



Technical Analysis: Beamforming vs. MIMO Antennas

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➔ Executive Summary

MIMO (Multiple Input Multiple Output) antennas operate by breaking high data rate signals into multiple lower data rate signals in Tx mode that are recombined at the receiver. In Rx mode the benefit is due to the Rx diversity that improves the receiver sensitivity. MIMO antennas typically have narrow beamwidths, with two or more columns of dipoles spaced a wavelength apart to maximize gain and minimize coupling between columns.

Beamforming arrays are inherently different from MIMO in that the multiple columns of dipoles work together to create a single high gain signal. The columns need to be closely spaced (half-wavelength) together and have wide beamwidths in order to scan the beam away from boresite, while maintaining the gain of the antenna.

While both techniques work well, an antenna optimized for one method, does not work well for the other. Compromise geometries exist, but the user is sacrificing the performance of the system in order to save money on the relatively inexpensive antenna.

If a beamforming solution is selected, the user will have the choice of an active or passive (switched-beam) solution. The active solution is steered and shaped by changing the power level and phases being output by the radios. Each column is fed by a dedicated radio, with a calibration port being used to guarantee the overall amplitude and phase that the antenna is seeing at its inputs. The beam can be steered to any angle within the specified range of the system and its sidelobes suppressed as needed.

A passive solution will have all phasing and amplitudes controlled by a power divider inside the antenna. The divider, also known as a Butler Matrix, is a passive device, so the number of beams, their pointing angles, and sidelobe levels cannot be changed. It is similar to breaking the sector into smaller sub-sectors. The user will see the benefits of higher gain and reduced interference due to the smaller sectors.

They will not receive the advantages of an active antenna that can steer the beam directly at the user or a null in the direction of an interferer. Because each switched beam, rather than each column, is powered by one radio, the overall EIRP of the passive antenna will be less than that of the active antenna that uses all the radios to form the beam.



Mobile data traffic is expected to grow 13-fold between 2012 and 2017, to a staggering 10+ exabytes per month.



Beamforming vs. MIMO Antennas

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Beamforming vs. MIMO Antennas

➔ Definitions

Dipole is a type of radiating element. A single dipole has a wide pattern in both the elevation/vertical orientation and the azimuth/horizontal orientation.

Linear Arrays consist of multiple dipoles in a single column to create a narrow elevation/vertical pattern, while maintaining a wide azimuth/horizontal pattern.

Element Pattern is a term used for the individual dipole's pattern in the array. It is a function of the antenna/dipole's architecture and is independent of the RF signal.

Linear Array Factor is the mathematic solution derived from feeding multiple dipoles together in phase. It is dependent upon the spacing between dipoles and the RF phase and amplitude being seen by each of the dipoles.

Linear Array Pattern is the combination of the element pattern and the array factor. It is the actual pattern created by the array and what is used by customers.

Rectangular Arrays consist of multiple columns of dipoles phased together to create a narrow azimuth/horizontal patterns. Each column is already a phased linear array.

Column Pattern is a term used for the individual column's pattern in the array. It is also known as the unit beam pattern. Typically the pattern of each column is as identical as possible to the other columns in the rectangular array. It is dependent upon the antenna/columns' architecture, but it is independent of the RF signal.

Rectangular Array Factor is the mathematic solution derived from feeding multiple columns together in phase. It is dependent upon the spacing between columns and the RF phase and amplitude being seen by each of the columns.

Rectangular Array Pattern is the combination of the column pattern and the rectangular array factor. It is the actual pattern created by the array and what is used by customers.

MIMO (Multiple Input Multiple Output) antennas operate by breaking high data rate signals into multiple lower data rate signals in Tx mode that are recombined at the receiver. In Rx mode the benefit is due to the Rx diversity that improves the receiver sensitivity. They contain multiple independent arrays, with each array transmitting part of the signal.

Beamformer antennas are rectangular arrays, whose columns work together to form a narrow beam that is steered to angles off boresite and shaped for improved sidelobes.



Beamforming vs. MIMO Antennas

➔ Definitions

Active or Adaptive antennas are beamformer antennas whose beam is steered and shaped by changing the power level and phases being output by the radios. The beam can be steered to any angle within the specified range of the system, which is the 3 dB beamwidth of the column pattern, and its sidelobes suppressed as needed. Each RF input to the antenna feeds one individual column.

Service Beam is another term used for the narrow, steerable beam created by feeding all of the columns together with a uniform phase progression.

Broadcast Beam is a wider beam used to replicate the column pattern. It is created by feeding the columns out of phase so that the overall pattern is not as narrow as it usually is. The wider beam has less gain and cannot be steered, but by using multiple radios, it would have a higher transmitted power than a normal base station antenna.

CAL Board is a calibration device within the antenna. It checks the phase and amplitudes of the signals arriving from the radios and provides feedback to allow the system to compensate for any differences caused by radios and jumper cables.

RAE (Remote e-Antenna Extension) is an extension of the AISG standard. This function can be found in a dedicated device or included in an existing device, such as the ACU. It contains all of the phase and amplitude information needed by the system in order to create broadcast or service beams, as well as steering the service beams.

ACU (Antenna Control Unit) is a motor that drives the phase shifter in variable tilt antennas. It contains information on how many turns of the motor are required to set the antenna elevation pattern to a specific tilt.

AISG (Antenna Interface Standards Group) is an industry wide association developed to make it possible for hardware from different vendors to interface together.

Passive or Switched-Beam antennas will have all phasing and amplitudes controlled by a power divider inside the antenna, so the number of beams, their pointing angles, and sidelobe levels cannot be changed. Each RF input to the antenna feeds all of the columns simultaneously to create a single beam. The system then switches between these beams.

Butler Matrix is a multiple-input, multiple-output power divider created by using multiple 90° hybrid couplers. Depending on which input is selected a different phase progression will appear across the outputs; this phase progression steers the beam.



Beamforming vs. MIMO Antennas

➔ Definitions

Main Beam is the useful portion of the service beam. It is mainly defined by its 3 dB beamwidth and pointing angle. This is the narrow angular region where all of the columns of the array add up in phase to create a higher gain signal.

Nulls are angular where the phasing of the columns is completely destructive. Steering a null at an interferer is sometimes preferable to steering the main beam to the user.

Sidelobes are angular regions where the columns add up in phase, but not as well as the main beam. These lobes are dependent upon the RF signal. Phase and amplitude errors cause them to increase, while phase and amplitude design techniques can reduce them.

Grating Lobe is a secondary solution to the array factor. It will add up in phase as well as the main beam; however, it falls outside the angular region of the column pattern, so it is suppressed when the array is not steered too far. When the main beam is steered too far, the grating lobe will fall within the column pattern and can grow to be the same level as the main beam. The definition of too far is determined by the spacing between columns and discussed in the paper.

EIRP (Equivalent Isotropic Radiated Power) defines how much power would need to be fed into an isotropic radiator to receive the same signal power at the user. It is a function of the gain of the base station antenna and the power being fed into the antenna.

EIRS (Equivalent Isotropic Receiver Sensitivity) is also known as EISL (Effective Isotropic Sensitivity Level) and it defines how sensitive a receiver connected to an isotropic antenna would need to be to have the same SNR as if it were connected to the base station antenna. It is also a function of the gain of the base station antenna, but is also influenced by noise in the antenna.



Beamforming vs. MIMO Antennas

➔ Introduction

A base station antenna is a passive device that does not typically care what technology is being used in the system. It is analogous to the nozzle of a garden hose; the nozzle can be adjusted from shower to jet (low gain to high gain), but any type of water-like liquid (AMPS, GSM, PCS, DCS, CDMA, ETC...) that flows through the hose (RF cable) will flow equally well out of the nozzle.

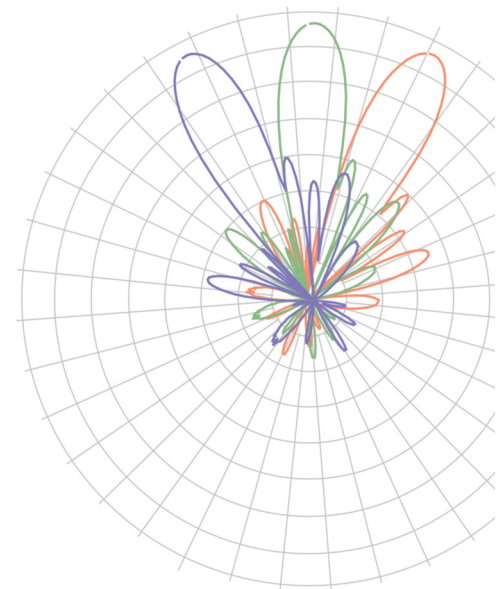


Occasionally, the opposite is not true and the success of certain systems is dependent upon the architecture of the antenna. The most obvious would be a polarization diversity system that will not work well if only vertically polarized antennas are available. Conversely, TDD systems are able to operate well with antennas that have poor PIM performance, since the transmit and receive frequencies are never used simultaneously. That same antenna with poor PIM could cause unacceptable noise in a FDD system.

This paper discusses the architectural differences between an antenna that has been designed for MIMO performance and one that has been optimized for beamforming. It will explain why antenna characteristics that are desirable for MIMO – widely spaced columns with narrow beamwidths – will result in a degradation of the beamforming ability of the antenna, which requires narrowly spaced columns with wide beamwidths.

The paper will also talk about the differences of beamforming antennas that are used in active and passive systems. While the same radiating structure can be used for either system, an active system has a separate radio with variable amplitude and phase control of every column within the antenna. In theory, an active antenna can form a beam pointing to any angle in the sector or can steer nulls towards interferers.

A passive, or switched-beam antenna, has all of its phasing and amplitude distribution controlled by a single circuit board within the antenna. The circuit board will have a number of outputs equal to the number of columns in the antenna and a number of inputs equal to the number of beams that can be created. Each beam points in a discrete angle and the system chooses which beam to use for a given mobile.





Beamforming vs. MIMO Antennas

➔ MIMO

Multiple In Multiple Out systems rely upon multiple antennas transmitting at the same frequency to create parallel channels that allow a high rate data signal to be broken up into several lower rate signals. If the antennas have sufficient diversity from one another, the MIMO receiver will be able to recombine the signals back into the original high rate data. In Rx mode the benefit is due to the Rx diversity that improves the receiver sensitivity. This diversity can come from a number of techniques, such as antennas having a different polarization or being spatially separated from one another.

A preferred method in the industry is to use two dual-polarized arrays spaced apart from each other to create four data channels. Each array consists of co-linear dual polarized radiating elements to minimize the amount of space required. The radiating element has two inputs, typically one in the $+45^\circ$ orientation and the other in the -45° orientation to maintain orthogonality and insuring both channels see the same path loss. This overcomes shortcomings of the original dual-polarized systems that used vertically and horizontally polarized elements.

The spacing of the two dual-polarized arrays is a compromise between two opposing factors. If the arrays are extremely close to each other, more arrays can be placed in the same aperture, creating more data channels. However, the closeness of the arrays increases coupling and reduces the spatial diversity between each channel making it harder for the receiver to separate the multiple signals. Conversely, a wide array spacing will improve spatial diversity, but fewer arrays will fit in the same aperture, which reduces the number of channels.

