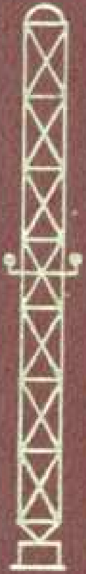

SECOND EDITION

BROADCAST ANTENNA SYSTEMS HANDBOOK

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No.T-44
$9.95

Broadcast Antenna Systems Handbook

SECOND EDITION

By The Editors of BM/E Magazine

TAB BOOKS
Blue Ridge Summit, Pa. 17214

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SECOND EDITION

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BROADCAST ANTENNA SYSTEMS
HANDBOOK

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Preface

One of the most important elements of a radio or television broadcast facility is the antenna system. Programming is the key to attracting and holding an audience; but unless that programming reaches the intended audience on a strong, clear signal, the best programming in the world is quite useless. Of course, the best possible signal coverage is achieved with an efficient, properly designed antenna system.

Although the basic theory of signal radiation is simple, factors such as terrain, site location, area propagational characteristics, co-channel and adjacent-channel interference, etc., compound the engineering problems. Add to these burdens the requirements imposed by the FCC and FAA. And when a directional system is desirable or necessary, the engineering technology involved in the design and operation often becomes extremely complex.

This volume, first published in late 1966, is intended to serve as an aid to broadcast engineers involved in antenna system engineering and maintenance. It begins with a look at the engineering data required for FCC Form 301 in applying for AM, FM, and TV transmitting plants. Following is an in-depth treatment of AM directional antenna system design, operation, and maintenance. Several chapters deal with TV antenna systems, then we go into FM antennas, including directional and dual polarization.

This second edition includes most of the material that appeared in the first edition, plus new data on AM, FM, and TV antenna systems. In some cases, you may find that economic inflation has caused increases in prices quoted. All material originally appeared in BM/E magazine and is published in this form as a one-source reference. We hope it serves you well.

The Editors

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Preparing Engineering Data for Form 301

AM Broadcast Stations Part 1

Harry A. Etkin

The most significant factor in assuring a successful filing of Form 301 is to supply all the specific data in complete detail. Thus, in planning a new station or changes in an existing station, a broadcaster should be familiar with the engineering know-how required. Familiarity with the FCC Rules will aid in making the necessary decisions regarding site location, equipment requirements, and antenna location and construction. The engineering staff should therefore be acquainted with the following: Vol. 1, Nov. 1963: Part 1—Practice and Procedure; Part 17—Construction, Marking, and Lighting of Antenna Structures; Vol. III, Jan. 1964: Part 73—Radio Broadcast Services; NAB Engineering Handbook 5th Edition, Section 2—Antennas, Towers and Wave Propagation.

Section V-A of the form applies to standard broadcast (AM) engineering data, Section V-B to FM data, and Section V-C to TV engineering data. Section V-G of the application specifically pertains to antenna and site information, although much of the engineering data required in the other applicable sections is directly related to the antenna system. Therefore, preparing data for Section V-A, for example, will provide most of the information for Section V-G.

Page 2 of Section V-A, item 12, pertains to the allocation study. This is the tough part, relating to the normally protected and interference free contours proposed by the application.

With today's crowded airwaves, it is becoming more and more difficult to find a location, frequency, and power that will fit the Commission's present allocation standards. Once this has been accomplished, however, preparing the data is a fairly straightforward engineering procedure.

Cost Considerations

One of the first points to be considered about costs is whether the chief engineer or a consulting engineer should make the calculations and perform the tests to obtain the necessary data. While many chief engineers may be capable of preparing much of the data required, it is generally advisable to use the services of an engineering consultant, especially if the antenna system is complex (such as a directional array).

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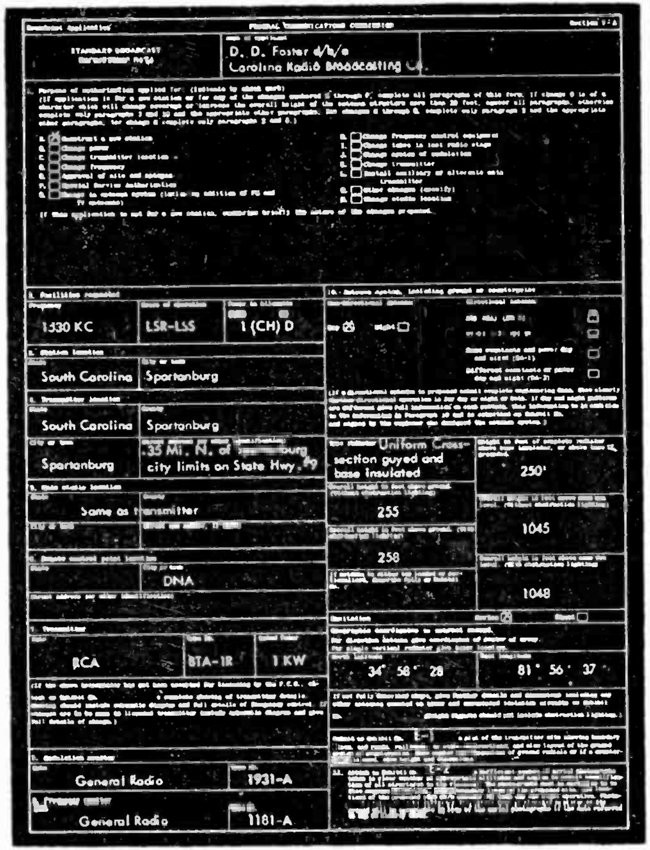

FEDERAL COMMUNICATIONS COMMISSION

Section V-A

STANDARD BROADCAST

D. D. Foster d/b/a
Carolina Radio Broadcasting Co.

1530 KC

LSR-LSS

1 (CH) D

South Carolina

Spartanburg

South Carolina

Spartanburg

Spartanburg

.35 Mi. N. of Spartanburg city limits on State Hwy. 9

Same as transmitter

DNA

RCA

BTA-1R

1 KW

General Radio

1931-A

General Radio

1181-A

Uniform Cross-section guyed and base insulated

250'

255

1045

258

1048

34° 58' 28

81° 56' 37

E-1

E-2

Fig. 1. Sample page 1 of Section V-A.

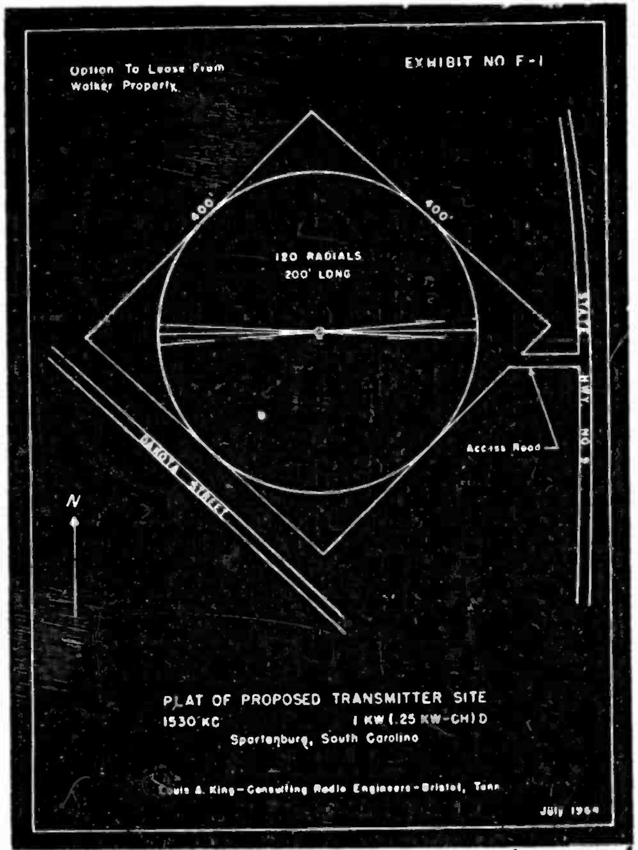

Fig. 2. Example of exhibit showing plot of proposed transmitter site.

Also, present-day regulations make it almost mandatory to enlist the aid of a consultant in making an allocations study and report for proposed facilities. In an operating station, engineering time is too valuable to perform the technical determinations. For a new station, however, it is most practical and economical for the chief engineer to work with a consulting engineer.

Engineering personnel assigned to the project should be advised of the necessity for keeping within the budget. Total cost for the engineering data will vary widely from station to station and area to area. As required tower heights and power outputs increase, costs will increase proportionately. Thus, the largest single cost generally involves preparation of antenna system data.

Preparing Section V-A

Section V-A deals specifically with all the engineering data required for a standard broadcast station. The reproduction in Fig. 1 shows the information required for Page 1, and Exhibit E-1 is shown in Fig. 2. In connection with the information requested, Vol. III, Paragraph 73.33, Antenna Systems, states that an application for authority to install a broadcast antenna shall specify a definite site and include full details of the antenna design and expected performance.

All data necessary to show compliance with the terms and conditions of the construction permit must be filed with the license application. If the station is using a directional antenna, a proof of performance must also be filed. If a directional antenna is proposed, complete engineering data and measurements must be submitted.

Paragraph 73.150 specifies that engineering data for a directional antenna shall include a complete description of the proposed system showing:

1. Number of elements
2. Type of each element (guyed or self-supporting, uniform cross-section or tapered, base width, grounded or insulated, etc.)
3. Complete engineering details of top loading or sectionalizing, if any.
4. Height of vertical lead of each element in feet, (height above base insulator, or base if grounded).
5. Overall height of each element above ground.
6. Details including sketches of ground system for each element (length and number of radials, dimensions of ground screen, if used, and depth buried) and outline of property.
7. Ratio of fields from elements (identifying elements).

In addition, calculated horizontal (ground) plane field intensity patterns for each mode of operation must be plotted to the largest scale possible (approximately 7" by 10") on standard letter size point coordinate paper using only scale divisions and subdivisions having values of 1, 2, 2.5 or 5 times 10^{nth}. The data must include:

1. Inverse field intensity at 1 mile and effective field intensity (RMS).
2. Direction of true north at zero azimuth.
3. Direction and distance of each existing station with

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which interference may be involved. All directions should be determined by accurate calculation, or from a Lambert Conformal Conic Projection Map such as United States Coast and Geodetic Survey Map No. 3060, or a map of equal accuracy. All distances should be determined by accurate calculation, or from a United States Albers Equal Area Projection Map Scale 1: 2,500,000, or map of equal accuracy.[1]

4. Orientation of array with respect to true north and time phasing of fields from elements, specifying degrees leading (+) or lagging (−) and space phasing of elements in feet as well as in degrees.
5. The location of all the minima in the pattern.

In those instances where radiation at angles above the horizontal plane is a pertinent factor in station allocation, field intensity vs. azimuth patterns must be calculated for every 5° of elevation through 60°. These patterns may be plotted along either polar or rectangular coordinates, but must be submitted one to a page. Minor lobe and null detail occurring between the 5° intervals need not be submitted.

Data used in computing field intensity patterns must also be submitted, along with the formula used for calculating the horizontal patterns, sample calculations, and

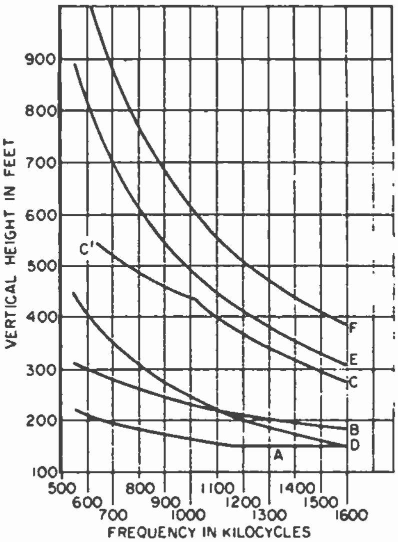

Fig. 3. Engineering Chart from Par. 73.190 of the Rules, used to determine minimum permissible antenna height.

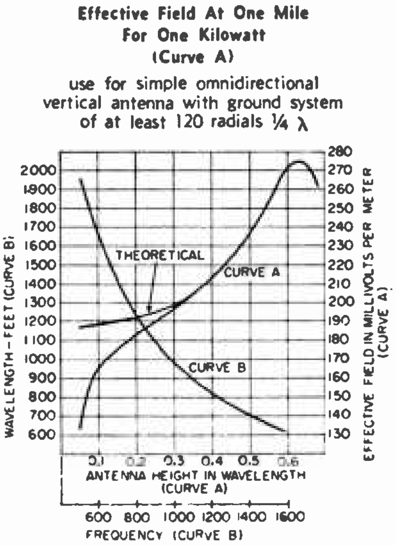

Fig. 4. Engineering Chart from Par. 73.190, for determining effective field of omnidirectional vertical antenna.

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[1] These may be obtained from the United States Coast and Geodetic Survey, Department of Commerce, Washington, D.C. 20235, and the United States Department of Interior, Geological Survey, Washington, D.C. 20240.

formula derivations if other than standard. Any assumption made must be stated, along with an explanation of its basis, including electrical height, current distribution and efficiency of each element, and ground conductivity. Complete tabulation of final calculated data used in plotting patterns. including data for determination of RMS value of pattern, is required.

Values of field intensity less than 10% of the effective field intensity of the pattern must be shown on an enlarged scale. If the values determined from actual measurements, particularly in sharp nulls, are different from the calculated values, maximum expected operating values (MEOV), as well as the calculated values, must be shown on both the full patterns and the enlarged sections. The requirements for field intensity measurements are elaborated in Paragraph 73.151, Field Intensity Measurements to establish Performance of Directional Antennas.

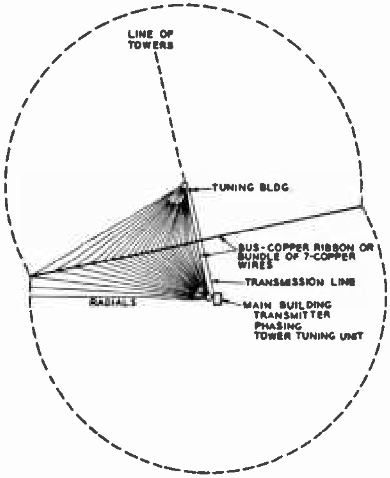

Fig. 5. Typical two-tower ground system.

Appropriate information relating to the type of radiator, overall heights, top-loading or sectionalized antenna and method of excitation is entered in the applicable blocks for Question 10 (see Fig. 1). Special maps and charts may be used to tabulate the information and data required for the last portion of Item 10.[2]

Some pertinent facts relating to standard broadcast antenna structures are:

1. All applicants for new, additional, or different broadcast facilities, and all licensees requesting authority to change the transmitter site of an existing station, shall specify a radiating system with an efficiency that complies with the requirements of good engineering practice for the class and power of the station.
2. No broadcast station licensee shall change the physical height of the transmitting antenna or supporting structure, or make any changes in the radiating system which will measurably alter the radiation pattern, except on application to and authority from the Commission.
3. The simultaneous use of a common antenna or antenna structure by more than one standard broadcast station,

[2] Ground level elevations may be obtained from the U.S.G.S. topographic quadrangle maps. Maps for specific areas may be obtained from U. S. Geological Survey, Department of the Interior, Washington, D. C. 20240. Maps of areas west of the Mississippi are available from U. S. Geological Survey, Denver 15, Colorado. Section aeronautical charts are available from United States Coast and Geodetic Survey, Department of Commerce, Washington, D. C., 20235.

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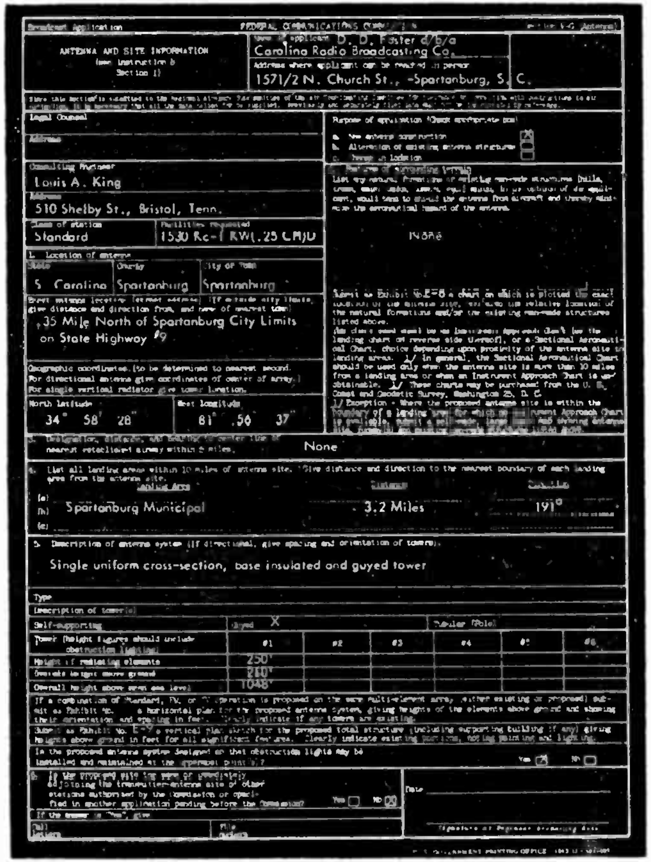

Broadcast Application FEDERAL COMMUNICATIONS COMMISSION Section V-G (Antenna)

ANTENNA AND SITE INFORMATION
(See Instruction 6
Section I)

Name of applicant D. D. Foster d/b/a Carolina Radio Broadcasting Co.

Address where applicant can be reached in person
157 1/2 N. Church St., Spartanburg, S. C.

Legal Counsel

Address

Consulting Engineer
Louis A. King

Address
510 Shelby St., Bristol, Tenn.

Class of station	Facilities requested
Standard	1530 Kc-1 KW(.25 CH)D

1. Location of antenna

State	County	City or Town
S Carolina	Spartanburg	Spartanburg

.35 Mile North of Spartanburg City Limits on State Highway #9

North latitude	West longitude
34° 58' 28"	81° 56' 37"

Purpose of application (Check appropriate box)

a. New antenna construction ☒
b. Alteration of existing antenna structure ☐
c. Change in location ☐

None

3. None

4. List all landing areas within 10 miles of antenna site. (Give distance and direction to the nearest boundary of each landing area from the antenna site.)

	Landing Area	Distance	Direction
(a)			
(b)	Spartanburg Municipal	3.2 Miles	191°
(c)			

5. Description of antenna system (If directional, give spacing and orientation of towers).

Single uniform cross-section, base insulated and guyed tower

Type

Description of tower(s)

Self-supporting	Guyed X	Tubular (Pole)

Tower (height figures should include obstruction lighting)	#1	#2	#3	#4	#5	#6
Height of radiating elements	250'					
Overall height above ground	260'					
Overall height above mean sea level	1048'					

Submit as Exhibit No. E-9 a vertical plan sketch for the proposed total structure

Is the proposed antenna system designed so that obstruction lights may be installed and maintained at the approved points? Yes ☒ No ☐

Yes ☐ No ☒

Date

Fig. 6. Sample application, Section V-G

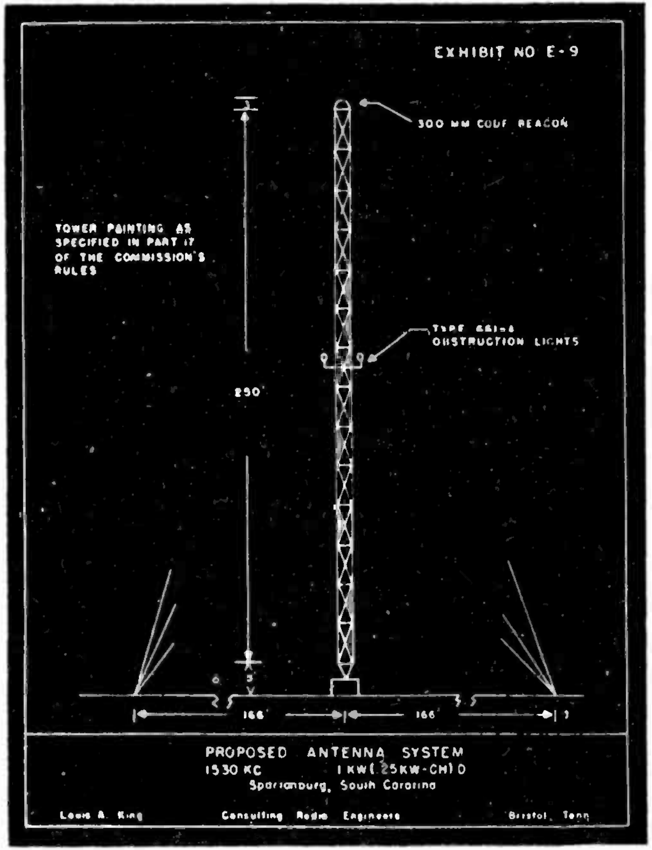

Fig. 7. Example of vertical plan sketch requested in

or by one or more standard broadcast stations and one or more broadcast stations of any other class or service, may be authorized provided:

a. Verified engineering data is submitted to show that satisfactory operation of each station will be obtained without adversely affecting the operation of the other.
b. The minimum antenna height or field intensity for each station complies with Item 1 above.

4. Paragraphs 73.189 and 73.-190 define the minimum antenna heights and field intensity requirements. Minimum physical heights of antennas permitted are shown in Fig. 3. Fig. 4 shows the requirements for effective field at one mile for one kilowatt.
5. Since the radiation pattern is computed on the basis of a perfectly conducting plane earth, a ground system of buried copper wires or ribbon must be installed in order to approach this condition as closely as possible. A properly installed and adequate ground system can contribute much to the efficiency and stability of a radiation pattern. The FCC minimum requirements consist of buried radial wires at least ¼ wavelength long. They should be evenly spaced, and in no event should less than 90 radials be used (see Fig. 5).
6. A station with an AM directional antenna system applying for remote control privileges must have an extremely stable antenna system and must also attest to its stability. The stability of directional AM antenna systems is important to successful remote control operation. In addition to the provision of

Engineering Data Costs

For construction of a new non-directional AM station, the average cost for engineering, design work, tests and measurements, calculations, computations, compiling of data, and the filing of Form 301 is normally between $1,500 and $2,000. This includes $100 for personnel expenses, and the cost of obtaining and entering data for:

a. Geographic coordinates
b. Topographic maps
c. Profile graphs
d. Sectional aeronautical charts
e. Aerial photography
f. Predicted field strength patterns and contours
g. Instrument approach or landing charts
h. Other incidental materials

With a directional antenna array, the cost would not be under $2,500 and may approach $4,000 for either day or night operation, and possibly $8,000 for both day and night operation.

Changes in existing facilities, such as for a new transmitter or monitoring equipment, require no formal application and only a small consulting charge is involved.

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an adequate ground system. attention should be given to bonding of the connecting elements, positioning of guy insulators. base insulators with sufficient leakage paths. and low-loss capacitors and inductors in the phasing and power-dividing networks.

7. The unattenuated inverse field strength at 1 mile is the field strength at 1 mile when the only attenuation is that of distance.
8. A sectionalized tower in addition to the base insulator, has one or more insulators in the tower above the base. This type of tower is usually constructed for the purpose of obtaining greater AM broadcast coverage.

The engineering data required for Pages 2 and 3 of Section V-A is directly related to the information described in the following paragraphs:

1. Paragraph 73.37 Minimum Separation Between Stations; Prohibited Overlap.
2. Paragraph 73.182 Engineering Standards of Allocation.
3. Paragraph 73.183 Groundwave Signals.
4. Paragraph 73.184 Groundwave Field Intensity Charts.
5. Paragraph 73.185 Computation of Interfering Signal from a Directional Antenna.
6. Paragraph 73.186 Field Intensity Measurements in Allocation.
7. Paragraph 73.187 Limitation on Daytime Radiation.

Antennas For Standard Broadcast Stations

Minimum Vertical Height of Antennas Permitted to be Installed (A.B.&C.)

A. Class IV stations, or a minimum effective field intensity of 150 mv/m. for 1 kw. (100 watts, 47.5 mv/m & 250 watts, 75 mv/m)
B. Class II & III stations, or a minimum effective field intensity of 175 mv/m for 1 kw
C. Class I stations, or a minimum effective field intensity of 225 mv/m for 1 kw
C.[1] Where it is shown that the civil aeronautics authority will not approve an antenna having height in excess of 500 feet at any location within the metropolitan area concerned, a height of 500 feet will be accepted.
D. 0.25 Wavelength
E. 0.50 Wavelength
F. 0.625 Wavelength

Section V-G, Antenna and Site Information

This part of Form 301, as shown in Fig. 6, is for the specific use of the Regional Airspace Subcommittee, which is concerned with obstructions to air navigation. Thus, even though most of the data requested duplicates engineering information called for in Section V-A, B, or C, it must not be entered by reference.

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FM Broadcast Stations
Part 2

Harry A. Etkin

THE first part of this series dealt with the data required by FCC Form 301 for a standard broadcast station. This part concerns the specific information required by Section V-B and the costs involved in preparing engineering data for FM facilities.

Selecting a Frequency

Available frequencies for FM broadcasting are listed in Par. 73.201: Numerical Designation of FM Broadcast Channels, Subpart B—FM Broadcast Stations (Vol. III of the Rules). The channel you request must be one assigned to your community (Table of Assignments, Par. 73.202). If your community has no channel assigned, or is not within 25 miles of the assignment, or if there are stations already on the channels in your area, a petition must be filed with the FCC to change the Table of Assignments as required by Par. 73.203.

Antenna Site Considerations

Applicants who propose to operate an FM antenna in the immediate vicinity (200 ft. or less) of another FM antenna, or TV antenna with frequencies adjacent to the FM band, must describe the effect the two systems will have upon each other.[1]

If an FM antenna is to be mounted on a nondirectional standard broadcast antenna tower, new resistance measurements must be made after the FM antenna is installed and tested. During the installation, and until the new resistance measurements are approved, the AM licensee should apply for authority (informal application) to use the indirect method of measuring power. The FM application will not be considered until the new resistance measurements are filed for the AM station. If the FM antenna is to be mounted on an element of an AM directional array, or on a tower in the vicinity of a directional array, a full engineering study of the effect on the performance of the AM array must be filed with application. In some cases, the FCC may require readjustment and certain field intensity measurements of the AM system when the FM antenna is in operation.

Section V-B

If you plan to use a dual polarized antenna, Tables I and II list data for horizontal and vertical polarization. Fig. 1 shows how data for dual polarization is entered on the form.

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[1] FCC Rules, Par. 73.316: Antenna Systems—Part e.

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The mathematical expressions for antenna field gain and power gain are:

Table I—Typical Horizontal FM Antenna Data

NO. OF SECTIONS	GAIN POWER KW	DB	FIELD
1	0.9	0.5	0.95
2	2.0	3.0	1.41
3	3.0	4.8	1.73
4	4.1	6.1	2.02
5	5.2	7.15	2.28
6	6.3	8.0	2.51
7	7.3	8.63	2.70
8	8.4	9.25	2.90
10	10.5	10.2	3.25
12	12.5	11.0	3.55
14	14.6	11.65	3.83
16	16.6	12.20	4.07
20	21.0	13.22	4.59

Table II—Typical Vertical FM Antenna Data

NO. OF SECTIONS	GAIN POWER KW	DB	FIELD
1	.95	.22	.97
2	1.97	2.94	1.40
3	3.12	4.94	1.79
4	4.20	6.23	2.05
5	5.31	7.25	2.30
6	6.39	8.06	2.53
7	7.50	8.75	2.74
8	8.57	9.33	2.93
9	9.76	9.89	3.12
10	10.93	10.40	3.31
11	11.87	10.74	3.45
12	13.20	11.20	3.63
13	14.03	11.47	3.75
14	15.29	11.84	3.91
15	16.30	12.12	4.04
16	17.48	12.43	4.18

Field gain = field intensity in mv/m for multielement antenna/137.6

Power gain = (Antenna field gain)^2

Authorized power and antenna requirements are illustrated in Table III. No minimum antenna height above average terrain is specified. Heights exceeding those listed in Table III may be used if ERP is reduced by the amount indicated by the appropriate curve in Fig. 2.

The height of the radiation center is the physical center of the radiating elements if uniform

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2. Ground level elevations may be obtained from the U. S. Geological Survey, Dept. of the Int., Wash., D. C. 20240. West of the Mississippi: U.S.G.S., Denver 15, Colo. Sectional aeronautical charts are available from the U. S. Coast and Geodetic Survey, Dept. of Commerce, Wash., D. C. 20235.

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power distribution is used. If a split-feed or power divider system and nonuniform power distribution are employed, the height of the radiation center is not the same as the physical center (the manufacturer will furnish this data).

A directional antenna may not be used solely for the purpose of reducing minimum mileage separation requirements; it is permissible if it will improve service, or permit the use of a particular site, and is designed for a noncircular radiation pattern. Directional antennas with a ratio of 15 db maximum to minimum radiation in the horizontal plane are not allowed.

Applications proposing the use of a directional antenna must be accompanied by:

1. A complete description of the proposed antenna system.
   (a). A description of how directivity will be obtained.
   (b). A means of determining the operational pattern and maintaining allowable tolerances, such as a rotatable reference antenna.
2. Horizontal and vertical plane radiation patterns showing the free space field strength in mv/m at 1 mile and ERP in dbk for each direction; a complete description of how the measurements were made, including the type equipment used and a tabulation of the measured data. If you compute directivity, methods used, formulae, sam-

Table III—Authorized Power and Antenna Requirements

Minimum Effective Radiated Power

CLASS A	100 watts (−10 dbk)
CLASS B	5 kw (7 dbk)
CLASS C	25 kw (14 dbk)

Maximum Erp And Antenna Height

CLASS	MAXIMUM POWER	MAXIMUM ANTENNA HEIGHT (feet above average terrain)
A	3 kw (4 8 dbk)	300
B	50 kw (17 0 dbk)	500
C	100 kw (20 0 dbk)	2000

Table IV—Operational Formulas

1. ERP in KW = Transmitter power in KW — Transmission Line loss in KW + Antenna Power Gain in KW. The transmission line loss includes the loss in harmonic filter and power divider when dual polarization is used.
2. ERP in DBK = Transmitter Power in DBK — Transmission line loss in db + Antenna power gain in db.
3. Power in dbk = $10 \text{ Log}_{10} \dfrac{\text{Power in KW}}{1.0}$
4. Power in KW = $\text{Antilog}_{10} \dfrac{\text{Power in dbk}}{10}$

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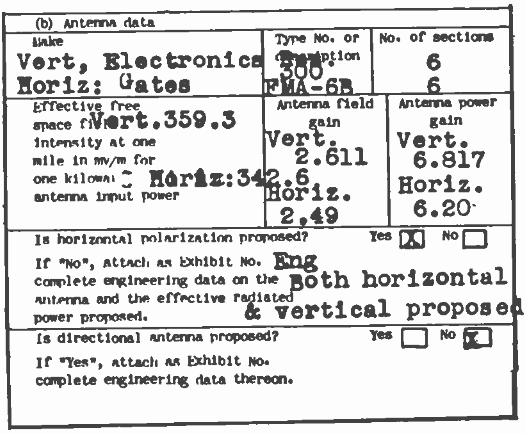
ple calculations[2] and tabulations of the data must accompany the application.

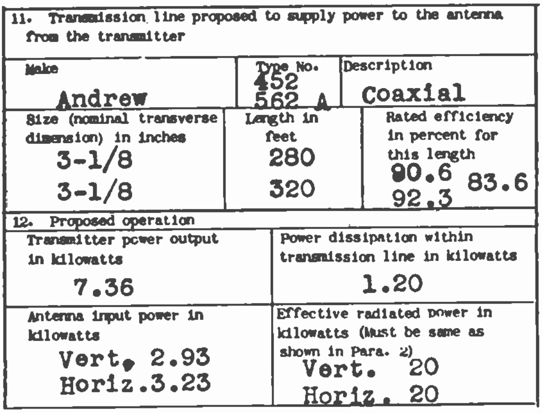
3. Radiation characteristics above and below the horizontal plane illustrated by vertical paterns. Complete information and patterns for angles of ±10° from the horizontal plane, and the portion lying between +10° and the zenith of −10° and the nadir, to conclusively demonstrate the absence of undesirable lobes in these areas.

4. The horizontal plane pattern must be plotted on polar coordinate paper with reference to true north. The vertical plane must be plotted on rectangular coordinate paper with reference to the horizontal plane.



(b) Antenna data		
Make Vert, Electronics Res. Horiz: Gates	Type No. or description 300 FMA-6B	No. of sections 6 6
Effective free space field intensity at one mile in mv/m for one kilowatt antenna input power Vert.359.3 Horiz:342.6	Antenna field gain Vert. 2.611 Horiz. 2.49	Antenna power gain Vert. 6.817 Horiz. 6.20
Is horizontal polarization proposed?	Yes ☒	No ☐
If "No", attach as Exhibit No. Eng complete engineering data on the antenna and the effective radiated power proposed. Both horizontal & vertical proposed.		
Is directional antenna proposed?	Yes ☐	No ☒
If "Yes", attach as Exhibit No. complete engineering data thereon.		

Fig. 1. Sample antenna data entries on Form 301.



11. Transmission line proposed to supply power to the antenna from the transmitter		
Make Andrew	Type No. 452 562 A	Description Coaxial
Size (nominal transverse dimension) in inches 3-1/8 3-1/8	Length in feet 280 320	Rated efficiency in percent for this length 90.6 92.3 83.6
12. Proposed operation		
Transmitter power output in kilowatts 7.36	Power dissipation within transmission line in kilowatts 1.20	
Antenna input power in kilowatts Vert. 2.93 Horiz.3.23	Effective radiated power in kilowatts (Must be same as shown in Para. 2) Vert. 20 Horiz. 20	

Fig. 3. Sample entries for transmission and proposed operation data.

Transmission Lines

Fig. 3 shows entries for the re-

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quired information on the transmission line. These characteristics vary with frequency: size in inches, coaxial or waveguide, efficiency to produce the desired ERP and, of course, cost considerations. The total length in feet includes the horizontal run from the harmonic filter to the base of the antenna tower and the length up the tower to the antenna terminal point where the gain is rated. Power loss for this length may be determined from the manufacturer's specifications. (See Table IV.)

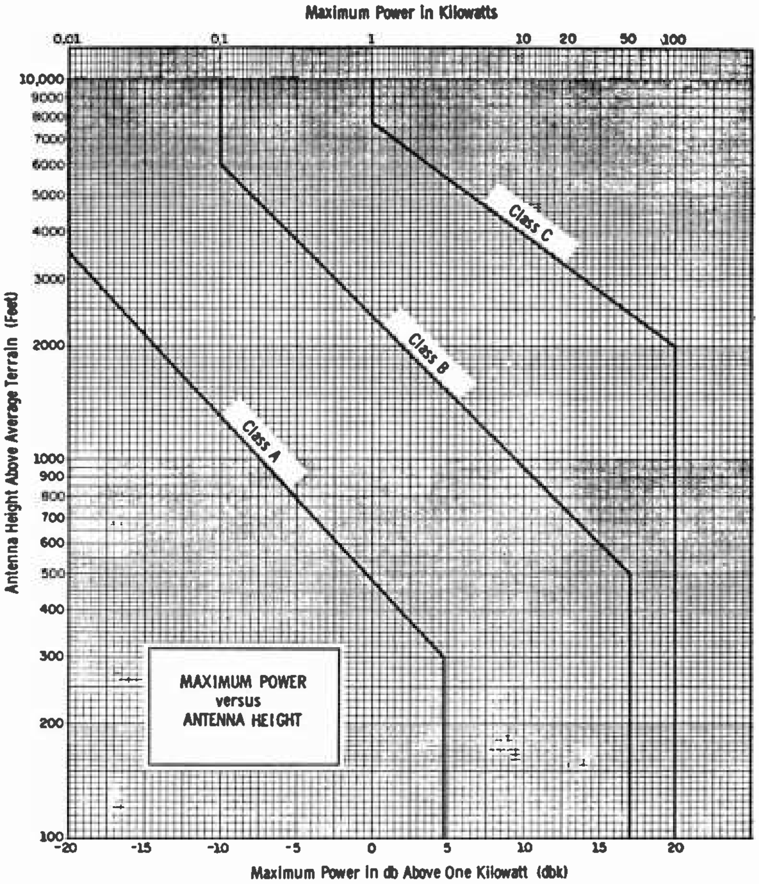

Fig. 2. Relationship between antenna height and power.

Expected Coverage Information

Profile graphs of the terrain, from 2 to 10 miles for 8 or more radials from the transmitter location, must accompany the application. One or more radials must extend through the principal city. All radials should be plotted on a topographic map.[3]

The graph for each radial should be plotted by contour inter-

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[3] Topographical maps for most areas are available at a nominal cost from U.S.G.S. If none is published for your area, use the information in Par. 73.312, subparagraph (a) FCC R&R.

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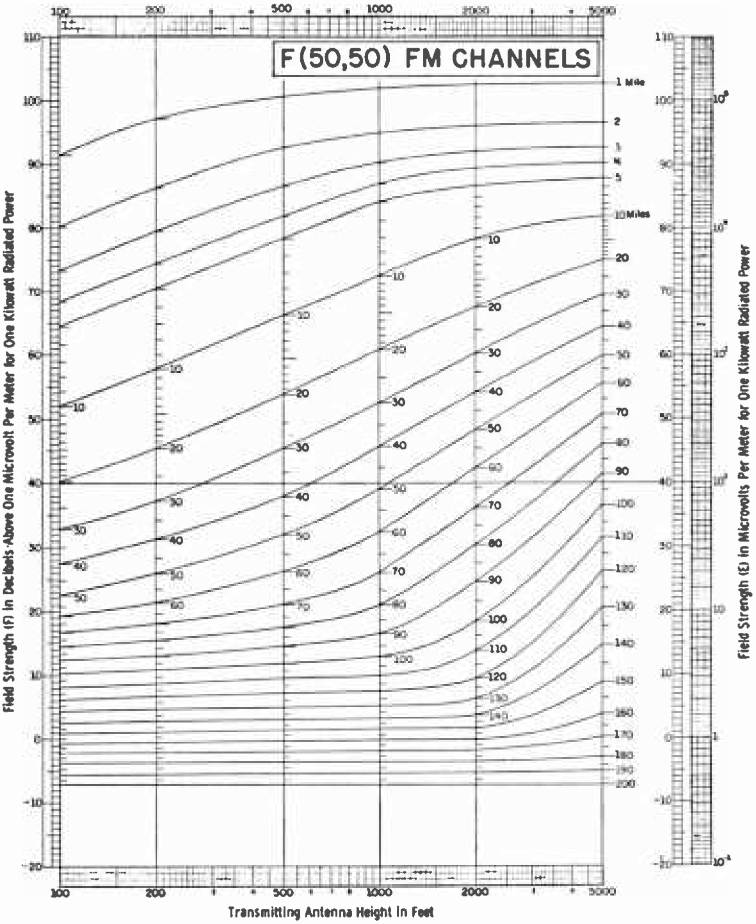
vals of from 40 to 100 feet and, where the data permits, at least 50 points of elevation should be used for each radial. The graphs should indicate the topography accurately and should be plotted with the distances in miles as the abscissa, and the elevation in feet above the mean sea level as the ordinate. The elevation of the antenna radiation center and the source of the topographic data should be indicated on each graph.



FM CHANNELS
ESTIMATED FIELD STRENGTH EXCEEDED AT 50 PERCENT OF THE POTENTIAL
RECEIVER LOCATIONS FOR AT LEAST 50 PERCENT OF THE TIME
AT A RECEIVING ANTENNA HEIGHT OF 30 FEET

Fig. 4. Chart for predicting field strength.

The F(50,50) field strength chart, Fig. 4, is used to predict field strength of the contours (Fig. 1 of Par. 73.33 may also be used). The chart is based on an effective power of 1 kw radiated from a half-wave dipole in free space, which produces an attenuated field strength at 1 mile of 103-

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db above 1 µv/m (137.6 mv/m).

The chart may be used for other powers; the sliding scale associated with the chart serves as the ordinate. Par. 73.313: Prediction of Coverage, explains its use.

If the terrain departs widely from the average elevation of the 2 to 10 mile sector, in one or more directions from the antenna site, the prediction method may indicate distances that are different from what may be expected in practice. For example, a mountain ridge may indicate the practical limit of service, while the prediction method indicates otherwise; the prediction method should be followed, accompanied by a supplemental exhibit concerning the contour distances as determined by a method based on actual conditions. The exhibit should describe the procedure employed and include sample calculations. Maps of predicted cover-

Costs for FM Engineering Data

The average cost for engineering, design work, test and measurements, calculations, computations, compiling of data, and filing of Form 301 would be $500 to $1,000 for a nondirectional antenna. There is usually an additional charge of $100 for personnel expenses and the cost of obtaining and entering the data for:

a. Geographic coordinates
b. Topographical maps
c. Sectional aeronautical maps
d. Profile graphs
e. Aerial photography
f. Predicted field strength patterns and contours
g. Instrument approach or landing charts
h. Other incidental materials

Charges for an existing FM station, such as addition of vertical polarization, transmitter power increase, and directional antenna, would cost about $500.

Facts About FM Antenna Structures

An antenna located at a height above the service area, such as a mountain top, may have a pattern null falling in the vicinity of a heavily populated section of the principal city.

If a populated section lies within the area, the broadcaster should have the antenna manufacturer apply electrical beam tilt or null fill or a combination of both.

Polarization patterns, standing wave ratio, and gain may be affected by side mounting an antenna. A performance check should be made before deciding on a final location.

Additional Methods of Determining Topographical Data

Topographical data may be obtained on roads which are along radials from the transmitter site by using a sensitive altimeter.

The average elevation of each radial from 2 to 10 miles may be determined by averaging the mean values of mile or half mile segments.

The height of the antenna radiation center above the average elevation of the radial is: Height of radiation center above sea level minus the 2 to 10 mile average radial elevation.

The free space field intensity in mv/m at 1 mile is measured 1 mile from the antenna with 1-kw input in the half-wave dipole. At this 1-mile point, the field intensity for the half-wave dipole is equal to 137.6 mv/m. This measurement is made under conditions of free space field intensity; i.e., the signal is free from reflections from earth or other objects.

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age should include both methods of prediction.

When measurements are required, these should include the area obtained by the regular method and area obtained by the supplemental method. In directions where the terrain is such that negative antenna heights or heights below 100 feet for the 2 to 10 mile sector are encountered, a supplemental showing of expected coverage must be included with a description of the method used in predicting the coverage. The Commission may require additional information about terrain and coverage in such cases.

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TV Stations. Part 3.

Harry A. Etkin

THE DATA required by FCC Form 301 for standard and FM broadcast facilities has been dealt with in the two preceding parts. This third and final part concerns information required by Section V-C and the costs involved in preparing engineering data for TV facilities.

Channel Selection

Channels assigned to TV broadcasting are listed in Par. 73.603, subpart E, Vol. III of the Rules. The channel you request must be listed in the Table of Assignments, Par. 73.606. If the city has no assigned channel and does not qualify under the 15-mile regulations, or if authorizations have already been made on the channels listed in the Table, you will have to petition the FCC to change the Table. (Par. 73.607). The petition must comply with the separations in Par. 73.610.

