WHAT'S YOUR ANGLE?

BY KENNETH SCHOFIELD, *W1RIL

This article explains the relationship between the horizontal and vertical radiation patterns, antenna height and the vertical radiation angle.

My first few years as a radio amateur were filled with gaping voids on many aspects of the art. One of these voids was the understanding of antenna operation relative to the makeup of the fields forming the radiation pattern, and particularly the vertical angle of radiation.

Participation in an FAA training course at Oklahoma City in the late 1950's brought to me a greater depth of understanding in this area. From QSO's on the bands it becomes apparent that other hams are plagued with the same lack of understanding.

It is the intention of this article to tie together the horizontal and vertical radiation from an antenna of a given type and to show the relative effects of antenna height changes to the resultant vertical radiation angle.

True Ground

True ground is difficult to find without expensive research and specialized equipment not usually available to the average amateur. In order to circumvent this obstacle of true ground location, let us *assume* in all subsequent calculations in this article that true ground is the surface of the earth, is a perfect conductor, and will reflect the radiated signal totally, without loss of energy.

Past articles in amateur publications have listed pros and cons about antenna heights and types, *etc.* Most DX men will agree, that the higher the antenna the better. By delving into a little background, defining of terms, applying some simple trig, and taking examples of an antenna at different heights, it is relatively simple to show the effect height has upon the vertical angle.

Radiation Patterns

Figure 1 depicts a free space horizontal radiation pattern of a 2 element beam. (dipole with reflector) If it was possible to vaporize a drop of ink in the final tank coil to color the radiation pattern, fig. 1 would then depict a birds-eye view of what would be seen.

Putting the same fictitious ink again into the final tank coil, we color the vertical

*21 Forestdale Road, Paxton, Mass.

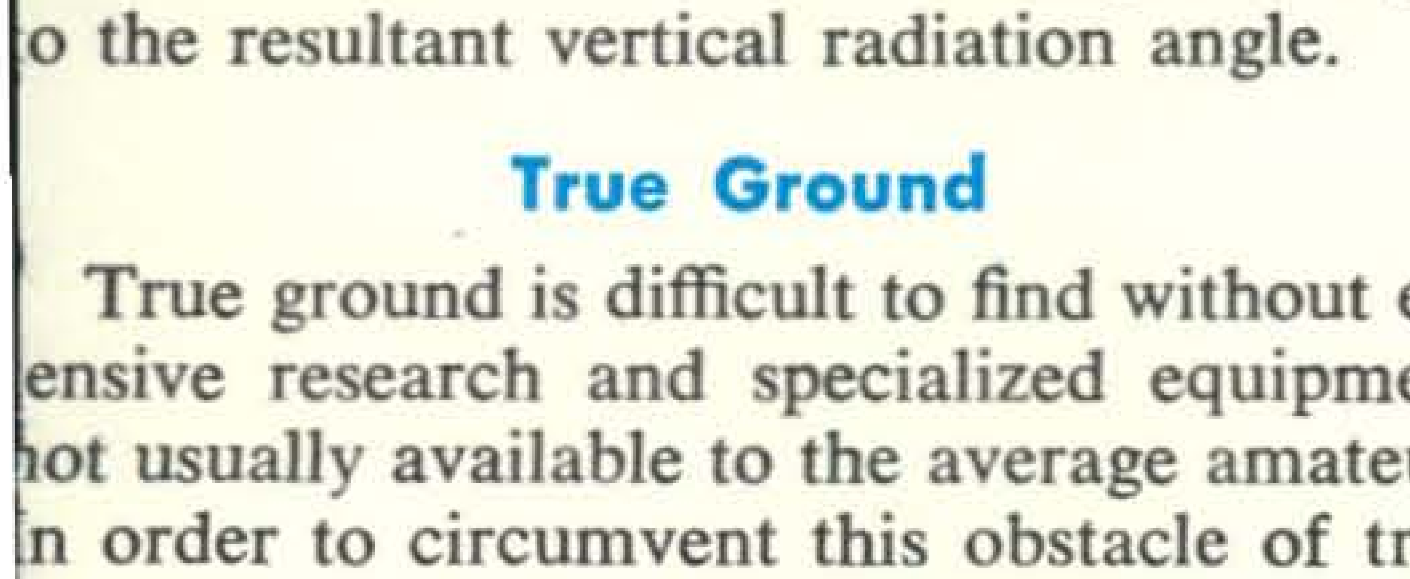

Fig. 1—Horizontal radiation pattern of a 2 element beam antenna.

