Introduction
Since the introduction and practical application of Log Periodic and frequency independent antennas, a wide range of truly broadband antennas has been developed to meet the varying demands imposed by specific requirements, such as area coverage and point-to-point circuits. The development of compatible terminal equipment such as baluns, impedance transformers and multicouplers has further enhanced the flexibility of these broadband radiating structures.

Choosing the right type of antenna for use on a HF link is very important if the best link performance is to be achieved. The choice of antenna types is large and, at times, baffling. A number of antennas that will more or less satisfy the requirements in question are available, finding the optimal solution is far from simple for the systems planner. It requires a knowledge of ionospheric behavior as well as antenna engineering, operating conditions and siting considerations. Because of this, the systems planner usually enlists the help of the antenna specialist to analyze the propagation conditions and find (or design, if necessary) an antenna to fit the requirement. In essence, the antenna specialist, to carry out this function effectively, needs to be a physicist, applications engineer, structural engineer and applied mathematician.

This bulletin sets out to dispel that myth, explain how antenna types vary in performance and how these differences can be most effectively exploited.

Basic Parameters
To differentiate between the various antennas available, an understanding not only of the basic parameters of antenna performance, but the different ways in which this information is presented by various manufacturers is required.

The following notes are not intended as definitions but rather as comments which may be helpful when examining manufacturer's technical bulletins.

The Radiation Pattern of an antenna indicates the power (or field strength) radiated in any direction relative to that in the direction of maximum radiation. Both relative power and relative field diagrams are in use and often no clear statement is made as to which is presented.

The actual radiation pattern of any antenna is really a three-dimensional function, however, for the sake of simplicity, only cuts through this solid in the horizontal (azimuth) and vertical (elevation) plane as usually presented. These planes are referred to as the principle planes. For one important class of antennas, those used on short range paths via the ionosphere (i.e., vertical incidence), this practice is not observed for the following reasons.

When considering the behavior of an antenna operating over a short path and consequently required to direct energy at high angles of elevation, the conventional principle plane radiation pattern would be misleading, in so far that the normal "azimuth radiation pattern" will only indicate the variation in field strength at 90° to the zenith, a circle in the horizontal plane of the antenna, and not that being reflected at the ionosphere. A more useful set of data is obtained by traversing a path which joins all points with constant elevation angle and lie equal distance from the antenna.

The radiation pattern so defined is always circular at the zenith as this is the trivial case, and the familiar patterns will be obtained normal to this. Patterns for a variety of elevation angles from 50° upwards are commonly published. It should be noted that the sense of polarization of the radiated field changes with bearing, therefore, the polarization direction of the antenna for such operations is not usually quoted, it is meaningless. The radiation pattern in the elevation plane is strongly influenced by the presence of the ground beneath the antenna as the radiated signal is the sum of the signal radiated directly from the antenna and that reflected by the ground. The relative phase of these components changes with the antenna's height above ground, electrical properties of the ground and polarization, either adding to or cancelling the field due to the direct ray. Manufacturers' data generally refer to "average ground" usually taken to have a conductivity of 10 mS/m and a relative permittivity of 10. These figures are typical of ground where grass or agricultural crops are growing. Data quoted for "ideal ground" should be viewed with reservation because, of course, no such ground exists, except perhaps sea water, and an extensive earthment of copper wires will be required to obtain an approximation to the published performance. A further characteristic of radiation pattern performance often quoted is the beamwidth, or properly the half power beamwidth. This is the angle between the points on either side of the direction of maximum radiation at which the intensity of power radiated has fallen to half the maximum. Care is necessary as in some cases only half
this angle is quoted. Specifying the beamwidth as ± degrees removes any ambiguity, unfortunately this is not always the case.

**Power gain** indicates how much the signal radiated in the direction of maximum radiation is increased over and above that that would be obtained if the antenna referred to is substituted for some standard reference antenna fed with the same input power. Here again there are possibilities for confusion. The reference antenna may be either a half wave dipole (usually used for VHF and UHF antennas) or an isotropic radiator (in the case of HF and SHF antennas). The isotropic radiator is a hypothetical device radiating energy uniformly in all directions in 3-dimensional space. As the power gain of an isolated halfwave dipole is 2.2 dB over that of an isotropic radiator, it is important to know which reference is used. Reference to an isotropic radiator is normally indicated by dBi. Quoted gains normally allow for the enhancement of signal provided by ground reflection, but again the assumed ground conditions are often omitted.

**Maximum input power** will generally be determined by the onset of one of three effects:

1. Dielectric losses causing overheating of insulators.
2. Ohmic losses as a result of conductors carrying large currents.
3. Corona discharge from insulators, element tips or other parts.

As some of these effects are current determined and others voltage determined, the ratio of power ratings quoted for different classes of emission will vary. Take care if transmitters are to be parallel operated into one antenna as very high peak voltages may be produced.

**Input Impedance.** As the transmission line feeding an antenna must have the same characteristic impedance as the antenna input impedance, it is often the economics and practicalities of transmission line design which determine suitable antenna input impedances. A wide range of efficient broadband transformers are available allowing changes in impedance level and from balanced to unbalanced line systems.

