Some Thoughts On

DIRECTIONAL ANTENNAS FOR SHORTWAVE

Mitch Sams

I've often been envious of the extreme antenna beam precision available at microwave frequencies (such as radar). At these frequencies the antenna main beam can be shaped, molded, manipulated and scanned electronically in a very effective manner. While dealing with this level of performance professionally, I've often wondered what SWBC DX would be like with this type of antenna. Wouldn't it be nice to steer a narrow beam around in azimuth and elevation quickly and easily while watching stations fade in and out with respect to each other?

The purpose of this discussion is to look at a few common antenna types and their directional properties, then finish with a discussion on an array of elements and the resulting directionality. The goal is to stimulate further discussion and experimentation with directional antenna systems for shortwave DX, a somewhat neglected area of our hobby.

What amount of directionality is useful to DXers? A rough estimate can be made by visualizing the scenarios that a DXer is faced with. This is made easier with a graphical presentation, such as the azimuthal equidistant maps, included in the PROCEEDINGS 1988 article "Terminator Mechanics and Trans Polar Blanking" by John Bryant, which show the Central United States at the center of the globe. Bearings to all locations on the globe can easily be determined with a straight line. From this map, for example, we can see that Latin America occupies about 90 degrees in azimuth if viewed from the central United States. During the evenings in North America stations from Latin America frequently crowd one another on the 90, 60 and 49 meter bands. If we wanted to null a co-channel Guatemalan from a Brazilian and simultaneously avoid any US-based utility stations or African SWBCers that may be present, an azimuth beam width of approximately 50 degree, null-to-null, should do.

If we turn our attention to the case of African DX on 49 meters, a 50 degree main lobe beam width should null European and Latin American signals simultaneously. From this quick study it appears that an antenna main lobe beam width, null-to-null, of 50 degrees would meet our requirements. See figure 1. There may be less common situations where a beam width of less than 50 degrees would be useful. As far as the hobbyist is concerned, at shortwave frequencies, a 50 degree beam width should be considered as narrow.

The overcrowding and interference problem on shortwave today is something we are all painfully aware of, and this problem seems to be getting worse. That fact underscores the need for a high performance directional shortwave antenna system. There is only so much that can be done inside the receiver to combat interference. It would be best to "filter out" most of this interference at the antenna before it gets into the receiver. As a matter of fact, the antenna can be regarded as a spatial filter tacked on to the front end of the receiver. The term interference in this discussion includes not only other SWBC stations but also utilities, jammers, man-made noise or any other RF source that is not desirable.