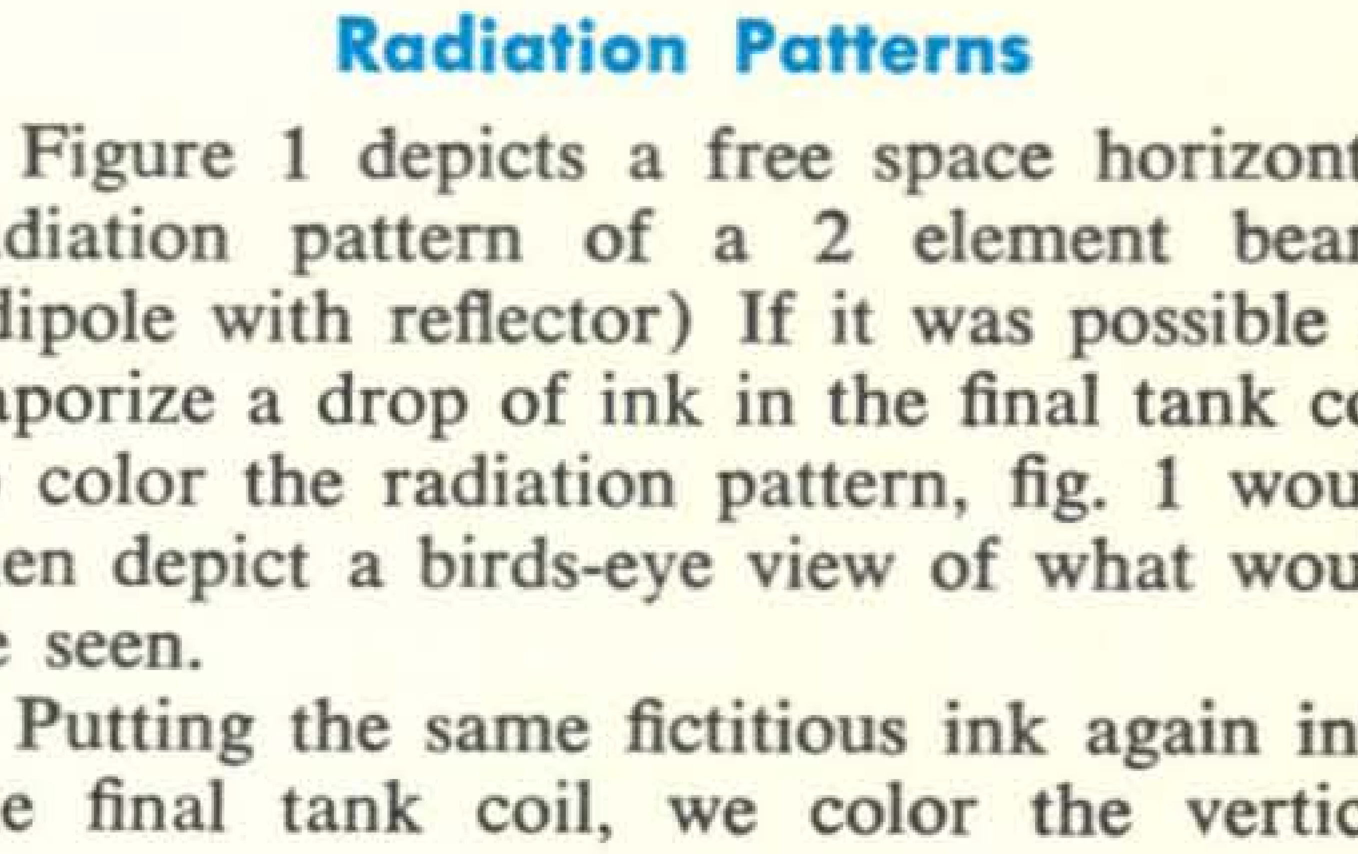

Fig. 2—Vertical radiation pattern of a 2 element beam antenna.

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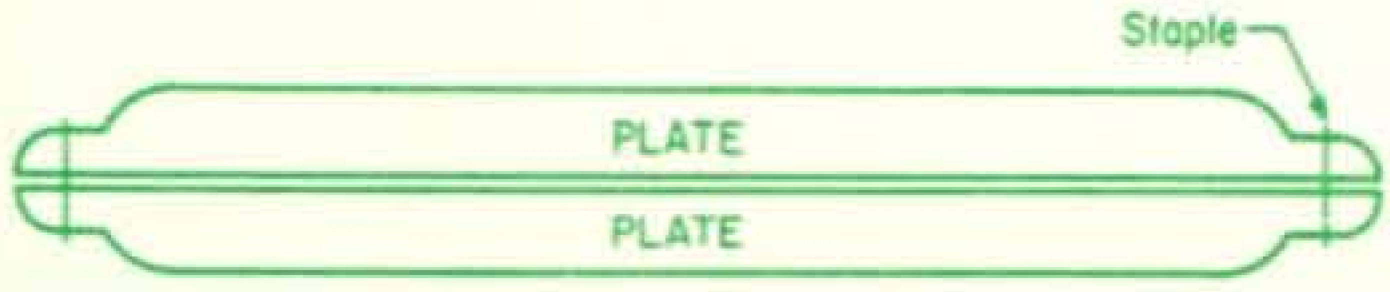

Fig. 3—Fabricating a model of a lobe using paper plates.

radiation pattern, and this might be viewed by standing on a hilltop looking toward the ends of the beam as per fig. 2.