Transmitter

Manufacturer's specifications list the rated power for both the aural and visual transmitters. If the rated power is listed in watts or kilowatts, the power in dbk may be determined by the formula:

$$\text{Power in dbk} = 10 \log_{10} \times \frac{\text{Power in kw}}{1.0}$$

Power output of transmitters is usually determined by feeding the output into a dummy load with a standard black picture input, and measured by a voltmeter coupled to the transmission line. Visual and aural reflectometers are directly calibrated to read power from the dummy. During normal operation, transmitter power is maintained by adjusting for a constant reflectometer reading. Method of control for each manu-

Table I—Maximum ERP and Antenna Height

Channel	ERP	Ant. Height Zone I	Ant. Height Zones II and III
2-6	20 dbk (100 kw)	1000 feet	2000 feet
7-13	25 dbk (316 kw)	1000 feet	2000 feet
14-83	30 dbk (1000 kw)	2000 feet	2000 feet

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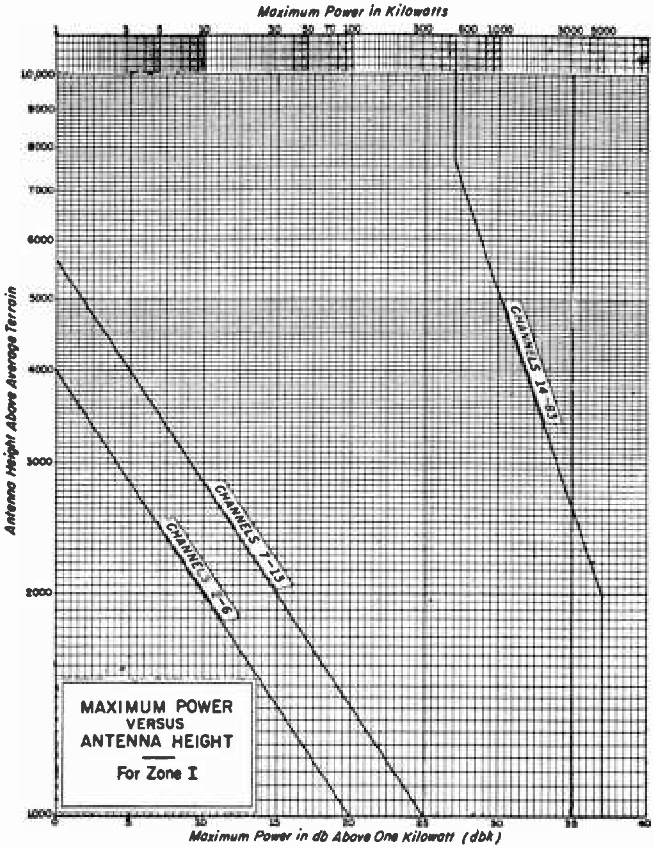

Fig. 1. Relationship between antenna height and power for Zone 1.

facturer and the accepted method is on file with the FCC.

Aural power can be directly or indirectly measured as required by the Rules, Par. 73.689 (2) Operating Power. Using the direct method, the operating power is the product of the plate voltage (Ep) and the plate current (Ip) of the final stage and an efficiency factor:

$$\text{Operating power} = E_p \times I_p \times F$$

The manufacturer's data will tell you the established efficiency factor.

Antenna Site and Structure

Applicants proposing to locate an antenna within 200 feet of another TV antenna operating on a channel within 20% of the frequency of the proposed channel, or if the channel applied for is 5 or 6 and is within 200 feet of an FM antenna, must describe the effect expected of such operation. (Par. 73.685).

If the tower of a standard broadcast station will be used as a supporting structure for the TV antenna, an application for changes in the radiating system of the AM station must be filed.

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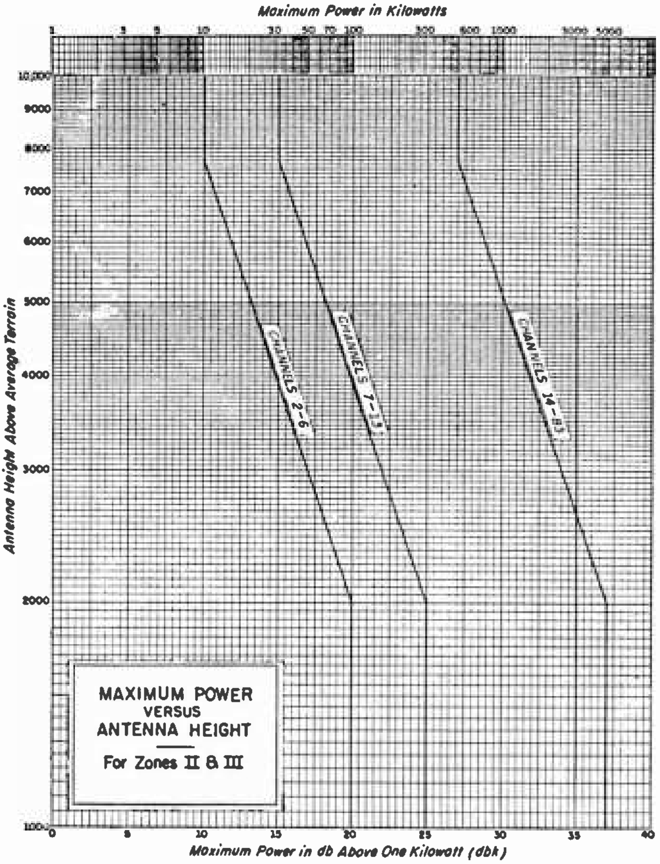

Fig. 2. Relationship between antenna height and power for Zones 2 and 3.

If a substantial change in height or radiation or radiation characteristics of the AM station antenna is necessary, a formal application (Form 301) must be filed, otherwise an informal application will be acceptable. When the tower of any other class of station will be used, an application may also be necessary.

If the TV antenna will be installed in the vicinity of an AM directional array, and it appears that the operation of the directional system may be affected, an engineering study must be filed with the TV application detailing the effect of the TV antenna on the AM pattern. Readjustment and field intensity measurements of the AM directional array may be required after the TV antenna is built.

The height of the antenna radiation center is the physical center of the radiating elements if uniform power distribution is used. If a split-feed system with nonuniform power distribution is to be used, the height of the radia-

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Table II—Required Field Intensities

Channel	Grade A	Grade B
2-6	68 dbu	47 dbu
7-13	71 dbu	56 dbu
14-83	74 dbu	64 dbu

tion center will not be the same as the physical center.[1] The formula for computing the power gain in db is:

$$\text{Gain in db} = 10 \log_{10} \times \text{power gain}$$

Normally, the visual and aural signals are diplexed through the same antenna.

A directional antenna may be used only to improve service, not to reduce minimum mileage separation requirements. The following regulations apply:

1. The ratio of maximum to minimum radiation in the horizontal plane must not exceed 10 db. (Max. 3.162/1).
2. Minimum ERP in any horizontal direction may not be less than the applicable minimum.
3. Maximum ERP in any horizontal or vertical direction must not exceed the applicable maximum listed in Table I and Figs. 1 and 2. When the antenna height above the average terrain is above the listed heights, the maximum designated ERP is reduced as shown in Figs. 1 and 2.
4. Radiation above the horizontal must be as low as state of the art allows and cannot exceed the value in the same vertical plane.

Applications for directional systems must be accompanied by:

1. Complete description of the proposed system.
2. Orientation of array with respect to true north, time phasing of fields from elements (degrees leading or lagging), space phasing of elements (in feet and degrees), and ratio of fields from elements.
3. Horizontal and vertical radiation patterns, showing free-space field intensity in millivolts per meter at one mile and the ERP in dbk for each direction. Methods used to compute or measure radiation patterns must be fully described, including formulas and equipment used, sample calculations and tabulations of data. Enough vertical plane patterns should be included to clearly show the radiation characteristics of the antenna above and below the horizontal plane. Horizontal plane patterns should be plotted on polar coordinate paper with reference to true north and vertical patterns on rectangular coordinate paper with reference to the horizontal plane.

Transmission Line

Transmission line make, type no., size in inches, coax or waveguide, is determined by frequency,

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[1] Ground level elevations can be determined from USGS topographical quadrangle maps. For specific area maps, contact the U.S. Geological Survey, Dept. of Int., Washington, D.C. 20240. West of the Mississippi: USGS, Denver 15, Colo. Sectional aeronautical charts are available from the U. S. Coast and Geodetic Survey, Dept. of Commerce, Washington, D. C. 20235.

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desired efficiency to produce the required ERP, and cost considerations. The length in feet is the horizontal run from the diplexer to the base of the tower plus the length up the tower to the point where the antenna gain is rated. The manufacturer's specifications should be used to determine the power loss in db for the length of line. The formulas for these calculations are:

> ERP in dbk equals transmitter power in dbk, less multiplexer loss in db, less transmission line loss in db, multiplied by antenna gain in db.

Power in dbk =

$$10 \log_{10} \frac{\text{Power in kw}}{1.0}$$

Power in kw =

$$\text{Antilog}_{10} \frac{\text{Power in dbk}}{10}$$

The rms value should be used if a directional array is employed; however, the maximum value must be entered for item 7(b) of Form 301.

The visual output is measured at the output of the vestigial sideband filter, if one is used. Visual and aural losses in the diplexer or multiplexer are given in the manufacturer's specifications.

Expected Coverage Information

Profile graphs of the terrain from 2 to 10 miles must be furnished for 8 or more radials from the transmitter location. At least 8 uniformly spaced radials, one or more passing through the principal city, should be plotted on a topographic map.[2] The profile graph for each radial should be plotted by contour intervals of from 40 to 100 feet, and where possible, at least 50 points of elevation should be used for each height of the antenna radiation center above average elevation of the radial is the height of the radiation center above sea level (item 7a on the form) minus the average radial elevation previously calculated. The ERP in each radial direction is equal for a nondirectional antenna (item 9a). For a directional antenna, the value should be taken from the radial. The graphs should show accurately the actual topography, and plotted with the distance in miles as the abscissa and the elevation in feet above mean sea level as the ordinate. The elevation of the antenna radiation center and the source of topographic information should be shown on each graph.

Table III—Permissible Field Strength Over Principal Community

Channel	dbu
2-6	74
7-13	77
14-83	80

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[2] Topographic maps for most areas are available at a nominal cost from U.S. Geological Survey, Dept. of Int., Washington, D. C. 20240. If maps are not published for your area, use the information in Par. 73.-684: Prediction of Coverage, subparagraph g.

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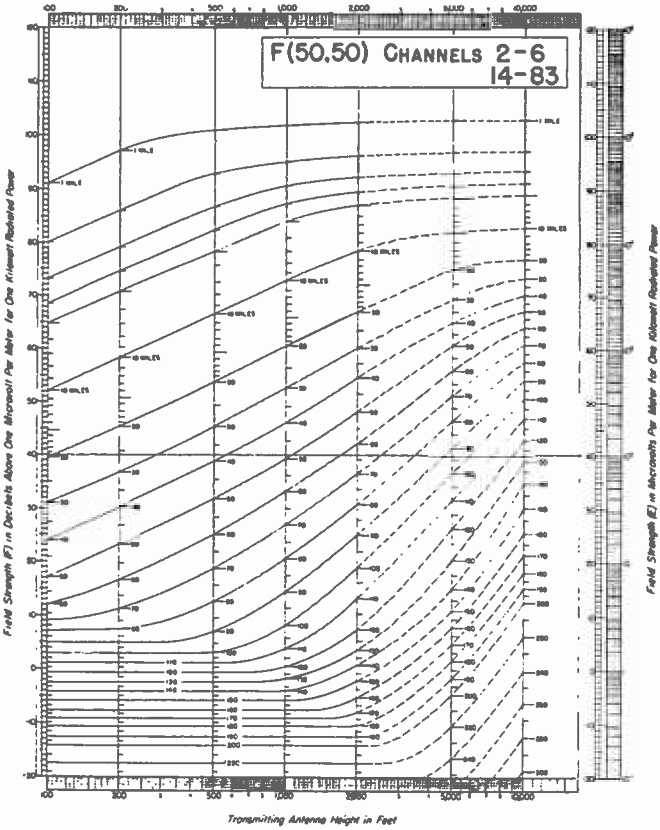

TELEVISION CHANNELS 2-6, 14-83
ESTIMATED FIELD STRENGTH EXCEEDED AT 50 PERCENT OF THE POTENTIAL
RECEIVER LOCATIONS FOR AT LEAST 50 PERCENT OF THE TIME
AT A RECEIVING ANTENNA HEIGHT OF 30 FEET

Fig. 3. Chart for predicting field strength for Channels 2-6, 14-83.

Topographic information may also be obtained along roads which are along radials from the transmitter by using a sensitive altimeter in an automobile. The average elevation of each radial may be determined from the profile graphs with a planimeter or by averaging the median values of mile or half mile segments. The height of the antenna radiation center above average elevation of the radial is the height of the radiation center above sea level (item 7a on the form) minus the average radial elevation previously calculated. The ERP in each radial direction is equal for a non-directional antenna (item 9a). For a directional antenna, the value should be taken from the horizontal pattern for each azimuth bearing of the individual radials.

The predicted distance to the Grade A and B contours are de-

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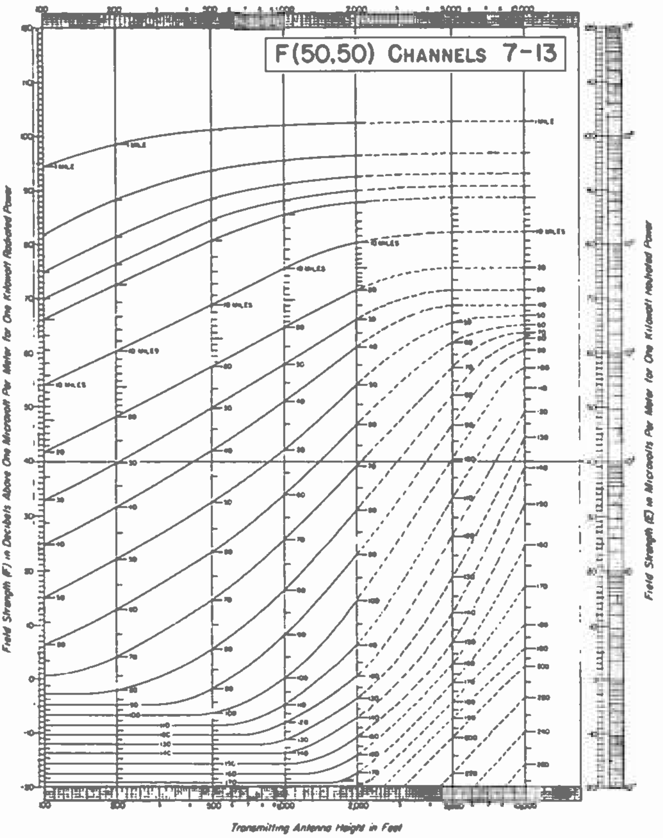

TELEVISION CHANNELS 7-13
ESTIMATED FIELD STRENGTH EXCEEDED AT 50 PERCENT OF THE POTENTIAL
RECEIVER LOCATIONS FOR AT LEAST 50 PERCENT OF THE TIME
AT A RECEIVING ANTENNA HEIGHT OF 30 FEET

Fig. 4. Chart for predicting field strength for channels 7-13.

termined from Figs. 3 and 4. The F(50,50) field intensity charts (Figs. 9 and 10 of the Rules, Par. 73.699) should be used to predict the field intensity contour distances. The charts are based on an effective power of 1 kw The sliding scale associated with the charts should be used as an ordinate scale for higher powers.[3] For example, if on channel 7 you have an ERP of 17 dbk and an antenna radiation center 2,000 feet above average terrain for radial A, the equivalent contour for Grade A service will be 71 dbu-17 db on the 1-kw curve on the 2,000 feet elevation line of Fig. 4 (Fig. 10 of the Rules, Par. 73.699). 54 dbu is at a distance of 54 miles.

The terrain in one or more directions from the antenna site may differ to some extent from the average elevation of the 2 to 10

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[3] See Par. 73.684: Prediction of Coverage for the proper application.

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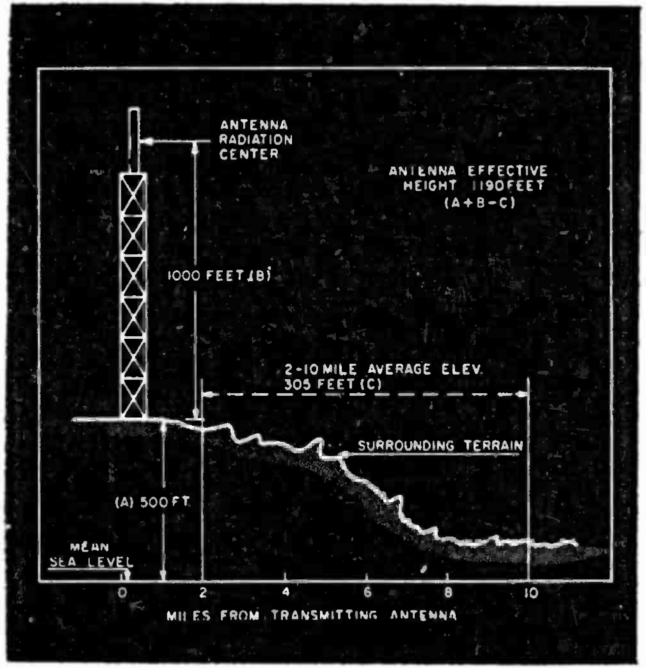

Fig. 5. Sketch showing computation of effective height for a typical radial.

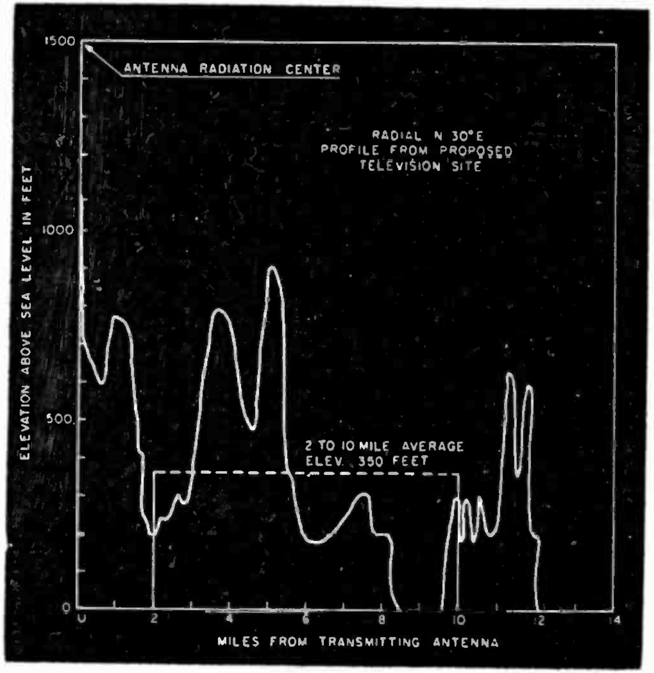

Fig. 6. Sketch of a typical radial profile graph.

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mile sector. The prediction method may indicate contour distance values different from what may be expected in practice; a mountainous area may indicate the practical limit of service while the prediction method indicates otherwise. The prediction method should be followed in these cases, but a supplemental tabulation indicating contour distances determined by other methods should be made, describing the procedure and including sample calculations. Maps of predicted coverage should include the predicted coverage by the supplemental and regular methods, the same information required when measurements are necessary. Where there are special terrain problems, a supplemental tabulation of expected coverage must be included together with a description of the method used to predict coverage. The FCC may require additional information about terrain and coverage. The transmitter location, the radials used in items 14a and 15, and the Grade A and B contours should be plotted.

The minimum field strength required over the principal community is shown in Table III. The field strength in your case may be

Significant Factors in Filing

If an application is submitted for changes in an existing station, all paragraphs relating to the proposed changes should be completed. The remaining paragraphs should be marked "On File—No Change."

Furnish engineering exhibits to support the application, but data submitted in previous Form 301 filings should not be repeated.

Costs for TV Engineering Data

The average cost for engineering, design work, tests and measurements, calculations, computations, compiling of data, and filing Form 301 for a TV facility would be between $750 and $1250. Usually, there is an additional charge of $100 for personnel expenses and the cost of obtaining and entering the data for:

- a. **Geographical coordinates**
- b. **Topographical maps**
- c. **Profile maps**
- d. **Sectional aeronautical maps**
- e. **Aerial photography**
- f. **Predicted field strength patterns and contours**
- g. **Instrument approach or landing charts**
- h. **Other incidental materials**

Charges for design and measurements for a directional array or other changes in an existing facility, would cost about $500.

Facts About TV Antennas

Stacking one element on top of another and feeding the elements in proper phase increases the far field voltage.

The field at the horizon increases with additional bays, and additional nulls and lobes appear between the first null and the horizon.

Nulls over populated areas can be avoided by phasing or power splitting or a combination of both. Determine the vertical angle to be covered.

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calculated by determining the depression angle below the horizon from the antenna height and distances to certain parts of the community. The dbu value may be determined from Figs. 9 and 10 of Par. 73.610, using the ERP value for the correct depression angle for the proposed antenna vertical pattern. Par. 73.610 and 73.611 explain separation requirements.

Figs. 5 and 6 are examples of typical graphs which must be filed for each of the eight radials with the transmitter at the center. Each radial is 45° apart and each is averaged for its effective antenna height figure; the contours are computed for the individual radial height.

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Design & Operation of Directional AM Antennas
Part 1
Basic Directional Considerations

John H. Battison

TO MANY radio engineers, the directional antenna is still a mystery-shrouded enigma. As a result, the demand for qualified directional antenna operators continues to grow. The following articles will acquaint operator-engineers and management personnel with the design and operation of DAs to the extent that they can develop a working familiarity with DA systems.

Basic Directional Considerations

A single vertical antenna will radiate an equal amount of power in all directions, providing a basically circular pattern. If a second vertical antenna is inserted into the field of the first, the pattern shape will no longer be circular; it may be elongated, "dented," or approximate a figure 8, depending on height, spacing, and current in the second antenna. Patterns shapes may be distorted if an antenna system is built too close to a water tower or a similar structure capable of re-radiating RF energy. The contrived introduction of the second antenna into the field of the first allows us to control its effects and achieve the pattern desired.

Three factors determine the radiation pattern of any array: spacing between the towers; phase relationship of tower currents; and the ratios between the amounts of current in each tower. By manipulating these parameters, almost any desired pattern can be achieved. In physical construction, each tower is treated as though it were an individual antenna as far as its ground system is concerned. All antennas must have the same number of radials. If tower spacing is such that the radials would overlap, each radial must be terminated where it meets another and the ends bonded together (Fig. 2). Bonding is necessary to obviate any high resistance joints that can cause power losses in the ground return path. Bonding also reduces the possibility of cross modulation and harmonic radiation due to corroded connections in the high power field surrounding an antenna.

The ground systems of all the antennas in an array should be identical. If they are not, and one antenna has fewer radials than another, there is a possibility that radiation in that direction may be impaired due to increased ground losses on that side. This is a theoretical problem; however, if an array design proposing a very seriously lopsided ground system is presented to the FCC, a special

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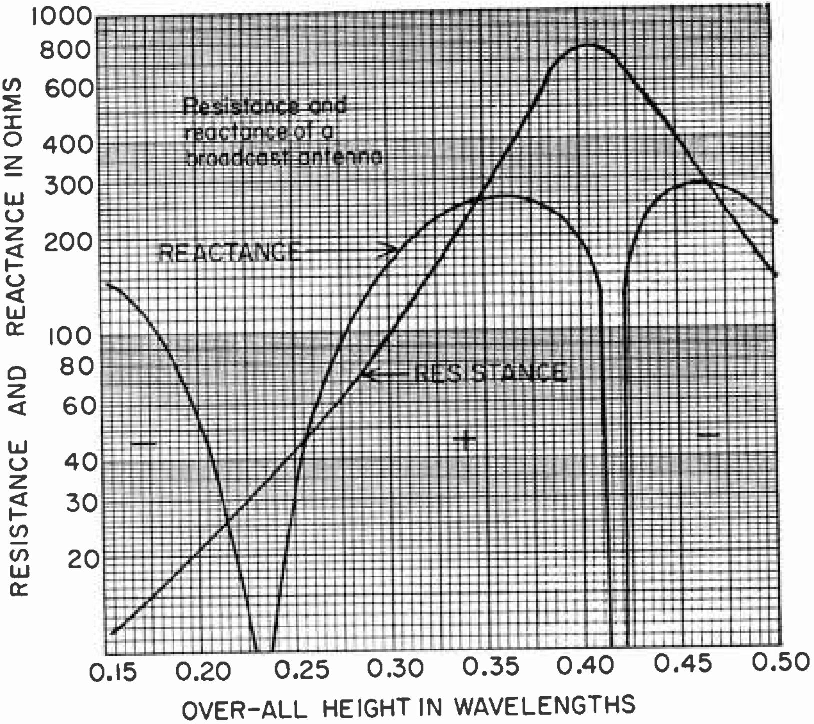

Fig. 1. Location of 1st and 2nd resonance points, and the resistance/reactance relationship in a broadcast antenna.

showing may be required to prove that the pattern and efficiency will not be impaired.

Two-Tower Arrays

Fig 2 is a plane representation of a typical two-tower array. It is convenient to assume that the currents in each tower are the same, the height of each tower is the same, and the current phasing in each tower is the same. The only thing that can affect the value of the radiation field is the position of the observer in relation to the combination. The towers are indicated as #1 and #2, the observer's positions as P1 and P2; these positions were chosen so that they are at least 10 wavelengths away from the towers, and in fact can be treated as though they were infinitely far away. For all practical purposes, the distance of P1 to both towers is the same. But no matter how far P2 is from the array, its distance from tower #2 will always be a maximum of a half wavelength (180°) greater than from tower #1. P1 and P2 may be moved 180° (P1 to the top of the illustration and P2 to the right of the array) and the result will be exactly the same.

Remembering that radiation from each tower is identical, let us look at the signals received at P1 and P2. At P1 the two radia-

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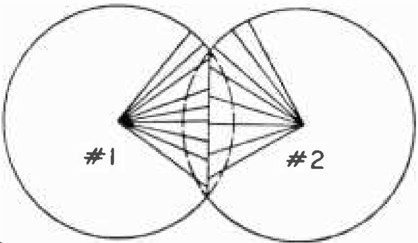
tion path lengths are identical; therefore, each signal will arrive with the same phase and magnitude (neglecting transmission path distortions). Since the signals will be in phase (and thus will add), signal strength will be twice the amplitude as from a single antenna (see Fig. 4).

At P2 the distance from tower #2 is the same as from P1, but the distance from tower #1 to P2 is 180° (a half wavelength) longer. Therefore, the signal from

Fig. 2. The ground radials of multitower arrays must be terminated and bonded at their junction.



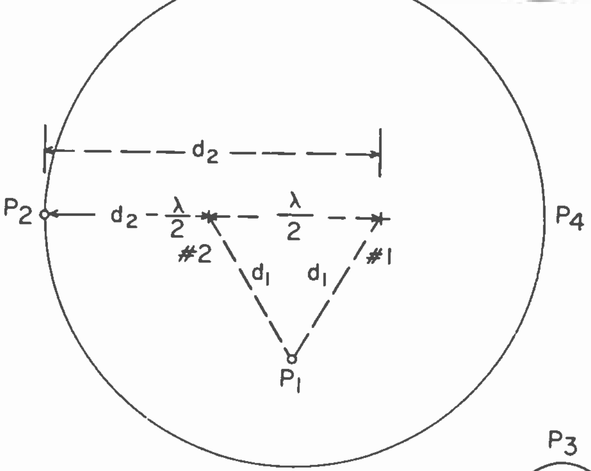


Fig. 3. Geometric layout of basic 2-tower array. P1 is equidistant from each tower; P2 is the same distance from tower #2 as P1, but ½ wavelength further from tower #1.

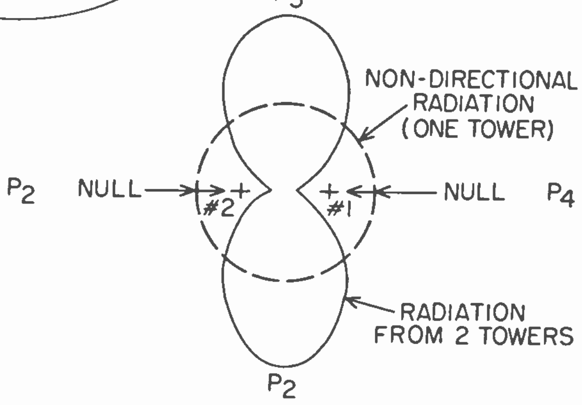


Fig. 4. Radiation of array in Fig. 3.

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Antenna Engineering Fundamentals

Radiation Measurement: The radiation standard used in all antenna computations is the millivolt per meter (mv/m) at one mile from the antenna. With non-directional antennas, radiation is referred to, for example, as 175 mv/m; the one mile is understood. Directional antenna radiation is given the same way, but an angle from True North is included to describe the azimuth bearing—for example, azimuth 110°, radiation 175 mv/m. The one mile distance still applies but only on this azimuth.

Bearings (azimuths) are measured from True North. During the actual design work, a line through the towers (line of towers) is used as the zero degree reference. After the pattern has been computed it is oriented to True North to obtain the required coverage.

Radiation Resistance: Radiation resistance can be computed by applying Ohm's Law. The actual radiated power equals the antenna current squared times the resistance. Therefore, a half-wave dipole with one amp of RF energy flowing through its center (note the specific location) will produce a field intensity of 37.42 mv/m at one mile. The radiation resistance measured at the antenna center would be 73.13 ohms. The power required to produce one amp of current (one amp squared times the resistance of 73.13) equals 73.13 watts.

Note that 73.13 ohms is the correct radiation resistance only at the point of measurement (center). The value at other points may be computed by applying the sine of the distance from the end of the antenna to the point of measurement. For example, suppose we measured 45° from the end of the antenna; the sine of 45° is 0.7071, or 0.7071 amps. Radiation resistance is computed by dividing the power (73.13 watts) by the current squared (0.5), 146 ohms.

Antenna resistance is generally computed at the point of maximum current; however, it is usually necessary to know the input resistance at the drive point of the antenna. It is usual to measure resistance at the input of the tower with all coupling equipment disconnected. In directional arrays, resistance must also be measured at the common feed point to all towers.

Antenna Resonance/Reactance: Transmission line theory applied to the dipole gives us a usable tool; in fact, the characteristic impedance of a half-wave dipole can be analyzed in the same manner as a transmission line, generally described

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by $Z=Z/j \tan \phi$. Applying this formula to the two elements of a half-wave dipole, we find that $Z=120\ (1_n\ 4S-1/d)$. At low frequencies, input impedance is largely capacitive and radiation resistance is low. Above the first resonance, resistance continues to increase and reactance becomes inductive. At the second resonance, reactance again falls to zero, theoretically, and resistance reaches a maximum (Fig. 1). The height of a typical broadcast antenna is approximately one-half wavelength at the second resonance.

Practical Broadcast Antennas: Quarter wavelength towers, using the "earth image" as one section of a half-wave dipole, are widely used in broadcasting. The two parts of the antenna (tower and earth) are separated by an insulator; one side of the transmission line is connected to the drive point of the tower, the other side is grounded. Thus, half the power goes into the antenna and the other half goes into the ground radiation field. Since the antenna input is divided in half, so is the impedance of the half-wave antenna. As a result of the capacity between the tower and ground, certain losses due to poor earth conductivity are inevitable. The loss is minimized by a system of buried wires radiating out from the base of the tower. Generally, there are 90 such radials ¼ or ½ wavelength long. Burial depth, size, and earth conductivity are less important than length of and distance between radials.

One amp in a half-wave antenna of 73.13 ohms resistance will produce 37.42 mv/m at one mile. Due to the apparent existence of the second portion of the half-wave antenna in the ground, a quarter-wave section will produce 37.42 mv/m at one mile with one amp flowing at its base. However, the radiation resistance of the quarter-wave tower is half that of a half-wave dipole, so the power required to drive the antenna with one amp is only 36.6 watts (radiation resistance is 36.6 ohms).

Field intensity is proportional to the square root of the power, with 1 kw as the usual reference. Thus, we refer our statements to 1 kw as :
$37.42\ \text{mv/m}\ \sqrt{1{,}000/36.6} = 196\ \text{mv/m}$ (one amp produces 37.42 mv/m at one mile). This says that with an ideal antenna (no losses and 100% efficiency), 1 kw fed into a quarter-wave antenna will produce 196 mv/m at one mile. If we want to judge how more power will increase field intensity at the same distance, we multiply 196 by the square root of the new power. For example, an increase from 1 to 10 kw will give us 610 mv/m (multiply 196 by 3.16, the square root of 10).

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Know the Rules

Contrary to popular belief, any engineer can present a design for a directional antenna to the FCC. In fact, any engineer can file any kind of FCC application. All he has to do in the case of a directional antenna is satisfy the Commission that he is properly qualified to perform the work. If he does not, chances are the application will be returned with a request for more information. In some cases it may simply be denied!

One word of warning is in order: Although it is quite true that **anyone** can file an FCC application, it is legal, as far as state professional engineering laws are concerned, **only** if it is for one's employer, or oneself. An engineer, no matter how qualified, cannot set himself up as an engineer for public consultation unless he has achieved registration as a professional engineer in his state.

The following FCC Rules describe the data to be provided by the applicant:

73.33 Antenna Systems, and **73.45 Radiating System:** Describes the basic showing required.

73.150 Data Required with Applications for Directional Antenna Systems: Call for a complete technical description with an actual sample calculation using the formula specified. Full constructional and antenna layout details are required in pictorial (sketch) form. All actual pattern data such as major and minor lobes as well as nulls must be plotted.

73.151 Field Intensity Measurements Required to Establish Performance of Directional Antennas: Governs the making of a proof of performance once the system is built. Its main objective is to demonstrate to the Commission's satisfaction that the antenna conforms in performance with the technical specification. This Rule tells **how** to make the measurements, **where** to make them, and **what** to do with them. It specifies how the resulting data should be presented, and defines the method for determining ground conductivity. It also asks for details concerning the monitoring points selected.

tower #2 will reach P2 before the signal from tower #1. In fact, it will reach P2 exactly 180° out of phase with the signal from tower #1. As a result, the two signals will exactly cancel each other so that there will be zero signal at P2.

The broken circle in Fig. 4 would be the radiation pattern from a single antenna at the same power, drawn to scale so that it can be seen that the radiation in the direction of P1 (and P3) is twice that expected from one antenna. On the other hand, the radiation at P2 (and P4) is zero, as shown by the tangents of the two major lobes. At other positions around the 360° circle surrounding the array, the pattern size and shape will vary according to the distances and the particular position.

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It must be remembered that this an idealized theoretical treatment of the situation so that the pattern comes out evenly. In practice, the radiation will not go to exactly zero under most conditions, nor can we literally expect twice the radiation at the maximum signal positions. Generally, these conditions may be assumed initially, then modifying factors are applied to obtain the actual operating parameters. It is well to remember that in practice the pattern is not formed until the induction field (strong signal field in the immediate area of the array) has been left behind, and the measurement point is far enough away for the field intensity to be modified by the phase of the arriving signals.

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Determining Pattern Shape
Part 2

John H. Battison

THE DESIGN of a two-tower directional antenna system requires computations for both the *size* and *shape* of the radiation contour pattern. Pattern size, of course, is determined by radiated power; however, before you can compute radiation you must know how far you want your signal to go in each direction. Thus, the shape of the pattern must be determined first.

Pattern Shape

Signal strength at any point around the array is determined by the phase and magnitude of the arriving waves; therefore, a prediction of signal strength at any particular position requires the addition of vectors. Assuming the currents in each tower are equal, and that the towers have the same height, the only remaining factor which can influence the signal at any point is the phase relationship between the respective waves.

Two factors control the phase relationship between the arriving waves—current phasing in each tower (in our example they are equal) and space phasing (the difference in path length between the towers and the reference point). Fig. 1 shows the mathematical relationship between these factors. It is usual to refer to Tower #1 as the reference tower. Since we are interested only in the pattern *shape* at this point, we arbitrarily say that Tower #1 is carrying unity current at the reference phase, expressed as $1\underline{/0^\circ}$. The current in Tower #2 is then referenced to #1, with its magnitude stated as "B" times the current in #1 and its phase designated by ϕ (Greek letter Phi). Point

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P in Fig. 1 can be anywhere in a 360° arc (always the same distance from the array).

In Fig. 1, a right triangle is formed by the towers and point X. Side S° is the spacing between towers, expressed in degrees, and angle θ (Greek letter Theta) indicates the horizontal angle from the center of the array. Obviously, the distance from P to Tower #1 is greater than the distance to #2 by the measure from X to #1, expressed as S cos θ. This means that the signal arriving at P from #2 will lead the signal from #1 by the distance from #1 to point X (determined by multiplying S° by the cosine of angle θ). Since this relationship is consistent, all we have to know to predict space phasing, or the relative strength of the signals arriving at P, is the tower spacing in degrees (S°) and the horizontal angle θ. The field intensities, of course, at P are proportional to the antenna currents; in this case we set them at unity, or equal to each other.

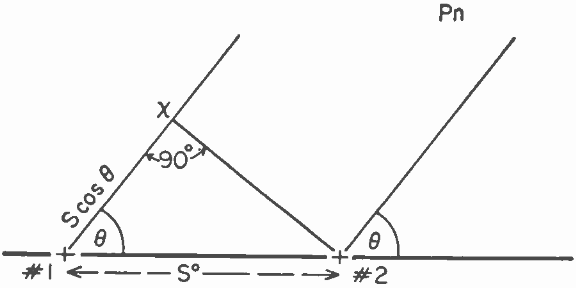

Fig. 1. Trigonometric relationships used to compute the shape of a DA pattern. Symbol designations: φ = electrical phase; S = spacing in degrees; B = horizontal angle from center of array; 1/ 0° expresses unity current in reference tower; B/ φ° expresses current in #2, B times that in #1 and leading by φ°.

Center of the Array

Whenever referring to a directional antenna, the coordinates are always given for a position at the midpoint of the array. This means midway between two towers, the middle tower (or middle) of a three-tower array, the center of a rectangular array, etc. To plot the directional pattern, polar coordinate paper is used, and the center of the paper is assumed to be the center of the array. Therefore, the angular

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value·θ is based on a line from the center of the array to P, and determined by the location of P in a complete circle around the array. When computing field intensity contours using the radiation pattern, all radials and radiated powers are measured from a map location which represents the midpoint of the array. A tower (unless it is the middle point in a 3-tower array) should never be used as a measuring point when plotting coverage or completing Form 301.

Computations for two-tower arrays with equalized powers are the simplest to work with since only half or one side of the pattern shape has to be determined. (Since there are only two towers, the pattern has to be symmetrical. An angle of 110° will have the same radiation as an angle of 250°; i.e., each side of the line of towers is the same at a corresponding angle.)

Line of Towers

The line of towers is very important in directional antenna design. Up to this point, we have considered only the pattern shape, without regard to the orientation intended for it. We can take a specific pattern and rotate it through 360° on a map until its nulls and major lobes point in the proper directions to provide the desired coverage. The line of towers may (but generally do not) line up with the bearing joining the proposed site to the area to be protected or covered. In Fig. 2, we have a proposed site X with a broken line running from it to a city Y which must be protected. This angle is 285° from True North, measured in a clockwise direction. The proposed pattern is designed to serve X and protect Y; therefore, the line of towers is oriented as shown—in this case, at 90° to the line from X to Y, or 15° from True North (285° plus 90°). Thus, radiation has to be specified with reference to one meridian or the other, and it is very important to state clearly whether a given radial is with respect to the line of towers or True North. The term *azimuth* is used when referring to True bearings from North.

Nulls and Lobes

If the currents in the towers are not precisely equal (as they are in our example), radiation

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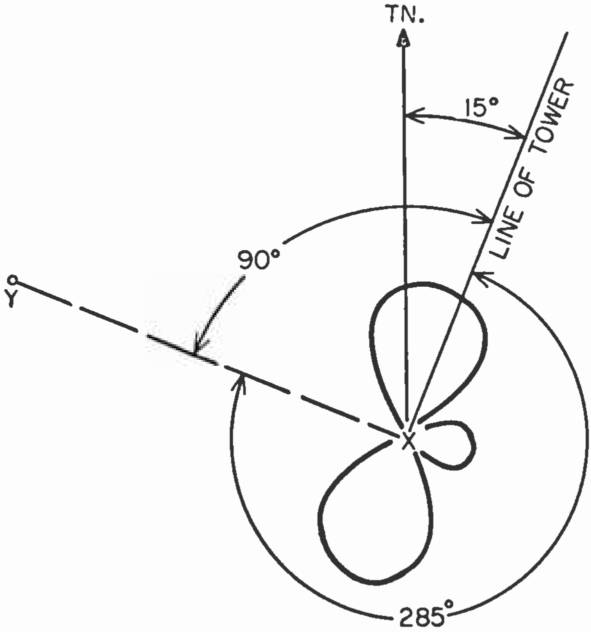

Fig. 2. Illustration of the relationship between the line of towers and azimuth bearings.

in the null areas can *never* reduce to a zero value. This is quite important in practice; if the FCC receives a DA application in which the radiation in the nulls diminishes to zero, it is quite certain that the proposal will be carefully scrutinized by Commission engineers, and the odds are about a million to one that it will be rejected—especially if the proposal depends on zero radiation in a critical direction. Absolute zero is impossible to achieve because of the multitude of external factors which can affect an antenna pattern (guy wires, transmission lines, towers, etc.).

On the other hand, by allowing a small pip of radiation in the center of a null; it is very often possible to obtain a broad null which quite easily provides the required protection. The importance of this design will become obvious when the engineer attempts to adjust the antenna. Antenna adjustment is very critical for sharp and deep nulls, but for a broader one, say 60° wide, with a small pip in the middle and no lower than 10 to 15 mv/m, adjustment

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Table I. Pattern Shape Computation Matrix

(1) θ	(2) Cos θ	(3) 90 Cos θ	(4) (3) +100	(5) (4) +1.0	(6) (5) +1 /0	(7) P_{sf}	(8) Rad. mv /m
0	1.00	80.00	180.	−1 + *j*0	0 + *j*0	0 < 0	0
10	0.9845	78.45	178.45	−0.999 + *j*0.2705	0.001 + *j*.027	0.02705 < 87.88°	0.94
20	0.9379	75.00	175.00	−0.996 + *j*0.0872	0.004 + *j*0.0872	0.0872 < 87.36°	19.4
30	0.8660	69.40	168.40	−0.976 + *j*0.218	0.024 + *j*0.218	0.2309 < 83.78°	30.06
40	0.7660	61.20	161.20	−0.946 + *j*0.322	0.054 + *j*0.322	0.3264 < 80.47°	62.5
50	0.6428	51.40	151.40	−0.878 + *j*0.479	0.122 + *j*0.479	0.4825 < 75.7°	91.8
60	0.5000	40.00	140.00	−0.766 + *j*0.643	0.234 + *j*0.643	0.684 < 70°	101.0
70	0.3420	27.30	127.30	−0.616 + *j*0.78801	0.384 + *j*0.788	0.876 < 64°	121.2
80	0.1736	13.80	113.80	−0.394 + *j*0.919	0.606 + *j*0.919	1.102 < 55.3°	159.0
90	0.0000	00.00	100.	−0.174 + *j*0.984	0.826 + *j*0.984	1.283 < 49°	185.5
100	−0.1736	−13.80	−86.2	0.066 − *j*0.998	1.066 − *j*0.998	1.461 < 42°	208.0
110	−0.3420	−27.30	−72.70	0.297 − *j*0.955	1.297 − *j*0.955	1.610 < −36.4°	232.0
120	−0.5000	−40.00	−60.00	0.500 − *j*0.866	1.500 − *j*0.866	1.734 < −30°	248.0
130	−0.6428	−51.40	−48.6	0.669 − *j*0.743	1.669 − *j*0.743	1.829 < −24°	260.0
140	−0.7660	−61.20	−38.8	0.788 − *j*.616	1.788 − *j*0.616	1.890 < −19°	268.0
150	−0.8660	−69.40	−30.6	0.866 − *j*0.5	1.866 − *j*0.50	1.932 < −15°	275.0
160	−0.9379	−75.00	−25.00	0.906 − *j*.423	1.906 − *j*0.423	1.953 < −12.5°	277.0
170	−0.9845	−78.45	−21.55	0.930 − *j*.367	1.930 − *j*0.367	1.960 < −10.8°	281.0
180	−1.0000	−80.00	−20.00	0.940 − *j*0.342	1.940 − *j*0.342	1.972 < −10°	284.0

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Pattern Shape Computations

The field intensity at P in Fig. 1 can be expressed as:

$E = 1\angle 0^\circ + B\angle(\phi + S\cos\theta)$

S is the spacing in degrees between towers

B is the ratio of the tower currents

ϕ is current phase (leading or lagging)

θ is the horizontal angle from the center of the array, generally measured in steps of 10°, except in cases where a small angular change is important.