While there is still debate within in the industry as to what the ideal spacing between columns should be, most companies have settled on one wavelength being an acceptable compromise between aperture size and diversity. Since companies are seeking MIMO antennas to upgrade existing sites, they prefer them to have the same azimuth beamwidth, which is normally 65° . This also allows for each array to have a higher individual gain than if they were using a wider beamwidth such as 90° or 120° . The higher the gain of each array will improve its resilience to the effects of noise and increase range.

The array shown in **Figure 1** is typical of a two-column dual-polarized array being used for MIMO applications in the field. The spacing between the arrays is 150 mm, which is roughly a

wavelength for frequencies in the 2 GHz range. On ultra-broadband antennas, such as the ones that operate in the 1.7-2.7 GHz frequency range, the column spacing is generally selected to give the lower frequency range a wavelength spacing, with the upper frequency having up to one

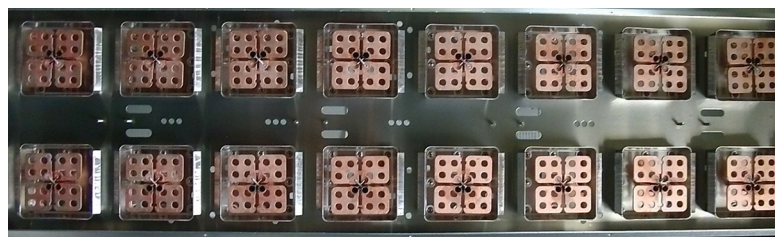


Figure 1 2GHz MIMO Array Using Two Dual-Polarized Columns



Beamforming vs. MIMO Antennas

➔ MIMO

and a half wavelengths between columns, with the view that the extra distance will help to improve spatial diversity at the high end of the band.

In **Figure 2**, some antenna designers take advantage of the large spacing between the columns by adding a third array consisting of lower frequency elements in the 800 MHz range. Placing the low band dipoles down the centerline of the antenna is critical to ensuring that both high band arrays have similar antenna pattern performance. While the low band dipole has the greater impact on the high band dipoles, both the high band and low band dipole need to be modified to take into account the effects that each has on the other.

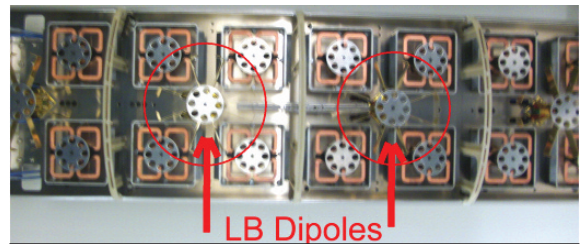


Figure 2 Cellular Array Positioned Between MIMO Columns

A third option shown in **Figure 3** is to place four arrays spaced less than a wavelength apart in a single chassis, with two columns being used for one MIMO application and the other two being used for a second MIMO application. The columns being used for each MIMO application are not adjacent to each other, so the minimum MIMO spacing of one wavelength is still maintained, despite the close columns.

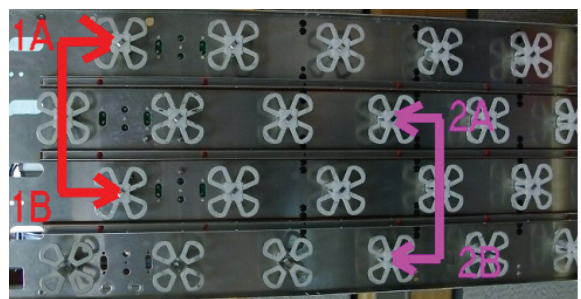


Figure 3 Compromise Antenna for MIMO & Beamforming

This type of configuration gives the user the flexibility to use the antenna in either MIMO mode or as a beamforming array. The next section goes into greater detail regarding the requirements of beamformers, but one of the key characteristics is the narrow column spacing of approximately a half-wavelength at the operating frequency.

This antenna represents a compromise between MIMO and beamforming. To achieve the 65° patterns desired by MIMO, the columns need to be at least .65 wavelengths apart, which degrades the performance of the antenna as a beamforming array. If the columns are the half-wavelength apart desired by beamforming theory, the beamwidth of each column will be approximately 90°. This will reduce the gain of each column by one and a half decibels, which degrades the MIMO performance.

To better understand this, it is necessary to review some of the basics of antenna array theory, such as the array factor, column/element pattern, and grating lobes.



Beamforming vs. MIMO Antennas

➔ Beamforming Using Half-Wavelength Spacing

An antenna pattern created by a phased array is the product of two key characteristics of the array, the array factor and the element pattern. The array factor is determined by the column spacing, amplitude, and phase distributions. Below is the array factor of a four column antenna, with each column spaced a half-wavelength apart and receiving equal amplitude and phases (no sidelobe suppression and no beamsteering).

The array factor in **Figure 4** looks different from the patterns most customers see, with multiple peaks repeating themselves due to the sinusoidal nature of the equations that create the array factor. Each main peak represents where all of the dipoles in the column add up in phase constructively, while each null is where they add up destructively. The lower power sidelobes are local maxima where the dipoles add up in phase, but not as well as the main beams. It will be shown that sidelobes can be significantly reduced, but not the secondary solutions of the main beam, which will lead to problems when steering too far off of the zero-degree axis.

The element or column pattern is created by physical features such as the dipole height, chassis width, internal wall structures, and the column spacings. In **Figure 5**, it looks more similar to the normal “fan-beam” patterns of a standard base station array. The column pattern will remain unchanged no matter what phase or amplitude distribution is placed across the array. Its 3 dB beamwidth will also limit the scan angle of the beam.

The array factor can be viewed in systems terminology as an “angular amplifier”, while the column pattern is the original signal that is being amplified. The array factor will “amplify” a small angular region of the original signal to create a

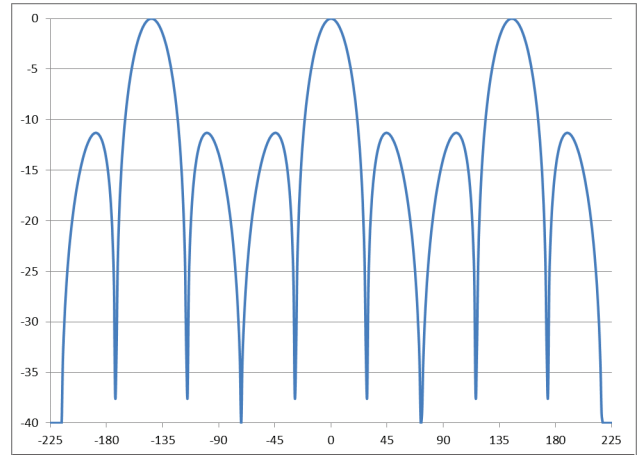


Figure 4 Array Factor of a Half-Wavelength Four Column Antenna

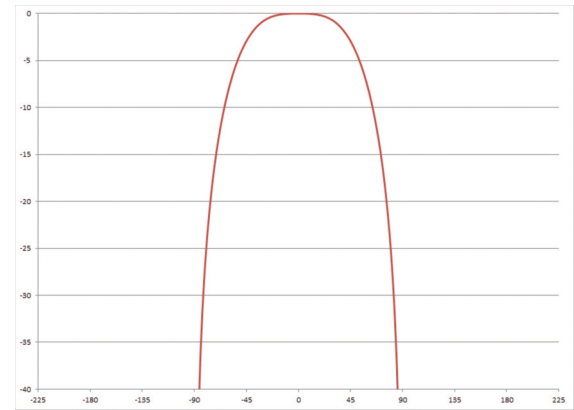


Figure 5 Ideal 90° Column Pattern

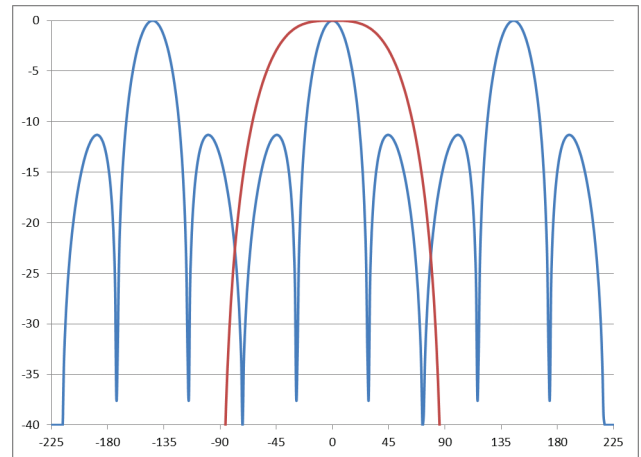


Figure 6 Overlay of Array Factor and Column Pattern



Beamforming vs. MIMO Antennas

➔ Beamforming Using Half-Wavelength Spacing

stronger, tighter signal with more gain. However, if the array factor tries to amplify an angular region outside of the original signal, like the two beam peaks to the left and right of the column pattern, nothing will be created since there is no signal to amplify. We will show that the beam cannot be steered much beyond the 3 dB beamwidth of the column pattern, because the resulting patterns will have much lower gain, high sidelobes and grating lobes.

The two separate patterns above in **Figure 6** are summed together to create the final pattern in **Figure 7**. The reader can see the main beam and first sidelobes of the array factor are almost identical to the final pattern. The azimuth beamwidth of the array is 25° and sidelobes are at the -13 dB level expected for a uniform distribution. Another analogy for the column pattern is that it functions as a filter that cuts off the secondary solutions and their sidelobes. The typical column pattern for this type of array is between 90°→110°. While this is ideal for beamforming it is not preferable for MIMO due to the column gain drop.

If the user wishes to steer the beam 30° to the right, this is done by placing a phase progression across the columns that shifts the array factor 30° to the right. This phase shift does not change the column pattern which is controlled only by the physical features of the antenna. It can be seen in **Figure 8** that the peak of the array factor no longer aligns with the peak of the column pattern. The first sidelobe of the array factor is very close to the peak of the column pattern and the sidelobe of the secondary solution is no longer being filtered by the column pattern. The net result in **Figure 9** is the gain of the antenna drops and the sidelobe levels grow beyond the -13 dB point seen on boresite.