These two patterns, horizontal and vertical, are combined and form the radiation from the antenna which is essentially a three dimensional phenomenon. A small scale model of a radiation pattern can be constructed using paper plates, to give an overall picture of the combination of the 2 patterns. Place two large paper plates together face to face and staple the edges as in fig. 3. This is used as lobe 1 as shown in fig. 2. Repeat with two slightly smaller plates for lobe 2. Using 4 small plates construct lobes 3 and 4. Staple lobes 1, 2, 3 and 4 together at point *X* (fig. 2) and bend the lobes to resemble fig. 2 as viewed from the side. The minor lobes, 5 and 6 can be added using smaller diameter plates if desired and attached to each side at point *X*.

Vertical Radiation

Now that we understand the combined patterns we can go on to the vertical radiation angle. Figure 4 illustrates a vertical radiation pattern (as viewed off the ends of the beam), plotted on a degree scale. Zero degrees represents the front of the antenna, 90 degrees is directly above the center of the antenna and 180 degrees is off the back of the antenna. At point *A* we find a maximum radiation in the first *major* lobe. At point *A'* we find a maximum radiation in the second lobe. Points *B* and *B'* are nulls (minimum radiation).

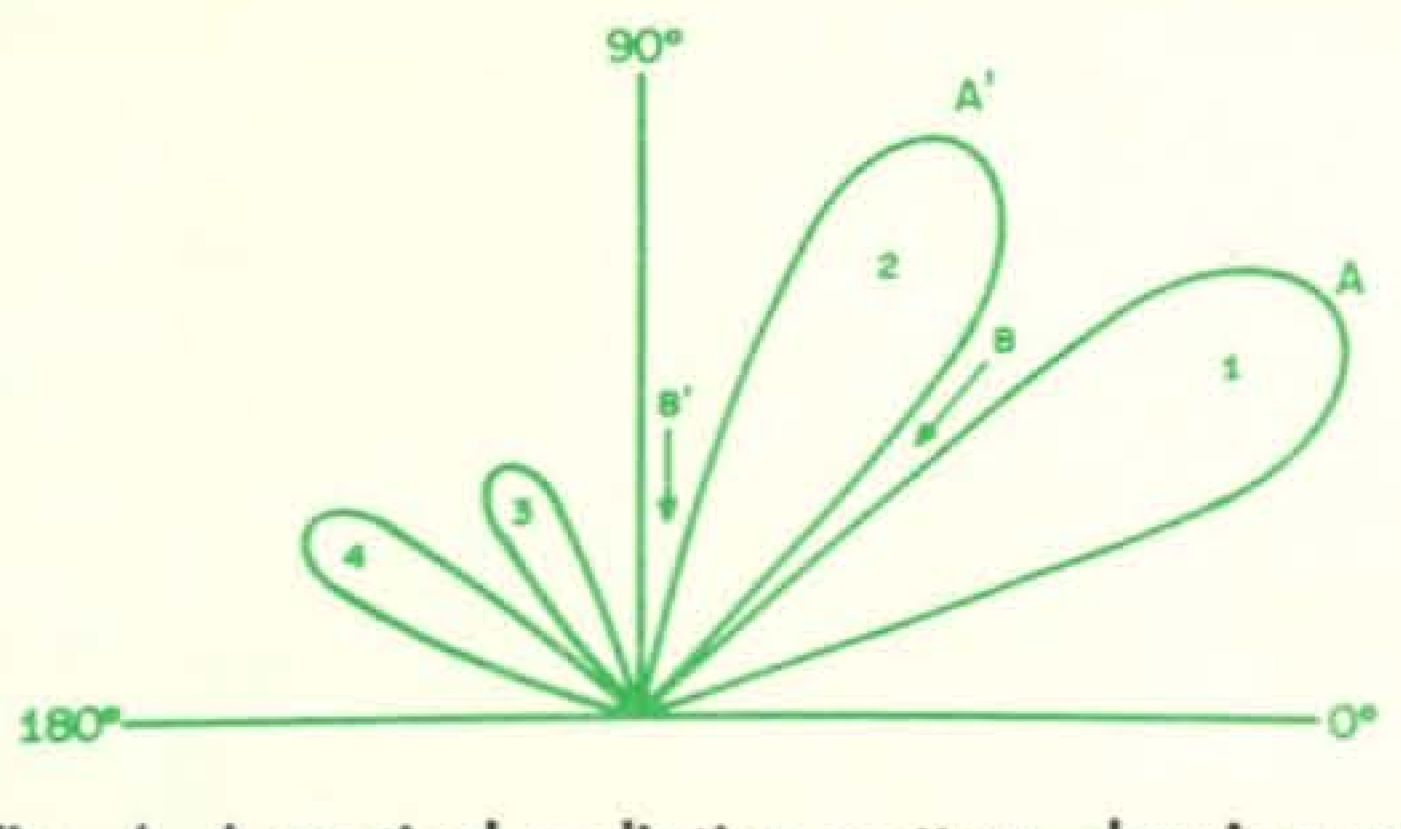

Fig. 4—A vertical radiation pattern showing major and minor lobes and the mirror image angular relationships explained in the text.

The area between 90 degrees and counterclockwise to 180 degrees will be a mirror image of the pattern found between 0 and 90 degrees insofar as location of maximum and nulls are concerned. The only difference will be the intensity of the lobes will be greatly reduced and are called *minor* lobes. The angle of the fourth lobe to the 180 — 0 degree line will be the same as that of the first lobe to the 0 — 180 degree line, and the angle of the third lobe will be the same as that of the second lobe.

The number of lobes is determined principally by the height of the antenna above ground. The angle formed by the first major lobe to the 0 degree line is the vertical angle of radiation of interest. The smaller the angle at which the wave leaves the antenna the less will be the bending required in the ionosphere to bring it back, and generally, the greater the distance covered.

Vertical Angle

Let us now calculate the vertical angle of a two element beam at various heights.

Given: *Height:* 46 feet above ground (earth's surface).

Frequency: 21.391304 mc (used only to simplify calculations).

Antenna: 2 element beam, dipole with reflector at 90 degree spacing.

Polarization: Horizontal.

Determine the height of the antenna in electrical degrees:

$$\text{Wavelength in feet} = \frac{984}{f_{mc}} = \frac{984}{21.391304} = 46 \text{ feet.}$$

Since the antenna height is 46 feet we are I wavelength high, or 360 electrical degrees above ground.

Image Antenna

Figure 5 depicts this antenna illustrating the real antenna 360 degrees above ground. Let us assume that an r.f. current I_r is flowing in the real antenna. At point *P* (a receiving point), energy will be received over the direct path P_1 and also by way of a

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eflected path P_2. From the geometry of ig. 5, wave P_2 could be considered to have een radiated by an antenna located 360 degrees below ground. This imaginary antenna s called the *image* antenna.

Consider fig. 6. When point P is very nuch greater than the distance h (360 degrees), path P_1, P_2 and P_o (midpoint between eal and image antennas) can be considered arallel as illustrated. Through geometric elationships, distance D is equal to $h \sin a$. This, $h \sin a$, is the vertical directivity factor. Energy can be assumed to be radiating from he midpoint of the real and image antennas.

Phasing

At the beginning of this article we asumed our ground to be a perfect conductor vith no losses to reflected energy. Considerng this, horizontally polarized waves will e reflected without change in amplitude ut with a 180 degree change in phase beween the incident and reflected waves.

Referring to fig. 7, we see the real antenna 60 degrees above ground and the image ntenna 360 degrees below ground. An asumed current, I_{real}, is flowing in the real ntenna at a phase angle of 0 degrees. (I_{real} 0.) Also, current I_{image} at 180 degrees, ows in the image antenna. (I_{image} 180.) t point X, half way between the real and nage antennas we find that I_{real} /0 has aveled 360 degrees from the real antenna nd will arrive at point X at the same phase ngle of 0 degrees. (360 degrees is the same s 0 degrees.) At this same point X, current $_{mage}$ /180 has traveled 360 degrees from he image antenna and will arrive at point X t the same phase angle of 180 degrees. /180 + 360 = /180) Therefore at point , I_{real} and I_{image} are 180 degrees out of hase and cancel, resulting in a null.

Now consider point X', 90 degrees above round, shown on fig. 7. The current from he real antenna will reach this point in 270 egrees, whereas to the ground line it is 60 degrees. In other words, the current $_{eal}$ has been advanced 90 degrees.[1] (repesented on the vector diagram, fig. 8, as a ounterclockwise rotation of the I_{real} vecr.) The current from the image antenna avels 360 degrees to reach the ground line ut now has to travel 90 degrees further to he point X'. This current is therefore rerded 90 degrees and is represented on the ector, showing I_{image} rotating clockwise 0 degrees.