**Input VSWR.** The maximum permissible input VSWR for a transmitting antenna is generally determined by:

1. The economic need to minimize the size of the transmission line required, especially when large diameter semiflexible coaxial cable is used. The power rating of a cable reduces approximately \(1/\sigma\) where \(\sigma\) is the VSWR.
2. The ability of the transmitter output circuit to match a non-optimal impedance.

In practice, condition 2 often dominates. Naturally, wide-band antennas provide most problems in respect of VSWR as narrow band systems may always be matched on site with little difficulty.

Receiving systems seldom require a closely specified VSWR. The VSWR data should be taken from actual antennas of the generic type when correctly installed under normal site conditions.

1. Ground Type-Average soil as defined by CCIR
2. Ground Constants-Conductivity 10 m S/m; Permittivity 10
3. Flatness:- ± 1 metre
4. Slope-Nil

5. Obstructions-Presence of other antennas, towers, power lines, metallic structures, etc., at a distance having negligible mutual coupling effect

6. Reference Point-Antenna input (ground level)

VSWR can be quoted in two ways:

1. Nominal-Signifies a value not exceeded throughout 90% of the specified frequency range.
2. Max. or Peak-Signifies value not exceeded throughout worst 10% of frequency range.

**Polarization.** This parameter describes the direction of the electric field vector of a propagating electromagnetic wave. When referring to a directional antenna, it generally describes the polarization radiated or received in the direction of the radiation pattern maximum. Often signals of other polarizations are radiated in other directions. At low angles of radiation, this can simply be defined as vertical polarization being normal to the earth's surface and horizontal being that which is parallel. However, at zenith both are parallel, forming a cross directly above the point of reference.

**Antenna Specifications**

In order to select the optimum antenna for a given HF communication requirement, it is necessary to establish a number of important parameters; e.g.:

**ElectricalSpecifications:**

1. Frequency range
2. Polarization
Having defined the basic requirements, we shall now consider the system requirements and methods for establishing specifications and their relationship.

**Frequency Range.** For predictions of usable frequencies reference can be made to a number of sources; e.g., monthly ionospheric predictions which give maps of the world for various times of the day on which contours of the maximum usable frequencies (MUF) are superimposed. By properly interpreting these charts which apply to the particular location and times of interest, the usable frequencies can be predicted. This method provides a long range average prediction and, although variations in actual conditions occur from day to day, they are useful for preliminary circuit planning. With the increased computing capacity of personal computers (PCs), programs such as ASAPS & VOACAP are now readily available to the antenna specialist. Such ionospheric models can predict circuit behavior statistically by taking into account a great many factors; where the old monthly charts gave a smoothed average of a relatively small number of observations, they are able to accommodate many more possible circuits. Taking due cognizance of such factors as sunspot activity and the behavior of the E and F layers of the ionosphere, including sporadic modes has increased our ability to predict the effects of seasonal and diurnal fluctuations in the ionosphere. The inclusion of ground reflectivity, noise levels, signal-to-noise ratios and circuit reliability further enhances the accuracy.

HF operation at 30° north latitude has been found to be reasonably indicative of operation throughout the northern hemisphere, with the exception of the region near the polar caps. Figure 1 shows the extreme values of Frequency of Optimum Traffic (FOT) for paths centered at 30° north latitude as a function of path length. This chart and the General Propagation Chart, Figure 2, provide the antenna designer with an approximation which serves as a useful guide in selecting a suitable antenna. To use the chart, a line from the desired path length is drawn down from the minimum and maximum FOT scales and across from the minimum layer height scales. The region enclosed by the rectangle on the chart determines the maximum frequency range and take-off angles for the circuit. As an example, assume a 1000km point-to-point circuit. The frequency range (3.7 to 16.5MHz) is obtained by selecting the corresponding frequency interval between 1000 km on the minimum FOT scale and 1000km on the maximum FOT scale. The required take-off angle range (24° to 40°) is found by selecting the corresponding take-off angle interval between 1000 km on the 240 km layer height scale and 1000km on the 450 km height scale.

Obviously it is generally desirable to incorporate maximum bandwidth capability to prolong the operational lifetime of the antenna system. The logarithmically periodic antenna and the application of the "angle condition" (such as conical and equiangular antennas) have been the principle developments in the field of broadband high performance antennas over the past few decades. In fact, the very meaning of broadband changed with the introduction of frequency independent antennas of which the log-periodic class has been the principle embodiment. For this class of antennas, bandwidth limits are set by practical, not theoretical, limitations, principle developments in the field of broadband high performance antennas over the past few decades. The low end of the band having primary influence on the size...
of the antenna, dimensions of the active portion of the antenna being comparable to the wavelength at the lowest operating frequency; restrictions to the high end of the band are usually set by fabrication techniques and tolerances consistent with the structural requirements.

**Polarization.** When ionospheric paths are involved, the rotation of polarization which occurs within the ionosphere generally has the effect that the performance difference between vertical and horizontal polarizations is negligible, providing that the effective gain of the two antennas is identical. For transmitting, then, the antenna choice should be made on the basis of the elevation pattern which provides the highest effective gain at the expected take-off angles determined by geometry, without regard to polarization. For receiving antennas, the choice is complicated by an additional factor - the atmospheric noise pick-up. For locally generated noise; i.e., man-made or natural static arriving at the receiving site by groundwave propagation, the noise pick-up is almost always somewhat higher with vertical than with horizontal polarization.

