Optimum Antenna Design for DX

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In order to work DX effectively the vertical angle of radiation must be as low as possible. The author discusses the effects of antenna types and height upon this angle of radiation.

ONE of the most important factors in the planning of a high frequency communications system is antenna design. For a specific point-to-point circuit, both receiving and transmitting antennas are optimized as to forward gain, front-to-back ratio, vertical angle of radiation, vertical pattern shape, and available space. This process usually results in a large antenna which points in a fixed direction and which has a large number of elements or large aperture area.

For the average amateur, the process of antenna design for the higher frequencies, if it can be so called, usually consists of buying a prefabricated Yagi array, mounting it on a short tower or on his house top, and going on the air. Those who prefer the lower frequency bands, on the other hand, may end up with a random length of wire, loaded up by means of a matching network and at some height above ground which is usually far from optimum. When one considers the lack of thought which is given to such matters, or the surroundings which may consist of trees, other houses, or power lines, it is sometimes amazing that signals get out of the backyard at all.

The field of propagation and antenna design is a most fascinating subject, and one which has so many ramifications that it would be impossible to cover all of them, even in a series of a dozen articles. However, I do wish to direct this article, and one which is to follow in the future, to those who are interested in optimizing an antenna design for amateur DX work. It is here that proper antenna design can really pay off.

Vertical Radiation Angle

Take a long look at fig. 1. This graph shows the relation of vertical angle of radiation to the distance to the first reflection point via F-Layer ionospheric reflection. The height of the F-layer varies between approximate limits of 200 and 350 kilometers, under day-night conditions. Pick out the vertical angle of 20 degrees above the horizon, for example, and you will note that the first reflection zone will be somewhere in the neighborhood of 600 to 900 miles. A vertical angle of 50 degrees will give a first reflection zone of 200 to 300 miles. On the other hand, a vertical angle of 5 degrees will give a first reflection zone between 1400 and 1900 miles. And an even lower angle of 3 degrees, if obtainable, will move the first reflection zone out to 1600 to 2100 miles! Do you want to work DX? Then get that vertical angle down!

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The next thought that comes to mind is that for long distances there will be more than one reflection. This is certainly true, for to get from Washington, D.C., to Australia, for example, will require several reflections. Due to the simple geometry of the situation, we are limited to 2500 miles per hop. However, reflection losses run in the neighborhood of 3 to 6 db per reflection, depending on the absorptive and scattering nature of the reflecting surface. When one also adds in the ionospheric absorption which occurs for each ionospheric reflection (and this absorption can be quite variable with sunspot conditions), one can easily arrive at the conclusion that for a good strong signal at an overseas receiver, the fewer the reflections the better. In other words, get that vertical angle down! Vertical angles of 3 to 10 degrees are most desirable. Curtain antenna arrays using 4 × 4 or 4 × 6 arrangements of dipole elements, such as are used