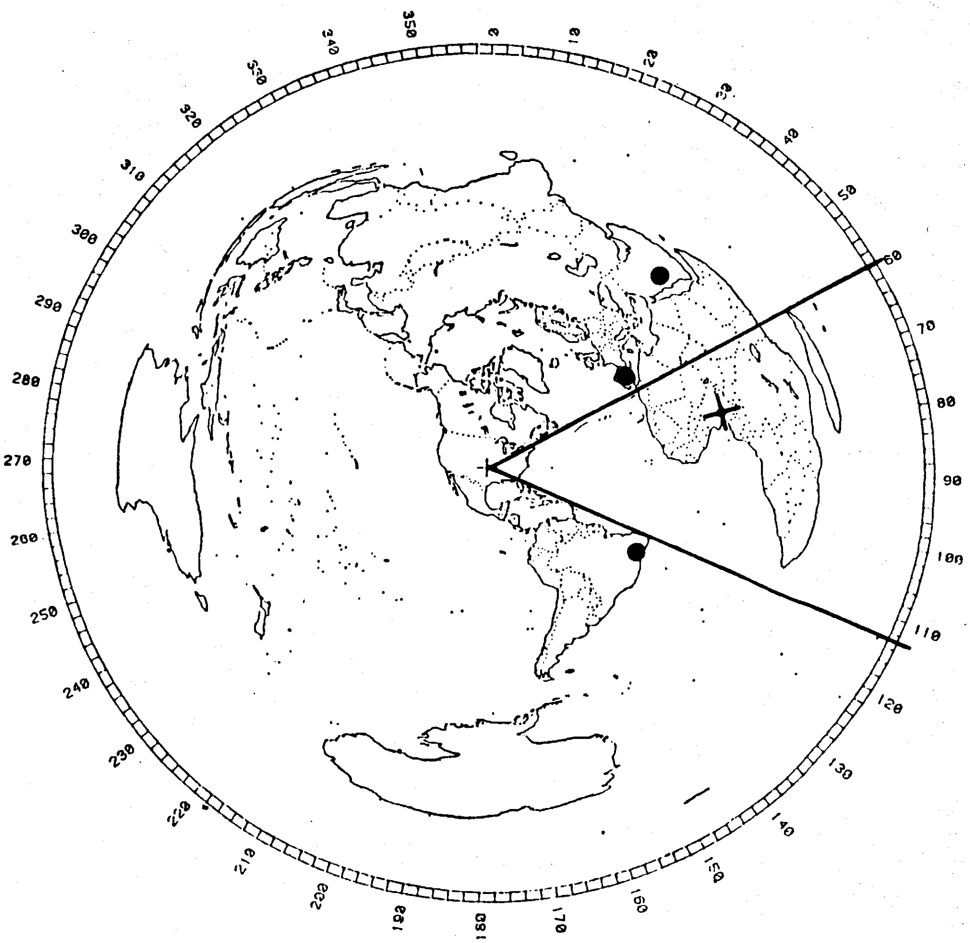


Figure 1. Azimuthal equidistant map showing angular relationships to target station in Nigeria vs "interference" signals in South America , Europe and Mid East. Placing the "interference" in a null would require app. 50 deg. main lobe beam width over Africa with the first nulls falling on South America and Europe/Mid East. ***From Bryant, PROCEEDINGS 1988.***

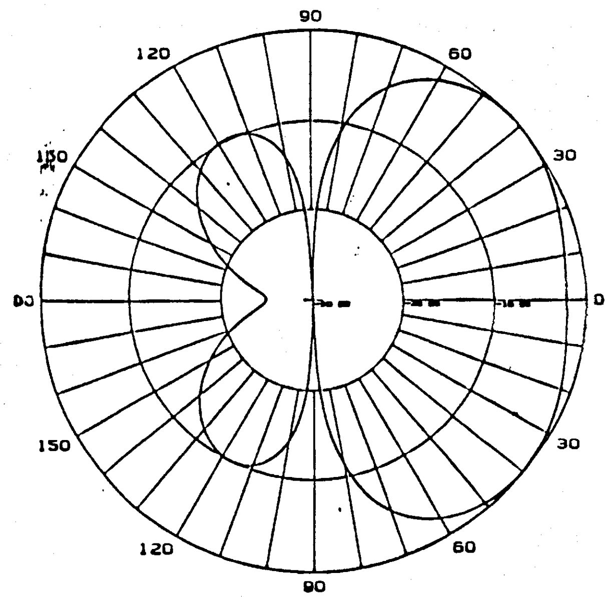


Figure 2. Typical antenna pattern showing broad main lobe beam and the associated first nulls at +/- 90 degrees azimuth. ***From Misek.***

These problems are well known and have been tackled with various directional antenna configurations such as the beverage, the loop, the dipole and with variations of these. Generally the antenna system consists of one element which is fixed in orientation so that the mainbeam is always pointing in one direction. The loop is an exception, it can be mechanically steered so as to change the directionality, this is not easily accomplished with other antennas. Another approach to directionality is to erect two or more elements with different orientations. This allows the operator to change the pointing angle of the antenna by selecting from the different elements. This of course takes quite a bit of area for antenna construction and does not allow the operator to fine tune the pointing angle of the antenna since he or she would be limited to discrete angular positions.

An approach which offers real promise in terms of high performance is the combining of elements to create an array. This allows the beam width to be narrowed beyond what the individual element could achieve. The inputs from these elements can be combined in various ways to create nulls or steer the beam.

Lets first look at three common antenna types which offer directional characteristics at shortwave frequencies:

●THE BEVERAGE ANTENNA The beverage is probably one of the best single-element antenna solutions to directionality. With increasing length, this horizontal longwire's mainbeam sharpens, and assumes a lower profile with respect to the horizon providing good directionality. and optimum long distance reception The antenna is directional from both ends of the wire if the "free" end is not grounded. If the "free" end is grounded then the beverage is directional toward the "free" end direction. See Figure 3.