For distant noise sources, the relative noise pick-up depends on the effective antenna gain, not on the polarization, as for any other signal source. The relative noise pick-up advantage of horizontal polarization depends on many factors, most of which are difficult to determine so that actual numbers are unavailable.

Horizontally polarized antennas are to some extent more versatile than vertically polarized antennas, because the elevation plane radiation pattern can be readily varied to suit the path requirements by changing the height of the radiator above the ground plane. In general, if the radiator is one quarter wavelength or less above the ground, radiation is essentially upwards, and raising the antenna further above the ground tends to lower the radiation angle towards the horizon. The rapidly increasing side-lobe level (in the elevation plane pattern) for radiator heights greater than about one wavelength places a practical limit on this, and use of horizontally polarized log-periodics are not generally recommended where the nominal beam angle is less than 15°. Obviously the horizontal log-periodics are most useful for short and medium range circuits (requiring take-off angles in the order of 50° and 25°, respectively).

Vertically polarized antennas, on the other hand, tend to have their maximum radiation at lower angles in theory towards the horizon when the ground is perfectly conducting. However, the earth is not perfectly conducting and the ground parameters have considerable influence on the actual radiation pattern of the antenna, but nevertheless, a vertically polarized log-periodic with an adequate ground screen is found to be best suited for propagation at low elevation angles.

One further fundamental difference of operational significance is that a narrower beam is obtained in the principle plane which is parallel to the dipoles or radiators of the array. Nature has a way of trading beamwidth from one principle plane to another, so that the maximum gain obtainable from an optimized array of horizontally dipoles is about the same as that obtainable with an optimized array of vertical dipoles.

Elliptical polarization is a combination of the two fundamental planes, the ellipticity being determined by the ratio of horizontal to vertical components. If both were equal, the resultant wave would, in fact, be circular. This mixed polarization minimizes the loss effects which result due to the rotation of polarization which occurs within the ionosphere. The overall advantages can be likened to that achieved through polarization diversity where two antennas of opposite polarization ensure the reception of the maximum available field. Vertically polarized antennas cannot always provide reliable short range coverage because of limitations in the radiation pattern around zenith or excessive attenuation of the groundwave. Existing horizontally polarized antennas are limited in capability to provide reliable long range communications because of the lack of control of radiation patterns over an adequate frequency range. However, communication performance beyond that achieved with linear polarized antennas is possible using elliptical polarization.

**Elevation Plane Radiation Pattern.** The matter of take-off angles from the transmitting antenna and angle of arrival at the receiving antenna is very important in selecting an antenna for
any particular circuit: so the natural question arises, "How do we know what this angle is?" One approach is to make a scale drawing of the ray path which may be done readily by adding distance and angular scales to diagrams of the type illustrated by Figures 3a and 3b, sketching in the ray for a given range and layer height and noting the elevation angle of the ray at the antenna location for this particular path. We frequently use for this purpose the Skywave Transmission Plot shown in Figure 4. The scales on the chart indicates the distance along the surface between the antennas or reflection points, the height of the reflection layer and the take-off angle. A HF Antenna Selector is available which has the elevation patterns for most antennas superimposed onto Skywave Transmission Plots (request Bulletin 1401).

A simple example will illustrate the use of this chart. Suppose we are concerned with a circuit of 1000 kilometres great circular distance. The ionospheric reflection point will occur halfway between the stations, and for F2 layer reflections the effective height may be assumed to occur at about 300 km. By laying a straight edge on the chart (Figure 4) between the antenna location (at the lower left corner) and this assumed reflection point, the take-off angle can be read on the scale at the top of the chart. In this case, the answer is 28°. In actual operation, of course, the elevation angle of the signal path changes from time to time as ionospheric conditions change. However, the usual situation can be bracketed by assuming F2 layer reflections at about 300 km. On longer range circuits where multihop modes will occur, the typical conditions can be obtained by following the procedures outlined above for various submultiples of distance. If the vertical angle is below 4°, repeat using an additional hop. The mode involving the least number of reflections will almost always incur the lowest attenuation, so this mode and perhaps the next one or two more complex ones will be of greatest interest. Examples of multiple hop transmission for E and F layer reflection can be found in Figure 5.

Figure 3b shows reflection of a signal from a lower layer in the atmosphere the E layer, which occurs at a much lower height (about 100 kilometres) and is active primarily during the day. The elevation angle of the signal path is lower in this case than shown previously for reflections from higher layers. In addition to these simple modes, many more complex ones are possible on occasion, for example, those which involve E layer reflections along one part of the path and F layer reflections along the next. This might suggest that in antenna design there is a problem of meeting a wide range of conditions. This is certainly true, and a wide range of possible signal paths must be accommodated in order to ensure reliable circuit performance over a long period of time.