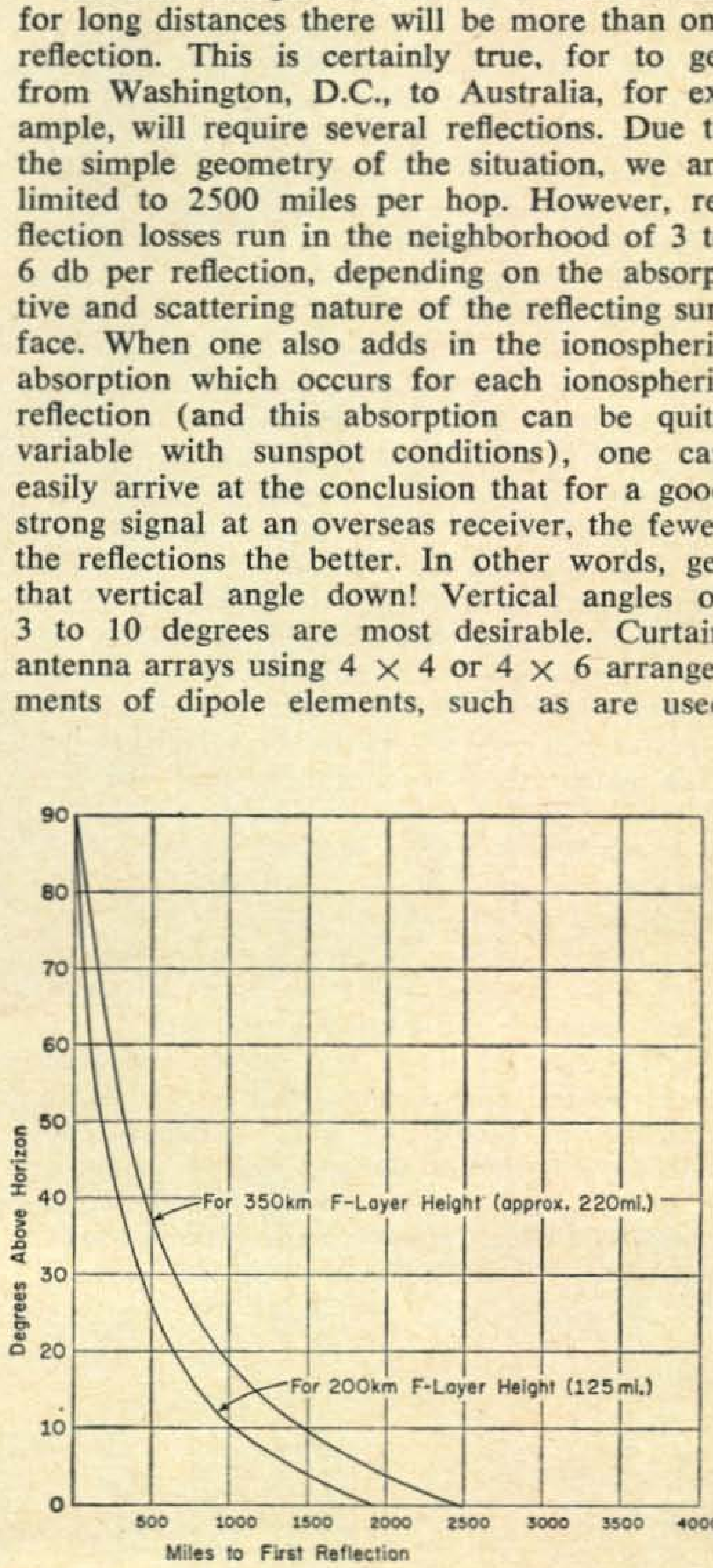

Fig. 1—Vertical radiation angle versus distance to the first reflection.

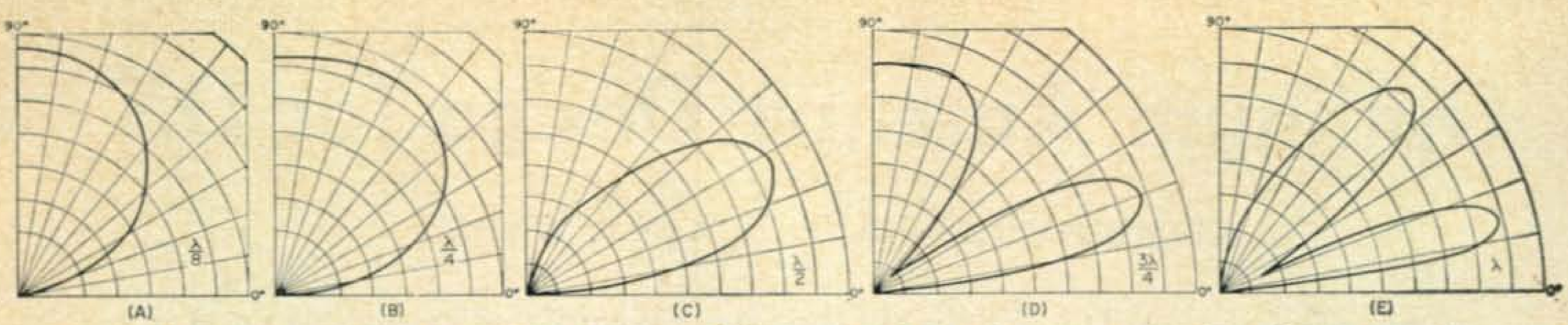

Fig. 2—Vertical radiation patterns for half wavelength dipoles various heights above ground as indicated in each graph.

by the Voice of America or the British Broadcasting Corporation, are optimized for low angles of this kind, in order to place the first reflection point as far out as possible.