The extreme length of the antenna (usually 3-4 wavelengths) can have an averaging, or smoothing, affect on the random phase differences in the arriving signal, helping reduce somewhat the difficulty in steering a null when phasing is used. If the length of the beverage extends past approximately 4 wavelengths the phase smoothing essentially becomes phase interference resulting in some degradation to the gain pattern. The gain of an antenna is a function of the physical area of the antenna, and as you can guess, the beverage has very good gain characteristics (after all, you have a very large aperture area to present to the incoming wave front). The beverage is not complex to construct, save for important impedance matching considerations (see the PROCEEDINGS 1988 article - "Impedance Matching A Beverage Antenna To A Receiver" by Nicholas Hall-Patch and John Bryant).

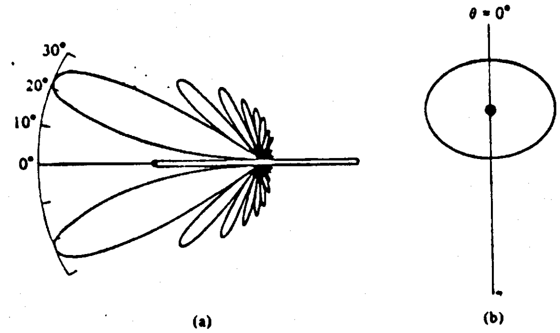


Figure 3. Beverage antenna elevation pattern in free space, viewed from the side of the wire (a) and from the end of the wire. ***From Elliot.***

Achieving high performance with the beverage antenna is exacted at the price of real estate. A 3 to 4 wavelength beverage on the tropical bands could be as long as 1200 feet.

The field strength pattern of a beverage antenna of length, L , at wavelength, W, can be found from the following equation:

$$f(\phi,\beta) = \frac{\text{SIN}(X)}{X}$$

where X = ((PI*L)/W)*(1-SIN(ø)*COS(ß))

ß is the angle in azimuth being considered, while ø is the angle in elevation being considered. ø is equal to 90 degrees when an elevation tilt angle of 0 is used. If, for example, an elevation angle of 20 degrees above flat earth were being evaluated, ø would be 90-20 = 70 degrees. This equation basically defines a blob centered over the end(s) of the wire. At short lengths the blob is large and broad in both azimuth and elevation. At longer lengths both beam widths narrow and the peak gain in elevation moves down towards horizon. See figure 4. Table 1 lists the length of the beverage in portions of a wavelength;,then the angular location in elevation of the peak of the beam; the elevation beam width at that point; then finally the azimuth beam width at that point in elevation.

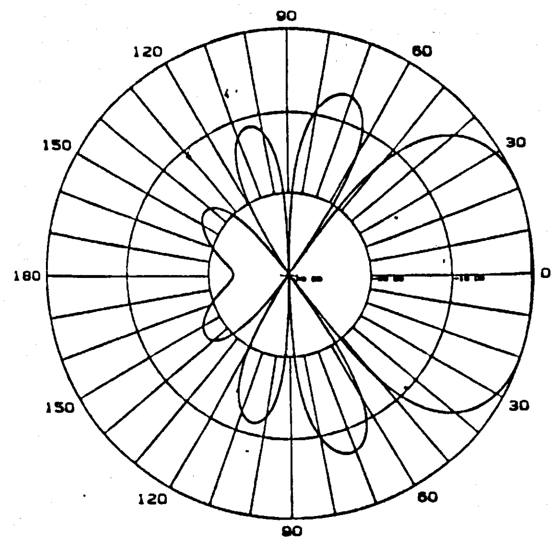


Figure 4. Beverage antenna azimuth pattern for length = 2 wavelengths. *From Misek*

LENGTH wavelengths	EL. PEAK degrees	EL BEAMWIDTH degrees	AZ BEAMWIDTH degrees
0.25	85	160	360
0.5	80	135	360
1.0	54	82	180
1.5	45	60	124
2.0	38	50	100
2.5	33	48	88
3.0	30	44	80
3.5	28	40	72
4.0	26	36	68
4.5	24	34	64
5.0	22	32	60

Table 1. Antenna length versus elevation peak location, elevation beam width , and azimuth beam width. Azimuth peak location is always 0 degrees in azimuth (at the end of the wire). beam widths are null-to-null.