Computing the Pattern

The data in Table I is often called a matrix, although it is really a tabulation. Assume the directional pattern to be computed is expressed by the following:

Spacing (S)=80°

Tower currents: $1.0\angle 0$

$1.0\angle 100^\circ$

Current ratio 1:1

Current phasing 100° (Note: this can also be written $\angle -50 : \angle 50$)

Pattern Shape Factor equals: $1\angle 0^\circ + B\angle(\phi + S\cos\theta) = 1.0\angle 0^\circ + 1.0\angle(100^\circ + 80^\circ\cos\theta)$

The operation shown at the top of each column in Table I is performed, and each column in turn is processed by the next one. The operation between columns 4 and 5, the conversion of degrees into rectangular vector coordinates, may not be obvious. Column 4 is the magnitude and phase produced by adding 1.0 at phase angle 100°; i.e., the value of column 4 for $\theta = 0^\circ$ is $\angle 100^\circ$. Column 6 is merely the addition of the signal from #1 tower. This is $\angle 0^\circ$, written $1 + j0$. Column 7 is completed by converting the rectangular coordinates into polar form to give the magnitude of the radial. The angular (phase) data provided by this conversion is not needed, so only the magnitude is entered in column 7. Pattern shape can be plotted in terms of relative values, but to compute coverage, radiation along each radial must be converted to millivolts per meter (mv/m). Pattern value can be computed as follows:

$$\text{Radiation} \times \frac{\text{Radius}}{\text{Radial length}}$$

at desired azimuth for $180^\circ = 196 \times \dfrac{3.9\text{ mv/m}}{2.73}$.

Column 8 has been completed using this formulation. Fig. 3 can also be used to scale off any other desired azimuth values.

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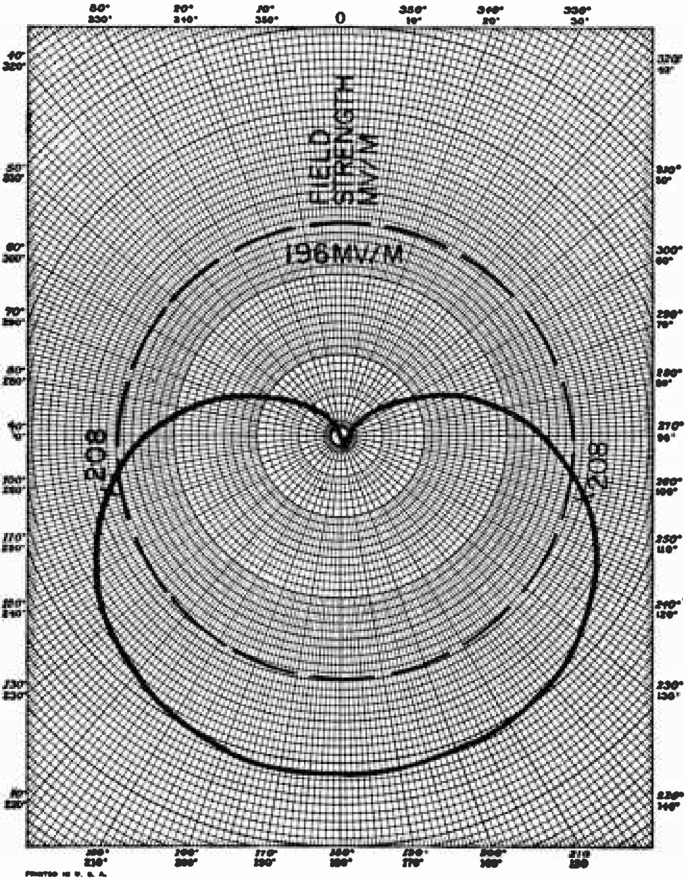

Fig. 3. Dashed circle shows field strength of 196 mv/m for 1 kw. DA radiation values may be scaled off.

becomes far easier. Also. even though calculations work out beautifully in theory, actual performance is usually very different. So whenever possible. it is best to make allowances by developing an MEOV (Maximum Expected Operating Value). As a matter of fact, the FCC now requires that an MEOV be provided in all critical directions. Some consulting engineers provide an MEOV around the entire pattern to give themselves a buffer.

The MEOV factor is generally computed by taking about 5% of the radiation and adding it to the minimum allowable radiation. One approach is to compute the absolute maximum

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permitted, then subtract 5 to 10% and use this figure as the desired minimum radiation. Generally, MEOV is shown on the pattern as a dotted line around the solid line of the computed contour.

Interference contours must always be calculated using the MEOV radiation, not the base figures. The reason for this is that the FCC, when making allocation studies, relies on the anticipated *maximum* radiation that could be permitted under the specifications of the construction permit. If they do this, and if everyone does it when preparing new station applications, there will be no difference between FCC figures and those of applicants. If the applicant allows himself an adequate MEOV in a null area, and during the proof encounters difficulty in meeting pattern minima, it is frequently possible to bring the pattern within the MEOV figures and thus meet the CP requirements. Many a station has been able to get on the air more easily because of the existence of the MEOV cushion.

Computing Power

In order to relate the pattern shape to actual power in mv/m, a reference is needed. Fortunately, we have such a reference—the standard of X mv/m at one mile. Depending on the proposed power and tower heights, an appropriate radiation value such as 196 mv/m at one mile for a 90° tower can be used. It is only necessary to compute the area bounded by the pattern already computed, and then convert this to a circle of equal area by using the formula for the area of a circle ($A = \pi r^2$; $r = \sqrt{A/\pi}$).

Fig. 3 depicts the 196 mv/m circle (with 1-kw transmitter power) drawn on the DA pattern shape. Using the lengths of the various radials to the DA pattern, we can compute the actual pattern values (see box). The pattern shown in Fig. 3 is based strictly on the relationships between the various magnitudes and angles, and therefore does not have any meaning as far as actual operation is concerned. The shape is what we are after.

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Determining Pattern Size
Part 3

John H. Battison

THE SHAPE of a directional antenna pattern indicates the *relative* radiation in each direction; it is used to determine the coordinate locations of nulls and lobes so that proper protection will be afforded co-channel and adjacent channel stations. Pattern shape computations do not specify the exact *area* which the pattern will cover, however, and additional computations must be made to prove that a proposed contour will not cause any objectionable interference in any direction.

Pattern Area Computations

One method of measuring pattern area is to use a planimeter, a small instrument designed to measure the area of an irregular plane figure.

Another way to determine pattern area is to lay the sketch over a sheet of suitable sized squares representing the proper scale.

For daytime operation, vertical (or high angle) radiation is generally of no consequence; an exception would be transition period radiation (2 hours before sunrise) of Class II stations. In such cases, vertical radiation must be limited to the point where it will not interfere with the dominant Class II station.

For nighttime operation, vertical radiation assumes much greater importance, so much so that the FCC charts are quite precise in prescribing allowable limits. (Even though strict control may be maintained over horizontal radiation, high angle radiation can literally blast the protected station off the air.) Eliminating objectionable vertical radiation usually requires cut-and-try methods, one of the main reasons that the preparation of nighttime applications is often expensive.

Vertical radiation must be computed at every horizontal radial. The high angle radiation characteristic is known as F (θ), and is published as a standard factor for every 50° of horizontal azimuth and vertical elevation. Fig. 1 shows how this factor varies.

Vertical radiation at any horizontal angle (θ) may be computed by:

$$V_{SF} = F(\theta)\ [\angle 0^\circ + B \angle (\theta + S \cos\theta \cos V)]$$

However, because V, the vertical angle, and horizontal angle θ appear only as cosines in this expression, they merge and appear as the result of only one angle; thus, they can be treated as the cosine of a single angle. It is therefore necessary to compute

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only the horizontal shape and apply the vertical factor F(θ).

For example, let's assume that the horizontal angle (θ) is 100° and compute the vertical radiation at 30°. The cosine of 100° is −0.9848; the cosine of 30° is 0.8660. The product of these two values is 0.8540. A cosine table shows the angle equivalent to this value to be 148.6°. At this angle the horizontal value is 3.85 (see Part 2). In Fig. 1, the F(θ) value for 30° of elevation is 0.825, for a tower height of 90°. The product of 0.825 and 3.85 is 3.12. the vertical radiation in the same units as Fig. 1. To convert to mv/m, we multiply 148.6° by the power ratio, which equals 226 mv/m vertical radiation at 30° above the horizon.

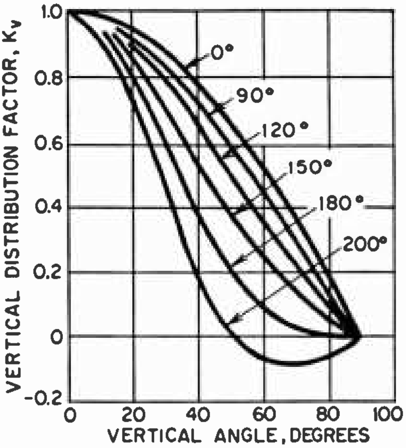

Fig. 1. Effect of phase angle change for the pattern in Fig. 2.

Towers of Unequal Height

Towers of equal height should, of course, be used wherever possible to avoid unnecessary complications. However, if an existing tower (or towers), must be used in a new array for increased power or for nighttime operation, compensating adjustments must be made in the tower feeder system.

Simplified DA Calculations

If the currents in each tower are equal, the pattern formula can be reduced to:

$E = K \cos (S/2 \cos \theta + \phi/2)$
where E is the field in mv/m.

K is a constant that will produce an expected RMS from the antenna system, based on the experience of the engineer. In this case, we will assume it to be 200, which is reasonable for 500 watts.

S is the tower spacing in degrees.
θ is the azimuth angle.

RMS indicates the efficiency of the array in mv/m; in our example it is 134.4 mv/m.

Based on parameters in Fig. 2, the radiation at 60° would be 65.12 mv/m.

It then became necessary to amend the pattern slightly to reduce radiation in the null area. The antenna parameters were changed slightly to reflect a phase difference of 100° instead of 102°, and the line of towers was changed from 090° to 080°. Everything else remained the same. The effect of the phase change is shown in Fig. 3.

Very little change has occurred in the broad main lobe values, but a very significant change has occurred in the null area—the "pip" has disappeared. Seemingly small changes such as this can play a major role in the success or failure of an application.

The important thing to remember is that the ratio of the antenna fields, or the field ratio, determines the radiation pattern. The field ratio is, of course, directly related to the tower current ratio,

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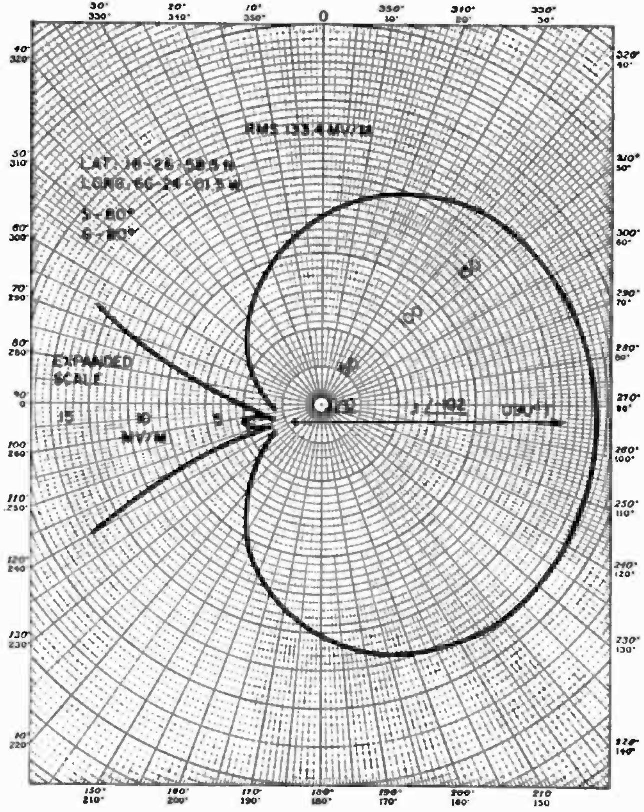

Fig. 2. Vertical shape factor for various antenna heights.

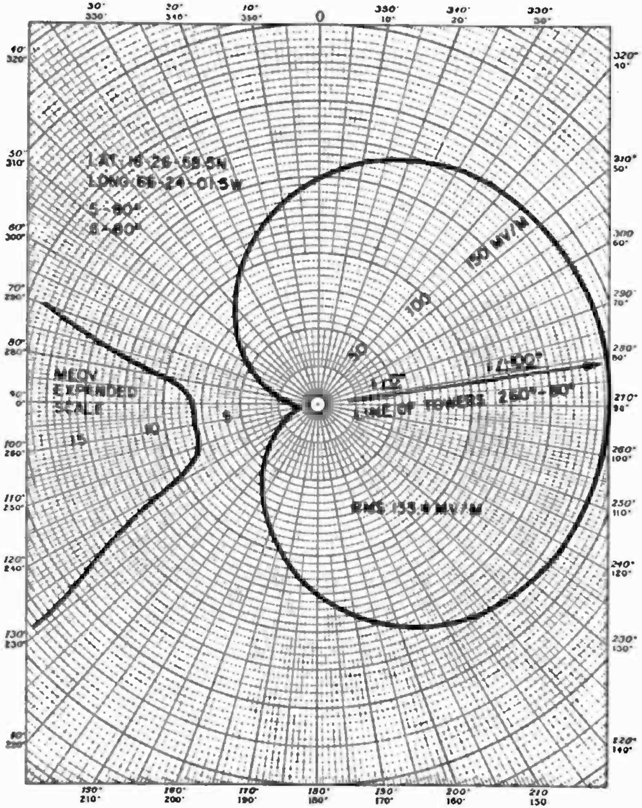

Fig. 3. Pattern computed by simplified method for towers with equal current.

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Table I. Azimuth Bearings and Radiation for Fig. 2.

Azimuth	θ	Radiation MV/M
260°T	0	0
270	10	2.10
280	20	8.38
290	30	18.84
300	40	31.64
310	50	49.4
320	60	68.4
330	70	88.62
340	80	108.92
350	90	128.56
360	100	146.3
010	110	161.2
020	120	173.2
030	130	182.3
040	140	188.89
050	150	192.9
060	160	195.34
070	170	196.58
080	180	196.96

Table II. Azimuth Bearings and Radiation for Fig. 3

Az.	θ	Radiation MV/M
270	0	3.5
280	10	1.4
290	20	4.9
300	30	15.0
310	40	28.0
320	50	46.0
330	60	65.0
340	70	86.0
350	80	106.0
000	90	126.0
010	100	144.0
020	110	159.0
030	120	172.0
040	130	181.0
050	140	187.0
060	150	192.0
070	160	194.0
080	170	197.0
090	180	198.0

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and can be neglected only when it is unity (i.e., when both towers have the same currents and fields). If the tower heights are unequal, the actual current ratio required to produce the desired field ratio must be computed.

For example, if we want one tower that is 90° high and another that is 135° high, we must determine the field of each tower at one mile for 1 kw. This can be determined by referring to antenna radiation charts. Actually, it will be necessary to reduce the current in the taller tower to a value that will produce the same power as the shorter tower at one mile. Without any adjustment, the 135° tower theoretically will produce 213 mv/m at one mile whereas the 90° tower will produce 196 mv/m, with 1 kw fed to each tower. If the power in the shorter tower is 1 kw, then by application of Ohm's law we find that only 840 watts will be required to produce a 196 mv/m field from the taller tower (power varies as the square of the field intensity).

In making adjustments in the tower current ratio to equalize the radiation field, tower base resistances must be considered. The base resistance of the 90° tower will probably be around 37 to 40 ohms whereas the base resistance of the 135° tower will be around 300 ohms. Using these figures, we can compute the currents required to produce the 1 kw (for the 90° tower) and 840 watts (for the 135° tower) by using Ohm's law ($P = I^2R$). This gives us 5 amps for the 90° tower and about 1.7 amps for the 135° tower. Therefore, the current ratio for equal fields is 5:1.7, or about 3:1. The problem then becomes a matter of adjusting tower currents, which requires some cut and try, until the desired field (current) ratio is obtained.

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Multiple-Tower Arrays
Part 4

John H. Battison

THE TWO-TOWER antenna system is the basic directional array. It can produce a large number of basic patterns. In fact, the results are so standardized that a set of patterns can be drawn using the parameters shown in Fig. 1 .

However, the 2-tower array cannot produce non-symmetrical patterns, nor can it always adequately suppress radiation over a wide angle. If a narrow, but concentrated, lobe is needed, a multiple-tower array must be used.

The 3-Tower Array

The in-line 3-tower configuration is the simplest multi-tower array to handle. Fig. 2 shows the basic vector relationship, which is very similar to that used for 2-tower arrays.

The formula for the pattern produced by three in-line equally-spaced towers is:

$$F_{px} = 1\angle 0^\circ + BL(\phi_2 + 5 \cos \theta) + CL(\phi_3 + 2\,S \cos \theta)$$

where θ is the angle between the line of towers and the line joining point P to the tower (azimuth),

S is the distance between the towers in degrees.

ϕ is the electrical phasing between tower currents.

B and C represent tower current ratios referenced to tower T_1

S Cos θ is the space phasing difference between the fields of the three antennas.

If unequal tower spacing is employed, 2S in the right-hand expression becomes $[\phi + (S_1 + S_2)$ Cos $\theta]$. In other words the physical tower spacing is mathematically added, and the total is used as the physical spacing term.

If symmetrical electrical phasing and current ratios are used, and if the 3-tower array is completely symmetrical about the center tower, the solution will be much simpler because the formula simplifies itself.

Consider the array defined by these specifications:

T_2	T_1	T_3
$2\angle\phi_2$	$1\angle 0^\circ$	$2\angle\phi_3$

Parameters:
$S_1 = S_2$
G (tower height) $= G_2 = G_3$
Current Ratios:
T_1 center tower = 1
T_2 & T_3 (outer towers) = 2
Electrical Phase Angles:
$\theta_2 = \theta_3$

The two vectors produced by T_2 and T_3 are plotted as shown in Fig. 3. The actual angles or their magnitudes (length) are unimportant at this point; therefore, the vectors may be placed in the first quadrangle and the current phase

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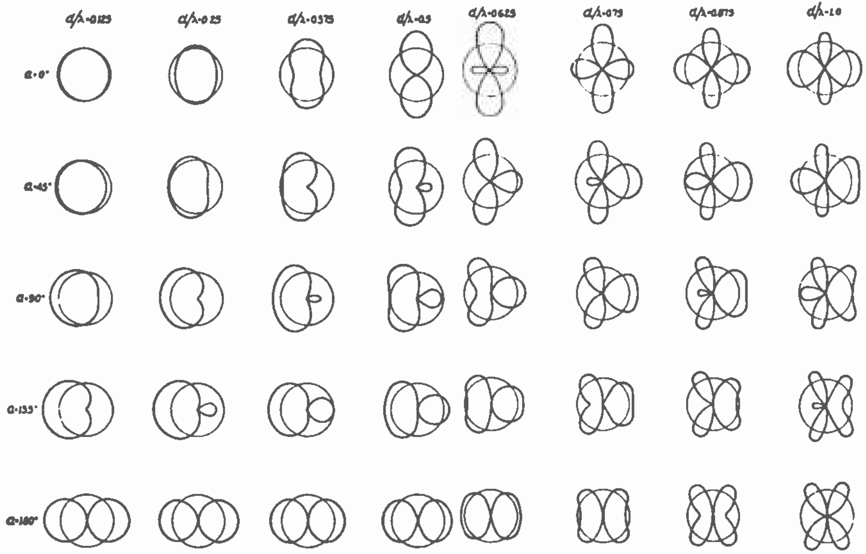

Fig. 1. Variations of patterns obtainable with two towers.

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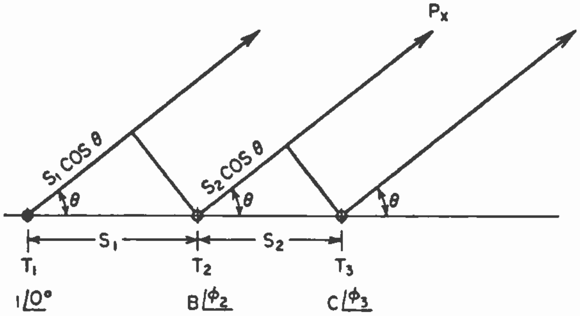

Fig. 2. Vector relationship of simple 3-tower array.

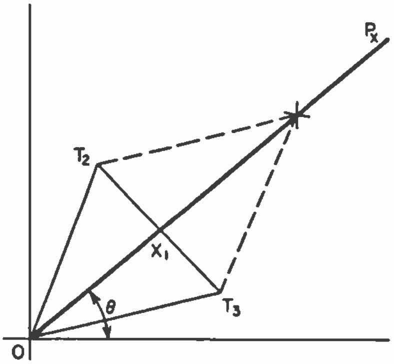

Fig. 3. Vectorial representation of 3-tower symmetrical array.

angle (OP_x) drawn at any value. The vector for T_2 (OT_2) is drawn above OP_x and T_3 (OT_3) is drawn below. Each vector has the same direction and magnitude in reference to OP_x, except that one is more (plus), and one is less (minus).

By completing the parallelogram, we find the length (or strength) of the pattern component produced by the two end (or outer) towers. (The parallelogram is completed by drawing a line from T_2 to X parallel to OT_3, and and another line from T_3 to X parallel to OT_2. The point where they intersect is X. Joining O and X gives the resultant. The distance OX_1 is the same as $X_1 - X$.)

Because the array is symmetrical and their resultant (OX) indicates the direction of the combined effect. To compute the length of OX, we use the distance OX_1, 2 cos (S cos θ), in the equation:

$$OX = 2\,[2 \cos (S \cos \theta)] = 4 \cos (S \cos \theta)$$

To find the total field in the direction θ, we merely add the radiation from T_1 and include the phase angle θ of the end tower

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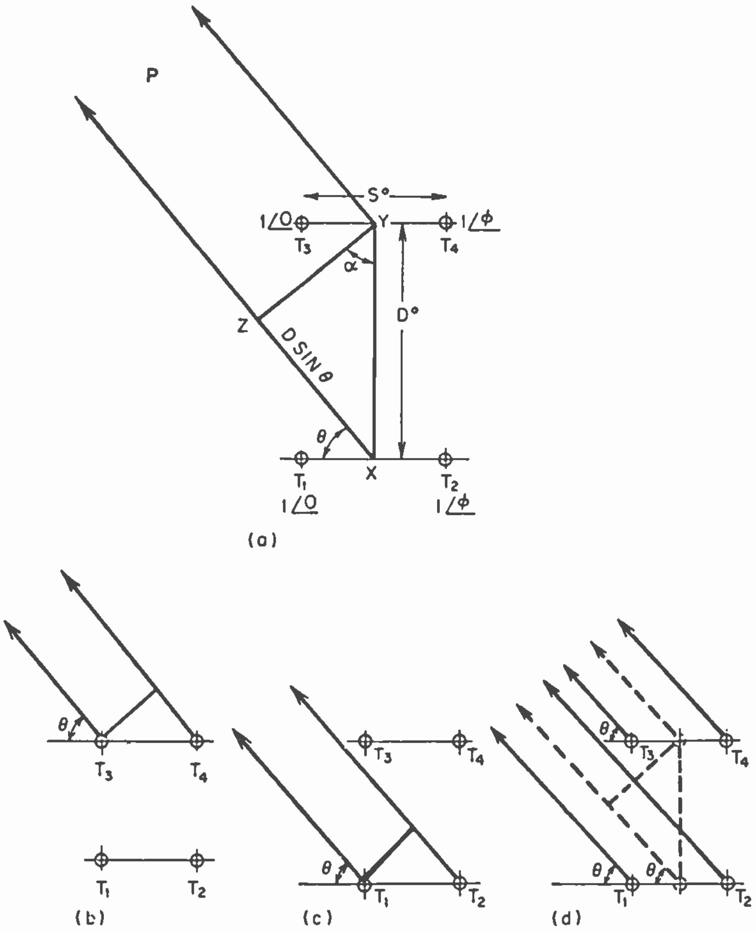

Fig. 4. (a) 4-tower array with symmetrical pairs; (b and c) vectorial treatment of each pair of antennas, T_1 and T_2, T_3 and T_4; (d) vectorial combination of the 2-tower pairs.

radiation to obtain:

$$F_{px} = 1\angle 0° + 4\cos\ (S\cos\phi)\ L\phi$$

Actual values in mv/m can be calculated after the pattern is plotted on polar graph paper.

It is interesting to note that if the current ratio had been 0.5 instead of 2, the expression would have been:

$$F_{px} = 1\angle 0° + .5\cos\ (S\cos\theta)\ L\phi$$

Four-Tower Arrays

So far in this series we have considered the fields from two antennas, three antennas, and symmetrical pairs (i.e., three towers with the outer two symmetrically arranged in phase, power, and

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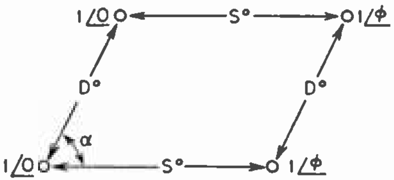

Fig. 5. Typical parallelogram or rhomboid tower configuration.

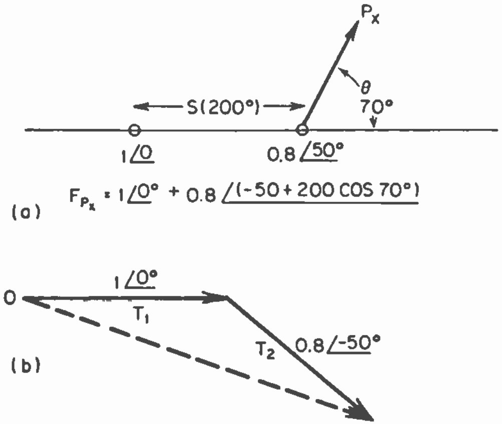

Fig. 7. Typical vectorial representation of a 2-tower array.

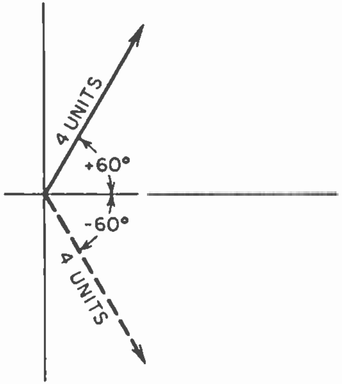

Fig. 6. Plotting vectors.

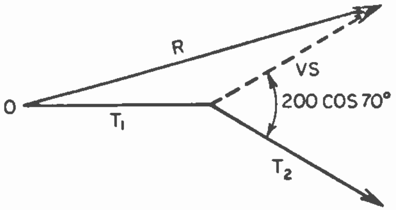

Fig. 8. The effect of space phasing on the vectorial relationship.

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Fundamentals of Vector Relationship

A vector has both magnitude and direction. For example, a vector described as $4\ \underline{/60^\circ}$ is 4 units long at an angle of 60°. This can be plotted as shown in Fig. 5. If the vector had been $4\ \underline{/-60^\circ}$ it would be shown as the dotted line.

Applying the principle to vectors produced by a two-tower array, the process is the same but extended and repeated. Consider the array shown in Fig. 7A. The field at point X produced by the currents in the two towers is expressed as:

$$1\ \underline{/0^\circ} + BL\,(\phi + S\cos\theta)$$

The vector for tower 1 (Fig. 7) is drawn one unit long at 0° from the origin "0". Continuing in the same direction, the vector for tower T_2 is drawn at an angle of −50° (down from the origin line) and 0.8 units long. The units can be any suitable scale, inches, centimeters, etc. Joining the origin to the last arrow produces a vector (broken line) indicating the magnitude and direction of the field produced by the two towers at azimuth 70°. (This will be true only when $S\cos\theta$ is zero, at 90° or 270°.) In addition to the current phase relationship, space phasing at the desired azimuth θ must be added; space phasing is 200 cos 70° and the vectors are shown in Fig. 8.

$$\text{Cos } 70^\circ = 0.342;\ 200\ (0.342) = 68^\circ$$

Therefore, the effect of tower T_2 is modified by the space phasing and it is necessary to rotate vector T_2 68° in a positive (counterclockwise) direction, measured from T_2 **(not from the origin line).**

The length of the vector (.8 units) remains the same because the space phasing did not affect the current in the towers. So T_2 is kept at 0.8 units while it is rotated up to 68° as shown by the dotted vector line VS.

The direction and magnitude of the field produced by the combination of tower currents, electrical phasing, and space phasing, are shown by the angle between R and the origin (horizontal) line. The length of R is measured in the same units as T_1 and T_2. The same process can be followed for any value of θ.

This approach can also be used any number of towers. In the case of a four-tower array, the two pairs are computed and the resulting vectors added in a third computation. (Vector arrows must follow each other because the vectors are being added). To generate the final vector, the spacing between the pairs of towers (mid-point of each pair) is applied as $D\cos\theta$, (Fig. 4) the dimension D° (XY).

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spacing). For computational purposes, it is convenient to consider multi-element arrays in pairs. For example, the 4-tower array (Fig. 4a), can be considered as two groups of two towers. The radiation from each pair of towers (Fig. 4b and 4c) is computed as though coming from a single separate pair. Then these two tower radiation figures are considered as emanating from single towers and combined once more (Fig. 4d). The result is the effective vector pattern from the four towers. The angle X at the apex of the right triangle is the same as angle θ, the azimuth angle; therefore, XZ can be written as D sine θ which means that the length of the line XZ is D times the sine of the angle θ. Line XY represents the phase spacing of the two pairs of towers. Thus, the equation can be written:

$F_{px} = 1\angle 0^\circ + 1L\ (\phi + S\cos\theta) + [1\angle 0^\circ + 1L\ (\phi + X\cos\theta)]\ LD \sin\theta$

Unsymmetrical DA Patterns

In cases where a symmetrical radiation pattern will not provide protection in required directions, a pattern that is non-symmetrical or asymmetric, is needed. This can be done with an array that produces unequal radiation on each side of a center line. A parallelogram tower configuration (see Fig. 5) will accomplish the purpose. The pattern produced by a parallelogram array can be calculated by:

Field at distant Point X $= 1\angle 0^\circ + 1L\ (\phi + S\cos\theta) + [1\angle 0^\circ + 1L\ (\phi + S\cos\theta)]\ LD\cos(\infty - \theta)$

This formula can be simplified using previously described methods.

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Measuring Operating Impedances
Part 5

John H. Battison

NO DISSERTATION on directional antennas would be complete without considering mutual impedance. The first necessity is to understand what we mean by, and what constitutes, mutual impedance.

What Is Mutual Impedance?

If two inductances are placed close to each other—in a transformer, for example — there is some inductance common to both windings. As a result of the proximity of the two coils, a voltage is induced by the primary into the secondary. This is known as mutual inductance. If we multiply the current in the primary winding by the *reactance* of the mutual inductance, the open circuit secondary voltage will be obtained.

Basically, the same relationship exists between the towers of a multi-tower array. In a two-tower array, for example, the voltage induced in Z_2 by Z_1 is directly related to the phase angle. The phase angle is referenced to the current in Z_1 and its value will depend on the distance between the two antennas. Because of this, the coupling factor has to be described as an impedance and this, in turn, requires that it be labeled in terms of magnitude and angle.

Mutual inductance can, therefore, be defined as the impedance required to produce a given voltage drop with a given current. Due consideration must be given the phase angle between the voltage drop and the current or the ratio of the voltage induced in the receiving antenna by the transmitting antenna (in this case the terms "receiving" and "transmitting" refer to the indvidual towers in the array; not to a discrete "receiving" or "transmitting" antenna as such).

Why Is Mutual Impedance Important?

The mutual impedance coupling between towers has a very strong effect upon antenna performance, the feeder and phasor system, and the ease of array adjustment. These calculations are probably the most boring and hard to follow, as well as being laborious to perform, but they have to be performed in order to be able to check the antenna operating parameters and to be sure that no undesirable effects have been introduced. Unless the effects of mutual impedance are known, we cannot design the phasing equip-

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ment. Let us consider the array:

$$\begin{array}{ccc} T_1 & & T_2 \\ \bigcirc\text{——} & S^\circ & \text{——}\bigcirc \\ 1\underline{/0^\circ} & G = 90^\circ & 0.8\underline{/130^\circ} \\ & S = 90^\circ & \end{array}$$

The base operating impedances and the expected current in each tower must be determined so that the power and phasing equipment can be designed. Also, in some cases, it is necessary to calculate the RF voltage appearing at voltage nodes if high powers are used and insulation becomes a problem.

The basic formula for the mutual impedance of two or more towers has to take into consideration the effect of the radiated and re-radiated currents in each tower. For two towers it is:

$$Z_1 = Z_{11}\frac{I_1}{I_1} + Z_{21}\frac{I_2}{I_1}.$$

$$Z_2 = Z_{12}\frac{I_1}{I_2} + Z_{22}\frac{I_2}{I_2}$$

The subscript, Z_{11} is read as "Z one one," not Z eleven.

Z_1=mutual impedance of towers 1 and 2

Z_2=mutual impedance of towers 2 and 1 (by reciprocity it is the same as Z_1)

Z_{11}=self impedance of tower T_1

Z_{22}=self impedance of tower T_2

I_1=current in tower 1

I_2=current in tower 2

We can use a matrix to set out the problem (Table I). This helps to avoid error and shows what is being done at each step.

The self impedance of a quarter wave (90°) tower, 45 + j40, is entered in the blank corresponding to the term Z_{11} in the right hand column, and also for Z_{22}.

Table I—Mutual Impedance Matrix

Practical

Self & Mutual Z	
Z_{11}	Z_{12}
Z_{21}	Z_{22}
Current Ratios	
I_1/I_1	I_1/I_2
I_2/I_1	I_2/I_2
Coupled Z	
$Z_{11}\ I_1/I_1$	$Z_{12}\ I_1/I_2$
$Z_{21}\ I_2/I_1$	$Z_{22}\ I_2/I_2$
Rectangular Form	
R + jx	R + jx
R + jx	R × jx
Operating Base Z	
$R_1 + jx_1$	$R_2 + jx_2$

Theoretical

Self & Mutual Z	
45 + j40	$31\ \underline{/-36}$
$31\ \underline{/-36}$	45 + j40
Current Ratios	
$1\underline{/0^\circ}$	$0.8\underline{/130}$
$1.25\underline{/-130}$	$1\underline{/0^\circ}$
Coupled Z	
45 + j40	$25\underline{/-94}$
$50\underline{/-90}$	45 + j40
Rectangular Form	
45 + j40	−1.75 + j24.95
0 − j56	45 + j40
Operating Base Z	
45 − j16	43.25 + j65

The mutual impedance and current ratios for two towers of equal height are shown in Fig. 1. We multiply $0.68\ \underline{/-36}$ by the self resistance of the tower (the real

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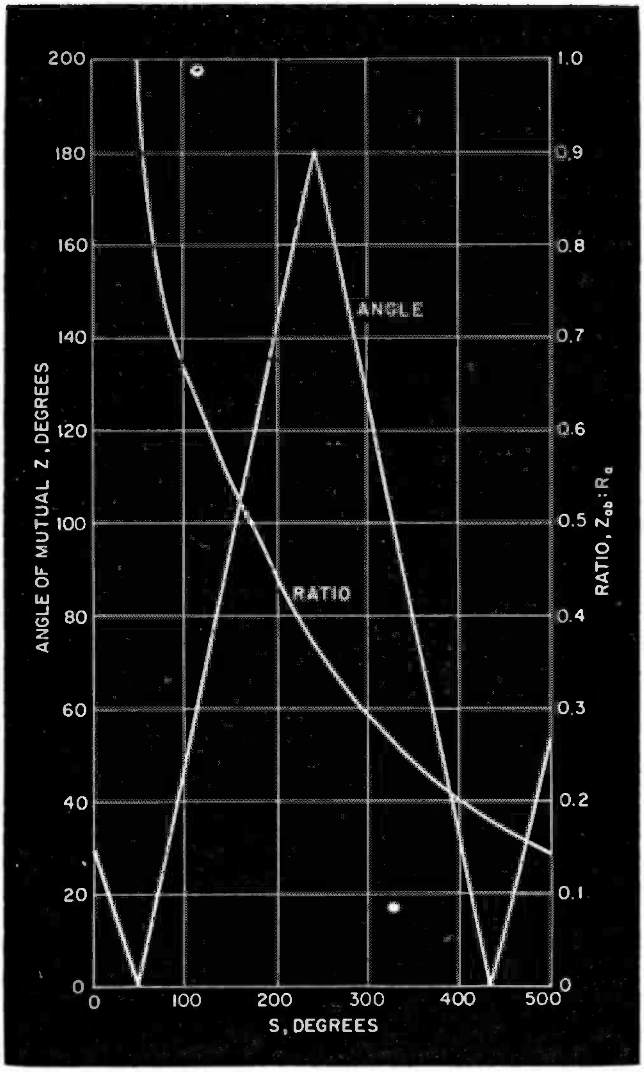

Fig. 1. Mutual impedance and current ratios for two towers of equal height (based on measurements and calculations).

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resistance of the tower (the real resistance part of $45 + j40$); we multiply only by the magnitudes (or ratio) in $0.68 \angle -36$ (the angle is unchanged). The result of this operation is $31 \angle -36°$ which we enter as shown.

Next, the current ratios must be computed. Note that in every case the same value is repeated for the reverse relationship of the towers. Because one tower is the reference tower, we enter $1 \angle 0°$ for this tower. The first set of boxes now shows self and mutual impedances.

The coupled impedances are computed by multiplying each number in the current ratio box by the corresponding self and mutual impedances from the first box. The coupled impedances are now converted to rectangular form and entered in the rectangular form boxes. To obtain the actual base operating impedances and reactances, we merely add all the real numbers in the last set of boxes (rectangular form) and enter on the last line; then, add all the imaginary numbers in that box. Now we have the actual computed base operating resistance and reactance, and from these parameters we can calculate the required power and coupling components.

Designing a System

Let us design a two-tower array applying some of the principles covered in this series. The rather heavy earlier concentration on vectors, and similar (somewhat theoretical) material was presented to illustrate the principles on which the directional pattern is built. The actual application is merely a continuation of these principles with the addition of applied math. This example could be a part of an FCC application, although it is not generally necessary to be so comprehensive. However, it is always essential to go through these computations even though they are not shown in the application. A seasoned consulting engineer will often know the electrical characteristics of a proposed array and will not find it necessary to go through the whole process every time. But, in order to compute the phasing and feeder system, he has to know all the parameters presented here.

Let us assume that we are designing a two-tower array to provide minimum radiation on one side and maximum on the other; in other words, a form of cardioid or heart shaped pattern. Due to high costs, only a small piece of ground is available. This will require short tower spacing (remember, it is necessary to have sufficient land for the radials which must equal the tower height). We have decided to use quarter-wave towers to provide reasonable radiation, and help toward ease of adjustment. We do not specify any special frequency for this application; the example is intended to show what is needed for any frequency. Therefore, we use only electrical degrees which can be translated into wavelength by using the ratio $\frac{300{,}000}{F_{kc}}$

This gives the wavelength in meters (multiply by 3.3 for approximate length in feet).

We assume that the array is to be built on perfectly conducting earth. This is not the case, of course, but a good ground system

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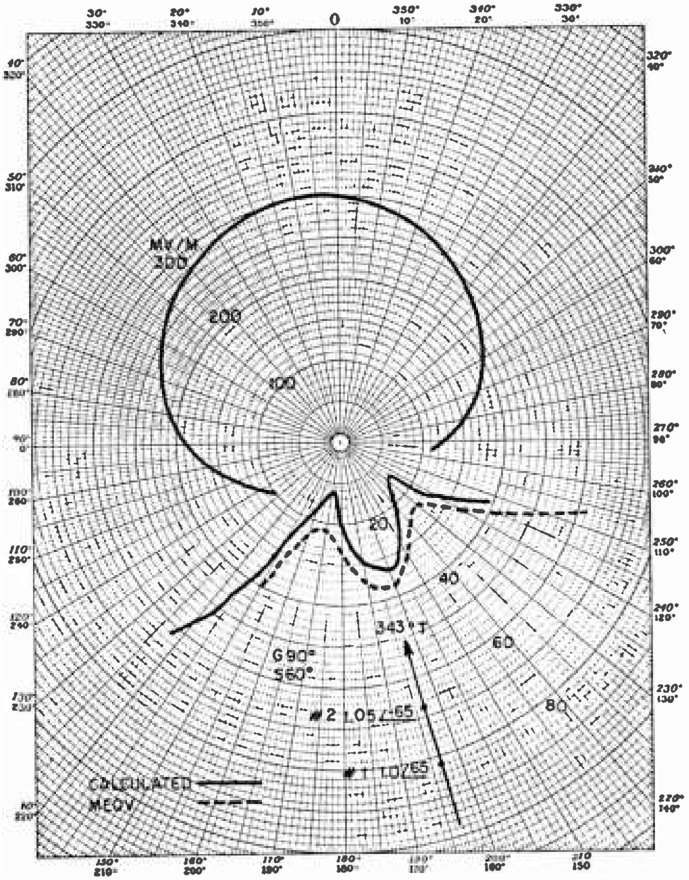

Fig. 2. Pattern of two-tower array computations (1.05 $\underline{/0^\circ}$ and 1.00 $\underline{/130^\circ}$ are the same as 1.05 $\underline{/-65^\circ}$ and 1.00 $\underline{/65^\circ}$).

helps, and, in any case, some standard of comparison has to be made. Assuming the best means that any errors will be on the side of poorer coverage, rather than better coverage. Therefore, interference problems will be generally slightly less than the theoretical.