How does the antenna used by Mr. Average Amateur compare with these optimum requirements? To answer this question, I have shown in fig. 2, A through E, the vertical radiation patterns of a ½ wave horizontal dipole for several heights above ground of average conductivity. The patterns are in a plane at right angles to the dipole. Let's look at some common backyard cases. Consider the case of a ½ wave dipole ½ wave high, shown in fig. 2C. This corresponds to a 33 foot dipole about 35 feet above ground at 14 mc. Note that the useful lobe is between approximately 15 and 45 degrees. Reference to fig. 1 will show that this lobe will give a first reflection zone of 200 to 1100 miles. Transmitted power is thus being scattered over quite a wide zone. Let's now think of the fellow who has a 3.9 mc dipole, hung between a couple of trees, perhaps, at a height of 30 to 50 feet. Note from figs. 2A and B that dipole heights of ⅛ to ¼ wave give a useful vertical angle of about 30 up to 90 degrees. Did I say "useful?" This type of vertical pattern is useful only for distances out to about 500 to 600 miles, and even so, a lot of power is being wasted at very high angles which penetrate the ionosphere and are not reflected at all! It looks as though we should move our dipole higher, doesn't it? Well, let's take the case of a dipole ¾ wave high. This corresponds to a height of 180 feet at 3.9 mc, or 50 feet at 14 mc. Figure 2D shows that we now have a lobe of radiation from 10 to 30 degrees, which is an improvement, but a high angle lobe of 55 to 90 degrees has appeared, which wastes considerable power at angles which are not useful and which probably penetrate the ionosphere and are lost. If we move the 14 mc dipole up to a wave length height, 66 feet on 14 mc, our low angle lobe sharpens, from about 10 to 20 degrees now, but we still have a large lobe at 38 to 60 degrees which is a waste of power. If we move our 14 mc dipole even higher, the low angle lobe will shrink in size, several high angle lobes will appear, and our vertical pattern becomes quite useless for any DX work.

Yagi Antennas

The next thought that occurs is, "Can't we improve this by using a Yagi array?" The answer to that is that a horizontal Yagil will cut down the size of the undesired high angles lobes somewhat, but that it will do absolutely nothing at all to lower the angle of the desired main lobe. Figures 3A through D show the vertical patterns of a Yagi array at various heights above ground of average conductivity. It will be noted that these figures correspond, case for case, with those pertaining to the single horizontal dipole. With a 14 mc Yagi which is 66 feet high, we are still wasting considerable power at a useless angle of 38 to 60 degrees, and the vertical angle of the main lobe is still from 10 to 20 degrees.

How can we get lower angles than this? There is only one way to do it with horizontal dipoles, and that is by stacking them vertically. One horizontal dipole ½ wave high, with another ½ wave above it and in phase with it, will give a useful lobe from 8 to 28 degrees. Stacking a third in-phase dipole at an additional height of ½ wave, will bring the lobe down to 5 to 15 degrees. Four of them stacked will bring the lobe down to 3 to 12 degrees. Perhaps these statements will inspire some rugged individual to stack two or three 3-element full-size Yagis on 14 mc! This is something which is done quite often by the v.h.f.-u.h.f. fraternity at frequencies where size is reasonable, but personally I don't care to do it at 14 mc!

Verticals

There is another way of getting low angles, and this is by using a vertical antenna. Let's look at figs. 4A through D for awhile. Here are plotted the vertical patterns of vertical

