with a slant at each end of the wireless path, and this may change with fluctuations. With multi-polarization, overall SNR is better and is the best for predictability, leaving out chance as a factor.

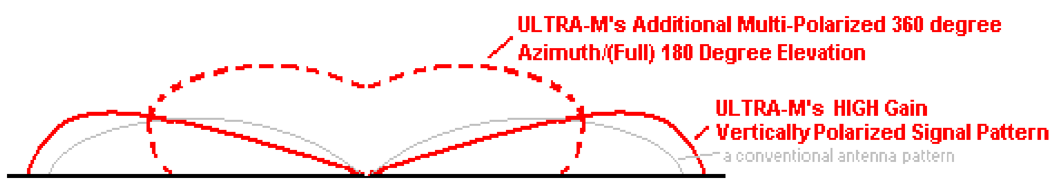
NLOS 2: Obstructions such that the path of greatest magnitude is off the direct A to B axis; preferred polarization in terms of production and after altered pathway is quite unpredictable. Multi-polarization at each end of the wireless link is essential.

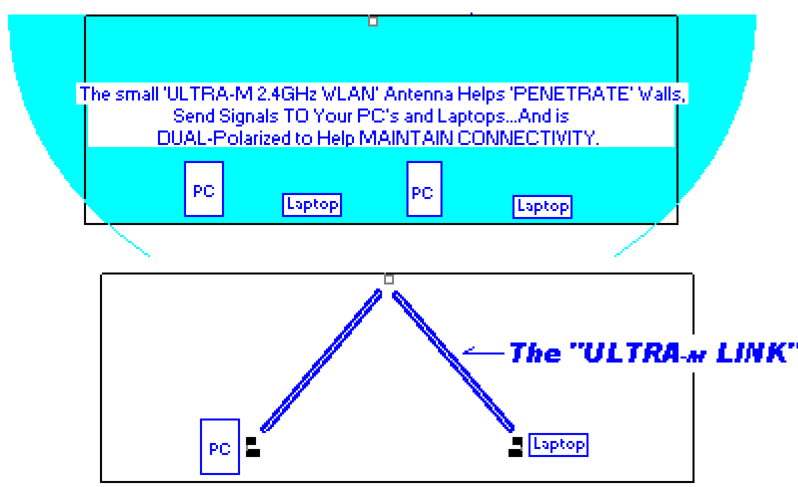
NLOS 3: Sub-category of NLOS 1 where obstructions are specifically of vertical and horizontal man-made structures/edges, where clearly slant polarization is favored (signal is less affected by diffraction, resulting in greater direct path signal magnitude and in lesser same-polarization phase cancellation multi-path). Greater overall SNR with multi-polarization (including slant polarization signals in X, Y, and Z axes).

5.0 The 'ULTRA-M OMNI' Antenna

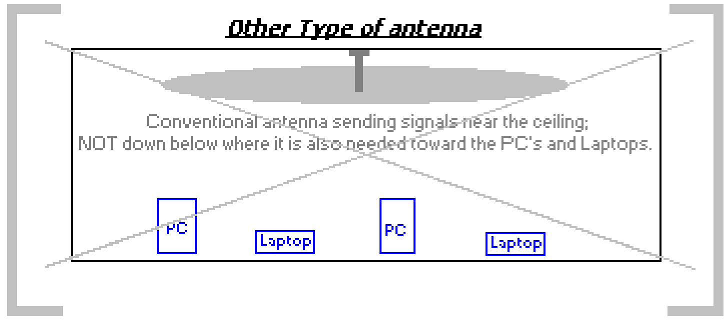
The standard, higher gain (at/near the horizon) omni antenna does poorly when in a valley (the strong signal striking the side of the valley).

The ULTRA-M OMNI has a high gain, near-the-horizon, vertically polarized signal, as well as a dual/multi-polarized lobe that continues up to the 90 degree elevation for out-of-the-valley & higher tower/bldg./satellite performance, as well as the coined Geometric Spatial Capture of Signal design characteristics for reduced flutter and multi-path benefits. And when mounted upside-down on the ceiling, it greatly enhances WLAN capabilities both to handheld devices and laptops below, as well as to radio cards on the other side of the wall.