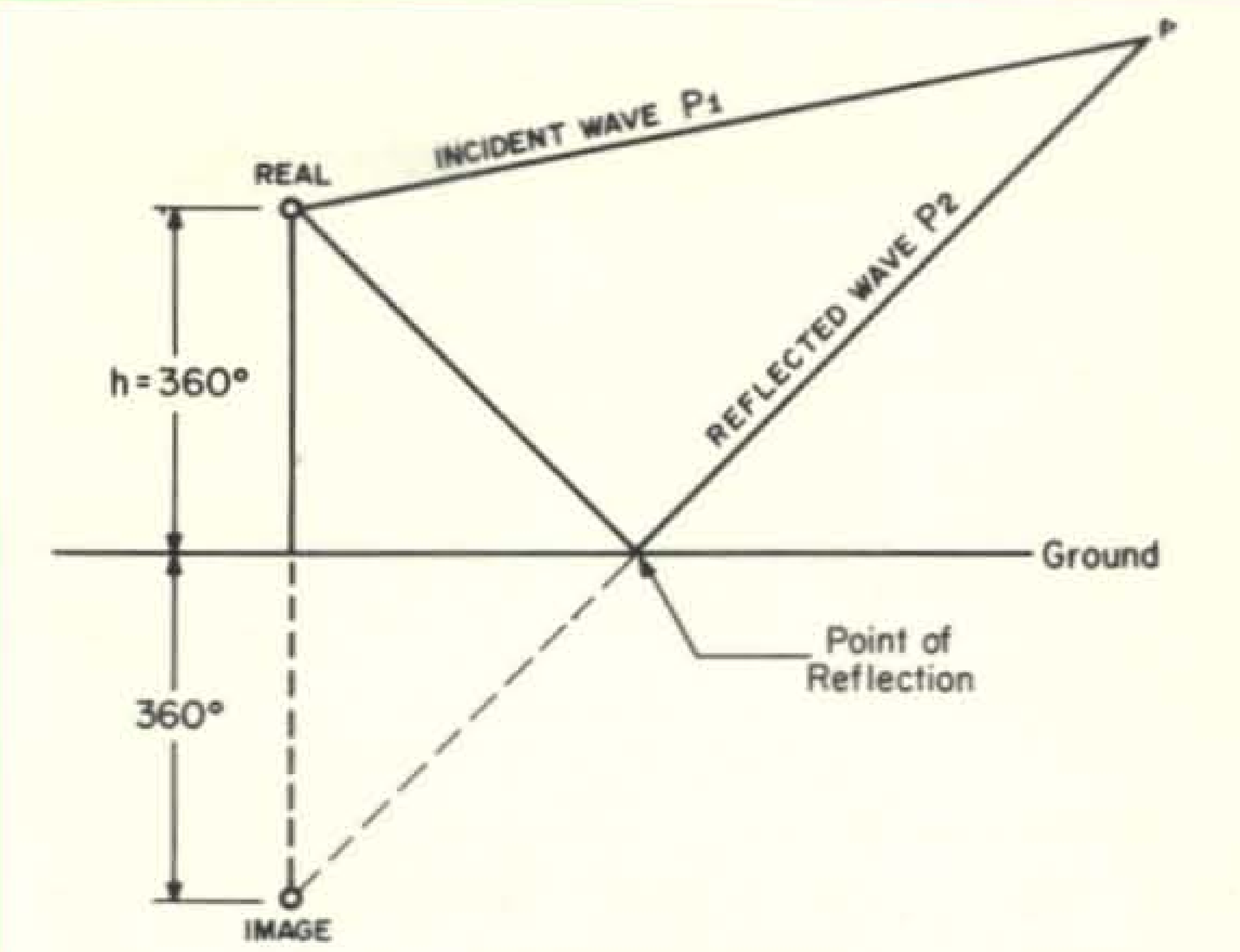

Fig. 5—Relationships between the real and image antenna and the incident and reflected waves.

Consider point P in space. By geometric construction it can be proven that at point P, the same situation will evolve, that is to say, the phase of the real current will be advanced and the phase of the image current will be retarded, relative to point X.

Vertical Angle Calculations

On the vector diagram, fig. 8, the currents I_{real} and I_{image} are shown. If the I_{real} is advanced 90 degrees and the I_{image} is retarded 90 degrees they are then in phase and add, and we have a maximum radiation. The vertical directivity factor, $h \sin a$ will be set to equal the points at which these

[1] As an electromagnetic wave is propagated into space its phase is considered to be retarded in respect to the point of origin.