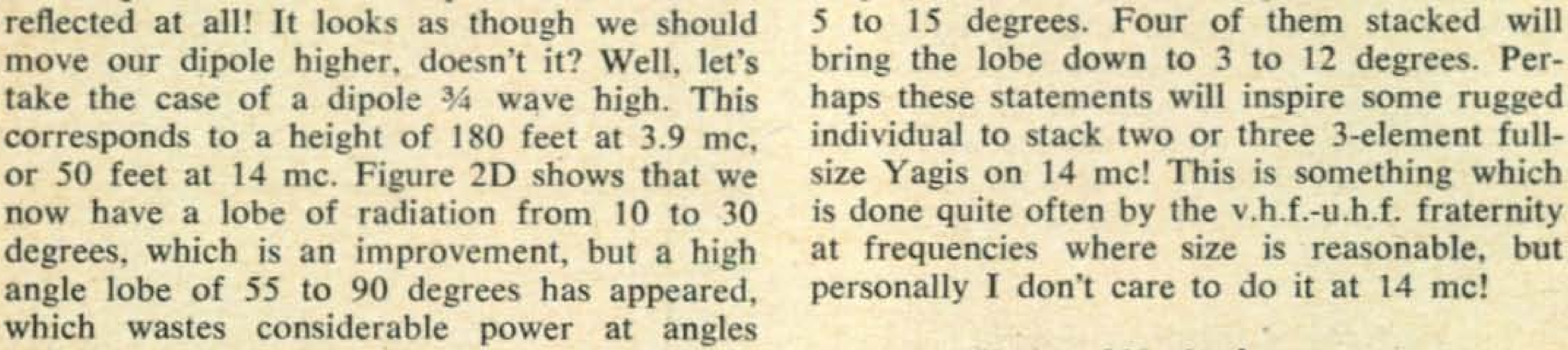

Fig. 3—Vertical radiation patterns for half wavelength yagi antennas various heights above ground as indicated in each graph.

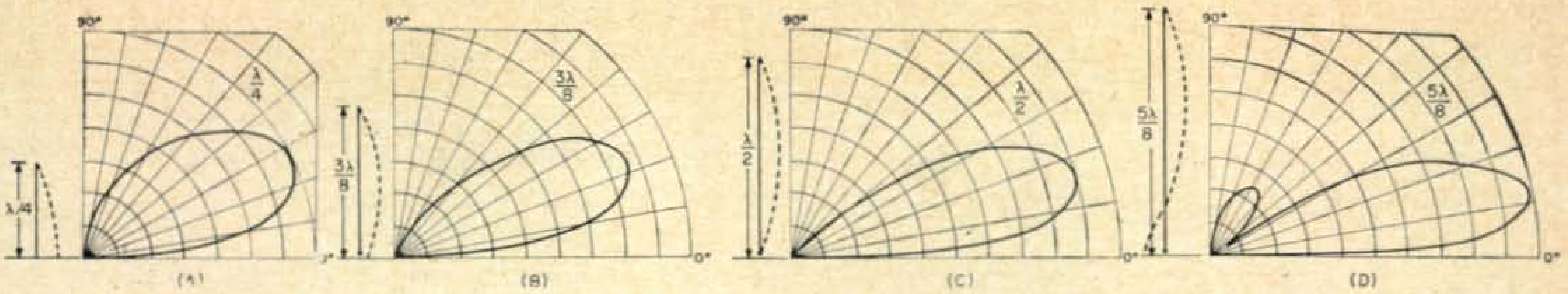

Fig. 4—Vertical radiation patterns for vertical antennas from quarter to five eighths wavelengths long.

antennas of several heights when worked against ground of average conductivity. The ¼ wave vertical gives a useful vertical lobe from about 10 to 55 degrees. A ⅜ wave vertical will drop the lobe somewhat, from 8 to 40 degrees. A ½ wave vertical is quite an improvement, giving a useful lobe from about 5 to 35 degrees. The ⅝ wave vertical, which is the optimum height used by many broadcast stations to get maximum field intensity along the ground, is the best we can do with a single vertical element, giving a useful lobe from about 3 to 27 degrees, ideal for DX work. This height was used in the "Mark II DX Antenna" for optimized performance on 14 mc.[1] A vertical element becomes useless as its height increases above ⅝ wave length, for the low angle lobe shrinks very rapidly, the high angle lobe grows rapidly and splits into several lobes, all of which are at angles too high to be of any value whatever.