**Azimuth Plane Beamwidth.** Systems considerations that effect this parameter are, of course, azimuth plane coverage requirements, such as omnidirectional for some ground/air and shore/ship applications and possible use of multicouplers in a broadband antenna whose elevation pattern is suitable for simultaneous operation of various point-to-point circuits. Other factors affecting azimuth beamwidth specifications are gain, possible interference to (or from) other services, and off-great circle propagation effects (which place a lower limit in the order of 10°to 15°to azimuth beamwidth).

Broadband antenna types with different azimuth plane coverage are discussed below in the sections dealing with point-to-point and area coverage circuits.

The spread in azimuth beamwidth is from about 60° to 110°.
Side Lobe Level and Front-to-Back Radio. Ideally an antenna should have no side lobes and infinite front-to-back ratio. This is, of course, unrealistic so the question is what should be specified and what can be attained. Firstly, however, it is useful to evaluate the effects of secondary lobes upon system performance. They are:

1. Reduction in gain. Due account must be given to the power radiated in the side lobes as it detracts from the directive gain of the main beam. True directive gain of the antenna is established by integration of the total power radiated.

2. Interference to (or from) other services. In this matter of interference caused by antenna side lobes, consideration must be given to individual applications, proper evaluation of propagation factors and antenna radiation pattern must be made to determine susceptibility to interference. This is particularly true with regard to side lobes in the elevation plane. The section regarding antenna polarization points out the dependence of elevation plane side lobe level upon height of a horizontally polarized antenna above ground to achieve low take-off angles. If elevation plane side lobes are a major consideration, take-off angles less than about 20° should not be attempted with horizontally polarized structures of the log-periodic type. With log-periodic antennas of not undue complexity, side lobe levels in the order of -12 dB are attainable.

Gain. It is important to note that when considering antennas for HF communication systems, a distinction can sometimes be made between transmitting and receiving applications with regard to the significant definition of antenna gain. The distinction is that while the transmitting antenna must meet a specification for power gain (which includes in addition to directive gain a measure of the antenna efficiency), the receiving antenna should only be required to meet a specification for directive gain. This is because in most HF communications situations, the system noise level is determined by atmospheric noise.

Practical applications of this fact can result in a reduction in size of the receiving antennas, however, the system planner must ensure that other factors such as logistics are not unduly complicated by requiring different types of transmitting and receiving antennas. This may be particularly true in transportable applications.

With broadband radiating structures of the log-periodic type when imaged above the ground, directive gain figures ranging from 10 to 15 dB are obtained. The effect of ground depends on various factors such as the electrical constant of the ground, height of the antenna above ground, antenna polarization, geometry of the ground screen and take-off angle. For the case of horizontally polarized antennas, the effect of ground is usually negligible for heights greater than about 0.2 wavelengths. It is difficult to generalize on the effect finite ground conductivity has upon the gain of vertically polarized antennas, however, a few general remarks can be made. For a vertically polarized antenna of the quarter-wave monopole type, a ground screen is required to provide a low loss ground return path to the current at the feed point and to provide a good reflection plane for radiation at angles close (in the order of 10°) to the horizon. In the case of vertically polarized antennas of the half-wave dipole type, the requirement for a ground screen is to
provide radiation at low take-off angles. These facts must be kept in mind when considering antenna types for specific applications.

Feedpoint Impedance. From the standpoint of systems requirements, most cases involve either 50 ohms coaxial cable or 600 ohms balanced line, although at times 300 ohm balanced line is used for high power transmitting systems. Unfortunately, most of the practical and economical log-periodic antennas do not have input impedance values that are either 50 ohms coaxial or 600 ohms balanced, it is, therefore, necessary to provide baluns or transformers. Availability of these devices has allowed the antenna designer the freedom to design with relative abandon of input impedance level (provided VSWR with respect to this level does not exceed a predetermined point) in order to optimize the structure from other electrical and mechanical considerations.

VSWR. For the applications discussed herein, VSWR of the antenna is of importance primarily to the transmitting case. A low VSWR is essential for low power solid state transmitters whose output stage design is such that in order to keep voltages and/or currents to a minimum, the output automatically reduces in the event that a predetermined terminal VSWR is exceeded, it also facilitates the task of the tuning mechanisms in a fast tuned transmitter. A low VSWR also permits near optimum utilization of the minimum size transmission line for the applied power and reduces losses along the line. A VSWR of 2:1 with respect to antenna feedpoint impedance is typical for broadband radiating structures of the log-periodic, spiral or conical types.

Power Handling Capability. A trend exists towards increasing the transmitted power level in HF systems. This trend is not entirely unjustified in view of the usage of multichannel or multimode transmission; the overall power capability of the transmission system must be sufficient to allow adequate power levels per channel. Another reason for operating at high power levels is to increase reliability, particularly in an emergency situation. Aside from cost, the main detraction from high power operation is the problem of interference; improvements in radiation pattern characteristics and in frequency management has, however, alleviated this situation.

Wind Speed and Ice Loading. On the matter of mechanical specification realism in regard to wind and ice loading is in keeping costs to a reasonable level. This is due, of course, to the fact that loading is proportional to the square of the wind velocity, and icing not only increases the weight of the structure, but also adds wind drag area without increasing strength. Many of the larger log-periodic arrays are capable of withstanding 1 cm radial ice simultaneously with winds of 160 kph.