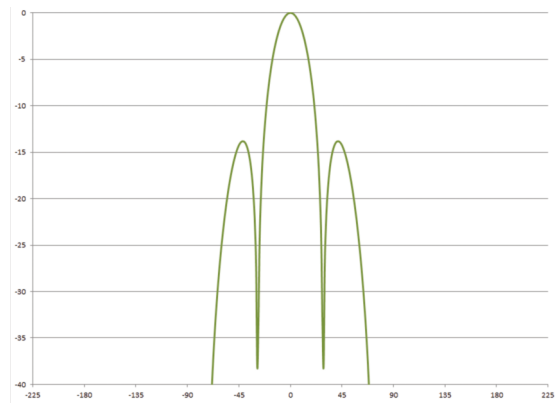


Figure 7 Summation of Array Factor and Column Pattern to Create Final Pattern

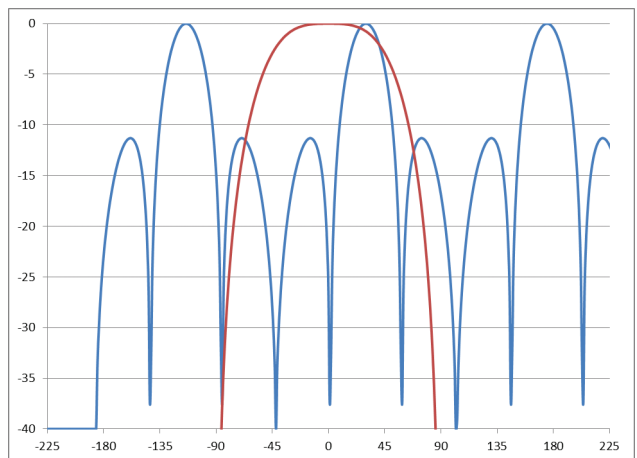


Figure 8 Array Factor Steered 30° Overlaid with Column Pattern

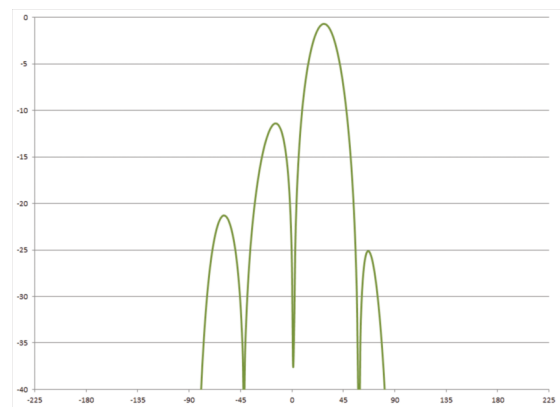


Figure 9 Summation of Shifted Array Factor Steered 30° and Column Pattern



Beamforming vs. MIMO Antennas

➤ Beamforming Using Half-Wavelength Spacing

If the higher sidelobes of the scanned beam are unacceptable, amplitude taper may be applied across the columns in order to achieve sidelobe suppression within the array factor. **Figure 10** shows a -25 dB sidelobe suppression in the array factor. **Figure 11** shows that this results in -24 dB in the actual antenna due to the gain drop-off of the main beam inherent to scanning the beam 30° off of boresite.

If the antenna is scanned even further to 45° it starts to run into two inherent limitations of the array. The first is the beamwidth of the element pattern. Since it is only a 90° beamwidth, it will be down -3 dB, 45° off of boresite. Beyond that the element pattern falls off so sharply, that it is not possible to make the beam scan further. **The element pattern would need to be at least 100° wide if the antenna were to scan to ±50°.** The second limitation can be seen on the left hand side of the antenna pattern. The secondary solution of the array factor is starting to coincide with the element pattern. This is known as the grating lobe and will be discussed more in the next section.

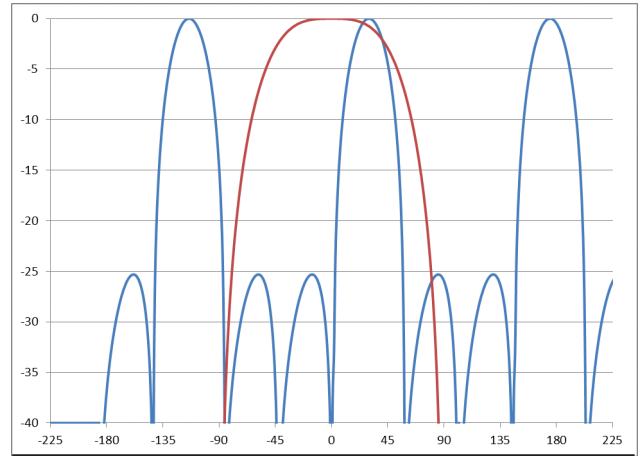


Figure 10 Array Factor with 25 dB Suppression and Steered 30°

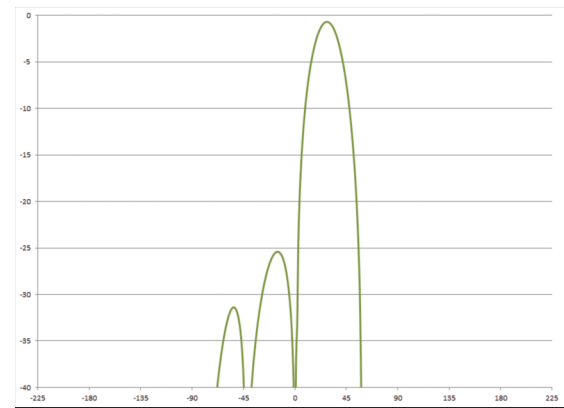


Figure 11 Summation of Shifted/Suppressed Array Factor Steered 30° and Column Pattern

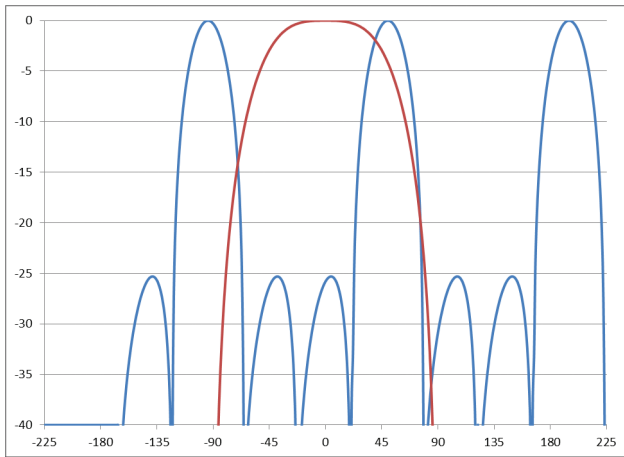


Figure 12 Array Factor with 25 dB Suppression and Steered 45°

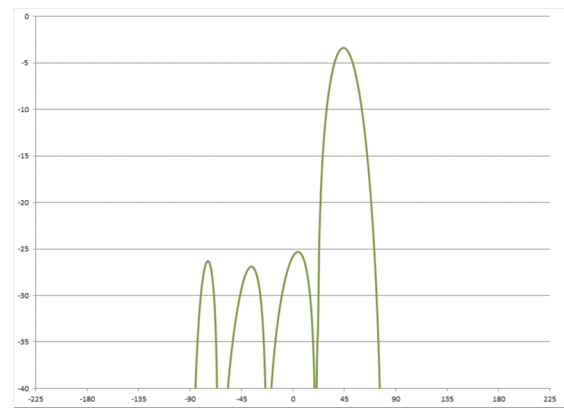


Figure 13 Summation of Shifted/Suppressed Array Factor Steered 45° and Column Pattern



Beamforming vs. MIMO Antennas

➔ Beamforming Using Full-Wavelength Spacing

MIMO users did not like the half-wavelength spacing, because it increased coupling between columns and it was not possible to achieve the 65° column pattern preferred for MIMO applications. They inquired into the feasibility of using a four-column $\pm 45^\circ$ dual-polarized antenna with one wavelength spacing as a beamformer that could also be used for MIMO. **Figure 14** shows that the wider spacing causes the secondary solutions of the array factor to move into the angular range of the element pattern. In **Figure 15**, the outer lobes of the overall antenna pattern are grating lobes that cannot be suppressed.

Figures 16 & 17 show that with a 25 dB sidelobe suppression distribution applied to the array factor, the secondary solution near -60° does not shrink at all. The resulting antenna pattern has good suppression for the first two sidelobes, but the grating lobes remain about -13 dB down from the beampeak.

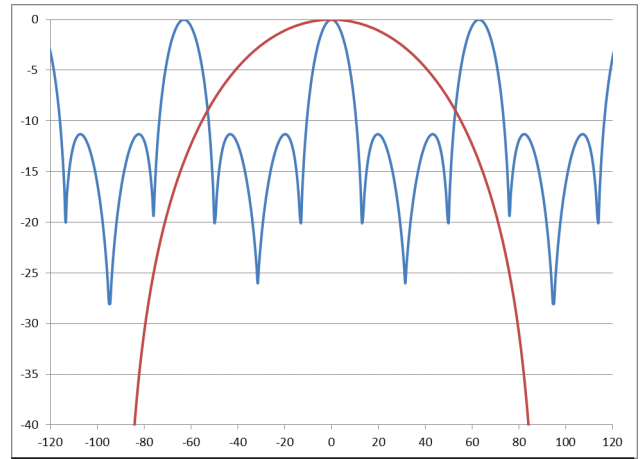


Figure 14 Array Factor Using One-Wavelength Spaced Columns

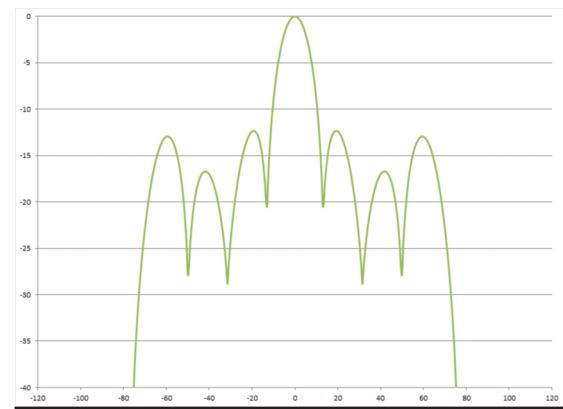


Figure 15 Summation of Array Factor and Column Pattern

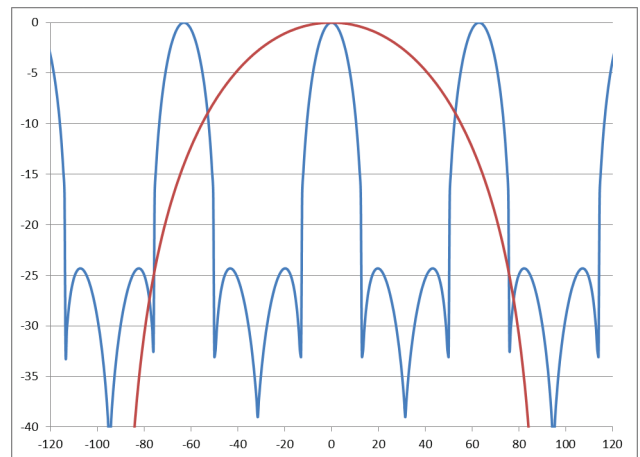


Figure 16 Array Factor with 25 dB Suppression



Beamforming vs. MIMO Antennas

➔ Beamforming Using Full-Wavelength Spacing

Figures 18 & 19 show that if the array is steered as little as 20°, the secondary grating lobe is only 3 dB down from the main beam. Steering to 30° would result in a split beam where the grating lobe was at the same power level as the main beam. Since this results in the system not knowing if the user is to the left or right of the antenna, as well as having a significant gain drop off, full-wavelength spacing was unacceptable.