Vertical Stacking

The next logical step is vertical stacking of vertical in-phase ½ wave elements, which results in a colinear antenna.[2] In the early days these were known as Franklin antennas. The free space pattern of a two-element antenna is shown in fig. 5A. It has a gain of 1.9 db over a dipole. The two-element colinear in free space is the same as a ½ wave working against ground (consider the mirror image as the other ½ wave element). There is one factor which is often overlooked when considering vertical antennas working against ground, however. It is the fact that when the mirror image is replaced by a ground plane and all the power is put in the remaining upper half of the antenna, an additional theoretical 3 db gain results. The actual amount of gain thus realized will depend on the conductivity of the ground plane, but with ground of average conductivity we will have some gain, perhaps 1 or 2 db. The three-element colinear has a free space pattern shown in fig. 5B. It has a gain of 3.2 db over a dipole. This antenna in free space is the same as a ½ wave element over and in phase with a ¼ wave element, worked against ground, as shown in fig. 5D. In this latter case our vertical pattern is useful from 3 to 20 degrees. If we go further, and use a four element colinear, or two ½ wave elements in phase against ground, the patterns of figs. 5C and 5E apply. The vertical angle in fig. 5E is even lower, from 3 to 15 degrees. The gain of a four element colinear is 4.3 db over a dipole.

There are several ways of accomplishing the necessary phase reversal between colinear elements—a quarter-wave stub, coaxial sleeve, or tuned circuit—to make a colinear antenna. To sum all this up, it is apparent that stacking in a vertical plane, of either horizontal or vertical in-phase ½ wave elements, is a way by which one can achieve low angles of radiation in the vertical plane. So, what shall it be —horizontal or vertical? Let's draw some quick but accurate comparisons between the two.

Vertical vs Horizontal

1. Low angles are easily obtainable with a simple vertical antenna.

2. The vertical is simpler in construction. Even 50 or 60 foot self-supporting pipe masts are easily erected.

3. The vertical itself requires less space. Ground radials or a ground plane of some sort are required for efficient operation. However, radials can be bent in directions which fit one's available space.

4. The vertical is easy to feed at its base with unbalanced coaxial feed, using a "gamma" type of feed, or a matching network if required.

5. The vertical discriminates *against* TVI, because TV antennas are horizontally polarized. Some claim that it increases BCI. If this should happen, it is not due to its vertical nature, but to its strong, low angle radiation. *Any* antennas which gives strong low angle radiation, such as stacked Yagis, could also cause BCI.

6. The vertical is somewhat more susceptible to rain and snow static, and to noise impulses in the neighborhood when used for receiving.

7. The vertical is non-directional, and thus cannot discriminate against interference from unwanted directions when receiving. However, one can erect three vertical elements and make a very neat switchable directional array to cover 60 degree sectors in azimuth.[3]

8. The vertical is unobtrusive and pleasing to the eye of one's neighbors.

9. The gain of a colinear vertical can approach that of a three-element horizontal Yagi. It is actually greater at the low angles of interest.

[1] Lee, Paul H., "The Four Band Vertical DX Antenna, Mark II," *CQ*, July 1960, p 28.

[2] Kaspar, H. W., "Added Gain Using Vertical Antennas," *CQ*, December 1960, p 50.

[3] Dixon, Robert S., "A Forty Meter Vertical Beam," *CQ*, July 1962, p 52.