Land Area and Tower Height. Undoubtedly, an important factor in usefulness of log-periodic antennas in HF communication systems is the reduced requirement for land, compared to that of the rhombic type antenna. It is true that large rhombic antennas have greater maximum gain (by about 5 dB to 10 dB) than practical log-periodic antenna designs; however, it must also be recognized that in the case of rhombics the maximum gain is orientated in the proper projection over a relatively narrow frequency range. Real estate is a major cost factor in HF antenna farms and the availability of multimode antennas, such as the SPIRA-CONE, help to minimize these costs by reducing the number of antennas required to accomplish a given operational requirement, especially when considering diverse range requirements of ship/shore, ground/air communications.

Tower height requirements are determined from specifications of low frequency cut-off and for horizontally polarized antennas, the additional specification of take-off angle. For high performance vertically polarized log-periodic arrays of the half-wave dipole type, the last radiating element is half-wavelength at the lowest operating frequency, tower height is about 0.7 wavelengths at the lowest operating frequency; for antennas of the quarter wave monopole type this figure is halved.

Antenna Siting
A usual problem in planning a HF communication system is the matter of antenna siting and to assist in this matter a few comments and useful references will be given. Firstly, it may be helpful to note certain basic distinctions between horizontally and vertically polarized antennas as each has to be treated a little differently.

A vertically polarized antenna, for example, may require a ground screen, and the nature of the terrain immediately around the antenna under which the ground screen must be buried may influence the exact placement and manner of installation of the antenna.
The signal in the direction of interest will always be a combination of direct radiation from the antenna and energy reflected from the ground in front of it even beyond the ground screen, if one is used. Therefore, to ensure having a well directed beam in space, it is necessary that a fairly smooth area be available for a reasonable distance in front of the antenna. This distance may be as short as a few hundred metres for fairly high angle radiation or as long as a few thousand metres when low angle radiation is of greatest interest. The distant terrain, up to several kilometers from the site, must also be considered, and the usual rule of thumb is that the angular elevation of the top of a distant range of hills in the direction of propagation should not be greater than one-half of the nominal take-off angle of the signal path. This may influence the selection of the site, although economic or political factors are probably the dominant factor.

Man-made objects near the antenna must also be considered, and for vertically polarized antennas, vertical objects such as steel towers and the like will naturally have the greatest potential for radiation pattern distortion. There are no general rules of thumb for required separation, but when the question arises a reasonable estimate can usually be made by estimating the mutual and self impedances of the elements involved and the currents which might flow in the parasitic radiator. The required separation is governed by the type of interference which is of greatest concern. Depending on the individual case, antenna VSWR, transmitter interaction, transmitter receiver coupling, or radiation pattern distortion may set the criteria for clearance around the antenna.

In the case of horizontally polarized antennas, the immediate area underneath the antenna has very little effect on the antenna performance, particularly on the antenna impedance, and little grading is required. However, the reflection area in front of the antenna is still important, and the terrain must be relatively smooth for distances of a few thousand metres, depending on the frequency and the elevation angle of interest. Man-made objects will also be of concern; here the problem would primarily involve horizontal conducting objects such as power lines rather than vertical conducting objects. The establishment of minimum separations would be the same as was mentioned for vertical antennas.


The matter of relative spacing and orientation between antennas is important because it affects land area requirements and electrical performance. When transmitting, an antenna will transfer some of its radiated energy to any other antenna in relatively close proximity, and this transferred energy will affect the performance of the other antenna. Ideally HF antennas of unlike functions, transmitting and receiving, should be separated by several kilometers (some authorities stipulate a minimum distance of 24 kilometres) if the latter's performance is not to be degraded due to interference from the former. This interference can be caused by adjacent channel operation, harmonics, keying transients and parasitic oscillations.

Also, cross modulation products can be generated in HF pre-amplifiers and receivers by strong RF fields, even though normal receiving frequencies are widely separated from the frequencies of such fields.

The amount of energy coupled between antennas of like functions, all receiving or all transmitting, can be calculated accurately by solving the fundamental electromagnetic equations using a comprehensive antenna analysis computer program. However, the following criteria serve as a useful reference for planning purposes. All distances, unless otherwise noted, are based on the antenna's lowest design frequency. The larger of the two distances in each case is used as the spacing distance. The points of measurement are between the reference points listed for each type of antenna.

1. **Horizontal Log Periodic Antenna**
   - space two wavelengths from the main lobe and one wavelength outside the main lobe, measured from the main supporting structure (midway between supporting structures for two tower configurations).

2. **Vertical Log Periodic Antenna**
   - spacing requirements are the same as for horizontal log periodic antennas.

3. **Rotatable Log Periodic Antenna**
   - space two wavelengths from horizontally polarized antennas. The separation requirement from a vertically polarized antenna is determined by the spacing requirement of the vertical antenna. In all cases, spacing must not be less than 45 metres.

4. **Inverted Cone**
   - space one wavelength measured from the antenna center.

5. **Conical Monopole**
   - spacing requirements are the same as for the inverted cones.
6. Sector Log Periodic
   - space two wavelengths measured from the main supporting structure.