The formula for computing a two-tower array is (taking every parameter into account):

$$E = K f(\theta)$$
$$[E_1 \underline{|B/2 + (S/2)\ \text{Cos}_c\ \phi\ \text{Cos}\ \theta}$$
$$+ E_2 \underline{|-B/2 - (S/2)\ \text{Cos}_c \phi \text{Cos}\ \theta\,]}$$

This reduces to:

$$E = 2K f(\theta)\ E_1\ E_2\ \text{Cos}^2$$
$$[B/2\ (S/2)\ \text{Cos}_c\ \phi\ \text{Cos}\ \theta]$$
$$+ (E_1 - E_2)^{2/4} \}^{1/2} \qquad (1)$$

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Where:

E = attenuated field in mv/m (at one mile)

E_1 = relative field from tower #1 (1.0 for this example)

E_2 = relative field from tower #2 (1.05 for this example)

B = electrical phasing (130°)

S = tower spacing (60°)

G = tower height (90°)

ϕ = horizontal angle

θ = vertical angle (not needed in this case because we are not concerned with vertical radiation in a daytime station). Elimination of the vertical angle reduces θ to zero.

The results of the computation have to be converted to mv/m by the factor 2K, which equals:

$$\frac{2E_{rms}}{[E_1^2+E_2^2+2E_1E_2 \text{Cos} B \text{ Jo } (S)]^{1/2}} \quad (2)$$

The expression, Jo (S) = Jo, is a Bessel function. It is found in the NAB Engineering Handbook (or similar engineering tables).

E_{rms} = array RMS = E_t VG × LF (3)

E_t = theoretical radiation from one tower 90° high with no losses.

For our example, 500 watts input power equals 139 mv/v. Vertical gain is:

$$VG = \frac{[E_1^2+E_2^2+2E_1E_2 \text{Cos} B \text{ Jo } (S)]^{1/2}}{[E_1^2+E_2^2+2E_1E_2 \text{Cos} B (R_m/R_s)]^{1/2}} \quad (4)$$

R_m=mutual resistance between #1 and #2=29 ohms

R_s=self resistance of each tower (36.6 ohms)

Substituting in equation (4), VG equals 1.034.

Loss factor (LF) equals:

$$\frac{[I_1^2 R_1 + I_2^2 R_2]^{1/2}}{[I_1^2 R_1 + I_1^2 R^2 + (I_1^2 + I_2^2) R_L]^{1/2}}$$

Where:

I_1=relative current in tower No. 1 (1.0)

I_2=relative current in tower No. 2 (1.05)

R_L is the assumed loss in each tower (2.5 is an acceptable figure)

R_1=operating base resistance of No. 1

$= R_s + (I_2/I_1)/Z/\text{Cos } (B + p)$ (6)

Where:

Z=mutual impedance between towers (29.6)

P=phase angle of Z (—11)

That completes the basic preparation of the data sheet. Many engineers print up similar pages with blanks for the variables and merely enter these values for each different antenna array. This saves a great deal of time, because the completed sheet can be included as part of the engineering exhibit if desired.

Next, we insert these values in equation (6): R_1=12.5 ohms; R_2=22.9 ohms. In equation (5) Loss Factor (LF), we use 0.94; in equation (3) E_{rms}=135 mv/m; 2K (the conversion factor) (Z) =257.

Now putting all these items together in equation (1) we can compute the actual radiation for any azimuth (horizontal angle). It is simplest to reduce the equation to:

$$E = 257\ [1.05 \text{ Cos}^2 (65 + 30 \text{ Cos } \phi) + .0006]^{1/2}$$

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To prepare the required information for the FCC, we can take any desired angle and substitute it for ϕ. By doing this equation (1) becomes:

E=23.7 mv/m radiation at 0° or (360°)

The remainder of the pattern is computed by setting up a matrix as was shown in Part 2 of this series. Different headings are used and the radiation is computed for every 10° from 0° through 180°. Beyond 180° the values begin to decrease with the horizontal angle so that, in drawing the antenna pattern, the corresponding value is plotted for each corresponding angle on the other side of the 180° line. The computed pattern is shown in Fig. 2.

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Power Distribution and Phasing

Part 6

John H. Battison

THE OPERATION of a directional antenna system requires, of course, that each tower be fed with the proper amount of current of the required phase relationship. Therefore, in this final installment we shall cover power distribution and phasing methods, plus a practical illustration of a 4-tower array computation for night operation.

Power Division and Phasing Related

Power distribution and phasing are inseparably related to each other. Generally, a power distribution system will introduce some degree of phase change which can either be used to advantage or minimized so that it has little affect on the operation of the system. However, since there is a built-in phase shift in most power distribution systems, it is economically sound to employ the effect as part of the phase shift network. Since mechanical design has a bearing on the operational characteristics of such a system, it is a good idea to locate, wherever possible, all power division and phasing components in one cubicle or in one general group.

A Collection of Pluses and Minuses

The phase relationship between components of a DA system can be considered as a collection of pluses and minuses—that way its operation and treatment will be much simpler.

Let's consider the 3-tower antenna shown in Fig. 1. The reference tower is shown as 0°. The electrical phase of #2 tower is −30°, and that of #3 is +120°. At this point, the antenna currents or their ratios need not be considered. All we need to know is how much undesired phase shift will be introduced by the coupling equipment, and how much of this shift can be designed into the system.

In a very simple array with, say, 90° electrical phasing and similar tower spacing, there is usually a strong temptation, for economy reasons, to use the actual transmission lines to introduce and control the phasing. By using the velocity of propagation factor, it is fairly simple to design the transmitter-to-array transmission line so that it will introduce a 90° phase shift. If directional phasing is achieved in this manner, it will have no means of adjustment.

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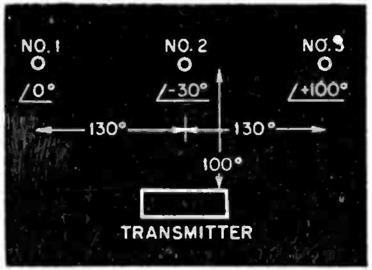

Fig. 1. Typical phase spacing between towers and transmitter.

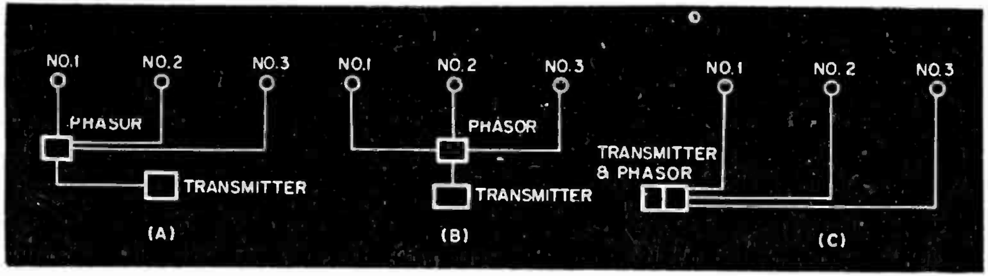

Fig. 2. Possible locations of the phasor unit.

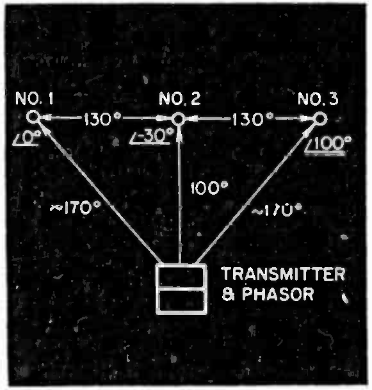

Fig. 3. Alternative transmission line layout for Fig. 1.

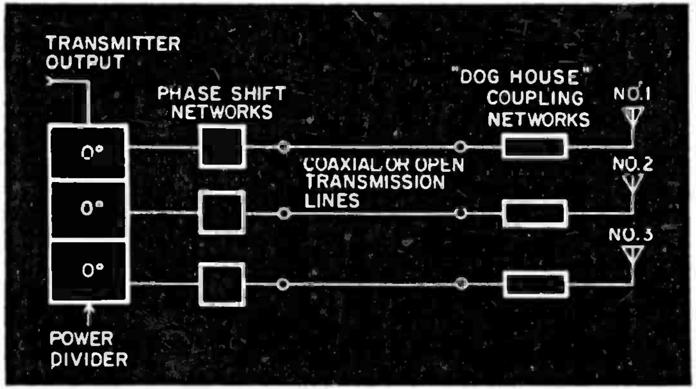

Fig. 4. Block diagram of a practical phasing and coupling system. Power divider phase shift is assumed to be 0°

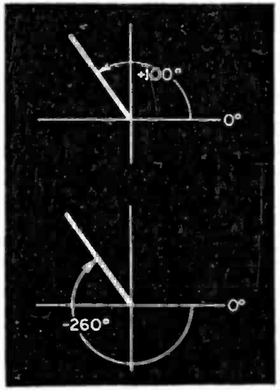

Fig. 5. Both +100° and −260° vectors are identical in direction. Negative vectors are measured counter-clockwise.

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In practice, even the most carefully designed array will have some unexpected variations; therefore, it is absolutely essential that an adjustment network be included in the design.

Built-in Phase Shift

Two "built-in" phase shifts—between the individual towers and between the towers and the transmitter—have to be considered. The towers can be fed by a transmission line from the transmitter to the reference tower, and then by an individual line to each tower (Fig. 2a). However, the drawbacks to such an arrangement are rather obvious, either from the point of view of transmission line length and therefore RF loss, or from a consideration of the manpower required to operate the phasor at a point remote from the transmitter. Therefore, it is most usual to include the phasor and power distributor as an integral part of the transmitter group (Fig. 2c).

When dealing with electrical phasing we add and subtract according to the signs. After 360° is reached, we are back where we started; 496° is only another way of writing 136° (496° − 360°). Table I is a tabulation of the built-in phase shift of the array in Fig. 1. (Note that the derived electrical phase of each antenna is not included in the total phase shift.) The "built-in" phase shift is 100°, plus 230° for towers #1 and #3 and 100° for #2.

Table 1—Built-in Shift of Array in Fig. 1.

	Electrical Phase	Xmtr to Center of array	Tower 2/1 2/3	Total Shift
Tower #1	0	100	130	230
Tower #2	—30	100	...	100
Tower #3	100	100	130	230

Table 2—Combined Built-in Phase of Array in Fig. 4.

	Phase Shift Net	Line Phase Shift	Dog House Shift	Total
Tower #1	—90	—241	— 75	—406
Tower #2	—90	—105	+119	— 76
Tower #3	0	—241	— 65	—306

Next, we must determine the influence of the transmission line's velocity of propagation characteristic. Taking 95% (or a different figure if the manufacturer gives one), we have an *effective* phase shift of 241° for the 230° lines, and 105° for the 100° line.

Fig. 3 shows another method of connecting the transmission lines in Fig. 1. Quite likely, the physical layout in Fig. 3 would be used in practice.

Fig. 4 is a block diagram of a practical phasing and coupling network. Assuming the distribution tank is properly designed so that the phase shift is negligible,

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we begin with the phase shift control networks. Generally, they are designed to handle from about +20° to −20° of actual shift without appreciable impedance change. These units are used to tune the towers to the final operating impedances, which are quite likely to be slightly different from the theoretical.

The transmission line to power match is achieved by coupling units located in a "dog house" near the base of each tower. Here again we encounter a phase shift not designed into the system, but, as before, it can be used. The phase shift introduced by the dog house networks should be between 60° and 120° to avoid large power losses. To determine initial settings on the phasor, we add up what we have to use. Values for the phase shift networks have been chosen so that our operating ranges should give us sufficient scope to take care of the system requirements, as shown in Table II.

By subtracting 360° from −406°, the built-in phase shift for (reference) tower #1 is −46°. However, our original specifications at #1 called for a 0° phase shift. But since #1 is the reference tower and all other towers are referenced to #1, we can call it anything we like as long as we adjust the other towers by the same amount. Therefore, we will consider #1 to be at zero degrees (0°) and adjust towers 2 and 3 by +46°. Accordingly, #2 will then have a −30° phase relationship to #1 (−76 + 46). and #3 will have a −260° relationship to #1 (−306 + 46). Therefore, we have obtained our required final phases relationships between the towers.

Power Dividers

The basic function of power dividing networks is to feed the desired amount of RF current to each tower. For various reasons it is not practical to establish design parameters, then build fixed equipment that will give the desired results. From our design work, we know the base operating impedance of each tower. We know, too, the radiated power required of each tower; therefore,

Table 3—Night Time Horizontal Plane Pattern

A (degrees)	E (MV/M)
0	86.3
10	78.5
20	58.9
30	34.3
40	14.4
50	11.9
60	15.1
70	16.2
80	20.3
90	26.0
100	25.1
110	16.5
120	31.6
130	79.2
140	138.6
150	204.9
160	263.3
170	304.6
180	318.8
190	304.6
200	263.3
210	204.9
220	138.6
230	79.2
240	31.6
250	16.5
260	25.1
270	26.0
280	20.3
290	16.2
300	15.1
310	11.9
320	14.4
330	34.3
340	58.9
350	78.5
360	86.3

Where A equals 0 at Azimuth 148° True

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we know the approximate current at each tap. From this we can compute the effective load impedance. In the case of the 3- tower antenna just discussed, Fig. 6 shows how the currents are handled.

Although the simple DC approach is permissible at times, it does not take into account the Q factor of the circuit. The antenna currents can be added because they are in phase and may be regarded as a single equivalent output. The total *power* is the same, so we can consider that the total current is related to the load of the antennas by the standard power relation.

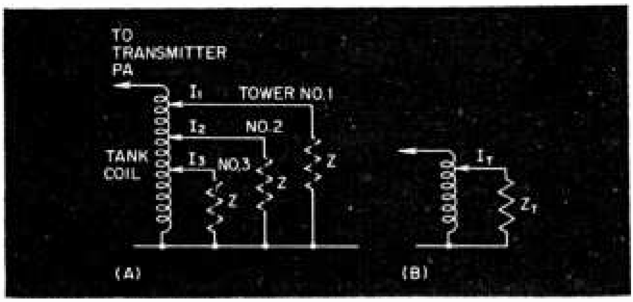

Fig. 6. Simplified power dividing network. Individual tower currents may be added and regarded as total current I_T.

Since the effective load being placed on the tank circuit is known, we can keep the Q within certain bounds, averaging about 3. If it is too high we shall have a narrow bandwidth and the audio quality will suffer through sideband attenuation; if Q is too low, changing one tap will affect the other taps and make adjustment even more difficult.

A 4-Tower Array

The array shown in Fig. 7 was designed to add night operation to a daytimer that already had two towers. Numbers 4 and 5 are the original towers, and 1, 2, and 3 are the new ones. At first it was hoped that both the existing towers could be used in the new 4-tower array, but the azimuth was not suitable, and spacing would have been extremely difficult. So, in the interests of efficiency and economy, three new towers were added.

Fig. 8 shows the polar diagram and operating parameters for the proposed system. The arrows converging on the center are the azimuths to stations which must be protected. Controlling the horizontal radiation was no particular problem because at night the co-channel and many adjacent channel stations go off the air. Even if they had been the only problem, we could not have retained the same daytime pattern. It is night-time vertical radiation that makes the job so hard. In this particular case we had to keep cutting and trying to keep the city within the 25 mv/m contour and, at the same time, keep the vertical radiation from becoming so great that distant co-channel stations received interference. (It is not very often that night-time adjacent channel interference becomes a problem; if the sky wave is strong enough

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Table 4A—Horizontal Radiation on the Ground (O° ground, $\phi = 148°$ true).

	A 45 Cos ϕ	B A+60	C Cos B	D 97 sin ϕ	E Cos D	F 106.93 Cos ϕ+65	G F+90	H Cos G	J 05H	K CxE	L J^2+K^2	M $\sqrt{L}$	330M
0	45	105	—.2588	0	1.0	45.2	135.2	—.7096	.0355	.2588	.0682	.2616	86.3
10	44.3	104.3	—.2470	16.8	.9573	27.7	117.7	.4648	.0232	.2365	.0565	.2380	78.5
20	42.3	102.3	—.2130	33.2	.8368	9.3	99.3	.1616	.0081	.1782	.0318	.1785	58.9
30	39.	99.	—.1564	48.5	.6626	—9.3	80.7	.1616	.0081	.1036	.0108	.1040	34.3
40	34.5	94.5	—.0785	62.4	.4633	—27.7	62.3	.4648	.0232	.0364	.0019	.0436	14.4
50	28.9	88.9	.0192	74.3	.2706	—45.2	44.8	.7096	.0355	.0052	.0013	.0360	11.9
60	22.5	82.5	.1305	84.0	.1045	61.3	28.7	.8771	.0439	.0136	.0021	.0458	15.1
70	15.4	75.4	.2521	91.2	—.0209	75.6	14.4	.9686	.0484	.0053	.0024	.0490	16.2
80	7.8	67.8	.3778	95.5	—.0958	87.6	2.4	.9991	.05	.0363	.0038	.0616	20.3
90	0	60.	.5000	97.0	—.1219	96.9	—6.9	.9928	.0496	.0610	.0062	.0788	26.0
100		52.2	.6129		—.0958	103.3	—13.3	.9732	.0487	.0587	.0058	.0761	25.1
110		44.6	.7120		—.0209	106.5	—16.5	.9588	.0479	.0149	.0025	.0500	16.5
120		37.5	.7934		.1045	106.5		.9588	.0479	.0829	.0092	.0959	31.6
130		31.1	.8563		.2706	103.3		.9732	.0487	.2342	.0572	.2400	79.2
140		25.5	.9026		.4633	96.9		.9928	.0496	.4182	.1774	.4200	138.6
150		21.	.9336		.6626	87.6		.9991	.05	.6186	.3852	.6210	204.9
160		17.7	.9527		.8358	75.6		.9686	.0484	.7972	.6379	.7980	263.3
170		15.7	.9627		.9573	61.3		.8771	.0439	.9216	.8513	.9230	304.6
180		15.0	.9659		1.0	—45.2		.7096	.0355	.9659	.9342	.9660	318.8

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Table 4B—Radiation in all directions at a vertical angle of 50°

	A 45 Cos ϕ Cos 50	B A +60	C Cos B	D 97 sin ϕ Cos 50	E Cos D	F 106.93 Cos 50 Cos ϕ +65	G F+90	H Cos G	J 05H	K CxE	L J^2+K^2	M $\sqrt{L}$	330M
0	28.93	88.9	.0192	0	1.0	29	119	.4848	.0242	.0192	.00095	.0308	5.7
10	28.5	88.5	.0262	10.8	.9823	17.8	107.8	.3057	.0153	.0257	.00089	.0298	5.5
20	27.2	87.2	.0488	21.3	.9317	6	96	.1045	.0052	.0455	.0021	.0458	8.5
30	25.1	85.1	.0854	31.1	.8563	—6	84	.1045	.0052	.0731	.0054	.0735	13.6
40	22.2	82.2	.1357	40.1	.7649	17.8	72.2	.3057	.0153	.1038	.0110	.1050	19.4
50	18.6	78.6	.1977	47.8	.6717	29	61	.4848	.0242	.1328	.0182	.1350	24.9
60	14.5	74.5	.2672	54	.5878	39.4	50.6	.6347	.0317	.1571	.0257	.1600	29.5
70	9.9	69.9	.3437	58.6	.5210	48.6	41.4	.7501	0375	.1791	.0334	.1830	33.8
80	5.0	65.	.4226	61.4	.4787	56.3	33.7	.8320	.0416	.2023	.0427	.2060	38.
90	0	60.	.5000	62.35	.4633	62.3	27.7	.8854	.0443	.2316	.0556	.2360	43.5
100		55.	.5736		.4787	66.4	23.6	.9164	.0458	.2746	.0775	.2780	51.3
110		50.1	.6414		.5210	68.5	21.5	.9304	.0465	.3342	.1139	.3370	62.2
120		45.5	.7009		.5878	68.5	21.5	.9304	.0465	.4120	.1719	.4145	76.5
130		41.4	.7501		6717	66.4	23.6	.9164	.0458	.5038	.2559	.5060	93.4
140		37.8	.7902		.7649	62.3	27.7	.8854	.0443	.6044	.3673	.6060	111.8
150		34.9	.8202		.8563	56.3	33.7	.8320	.0416	.7023	.4950	.7050	130.1
160		32.8	.8406		.9317	48.6		.7501	.0375	.7832	.6148	.7850	144.8
170		31.5	.8526		.9823	39.4		.6347	.0317	.8375	.7024	.8395	154.9
180		31.1	.8563		1.0	29.		.4848	.0242	.8563	.7338	.8565	158.0

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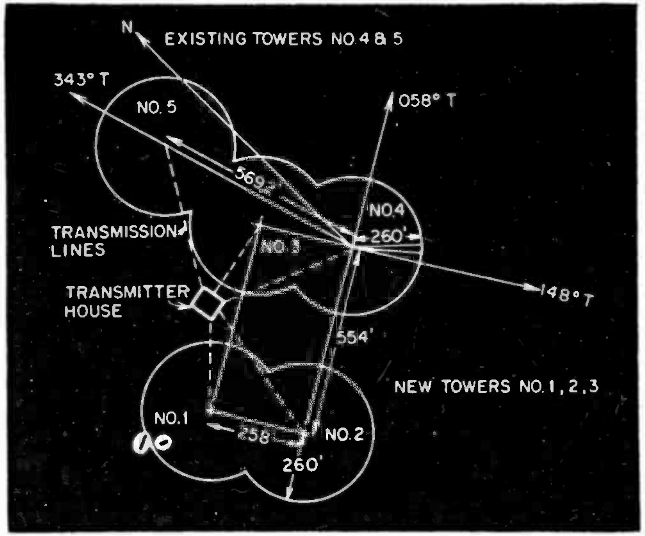

Fig. 7. For night-time operation, 3 new towers were added to an existing 2-tower daytime array.

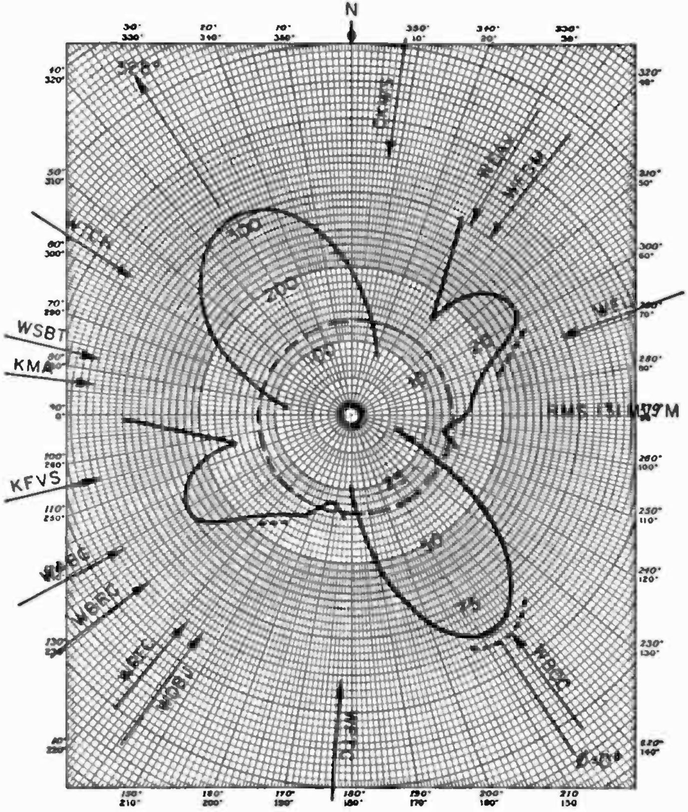

Fig. 8. Polar pattern for 4-tower array in Fig. 7. →

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to cause adjacent channel interference, it is sure to be far too strong on co-channel.)

The formula used to calculate horizontal and vertical plane radiation is:

$E = K\,F(V)\,[\cos (S'/2 \cos A \cos B - W'_{12/2}) \cos (S''/2 \cos (A + 90) \cos B + W''/2) + J0.05 \cos (S''' 2 \cos (A + 65) \cos B + W'''/2)\,]$

Where:

E = field in mv/m

K = a constant to produce the expected RMS = 330

S' = spacing between towers 1 and 2: 3 and 4 = 90°

S'' = spacing between towers 1 and 3: 2 and 4 = 194°

S''' = spacing between towers 1 and 4 = 213.86°

A = azimuth angle, 0° at 148° True.

B = vertical angle

W' = current phasing between towers 1 and 2: 3 and 4 = 120°

W'' = current phasing between towers 1 and 3: 2 and 4 = 0°

W''' = current phasing between towers 1 and 4 = 180°

$F(V)$ equals vertical radiation characteristic of 90° antenna

Table III shows a tabulation of horizontal plane radiation.

Horizontal radials seldom occur at the exact azimuths required to show the vertical radiation in the critical directions. For this reason it is necessary to make the additional computations to obtain the desired data. For example, the azimuth of WDBJ is 216° (Fig. 8). Table III does not show the radiation at this bearing, it must be calculated.

$E = 330 \times 0.869\,[\cos (90/2 \cos 68^\circ \cos 25^\circ + 120/2) \cos (97 \cos (68^\circ + 90^\circ) \cos 25^\circ \pm 0^\circ) + J0.05 \cos (213.86/2 \cos (68^\circ + 65^\circ) \cos 25^\circ + 180/2)]$

$E = 286.77\,[(25.38 \times 1478)^2 + (0451)^2]^{1/2}$

$= 286.77 \times 0.0591$

$= 16.95$ mv/m

Az. = 216°

$A = 68^\circ$

$B = 25^\circ$

Table IV is tabulation of the computations for the pattern in Fig. 6. Table IV-A shows horizontal radiation when the vertical angle B is zero; Table IV-B shows the vertical radiation at an angle of 50°. It is most informative to compare the radiations at various azimuths at the ground, and at 50° elevation.

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Measuring DA Operating Impedances

C. Ward Yelverton

UNFORTUNATELY, the measured impedance and the actual operating impedance of a circuit are sometimes two very different quantities. This is particularly true when the circuit is nonlinear with respect to changes in power or voltage (an incandescent light bulb, for example, or most transmitter dummy loads). In the case of a directional antenna system, on the other hand, the circuit may be so complex that it is impossible to introduce a conventional bridge without some effect on its operation.

Directional Antenna Measurements

A diagram of a simple two-tower array is shown in Fig. 1, and its simplified equivalent circuit is depicted in Fig. 2. Measuring the input or drive point of one tower in such a system is not a simple problem. If Tower No. 2 is disconnected and properly "floated" so that it draws no current, or better yet physically removed completely, input impedance Z_1 is eqaul to the self impedance Z_{11} and is easily measured with a conventional bridge. However, considerable effort is involved in adding tuning networks to all the elements in a multi-tower array in order to float all the towers except the one actually being measured.

In the operating configuration, the input impedance of Tower No. 1 is given by the equation:

$$Z_1 = Z_{11} + Z_{12}\left(\frac{I_2}{I_1}\right),$$

where $Z_{12}\left(\frac{I_2}{I_1}\right)$ is the coupled impedance Z_c. Mutual impedance Z_{12} is a function of the physical configuration of the towers and is constant for a given array. The complex current vector ratio is a function of the self and mutual inductances and the circuitry in the current paths.

Since the feed circuit for either tower is connected through the phasor to the other tower, the input impedance of one affects the current in the other. Thus, placing any impedance in the feed to one tower also affects the current in the other tower through the interconnecting phasor circuit. From the equation, it is obvious that a change in the current vector ratio results in a change of the coupled impedance and thus the input impedance.

Introducing a conventional bridge into the circuit so radically changes input impedance that measurements are meaningless. As a matter of fact, the only place a conventional bridge may be introduced into a directional array without changing the circuit parameters is at, or before, the common point. However, with an Operating Impedance Bridge (OIB) the voltage-current vector can be measured on the line. As shown in Fig. 3, the measuring circuit utilizes two controls in a

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null-balance circuit; the resistance control is calibrated in ohms normalized to 1 mc.

Conventional Antenna Measurements

Making accurate measurements on a conventional antenna is often difficult due to the adjacent co-channel and interference received in the detector. This problem is easily overcome for initial tune-ups by simply using higher power signal generators with the OIB. Even if transmitter power levels are not permissible due to FCC Rules, a higher power signal generator and the use of an external detector with the OIB will allow accurate measurements in the presence of the most persistent co-channel signal.

Adjusting Matching Networks

Once the rough setup on a directional array has been accomplished, the tower matching network may be readily set by measuring the operating impedance of the tower and then calculating the required values of the matching section components to give the impedance match and phase shift. The components may be set to their calculated values by operating the OIB as a conventional bridge with the low level signal and an external detector. With the components set to their required values, the OIB is connected in series with the input to the matching section and final touch-up of the components is made to give the exact match required. It is necessary, of course, to readjust the phases and current ratios at the phasor when a change is made in the matching network.

Monitoring the Common Point

One of the greatest difficulties involved in the final adjustment of a directional antenna system is the interaction between all of the phasor controls and the common point impedance. Without monitoring an excessive number of field points, it is impossible to determine if a field strength change is due to a radiation pattern change, or to a change in the overall radiated power. Even the common method of ratioing field measurements against a non-directional radiation pattern is not usable unless the input impedances to both the phasor common point and the non-directional antenna's drive point are accurately known.

When measuring tower operating impedances, it is easy to overlook shunting circuits feeding the tower particularly the lighting circuits. The safest approach is to connect the OIB directly in series with the base current ammeter at the ammeter terminal.

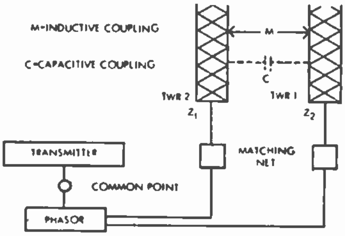

Fig. 1. Diagram of 2-tower antenna network.

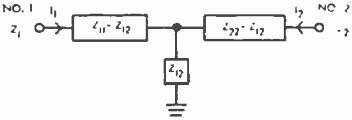

Fig. 2. Equivalent circuit of 2-tower antenna system.

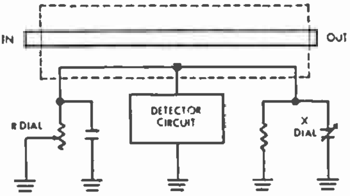

Fig. 3. Simplified schematic of the OIB.

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Sweep Frequency Measurement of Common Point Impedances

Jim Plumb

SWEEP-FREQUENCY TESTING can be used in broadcasting to measure such parameters as antenna impedance, video amplitude and phase linearity. The technique described here shows amplitude and phase vs frequency on an oscilloscope screen. You can measure input and output impedances as well as the gain or loss of the device or system under test. The equipment used has a phase resolution of less than one degree and amplitude resolution of less than one percent of the reference used. An overall accuracy of plus or minus one percent may be obtained if accurate reference impedances are used over a limited frequency and amplitude range.

In Section 73.54 of FCC Rules, detailed instructions are given for measuring the power input to an a-m broadcast antenna system. An antenna or common-point ammeter is used to indicate rf current, and power is computed by the formula

$$P = I^2 R$$

where P is power in watts, I is rms antenna or common-point current in amperes, and R is antenna or common-point resistance in ohms. The Rules require a series of measurements of both resistance and reactance at the operating frequency and at points 5, 10, 15 and 20 kHz on either side of the operating frequency. Good engineering practice and the Rules require that antenna or common-point reactance at the operating frequency be reduced as near to zero as practical.

The usual method of measuring antenna or common-point resistance and reactance is with an

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rf signal generator, an rf impedance bridge (such as the General Radio 1606-B or 916-AL or the Hewlett-Packard 250B) and a communications receiver as a null indicator. While this system has sufficient precision, it's time consuming; several minutes are required to make each measurement, you have to make at least nine readings, and some engineers prefer to take additional measurements to insure the accuracy of the smooth curve which is plotted and submitted to the FCC.

In many cases the radiating system must be adjusted to zero reactance, and this requires several sets of measurements before the goal is accomplished. These measurements are normally made late at night when the station is off the air. With the necessity for slow and painstaking work, it's not uncommon for the job to take all night, or even several nights. If your station programs 24 hours, the all-night programming must be suspended for as long as the measurements and adjustments take. That deprives the public of a broadcast service, and your company of revenue, for that period.

By contrast, the measurement technique described here maintains the required accuracy and takes less time than the bridge method. Also, antenna or common-point impedance is displayed on a crt and you can see the effect of system adjustments immediately.

Measurement Technique

These measurements are made with a sweep-signal generator and its associated tracking detector, such as the Hewlett-Packard Model 675A/676A network analyzer. If nighttime skywave interference at the antenna is no problem, the Hewlett-Packard 11138A impedance adapter may be used with the network analyzer to make impedance measurements. The circuit arrangement is shown in Fig 1.

The network analyzer is designed to make gain and phase measurements of low-impedance (50 or 75 ohms) amplifiers, filters, cables and similar circuits. It does this by supplying a con-

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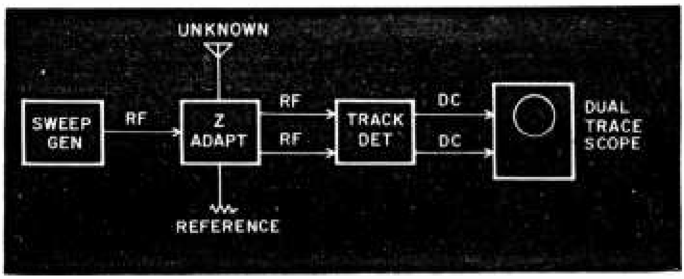

Fig. 1. Measuring equipment is connected as shown. Reference may be resistor or short piece of coaxial cable, depending on parameter being measured by analyzer.

stant-level, swept rf signal to the input of the circuit under test, and simultaneously to a reference, which is a precision resistor or a short piece of coax. After passing through the two networks, the signals are fed to the detector portion of the analyzer for measurement, and are converted to dc voltages. One such voltage is proportional to the gain or loss in decibels, another to the phase shift in degrees. A third is available which indicates the difference in gain in decibels between the test and the reference.

The dc voltages are fed to a dual-trace oscilloscope whose horizontal input is driven by the sweep generator to display the band of frequencies of interest.

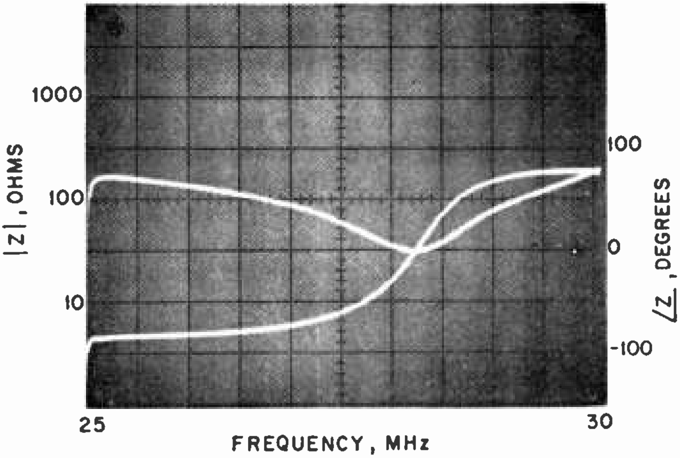

Fig. 2. Dipped trace indicates impedance, ascending trace phase angle, of a whip antenna under test.

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Generator current I flows in unknown impedance Z_x (the total resistance and reactance of the antenna or common point under test) and drops voltage E_0 across it. The analyzer measures the amplitude and phase of E_0.

The adapter converts the 50-ohm output of the network analyzer into a 33,000-ohm circuit, changing it from a voltage source to a current source. At the same time, it isolates the 50-ohm terminating impedance of the network analyzer, providing a high-impedance, voltage-sensing port for the measurement of E_0.

In practice, the antenna under test is connected to one analyzer channel, and a nonreactive, 100-ohm reference resistor is connected to the other. The result is shown in Fig. 2, where one scope trace indicates impedance in ohms, while the other indicates phase angle in degrees. The traces shown are for a loaded whip antenna. Measurement range can be expanded, as shown in Fig. 3, simply by increasing oscilloscope vertical sensitivity as desired.

The phase measurement is calibrated by pressing a pushbutton which feeds a fixed 5-degree signal (accurate within 0.2 degree) into the circuit, moving the scope trace 5 degrees. There is also a 100-degree button for other scales. Am-

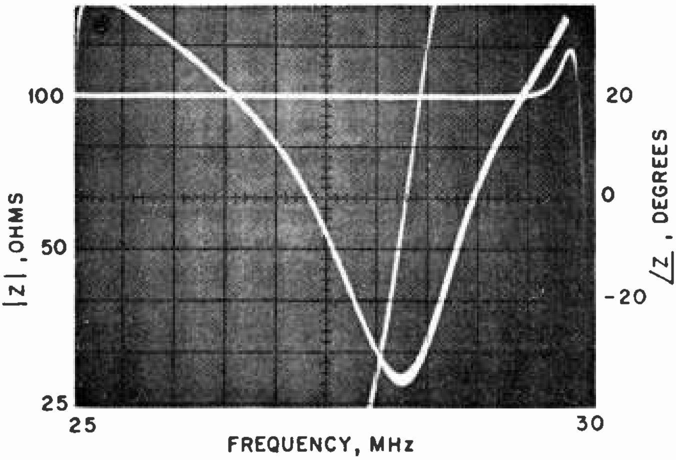

Fig. 3. Trace has been expanded vertically over that shown in Fig. 2 of same antenna.

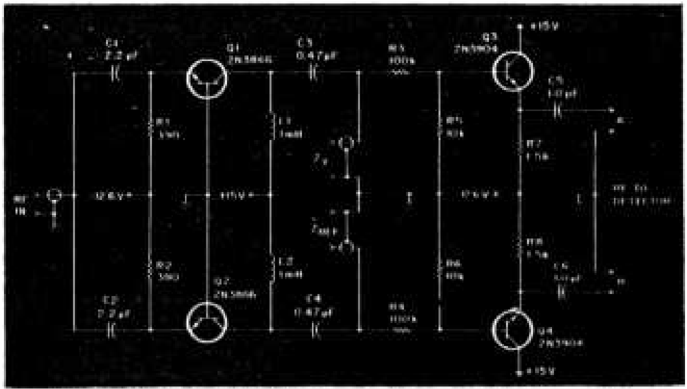

Fig. 4. This adapter, made with standard components, converts sweep generator output to match low impedance of broadcast antenna.

plitude measurements are calibrated with a precision attenuator in the sweep-signal generator.

Since the impedance adapter converts the network analyzer source impedance simply by putting a high resistance in series with it, available output current is reduced. As a result, the generator signal may easily be overridden at the antenna by interfering skywave signals from other broadcast stations. The solution to this problem is an impedance adapter using a current-amplifier stage. Fig.

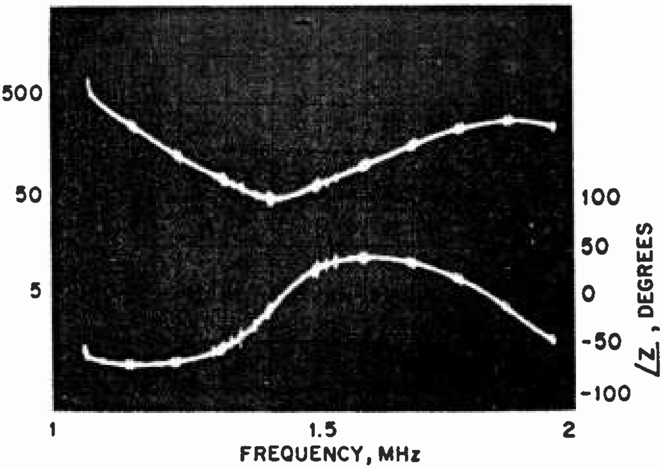

Fig. 5. Impedance of a 1570-kHz BC antenna. Pips are signals of stations on nearby channels.

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4 is the schematic of such an adapter, which is used in place of the one previously described.

Equipment Operation

Fig. 5 shows the results obtained when the analyzer and adapter were used to measure the impedance of a broadcast antenna whose operating frequency is 1570 kHz.

When using the bridge method, the operator reads out resistance and reactance as separate quantities on the bridge dials. You can't do this with the analyzer; on the other hand, you can read total impedance and phase angle on the scope screen.

Notice that in Fig. 5 the antenna is reactive at its operating frequency of 1570 kHz. For a detailed examination of this antenna, the expanded-scale feature was used. The results are shown in Fig. 6.

Signals from interfering stations can be seen in both Figs. 5 and 6; the carrier and sidebands are clearly visible. More important, though, is that the phase angle of the antenna is 37 degrees and its impedance is 100 ohms. The resistance is found by

$$R = Z \cos \phi = 100 \cos 37 = 80 \text{ ohms}$$

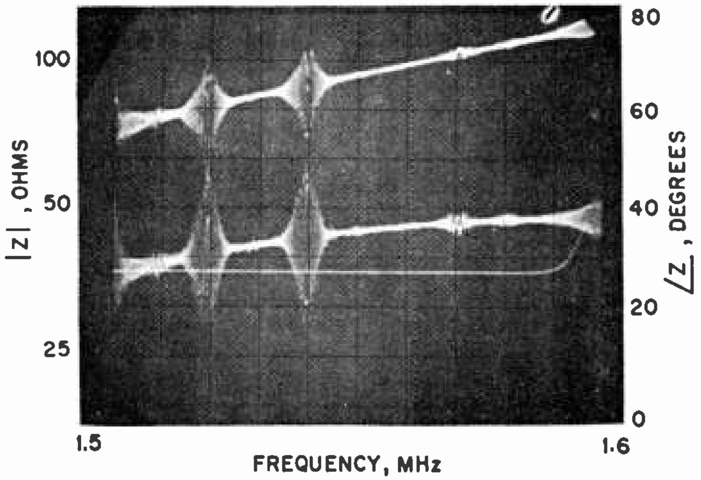

Fig. 6. This is both horizontal and vertical scale expansion of signals shown in Fig. 7

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In practice, you adjust the antenna system until the phase angle is reduced substantially to zero, removing nearly all reactance from the system. At that point, the impedance trace on the oscilloscope indicates the resistance value, which is used to compute rf power.

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Care & Treatment of Ailing DAs

John H. Battison

WITHIN RECENT YEARS the FCC has shown an ever-growing amount of interest in directional antenna operations. New stations going on the air are finding an increased emphasis on the part of the Commission in obtaining concrete proof of absolute adherence to the theoretical directional antenna patterns. Existing stations, when their licenses come up for renewal, are quite frequently in for a shock. Examination by the Commission's renewal branch engineers often discloses that the operating logs for the composite week indicate that the directional antenna system has been operating outside its licensed parameters!

Some of the older established stations are being required to update directional antenna proofs which may have been made twenty years ago or more. Many of these have not been re-proofed since the original license was issued. In some cases, the Commission's requirements are satisfied by an explanation of the discrepancies on the operating logs. In others, a skeleton or partial proof is the only thing that will satisfy the Commission's engineers.

Re-proofing directional arrays that were installed twenty years ago or more turns up problems. Many of the original measuring points along the radials have been built over, or are rendered useless by the proximity of buildings or overhead lines. Many times, too, monitoring points that have become old and trusted friends over the years, are found to be at the very least misleading —if not downright untruthful. You will find monitoring points that are still within the license limits even though the surrounding area has changed. Yet when the radial is run and analyzed, the inverse fields are higher than the MEOV!