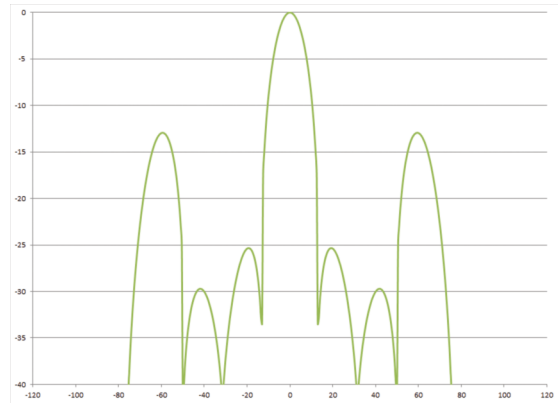


Figure 17 Summation of Suppressed Array Factor and Column Pattern

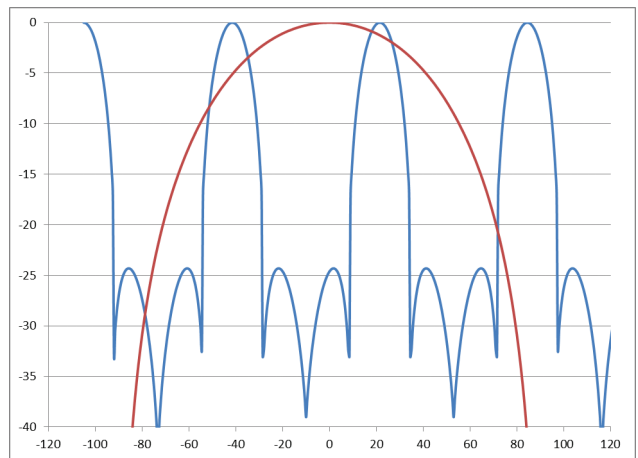


Figure 18 Array Factor with 25 dB Suppression and Steered 20°

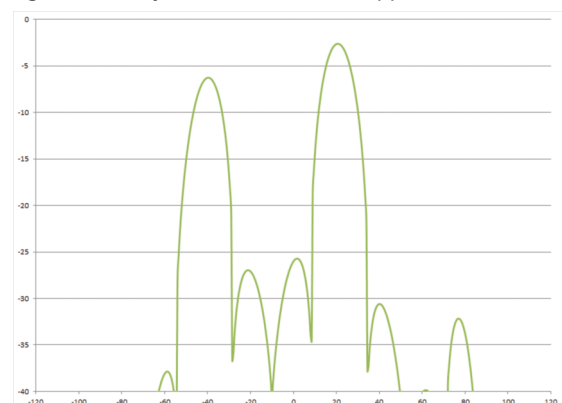


Figure 19 Summation of Suppressed/Steered Array Factor Steered 20° and Column Pattern



Beamforming vs. MIMO Antennas

➔ Beamforming Using .65 Wavelength Spacing

A compromise proposed by some vendors is to use .65 wavelength spacing between columns of $\pm 45^\circ$ dual-polarized dipoles. It allows for the narrower 65° column beamwidth preferred by MIMO applications, while not reducing the beamforming ability of the array as much as the initial one-wavelength spacing proposals caused.

The degradation of the beamforming ability can be seen when the antenna is scanned to 30° off boresite. The primary beam is very close to the 3 dB point of the element pattern, which reduces its gain by the same amount. At the same time, the secondary solution has entered the region of the element pattern resulting in a 7 dB grating lobe that can not be suppressed. This grating lobe further reduces the gain of the antenna. Scanning beyond 30° is also not feasible due to the limitations of the 65° element pattern.

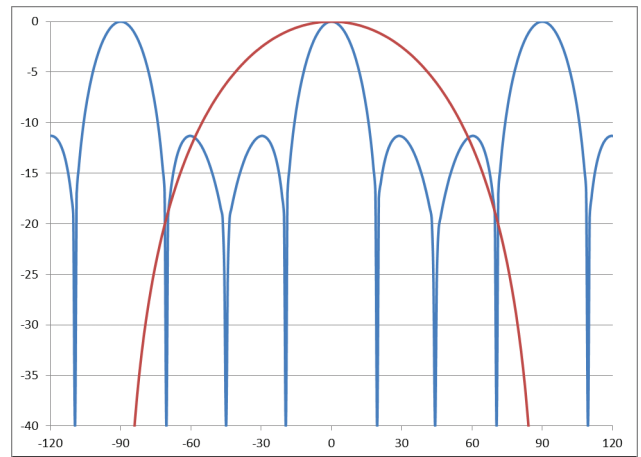


Figure 20 Array Factor Using .65-Wavelength Spaced Columns

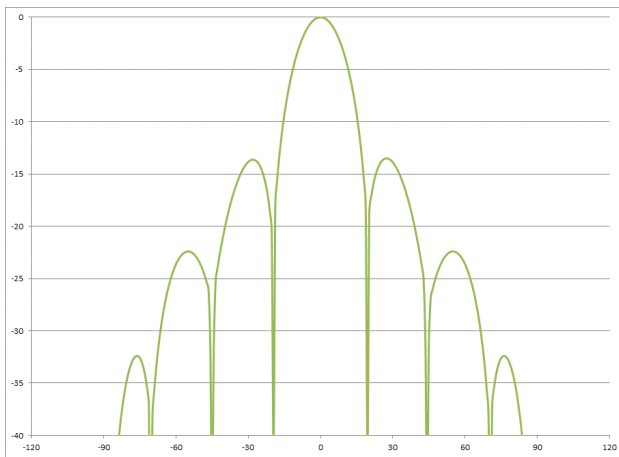


Figure 21 Summation of .65-Wavelength Spaced Array Factor and Column Pattern

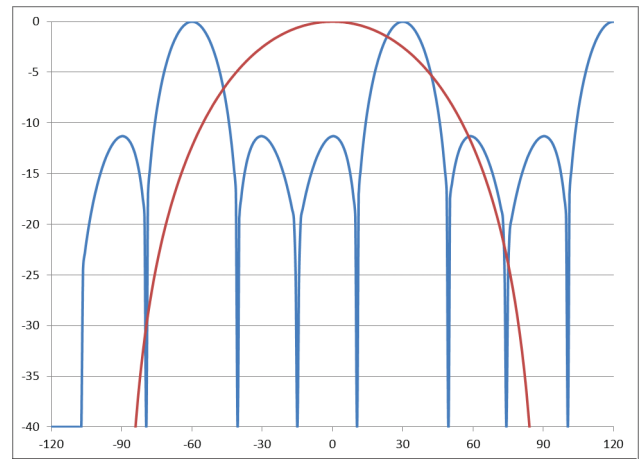


Figure 22 Array Factor Using .65-Wavelength Spaced Columns and Steered 30°



Beamforming vs. MIMO Antennas

➔ Beamforming Using .65 Wavelength Spacing

It has been stated several times that the column beamwidth is the effective range at which the beam may be scanned. This scenario shows what happens when an array with a 65° beamwidth is steered to 45° off of boresite. The resulting pattern is 6 dB down from the on-boresite pattern and has a grating lobe that is equal in strength to the main beam. The system will literally not be able to tell which direction the user is, which would make hand-offs to the adjacent sector difficult since it could be either of the adjacent sectors.

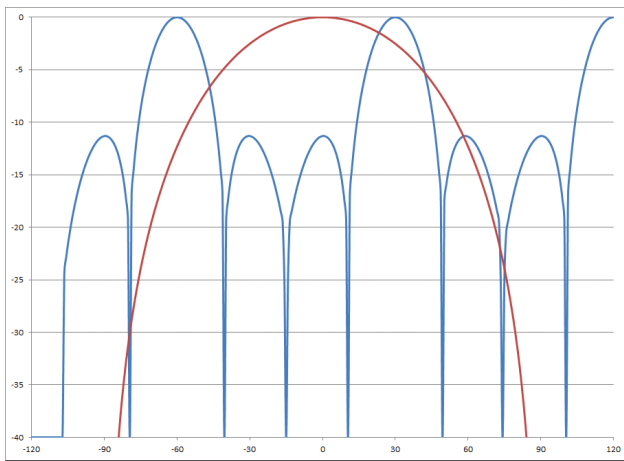


Figure 24 Array Factor Using .65-Wavelength Spaced Columns and Steered 45°

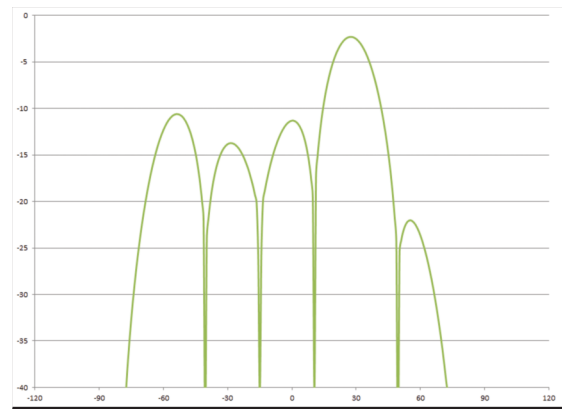


Figure 23 Summation of .65-Wavelength Spaced Steered 30° Array and Column Pattern

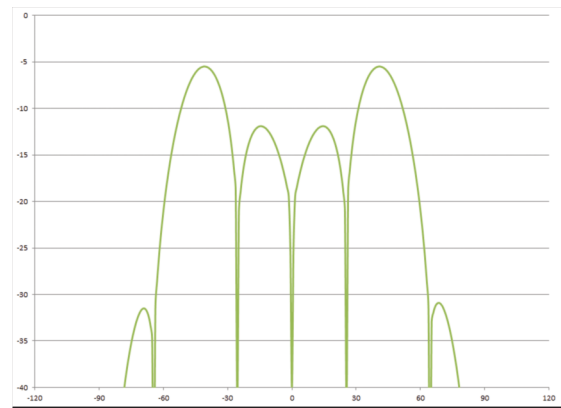


Figure 25 Summation of .65-Wavelength Spaced Steered 45° Array and Column Pattern



Beamforming vs. MIMO Antennas

➔ Beamforming vs. MIMO Antennas

While both MIMO and beamforming systems have proven to increase capacity, the methods they use to achieve this require very different antenna architectures. The columns of a MIMO array act almost independently of each other, having columns with narrow beamwidths spaced far apart, with each column “carrying” part of the load. The columns of a beamforming array act as a “team”, having columns with wide beamwidths spaced close together, to carry the whole data load simultaneously. If an operator plans on using four-column antennas in both MIMO and beamforming scenarios, two unique antennas are recommended to avoid compromising system performance.

The compromise .65 wavelength spaced $\pm 45^\circ$ dual-polarized antennas were initially used in broadband applications that covered the 1880-2690 range, where the 75mm spacing was about a half-wavelength at the low end of the band and was .65 wavelengths at the high end of the band. More recent requests have been for narrower band antennas that have the proper half-wavelength spacing for beamforming. Presumably the change was caused by the limited angular scan range or grating lobe interference.

It is the ability of a beamforming array to scan its beam towards a user, while at the same time suppressing signal strength in the direction of an interferer is what makes it such an effective tool for increasing capacity. The compromise antenna could not scan a sufficient amount or suppress grating lobes that were inherent to the wider spacing. Note that this benefit applies mainly to TDD networks. In an FDD network, since the Rx and Tx frequencies are different, the beamforming patterns are different at the duplex frequencies and the interferer rejection is likely to be less efficient.

An additional benefit that beamforming antennas have over MIMO antennas is their respective increases in both EIRP (Equivalent Isotropic Radiated Power) and EIRS (Equivalent Isotropic Receiver Sensitivity). EIRP is the more straightforward of the two; it defines how much power would need to be fed into an isotropic radiator to receive the same signal power at the user. It is a function of the gain of the base station antenna and the power being fed into the antenna. Since a beamforming antenna has higher gain than a MIMO antenna due to its narrow beam, it will have higher EIRP. Later, this paper will show why the EIRP benefit for active beamforming antennas compared to MIMO is even greater than the EIRP advantage passive beamformers have over MIMO antennas.