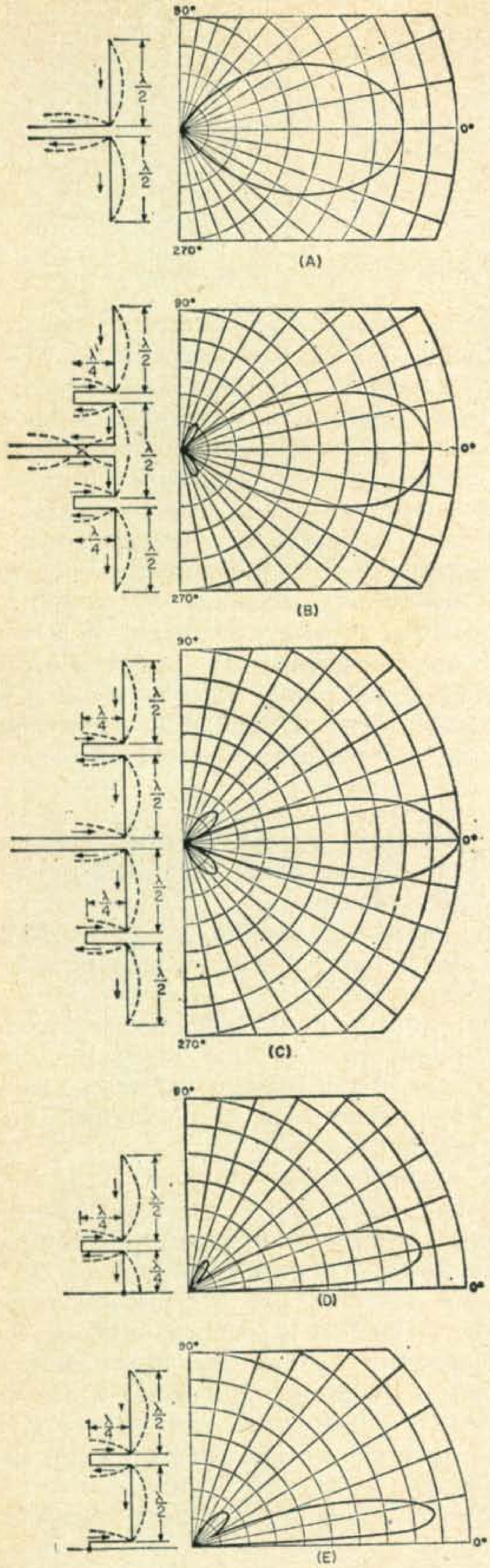

Fig. 5—Vertical radiation patterns for various types of collinear arrangements. (A) Two elements in free space. (B) Three elements in free space. (C) Four elements in free space. (D) One and one half elements against ground. (E) Two colinear elements against ground.

Horizontal vs Vertical

1. Rotatable Yagis can discriminate against interference. Best front-to-back ratio is obtained at the expense of forward gain, however.

2. Relatively large space is required for a 14 mc beam. On 7 and 3.9 mc a Yagi is not practical.

3. No ground system is needed for the horizontal antenna.

4. If a rotatable Yagi is used, there is always the problem of rotators freezing or sticking, and of the feedline becoming tangled or twisted.

5. Elements of a Yagi are subject to breakage due to ice or wind loading.

6. The horizontal antenna can give only higher takeoff angles, which are not optimum at the heights used by most amateurs. Lower takeoff angles can be obtained only with vertical stacking of in-phase horizontal elements, which at the heights and spacings required, becomes impractical.

7. For a single horizontal element or even for a Yagi, a height of one wave length is required to get the takeoff angle down to 10 to 20 degrees. Even then, this is not as low an angle as can be obtained with a vertical, and considerable power is wasted in high angle lobes.

8. Horizontal Yagis come in prepared kits, which require little or no mental design effort on the part of the average amateur. This is fine for the non-technical types who do not wish to design or build something which is optimized but which can be made to work after a fashion by almost anyone.

9. A horizontal Yagi on one's house or on a tower in the backyard can be the cause of much unfavorable concern on the part of neighbors. Horizontal antennas can cause much horizontally polarized TVI.

Exploding a Myth

There is another popular myth which I would like to "explode" right now. On the air one will hear fellows say that the signal from a vertical antenna cannot be received on a horizontal antenna as well as can the signal from another horizontal antenna, or vice versa. This statement is parroted as an argument against verticals, for most amateurs use horizontals. Nothing could be further from the truth than this general statement, I assure you. It *is* true that in the strictly line-of-sight case, as in v.h.f. or u.h.f. (in TV reception, for example), polarization of the antennas at each end makes a big difference. However, research has proven that at high frequencies which experience ionospheric reflection in propagating over long distances, the polarization of the transmitted signal, no matter what it originally was, is caused to turn around by the ionosphere in a random manner, and the signal which reaches the distant receiving antenna is no longer linearly polarized, but is eliptically or even sometimes circularly polarized. It has been quite well-proven that on long distance circuits, fading of a signal received on a linear antenna is not so much caused by a change in path loss or attenuation, but it results from a change in polarization of the signal caused by the ionosphere. This opens up the subject of polarization diversity, which might well be

[*Continued on page 138*]

Cliff Corne, K9EAF [*from page 35*]

"As you would imagine, I have elaborate files with all QSOs registered on Autodex and Roladex file cards . . . followups on QSL cards, work sheets for awards, correspondence files, etc. Incidental to ham operations, we have a collection of books, dolls, animals, figurines, novelties, etc. from all over the world. We keep up correspondence with scores of folks in many different countries. Stamp collecting and stamp distribution comes in for some attention. We are continuously moving our magazines call books, radio parts, post cards, etc., to friends all over the world. We agree with you that there is a lot more to amateur radio than just operating the rig.