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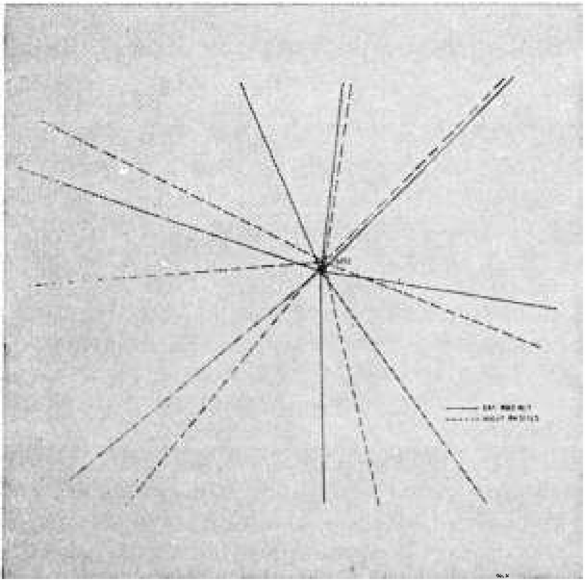

Fig. 1. Example of day-night radials from different towers. In this case, day radials (solid) originated in center of towers number 1, 2, and 6 and night radials from tower number 3.

In a situation like this, the only solution is to select new monitor points. If this is done, it will probably also entail making a series of new nondirectional measurements, utilizing the new measuring points along the radials, plus, of course, running a skeleton proof.

One can encounter some rather unusual problems when making a partial proof or re-proof of an older station. The number of towers used in one of the patterns may have changed since the original proof. A case like this may call for two different sets of radials—one for each pattern.

As a case in point, one of our client stations, which originally had a five tower in-line array for a DA-2 configuration, added a sixth tower to be used in the daytime pattern only. The reworked configuration used tower No. 6 and tower Nos. 1 and 2 of the original array which then formed the daytime antenna system.

The original proof-of-performance radials were drawn from the center, No. 3 tower, and were thus good for day and night measurement

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purposes. When the daytime array was modified, new radials were required from the center of the daytime array.

The nighttime pattern was still referenced to the No. 3 tower, and because of the spacing between this tower and the new No. 6, it was necessary to maintain two separate sets of radials, one each for the day-night patterns as shown in Fig 1.

The array was adjusted so that all the nighttime monitor points were within the license specifications, and the radials were run. Practically all of the points on the original radial were found to be useless because of the intrusion of overhead lines, and new construction, which in some cases completely obliterated the old points.

It was necessary to pick new regular and alternate monitor points, and also to select new points along the radials to complete the proof-of-performance. Even though not required to do so by the FCC, the licensee could probably have saved money by having the chief engineer make a skeleton proof from time to time. Deteriorating radial conditions would have been detected and alternate monitoring points selected.

Log keeping—keep alert

Some of the problems experienced by the broadcasters in connection with his antenna system are simply the results of inadequate and careless log keeping on the part of his operators. The Commission will usually accept phase monitor readings within 4° and plus or minus 5 percent of the current ratios as specified in the license except, of course, for those unfortunate licensees who have tolerances of plus or minus 1° and plus or minus 1 percent.

Careless logging, which represents phase angles to be consistently outside the 4° tolerance, and/or base current ratios that are consistently outside the tolerances allowed by the license, and for which no corrective action appears to have been taken (according to the log or the maintenance entries) almost always result in a requirement for a skeleton proof-of-performance. A num-

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ber of these cases have come to our attention recently in which DA adjustment and/or partial proofs were required. In some cases it was quite apparent that had proper attention been paid to log keeping during the preceding years, a costly (and license-renewal delaying) proof-of-performance would not have been required.

In fact, much of the consulting engineer's work is frequently due to carelessness, and inattention to detail on the part of log keepers, and the people whose job it is to insure that proper log entries are made. On the other hand, such items as widely varying phase and current ratios on a particular tower are usually indicative of changes in either the power supplied to the tower, or the phase monitor system.

If variations are indicated for a specific tower and the parameters for the other towers in the array are normal, an immediate inspection should be made of all the elements in the transmission line system. Starting at the phasor, all connections should be checked for tightness and, if practical, the line condition should be checked for intermittent shorts, or open circuits due to faulty soldered connections, etc. In such case the varying base current was traced to worn out and dirty contacts in the pattern-changing relay at the tower base. When the relay was replaced, the base current returned to normal.

Shortly after, the same tower began to exhibit random variations on the phase monitor. This particular trouble was eventually traced to an intermittent connection in the sampling loop on the tower. From ground level observation the loop had appeared sound, and it was not until a close-up physical check was made that its condition was discovered.

It is quite possible that a careless, inattentive, and disinterested operator would have been content to go along repeatedly entering normally expected phase monitor readings. Unless the erratic phase monitor readings occurred precisely during the time that parameters were being recorded or logged, these variations could have gone unnoticed.

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Monitor points, new and old

When a construction permit for a directional array is issued, certain monitor points are specified. These values show the maximum radiation that is permitted at these points. Normally, a licensee is required to measure and record these values once every seven days. A monitor point that is consistently high (in the absence of unusual circumstances such as extreme cold conditions which are acknowledged to increase conductivity) can usually be taken as an indication of misadjustment in the directional antenna system. This assumes, of course, that nothing has occurred in the vicinity of the monitor point to account for the consistently high readings. Great changes have taken place in local construction and power line installations in most areas in recent years. It is, therefore, a very wise precaution to select alternate monitoring points and obtain the Commission's approval to log and use these in addition to the regular points to demonstrate that the array is properly adjusted.

The use of alternate monitor points also serves a double purpose. Local conditions can cause a change in a regular monitoring point reading that might indicate excessive radiation. But if the alternate monitoring point does not also indicate excessive radiation, the increase may be due to a purely local condition. Knowledge of this fact may prevent an inexperienced operator from attempting to readjust an array that is already operating properly!

Any discussion of monitoring points brings up a topic which has become of increasing concern to engineers who are required to maintain directional antenna systems—cold weather. It has finally been accepted in engineering circles that cold weather produces an increase in ground conductivity in many parts of the country. Thus, a monitor point which has been running happily within 1 mv/m of its limit throughout the spring, summer and early fall, may begin to run perhaps 1 to 10 mv over its limit with the onset of winter conditions, when the ground freezes.

Inspection of the station's operating logs may lead to a citation, and perhaps a monetary for-

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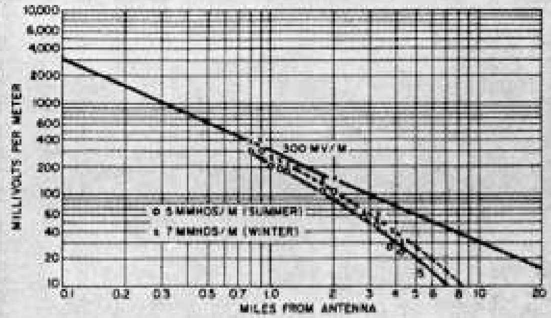

Fig. 2. Illustration of seasonal changes in conductivity. Note the inverse field remains the same, but the conductivity has increased from 5 mmhos/m to 7 mmhos/m.

feiture, if monitor points consistently run above their limits and no efforts have been made to account for this phenomenon.

One precaution which can be taken to prevent problems of this nature requires the making of a series of measurements along the radial, or radials, involved—if possible, at the same points at which the original proof-of-performance measurements were made.

The new figures should be plotted on log-log paper and reanalyzed. Frequently, it will be found that a new, higher, conductivity curve will fit these new figures, and that the inverse field measured at one mile remains within the MEOV. This is an indication that the radiated power is within the licensed parameters, and that the increase at the monitoring point is due to an increase in conductivity. See Fig. 2.

If the foregoing is the case, the correct step is to record all the information and file an application requesting a modification of license to specify a higher monitor point value during win-

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ter months. If interference considerations permit, a relaxation of the MEOV and a permanent increase in monitor point limits may also be requested.

Try phasor rocking—with caution

A technique that is employed to return a wandering directional antenna system to its licensed parameters is "phasor rocking." This is not a project to be undertaken lightly, and without making the proper preparations. It must also be done carefully if it is to be useful—this means it is time consuming. Carried to its ultimate conclusion, it involves the stationing of personnel equipped with field measuring sets and mobile radio equipment at each of the points to be monitored. After each change is made in a phasor setting, the fields measured at the monitor points are reported by radio to the engineer performing the adjustment. These values are then recorded in the appropriate columns against the specific adjustment. Fig. 3 shows a typical format for a phasor rocking operation. The top line should contain the licensed parameters for all the towers and the phenomena being measured.

The next line should contain the actual currently employed phasor and common point settings. This is very necessary, so that in the event that the array becomes unstable or goes out of control, it will be possible to return to the original operating conditions.

It is, of course, necessary to request an authorization from the Commission to operate with parameters at variance from the licensed values for a period of time to cover the proposed tests. Until the Commission has authorized this operation, it is essential that no departures from the licensed parameters are made!

If an operating bridge is available, it should be connected at the common point to ensure that abnormal departures from the licensed common point impedance, and hence current, do not occur. Normally, small variations in the common point impedance will be noted, and can be recorded as the phasor controls are rocked. But unless

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I_{cp}	Z_{cp}	Phasor #1 M	Phasor #1 φ	Phasor #2 M	Phasor #2 φ	Phasor #3 M	Phasor #3 φ	Phasor Monitor #1 M	Phasor Monitor #1 φ	Phasor Monitor #2 M	Phasor Monitor #2 φ	Phasor Monitor #3 M	Phasor Monitor #3 φ	Monitor Points mv/m 1	Monitor Points mv/m 2	Monitor Points mv/m 3	Monitor Points mv/m 4
10X	50+j0	9.5	3.6	8.5	4.0	7.0	6.3	0.6	∠56°	1	∠0°	0.35	∠85	21	15	36	49
		+.5											—	21	16	33	48
		−.5												19	15	37	50
				+.5										16	13	36	47
				−.5									—	20	13	30	48
						+.5								16	14	37	49
						−.5							—	13	11	29	40
			+.5											21	14	34	40
			−.5										—	22	13	34	38
							+.5						—	12	13	30	36
							−.5							23	16	29	36
10X		10.0		8.0		6.0	6.8	0.69	∠58°	1	∠0°	0.41	∠84	10.5	13	25	36
		+.5											—	10.5	13	21	34
		−.5												9	12.5	22	34.5
				+.8										7.5	11	21.5	34
				−.5									—	8.5	11	18	34
						+.5								8	10.5	18.5	34
						−.5							—	6.5	9	17	33
			+.5											6.5	8.5	16	29
			−.5											6.5	8.5	18	28
							+.5						—	5	7.5	17	27.5
							−.5							9	10	19	28
		10.5		7.5		6.5	7.3	0.74	∠60°	1	∠0°	0.5	∠85°	5	8	15	22

Fig. 3. Tabulation of readings after a D-A is brought back into spec by phasor rocking. See text for details.

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any very wide variations are noticed, which would indicate a very bad misadjustment of the phasor, these readings are not too important at this time. Of course, if a new set of phasor control settings is obtained, it will be necessary to measure and correct the common point impedance as required.

A good way to proceed with the phasor control rocking is to vary the controls systematically in turn, commencing with the magnitude control for tower 1 and advancing it about three-quarters of a turn clockwise. All phase monitor readings are then recorded with the reported reports of monitor point readings. The actual change in phasor settings will depend on individual preference and condition. The No. 1 tower magnitude control is then retarded one-and-one-half turns counterclockwise from its last setting, so that it is actually three-quarters of a turn counterclockwise from the original setting. Again, all phase monitor point readings are recorded. This magnitude control is now returned to its original setting and all readings should be the same as they were prior to the first movement of this control.

Next, the phase control of No. 1 tower is moved in a similar manner, as are all the other controls in turn. When the exercise has been completed, the tabulation will look like Fig. 3.

Analysis of these results should show that specific adjustments to certain towers will cause changes in the desired direction in monitor point readings and phase monitor readings. It is usually possible to determine from this tabulation which way the phasor controls should be moved to obtain the desired results. I must emphasize, however, that it is absolutely essential to record the phasor settings before any knob is turned, and to keep an accurate and concise record of every adjustment made. If you don't do this, you are liable to end up with an array that is completely out of adjustment!

DA-NDA switching made easy

Many of the directional stations that have been constructed in recent years embody control

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circuitry that make it possible, in the case of a DA-N station, to switch from nondirectional to directional operation and vice versa by pushing a button. In the case of DA-2 stations, although more complicated, it is frequently possible to switch from each pattern to a nondirectional and back again by means of push buttons. If any of you are contemplating the construction of a new antenna system, or an updating or modification of an existing one, I would strongly recommend that you include this facility. It doesn't cost a great deal of money and the convenience that it provides is priceless. As a matter of fact, there have been strong suggestions that the Commission will, before too long, require that this facility be embodied in all directional antenna systems. I firmly believe, not only from an engineer's viewpoint, but also from the point of view of management (whose interest lies in preserving continuity of signal pattern during DA measurements), that it is a very worthwile addition to any antenna system.

The DA-NDA system that I have described above speeds up every kind of measurement operation. It is possible to go to any measuring point once only, and to read any antenna pattern value at that point in the course of two or three minutes. These readings are made under identical weather and field strength meter orientation and adjustment conditions.

I might add, in connection with NDA readings, that when questionable readings are noted at a monitor point, or when trouble in a DA operation is suspected, nondirectional readings taken at the monitor point and ratioed to the directional readings give a very good indication of an antenna's performance and condition.

An item that is frequently overlooked, because its operation is normally trouble-free and consistent, is the phase monitor system. We are not going to talk about the instrument itself, but we will talk about the connections between the instrument and the antenna system. If you have inherited a directional antenna system whose installation details are not very familiar to you, you would be well advised to become familiar with

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every detail of the installation, not forgetting where the excess sampling lines are stored.

As we are all aware, it is necessary that all sampling lines have the same electrical length. This means that the line length is controlled by the distance to the furthest tower. The towers that are closer to the location of the phase monitor will have lines of the same length, but the excess line will have to be stored somewhere. It is an axiom of the FCC, and good engineering practice, that all excess line lengths be stored in such a way that equal lengths of all of the lines are subjected to the same climatic and temperature conditions. If this is not the case, the expansion or contraction of unequal lengths of line will cause a plus or minus change in the phases indicated on the phase monitor. If you experience changes of this type under extremes of weather condition, be prepared to check the location of the excess phase monitor sampling line.

Run transverse radials to spot nulls or lobes

Sometimes in the adjustment of a directional antenna, an unwanted null or an unwanted lobe may appear. It frequently happens when the monitor points have failed to show that the antenna is not correctly adjusted, i.e., the monitor points are within the FCC limits. But when a skeleton proof or radials are run, it is sometimes found that the inverse fields along these radials are higher than one would expect from the monitor point values. Or, of course, the points could be a great deal lower than the licensed monitor point values, and this again would be a cause for suspicion.

If an unwanted lobe or null is suspected, running a transverse, or cross radial, will frequently show up the unwanted effect. The technique of making a transverse radial is a little different from running a regular radial.

In the case of a transverse radial, it is a good idea to select an arc, or radius of a suitable value, perhaps two miles, and draw this arc with a radius covering the whole of the area under suspicion, Fig. 4. Good measuring points were picked

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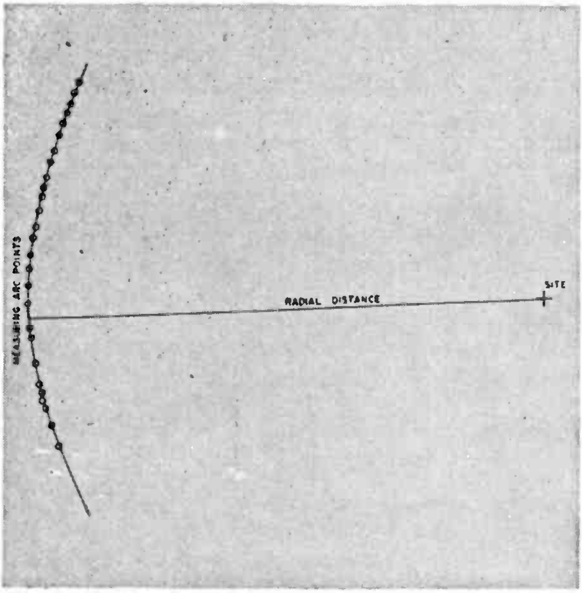

Fig. 4. Illustration of laying out a transverse radial when trying to locate null and lobe positions.

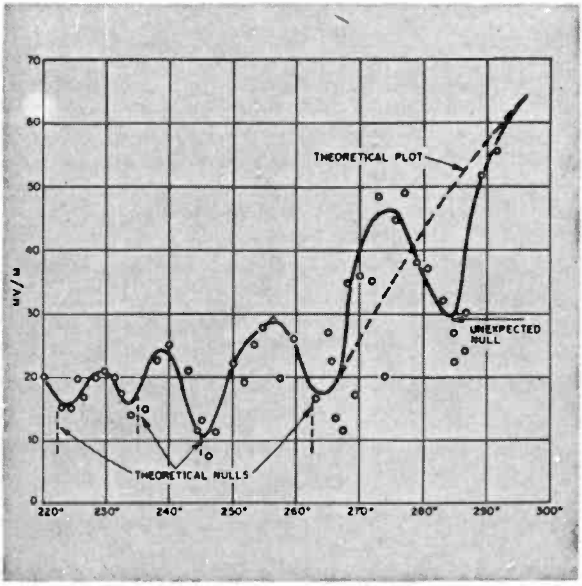

Fig. 5. Plot of transverse radial measurements showing azimuth versus field strength.

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at intervals of about 1/10th of a mile, or less, along this arc and a series of measurements made.

When these measurements were plotted on linear paper with the azimuth plotted in degrees along the abcissa, and the field strength in millivolts along the ordinate, the pattern shown in Fig. 5 was produced. The licensed pattern called for a null at 277°. To our surprise, we found the null to be at 287°!

The transverse radial could, of course, be run as a straight line in any desired direction. Then the distance from the antenna would vary for each point, and a third variable would be introduced into the problems. Use of a transverse radial is not very common in normal directional antenna work, nor is it required or even desired by the FCC. However, it is a tool that can be very useful at times.

In concluding these notes on directional antenna problems, I might re-emphasize that many of the problems that station engineers encounter can be prevented by proper maintenance. It seems to be an obvious thing, but you would be surprised at the number of times we encounter DA problems which are directly traceable to what I like to call "agricultural laziness!"

The antenna field should be kept clear of all brush type vegetation, and grass and weeds should be kept cut to a low level. Within the area around the tower base screens, the crushed rock—and only crushed rock should be used there—must be kept clear of weeds and vegetation. Weed killer applied here at regular intervals is very useful. One of the surest ways of encouraging varying DA meter readings is to allow high brush growth in this area.

One station that we inspected had a wild grape vine securely wrapped around the RF lead from the tuning house to the antenna base. Luckily we found it before the "Grapes of Wrath" of the FCC descended on the station.

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Retuning the Directional Antenna

Barry Atwood

THERE COMES A TIME in the life of many directional antenna arrays when, despite careful maintenance, the system no longer does what it was designed to do. The array simply fails to provide specified values of field intensity at one or more monitoring points.

The problem results from a change in the environment of the system, which encompasses not only the immediate vicinity of the array, but the entire coverage area. When excessive fields are noted, the station engineer usually tries to restore the monitoring point field intensity to normal by adjusting the antenna parameters, as close as possible, to the values specified on the station license. This usually does not work, since the conditions that existed when the array was first installed are no longer present. It thus becomes necessary to retune the antenna system.

The many articles covering the design of directional antenna systems prove to be of little value in the readjustment of an existing array. However, the method outlined, sometimes with slight variations, has been used by many consulting engineers in the final adjustment of an array after the design values have been established. Rare, indeed, is the directional antenna system that works exactly as designed with the original computed values. The refined "cut-and-try" procedure set forth in this article has no connection with any existing array, or any type of array, but rather serves to illustrate the principles involved.

First, Check The Monitoring System

Before proceeding with any actual retuning, test carefully to make sure that the monitoring

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system is functioning properly. The first thing is to be certain that you are in the exact location specified for the monitoring point. Most descriptions of monitor point locations pinpoint the location as an exact, specific number of feet from some fixed object, such as a road marker or telephone pole. Measure off the distance exactly, since an error of only 10 feet or so can cause an erroneous reading, particularly in deep null locations.

The second step is to check for correct antenna parameters. Check the station license, and make sure that the values of common point current, antenna phasing, and antenna base current ratios are as specified by the license. After you have verified that all of the antenna system parameters are correct, you should establish that the common point impedance is of the correct value. Actual measurements are best, but an approximate check can be made by computing the operating power by the indirect method.

Next, check the accuracy of the antenna base and common point ammeters. A meter of known accuracy should be inserted in series with each meter and a comparison of the two readings made.

The antenna phase monitor should also be checked. To do this, first remove all of the antenna sampling lines except for the line connected to the reference tower. Then, connect a capacitor (.01 μF or so) from the reference tower input jack of the monitor to the next input jack. Set up the phase monitor to read the phase angle between the two inputs. You should read a 90° phase difference.

Now check the field intensity meter. This can be accomplished by direct comparison with another meter, preferably one that has been recently calibrated by the factory.

The last thing to be checked is to make sure that the monitoring points which yield high values of field intensity have not gone "bad." This is done by making field intensity measurements at other points on the radial to see how they compare with the readings obtained in the same locations during the original proof.

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A very careful check should also be made of the antenna ground system. Usually, a fault in the ground system will cause the field intensity to drop at all monitoring locations since this type of fault reduces the antenna efficiency. However, a break in the main ground buss to one tower, or faults in the radials around one tower, may upset the pattern. If all of these checks prove positive, the only way to reduce the monitoring point field intensity is to retune the antenna system.

Next, Get FCC Clearance, Prepare Work Sheets

Before proceeding with any actual tuning, it will be necessary to obtain the authority of the FCC. A telegram should be sent to the FCC in Washington, D.C., requesting authority to operate the antenna system at variance from licensed parameters to facilitate retuning. Once this authority is granted, the telegram from the FCC is posted alongside the station license and you arc ready to proceed with actual retuning.

First, prepare a work sheet such as shown in Fig. 1. The work sheet illustrated is for a three tower array with four monitoring points. Any array configuration and number of monitoring points can be accommodated. The first six vertical columns list the phasor control settings. The first three relate to the phasor current controls, and the next three relate to the phasing controls. For example, "1A" refers to the tower number one current control on the phasor, "2A" is for the tower number two current control, and so on. A two tower array would have only four columns for phasor controls, an array with four towers would have eight, and so forth.

The *horizontal* row, fourth from the top, lists the present dial settings of the phasor controls, since most phasors have some form of counter dial on the controls. After the entries for phasor controls, entries are made for monitoring points. Be sure to list *all* of the monitoring points specified by the station license. Under the location of each monitor point, list the maximum permissible field intensity in mV/m for that point. In the fourth horizontal row, list the readings obtained

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at these points. In this example, the reading obtained at the first monitoring point is above limits. The reading is 27 mV/m, and the maximum permitted is 18 mV/m. The object in this example is to reduce the field intensity at monitoring point number one to below 18 mV/m.

Under each column entry for phasor controls, is an entry of "cw" and "ccw." These describe the movements that will be made of each control, first in a clockwise direction, then in a counterclockwise direction. The object of the game is to

PHASOR CONTROLS						MONITOR POINTS			
CURRENT			PHASING			#1 160°	#2 175°	#3 185°	#4 210°
1A	2A	3A	1Ø	2Ø	3Ø	18.0 mv/m	7.0 mv/m	34.5 mv/m	22.0 mv/m
3425	5029	4096	6395	2435	7253	27.0	5.2	29.6	19.1
CW									
CCW									
	CW								
	CCW								
		CW							
		CCW							
			CW						
			CCW						
				CW					
				CCW					
					CW				
					CCW				

Fig. 1. Sample worksheet with initial conditions filled in.

move each phasor control first one way and then the other, and observe the changes that occur in field intensity at each monitoring point location. Under each monitor point entry, there is a space to record the change in field intensity that occurs as the number one tower current control is varied in a clockwise direction. Just below that entry, there is a space to record the change as the tower number one current control is varied in a counterclockwise direction, and so on for each phasor control and monitor point. The exact procedure to be used will be detailed later. Some phasors do not have any controls for the reference tower in the system, since the other controls can be varied with reference to this tower. If this is the case with your phasor, simply omit the entries for this tower.

Obtain Needed Equipment

Before you start to turn the phasor controls, make sure you have the necessary equipment. You already have a field intensity meter and have tested it to assure yourself it is accurate. Do obtain fresh batteries for the instrument, since it will be in use quite a bit.

An accurate impedance bridge of some sort is also necessary, since readjustment of the array will change the common point impedance. The handiest type of bridge to have is the inline, operating impedance bridge. It is best to try to gain access to a standard rf impedance bridge, signal generator, and detector combination. It may be impossible to return to the original value of common point impedance, and it will be necessary to run new impedance curves in this case.

You should have some form of two-way radio system for communication between the transmitter phasor site and the various monitor points. For this type of operation, two engineers are required, one at the phasor controls, the other at the monitor points. One man can do the job without a two-way radio, but it takes a lot more time, particularly with a large array and many monitor points. If you obtain a two-way radio system, one unit should be set up at the transmitter site in some

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convenient location so that the transmitter engineer can converse by radio and manipulate the phasor controls. The second unit should be installed in a car. The mobile unit is then driven to the various monitoring point locations. Don't forget to keep a log of the transmissions made over the two way radio as required!

Some Initial Considerations

Before taking off in the car for the first monitor point, a few facts should be kept in mind. The first thing to consider is the change that will occur in the common point impedance as the phasor controls are varied. It will be necessary, therefore, to determine the operating power by the indirect method for the time being, and the transmitter engineer must keep a close watch over the power output. He should determine the plate current required for the normal power output of the transmitter, and disregard the reading of the common point meter.

Another factor to consider is the weather. Rain has an adverse effect on many directional antenna systems. Even after a rain, the array may exhibit some instability until the area has thoroughly dried out. It is best to start actual retuning only after you have some insurance of favorable weather conditions.

The last factor to consider is the time of day that field intensity measurements are made. Measurements should be made only within the period of from two hours after sunrise to two hours before sunset. Skywave interference may preclude valid readings at other than these times, particularly when dealing with very low values of field intensity. This type of interference increases very rapidly after sunset. If the station is licensed for operation with a nighttime power less than that of the daytime power, adjustment should be made on high power. (This assumes that the actual phasor configuration is the same for both day and night operation, and only the transmitter power is changed, since both day and night patterns are dependent on the same phasor settings.) In the event the station uses a different

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pattern shape (not to be confused with pattern size) for day and night operation, this procedure will have to be performed twice, once for each pattern. Such a system would have two separate phasors, or a switching system to change phasor components. For stations that are nondirectional during the day, and directional at night, adjustments will have to be made on the directional antenna system at the nighttime power, but during the day.

The Actual Tuning Procedure

With the transmitter engineer at the phasor controls and two-way radio, the field operator should proceed to the first monitor point. The car should be driven as close as possible to the actual point of measurement and a reading taken. Now, set the field intensity meter on the roof, or NO → hood of the car, and rotate the meter for maximum pickup, as in making normal field measurements. away from (The meter should be placed somewhere on the car that will permit the operator to watch the meter and converse with the transmitter engineer over the two-way radio.) Adjust the gain control of the meter to give the same reading as was obtained on foot at the exact monitor position.

The field operator now instructs the transmitter engineer to vary the first phasor current control one turn in the clockwise direction. When the control has been moved to this position, the transmitter engineer informs the field operator that the move has been made. The field operator now enters the field intensity reading in the appropriate place on the work sheet.

For example, let us assume that the field operator has gone to the first monitor point and measured 27 mV/m. This reading is entered under monitor point number one on the work sheet as shown in Fig. 2. The field operator then instructs the transmitter engineer to move the tower number one phasor current control one turn in the clockwise direction. Now, let us assume that after the transmitter engineer has made this move, that the field operator now reads 25.8 mV/m. He would then enter this reading

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directly below the original reading of 27 mV/m as shown in Fig. 2.

After the reading has been logged for the first move, the field operator instructs the transmitter engineer to move the first current control one turn in the counterclockwise direction from the original position. (This actually requires him to move the control two turns in the counterclockwise direction, since the object is to get one turn counterclockwise past the original setting of the control.)

After recording the ccw readings, the field operator now instructs the transmitter engineer to return the control to the original setting. (This would be one turn in the clockwise direction.) The field operator should now verify that the field intensity is the same value as originally read. For the example given in Fig. 2, the reading should return to 27 mV/m. The reason for this check, is that some phasor controls may exhibit some backlash and may not return to the exact same spot on the coil, even though the counter dials indicate the same reading. If this occurs, the transmitter engineer will have to juggle the control slightly while the field operator watches the meter, until the reading returns to the original value.

This procedure is now repeated for the rest of the current controls, and then again for the phase controls, and the results of each move entered on the work sheet. It will probably be found that the phase controls have a more pronounced effect on the readings than the current controls.

After readings are obtained at the first monitoring point for all variations of the phasor controls, the field operator should proceed to the next monitor point and repeat the procedure followed at the first point. The transmitter engineer should keep tabs on the transmitter power using the indirect method of measurement. The field operator should establish that the field intensity at each monitor point has returned to the original value before proceeding to the next point.

After the readings for all of the monitor points have been taken, the field operator can look at the completed work sheet and decide which move of

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PHASOR CONTROLS						MONITOR POINTS			
CURRENT			PHASING			#1 160°	#2 175°	#3 185°	#4 210°
1A	2A	3A	1φ	2φ	3φ	18.0 mv/m	7.0 mv/m	34.5 mv/m	22.0 mv/m
3425	5029	4096	6395	2435	7253	27.0	5.2	29.6	19.1
CW						25.8	5.0	28.0	19.3
CCW						27.2	5.3	28.9	18.3
	CW					26.2	5.9	29.0	18.0
	CCW					24.1	6.0	28.7	16.9
		CW				22.9	5.6	27.0	19.5
		CCW				24.0	6.6	26.8	20.1
			CW			91% 16.3	107% 7.5	78% 27.3	96% 18.9
			CCW			31.2	9.6	30.5	21.3
				CW		108 19.5	90 6.3	.87 30.1	98 21.6
				CCW		84% 15.1	71% 5.0	82% 28.3	84% 18.5
					CW	29.6	9.8	36.6	25.3
					CCW	21.6	8.3	32.1	21.6

Fig. 2. Examples of data entered. No 2 phase control CCW one turn brings field intensity to within required readings.

the phasor controls yields the best results. Referring to Fig. 2, at first glance, it would appear that moving the number one phase control one turn in the clockwise direction will bring the reading at the troublesome point, number one, to within limits. However, closer inspection reveals that this move also puts the reading at monitor point number two out of limits.

Moving the number two phase control one turn in the counterclockwise direction, as shown in Fig. 2, will bring all of the readings to within

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limits. This move is, therefore, the move that would be made, and this would complete the tuning procedure.

It will probably be found that the array will not be quite so cooperative, and it will be necessary to repeat the entire procedure several times before the desired results are obtained. For example, referring again to Fig. 2, if the move of the number two phase control one turn in the counterclockwise direction reduced the reading at the first monitor point to say, 19 mV/m, and left the other readings the same as indicated for this move, this would be the best initial move to make. The procedure would then be repeated with a fresh work sheet. It should be noted that it is best not to rotate the controls more than one turn at a time, for it may be noted that further rotation of the control will cause the reading at one point to go one way, and then reverse and go the other. In fact, if this condition is observed in the tuning process, the controls will have to be moved in increments of less than one complete turn, otherwise results will be invalid.

Check, and Adjust Common Point Impedance

With the array adjusted to yield the desired intensity at all monitor points, it is now necessary to check the common point impedance with the bridge. If the impedance has changed from the original value, an attempt should be made to return to this value.

If it is not possible to return to the original value, try to choose some value that will give some leeway for future adjustment in the position of the coil taps. Also, try to choose some value that you can live with, that is to say, a value that yields a convenient figure of common point current. Be sure that this new value of common point current will fall within the range of the common point ammeter as required by FCC rules. If a new value of common point impedance is established, it will be necessary to obtain authorization from the FCC to determine operating power by the indirect method, pending approval of the new common point impedance measurement report.

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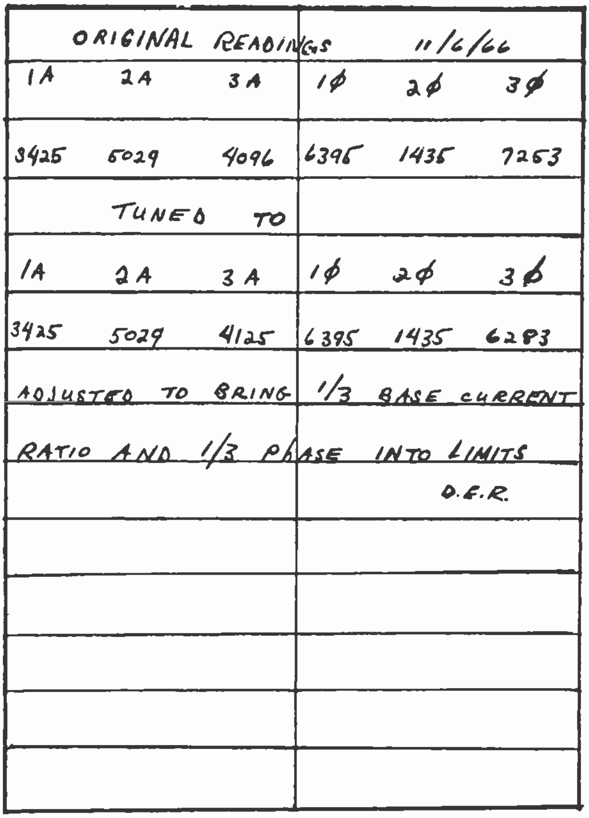

ORIGINAL READINGS			11/6/66		
1A	2A	3A	1φ	2φ	3φ
3425	5029	4096	6395	1435	7253
TUNED TO					
1A	2A	3A	1φ	2φ	3φ
3425	5029	4125	6395	1435	6283
ADJUSTED TO BRING 1/3 BASE CURRENT					
RATIO AND 1/3 PHASE INTO LIMITS					
			D.E.R.		

Fig. 3. Log listing all new parameters.

Determine New Parameters

With the common point impedance adjusted, and the antenna tuned to the new values, it would be wise to make up some type of table listing all of the new parameters. This list should include the measured common point impedance, common point current for direct method of power measurement, transmitter plate voltage and current, antenna phase monitor readings, remote meter readings, and antenna base current readings.

It is best to take an average of several base current readings for each tower, taken every hour or so over a period of several days, and establish this average of each tower as the base current.

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This chart should also list the limits for all parameters. It will also be found helpful to maintain a running log of any future phasor adjustments. A stenographer's note pad is quite handy for this purpose. Readings of phasor control settings should be entered in this book before any adjustments are made. The phasor dial readings after adjustment should also be entered, along with the date, explanation of why the phasor was adjusted, and the initials of the engineer who made the adjustments. This log will provide the station engineer with some means of accurately returning to original phasor settings, should anything go wrong. It is a good idea to log any adjustments that are made of the common point impedance, or of antenna tuning units. Fig. 3 illustrates one format for such a log.

Running the Proof

With the array in final adjustment, it will now be necessary to run a "skeleton" proof of performance of the antenna system to prove that the pattern is basically unchanged. Field intensity measurements will have to be made on at least five consecutive points on each radial. These measurements will have to be made in the same locations as measured in the original antenna proof of performance. It is best to make at least seven measurements, since some readings may prove to be invalid and have to be discarded.

A work sheet such as shown in Fig. 4 should be prepared. Graph paper with one-quarter-inch squares is ideal for this form. In the left hand column, list the radial bearing, and the location numbers obtained from the original proof. Vertical columns should be established to list readings obtained in the original proof, and the present readings for each pattern. The average of the original and the present readings should be noted for each location, and the overall average for the entire radial should also be tabulated. Some locations may yield an average which is abnormally high or low, but these readings may be discarded, so long as you end up with readings for at least five consecutive points. After all of the ra-

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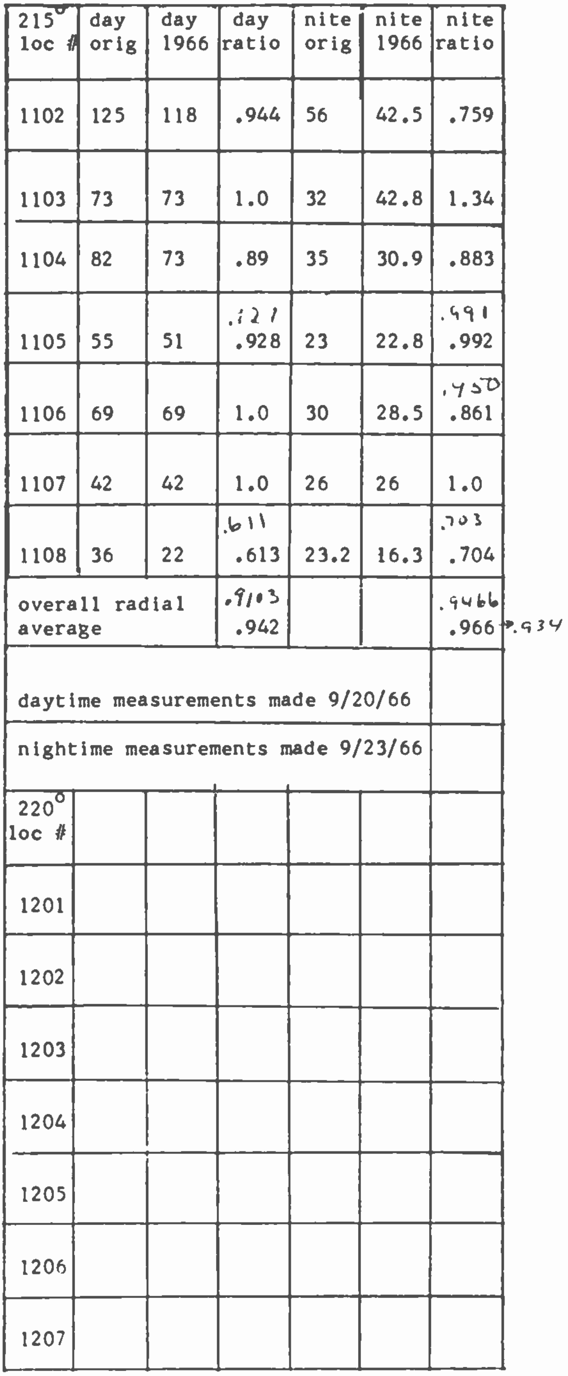

215° loc #	day orig	day 1966	day ratio	nite orig	nite 1966	nite ratio
1102	125	118	.944	56	42.5	.759
1103	73	73	1.0	32	42.8	1.34
1104	82	73	.89	35	30.9	.883
1105	55	51	.921 .928	23	22.8	.991 .992
1106	69	69	1.0	30	28.5	.950 .861
1107	42	42	1.0	26	26	1.0
1108	36	22	.611 .613	23.2	16.3	.703 .704
overall radial average			.9103 .942			.9466 .966 →.934
daytime measurements made 9/20/66						
nighttime measurements made 9/23/66						
220° loc #						
1201						
1202						
1203						
1204						
1205						
1206						
1207						

Fig. 4: Work sheet for antenna proof of performance measurements.

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dials are measured, the average of each radial should be checked. If the average of two or more radials falls outside the limits of 0.8 to 1.2, further retuning will be necessary. This is rather unlikely, however. As illustrated in Fig. 4, the reading obtained at location number 1108 on the 215° radial was discarded, since it would upset the average.

The dates that the readings are made should also be entered on the work sheet. Remember to make all field intensity measurements within the period of from two hours after sunrise to two hours before sunset. Before starting out each day, make measurements at the monitoring point locations to insure that the adjustment of the array has not shifted.

After all of the radials have been run, tabulate the overall average of all the radials. This is the average of all the radial averages. After the skeleton proof is completed, the common point impedance curves should be run. This step can be omitted if it was found possible to return to the original value of common point impedance. The impedance should be measured at the station frequency in steps of 5 kHz out to 30 kHz, either side of the station frequency. These measurements should be compiled in columnar form, and curves of the impedance characteristic plotted as shown in Fig. 5.

Compiling the Proof

After all of the necessary data has been taken, it should be assembled into neat order. The skeleton proof of performance should be submitted as one report, and the common point impedance as a separate report. These reports may be submitted in the form of three-ring notebook. The skeleton proof, and the common point impedance report should contain a signed and notarized affidavit, signed by the engineer who made the measurements. This affidavit should contain the qualifications of the engineer who made the measurements, a statement that he made the measurements, and his relationship to the station.

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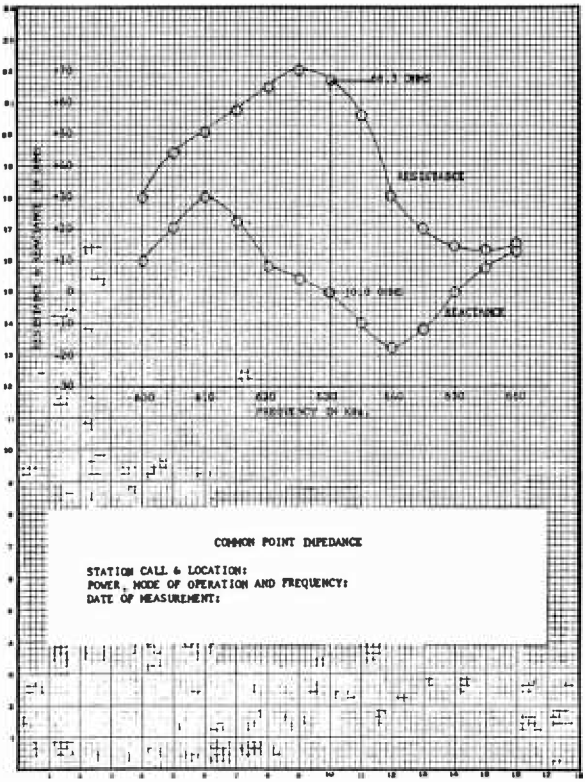

Fig. 5. Impedance characteristic plot.

The next page of each report should contain a description of the method used in making the measurements, the name of the manufacturers of the instruments used, and the rated accuracy. The date, accuracy, and by whom each instrument was last calibrated, along with the serial number of each instrument should also be included.

The next page of the skeleton proof should contain a tabulation of all the antenna and transmitter final stage parameters. The skeleton proof is then completed with a separate page for the readings of each radial, including all of the information shown in Fig. 4. Readings of abnormal averages should be omitted from the report.

The final page of the antenna skeleton proof of performance is a tabulation of the field intensity at all of the monitoring point locations. The common point impedance report is then completed

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with a tabulation of the measured impedance at each frequency, and a graph of the tabulated data as shown in Fig. 5.

File for Modified License

After all of the reports are completed, the station should file for a modified station license. This is done on FCC Form 302. This form and all reports must be filed in triplicate.

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Summer-to-Winter Changes in AM Coverage

Paul F. Godley, Jr.