EIRS is also known as EISL (Effective Isotropic Sensitivity Level) and it defines how sensitive a receiver connected to an isotropic antenna would need to be to have the same SNR as if it were connected to the base station antenna. It is also a function of the gain of the base station antenna, but it is also influenced by noise in the antenna. Studies have been done that show electrically downtilting the antenna will cause the antenna to detect thermal noise from the warm ground that is not present in the cold sky. A low noise system ($F=1.9$ dB) would see its sensitivity decreased by 1 dB when the antenna was down-tilted 5° and it decreased 1.3 dB when



Beamforming vs. MIMO Antennas

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the antenna was down-tilted 10°.

Antennas are electrically down-tilted for a number of reasons. Cell towers may be too close to each other, causing interference with the other cell. **Figure 26** shows the reduction of interference between cells as the antenna’s footprint shrinks. There may be too many mobiles in a densely populated cell and the cell size needs to shrink in order to reduce the number of mobiles handled by that particular antenna.

Figure 27 shows that some of the inter-cell interference can be reduced with a judicious use of beam steering so that for the same frequency, the red cell is steering its beam in the opposite direction as the blue cell. The same type of inter-cell interference is achieved as a normal base station that is electrically down-tilted, but by not pointing the antennas towards the ground, less thermal noise is seen and the system EIRS is maintained.

The beamforming antennas will also be able to handle more users for a given cell size, so the need to downtilt the antenna and reduce EIRS will be further reduced.

The next section will discuss the two primary types of beamforming arrays: active antennas and passive, switched beam antennas. Both antennas would require the narrowly spaced columns with wide beamwidths that have already been reviewed. The key differences will be how the array factor is created via amplitude and phase distributions, either in the radios or power dividers and phase shifters within the antenna.

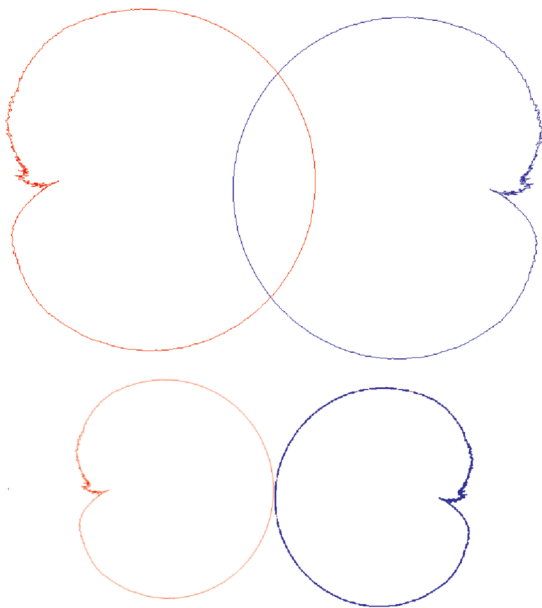


Figure 26 Electrically Down-tilting Antennas to Reduce Inter-Cell Overlap

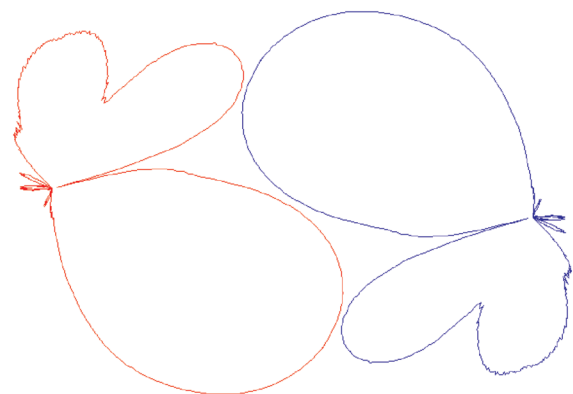


Figure 27 Electrically Steering Antennas to Reduce Inter-Cell Overlap



Beamforming vs. MIMO Antennas

➔ Active Antennas

In theory an active antenna has complete flexibility to change the amplitude and phase distributions for each of the columns within the antenna. This paper will look into the benefits of being able to scan the beam to any angle within the limits determined by the element pattern of the columns. It will also explore how it can improve sidelobe suppression as desired, with the exception of the grating lobe if the antenna is scanning a large amount off of boresite and has the ability to scan nulls to silence an interfering signal. One other advantage is that it will have an even higher EIRP than a passive array using the same sized radios, due to each column having a dedicated radio.

The first question the network planner must ask is how much extra gain do they desire above that of a typical 65° base station antenna. **The more columns the array has, the higher the gain increase. This will be balanced against how wide of an antenna can be allowed on the tower.** There have been some “special event” arrays with eight to twelve columns that are only installed temporarily to cover stadium parking lots. These arrays have extremely narrow beams of around 10°, but their size makes them impractical. They are removed after each stadium event, so they do not need the rugged mounting hardware associated with antennas installed on cell towers.

The most common permanently installed array seen in the industry has four columns spaced a half-wavelength apart, which results in a 25° beamwidth when a uniform amplitude distribution is used for maximum gain on boresite. This narrow beam will have approximately 4 dB higher gain on boresite when compared to a 65° antenna of the same size. Another advantage the array will have over the base station is that each column will be connected to its own radio, so for the same size radio as the existing base station, four times (6 dB) as much power can be transmitted. **The extra power combined with the increase in gain can result in as much as a 10 dB increase in EIRP over the normal base station.** The alternative would be for the user to install cheaper radios with a quarter of the power and still achieve the same amount of transmitted power.

This improvement is even greater when the array is scanned off of boresite. If the antenna is scanned to 40°, the gain will drop by about 2 dB due to the limits of the element pattern that were discussed in the previous section. However, compared to the rapid drop off of the standard sector antenna, the users in the areas between 40°→60° off of boresite will see an improvement of 7 dB in antenna gain.

Signal strength is only part of the equation for the adaptive array. If the user is at +30° and there is an interferer in the region of -40°, the amplitude distribution of the array can be adjusted by

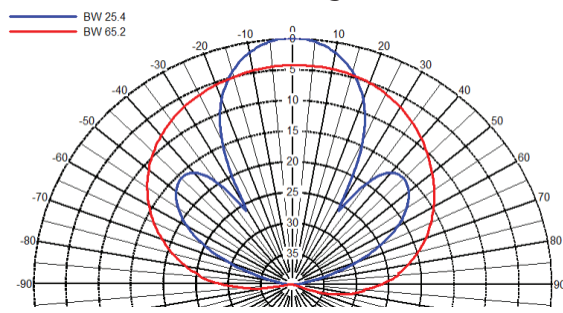


Figure 28 Gain Increase Seen from Reducing Beamwidth from 65°→25°

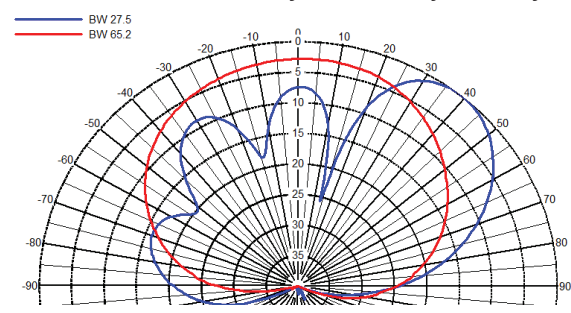


Figure 29 Off-Axis Gain Increase Seen from Reducing Beamwidth and Scanning



Beamforming vs. MIMO Antennas

➔ Active Antennas

reducing the power to the outer columns to reduce the sidelobes in the direction of the interferer. The orange trace below represents what happens when the power to the outer columns is reduced by 6 dB. The main beam will fatten (reducing gain), but the sidelobe in the direction of the interferer drops significantly. A one dB drop in gain will reduce the sidelobe by 8 dB for an difference of 7 dB. This will improve interference suppression from 12 dB to 19 dB, compared to the 1 dB that the standard base station would see due to its lack of flexibility.

Some network planners prefer not to implement this technique, because reducing the power to the outer columns will reduce the overall power going into the array and thus the EIRP. In the 6 dB example used above, that would be equivalent of having four 100W radios with 400W of total power seeing two of the radios reduced to 25W, for 250W of total power. This would be a 2 dB drop for the input power, which when combined with the 1 dB drop in gain, results in an overall drop of 3 dB in EIRP.

The way around this problem is to adjust the system software from steering the beam so the strongest signal reaches the user, to having the null steered towards the interferer. In our example, the user is still at +30°, while the interferer is at -40°. However, in this case the beam is only steered to +20°, which results in about a 1 dB drop in the gain pointing towards the user, but it places a null that is 10 dB deeper than the original pattern in the direction of the user. This will improve the interference suppression even better than the sidelobe reduction technique, while there is no need to reduce the power in the radios. The end result will be a 1 dB drop in EIRP due to the beam not steering to the user, compared to the 3 dB drop that was caused by sidelobe suppression.

The limiting factor in the null steering technique is that a four column array only has two nulls pointing away from the user and their spacing is not very flexible, so that only one interferer can be effectively nulled, while still keeping the beampeak close to the user. If the number of columns is increased, more nulls will be available, but the antenna may become too large to be practical for most customers.

The sidelobe suppression method costs the system more EIRP, but it reduces all of the sidelobes and thus multiple potential interferers can be combatted. The advantage of the adaptive array is that both methods can be used, with on the ground conditions determining which technique works better for that environment.

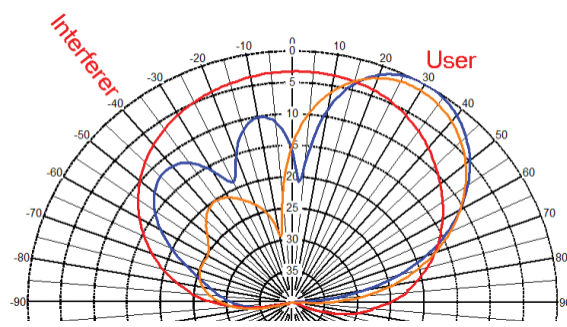


Figure 30 Interference Benefit of Scanning Beam and Suppressing Sidelobes

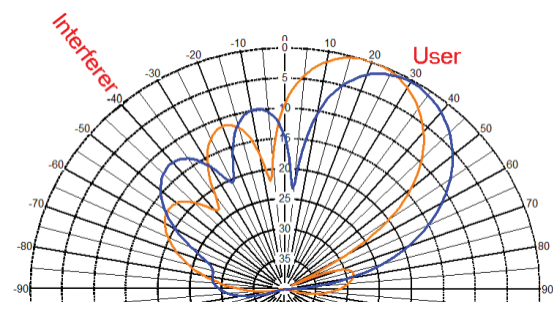


Figure 31 Interference Benefit of Scanning Null vs. Beam



Beamforming vs. MIMO Antennas

④ Calibration, RAE, & ACU

The patterns shown in the previous section are dependent upon the correct phases and amplitudes arriving at the antenna connectors from the radios. While most radios have very good phase and amplitude control at their outputs, the jumper cables connecting the radio and antenna tend not to be phase controlled. They are also long enough to experience temperature variations due to different cables seeing different amounts of sunlight. The solution to this problem is to sample the phase and amplitude at each connector via a coupler circuit that feeds back into a common calibration port. **Figure 32** shows an eight-port CAL board that samples the phases and amplitudes of four dual-polarized columns. Any variations due to the jumpers detected between the ports can be compensated for in the radios to bring the columns back into phase.