●THE LOOP The loop antenna has been used with great success on the broadcast or mediumwave band, but has seen little hobby use on shortwave. The loop antenna is directional parallel to the plane of the loop, or edgewise. See figure 5. The antenna creates a very broad beam with sharp nulls. The operator can steer the null into the interference by physically rotating the loop. Due to the typically smaller aperture size two problems exist. Smaller aperture area means less gain, sometimes much less. This can quickly become the limiting factor in DXing weak signals. One solution would be to add a preamp, however, that can create new problems with preamp-generated noise, intermodulation and loss in dynamic range. (These problems are not insurmountable is the preamp is designed correctly.) Another solution would be to increase the diameter of the loop in order to increase the area but then it becomes increasingly difficult to physically steer the loop. Another problem is the random phase changes that occur in the incoming shortwave signal. The small physical size of the antenna will not allow phase averaging as would be possible with the beverage. This makes phasing of multiple elements difficult at shortwave frequencies. (See Joe Farley's work elsewhere in PROCEEDINGS 1989).

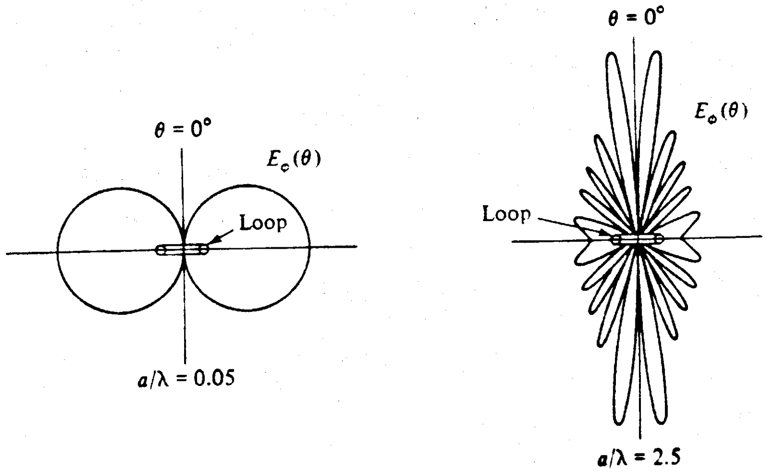


Figure 5. Typical loop antenna patterns. *From Elliot*

● **THE DIPOLE.** The dipole is an antenna which combines good gain with a fair amount of main-beam directionality. Peak response is broadside to the element (front and back) with nulls at the ends of the dipole. See figure 6. The dipole has nearly as much gain as a short beverage and a beam width similar to the loop. The physical size of the dipole falls between the two extremes of the loop and the beverage. This antenna is commonly used in array configuration.

The field strength pattern in azimuth of a dipole of length,L, at a wavelength, W, can be found from the following equation:

$$f(\phi) = \frac{COS((PI*L/W)*SIN(\phi))-COS(PI*L/W)}{COS(\phi)}$$

L is the total length of the dipole. The optimum length for a dipole is one half of a wavelength. The gain pattern for this length is donut shaped with about a 150 degree null-to-null beamwidth. If L exceeds a half wavelength then additional "grating" sidelobes appear in the pattern and tend to take away from a "clean" directional pattern.

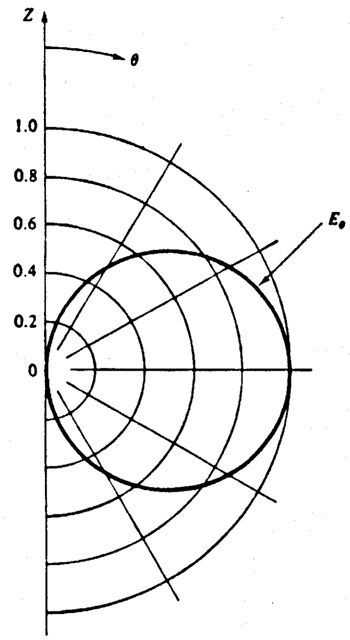


Figure 6. Dipole antenna pattern. ***From Elliot***

●THE PHASED ARRAY - All of the above antennas can be used alone but they need not be. When two or more elements are used together it is called an "array" (your TV antenna is an array). In most practical applications, the elements will be of a common type, equi-spaced, and oriented along the same axis. The relative physical positioning of the elements, the number of elements and the size of the individual elements are three parameters that can be used to exercise control over the shape of the gain pattern of an array.