MOST MANAGERS AND operators concerned with AM station performance are familiar with the problem of winter skywave-signal interference in the fringe area. Similarly in summer, electrical storms and other atmospheric disturbances can seriously affect AM coverage. Those with technical backgrounds may also be aware of seasonal changes in their station signal intensity. Operators responsible for directional antenna systems, particularly those who must make monitor-point measurements to satisfy FCC license requirements, are well aware that such monitor-point levels do not always remain constant. Long term noncyclic changes in signal intensity probably can be traced to transmission-plant problems. However, certain other cyclic variations may be caused by changes in effective conductivity, rather than by changes or misadjustments of the transmission system.

Over the years at this company, we have encountered seasonal variations in signal intensity and made positive observations thereof. Starting in 1962 with the cooperation of the engineering department of a clear-channel station, we began to accumulate data that demonstrate the magnitude of the seasonal variations which can be encountered even within a few miles of the antenna. From 1967 to 1969 we made regular measurements on six stations situated in different compass directions and at various distances from our office in Little Falls, N.J.

All the information thus obtained indicates that there can be 200% to 300% variations in AM signal levels at a given location. With the possibility of such large changes due to causes beyond

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a licensee's control, it is important to have some understanding of the effects.

Amount of Signal Variation

Figure 1 shows the measured variations in field intensity at our office, of the signal from WMTR Morristown, N.J., a 5-kW station which operates daytime on 1250 kHz with a directional array. Measurements were made almost daily from February 1967 to August 1969. As you can see, in winter the maximum signal level was as much as 50% above average, while in summer the minimum level was approximately 45% below average. The actual field intensity at our office, which is 13.7 miles from the WMTR antennas, varied from a low of 3.5 mV/m in June to a high of 9.7 mV/m in January.

To investigate the possible effects of different path lengths and compass headings, we measured other station signals at our office. The results are shown in the field-intensity measurements table.

The signal variations illustrated by Fig. 1 and listed in the table are typical of the cyclic variations we have encountered in the field. The clear-channel station study, which covered nearly a four-year period from 1962 to 1965, showed that stable antenna systems exhibit annual field-intensity variations. All stations which were checked during our study showed this evidence of seasonal variation.

The Cause: Temperature

Cyclic variations for a given path are more closely related to air-temperature changes than to soil-conductivity factors, such as soil moisture, freezing, snow and vegetation. The variations were found to occur from hour to hour. In fact, hourly measurements were made of WMTR one day in October when the temperature rose from 36°F at 8:30 a.m. to 65°F at 3 p.m. The 1250-kHz signal level decreased from 5.9 mV/m in the morning to 5.1 mV/m in the afternoon—a change of 14% in about six hours.

Although the signal level changes with air temperature (increasing with decreasing tempera-

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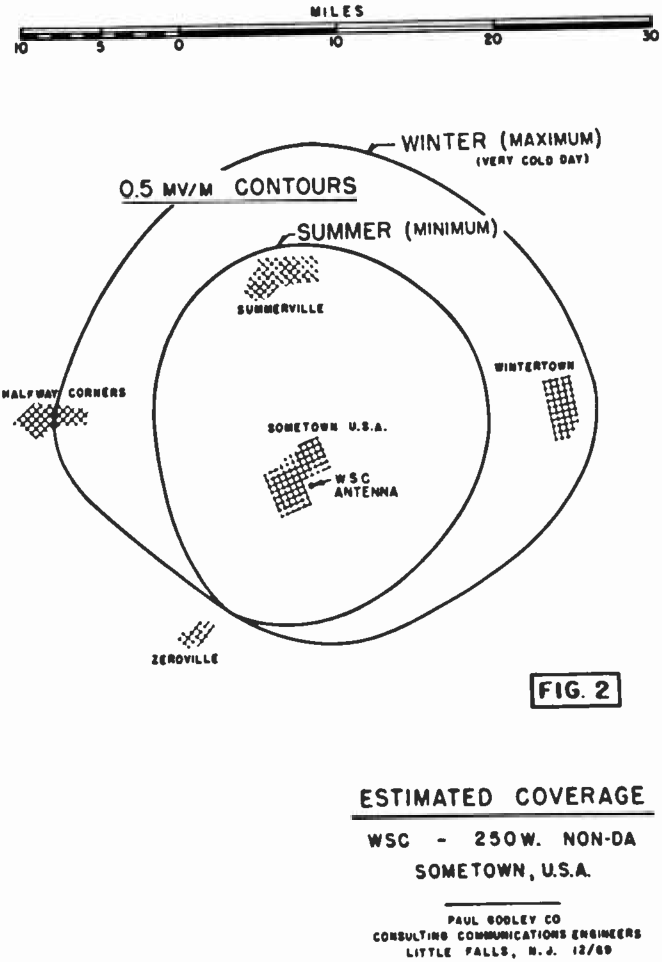

FIG. 2

Fig. 2. Winter/summer coverage of a hypothetical station.

The coverage map shows that Wintertown probably falls within the 0.5 mV/m contour only during the months of November, December, January and February. Halfway Corners is served only during extremely cold days in December, January and February. Zeroville happens to lie in a direction where the summer-winter variation is very small or nonexistent, and therefore is *never* included within the 0.5 mV/m contour—even on the very coldest days. Note that the coverage radius toward Wintertown is 12 miles in the summer and 19 miles in the winter. While the illustra-

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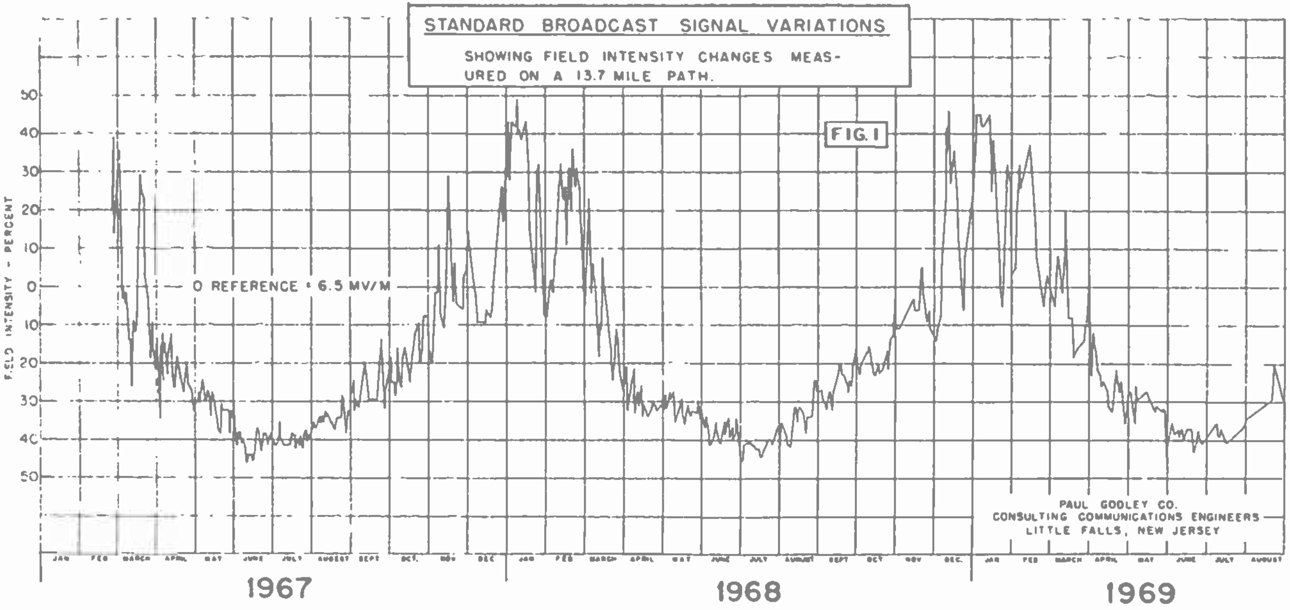

Fig. 1. Summer signal levels are low but stable, while winter levels are strong but variable.

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ture and vice-versa), the amount of variation is not the same for different paths. To date, it has not been possible to determine why there are varying degrees of signal-level change along different paths—even after considering effective conductivities, type of terrain, compass direction, operating frequency, and degree of urbanization. Until all factors which contribute to the signal-variation phenomenon have been identified, it will not be possible to compute the degree of variation which might be anticipated for a given path.

An Example of Coverage Change

Signal-level variations have a direct bearing not only on the apparent adjustment of a directional antenna, but also upon coverage contour locations for both directional and nondirectional operations. To illustrate coverage fluctuations which might occur, we have created hypothetical station WSC (Winter Summer Change). Fig. 2 shows the WSC 0.5 mV/m contour, using a composite of the variations listed in the table. Wsc, with its antenna in the business district of Sometown, USA, operates daytime with 250 watts on 1490 kHz, using a nondirectional antenna.

Terrain in the vicinity of Sometown, USA, is assumed to be hilly in some directions and marshy in other directions. To the north and east a greater variable factor has been arbitarily applied and to the southwest it has been assumed that there would be no difference between summer and winter signal levels.

Table: Field-Intensity Measurements

Station	Freq. in kHz	Distance in miles	Direction	Measured field in mV/m (min)	(max)	Ratio
WNBC	660	22.2	91°	23.0	31.0	1.35
WABC	770	7.3	85°	130.0	180.0	1.38
WCBS	880	22.2	91°	7.4	10.5	1.42
WMTR	1250	13.7	261°	3.5	9.7	2.77
WNJR	1430	11.9	189°	1.31	2.22	1.7
WKER	1500	8.5	332°	0.67	1.82	3.2
WRVA*	1140	1.7	30°	132.0	202.0	1.53

*Not a local station; included to show possible variations within two miles.

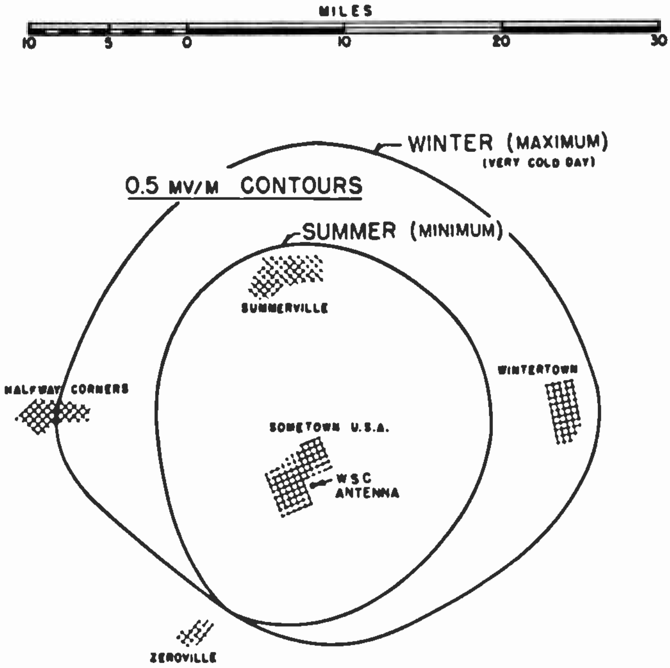

FIG. 2

ESTIMATED COVERAGE

WSC - 250W. NON-DA
SOMETOWN, U.S.A.

PAUL GODLEY CO
CONSULTING COMMUNICATIONS ENGINEERS
LITTLE FALLS, N.J. 12/69

Fig. 2. Winter/summer coverage of a hypothetical station.

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tion is hypothetical, the contour changes shown have actually been measured.

Most of the measurements referred to in Fig. 1 and the table were made between 8:30 and 9:00 a.m., when the sun has not had much time to increase temperatures above early morning values. In the summer, as shown by Fig. 1, the day-to-day variation in signal strength was minimal. Summer morning air temperatures normally remain in a narrow range between 60° and 80°F. Winter air temperatures in our area generally vary from 10° or 15°F to 50° or even 60°F—sometimes covering the entire range almost overnight. The large changes, which can occur in signal strength because of large winter air temperature variations, are illustrated in Fig. 1.

Included with the technical data we recorded were such parameters as rainfall, air temperature, snow depth and general weather conditions. Additionally, for most of one year a record was kept of the temperature of the upper one inch of soil at the measuring site. Detailed study of all of this information has indicated that factors such as precipitation, snow, frozen ground and soil moisture content appear to have very little effect on signal levels. Measurements made after a one-inch rainfall following two or three sunny summer or winter weeks without significant precipitation indicated a field-intensity increase of less than 2%. In the winter, hourly changes in the signal have been observed even when the ground has been covered with more than a foot of snow.

We feel that the snow cover protected and insulated the soil from hourly temperature changes. This reinforces our earlier observations that air temperature appears to affect signal levels more directly than any other single known factor.

Distance as a Factor

It appears that distance is not necessarily a criterion which affects the amount of signal-level change. Referring back to the table we see that the WKER signal changed 320% (ratio of 3.2 to 1) over an 8.5-mile path, while WNBC's signal changed only 135% over a 22.2-mile path. WNBC,

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WABC and WCBS are all east of our office; in fact, WNBC and WCBS multiplex into the same tower. It is interesting to note that the WABC signal-level change over a 7.3-mile path is essentially the same as the WNBC and WCBS changes for 22.3-mile paths. In Richmond, Virginia, WRVA signal level changes recorded for a 1.7-mile path were 153%.

Less frequent observations (usually twice a week) were made for two-year period on stations ranging in distance from 23 to 132 miles. No trend or clue with respect to frequency or distance was particularly evident. The greatest variation in the group was for WFIL, (560 kHz Philadelphia) which showed a signal-level change of 390% for a 76-mile path. A considerably smaller change of 150%, was found for WCAU, (1210 kHz Philadelphia) at a distance of 73 miles. While there is more than a two-to-one difference in frequency, the reason for the difference in seasonal signal-level ranges might be attributed to terrain.

(Ed. Note: Factors which might contribute to the difference: WCAU operates 50 kW nondirectional, while WFIL operates 5 kW with a different directional pattern day and night. WCAU's smaller variation might be due to the fact that the absolute field intensity measured was greater than the absolute value measured from WFIL. Furthermore, the measuring location might be on the highly variable edge of a steep null in either the day or night pattern of WFIL.)

WCAU's signal starts out up the Delaware River Valley and WFIL's signal must travel some 25 miles over hilly terrain before crossing the river. On the other hand, WTIC's 1080-kHz signal, which traverses a 96-mile path from Hartford over rugged and hilly terrain, was found to change only 210% from winter to summer.

If station coverage over a particular community or area is important, or if DA monitor point fields exceed licensed limits on cold days, management should determine whether or not seasonal factors beyond the station's control are involved. Discussions with the station's consulting engineer may be in order as a step toward identification and isolation of the problem. If the chief engineer does not have the equipment to make

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field checks, the consultant can plan such a program. Seasonal variations in signal strength can at times be at the root of listener complaints. This is particularly true if the listener is at an electrically noisy urban location, or a distant point which undergoes 200% or 300% changes in signal level.

It appears that any one station might encounter a broad range of possible summer-winter variations in different directions. According to measured data for the northeast part of the country, cyclical changes can go from practically nothing up to 300% or more. Furthermore, the only way of knowing for sure is to make actual field measurements in pertinent directions.

The apparent accuracy of weekly monitor-point measurements made on directional antennas can be greatly affected by summer-winter signal-level variations. Maximum monitor-point fields are usually based upon the level measured in the last full proof, plus a 5% to 10% tolerance. If the proof was done in summer, there is a good chance that monitor-point fields measured in winter could exceed license maximums.

What to Do

Where summer-winter changes affect directional monitor-point values, particularly in instances where license maximums are exceeded, a station should promptly inform the FCC. Information sent to the FCC should include sufficient data to demonstrate the summer-winter effect, which can be identified in several different ways. The first and perhaps most positive procedure is to redo nondirectional and directional measurements at the same sites in the problem direction. This is very easily done where the station normally operates with a nondirectional pattern daytime and directional night (or vice-versa in a limited number of instances).

A second method is to make complete radial measurements in the problem direction and reanalyze the data to show that the field has remained constant and that the conductivities differ from the original or reference data. A third method

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of demonstrating summer-winter effect is with data which cover a 12-month cycle of field variations. The cycle should, of course, repeat itself in the manner indicated in Fig. 1. If the problem is encountered before data for a 12-month period are available, partial information might be filed as an interim measure with complete data following as soon as a full cycle is made.

The magnitude of signal-level variation which can be caused by seasonal changes in effective conductivity dictates that this phenomenon be taken into account at any time proof, skeleton-proof or other field-intensity measurements are made. If at all possible, skeleton proofs and other pattern checks should be made in the same season that the last full proof was accomplished. In addition to the date and time of each measurement (a recent FCC requirement), the daily temperature or temperature range should be logged as an important aid in data analysis and comparison. Air temperature values should be recorded with weekly monitor-point measurements, to identify and separate antenna-system problems and seasonal variations in signal level.

Section 73.152 of the FCC Rules and Regulations indicates that actual field-intensity measurements will take precedence over computed projections. While the Rules and Regulations do not provide for summer-winter changes, the FCC realizes that such changes in effective conductivity can occur. Measurements taken in the summer often differ considerably with those taken in the winter, and many a competitive argument has ensued on this account. When differing data are presented and seasonal variation is the probable cause, the FCC is likely to accept a mean or average value of conductivity or contour location. In accordance with Section 73.152, properly made measurements—whether taken in summer, winter, spring or fall—are usually accepted in preference to theoretical projections.

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Detuning Radiation Structures

L. David Oliphant

RE-RADIATION IS A PROBLEM confronting more and more stations within the last few years in their maintenance of directional patterns. Re-radiation must be dealt with before the directional pattern can be adjusted to any degree of satisfaction.

Just what is this re-radiation problem which is plaguing radio stations? It's a population explosion type problem. Twenty or more years ago radio transmitters were built out in the country with very few buildings, or power lines about. Now the city or its suburbs is spreading out to these transmitter sites. And with this growth comes power lines and power poles, water tanks, etc. There are metal power poles, and guy wires. On the wooden poles are ground wires running the length of the pole. If these metal poles, guy wires, or groundwires are in the path of the strong side or path of the radio pattern, they will reflect or re-radiate the signal into the weak or null portion of the pattern. This reflected signal can be phase additive, or phase subtractive (or at any point in between) with the signal from the antenna array. Hence re-radiation can cause the reading at a certain point on the radial in the null to be high, or low, or relatively unaffected. When field strength readings are made along a radial in the null, as is done in making proofs of performance on directional patterns, the re-radiated signal can be phase additive at one point, phase subtractive at another and somewhere in between at other points causing the readings to be widely varying. They may be high at one point and low at another instead of holding a straight line relationship, or nearly so. If the problem is

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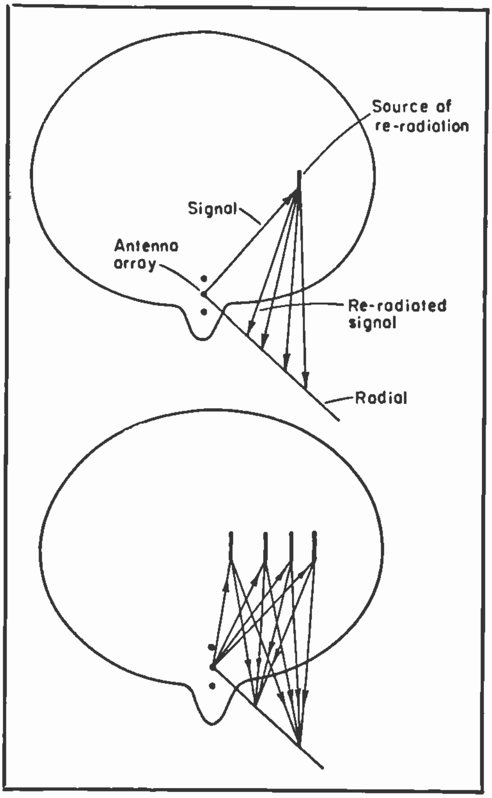

Fig. 1A and 1B. Re-radiation from single source (top) and several sources (bottom).

serious enough, the FCC will not accept the proof of performance. Fig. 1-A shows re-radiation from one source and Fig. 1-B shows re-radiation from several sources.

Several stations are being confronted with this problem. I am personally aware of six radio stations including KOMA fighting this problem. Besides KOMA, two are 50-kW and the others are 5-kW stations. So while this may have been at one time a problem only for high powered stations, 5-kW stations are facing it also.

Controlling Re-radiation

How can this problem of re-radiation be controlled to get the directional pattern into satisfac-

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tory adjustment? One is often tempted to take a hack saw and cut the ground wire. But there are always those who frown on that since the ground wire is protection to the power line equipment. Similarly, one can't dynamite the offending water tower. That leaves the solution of detuning the metal power pole, or the ground wire of wooden poles, or the guy wires, as the case may be.

Let's start with a wooden pole with a ground wire, Fig. 2-A. To detune a pole it is necessary to attach a wire near the top of the ground wire. Bring the wire to the opposite side of the pole, drop it to within 5 feet or so of the ground and staple it to the pole. It is important that the wire be as far from the ground wire as practically possible. Theoretically, to be perfect, it should be nine feet away from the ground wire. Of course that is impractical. Next place a capacitor between the detuning wire and the ground wire of such a size as to bring the rf current in the ground wire below the point of juncture to a minimum. See Fig. 2-B.

This brings up the problems of how to measure the rf current in the ground wire and what size capacitor to use. First I will describe the meter to be used to measure the rf current. Such

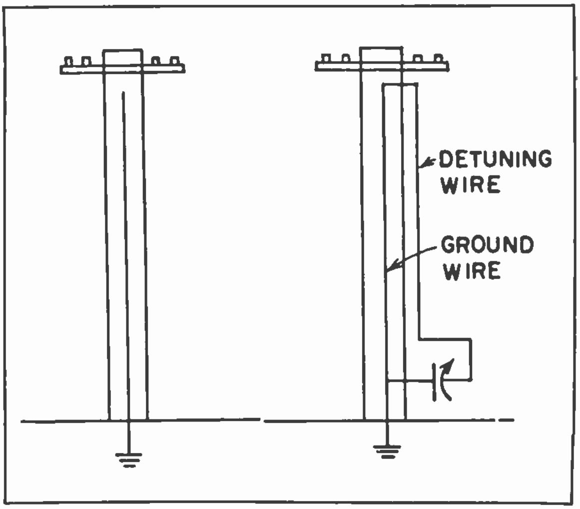

Fig. 2A and 2B. Pole with ground wire (left) and with detuning wire and capacitor (right).

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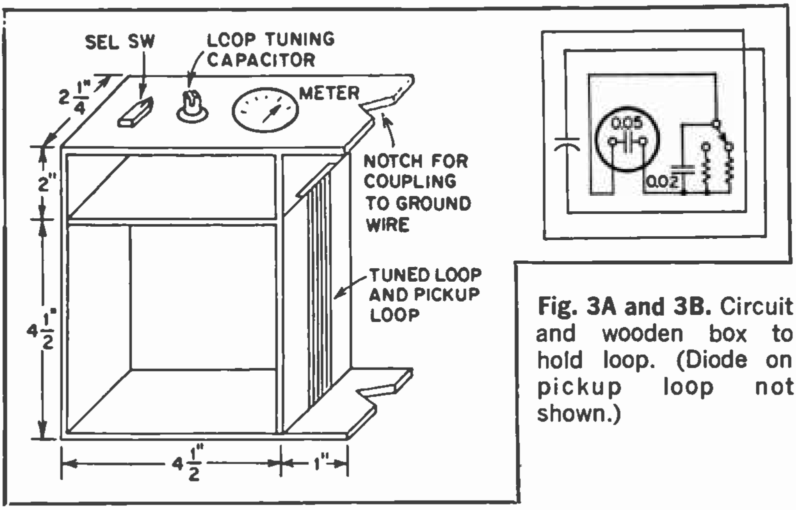

Fig. 3A and 3B. Circuit and wooden box to hold loop. (Diode on pickup loop not shown.)

a meter is illustrated in Fig. 3-A. It consists of a tuned loop of about six turns, though this number may vary with the frequency. This loop is tuned to the frequency of the station. Alongside the tuned loop is a pickup loop of one turn of wire which goes to the selector switch, diode, multiplying resistors, and the meter.

This is built into a wooden box as shown in Fig. 3-B. The tuning capacitor for the tuned loop is set in the center of the box and the leads of the loop go to it. The leads of the pickup loop are run to a terminal strip on which is mounted a 1N34 diode. A lead goes from the diode to the selector switch on which is mounted the multiplying resistors. A lead goes from them to the meter. The other side of the meter connects to the pickup loop. The meter used has a 0-1 mA movement. This has proven very satisfactory. A more sensitive meter can be used. A 0-500 mA scale was found to work quite well. (If the meter can be taken apart, the meter face can be taken off and a new scale pasted on.)

To calibrate the meter, go to a pole that has been equipped to be detuned. The detuning capacitor should be variable to get different readings of the rf current to ground. Cut the ground wire about six inches above the ground and insert a standard rf meter (I use one with a 0-250 mA

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range). Vary the detuning capacitor until you get some satisfactory reading, say 200 mA. Place the box meter next to the wire with the notches across the wire. Then select the proper multiplier resistor to get this box meter to read the same as the standard (200 mA). Once this is done, vary the detuning capacitor to see how well the box meter tracks with the rf meter. (With the meter mentioned, they should track together very well.) For the 0-5 A scale range, use a multiplier resistor ten times the value of the one used in the 0-500 mA range. The 5-A scale is not critical as to accuracy since poles are detuned to have a ground current somewhere in the 0-500 mA range. Adding 0-100 mA scale is desirable as some poles can be detuned to read in 50 mA or less. After the calibration. splice the cut back together.

The Actual Detuning

The object of detuning is to bring the ground current in the ground wire, the metal pole, or other object of re-radiation to a minimum. Thus the box meter and its loop are placed as close to the ground as possible (and far away from the detuning loop.) The method is not perfect but can bring the re-radiation down where it can be tolerated. The capacitor current rating depends a lot on the location of the pole and how much current will flow through the capacitor.

The problem of what poles shall be detuned, type capacitances to use, etc., remains. This is determined by the individual situation, the strength of tightness of the pattern, ratio of the strong side of the signal to the back side, nearness of the pole to the antenna array, etc. The chief engineer will have to work that out with the consultant.

The current flowing through the capacitor is the circulating current and can be several times the amount of the current flowing to the ground when the pole is detuned. This circulating current determines the size of the capacitor and what type to use. In a 50-kW field, the current can be several amperes and a G-2 capacitor is advisable.

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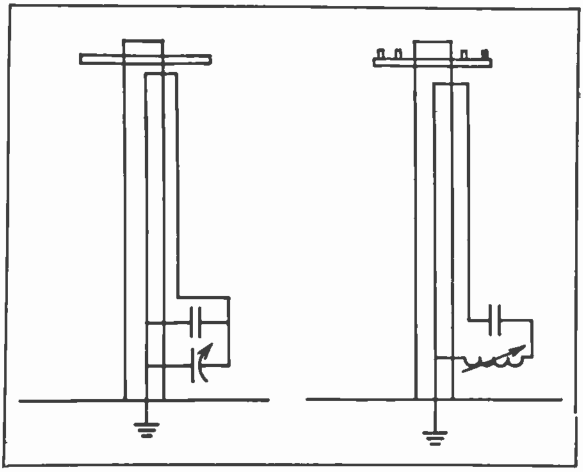

Fig. 4 (left). Variable capacitor is tuning unit.
Fig. 5 (right). Coil in series detunes circuit.

One way of going about detuning a ground wire is to get a capacitor somewhat smaller than necessary and parallel it with a variable capacitor (or capacitor decade) that may be tuned through the point of minimum ground current. Another alternative to extending the capacitance range and still get a tuning situation is to use a variable coil (such as the Johnson 229-202-1) between the capacitor and ground. This is more satisfac-

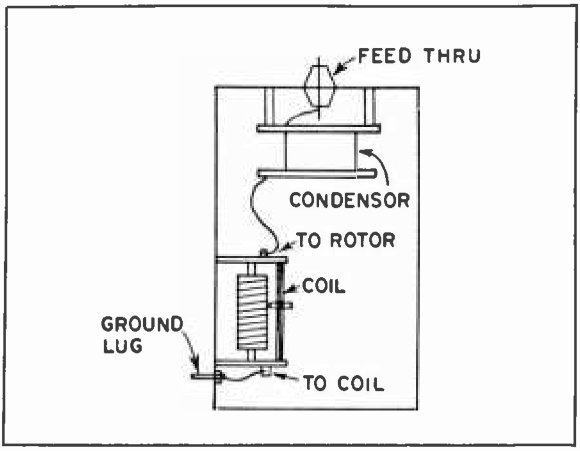

Fig. 6. Capacitor and coil in box.

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tory than the variable capacitor in parallel with a fixed unit as it is not as critical as to tuning and stays in adjustment better. This can be mounted in a metal box of proper size. Fig 4 illustrates a fixed capacitor shunted by a variable. Fig. 5 shows the coil in series with the capacitor. Fig. 6 shows the capacitor and coil mounted in a box. One disadvantage of the coil is that it will get dirty and make poor contact. Then the coil will have to be taken out and cleaned.

In certain situations, a fixed capacitor can be used and tuning accomplished by sliding the capacitor leads up and down on the pole attached to ground and detuning wires until minimum ground current is accomplished. Or place a calibrated variable capacitor across the ground and detuning wires and determine the size necessary. Then use the nearest fixed capacitor size and again slide the capacitor lead up and down as suggested to secure minimum current.

If the poles to be treated are metal power ones of the four legged variety, it will be necessary to put the detuning wire on each leg and detune each one. Attach the wire near the top on the leg held away by insulator standoffs and detune each one. Attach the wire about a foot away from the leg and bring it down to about five feet of the ground. Then attach the detuning capacitor between the wire and leg. As the legs are detuned the re-radiation current is chased around to the undetuned legs until all are detuned

Specific Detuning Problems

If a pole line is suspected of re-radiating, do not check one or two poles, but check them for some distance. Many times you could be a half mile or more from the transmitter plant and find a pole that has a large amount of current in it. The distance from the transmitter could vary according to the station power, etc. In other words, we have found hot poles a mile and a half from a transmitter that is radiating 50 kW of power into a directional array.

In one situation, we had to detune over 150 structures to get the array back to a stable condi-

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tion. We make approximately 300 re-radiation measurements a month. If a high reading is found in monitoring, check for a defective tuning box. Generally you will find that it has been hit by lightning and the capacitor destroyed.

A good detune adjustment should have a reduction of 10 to 1 in current flow. There are times when this value cannot be reached and a lesser value has to be accepted. In the detune adjustment, when the correct one has been reached, the meter will show a rise in current and then fall very rapidly to a minimum. This null or minimum is normally very sharp. Be sure to keep your portable loop meter far enough away from the detuning loop so no coupling will be experienced. The current in the detuning loop will increase many times as the loop is tuned. As an example, a pole with 500 mA flowing to ground could have 2 to 3, or more amperes of current circulating in the detuning loop after the rf current flow to ground has been cut off.

On an electric line, after each pole is detuned, be sure to recheck all the poles in that line because, as the current flow is cut off in one, it will change in others. On most occasions it will be reduced, but there have been occasions when the current in untreated poles would increase instead of decrease.

In the four-legged steel tower used by power companies, each one of the four legs must be treated on an individual basis. When a leg has been detuned, it causes the current to be higher in the others. A most important consideration in this type of tower is where the bracing ties into one point. All of the horizontal, diagonal and vertical members must be bolted together at the place where the detuning box is installed. If this is not done, current can get by the cut-off point and your detune is not very effective. Each detuning box may have to be adjusted a number of times until the optimum detuning has been reached. Total amount of current flowing in all legs indicates the amount of current flowing in the tower.

It is also important to check all towers that appear to need treating because the current flowing in all of the towers will change as a tower is completely detuned. As an example, a power company erected a new high line within 800 feet of an antenna array. There were 26 towers 113 feet high in this line. A decision was reached that the maximum allowable radiation from any of these towers should not exceed 5 mV/m at a mile. This meant that the total current flowing in any one tower could not exceed 200 mA. We have been successful in accomplishing this with the normal detuning configeration, even though some of the towers had over 1 A of current before any detuning, and the closest tower had nearly 2 A. As it finally turned

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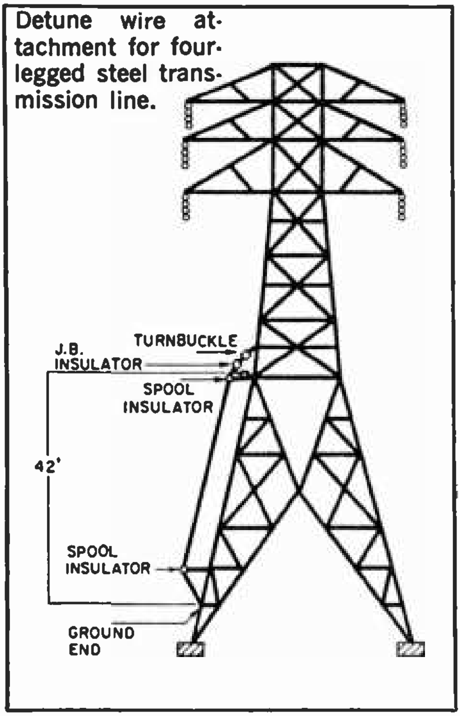
out, we had to detune 15 of the 26 towers involved. If for any reason a structure of this type does not detune properly with the method just discussed, there are some other procedures that can be followed. Two detuning wires can be installed on each leg and connected to a single detuning box. If this fails, an additional detuning wire can be attached down the center of the face of the tower closest to the array. This could have its own detuning box. In our case we had the full co-operation of the power company involved. They supplied all of the hardware for the detuning loops and also the installation. The station supplied the detuning boxes.

A third type of structure is the television tower. The towers are normally tall, and it takes very little current flowing to create a problem. As these are normally grounded towers, they can be treated the same as the others, but a more sophisticated physical installation should be used. In most cases there is more than one station signal on the structure, so in order to determine whose they are and the magnitude of each, place a Nems-Clark 120-E or equivalent field intensity meter in close proximity to the base of the tower with the loop headed directly to the tower (not over 1 foot away). Tune the meter


Detune wire attachment for four-legged steel transmission line.

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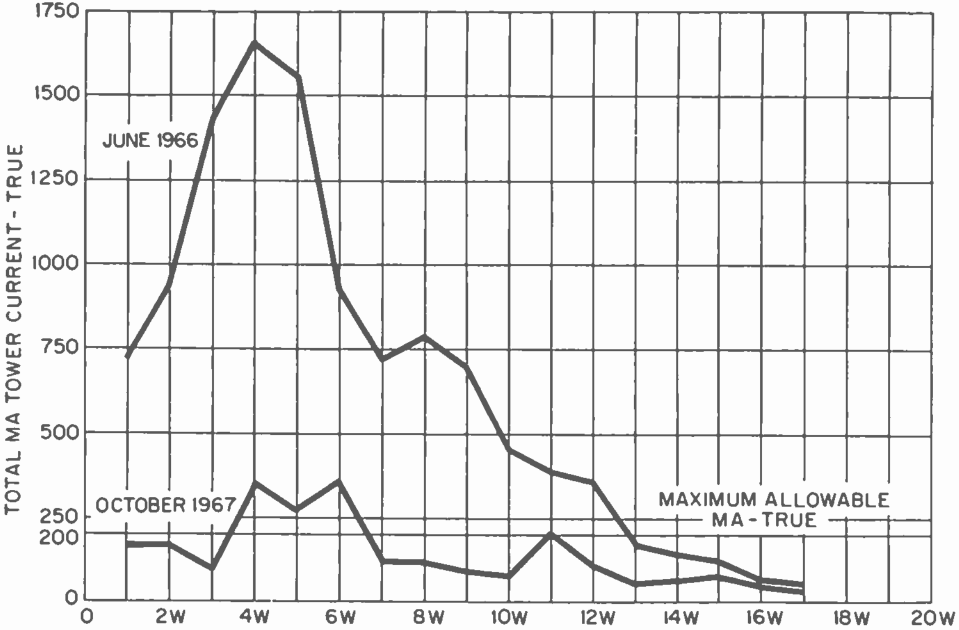

Tower current before and after. Source is 5-kW directional antenna, daytime. Numbers on abscissa refer to pole numbers.

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over the entire tuning range and record the readings. This will indicate what signals are on the tower.

In order to show the magnitude of the signal you want to detune, a meter and circuit should be constructed with the appropriate filters in it to bypass the unwanted signals to ground and leave only the one to the detuned showing in the monitor meter.

The procedure used for detuning two 800-foot TV towers located within 0.75 miles of one of our transmitters is as follows. The towers were treated with three chokes or detuning loops. These are separated and a pickup loop installed. The current in the pickup loops is fed back to the TV transmitter building where the meter has been permanently installed for monitoring purposes. An RG8/U line was used from the pickup loops to the meter. With the ability to monitor the readings daily, it is easy to keep a close check on conditions of the detuning on the towers. The detuning loops were approximately 180 feet in length with two vertical wires held off each leg about 18 inches. The wires that form the detuning loops should be at least No. 4 copper, either solid or stranded. In some cases aluminum wire can be used. In some areas aluminum wire will be more susceptible to corrosion. This should be carefully checked before the installation. The top end of the loop is connected directly with the tower at each leg. The lower end of the loop is connected together with a horizontal wire around the tower. This connects all the vertical wires to a common point. This in turn is connected to the detuning box. The detuning box is grounded to the tower. The pickup loops are made of ¾-in. copper tubing about 8 × 3 feet and are mounted on insulators. This is very similar to the sampling loops used on a-m towers.

Detuning is performed by adjusting the capacitor in the tuning box to the minimum indication on the meter in the building. It takes two men to accomplish this and some form of communication. This should be done to all loops. Generally, these will have to have more than one adjustment, as there are mutuals between the detuning loops. More than one loop should be used. The total depends upon the height of the tower.

It is easier, physically, to run all the vertical wires to the base of the tower anchor, by some convenient method, and install turnbuckles to tension the lines. The loops can be formed by adding some type of strain insulators—pyrex, fiberglass and epoxy, or the old standby, Johnny Ball insulator—all work equally well. Be sure to bond the upper end of each of the detuning loops to the tower at each leg.

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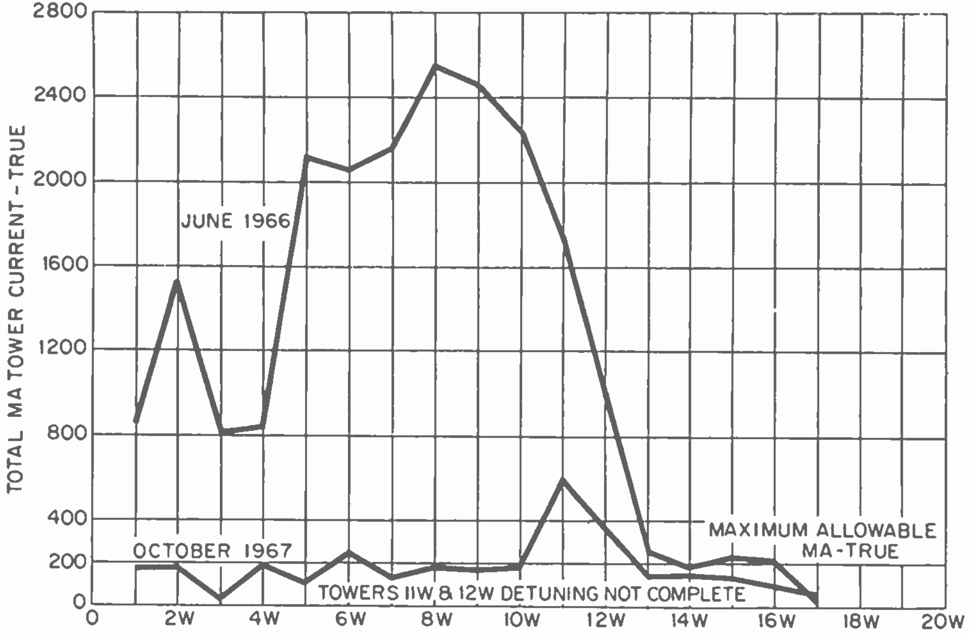

Same towers as above except nighttime readings, before and after, shown.

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To point out the reaction of a line of steel towers, the following work has just been concluded on a double line of towers. These were a little different than the four-legged variety. These towers were held upright by four guys and came to a pivot point at the base. They were 88 feet high overall, each tower supporting one set of high lines with one shield wire or ground wire at the very top. This problem was discussed with the power company and it was their decision to insulate the shield wire from the towers and at the same time install an arc gap. We felt at that time this would be the ultimate solution on this set of towers. The area was swampy and accessible only by marsh buggy or helicopter and detuning would be nearly impossible, so this seemed to be the best approach to the problem. The two sets of high lines ran at right angles through one of our major lobes on the nighttime DA, in an area where there was nearly 1 V of rf signal.

The power company proceeded to insulate the shield wire with excellent results. The current in all the towers is now below a maximum allowable that we established per tower and no further work is required.

Another type of problem developed in detuning at a baseball park. Each of eight 85-foot four-legged steel towers was top-loaded with a bank of flood lights. We were unable to do an acceptable detuning on any of these towers for some unknown reason. This project was undertaken in the months of December and January when ground conductivity was high. The below zero Minnesota weather did not help a bit. It turned out that the reason for our inability to detune any tower in this group was that all towers were tied together with an overhead ground wire and all transformers (one on each tower) were connected by a common hot line. In order to overcome this problem, a network consisting of a coil of wire and a capacitor (fixed) was added at each tower in both the ground line and the hot line. This isolated the towers from each other, thus making detuning possible. The detuning of these structures was done by the same method described for the four-legged towers on a high line.

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TV Antenna Engineering for Effective Coverage

Harry A. Etkin

A BROADCASTER is obliged to cover his *principal* market area with a signal of prescribed strength. Theoretically, this is simple: Find a high spot near the center of the area, erect an antenna, then crank up the power until the signal goes out far enough in all directions. Sometimes this theory will work, especially for low power and daytime radio stations, but in many cases, it's little more than a pipe dream for TV broadcasters. In the first place, the highest (or any high) spot near the center of an area may be undesirable for many reasons. Thus, the transmitter may have to be located on a lonely mountain top or a site bordering on the boondocks, miles from the center of the area. Hence, some tricky coverage problems may present themselves.

In addition to the antenna type, four basic factors, all variable, enter into the design of a radiation pattern: antenna *site*, antenna *gain*, antenna *height*, and transmitter *power*. These factors, in turn, depend on the operating channel, competitive coverage, condition of the terrain to be covered (flat, mountainous, adjacent to water, etc.), and of course adjacent and co-channel interference.