"Yes Clif, [K6BX] your CHC was an inspiration that has turned into a ball of fire . . . words cannot describe the world-wide impact. You have won your seat alongside old Saint Peter. Needless to say, ham radio and people like you, are the therapy which keeps me alive . . . Thank you, and God Bless you and all who follow in your footsteps."

Gosh Cliff, it's my pleasure being your friend and we know all hamdom is mighty proud of you.

Cliff works all bands and modes but you are most apt to find him hanging out on CHC frequency, 14075. Give Cliff a call and say Hello. You will marvel at his excelelnt fist and operating proficiency.

Yes, Cliff is an inspiration to all hamdom by his many achievements, now over 250 awards. What say we all send him a card at Christmas time with our well wishes. ■

Antenna Design [*from page 33*]

covered in detail in another article, but this is the reason why the Cubical Quad antenna has been used with such success. The Quad consists of orthogonally polarized elements, and it responds well to a signal whose polarization is changing.

Which type of antenna do I prefer? Personally, I prefer the vertical for sound technical reasons, and because it has given me the best all-round performance for many years. It has given me reliable long distance communications on 14 mc and excellent contacts at all distances out to 2000 miles and more, on 7 and 3.9 mc. An article appearing in this magazine will describe the construction and electrical details of the W3JHR "Mark III DX Antenna" which is a 1½ element colinear like the one in fig. 5D on 14 mc, and which is an ordinary 0.37 and 0.22 wave length vertical on 7 and 3.9 mc respectively. This article will show how the 14 mc phase reversal is accomplished by the use of a ¼ wave coaxial sleeve. This antenna has equalled or out-performed nearby rotary Yagis

[*Continued on page 171*]

Antenna Design [*from page 138*]

in working DX on 14 mc, and it lays down a very strong signal at all distances on 7 and 3.9 mc.

I will say one thing further, and that is that I talk to many amateurs who are surprised that I am putting out a strong signal from a vertical, and even some who say that a vertical is no good. These latter people have either been unfavorably influenced by experience with one of the factory-made so-called "all band" verticals which are not optimized for anything, or else they know very little about antennas and propagation. I am quite certain that this article will evoke much interest and comment, and I shall try to answer any inquiries which are accompanied by a stamped envelope.

I shall be glad to furnish a comprehensive list of references to any who wish to seriously study antenna design in their own. ■

Space [*from page 69*]

law the Communications Satellite Act of 1962. This act sets the stage for the development of a commercial global satellite communications system.

Commenting on the Act at the signing ceremony, the President said by enacting it "Congress has taken a step of historic importance. It promises significant benefits to our own people and to the whole world. Its purpose is to establish a commercial communication system utilizing space satellites which will serve our needs and those of other countries and contribute to world peace and understanding."

The President continued, "The benefits which a satellite system should make possible within a few years will stem largely from a vastly increased capacity to exchange information cheaply and reliably with all parts of the world by telephone, telegraph, radio and television. The ultimate result will be to encourage and facilitate world trade, education, entertainment, and many kinds of professional, political, and personal discourse which are essential to healthy human relationships and international understanding."

The Act authorizes the creation of a "Satellite Corporation," which will be privately financed and managed, but with representatives of the Government sitting on the board of directors. The Corporation will bring together as a team, private and government experts in the field of space communications so that a commercial system can be established as soon as possible.

Although communication satellites are operating experimentally at the present time (TELSTAR, RELAY, ECHO, *etc.*, the new act, and the Satellite Corporation which it creates, may bring about the initial stages of a globe-girdling commercial system within the next two years. 73, George, W3ASK