The benefits of using both or several antenna simultaneously can be realized through the use of "phasing". Phase is the degree to which the individual cycles of a wave or signal coincide with those of another wave or signal. Phase is commonly defined in terms of the points in time at which the amplitude of a signal goes through zero in a positive direction. The signal's phase, then, is the amount that these zero-crossings lead or lag the corresponding points in the reference signal. This amount can be expressed in several ways. Perhaps the simplest is as a fraction of a wavelength or cycle. Remember, a wavelength is the physical distance required for the intensity of the transmitted field to go from zero intensity to maximum intensity, reverse direction, and pass through zero intensity, maximum intensity, and return to zero. Simply put: one cycle of a sinusoidal wave. See figure 7. Phase is generally expressed in degrees - 360 degrees corresponding to a complete cycle. If, for instance, a wave is lagging a quarter of a wavelength behind a reference signal, its phase is 360 X 1/4 = 90 degrees.

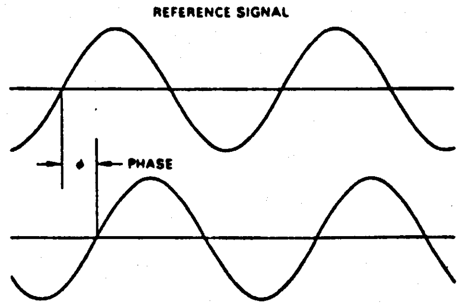


Figure 7. Phase is the degree to which the cycles of a wave or signal coincide with those of a reference signal of the same frequency

Phasing can be used to cancel out incoming signals present on two or more antenna at a given angular bearing. This particular approach is known as "null steering", in which case the width of the mainbeam is not that important. By introducing a lag or lead in the phase of one signal until a phase value is achieved which is just the opposite (180 degrees out) of the other, and then summing the two to zero, a null can be created at this point on the antenna. See figure 8. One way to introduce a lag in phase is to switch in a path length difference in one antenna element feedline. This will require the traveling wave in that element to propagate further, thus rotating through an additional portion of a wavelength and producing a phase differential with respect to the other antenna.Victor Misek has written an excellent book on the subject of null steering a two beverage system (short and long lengths) called THE BEVERAGE ANTENNA HANDBOOK. He has investigated the null steering of two parallel beverages, both short and long lengths, and results are promising. Nulls are between 15 and 20 degrees wide and are steerable primarily in elevation, not azimuth. Azimuth directionality may be more important to the DXer than is elevation directionality (however, the importance of elevation beamwidth should not be ignored completely). He doesn't say much at all about actual performance but he does note that it is difficult to create a null with skywave, multi-hop propagation, which is dominant on shortwave.

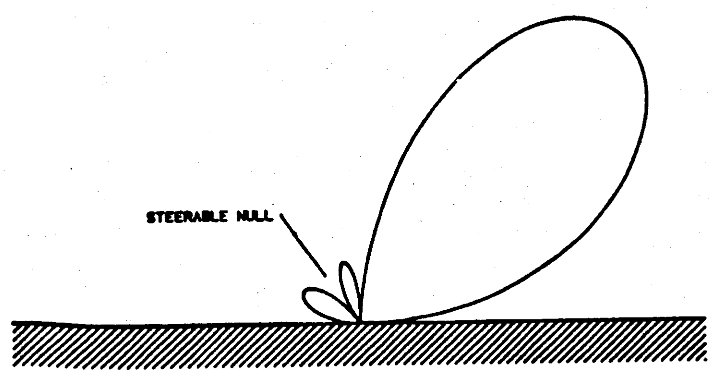


Figure 8. Pattern with steerable null resulting from combining two patterns. ***From Misek***

There are some basic problems which exist at the shortwave frequencies that make it difficult to develop a relatively simple, highly directional and steerable antenna for the hobbyist. The extreme random nature of the incoming wave front after multiple reflections off the ionosphere result in unpredictable phase; the signal arrives at the receiver in unpredictable angles; presence of multiple path lengths (usually a result of the different number of hops taken by individual components of the wave front). Some or all of these shortcomings are not prevalent at medium or microwave frequencies. This randomness present in the phase of the signal makes null steering difficult at shortwave frequencies since the null is generally very narrow.

I'm not sure if the attenuation outside of the mainbeam (i.e. max level of the sidelobes) would be more than that possible from null steering.