Photo A

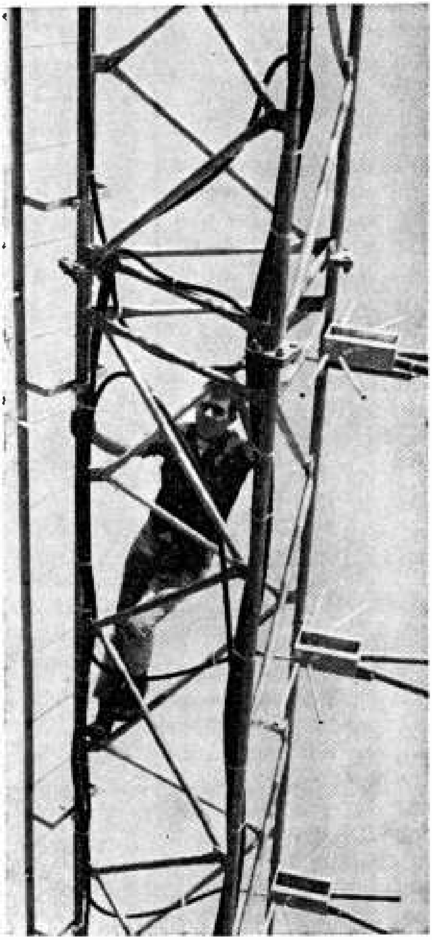

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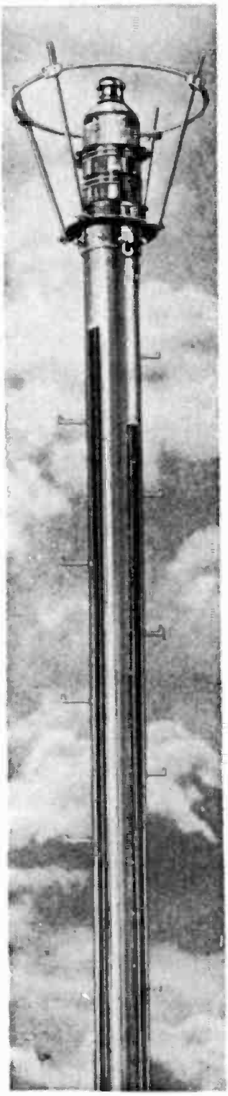
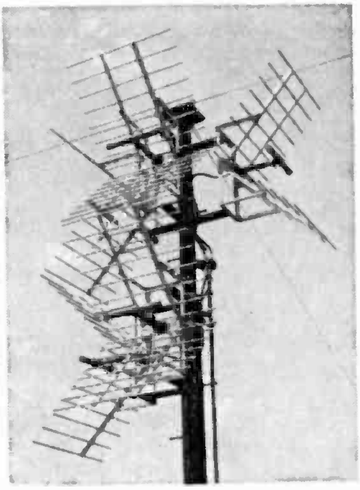
Photo E





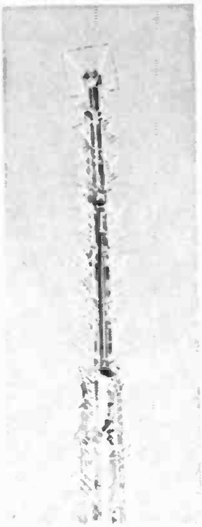


Photo B

Photo D ►

Photo C

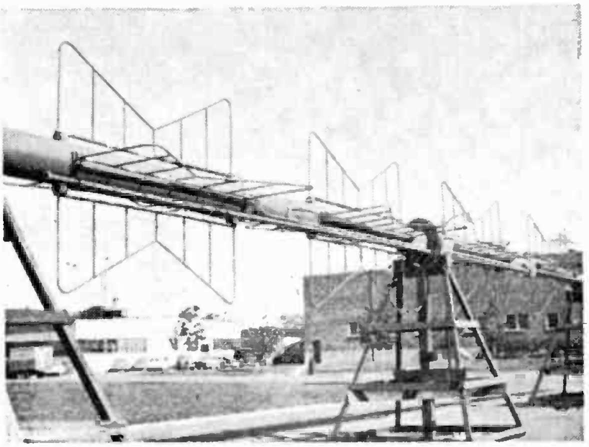


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Photo F

Photo G

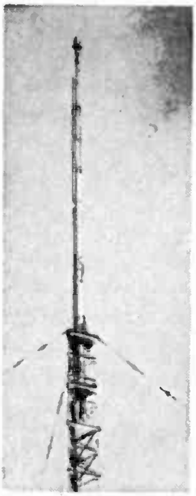
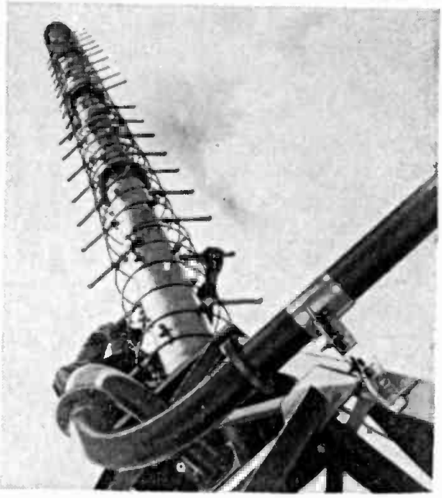


Photo H



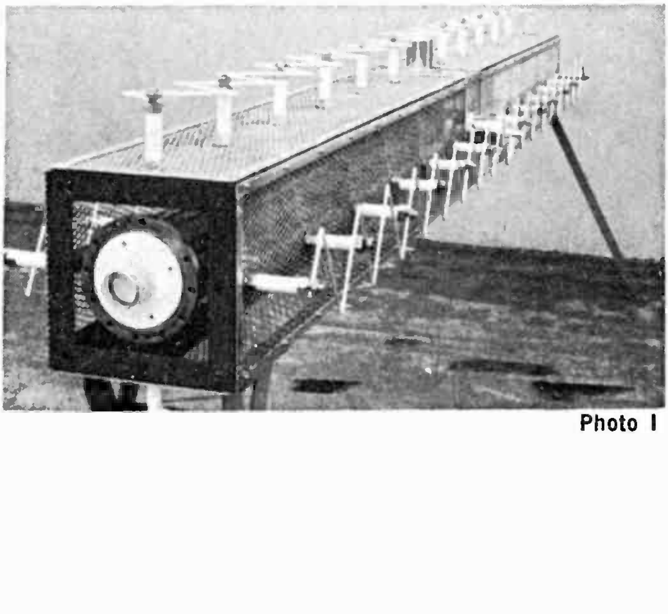


Photo I

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Photo A—**"V" Element** or corner reflector is directionalized by certain tower sections and/or reflectors. Vertical bay spacing is critical.

Photo B—**Screen dipole** is directionalized by the same methods as those used for the "V" element. Antenna shown is designed for Channel 12.

Photo C—**Batwing** uses a slot diplexer and phasing unit to produce directional patterns.

Photo D—Various power divisions between the two planes of **Superturnstile** radiators will produce different types of directional patterns. Directional degree is determined by dividing tees—a 10/1 feed results in a 10 db notch; a 100/1 split produces a 20 db notch. Feeding power to only one side produces a full depth notch.

Photo E—**Slotted cylinder** or traveling wave antenna provides a high degree of flexibility in pattern choice by changing the diameter over wavelength ratio and by varying the number of slots.

Photo F—**UHF pylon** is directionalized by methods similar to those used for the slotted cylinder.

Photo G—**Slotted ring** is directionalized by two beam shaping members, each connected to alternate rings. A substantial part of the current, which would normally flow in the rings, is carried in the beam shaping members, thereby causing them to function as fed radiators. Beam members shape and length, as well as angle between them, determines pattern.

Photo H—**Helical** directional patterns are achieved by attaching stubs to the radiators at certain positions on each section. The stubs act like end-fed dipoles which distort the horizontal pattern by reinforcing the radiation field in a direction at right angles to the stubs. Directionalization may be changed by adding or removing stubs; stub length is not critical, usually 0.1 to 0.15 wavelength.

Photo I—Four **zig-zag** panels, forming a square cross-section, provide a wide range of orientations for a variety of patterns. Cross-sectional dimensions, distance between elements and reflecting screen, element phasing and amplitude, and power distribution to each panel determine directionalization.

Site Selection

Ideally, the antenna site must provide an unobstructed line-of-sight path over the area to be served. This is best obtained, obviously, from a tall building, a mountain, or other points with terrain or structural height advantages. A centrally located antenna will radiate equal amounts of energy in all directions (omnidirectional) and, when fed with enough power, will provide the necessary Grade A coverage (Fig. 1A).

If, on the other hand, the only available (and most logical) site happens to be near the *edge* of the principle area (Fig. 1B), greatly increased transmitter power (or more antenna gain or greater height) will be required to provide proper coverage. If the omnidirectional radiation were increased, as it would have to be in Fig. 1B, additional coverage out-

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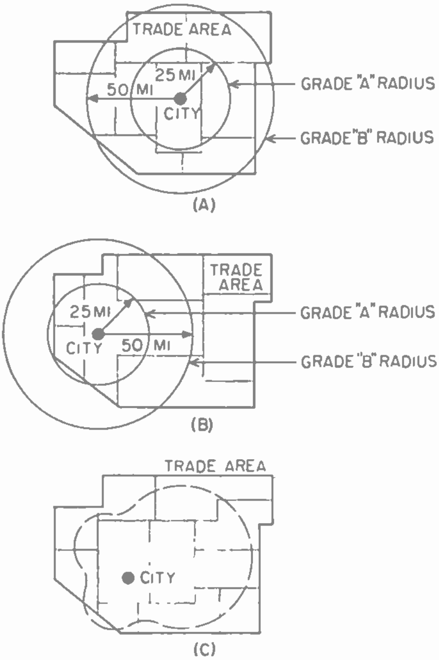

Fig. 1. A directional antenna (C) will cover (with similar ERP) the market area as well as a centrally located omnidirectional antenna (A).

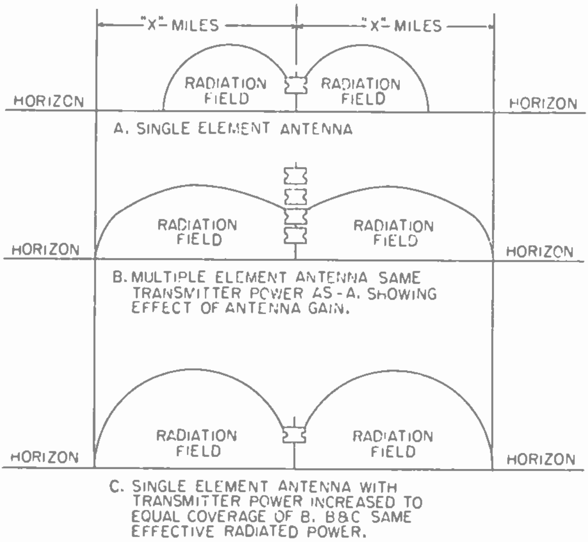

Fig. 2. A multiple element antenna covers more area with less transmitter power.

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side the principle area must justify the increased capital costs in the form of additional TV homes and greater potential revenue. An alternative solution, and in many cases the most logical, is to use a lower power transmitter and a *directional* antenna (Fig. 1C).

For these reasons, an applicant must consider transmitter location, height, and proximity to (or in) the principle community. Generally, it is wise to conduct experimental transmissions (which your consultant can perform) from prospective sites so that, from field strength measurements, an accurate prediction of coverage may be made.

Antenna vs Transmitter

For reasons of economy, both initial and operating, it is better to use a lower power transmitter and a higher (above average terrain) antenna than it is the other way around. However, there are antenna height limitations, and when this point is reached, the only alternative is a higher power transmitter and higher gain antenna—up to the maximum ERP allowed by the Rules (see Table I). Normally, ERP will exceed actual power due to antenna gain. The cost (initial and operating) of a 316-kw transmitter and single bay antenna, compared to that of a 25- or 50-kw transmitter and a high gain antenna designed to produce 316-kw ERP, strongly demonstrates the economy of high gain antennas.

From Figs. 3 and 4, we can see that a signal exceeding FCC minimum principle community requirements can be obtained beyond 10 miles with a 500′ antenna and a relatively low ERP. Further, a typical 4-bay antenna and a 25-kw transmitter or a 5-bay antenna and a 20-kw transmitter will furnish an ERP of 316 kw. With directional arrays, the gain per bay may be as high as 7.2; thus, an ERP of 316 kw may be obtained with a 3-bay directional antenna and a 20- or 25-kw transmitter.

Directional Antenna

The trend toward higher gain antennas, higher towers, and

Table I. Maximum Effective Radiated Power for Visual TV Transmitters

Channel No.	Maximum ERP in db above 1 kw (DBK)
2-6	20 DBK (100 kw)
7-13	25 DBK (316 kw)
14-83	37 DBK (5000 kw)

Table II. Typical Antenna Costs

No. Bays	Channel	System Input (kw)	Price
	VHF Batwing and Turnstile		
1	2-3	20	$ 9,500
3	2-3	50	$19.000
6	2-3	50	$39,000
1	4-6	20	$ 9,500
3	4-6	50	$19,000
6	4-6	50	$36,000
2	7-13	20	$ 9,200
6	7-13	50	$21,000
12	7-13	50	$47,000
	VHF Helical		
1	2	50	$30.000
3	7-13	60	$55,000
	VHF Slotted Ring		
1	7-13	—	$ 9.000
3	7-13	—	$32,000
5	7-13	—	$52,000
	UHF Helical		
4	14-56	60	$23,000
4	57-68	45	$23,000
4	68-83	30	$23.000
6	14-56	60	$35,000
6	57-68	45	$35,000
6	69-83	30	$35,000
12	14-43	60	$100,000

Prices will vary according to channel, power, gain and directional requirements. Prices include transmission line but exclude de-icers which range from $900 to $3,000. Prices for supporting mast and tower are extra.

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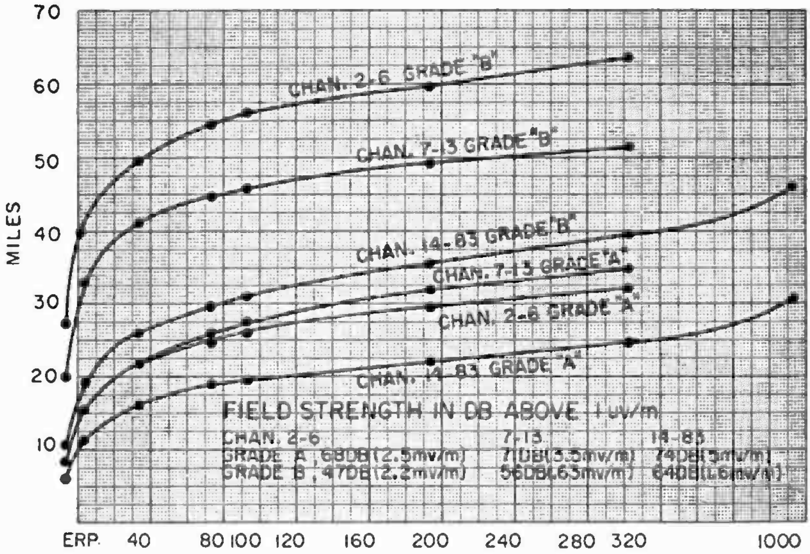

Fig. 3. A 500′ high antenna generally provides adequate coverage. Obvious here are propagation characteristics at various frequencies.

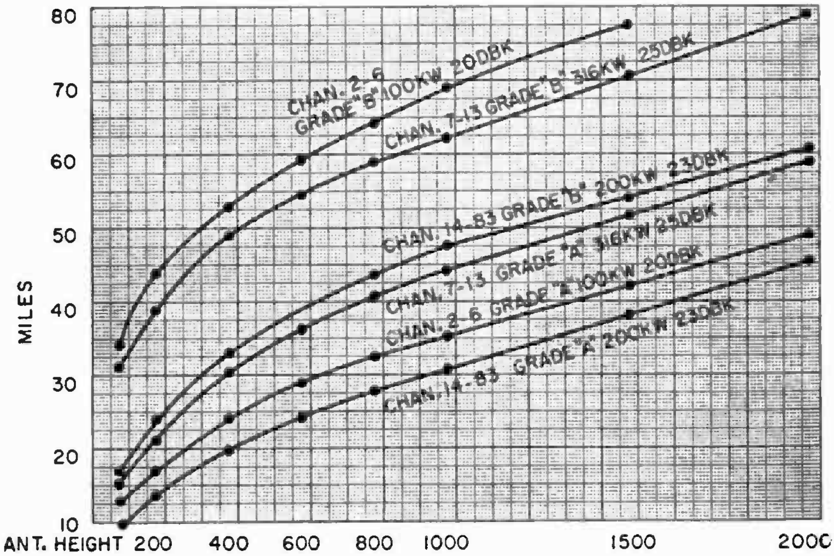

Fig. 4. Antenna height increases coverage when the ERP limit has been reached.

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greater distances between transmitters and the communities they serve has led to some fundamental coverage problems, many which can be solved with a directional antenna.

In many cases, the population concentration is such that a circular pattern can not efficiently cover the desired area. If, viewed from the antenna site, most of the potential audience is concentrated in one or two major localities, it may be impossible to cover all the desired area with a circular pattern. Under these circumstances, signal radiation over unpopulated areas (oceans, lakes, mountains, etc.) is wasteful, not to mention the very real possibility of reflection problems from mountains or other obstacles.

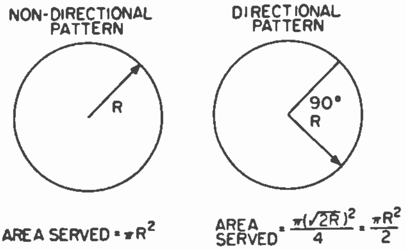

Fig. 5. Mathematical relationship between directional and non-directional antenna patterns.

Directional Operation

With a directional array, it is possible to concentrate the signal in a specific area (or areas) without using excessive power or extremely high gain antennas. An antenna may, within reasonable limits, be modified (usually at higher cost) to provide more effective coverage of the desired area(s).

Fig. 5 illustrates the mathematical relationship between a directional and omnidirectional antenna; the directional pattern serves one-half the area of the circular pattern, but four times the circular pattern power is concentrated in the directional pattern. Hence, the field strength is doubled and the directional radius is extended by $\sqrt{2}R$. (As a general approximation, the service radius varies as a fourth root of the power.)

Almost any shape horizontal pattern—cardioid, figure eight, peanut-shaped, etc. — may be achieved. With the cardioid pattern in Fig. 6A, one major population area can be covered from a transmitter location at the edge of the principle area. Fig. 6B shows a peanut-shaped pattern which will cover two major areas with a centrally located transmitter. Each antenna type requires specific mechanical or electrical modification to achieve the desired directional radiation.

VHF vs UHF

Low and high band VHF and UHF signal propagation characteristics differ; hence, the FCC power limitations (see box). Coverage at UHF frequencies will not equal coverage at VHF frequencies when antenna height and ERP are equal; however, planned adjustments in antenna height and power will permit UHF coverage to be competitive with VHF. UHF has one advantage over VHF in that man-made interference and natural static are practically non-existent, depending of course on TV receiver noise level and sensitivity under low signal levels.

The directional coverage of an antenna may be further modified

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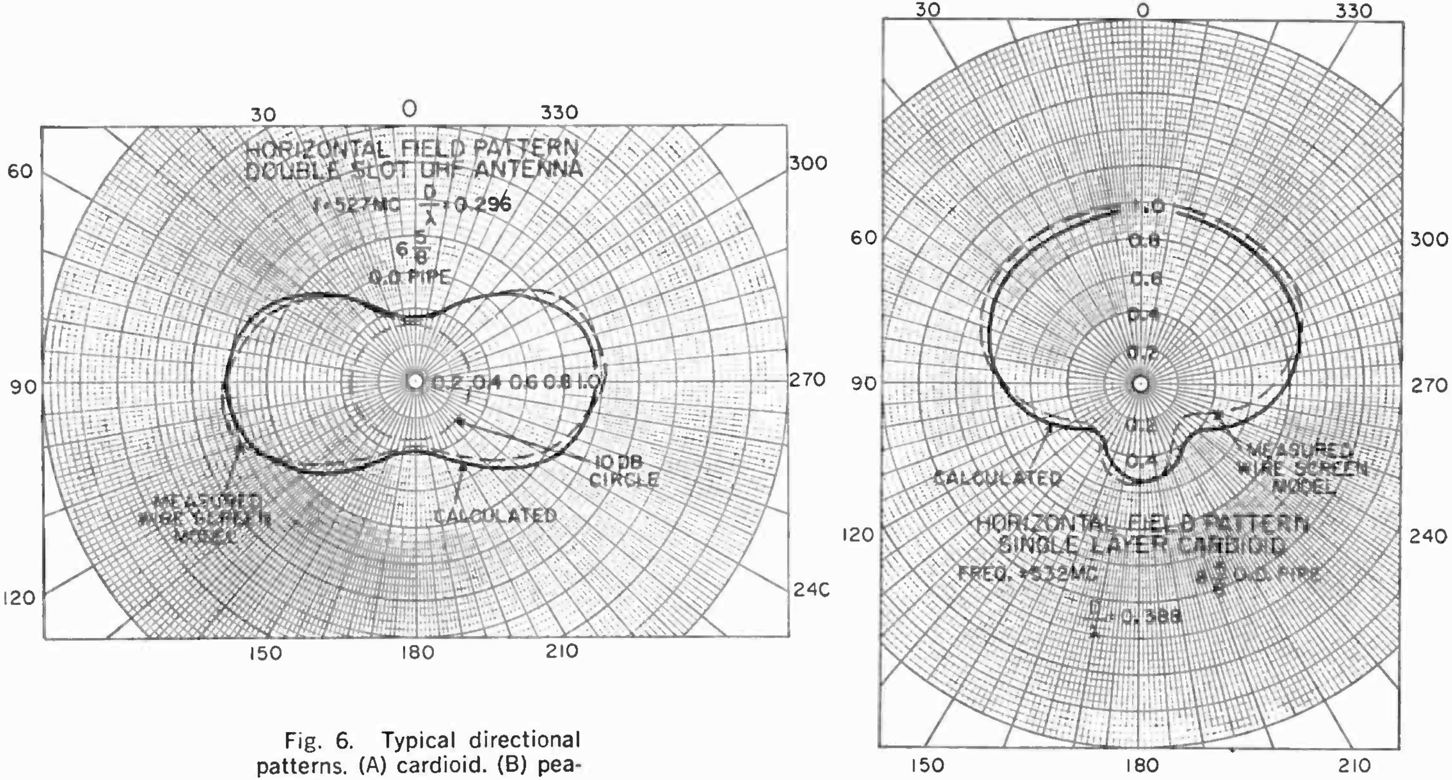

Fig. 6. Typical directional patterns. (A) cardioid. (B) peanut shaped.

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by controlling the *vertical* plane radiation. The vertical pattern is considered to be a cross-section of the relative radiation in a plane perpendicular to the horizontal. In any given direction from the antenna, the vertical pattern has a major lobe, or main beam, which radiates most of the RF energy, and several minor lobes which of course radiate lesser amounts of RF.

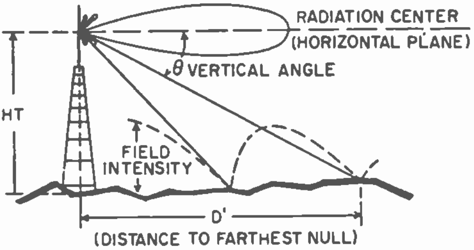

Fig. 7. The effect of vertical pattern nulls on close-in coverage.

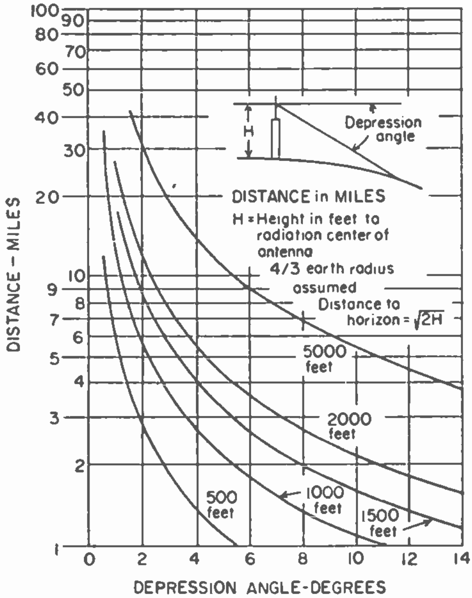

Fig. 8. Vertical angle vs Distance curves for various antenna.

Beam Tilt and Null Fill-In

Nulls occur between major and minor lobes at certain angles in the vertical pattern; the dis-

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Selecting the Antenna Type

This information is furnished to aid the system designer in selecting the most desirable antenna for a given set of conditions.

Batwing and Superturnstile (VHF)

The batwing and superturnstile design is popular for directionalizing VHF systems. Mechanical design reduces antenna weight, resulting in lower erection and supporting tower costs. In a typical multi-bay installation, equal power fed to both sections will result in a vertical pattern null approximately 8° below the horizon. Thus, at level terrain, with a tower height of 500′, the first null will occur at approximately ¾ mile. If the antenna tower is located on a hill or mountain, contouring the vertical pattern is very important. An antenna located on a hill 1500 feet high and overlooking the principal city two miles away, would produce a null over the service area. Nulls can be changed by using the proper antenna gain, or by null fill-ins. Null fill-in is achieved by supplying unequal power in the various bays. Common practice is to feed 70/30 split to the top and bottom sections. Another method is to delay the phase of the current to the lower bays. Both methods provide null fill-in with only a small reduction in gain. Power required for null fill-in is usually not large. Additional costs for such special variations will be small. When the service area is located only on one side of the tower, a batwing or turnstile directional antenna can be used to advantage. This type of antenna is designed for applying numerous electrical and mechanical variations for the best area coverage in any situation.

"V" Element or Corner Reflector (VHF)

Where the service area is located in a mountainous region, the use of the "V" element or reflector in a directional system would be desirable. Directivity is affected by positioning of reflector and radiation elements; beam tilt and null fill in is achieved by distribution of power and phasing between upper and lower elements. Structural members of the tower and radiating elements are usually light in weight. Simplification in design and flexible performance make this type of antenna acceptable for good coverage of service areas in mountain ranges. Spacing of the radiating element in a stacked antenna array is critical.

Helical (VHF and UHF)

The helical antenna is designed to radiate in "side-fire" fashion. Thus, the beam maximizes at right angles to the helix axis. Since the gain achieved with most helical antennas is usually high, the desirability or need for pattern contouring must be carefully considered. This antenna is designed especially for ease of contouring and an infinite number of patterns are available. In selecting a particular antenna for a specific application, vertical beam tilt, null fill-in, and horizontal directivity should be considered.

Beam tilting without appreciable null fill-in may be achieved easily by introducing phase shift between successive sections. This is accomplished by using a different length of feed line between the power divider and feed elbow of each section, or by rotating the individual sections with respect to each other. The most distant or first null is generally the one which

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causes concern (most likely to fall in populated areas close to the transmitter site). Null fill-in is obtained by proper power distribution and current phase in each bay.

Directionalizing the horizontal patterns may prove to be advantageous in certain geographical locations such as coastal areas, near a lake or large unpopulated areas. In horizontal directionalizing, power gain in certain directions can be approximately double that of a standard omnidirectional antenna. Horizontal directionalizing may be changed in the field by adding or taking off stubs. Vertical pattern may be contoured, main beam may be tilted for better coverage, special horizontal directional patterns may easily be achieved.

Zig-Zag (VHF and UHF)

The Zig-Zag panel antenna uses the traveling-wave principle to excite a large wide aperture from a single feed point. This antenna is an excellent building block for many different types of antenna arrays. An unlimited range of patterns can be achieved with panel arrangement. Maximum gains of 75 or more have been attained with practical directional patterns.

Zig-Zag panels are normally assembled on a tower section in custom arrays. A wide variety of orientations and arrangements is possible, depending on requirements for gain, directivity, beam tilt and vertical contouring. It provides for vertical pattern contouring for special coverage requirements, electrical beam tilt adjustment for unusual terrain conditions, and directional horizontal patterns for coastal installations. Thus, this design is generally the best available for special coverage or special structural considerations.

Slotted Ring (VHF)

The slotted ring antenna is designed for VHF service. Arrays can be supplied with null fill-in and beam tilt to provide close-in coverage. This is achieved through the proper selection of line transformers and transmission line lengths in the coaxial feed line between bays. Measurements show that the length of the beam-shaping elements used for directionalizing is not critical in the sense that an inch or two has small effect on the pattern. The angle between the beam-shaping elements has substantial effect on the shape of the pattern, and therefore stabilizing members are used to make sure these angles remain fixed. Special horizontal patterns for particular locations may be achieved with relative ease. The antenna itself is rugged and can be used for all types of environment and terrain conditions.

Traveling Wave and Pylon (VHF and UHF)

In the traveling wave and pylon antenna (slotted cylinder), electrical beam tilt is usually built into each antenna and cannot be changed after construction. Mechanical beam tilting may be incorporated by using shims. Since the dead weight of the antenna is added, antenna and tower stresses must be recalculated. When the antenna is located on a plateau or mountain range overlooking a valley and where little coverage is required to the rear, electrical and mechanical beam tilt in conjunction with horizontal directionalizing may be employed advantageously to improve signal level in a particular direction. Hence, it is important to evaluate not only gain but also the amount of horizontal directivity, beam tilt, null fill-in and the general shape of the vertical pattern for the terrain involved.

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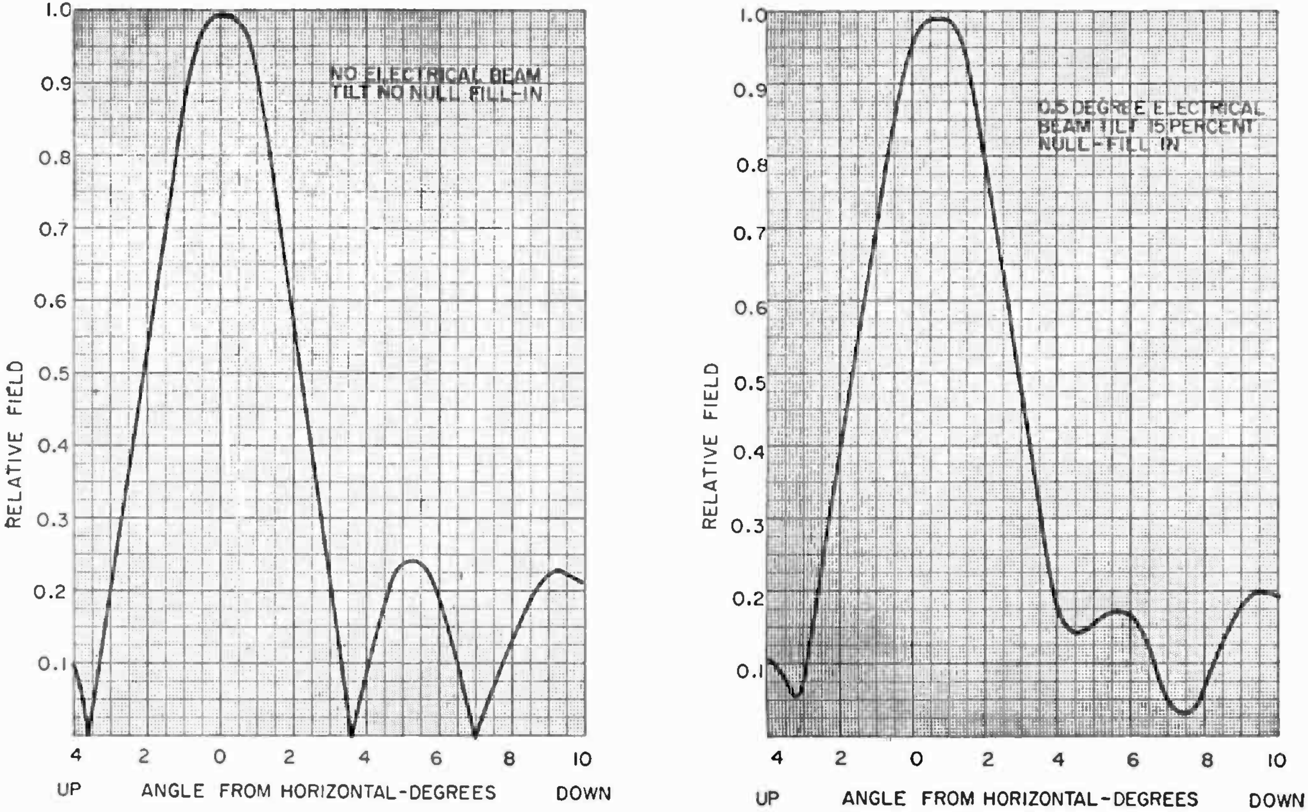

Fig. 9. The effect of null fill-in and beam tilt.

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FCC Rules Governing Coverage and Site

Paragraph 73.685 of Vol. III.

☐ Minimum field intensity in db above 1 mv/m (dbu) over the entire principle community must be: 74 dbu, Channels 2-6; 77 dbu, Channels 7-13; 80 dbu, Channels 14-83. The antenna must be located at a point where the shadow effect on propagation, caused by hills and buildings, is reduced to a minimum over the principle area. In no event should there be any obstruction in the line-of-sight path from the antenna over the principle community. In cases of questionable locations, propagation tests should be conducted to indicate expected field intensity in the principle area.

☐ Directional antennas may be used to improve service upon an appropriate showing of need. Stations operating on Channels 2-13 will not be permitted to employ a directional antenna having a ratio of maximum-to-minimum horizontal radiation in excess of 10db; stations operating on Channels 14-83 with transmitters delivering a peak visual power output of more than 1 kw may employ directional antennas with a maximum - to - minimum horizontal radiation of not more than 15 db; stations operating on Channels 14-83 with less than 1 kw visual transmitter output are not limited.

☐ Applications proposing the use of directional antennas must include a complete description of a proposed system and horizontal and vertical plane radiation patterns.

tances from the antenna to the nulls is a function of antenna gain and height. Close-in coverage is affected by these nulls (Fig. 7), and therefore must be considered in any coverage problem.

As antenna gain is increased (to improve horizontal radiation), the main beam thickness in the vertical plane decreases; as the main beam is narrowed, more and more radiation will tend to miss the horizon and go on into space(Fig. 8).

It is fairly obvious that antenna height, as well as gain, has a direct bearing on radiation angle. But rather than lower the antenna (and lose distant coverage), the main beam may be tilted downward so that it just grazes the horizon. Since simple beam tilt also moves the location of the vertical pattern nulls, it may improve close or medium distance coverage. Were it not for beam tilt or null fill-in, the principle city area may have large variations in signal level. Beam tilting, without appreciable null fill-in, in the range of one to two degrees does not basically change the location of vertical pattern nulls; beam tilts of this order assures the best possible coverage with minimum power loss in the vertical region.

Nulls may be eliminated, or their effect minimized, by proper power distribution and phasing in each antenna bay. Some gain must be sacrificed to fill in nulls; therefore, the more null fill-in required, the less actual gain possible from a given antenna. However, the higher signal level over nearby areas usually justifies the gain loss. The calculated effect of null fill-in in conjunction

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with a 0.5° beam tilt, is shown in Fig. 9.

Conclusion

TV viewer demands for better pictures gives the broadcaster little choice—he must either put out a good strong, high quality signal, or his wares will go a-begging. By careful design, an economical and efficient antenna system will spread a strong signal, over desired areas, from a relatively low power transmitter.

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Guidelines for Selecting a UHF Antenna

Herman E. Gihring

UHF signal propagation requires special considerations—not generally comparable to existing and the more familiar VHF frequencies. The following will be of value to currently active, as well as future CP's. The information will enable the best choice of UHF antenna for a given set of conditions.. Station location and necessary ERP for good coverage dictate the type of antenna and the required transmitter power. The additional factors to be considered are:

1. What is the geographical area to be covered?
2. How does the field strength of the present installation compare with competitive installations?
3. What is the height of the existing antenna compared with competition?
4. In what direction are most receiving antennas oriented?
5. Is the terrain flat or hilly?
6. Should an omnidirectional or directional antenna be used?
7. Is a multiple installation with other stations feasible?
8. Can an existing tower be used to advantage?

The first five questions can be answered from available information. From this the following can be determined:

1. The vertical gain of the antenna
2. Height above the service area
3. ERP
4. Beam tilt
5. The type of vertical pattern

1. **Gain.** A high gain antenna results when the main beam is narrowed. The relationship between gain and beam width at the half power point is: Beam width in degrees = 60/gain over a dipole. The higher the gain, the narrower the beam width. (This is an approximate relationship and applies primarily to a uniformly illuminated antenna.)

Fig. 1 illustrates how a high gain and a low gain antenna would cover a given area for the same input power. Assuming that the main beam is directed toward the horizon, the high gain antenna provides an increased field intensity of 3.2 db. However, it provides 4 db less field intensity in the region of 2° and 4° (a distance of 5.5 and 2.7 miles of a 1000′ elevation).

Generally, field strength should not be lowered if an existing antenna is replaced, even if field strengths are City Grade Level or better; receiving installations tend to be barely good enough to receive an established signal. The

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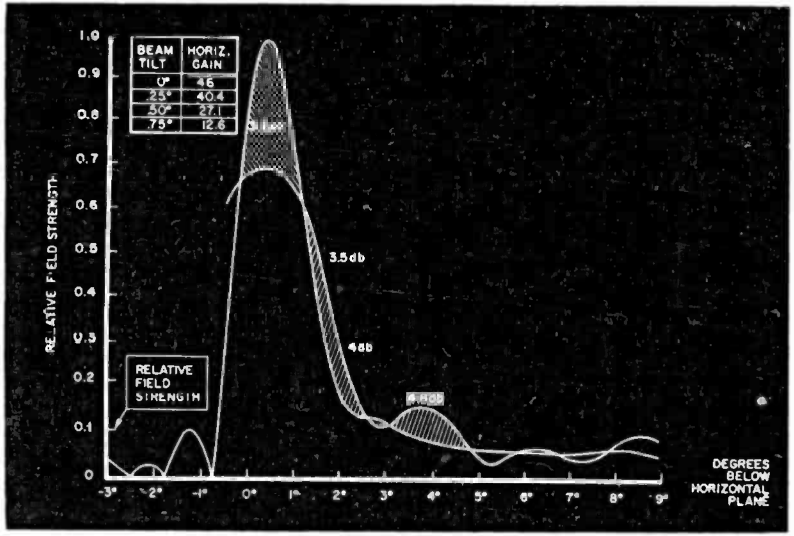

Fig. 1. Shading indicates regions in which increases and decreases in field strength will occur when a high gain antenna is substituted for a medium gain antenna. TFU-46K vertical pattern—beam tilt: 0.50°; effective gain: 46.0. FUT-24DL vertical pattern—beam tilt: 0.50°; effective gain: 22.1.

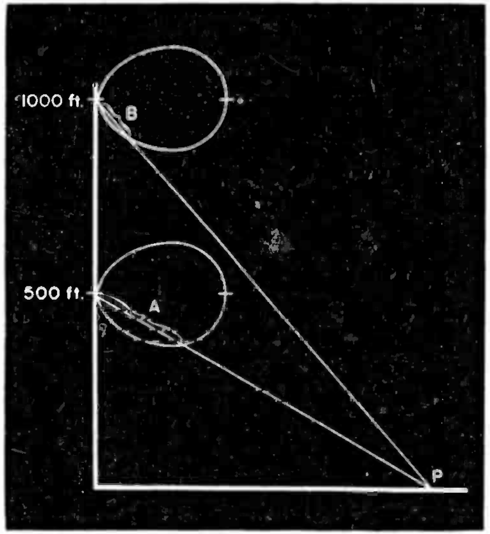

Fig. 2. Intercepts A and B indicate loss in field strength at P when the same antenna is raised from 500 to 1000 feet.

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same axiom applies with respect to a competitive signal. In general, higher gain antennas should be used with higher power transmitters.

For rough terrain it is advisable to concentrate extremely high field strengths in the primary service area to obtain adequate signals behind hills. A medium or low gain antenna and higher transmitter power are preferable for a given ERP.

2. Height. In general, an increase in height may always seem desirable. This is true when the signal at the horizon is considered. However, the effect on the close-in coverage can be detrimental, as shown in Fig. 2. It will be noticed that intercept "B" is much smaller than intercept "A" for a lower height when the field at point "P" is considered. Curves 3 and 4 of Fig. 3 indicate the reduction in field strength which occurs. Hence, an increase in height may also require an increase in transmitter power to maintain existing fields if the same antenna is used. If a higher gain antenna is used simultaneously with an increase in height, a loss of as much as 10 db could occur in the first few miles. Here again, this loss can be offset by an increase in transmitter power.

3. Effective Radiated Power. The product of gain, transmitter power and transmission line efficiency determines ERP. This in turn directly affects field strength at various distances. Fortunately, an adequately high limit of 5 megawatts ERP is permitted for UHF operation. Antennas capable of radiating this power are already available and transmitters are being designed.

4. Beam Tilt. Table I indicates the angle to the radio horizon for various heights.

It is advisable to use a beam tilt which will aim the main lobe at the radio horizon. Figure 4 demonstrates the increase in local coverage as the beam tilt is increased. These curves are for a TFU46K high gain antenna radiating one megawatt of effective radiated power. It should also be noted that the decrease at the

Table I. Depression angle in degrees to the radio horizon for various heights.

Feet	Angle to Radio Horizon
400	.304
500	.343
600	.375
700	.405
800	.435
900	.452
1000	.487
1200	.530
1400	.577
1600	.620
1800	.650
2000	.683
5000	1.08

H—Height in feet to Electrical center of antenna

D_h—Distance to horizon $= \sqrt{2H}$ (4/3 earth radius)

A_h—Depression angle to horizon $= \frac{.0216H}{D_h}$

The relationship $D = \frac{.0109\,H}{A}$ holds to right of staggered line in table below within 4%

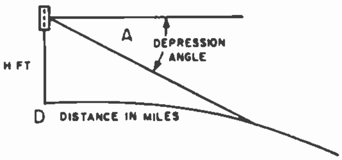

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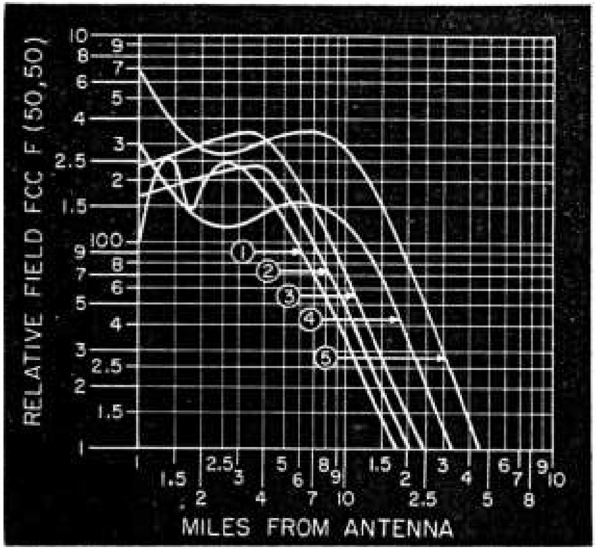
Fig. 3. The effect of gain, elevation, and ERP on coverage*.



*The studies are based on the FCC F (50, 50) curves and are not applicable for any given situation since terrain can influence the values up to 20 db or more. (See statement concerning their application in FCC's Sixth Order and Report par. 3.683). They are used for comparative purposes only in order to bring out certain facts which will aid in choosing the best combination of parameters for certain conditions

Curve No.	Antenna²	Gain	Beam Tilt	Elevation	ERP KW
(1)	TFU-24DL	20.5	0.75	500	225
(2)	TFU-46K	46	0.75	500	500
(3)	TFU-46K	46	0.75	500	1,000
(4)	TFU-46K	46	0.75	1,000	1,000
(5)	TFU-46K	46	0.75	1,000	5,000

Curves (1) and (2) show the relative fields when a TFU-46K replaces a TFU-24DL with the same 12.5 KW transmitter at 500 feet.
Curve (3) shows the relative field with the TFU-46K antenna and an increase in transmitter power to 25 KW.
Curve (4) shows the relative field with the TFU-46K antenna and a transmitter power of 25 KW with an increase in height to 1,000 ft.
Curve (5) shows the relative field with the same conditions as (4) except with an ERP of 5,000 KW.