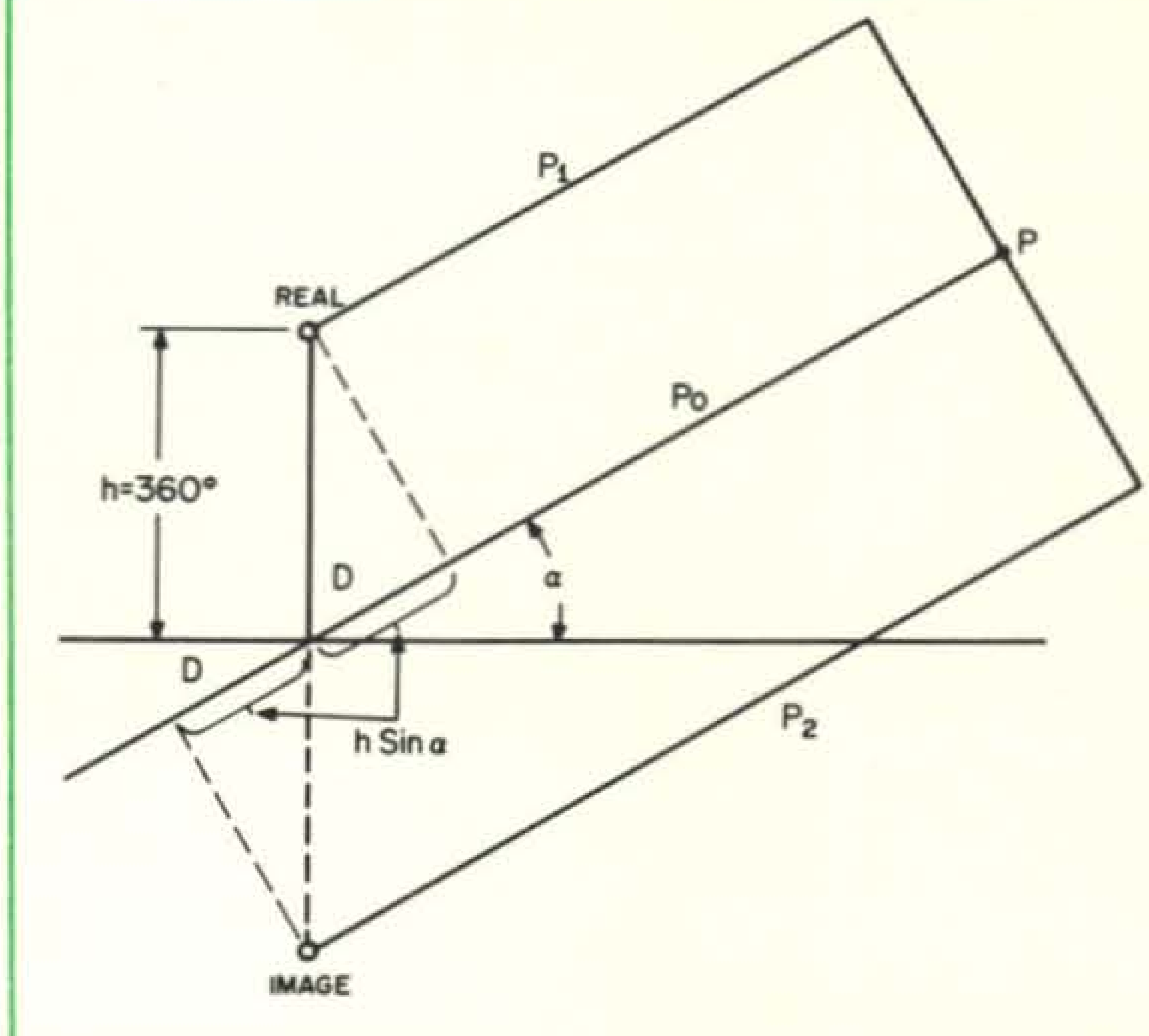

Fig. 6—Geometric construction showing how energy can be thought of as radiating from the midpoint of the real and image antennas.