In an array, a relationship between the number of individual elements - N, spacing - d, and wavelength - L can be shown. See figures 9 and 10. This represents the gain pattern for an array:

$$G(\varnothing) = \frac{\mathrm{SIN}\,[N*pi*(d/L)*\mathrm{SIN}(\varnothing)]}{N * \mathrm{SIN}[pi*(d/L)*\mathrm{SIN}(\varnothing)]}$$

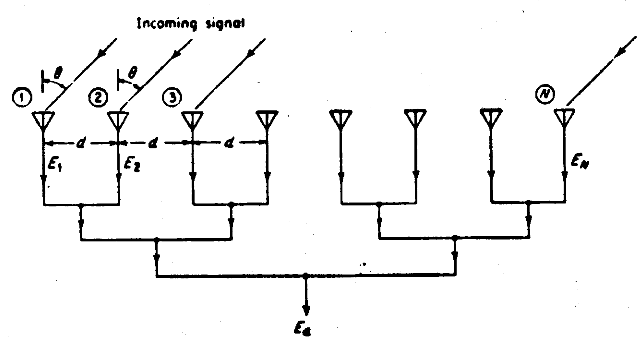


Figure 9. N-element array. ***From Skolnik***

ø is the angle in the gain pattern being considered. This equation calculates only the gain due to the array (also known as the array factor). To include the effects due to the gain pattern of the individual elements (called Ge(ø)) you simply multiply G(ø) by Ge(ø). This equation, however, is a rough approximation and does not take into consideration the effects due to mutual coupling between the individual elements.

The half-power beam width is approximately:

$$\text{Beam width} = \frac{0.886 * L}{N * d}$$

Of more importance to the user is the null-to-null beam width which can be calculated by finding the value for ø which causes G(ø) to go to zero.

We should be able to create an approximately 120 degree null-to-null azimuth beam width with 2 half-wave dipoles spaced horizontally a half-wavelength apart. At 49 meters (6 MHz), that would result in 2 dipoles of individual length 80 feet spaced 80 feet center-to-center for a total array length tip-to-tip of about 160 feet. We have now narrowed the half-power beam width of a single half-wave dipole from approximately 150 degrees to a resultant 120 degrees using two elements. If we add a third element, which increases the overall array length to 250 feet, we can now achieve a beam width of approximately 80 degrees. That's comparable to the azimuth beam width possible with a 3 wavelength beverage (480 feet at 49 meters).

The following table shows the resultant null-to-null beam width possible with an array of half wavelength dipoles spaced at half wavelength intervals, and the associated total array lengths for several of the SWBC bands. Number of elements in the array is listed at the far left of the table.

#	AZ B.W..	16m	19m	25m	31m	41m	49m	60m	90m
2	120	56	65	83	102	137	163	200	297
3	80	83	97	125	154	205	250	301	447
4	60	111	130	166	205	274	333	402	596
5	40	139	163	208	256	342	407	502	745

Table 2. Array lengths, in feet, as a function of number of elements, #, azimuth null-to-null beam width in degrees, AZ B.W., for several shortwave bands.

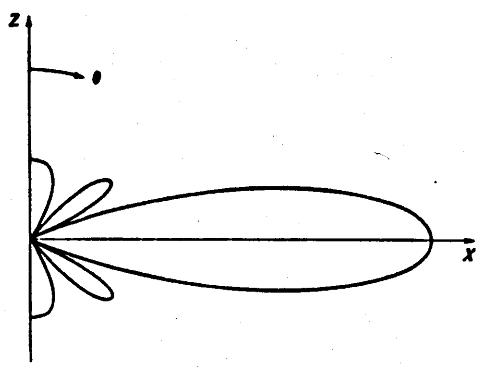


Figure 10. Broadside array pattern, 5 element.

This configuration produces a fixed beam on both sides broadside to the array , which means that any signals outside of the mainbeam, front and back of the array, would be attenuated. This would limit somewhat the station bearings we could DX. If we are interested in a particular bearing and frequency range then this fixed array might be a very satisfactory answer. But, after going to this much trouble to erect an array, it would be desirable to add some flexibility to the system so that we might change direction of the mainbeam ("scan"). This scanning can be accomplished electronically by introducing an equal phase lag, P, between each element of the array. The resulting gain pattern will produce a mainbeam which is directed at some angle, ß, off of broadside. The equation for an array gain pattern discussed earlier can be modified to show this effect. The SIN(ø) term is replaced with a SIN(ø)-SIN(ß) term in both the numerator and denominator:

$$G(\phi) = \frac{\mathrm{SIN}\,[N*pi*(d/L)*(\mathrm{SIN}(\phi)-\mathrm{SIN}(\beta))]}{N*\mathrm{SIN}[pi*(d/L)*(\mathrm{SIN}(\phi)-\mathrm{SIN}(\beta))]}$$