Antenna Selection
Point-to-Point Circuits.
The details of the propagation phenomena which affect antenna selection have been covered previously, but is useful to review the major aspects briefly. In point-to-point communications, it is assumed that the bearing of the opposite station is known and that the signal energy will be concentrated in this azimuthal direction to the highest degree which is consistent with antenna size and cost. The elevation angle toward which the signal should be concentrated or for which a receiving antenna should be made most sensitive is another matter altogether, and varies with the distance to the other station and with the propagation conditions existing at the moment. In fact, the optimum angle varies with time over a fairly wide range in some cases, and the chosen coverage must be a compromise giving adequate signal strength under the most common conditions. As a frame of reference for this section, Figure 6 shows the takeoff angle required as a function of circuit length (solid curve) assuming reflection effectively at a height of 300 km for single and multihop propagation. For very short ranges, near vertical transmission is required, while ranges longer than about 2000 km call for elevation less than 10 degrees as a practical manner as close to the horizon as can be obtained, assuming that single hop propagation is the predominant mode (the section dealing with Elevation Plane Radiation Pattern refers).

For intermediate range circuits from 400 to 2000 km, elevation beam angles between 50 and 15 degrees are required.

As will be seen, horizontally polarized antennas are most useful for Skywave transmission at short and intermediate ranges, while vertically polarized antennas offer certain advantages at longer ranges. There are obviously exceptions and a few examples are given below.

Horizontally Polarized Log-Periodic Antennas
Model 2701 and 2702. Typical design parameters of these antennas are adjusted so that they have beam center elevation angles of 49 and 37 degrees, respectively. The elevation plane beamwidths and approximate range of path lengths for which these antennas would be useful are illustrated in Figure 6, the half power points in the elevation plane for Model 2701 (1) for example, are 21 and 78° and this antenna is primarily useful on path lengths between 100 and 1300 km.

The second half of the last statement is, of course, oversimplified and not necessarily true for all general areas of the globe or where other restrictions are imposed.

The emphasis must be placed on the elevation angles which will be obtained under typical and extreme conditions. For the specific locations and from published data on average conditions or from special computations, one may obtain the elevation angles of the signal paths for a variety of times of day, seasons of the year, and levels of sunspot activity. Consideration of these results may, perhaps, indicate that either the high or the low angles should be emphasized.
In any case, the versatility of the horizontally polarized antenna in meeting the requirements will be apparent. The conventional configuration of a single bay horizontally polarized log periodic antenna is shown in Figure 7. It is designed in a manner which provides a constant elevation plane coverage as a function of frequency. This characteristic is achieved by placement of the apex of the antenna at, or very near, ground level and arranging that the dipole elements above the ground, measured in wavelengths, is constant for all radiators.

Results of ionospheric propagation analysis shows that for longer range circuits, a variable take-off angle as a function of frequency is desirable in order to optimize system performance. It is possible to achieve the required elevation plane radiation coverage by appropriate elevation of the apex of a horizontally polarized log-periodic antenna. Antenna Application Note Number 2 shows 2731 rotatable log-periodic antennas when mounted are examples of this effect.

In the extreme condition; i.e., with the antenna parallel to the ground as in Figure 3A of Application Note Number 2, the elevation plane coverage is identical to that of Models 2004 or similar height above ground. Further examples of the effects of height variation on elevation plane coverage for these types of antennas are provided in Antenna Application Number 3.

Conversely, it is also an established fact that the lower part of the HF spectrum is only suitable for relatively short range communication either by ground or skywave. As previously mentioned, if the radiator is one-quarter wavelength or less above the ground, radiation is essentially upwards. Model 747, a horizontally polarized log-periodic antenna mounted on a single tower as depicted in Figure 8, exploits this fact and offers several economic and logistical advantages over the more conventional configurations.

Azimuth plane coverage between half power points is in the order of 60°for all of the above referenced antennas.

**Vertically Polarized Log-Periodic Antennas.** Two basic types of this class of antenna exist, one is an array of quarterwave monopoles erected above a ground screen, Model 2726, and the other Model 1703 is an array of halfwave dipoles. For the quarterwave type, see Figure 9, since the basic radiator is a monopole, a ground screen is mandatory for proper operation of the array. To obtain good VSWR, the ground screen need only be placed around the antenna, but low angle radiation may be improved by providing a ground screen out in front of the antenna to serve more as a good reflector. The main advantage of this configuration is that the basic monopole radiator is the shortest resonant element which essentially radiates towards the horizon, so the structure requires a relatively short tower, approximately one-quarter wavelength at the lowest operating frequency plus 43% for the catenary. For the theoretical case of a perfectly conducting ground, the upper half power point is 30°, so its range of applications might be approximately as shown by curve (3) in Figure 6 (Page 9). The antenna actually provides good coverage for all ranges greater than about 900 km and, consequently, has been widely used for ground-to-air and shore-to-ship communications where the distance to the opposite station is variable as well as for communication between fixed stations. In the former case, the antenna may be considered to be well adaptable to area coverage for which its relatively broad azimuth beamwidth, about 110°, is an advantage.