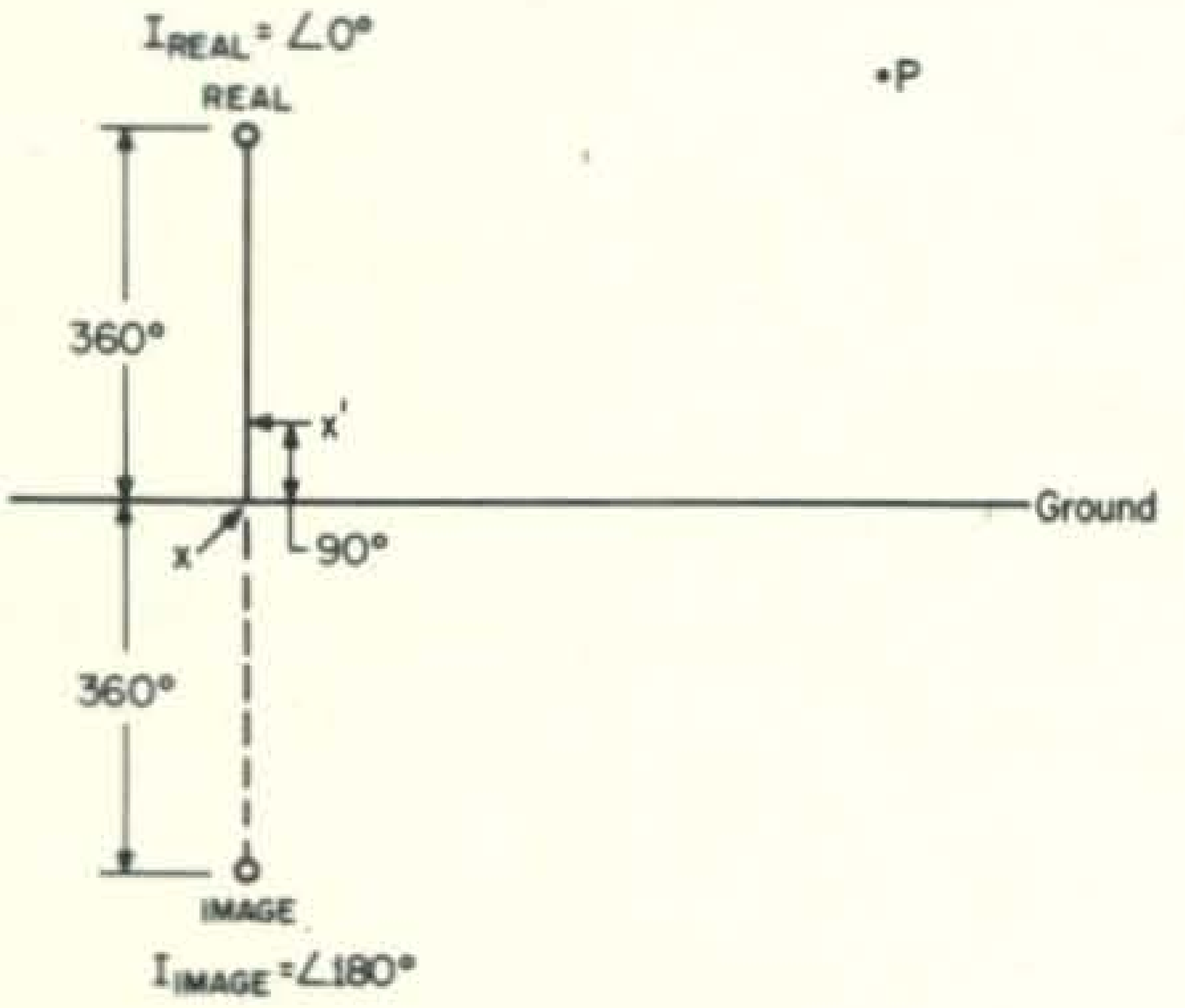

Fig. 7—Phase relationship between I_{real} and I_{image}.