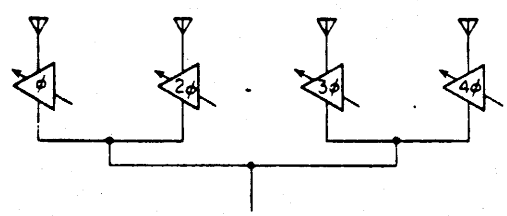


Figure 11. N element phased array. Phase shift P = ø.
From Skolnik

The amount of phase shift, P, required to produce a main beam angle, ß is:

$$P = 2*pi*(d/WAV)*\mathrm{SIN}(\beta) \quad , \text{ where WAV=wavelength.}$$

By changing this phase shift value, P, the mainbeam can be scanned back and forth in azimuth at an angle, ß. See figure 12. As the mainbeam is scanned further off of broadside it begins to distort and broaden. This change in beam width is found by modifying the original beam width equation:

$$\text{Beam width} = \frac{0.886 * L}{N * d * COS(\beta)}$$

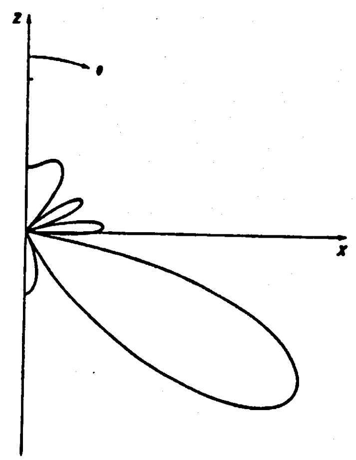


Figure 12. Phased array scanned off-broadside.

Taking this approach one step further, a computer could be used to control this scan. The beam could automatically be scanned 180 degrees in azimuth, or operator selectable sectors of some amount less than 180, to peak detect the strongest signal level and then position the mainbeam at that optimum angle. With a computer controlled receiver, the frequency would be stepped through a band. At each frequency interval the antenna beam would be scanned between two preset limits. For example, the computer could be commanded to scan the receiver between 3.4 and 4.0 MHz while scanning the antenna between 285 and 345 degrees azimuth in an attempt to locate out-of-band Indonesians. ,The computer would be used to peak detect the incoming signal. This would allow the operator to set the signal strength threshold which the signal would have to exceed before a detection would be noted. In addition, a threshold maximum could be set which would reject any signals that exceeded this upper limit thus eliminating extremely strong (and possibly common) stations. There are several unknowns here that we do not have a good answer for at this point. Such as, what are the statistical characteristics of typical signal angles-of-arrival from shortwave stations? The beam width needs to be wide enough to capture the angle fluctuations of a signal, that requirement will dictate how narrow a beam width we can tolerate. How easily can we control phase in this system? Will we have the same difficulties in this area that are encountered with null-steering?

When electronically steering the beam in azimuth, the beam width will widen as it is scanned off of broadside. It effectively doubles by the time it is off the ends of the array. See figure 13.

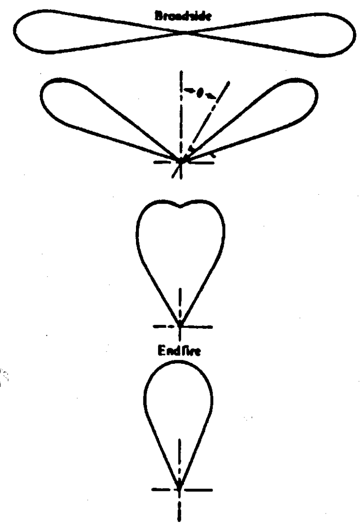


Figure 13. Change in beam width vs scan angle

At this point, the discussion has been limited to a horizontal linear array which allows the beam to be steered only in azimuth (horizontally). If we were able to place another array of elements above this array we could then phase elements vertically to control the scan in elevation as well as azimuth (this is exactly what "phased curtain array" SWBC transmitting antennas do!). See figure 14. This of course becomes physically impossible for just about any hobbyist. A possible solution is the use of vertical wires, which are directional in elevation (vertically) phased with horizontal wires directional in azimuth (horizontally).