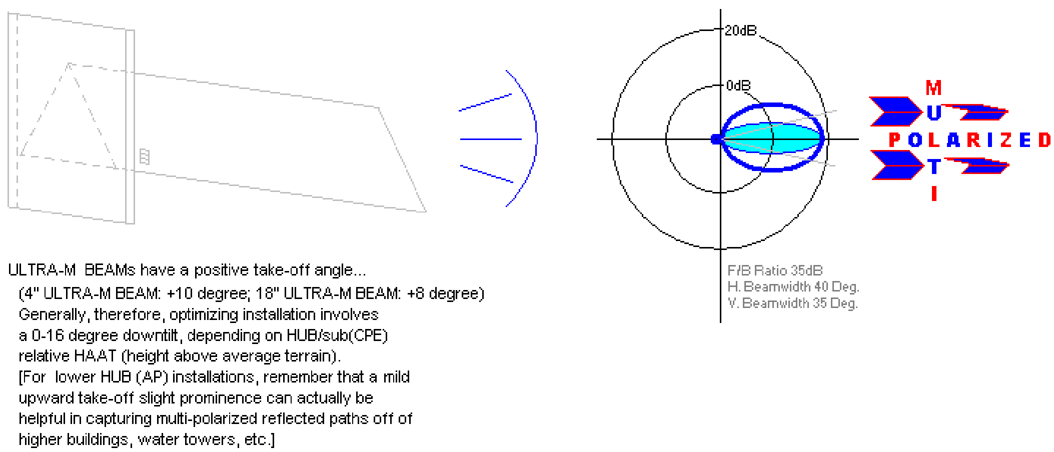


"ULTRA-M LINK"...
'ULTRA-M 2.4 GHz WLAN' Ceiling Antenna to
'ULTRA-M 2.4 GHz Omni Desk Stand/BULLET' antenna!



5.1 The 'ULTRA-M BEAM' Antenna

The ULTRA-M BEAM captures signals whether polarized vertically, horizontally, or anything in-between. Benefiting from a uniquely formulated electromagnetic interaction structured design and a modified, extended ground plane application, it also has surprising gain (for its size). Even more significant is its ability, via multi-polarization, to be able to produce communications, where the very large, "highest gain" singularly polarized (semi) parabolic reflector antennas could not perform in the obstructed environments observed.



5.2 The 'TETRAD-M ARRAY': Deep Dish 'Omni-Front-Fed' Parabolic Reflector

Progressing, a Multi-Polarized 'TETRAD-M ARRAY' maximally exhibits the 'signal holding' capabilities of Geometric Spatial Capture of Signal, with a high 22dBi gain in a small package.

It, and an All-Polarized, Obstruction-Penetrating, high gain ULTRA-M Omni-Fed Parabolic Reflector, in tests, at times alleviates the need to expensively situate long-range P-P microwave antennas high above all in-path obstructions. The Multi-Polarization characteristic has also provided benefit with temperature and humidity inversions (in even line-of-sight, non-obstructed, non-Freznel-zone-problem, visual wireless paths).
Addendum:

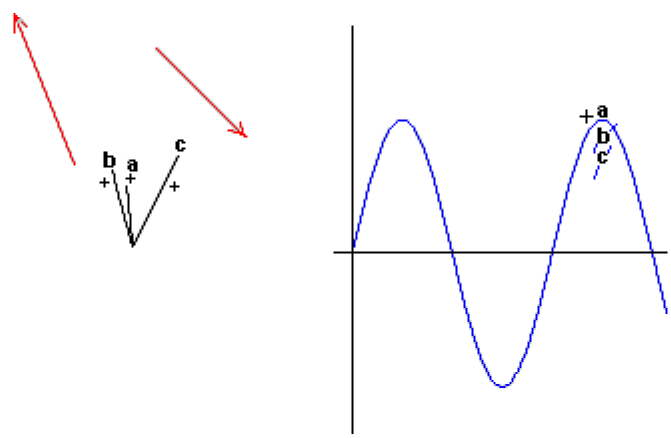
When two active vertical ¼-wave elements are separated, e.g. ¼-wave apart, and fed in phase, the prominence of the azimuth signal pattern occurs about the line midway and perpendicular to the line that joins the two active elements. This similarly occurs with two of the active slant (tri-) elements here.

If the two vertical ¼-wave elements are fed ¼-wave out of phase, clear prominence occurs in the direction of the delay-fed element. With the slant (tri-) elements slightly different in length, there is also some of such characteristic and some phase-shift with it. All considered (with vector analysis), there are some phase/frequency-shift directives occurring.

Particularly in a multi-antenna array, these phase-shift directives can be beneficial, in and of themselves, individually per antenna in NLOS scenarios, and in a statistically advantageous manner similar to Multi-path Fractional Sinusoidal Additionals (a later subject) for maintenance of some (useable) signal.

Furthermore, when the driven (tri-) element is mechanically rotated on axis (spun), with these phase-shift (vector) directives considered, the benefits of (V)OFDM circuitry are further mimicked and are coined 'DFDM – Doppler Frequency Division Multiplexing'.

An optimized RPM is found in a stable NLOS environment and continued variations in the RPM benefits the changing obstructing environment.



The following circuitry technologies, among others, that when combined with the radio wave/antenna technologies herein, produce even further benefits:

- (V)OFDM - Increasing S/N ratio even further with reduction of out-of-phase minor magnitude pathway signals.
- Switching phased arrays
- Doppler switching circuitry of the active slant elements
- Circular phase delay feed of the active slant elements (using circuit board strips, etc.) - Although terrestrial and satellite signals are benefited by the technology presented herein as is, this combo has been shown to clearly improve mobile (data) satellite radio ("XM" and "Sirius", as examples).
- Other circuitry methods, not yet developed around the technology presented herein.