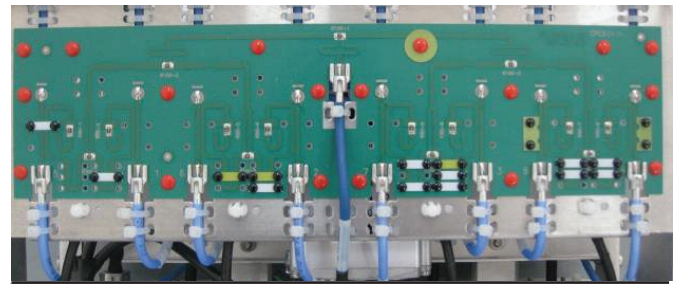


Figure 32 8-Port Calibration Board

Customers have requested that all of the phase and amplitude information needed by the system in order to create broadcast or service beams, as well as steering the service beam be stored within the antenna according to the RAE (Remote e-Antenna Extension) [5]. The RAE is an extension of the AISG standard. This function can be found in a dedicated device or included in an existing device, such as the ACU (Antenna Control Unit). An ACU is a motor that drives the phase shifter in variable tilt antennas. It contains information on how many turns of the motor are required to set the antenna elevation pattern to a specific tilt.

The passive antennas discussed next do not need CAL boards or RAEs, because all of the phasing and amplitudes are determined by a power divider within the passive antenna.

The **figures below** show the importance of proper phase control at the antenna inputs. If there is an RMS phase error of 30°, the pattern still looks recognizable, but notice the 50 dB null that was directed at an interferer 40° to the left of boresite has become shallower and shifted so that same interferer would only be suppressed 20 dB. If the phase error increases to 60° RMS, the nulls are almost completely filled. This may seem extreme, but at frequencies of 2.6 GHz, this may only be a 15 mm cable cutting error.

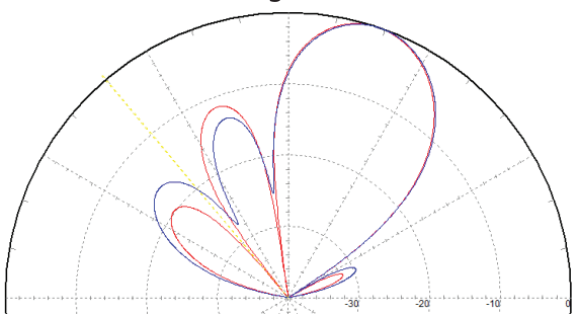


Figure 33 Perfect Phasing vs. 30° RMS Error

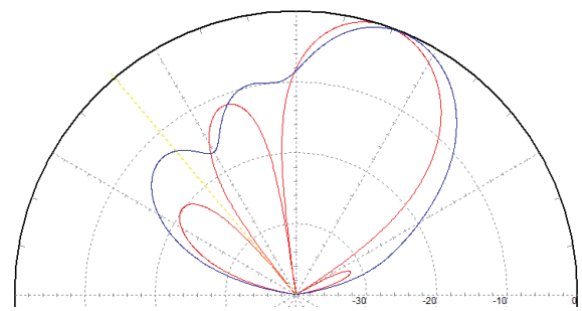


Figure 34 Perfect Phasing vs. 60° RMS Error



Beamforming vs. MIMO Antennas

➔ Passive Switched Beam Antennas

A passive antenna is often referred to as a switched-beam antenna, because while it creates narrow beams similar to the active array, they are limited to a fixed number of scan directions that the system “switches” back and forth from depending upon where the mobile user may be. An active antenna uses all of the radios to steer a single beam to follow the mobile. A passive antenna uses one radio for a specific angular region covered by one of its beams and then hands over the user to another radio that creates the beam covering the adjacent angular region. The four-beam passive method can be thought of as splitting the standard 120° sector into narrower sub-sectors of 30°.

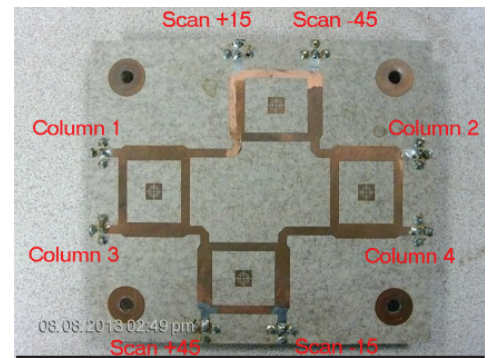


Figure 35 1850-1990 Four-by-Four Butler Matrix

This means that the user must determine how many sub-sectors they want to split their 120° sector into, with one beam for each sector. The cross-over or hand-off levels between the beams is another critical design parameter, since different technologies prefer different hand-off levels. Lastly, what amount of sidelobe suppression, if any, needs to be specified. Of course, all of this must be balanced against how wide of an antenna the user is willing to install, which would limit the number of columns. Eight columns spaced half a wavelength at 2.6 GHz is less than half a meter wide. Those same eight columns at 700 MHz would be two meters wide. With this information, the number of columns and phase progressions between columns can be determined and a combination phase shifter and power divider designed to create the correct beam patterns.

Once these antenna parameters have been set, it will be extremely difficult to make any changes to the beamwidths, scan angles, or sidelobe suppression without replacing the antenna. This is because most customers prefer the power divider controlling the beams to be internal to the antenna. This configuration makes the beamforming impervious to any amplitude or phase variations coming from the radios and jumpers. The alternative would be for the divider to be outside the antenna, closer to the radios, but then the CAL board discussed in the active antenna section would be required. This increase in system complexity has been seen as not worth the benefit coming from an external divider.

The method to achieve this switching is to use what is known as a Butler Matrix. Above in **Figure 35** is a four-input, four-output matrix that consists of four 90° hybrid couplers linked together to create an equal amplitude power divider. What is special is that depending on which input is selected, a different phase progression is created across the outputs to the antenna columns, which creates four unique scan angles.



Beamforming vs. MIMO Antennas

Passive Switched Beam Antennas

Relative Phase	Column 1	Column 2	Column 3	Column 4
Scan -45°	0°	-135°	+90°	-45°
Scan -15°	0°	-45°	-90°	-135°
Scan +15°	0°	+45°	+90°	+135°
Scan +45°	0°	+135°	-90°	+45°

Table 1 This table shows the phase progressions created by the Butler Matrix for each of the four beams. The result will be the four 30° beams spaced about 30° apart seen in Figure 36.

This matrix uses two-branch couplers, which have sufficient bandwidth to cover the PCS (1850-1990) band. Wider bandwidths can be achieved using three-branch couplers. Beyond three-branches, some of the traces will become extremely thin due to the high impedances required by four-stage and higher couplers.

The four switched beams are spaced about 30° apart from each other with beamwidths of roughly 30°, which results in cross-overs between the beams of about 3 dB. The drop off in gain of the outer beams is due to the limitations of the column pattern. This particular antenna had a column pattern of 100°, so a beam scanned 45° was a little more than a dB down from the beams that were only scanned 15°.

While the standard Butler Matrix has equal amplitude outputs, which should result in sidelobes higher than 10 dB, a method around this problem is a technique known as aperture tapering. The outer columns of this array have half the number of dipoles as the inner columns. The result is equivalent to turning down their power by 3 dB. The beginning of the grating lobes is also visible on the outer beams and they will not shrink no matter how much aperture taper is used to suppress the other sidelobes.

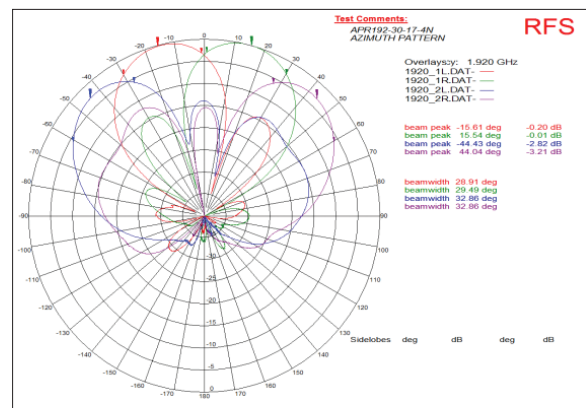


Figure 36 1850-1990 Four-by-Four Butler Matrix

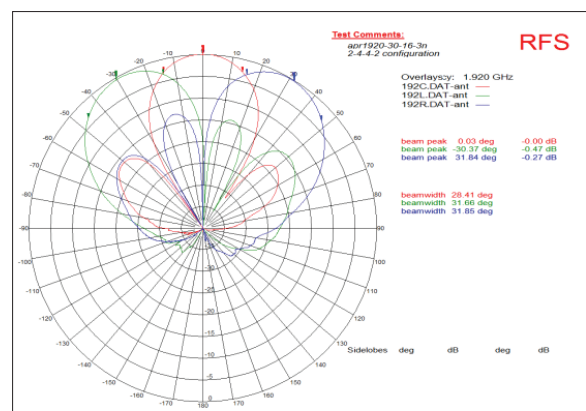


Figure 37 Three 30° Beams Created by a 3x4 Butler Matrix



Beamforming vs. MIMO Antennas

➔ Passive Switched Beam Antennas

Some customers do not wish to see the grating lobes or gain drop off in the main beam. They prefer one beam on boresite, a second beam steered 30° to the left and a third beam steered 30°. The net result is three beams seen in **Figure 37** with almost equal levels of gain and better overall sidelobe suppression using the same 50% aperture taper that the four beam antenna employed. This was accomplished by steering each of the original four beams an extra 15° to the right.

The unused angle has a phase progression of 180° degrees between each column, which results in a “split beam” pattern where the grating lobe is the same size as the main beam.

If the user has the ability to install an eight column antenna, it can be fed with an eight-input, eight output-Butler Matrix to create eight patterns. The eight switched beams in **Figure 38** are spaced about 15° apart from each other with beamwidths of roughly 15°, which results in cross-overs between the beams of about 3 dB. The drop off in gain of the outer beams is due to the column pattern of 100°, so a beam scanned 55° was a little more than four dB down from the beams that were not scanned far off of boresite.

Due to the large drop off of the outer beams, some sacrifice one of the beams in order to have a beam on boresite and three beams to either side for an overall total of seven beams, with the outermost beams only steering a little past 45°. This will reduce the drop off to about 2 dB and minimize any grating lobes.

A more extreme example of grating lobe suppression is shown on the following pages. By

Original Scan Angle	Shifted Scan Angle
-45°	-30°
-15°	0°
+15°	+30°
+45°	Unused

Table 2

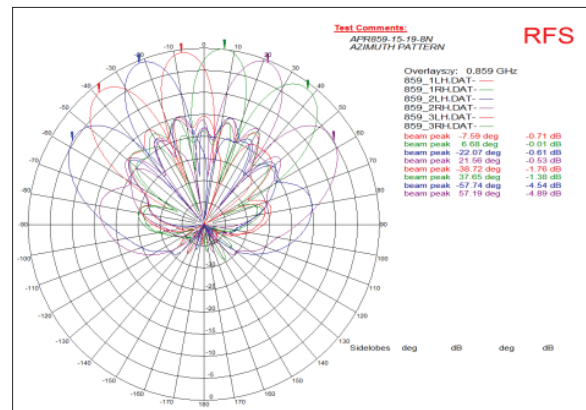


Figure 38 Eight 15° Beams Created by an 8x8 Butler Matrix

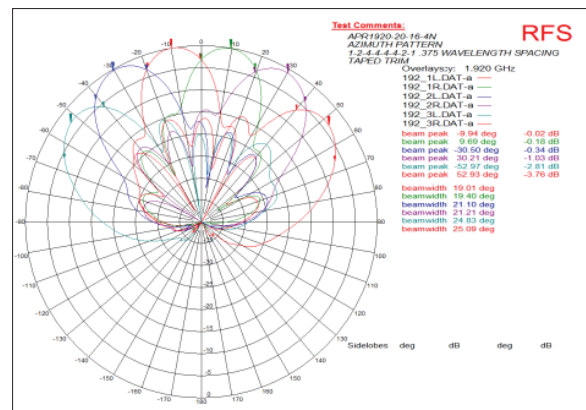


Figure 39 Six 20° Beams Created by a 6x8 Butler Matrix



Beamforming vs. MIMO Antennas

➤ Passive Switched Beam Antennas

reducing the column spacing from .5 wavelengths to .375 (Figures 39 & 40) or even .25 (Figures 41 & 42) wavelengths, the grating lobes will be completely eliminated. The cost of this method is that the mutual coupling between columns reduces the gain of the array so much that it will outweigh the benefit of suppressing the grating lobe.