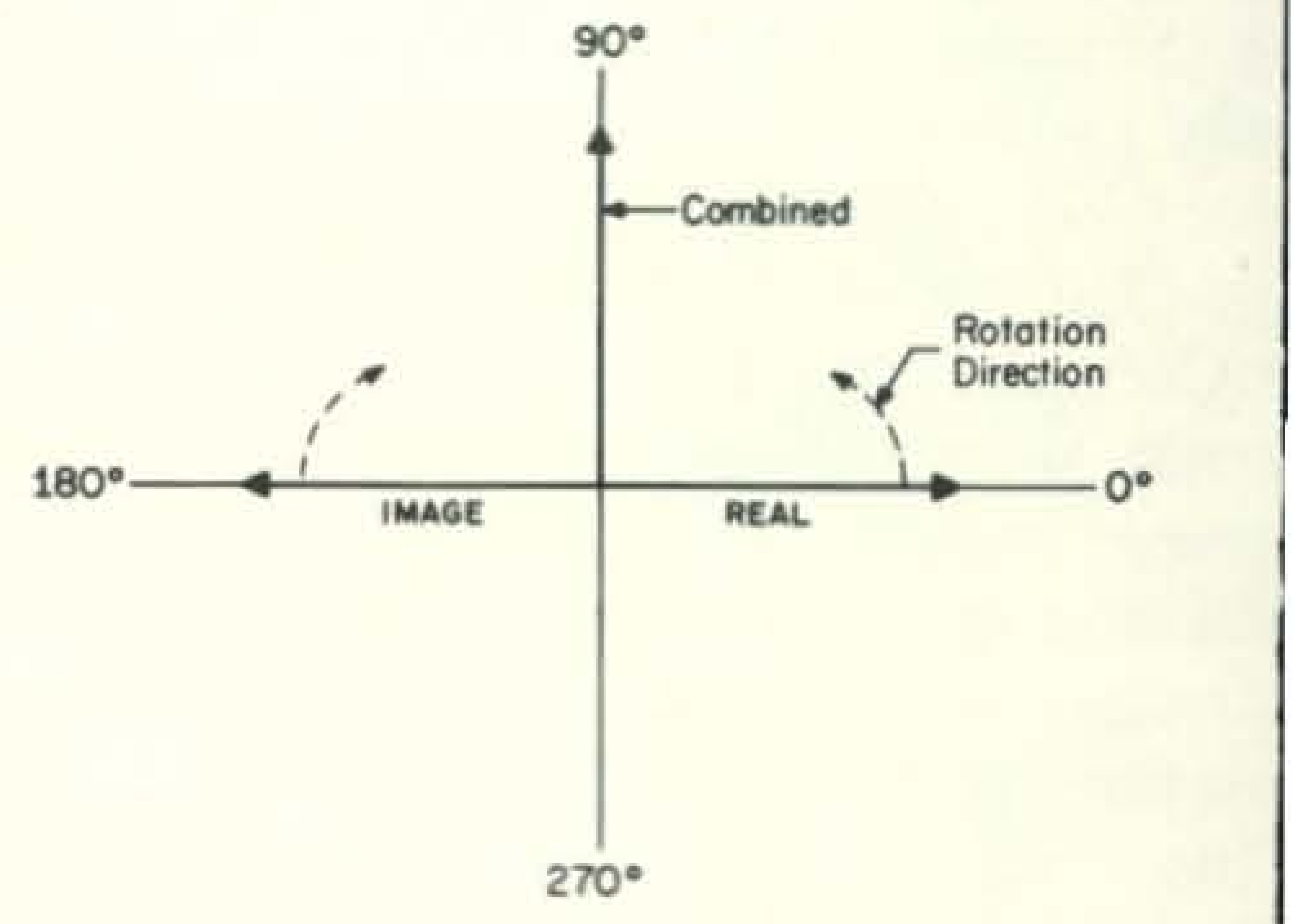

Fig. 8—Vector relationship between I_{real} an I_{image}.

two currents are in phase, 90 degrees, 270 degrees, 450 degrees, *etc.*, and we can now calculate the vertical angles of radiation for the antenna.

Substituting our known value of h we have:

$$
\begin{array}{rlll}
360\ sine\ a = & 90 & 270 & 450 \\
sin\ a = & \dfrac{90}{360} & \dfrac{270}{360} & \dfrac{450}{360} \\
a = & 14.5 & 48.5 & \text{(Not valid)}
\end{array}
$$

This, 14.5° equals the angle of the 1st major vertical lobe, and 48.5° equals the angle of the second vertical lobe.

Raising the antenna from 46 feet to 69 feet will give the following radiation angles: 69 feet is equal to 540 electrical degrees. Thus, *h,* in *h sin a,* is now equal to 540 degrees.

$$
\begin{array}{rllll}
540\ sin\ a = & 90 & 270 & 450 & 630 \\
sin\ a = & \dfrac{90}{540} & \dfrac{270}{540} & \dfrac{450}{540} & \dfrac{630}{540} \\
a = & 9.6 & 30 & 56.5 & \text{(Not Valid)}
\end{array}
$$

Now, 9.6° is the angle of the 1st major vertical lobe, and 30° is the angle of the second vertical lobe. The angle of the third vertical lobe equals 56.5°

The increased height has resulted in the addition of a third vertical lobe at 56.5 degrees which was not present at the 46 foot level. Notice, also, that the radiation angle of particular interest has dropped from 14.5 degrees to 9.6 degrees.

At an antenna height of 92 feet (720 degrees) the vertical angle of the first major lobe will be 7.2 degrees. The second and third lobes will not reach the maximum intensity of the first lobe because of antenna directivity. Those calculations are not within the scope of this article.

Back to reality—the ground under ama teur antenna installations is not perfect no can the height of the antenna be determine easily. Imperfect ground reflections reduc the amplitude of the maximum lobes an increase the amplitude of the mins (nuls) If however, we can consider it perfect an take the idealized conditions approximat angles of radiation can be calculated. What' your angle? ■

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