The requirement of a ground screen around the antenna to obtain good VSWR is eliminated by the use of halfwave elements in the array. Another advantage results in that the vertical plane beamwidth is narrower and the gain is higher. This is, of course, a natural consequence of the use of a radiator which is twice as long.
Because of its performance characteristics, the halfwave type antenna is finding good acceptance for long range circuits. Coverage characteristics are shown by curve (4) in Figure 6 (Page 9). It is also more versatile in installation. While intended to be erected over relatively level ground, it has been adapted for installation over rough terrain, over rocks at a coastline and over seawater. These installations would, of course, be very difficult or impractical with those types of vertical radiators which require an elaborate ground screen.

However, the addition of ground wires in front of the vertical dipole type antenna will enhance radiation at low elevation angles. The general configuration is shown by Figure 10.

Arraying Log-Periodic Antennas for Higher Gain. So far we have restricted our discussions to standard single curtain arrays. However, for long range circuits with a requirement for increased antenna gain, it is possible to array two, three or four either horizontally or vertically polarized antennas. Model 748 is an example of multiple horizontally polarized arrays. In the case of vertically polarized arrays in a bayed configuration (i.e., side-by-side), the frequency independent characteristics of the basic antenna can be preserved by ensuring that the electrical spacing between phase center remains constant with changes in frequency. The elevation plane pattern is, of course, the same as for a single structure but the azimuth plane radiation is narrowed to a half-power beamwidth of about 55° for a three element array, and the gain is consequently increased 3 dB over that obtained from a single structure. For an array of two elements, the azimuth beamwidth is about 75°.

Horizontally polarized antennas, however, can be arrayed both in a bayed or stacked (one above the other) configuration, or both. In a two bayed configuration, the azimuth plane radiation is narrowed to a halfpower beamwidth of about 35°, whilst the elevation plane radiation remains unaltered, and the gain consequently increased by approximately 2.5 dB.

Stacking arrays, however, has the opposite effect, the azimuthal coverage is maintained while the elevation plane radiation is narrowed and lowered with a similar increase in gain. Whilst stacking arrays does introduce higher secondary lobes, the merits, especially when combined with a bayed configuration, provide a good broadband alternative to the narrow band rhombic type system.

Multiple arrays such as those described above, are uniquely configured to meet specific requirements.

Area Coverage Circuits
There are a number of broadband antennas that have been developed for these applications. First are the omnidirectional type; second are those which provide a beam which is steerable in azimuth.

Omnidirectional Antennas. For the omnidirectional azimuth coverage, the conical type of antenna, Model 1794 and Model 2753 have traditionally provided optimum performance with bandwidths as great as 15 to 1 in the case of the former type, VSWR not greater than 2 to 1 with respect to 50 ohms and elevation plane patterns well suited to medium and long range coverage via skywave propagation and short range coverage via ground wave propagation. Where the requirement does not necessitate total coverage of the HF spectrum, the 2753, with its 6 to 1 frequency bandwidth, offers considerable economical advantages.

Height of these structures is, depending on type, approximately 0.16 to 0.18 wavelengths at the lowest operating frequency and real estate is determined by diameter of ground screen, usually 0.5 wavelengths long at the lowest operating frequency. Figure 11 (page 12) presents a typical view of this class of antenna. Where environmental considerations are of paramount concern, Model 794 with the conical radiator suspended from wooden poles (to avoid azimuthal coverage degradation) positioned around the periphery of the cone offers a useful alternative.

By virtue of the fact that both of the above antennas are vertically polarized, their ability to provide high angle skywave coverage for short range communication over difficult terrain is limited by the inherent null in elevation plane coverage around the zenith. Existing horizontally polarized antennas are limited in capability to provide reliable medium range communications because of
lack of control of radiation patterns over adequate frequency ranges. However, communication performance beyond that achieved with vertically or horizontally polarized antennas is possible with elliptically polarized antennas; i.e., Model 2001 and 3000 series. Whilst the elevation plane coverage of the 2001 series was arranged primarily to cater for short to medium range communication circuits the reduction in losses, due to ionospheric rotation of the electric field, of the elliptically polarized signal provides a useful multi-hop, long-range communication capability. This type of antenna is depicted in Figure 12.

The 3000 series, whilst exploiting the virtues of elliptical polarization, offers a unique solution to a diverse range of communication requirements. The 3001 and 3002 antennas, depicted in Figures 13 and 14 are log-periodic spiral arrays supported on a single guyed tower for simplicity of installation. The apex of the hexagonal cone points towards the ground and its height above the ground determines the take-off angle of the main lobe. Being positioned at a constant physical height above ground, the take-off angle of the elevation plane radiation reduces as the frequency increases; ideal for medium and long range communications.

An important fact to note is that the property of the ionosphere that caused fading also determined the optimum utilization of an elliptical signal. The sense of polarization (clockwise or counter clockwise) is uniquely determined by the location of the antenna in the Northern or Southern Hemisphere. Both the 2001 and the 3000 series have been designed to accommodate on-site selection of the polarization sense.

Whilst the broadband dipole, series 1765 and 3065, has true omnidirectional azimuthal coverage over only a 4 to 1 bandwidth, the broadband frequency coverage provides a good low-cost alternative to many short to medium range requirements. The unique configuration of this range of antennas is shown in Figure 15.