It would be beneficial to steer the beam of the antenna in elevation since we could then discriminate against short distance versus long distance signals. Long distance (multi-hop) signals arrive at much lower elevation angles, which are closer to horizon, than do single-hop short range stations. From central North America, for example, a DXer might be able to attenuate somewhat the Radio Rebelde, Cuba outlet on 5025 kHz enough to DX a South American propagating at a greater distance on or near this channel.

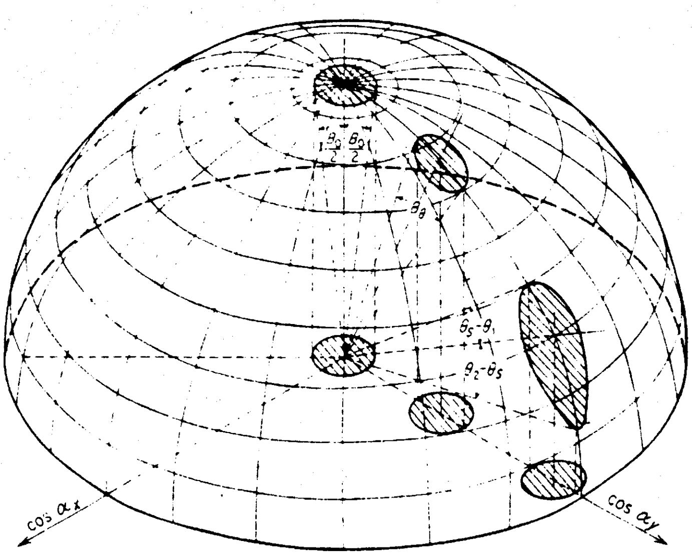
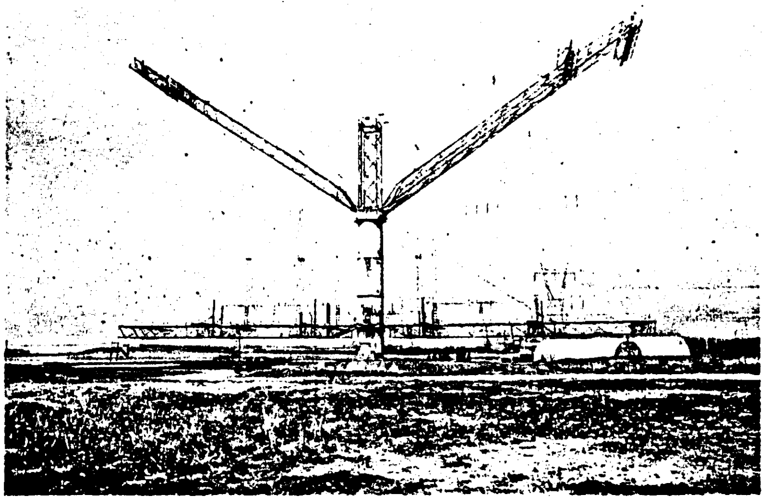


Figure 14. beam width and eccentricity of the scanned beam. ***From Skolnik, Von Aulock, Proc. IRE.***

One nice fallout of a directional antenna is, of course, it's ability to determine the bearing of a station to within basically the beam width of the antenna. If two or more people, who are geographically separated at some distance from one another measured their relative bearing to the same station then the two bearings obtained could be plotted on a map to determine the probable location of the station. This would of course be a tremendous help when attempting to identify an unidentified station.

We may be dreaming, but I do think that some very exciting and useful progress could be made by the shortwave hobby community in the area of multi-element phased array antennas. The basic computer controlled electronically steerable phased array antenna concept just described is commonly used in today's fire control radar systems. The use of phasing presents a challenge and the overall array lengths can get cumbersome,. That is still a major drawback to high performance antennas at shortwave frequencies. Null steering with two parallel beverage antennas, as described by Misek in THE BEVERAGE ANTENNA HANDBOOK, is promising and can alleviate the array size problem somewhat, but this configuration steers the null in elevation, not azimuth. A broadside array of phased dipoles provides excellent directivity in azimuth, but can get lengthy.

The ultimate antenna? How about one that is owned by the Voice of Turkey - a 170 ton mechanically revolving antenna measuring about 80 meters in diameter and 46 meters high. This antenna will complete a 180 degree turn in just 3 minutes!



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