6.0 Multi-Polarized Antennas – Real-Life Benefits and Comparative Analyses

The "Bottom Line", real world benefits, most prevalent when using patented technology inherent in Multi-Polarized WIFI-PLUS antennas at both ends of the wireless connection:

A. Overall Greater Consistency of Signal & Reduced Noise	B. Further Obstructed Environment Reach

Proper Methodology for Antenna Comparisons/Evaluation
(Comparative Test Analyses)

Improved antenna performance reduces costs

Use the following software or equipment tests (in a number of locations for overall comparison, if necessary) to compare 'apples-with-apples' and to document the improved performance of similar gain (and at times even lower gain) WIFI-PLUS antennas.

Using Multi-Polarized antenna technology at both ends of the wireless communication shows further performance improvements.

1.) Note that with our in-built spatial diversity, you can move our antennas around more without as much loss of signal. They are easier to point at the source, if necessary.
2.) Note that with our 'ULTRA-M Bullet' laptop, PDA, etc., antenna you can change positions freely (unlike with rubber ducks, verticals, etc.) and still get high performance.
3.) On your wireless software, check not just signal strength, but also noise level, signal-to-noise ratio (the higher the difference/level, the better), the 'quality' of signal, & beacon/packet retries/errors.
4.) Use site survey software/equipment such as Netstumbler/Locust for detailing and tallying signal-to-noise ratios (useable signal) and other characteristics noted in the previous item.
5.) Compare actual connectivity speeds.
6.) Document usability in far reach and/or high obstruction sites where the other antenna types 'don't quite make it' (borderline or non-usable).

7.0 Summary

Multi-Polarization solves reflection and obstruction problems using a passive design. This allows the technology to be easily and readily adapted in to existing communication devices. MP will increase coverage areas without adding radios. It will provide superior signal in difficult moving and roaming environments. Multi-Polarization will become a commercial standard as outdoor and indoor wireless becomes a necessity with the advent of hot-spots, WISP's, and Voice over IP needs. Ever changing environments will require an antenna that can collect signal in harsh urban environments as well as tree obstructed areas. Line of sight will rarely be an option for connectivity. Reliance on new communications alternatives by emergency and first responders will demand that signal is available without holes in the coverage.

The Multi-Polarization / Geometric Spatial Diversity Capture / Beneficial Patterning / Phase-shift Directives / 'D(Doppler)FDM' antennas have been shown to clearly have Signal-Holding / Stabilizing Capabilities with Position-Independency, Null-Spot Reduction, Beneficial Patterning, Noise-Reduction & Obstruction Penetrating capabilities.

The discussed designs better utilize already existing radio technology, modulation schemes, formats and deployments, including Ethernet.

They also pave the way, in and of themselves, and in combination with advanced circuitry, for extraordinary future land, mobile, maritime, aviation, satellite, space, and planetary radio communications.

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About the Author:

Dr. Jack Nilsson is Chief Science Officer for Wifi-Plus Inc. In 2001, Dr. Jack Nilsson was awarded patent for MP Antennas. He designed and developed an advanced microwave antenna theory that utilizes pattern and polarity with in a passive design that captures signal on x,y, and z planes. This antenna was tested by independent outside laboratories, and was found to provide superior coverage, reduced signal loss and better bit error handling in heavy multi-path areas. The designs outperformed similar and higher gain antennas. Dr. Nilsson has invented and holds patent and patent pending status on a 8 antennas all of which are Multi-Polarized, and have OBSTRUCTION-PENETRATING characteristics.

He is a principal and serving Chief Science Officer for WiFi-Plus, Advanced Antennas Inc., he continues to develop revolutionary advancements in Multi-Polarized antenna solutions and is one of the premier experts in Multi-Dimensional capture of signal. In 1979, Jack graduated Summa Cum Laude, receiving a Bachelor of Science degree from the University of Akron with a pursuit of physics and mathematics. He received an M.D. from Northeastern Ohio Universities College of Medicine in 1983. In 1989 he was named Chairman of the Continuing Education of Family Medicine Department at Southwest General Medical Center.

Through his love of physics, mathematics and studying all various forms of radio, television, microwave and satellite signals, and taking into account the composition, thickness, size, and types of metals used, he developed unique electromagnetic interaction theorems to create advanced antenna designs. These designs have been for both stationary and mobile antennas. Dr. Nilsson has developed numerous patented and right-to-patent designs in use in commercial, government and military venues working with various RF companies.

About WiFi-Plus, Inc.
Wifi-Plus, Inc. holds exclusive patent rights on its proprietary antenna designs, which gathers multi-path reflection and refractions in multiple polarizations and multiple planes, achieving superior coverage in areas that other antennas will receive noise or drop out. WiFi-Plus multi-polarized (MP) antennas collect the available signal in a Doppler-like, 3 dimensional space and combine these signals to produce a signal that would otherwise be considered non-existent. WiFi-Plus is the only antenna manufacturer able to make such a claim.

WiFi-Plus's customer antenna users include municipalities, telecom providers, retailers, corporations, military, public safety, emergency response, academic, research and government organizations. The firm operates through various distribution channels.

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WiFi-Plus, Inc.