Steerable Antennas. Simple arrangements of log-periodic arrays oriented in different directions provides us with the capability of beam steering in the azimuth plane, either from horizontally or vertically polarized arrays. Models 757 and 779 are typical examples of the latter.
Previously, mention was made of the versatility of horizontally polarized antennas in providing a considerable range of elevation plane coverage by adjustment of the electrical height of the antenna above ground. This characteristic has been employed in log-periodic antenna designs to accommodate requirements for communications at variable ranges, as occurs on ground-air circuits and transportable systems.

The basic requirement is for lower take-off angles as operating frequency is increased. This is achieved with a log-periodic antenna by elevating the apex, or feed point, of the antenna above ground.

Elevation plane coverage from near zenith to about 15 degrees above the horizon (including the half-power points) is readily achieved without undue complication in antenna support structure. See Antenna Application Note Number 2. Another type of broadband antenna with azimuth plane scan capability is, of course, the mechanically rotated log-periodic antenna Models 2004 and 2731. Both are similar in concept; see Figure 16, utilizing full half-wave length radiators, to provide maximum efficiency configured in a chevron arrangement (sloping the wire radiators forward) to minimize the overall turning radius; an important factor especially as in many cases these antennas are installed on the roofs of buildings which are replete with obstructions and not necessarily flat and, thereby, minimizing the probability of physical interference.

The 2731 series provides provides greater frequency bandwidth and higher power handling capability making it suitable for a larger number of applications, especially ground mounted situations. The 2004, on the other hand, with its small size and and high efficiency, makes it a natural selection for use by embassies, airports, headquarters buildings, oil companies and many other similar organizations. The azimuthal plane radiation is typically 70° between half-power points but the elevation plane radiation is dependent on effective height above ground (i.e., in a roof mounted configuration the height of the building is included).

Graphs showing the variation of take-off angle for various heights above ground are included in Antenna Application Note Number 3. Antennas like the 2004 can be provided as fixed arrays for point-to-point circuits and, being mounted at a constant physical height above ground, they accommodate the requirement for communications at variable ranges.

Transmission Line Accessories Baluns and Impedance Transformers.
The unit shown in Figure 17 (Page 14) is typical of the type used for either the coaxial to balanced line transformer or the antenna drive unit. It is intended for outdoor service and, in the case of the higher power versions, (25 kw average/100 kw PEP), is filled with transformer oil which serves both as an electrical insulating material and as a natural convection cooling system.

The connections for the balanced line are brought out on the side through high strength alumina terminal bushings.

Figure 14. Roof Mounted SPIRACONE Model 3002

Antenna drive units of this type are available to meet the same power handling capability, the same frequency range, and the same performance specifications as the antenna. For example, if the antenna is designed to present 2:1 maximum VSWR to a balanced, open-wire transmission line, the balun transformer antenna combination will provide the same 2:1 maximum VSWR to a coaxial transmission line. The line matching transformer provides impedance transformation between coaxial lines and balanced, open-wire lines. Lower power units and receive only broadband baluns are, of course, available.

The significance of the availability of broadband balun and impedance advantages of power transmission over open wire line, compared to transmission via coaxial line, is well known. However, it is also known that use of coaxial lines and components for power distribution and switching within, and close to, the transmitting station offers technical and operating advantages. Availability of high performance baluns and impedance transformers allow a near optimum combination of power transmission and switching methods.
Transmitting Multicouplers. The use of multicouplers on receiving antennas is common in receiving stations. Several receivers can be connected in parallel to a single receiving antenna to reduce the total quantity of antennas needed. This has not been so at transmitting stations, however, the rising cost of real estate and the restrictions in land availability is making its use more common.

A transmitting multicoupler will permit the connection of two or more transmitters to a single antenna. The transmitting multicoupler, unlike the receiving multicoupler which normally includes an amplifier, is a passive device that has no amplifiers or non linear elements.

The transmitting multicoupler provides a path to the antenna while providing adequate isolation of one transmitter output from the other. As will be explained later, a small frequency separation is necessary to secure the desired degree of transmitter output isolation.

There are two basic types of transmitting multicoupler in use on HF systems. One makes use of tuned trap circuits to secure transmitter isolation. The other combines a low-pass and high-pass filter. The two filter multicoupler is much easier to apply to an antenna system than the tuned variety. In the tuned trap multicoupler, a series of sharply tuned trap circuits must be resonated to properly isolate the transmitter outputs. Initially at the time of installation, great care must be used in properly adjusting the tuning elements because there is interaction between controls. If the frequency of each transmitter is fixed, then the initial tuning can be justified. However, each time any transmitter frequency is changed, a readjustment of tuning controls is necessary. A high degree of operator proficiency or complicated servo-mechanisms are needed to adjust the tuned transmitting multicouplers.

Contrast to this is the low-pass/high-pass filter multicoupler. Contrast to this is the low-pass/high-pass filter multicoupler where there is complete freedom of movement about each of the filter band-pass areas.

Transmitters can be removed and interchanged with no operator adjustment. There is a forbidden zone at the multicoupler dividing frequency extending 10% below and 10% above the dividing frequency. The lower and upper limits of the frequency is preset before installation of the equipment.