Both of these antennas had eight columns spaced .375 wavelengths apart. Because of the tighter spacing each beam is wider (20° vs 15°) and scans further in order to maintain the 3 dB cross-overs. The outer beams (4L and 4R) scan beyond the element pattern of the column, so they do not form usable patterns.

Both of these antennas had eight columns spaced .25 wavelengths apart. Because of the tighter spacing each beam is wider (30° vs 15°) and scans further in order to maintain the 3 dB cross-overs. The outer beams (3L/4L and 3R/4R) scan beyond the element pattern of the column, so they do not form usable patterns.

All of the antennas shown so far have had a common characteristic; no matter what the beam width or scan angle, the cross-over point between two adjacent beams has been about 3 dB down from the beam peak. This is typical of any switched beam antenna with half-wavelength columns with the same number of inputs as outputs. The 3 dB cross-overs have been found to be undesirable in some systems. Different technologies have different targets for their cross-overs with the second most common in the 5-10 dB range. There have also been requests for cross-overs between 10-15 dB in order to better simulate the sector edge hand-offs seen in systems that are designed with 65° base station antennas.

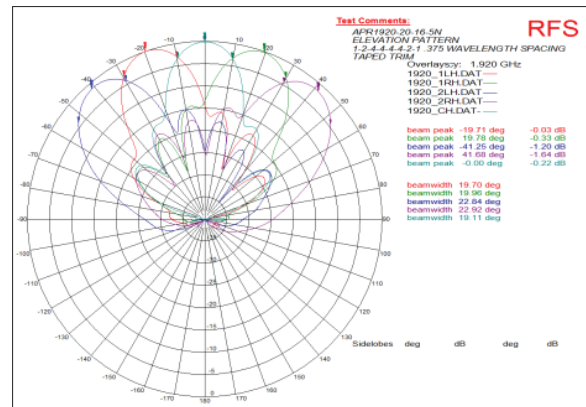


Figure 40 Five 20° Beams Created by a 5x8 Butler Matrix

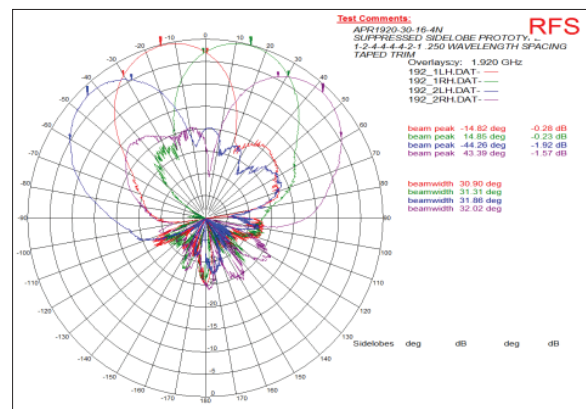


Figure 41 Four 30° Beams Created by a 4x8 Butler Matrix

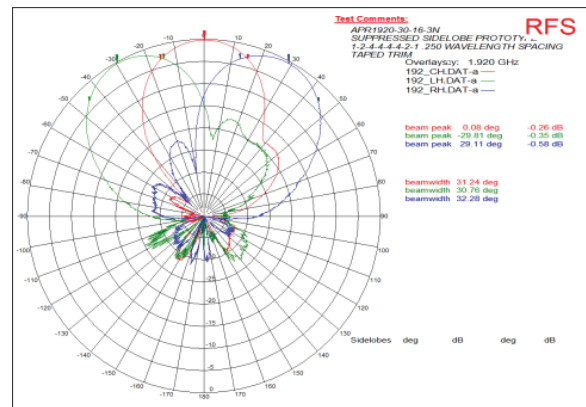


Figure 42 Three 30° Beams Created by a 3x8 Butler Matrix



Beamforming vs. MIMO Antennas

Passive Switched Beam Antennas

Figure 43 is an example of antenna with a six-way Butler Matrix whose adjacent inputs have been paired so that it will only create three beams. The pairing puts a large amplitude taper across the columns, creating sidelobe suppression and the three resulting 22° beams are spaced about 38° apart with the customer's desired 10 dB cross-overs.

The shortcoming of the paired input method is that while the sidelobe suppression is quite good, it makes for an inefficient use of the aperture. The outer columns have about 10 dB less power than the center ones, which will reduce the gain by about 1 dB compared to a more uniformly illuminated antenna. The alternative is to use the periodicity of the Butler's phase outputs to "split" the outputs in order to feed more columns.

A normal three-beam, three-column array is shown below with its associated Butler Matrix. It has beams that are about 30° wide that are separated by about 30°. It can be seen that if there were a fourth column, from the periodicity of the phases, it would have the same phase as what Column 1 sees.

Splitting Output 1 in half to feed a fourth column, tightens the beamwidth to 27°, while the scan angles are unchanged, resulting in a 5 dB cross-over and improved sidelobes.

Splitting two outputs to feed five columns, tightens the beamwidth to 23°, while the scan angles are unchanged, resulting in a 8 dB cross-over and improved sidelobes.

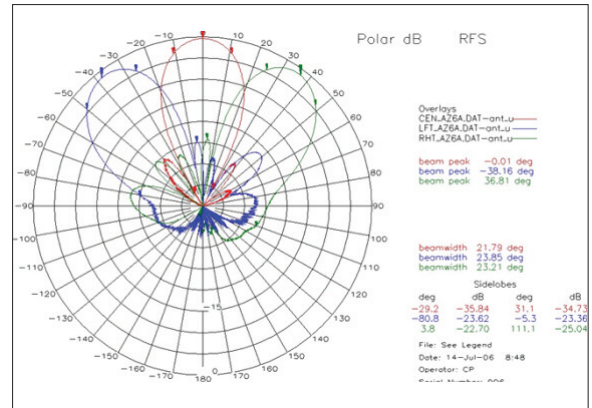


Figure 43 Three 22° Beams Created by a 3x6 Butler Matrix

Original Scan Angles of Un-Paired Inputs	Resulting Scan Angles of Paired Inputs
-50° and -30°	-38°
-10° and +10°	0°
+50° and +30°	-38°

Table 3

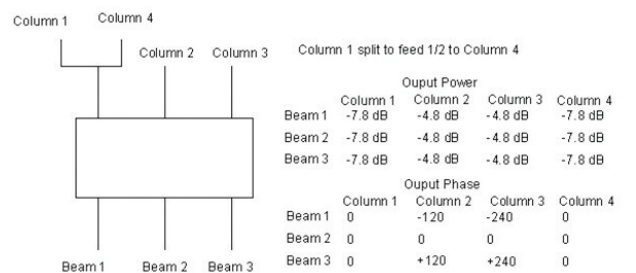
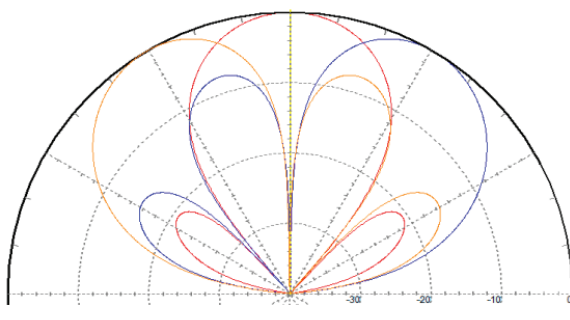


Figure 44 Three 30° Beams with 3 dB Cross-Overs Created by a 3x3 Butler Matrix



Beamforming vs. MIMO Antennas

➤ Passive Switched Beam Antennas

Splitting all three outputs, tightens the beamwidth to 20°, while the scan angles are unchanged, resulting in a 12 dB cross-over and improved sidelobes.

This process can be continued even further if necessary, since a theoretical Column 7 would have the same phase as Columns 1 & 4. It would be up to the user to determine the proper balance between beam cross-over points and the physical size of the array.

Without repeating the entire output splitting process again, a four-way Butler Matrix displays the same periodicity that allows the user to reduce the cross-overs.

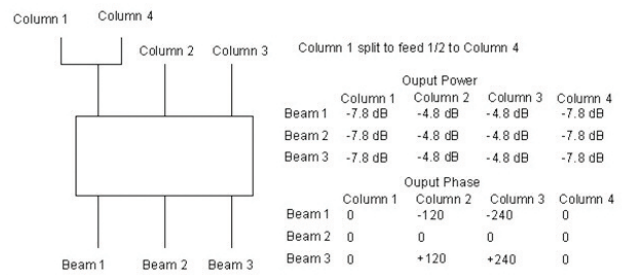
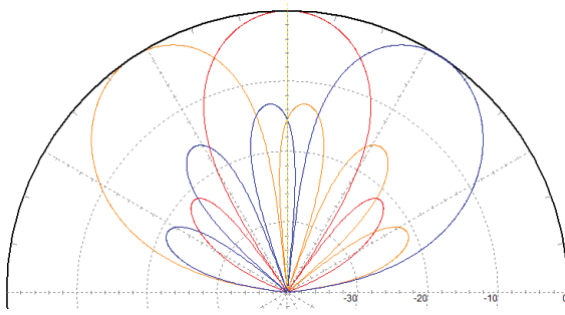


Figure 45 Three 27° Beams with 5 dB Cross-Over Created by a 3x4 Butler Matrix

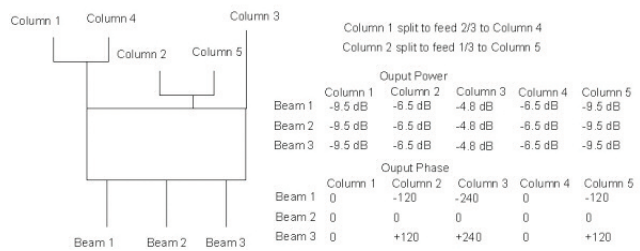
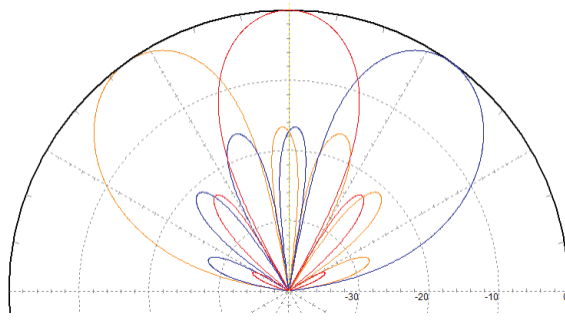


Figure 46 Three 23° Beams with 8 dB Cross-Over Created by a 3x5 Butler Matrix

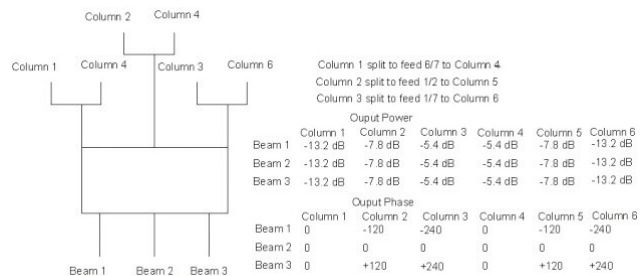
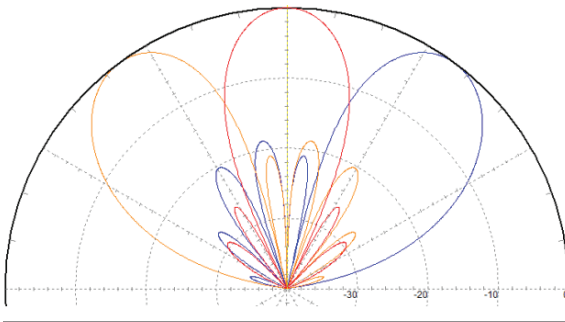


Figure 47 Three 20° Beams with 12 dB Cross-Over Created by a 3x6 Butler Matrix



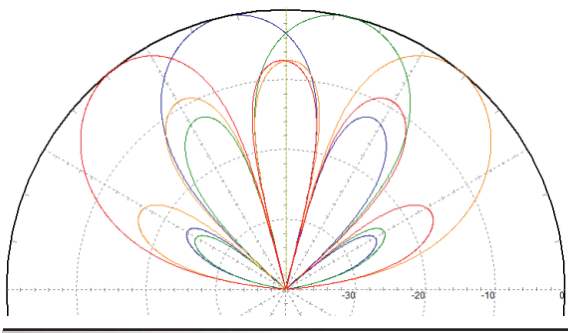
Beamforming vs. MIMO Antennas

Passive Switched Beam Antennas

The only difference is that Column 5 will be 180° out of phase with Column 1 and each extra column will also be 180° out of phase with the column they are sharing power with.

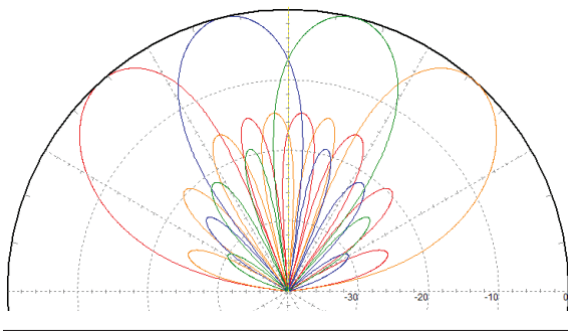
Splitting two outputs to feed six columns, tightens the beamwidth to 20°, while the scan angles are unchanged, resulting in a 8 dB cross-over and improved sidelobes.

Splitting all outputs to feed eight columns, tightens the beamwidth to 15°, while the scan angles are unchanged, resulting in a 12 dB cross-over and improved sidelobes.



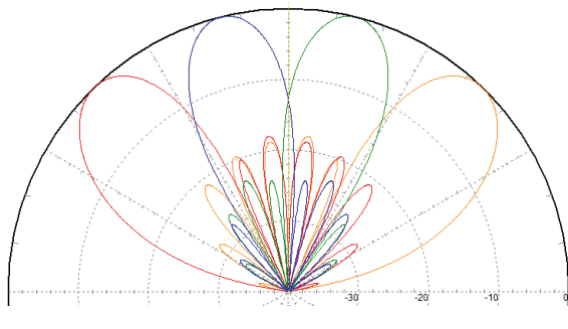
Column 1	Column 2	Column 3	Column 4
Standard 4 Input 4 Output Butler Matrix			
Output Power			
Column 1	Column 2	Column 3	Column 4
Beam 1	-6.0 dB	-6.0 dB	-6.0 dB
Beam 2	-6.0 dB	-6.0 dB	-6.0 dB
Beam 3	-6.0 dB	-6.0 dB	-6.0 dB
Beam 4	-6.0 dB	-6.0 dB	-6.0 dB
Output Phase			
Column 1	Column 2	Column 3	Column 4
Beam 1	0	-135	-270
Beam 2	0	-45	-90
Beam 3	0	+45	+90
Beam 4	0	+135	+405(+45)

Figure 48 Four 30° Beams with 3 dB Cross-Over Created by a 4x4 Butler Matrix



Column 1	Column 5	Column 3	Column 4
Column 1 split to feed 2/3 to Column 5 w/180 Degree Shift Column 2 split to feed 1/3 to Column 6 w/180 Degree Shift			
Output Power			
Column 1	Column 2	Column 3	Column 4
Beam 1	-10.0 dB	-7.8 dB	-6.0 dB
Beam 2	-10.0 dB	-7.8 dB	-6.0 dB
Beam 3	-10.0 dB	-7.8 dB	-6.0 dB
Beam 4	-10.0 dB	-7.8 dB	-6.0 dB
Output Phase			
Column 1	Column 2	Column 3	Column 4
Beam 1	0	-135	-270
Beam 2	0	-45	-90
Beam 3	0	+45	+90
Beam 4	0	+135	+270

Figure 49 Four 20° Beams with 8 dB Cross-Over Created by a 4x6 Butler Matrix



Column 1	Column 5	Column 3	Column 7
Column 1 split to feed 6/7 to Column 5 w/180 Degree Shift Column 2 split to feed 2/3 to Column 6 w/180 Degree Shift Column 3 split to feed 1/3 to Column 7 w/180 Degree Shift Column 4 split to feed 1/7 to Column 8 w/180 Degree Shift			
Output Power			
Column 1	Column 2	Column 3	Column 4
Beam 1	-14.5 dB	-10.0 dB	-7.8 dB
Beam 2	-14.5 dB	-10.0 dB	-7.8 dB
Beam 3	-14.5 dB	-10.0 dB	-7.8 dB
Beam 4	-14.5 dB	-10.0 dB	-7.8 dB
Output Phase			
Column 1	Column 2	Column 3	Column 4
Beam 1	0	-135	-270
Beam 2	0	-45	-90
Beam 3	0	+45	+90
Beam 4	0	+135	+270

Figure 50 Four 15° Beams with 12 dB Cross-Over Created by a 4x8 Butler Matrix



Beamforming vs. MIMO Antennas

➔ Passive Antenna Limitations

The primary limitation to the Butler Matrix is the finite number of angles that can be scanned by the array. The odds of the user being exactly where the beam peak is are rather low. If the system has been designed with shallow 3 dB cross-overs, this probably won't matter since there are no deep nulls that would drop the user. If the system is one with 10-15 dB cross-overs the chance of signal strength dead zones increases.

The antennas also lack the ability to steer their nulls to cancel out interfering signals. Some sort of sidelobe suppression must be used to keep the interferers under control. This could be via aperture tapering, pairing the inputs, or splitting the outputs, but all of these methods are a fixed feature of the antenna. Once the antenna has been installed, there is no flexibility to change the level of suppression if conditions change.

Installing a switched beam antenna is very similar to splitting the sector, with each of the switched beams being driven by its own radio. While a four column active array being fed by four 100W signals will combine all four radio signal strengths together, the switched beam antenna will only be able to use the power coming from the radio that is dedicated to each beam and will not see the 6 dB increase in EIRP from four radios working together to form a single scanned beam.

This can also be viewed as a reliability concern. If one radio of a four-beam, passive antenna fails, an entire sub-sector will receive no coverage. If one radio of an active antenna fails, the system could adjust its algorithms based upon what sort of beams can be created using three columns. In the most extreme example, if three of the four radios fail, the passive array is not covering 75% of its users. The active array will still function as a single column base station antenna, which while having lower gain, will get some sort of signal to all of the users until the radios can be repaired.



Beamforming vs. MIMO Antennas

➔ Conclusion

Both MIMO and beamforming antennas are powerful tools that improve data rates and reduce the impact of noise and fading in their systems. As was discussed earlier, the way they achieve these improvements is very different from one another and they require very different antenna architectures. The columns of a MIMO array act almost independently of each other, having columns with narrow beamwidths spaced far apart, with each column “carrying” part of the load. The columns of a beamforming array act as a “team”, having columns with wide beamwidths spaced close together, to carry the whole data load simultaneously. If an operator plans on using four-column antennas in both MIMO and beamforming scenarios, two unique antennas are recommended to avoid compromising system performance.

A fully adaptive array is extremely flexible in its ability to steer the beam or the null depending on which method provides the best result. The primary design choice for this antenna, assuming it is using the ideal half-wavelength column spacing, is how many columns can be supported by the radio system and allowed by the zoning authorities. Every extra column reduces the beamwidth, and adds gain, EIRP and EIRS, but makes for a wider, more expensive antenna as well as a more complex system to operate it.

The passive switched beam antennas require the network planner to make more choices up front, since they cannot be changed after installation. The first choice will still be the number of columns, which will determine beamwidth, gain, and width. After that, the number of beams the system will use needs to be decided. The maximum number of beams is limited to the number of columns within the array, but this might not be the most desirable choice for the system. By reducing the number of beams

If an operator plans on using four-column antennas in both **MIMO** and **BEAMFORMING** scenarios, two unique antennas are recommended to avoid compromising system performance.



Beamforming vs. MIMO Antennas

➔ Conclusion

other RF parameters (such as sidelobes or beam cross-overs) can be optimized. Once these design parameters have been determined, all beamsteering will occur within the Butler Matrix inside the antenna. Each beam of the passive antenna will act as a small sector with its own radio.

Passive antennas were more widely used in the past, because of the simplicity of the system. The network planner did not need to control the phase and amplitudes of their radios, because all of those settings were predetermined by the Butler Matrix. Adding a switched-beam antenna was no more complicated to the system than splitting the sector up into several sub-sectors using multiple narrow-beam antennas. This simplicity came at a cost though, when compared to a truly adaptive beam-steering antenna.

Today's systems with the radios near the antennas and capable of varying their phase and amplitude with a good degree of accuracy make adaptive antennas the preferred choice of network planners. The calibration boards within the antennas guarantee the antenna pattern will be pointing in the direction the system expects, the sidelobes are suppressed and the nulls will be as deep as possible to combat interferers. If the network planner wants to switch from narrow service beams to a wider broadcast beam, this can be done by simply changing the radio settings. The largest advantage the adaptive array has over the passive array may be the radio power sharing across the columns. It significantly increases the EIRP of the network while improving system reliability in case one or more radios fail.



Beamforming vs. MIMO Antennas

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Beamforming vs. MIMO Antennas

➔ Company Profile

Radio Frequency Systems (RFS) is a global designer and manufacturer of cable, antenna and tower systems, plus active and passive RF conditioning modules, providing total-package solutions for outdoor and indoor wireless infrastructure.

RFS serves OEMs, distributors, system integrators, operators and installers in the broadcast, wireless communications, land-mobile and microwave market sectors. As an ISO compliant organization with manufacturing and customer service facilities that span the globe, RFS offers cutting-edge engineering capabilities, superior field support and innovative product design. RFS is a leader in wireless infrastructure.