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[2] The same results apply for antennas with similar gains and vertical patterns.

Based on these curves, a few general observations can be made:

1. **For local coverage, a combination such as (1) can be used.**
2. **The service radius can be increased by raising antenna gain, raising transmitter power, or raising height.**
3. **When raising antenna gain the effect on local coverage should be studied; if it is lower an increase in transmitter power is also necessary.**
4. **When raising height, especially with a high gain antenna, the transmitter power must be increased.**

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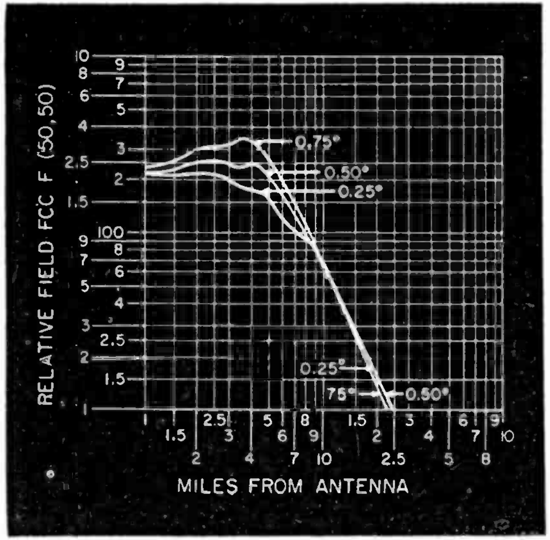

Fig. 4. These curves show how the local field strength increases and the loss in distant coverage is relatively small for a selected beam tilt.

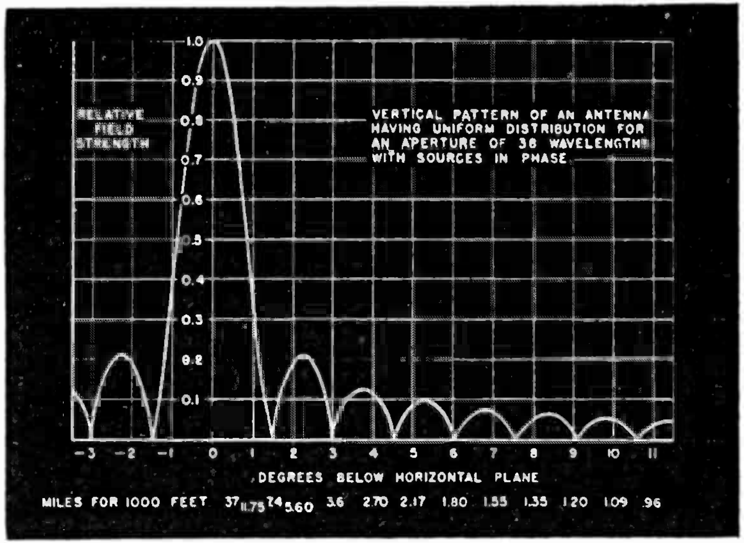

Fig. 5. Vertical pattern of an antenna with a gain of 38 having a sin x/x pattern produced by uniform illumination.

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horizon is quite small. The horizontal gain of this antenna for the beam tilts shown are as follows:

Beam Tilt	*Horizontal Gain*
—	46.0
.25	40.4
.5	27.1
.75	12.6

The rapid decrease in this gain figure may at times be a deterring influence for using beam tilt. However, the coverage is most effective when the main beam is directed toward the horizon or slightly below. Both the main beam gain and the horizontal gain can be filed in the license application.

5. Vertical Pattern. There are, broadly speaking, three types of vertical patterns:

1. Sin x/x
2. Filled
3. Shaped

A sin x/x pattern for a gain of 38 is shown in Fig. 5. It will be noted that the first null occurs at 7.4 miles for a 1000′ elevation. After that, zero nulls occur at ½, ⅓, ¼, etc., of this distance.

A filled pattern is accomplished by varying the amplitude and the phase of the current in each radiating element or in groups of elements. An amplitude step near the center of the antenna will fill in the odd nulls such as the 1st, 3rd, 5th, etc. Some phase variation is required to fill in the even nulls. Filled patterns are generally acceptable and are rendering excellent service in all parts of the country. Most of the antennas in service provide patterns of this type.

Fig. 1 is a good example of a shaped pattern. The amplitude and phase of each layer is varied along the whole length of the antenna to produce the pattern. This antenna is more complex to design and build but it does produce an optimum pattern.

Fig. 3 and its accompanying table reveal the effect of gain, height, ERP, and type of vertical pattern. By choosing these parameters properly, considerable flexibility is possible in serving a given area.

Coverage With A Directional Antenna

A directional antenna has a number of useful applications. It

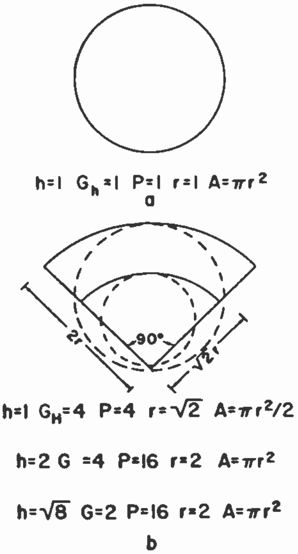

Fig. 6 The most efficient coverage is obtained when the antenna is located centrally in the service area. Only one half of the area is covered with the same input power at the same height from the perimeter using a directional antenna.

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has been used successfully to cover the San Joaquin Valley in California and also to cover service areas adjacent to large bodies of water. There are situations, however, when their use is questionable from a viewpoint of coverage efficiency. Coverage efficiency can be defined as covering a given area with a given field intensity with a minum amount of effective radiated power. Height is also a factor as will be shown below. Some relative approximate relationships can be deduced from propagation formulas which pertain within the radio horizon over plane earth as follows:

$$r \propto \sqrt[4]{p}$$
$$A \propto \sqrt{p}$$
$$P \propto h^2$$

Where r is the distance to a given field contour

P* is the "effective radiated power" in the main beam

A is the area served within a given field contour

h is the height of the antenna above the service areas.

In Figure 6a the area enclosed by a given field intensity contour for a relative "effective radiated power" of "1" and a relative height of "1" is πr^2. The transmitting site can also be moved to the perimeter of the circle and a directional antenna employed which has a horizontal pattern in the shape of a quarter of a circle as shown in Fig. 6b. The horizontal gain of such an antenna is four, hence P=4.

From the relationship above $r \propto \sqrt[4]{p}$, r becomes the $\sqrt{2}$. The area to the same field intensity contour served is then

$$A = \frac{\pi(\sqrt{2}r)^2}{4} = \frac{\pi r^2}{2}$$

Hence, using the same transmitter power with an optimum directional antenna with a horizontal gain of 4, only one half of the area is covered as compared to 6a and hence the coverage efficiency is 50%.

It can be stated generally that because of the fourth root relationship between distance and radiated power that the center of the area to be covered is the best location for maximum coverage efficiency.

However, another factor pertains and that is height. From the relationship above it is noted that if the height is doubled, the "effective radiated power" increases four times. Hence, in Fig. 6b, doubling the height will provide "effective radiated power" "P" of 16 and "r" becomes 2. The area covered is then $A = \frac{\pi(2r)^2}{4} = \pi r^2$ which is the same as for "a".

The antenna postulated in "b", however, is not permitted under the 15 db rule. A practical antenna may have a horizontal gain of about 2. To obtain an "effective radiated power" of 16 will require a height increase of $\sqrt{8}$ or 2.8 times.

Another general rule is that where a sufficient natural height can be obtained, a directional antenna can be an advantage. To obtain any advantage, however, heights beyond a relative value of

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*The value here used is not only the product of transmitter power and antenna gain, but also the increase in "effective radiated power" due to an increase in height.

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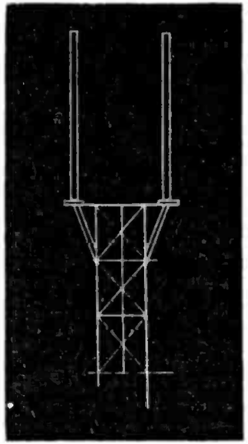

Fig. 7. Good circularities are possible with spacings of only 10 to 15 feet for two UHF antennas.

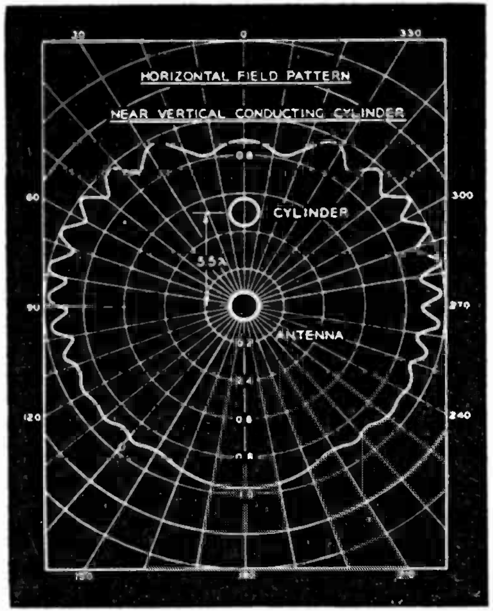

Fig. 8. Measured diffraction pattern for an antenna and a cylinder spaced 2.5 wavelengths.

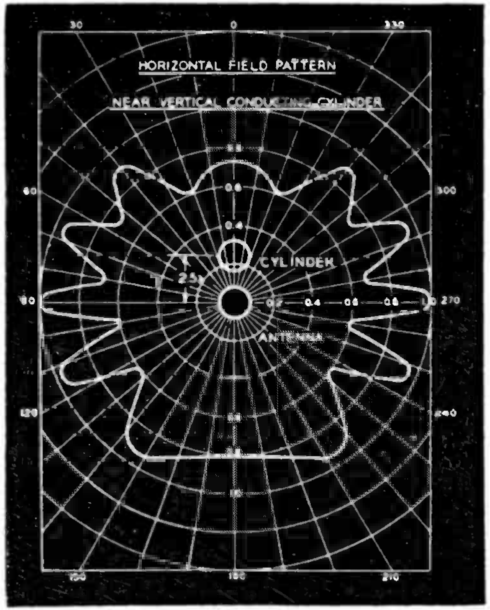

Fig. 9. Measured diffraction pattern for an antenna and a cylinder spaced 5.5 wavelengths.

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2.8 must be obtained under the conditions postulated above.

Multiple Installations ("Antenna Farms")

Multiple installations are becoming more common for a number of reasons:

1. Airlanes around metropolitan centers leave only a few areas available for tall structures.
2. A common location of all stations is desirable because of receiving antenna orientation.
3. Installation cost economies may result, especially at UHF frequencies.

There are a number of ways in which multiple installations can be made:

1. Candelabra. A number of VHF installations using candelabras are operating successfully. This technique is even more applicable for UHF.
2. Stacked antennas above the tower top. This method has been fairly successful at VHF but has limitations at UHF.
3. Standard UHF antennas side-mounted on an existing tower. This method has good possibilities under certain conditions.
4. Special Panel type antennas side-mounted on existing or new towers. This method also has good possibilities under certain conditions.

Each of the above methods will be discussed in more detail.

Candelabra Arrays

While spacings between antennas are 80 to 100 feet at VHF they reduce markedly at UHF so that good circularities are obtained at spacings of only 10 to 15 feet. (Circularities of ± 2 db for a 10 foot separation to ± 1 db for a 500 foot separation can be obtained for smaller antennas; and ± 3 to ± 2 db for larger antennas. This figure includes the circularity of the antenna itself.) The isolation between antennas is more than adequate for slotted cylinder types of antennas.

Considering the fact that most standard triangular towers above 500 feet are 7¼ feet on each face, a relatively small outrigger is required for a 10′ to 15′ separation as shown in Fig. 9.

Hence, the increase in tower cost for supporting several antennas is relatively small. Furthermore, standard antennas can be used which are more economical to build. The advantages of a separate antenna for each station, which permits complete flexibility, is another important factor.

Reasonable circularities can also be obtained for three or even six antennas disposed in this arrangement. Hence, this method appears as the most logical method of providing multiple UHF installations.

Vertically Stacked Arrays

Vertically stacked arrays have been in use for many years. They are quite suitable for panel type arrays and Superturnstile antennas in which various portions of the antenna operate at various channels. However, standard UHF antennas are not constructed to support other antennas; hence, special designs are required of either a heavier cylindrical or panel type, both of which tend to be more costly.

UHF stacking is thus somewhat less desirable than the

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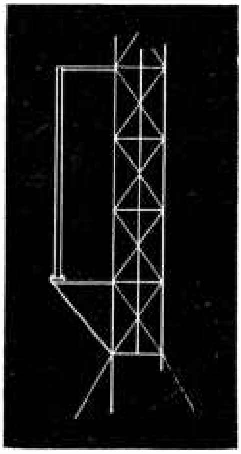
candelabra, from both an economic viewpoint and also for a lack of flexibility in changing or replacing an antenna in the stack. There are no technical limitations in using this method, however, if it seems desirable for other reasons.

Side-Mounted Antennas

When a UHF antenna is mounted in the proximity of a tower, it influences the performance of the antenna in several ways. The presence of the steel in the tower affects the impedance, and also the horizontal pattern. The vertical pattern may also be affected at steep angles, but only in a minor way in the main beam.



◀ Fig. 10. Side mounted antennas should be base mounted preferably above a guy point. Best circularities are obtained with a minimum of metallic objects on the tower.

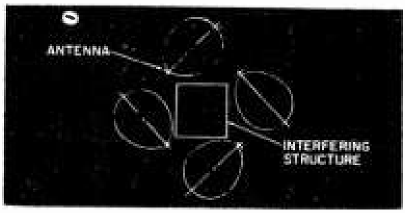


Fig. 11. Radiators can be placed at an angle to the tower faces to produce a pattern of ± 5 db.

The effect on impedance can be practically eliminated by proper spacing. However, the effect on the horizontal pattern decays very slowly with spacing. For instance, an improvement of less than 1 db would be obtained by using a spacing of 10 feet as compared, say, to 7 feet.

Metallic objects in the tower affect the pattern. The more metal objects, the greater will be the non-circularity. The tower legs may contribute ± 2 to ± 3 db. Other items such as horizontal and diagonal tower members, transmission lines, ladders, power and telephone cables, elevator rails, etc., increase non-circularity. It is difficult to give values since much depends on the individual installation. Some calculations made on a standard triangular tower 7-½ ft. on each face indicate ± 7 db with all of the items listed above. On the other hand, a tower which is relatively transparent with only the tower members may be of the order of ± 3 db. It is also reasonable to expect in both cases that there may be several peaks or valleys which will be appreciably greater than this value where a number of these items add in amplitude and phase.

When side-mounting an antenna it is advisable to provide a base so that a standard antenna can be used. (See Fig. 10). Bracing at the top and sometimes at the center is also necessary. Guys

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should be avoided in the field as much as possible. It is desirable to locate the antenna immediately above a guy point and also at a point where there are a minimum of metallic objects.

When the service area is located on only one side of the tower, a directional antenna can be used to advantage with the null directed towards the tower. This will generally reduce the variations towards the service area. On the back side of the tower the nulls may be appreciably deeper than the pattern null due to the shadowing effect of the tower.

Panel Type Arrays

Panels which are side mounted may consist of either a dipole configuration or a dipole type array. Radiators are fastened to their individual reflectors, and panels can either be face mounted against the sides of the tower, or skewed as shown in Fig. 11. Face mounting has the advantage of lower interference to the pattern resulting from structural members, or other objects inside the tower. Circularities of ± 1 to 2 db can be obtained for towers with dimensions of one wavelength per side. For towers which have a dimension of five wavelengths per side, circularities of the order of ± 5 db can be achieved. This presumes a well designed panel having the proper beam width and minimum back lobes.

For larger structures, skewing can be employed with circularities of the order of ± 5 db. While smaller values are theoretically possible, the effect of back lobes and reflections from the tower tend to hold the value in this vicinity.

Summary

From the above considerations, it can be seen that the choice of the antenna, whether omnidirectional or directional; whether used in a single or multiple installation; its characteristics such as gain, beam tilt, and vertical pattern; its location and height are all important considerations which require considerable thought and study. It is hoped that this information will be helpful in guiding others in the successful choice of a UHF television antenna.

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TV Antenna System Performance & Measurement

H. E. Gihring & M. S. Siukola

ALONG WITH the growth of TV broadcasting, the state of the art has greatly improved. At the same time, the complexity of the antenna system has increased. As a result, the requirements for both performance and realiability must be re-evaluated. These requirements are:

1. No visible ghost.
2. Properly installed fault-free components.
3. Proper load presented to the transmitter.

The required specifications to meet these requirements include a means of determining the far-end reflection and the reflections from each component, and a limit on the impedance value presented to the transmitter.

Antenna System Requirements

About 20 years ago, when TV antennas were first designed for quantity production in the present VHF bands, the ghost arising from too great a mismatch was recognized as a limiting factor. Tests were made on a long line to determine what far-end mismatch would produce a visible ghost. It was found that a mismatch giving a VSWR of 1.15 was clearly visible. A 1.1 VSWR was just below threshold at normal contrast and was chosen as an acceptable value. The specification was applied only to the far-end reflection, from the antenna only. This was a good standard to follow in view of the type of antenna systems employed at the time, but changes in present-day systems and requirements have outdated it. The VSWR value of 1.1 was a means to an end—*namely, that there be no visible ghost under normal viewing conditions.*

Early TV installations were fairly simple. The transmitter was often located in a downtown building and towers were generally only 200 or 300 feet high. A superturnstile antenna was placed on the tower and two 3-inch coaxial lines ran directly through a diplexer into the transmitter. Since then, however, transmitter sites have been moved beyond the city limits, where space permitted the erection of taller guyed towers. The transmitter building is usually located some distance from the tower base to minimize damage from falling ice. This necessitated longer transmission line runs. In the move from downtown, new equipment was often obtained so that a spare transmitter became available. This necessitated a switching sys-

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tem. As a means of assuring that all of the components met requirements, the 1.1 specification was applied not only to the antenna but to the whole antenna system. Towers were still of the order of 500 feet and systems were not too complex.

Now, 1,000-foot towers have become common, and the complexity of systems has increased still further. Other items, such as harmonic filters, patch panels, 6″ line with adaptors and transformers to 3″ line and similar equipment, are now being used. As systems become more complex, it is increasingly difficult to meet the 1.1 VSWR system specification. Sometimes there are so many components that the VSWR up to the building wall approaches 1.1. Meeting both the performance and reliability requirements, with a VSWR specification only, is becoming increasingly difficult—and, as it turns out, also unnecessarily stringent. A different and more appropriate method is necessary—*namely, a means of determining that all of the components are performing properly and are correctly installed.*

When making system impedance measurements, VSWR readings are often taken every 0.1 megacycle across the 6-mc channel. In these readings, a cyclical variation takes place, as shown in Fig. 1. The cause of this variation can be explained in the following manner: There are, in most TV antenna systems, two groups of components—the close-in components in the station, such as elbows, gas stops, etc, and the far-end components such as the antenna and also some additional elbows. The close-in and far-end components are connected by a run of vertical transmission run, as shown in Fig. 2. At a given frequency within the channel, the close-in and the far-end component reflections add, giving a relatively high value of VSWR. At a slightly higher frequency, the electrical length of the line is one quarter of a wavelength longer, causing the close-in and the far-end components to cancel, resulting in a relatively low VSWR. For a 1,000 foot line there will be about 12 cycles, as shown in Fig. 1.

The number of cycles is independent of frequency, and is therefore the same for all TV channels. It depends only upon the total length of the transmission line and the velocity of propagation. For an air dielectric line, the approximate number of cycles for a 6-mc channel is L/82, where L is the total length of the line in feet. Depending upon the reflection values of the far-end and close-in components, the VSWR could, for instance, range from a very low value up to 1.2 or 1.3. Hence, the question arises: *What type of impedance should be presented to the transmitter by a TV antenna system to assure proper transmitter performance and safety of the components?*

Research has shown that good system performance can be obtained by following certain methods. Some areas are critical and some are not. To apply the same design criteria to the whole system and at all frequencies in the channel is unduly restrictive in some areas and not sufficiently restrictive in others.

All ghosting as a rule is the result of far-end reflection. The far-end components consist of

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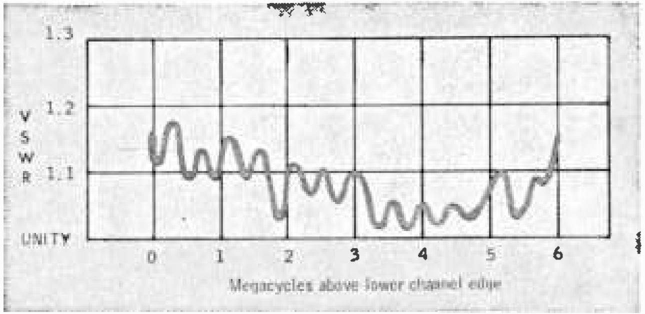

Fig. 1. Plot of VSWR vs frequency for a typical TV antenna system when the total transmission line length is 1100 feet.

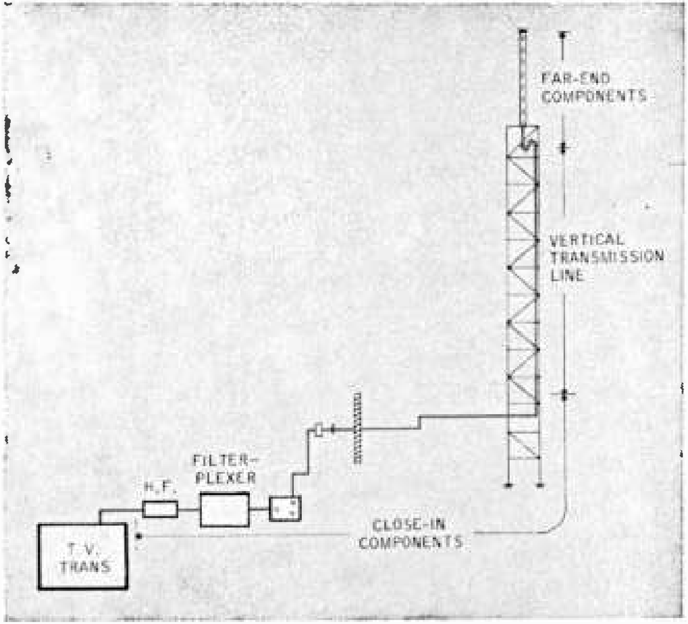

Fig. 2. In typical antenna systems, reflections from the discontinuities of close-in and far-end components alternately add or subtract as the electrical length of the transmission line varies with frequency. The resulting cyclical variation is shown in Fig. 1.

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the antenna and usually an elbow complex of some type. Historically, antennas have been built to a VSWR specification of 1.1 for all frequencies in the 6-mc channel. If an antenna having a VSWR of exactly 1.1 across the channel were built, the reflection percentage would be very close to 4.75, which, at the end of a long transmission line, would produce a visible ghost. Knowing this, manufacturers have for many years designed antennas with lower VSWR values (as far as the state of the art has allowed) at the important portions of the channel, thus producing better antennas which would minimize visible ghosts. Hence, in determining far-end reflection limits, either a modified VSWR specification or an RF pulse specification may be used.

However, if an RF pulse specification is used, there are good reasons for not using the VSWR specifications simultaneously, since the two are often mutually incompatible and the results may be detrimental to best performance. For example, the upper left portion of Fig. 3 shows the Smith Chart plot of a TFU46K antenna enclosed by a 1.1 circle. For this condition, the VSWR at the picture carrier frequency would be 1.06 and at .75 mc higher would be 1.08. The reflected signal calculates to be 3½%, as shown.

On the other hand, if the designer were permitted the liberty of placing the impedance plot on the Smith Chart in relation to the 1.1 circle as shown on the right in Fig. 3, the VSWR at the picture carrier and somewhat above it would be less than 1.015. The calculated reflected signal in this case is 0.8%, notwithstanding the fact that the VSWR at the low and high ends of the band are no longer at 1.1 but 1.13. But since the lower and upper 1/2 mc are not in the picture pass band, as can be seen from Fig. 4, and for other reasons, a VSWR specification would be more beneficial if it were V-shaped instead of flat —for instance, one that would allow a 1.2 specification in the lower and upper half megacycle of the channel and a lower value such as 1.05 at picture carrier, as shown in Fig. 5. However, if an RF pulse value is specified, a simultaneous VSWR specification would only be redundant and may result in a situation where best performance is not possible.

Elbow Complex

As for the far-end elbow complex, Fig. 2 depicts a common method for connecting the input of the antenna to the vertical transmission line run. With 3-inch line, a two-elbow complex is possible since the vertical run could be moved sufficiently to disengage the elbows. However, with 6-inch and larger transmission lines, a group of four elbows is usually used. Components of this type, especially when they cover a large frequency band, cannot be made completely transparent and some small reflections will occur. Often, due to space restrictions, it is not possible to select the best separation between elbows so that the small VSWR of each may add directly. The cumulative VSWR can be significant, especially since the picture signal "sees" all of the tower top components, including the elbows, as one reflection point. Hence, it is general practice to match the elbow complex with a slug to

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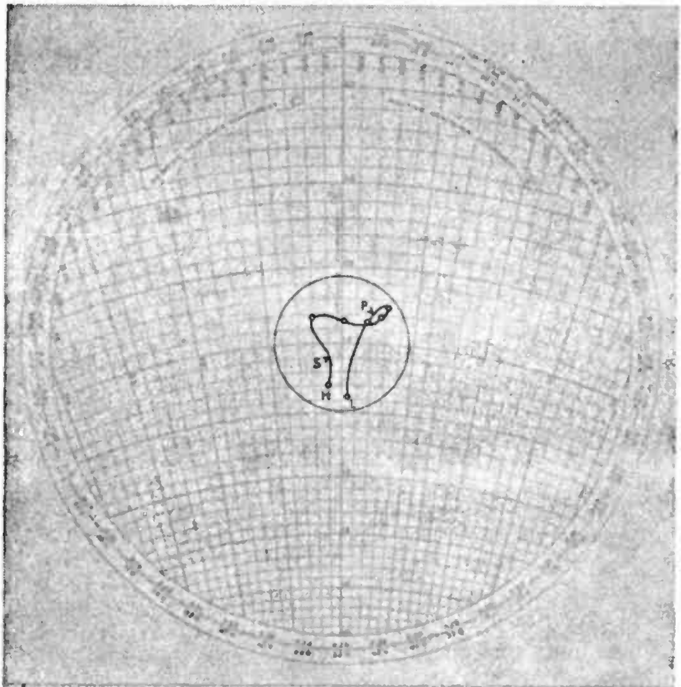
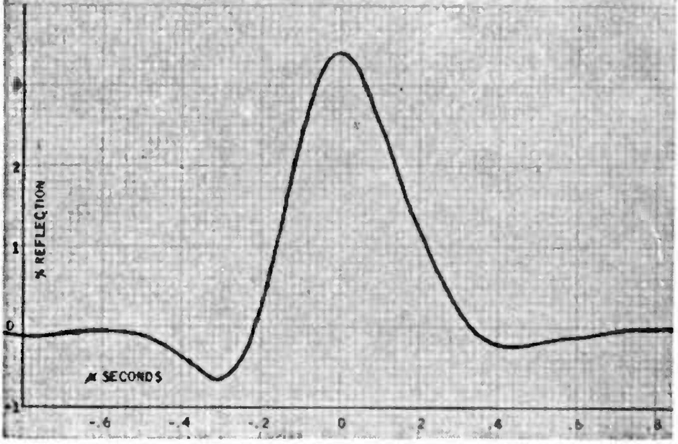
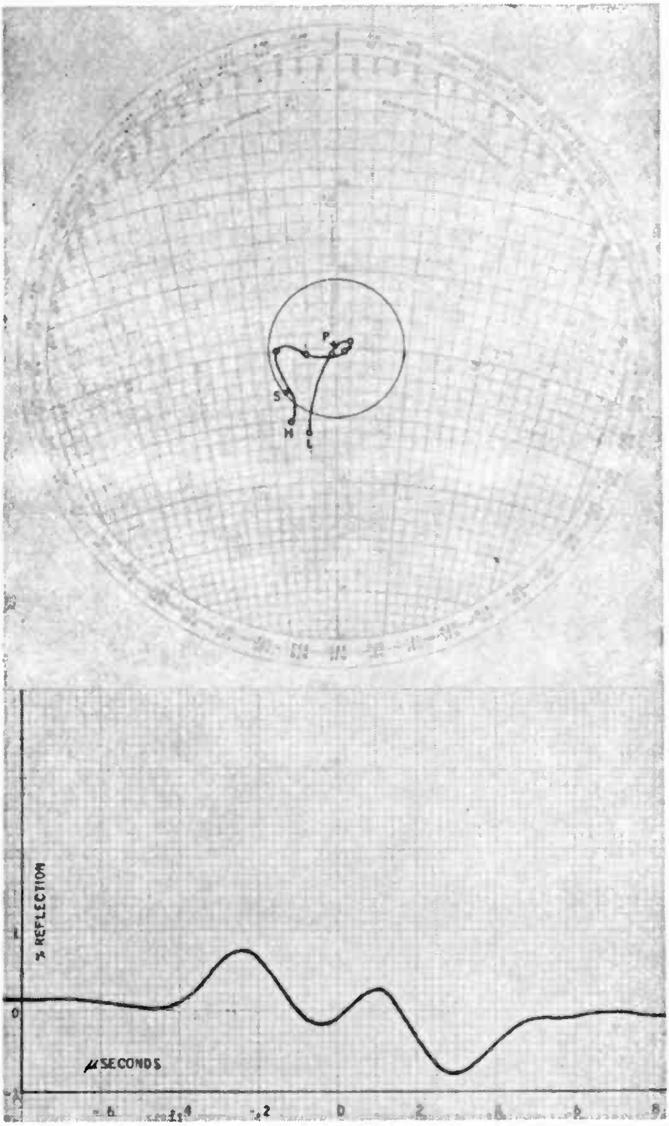
Fig. 3. Impedance plot enclosed by a
low and high ends of the 6-mc channel. P
and sound carriers. All other dots are 1





1.1 circle. Symbols L and H are the
and S are the locations of the picture
mc apart.



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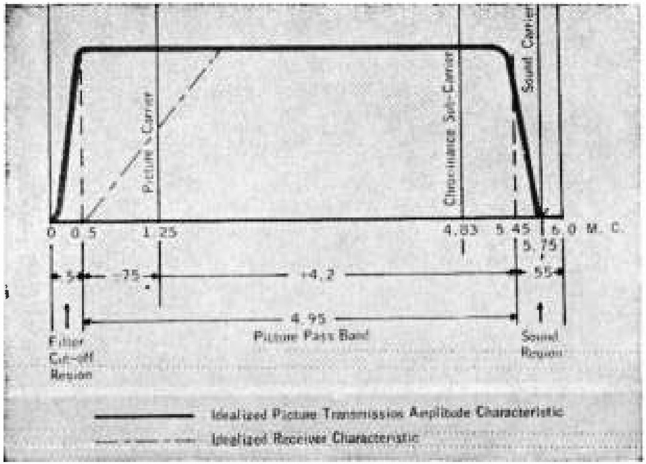

Fig. 4. Idealized picture transmission amplitude receiver characteristics. Note that the lower and upper 0.5-mc segments are not in the picture pass band.

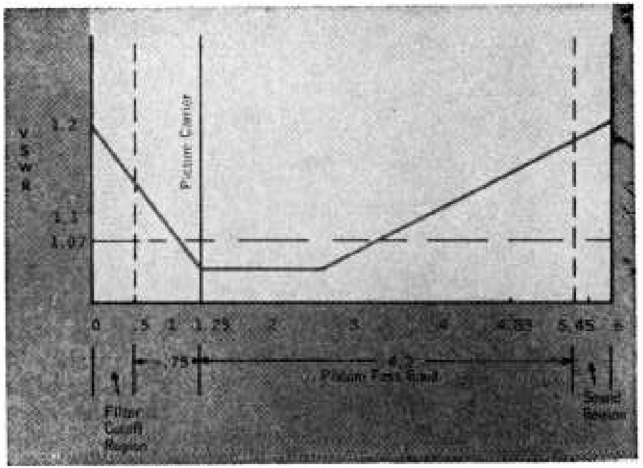

Fig. 5. If the RF pulse method is not used, a V-shaped VSWR antenna specification will provide a lower value of reflection than a flat VSWR specification.

minimize its reflections.

There is also a practice followed in certain situations to optimize far-end impedance by use of a variable transformer. Consisting of a piece of transmission line containing a series of movable probes, it is adjusted for a minimum RF pulse reflection value. Such a method has considerable merit but must be used with some discretion; its effectiveness depends on the electrical separation between the reflection source and the variable transformer (generally the electrical length between them, but in some cases, depending upon the "shape of the impedance curve," it may be appreciably more). The optimizing becomes gradually less effective as the separation becomes greater and ceases to be effective at about 100 feet for air dielectric lines, since the negative "bump" from the transformer becomes displaced in time from the reflection it is supposed to eliminate.

Generally, it is more desirable to initially design antennas with an impedance characteristic which will provide a minimum reflection from an RF pulse, rather than to optimize after erection. However, this may not be possible in some situations. Certain mathematical analyses indicate that the frequencies from the picture carrier upwards for about a megacycle must have the best match for a minimum RF pulse reflection. If the antenna is designed and built in accordance with the curve at right in Fig. 3, or with Fig. 5 in general, optimizing will probably not be necessary or, at the most, used only as a means of gaining a slight additional improvement. Hence, by the proper use of techniques which will permit the antenna system to be designed for minimum RF pulse reflection, optimization would not be necessary in most cases.

Properly Installed Components

Naturally, high quality components having the latest engigineering improvements should be specified. Also, proper transmission line lengths must be used to prevent the addition of discontinuities within the channel. Equally important is the layout of the transmission line system. Transmission line components, including elbows, gas stops, reducers, transformers, etc., are not completely transparent. Thus, a minimum number should be used. The tower top elbow complex should be matched to make it as transparent as possible. It may also be desirable to match the components at the tower base, especially if there are more than one and the horizontal run is more than 50 feet.

Components in the station do not affect picture performance, but they may change the impedance of the transmitter termination. If the number of components used are such that the VSWR from the transmitter to the station wall could appreciably exceed 1.1, it may be advisable to optimize them in order to have a total system VSWR, as seen by the transmitter, at a safe level, such as 1.3.

If installation of the transmission line starts at the transmitter and proceeds toward the antenna, progress can be watched with .02-μs pulse equipment and reflection values above the general level investigated immediate-

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ly. Installation practices recommended by the manufacturer should be followed.

To meet the performance standards for today's TV antenna systems, the RF pulse method is best for determining far-end reflection since the percentage values can be directly related to ghost visibility. Typical values are of the order of 3%, although in some of the earlier designs, variable transformers may be required to meet this specification. As an alternative specification, the RF sweep method determines VSWR values of the far-end components and provides a usable evaluation with simpler equipment. A V-shaped VSWR curve will give lower reflection values than flat 1.1 VSWR specs.

The RF pulse method will spread out the entire system on a time base and show the location of faults. Typical reflection percentages are 1%. As an adjunct, and not a specification, an RF pulse of .02-μs can be used to locate faults more precisely. A DC pulse can be used if its limitations are recognized. The effect on picture transmission is best analyzed with the 0.25-us pulse. The .02-μs pulse equipment is more of a diagnostic tool to find the exact location .

The best approach to proper impedance termination at the transmitter is a VSWR measurement using either an RF sweeper or measuring line. The purpose of this measurement is not to check ghosting or system discontinuities, but only to see that the impedance presented to the transmitter is acceptable. A value of 1.3 at the carriers has proven to be generally acceptable.

Measuring TV Antenna System Performance

There are three general methods for determining design specifications and measuring performance: System VSWR measurements, RF sweeper method, and RF pulse method.

System VSWR Measurements: A signal generator, slotted measuring line, and VSWR meter are required. Readings are taken every 0.25 or 0.1 mc, depending on the length of the transmission line run. The equipment is relatively simple and readily available, and the whole system can be measured, thus providing a steady state value of VSWR for the sum of all the components.

Disadvantages: All discontinuities in the system are added vectorially, making the result difficult to analyze. This can be seen from Fig. A, which depicts several periodicities. The rapid fluctuation every 0.5 mc indicates that the length of the transmission line run is about 980 feet. There is also a 4-mc period indicating that there are two discontinuities 120 feet apart—the mean value a-b, which is 1.12, and a variation from this value, line d-e-f, which is ±1.03. The latter could be the tower base elbows, while the 1.12 value could be the close-in components in the transmitter building.

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Summary of the Three Measurement Methods

Requirement	METHOD		
	VSWR with slotted line	VSWR with RF Sweep	RF Pulse
No visible ghost	Indefinite	Medium	Excellent
Properly installed components	Poor	Poor	Good beyond 150'*
Proper impedance termination to transmitter	Good	Fair	Poor

*Excellent if an RF 0.02 µs RF pulse width is used. A DC pulse method can also be used.

Now the analysis becomes more difficult. The average value of the rapid fluctuations (line d-e-f) could be the summation of the close-in components, while the value "c", which is one-half the 0.5-mc period fluctuation, could be the far-end components. On the other hand, the two could be reversed. Furthermore, since the curve touches the unity value of VSWR at 2 mc, the values could switch at this point so that line d-e-f could represent the far-end components from 0 to 2 mc. and the close-in components from 2 to 6 mc, or vice versa. Such a conclusion would, of course, invalidate the 4-mc analysis made above.

While a number of hypotheses can be formulated from these measurements, the most important value, namely the VSWR of the far-end components, is extremely difficult to determine. Additional information can be obtained by making changes in the station or by having a rigger make tower top changes which would indicate which value was "close-in" or "far-end". However, such a procedure is somewhat laborious.

System VSWR measurements are not well suited for periodic check-up purposes, since results may vary depending upon the location of the measuring point, the adaptor components utilized, and for UHF the VSWR vs frequency curve may change with temperature. (A 50°F change for a 1,000-foot transmission line will change the physical length of the line by a quarter wavelength at about Channel 25.)

Plots of VSWR vs frequency, similar to the one in Fig. A, have a sinusoidal type of variation in which the values may range, say, from a match to as high as 1.3. This variation is usually the summation of two fixed values of impedance separated by a transmission line. If a proper analysis of this impedance is not made, false conclusions may be reached regarding the operation of the antenna system and also the effect on the transmitter.

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RF Sweeper Method: In this method, an oscillator is varied to produce the RF frequencies in the 6-mc band at a sweep rate of 60 cycles or more so as to obtain a bright enough image on an oscilloscope. A delay line about 500 feet in length is used in series with the station transmission line as shown in Fig. B. A calibration point for 100% mismatch is obtained by opening the line at "m". The peak to peak oscilloscope deflection is usually set at some given figure, such as 4 inches, as shown at "a". A trace is then photographed when the delay line is terminated in a matched load at point "n". If the delay line is perfect, the trace should be a straight line as at "b". With the delay line connected to the antenna, a trace as at "c" is obtained.

The far-end VSWR can be calculated from this trace as shown at "d". A low frequency deviation may also occur as shown. This is a measure of the close-in mismatches and can be calculated both in magnitude and location in a similar manner. The equipment is more portable than a measuring line, especially for the lower channels. Also, this method overcomes one disadvantage of the measuring line in that VSWR values of far-end components having a more rapid variation, ΔF_1, can be separated from the close-in and delay line effects. The close-in components will cause the periodicity corresponding to ΔF_2 in Fig. B. Because of this, the method is most useful for checking antenna systems as well as the far-end components of the system.

Disadvantages: The location of faults in the transmission line has almost the same severe limitations as VSWR measurements. In addition, a good portable delay line is not available at UHF channels. While a 1/2-inch styroflex line has been used, the high attentuation makes a very high power oscillator necessary. The line to the antenna can be used, but obtaining a calibration point by, for instance, opening the line near the top the tower, imposes difficulties. Furthermore, the close-in VSWR values will not be obtained. Finally, while the oscilloscope trace provides a measure of the impedance presented to the transmitter, it is not as precise in this respect as the measuring-line method.

RF Pulse Method: In this method, actual picture transmission conditions are simulated by sending an RF pulse through the antenna system. The pulse often used is 0.25 μs at the −6 db level, representing the narrowest pulse that can be transmitted through the TV system and also one which has the highest energy content in the higher order sidebands. The carrier of the pulse is centered at the visual carrier of the channel to simulate the visual transmitter. A reflectometer is used to sample both the incident and the

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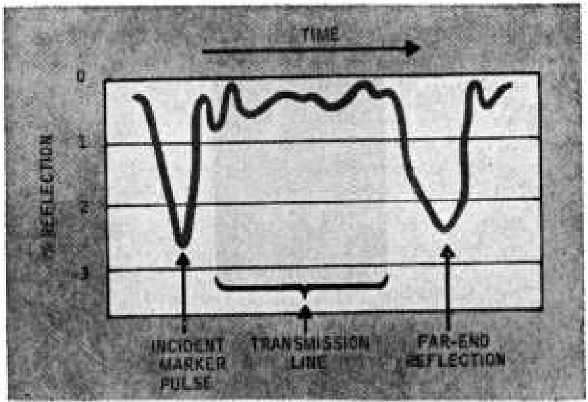

Fig. D. A typical oscilloscope display using the RF pulse method.

are shown with respect to both their amplitude and location.

Disadvantages: More instrumentation is required than for the other methods. However, the quantity and complexity of equipment has been reduced considerably in the past few years. While the RF pulse method pinpoints line faults more accurately and reliably than the other two methods, the pulse width of 0.25 μs precludes their location to within 100 feet. However, by using a narrower RF pulse of about 0.02 μs with the same basic equipment, faults can be located to within 10 feet, including the first 150 feet from the transmitter. The method does not, however, indicate the impedance presented to the transmitter.

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Customized TV Antennas with Time-Sharing Computer

James D. Kearney

THE VERTICAL FIELD of a helical or zig-zag TV antenna can be calculated by a computer in ½ hour. The theoretical formulas, boundary conditions, etc., for calculating the far field of such antennas have been well documented and converted to computer programs. The flow chart, Fig. 1, indicates how the computer tackles the problem. The input data is set forth in three blocks. This is done so that nondependent variable parameters can be changed readily to optimize the vertical pattern.

The input data for number of bays, wavelength, initial, final and incremental angle of depression are usually fixed by the specific antenna application. However, bay spacing and amplitude and phase of current to each bay are subject to the designers judgment. Likewise, the one bay data can be either a cosine^2 function or the more practical measured one bay data as collected from scale model or production antennas. Since the array factor is the vector sum of the individual elements, it is not practical to synthesize from overall requirements because of an infinite number of solutions. Therefore, the designer's experience dictates a starting point and the parameters may then be optimized one by one to meet or exceed the contractual requirements.

For instance, Fig. 2, illustrates three vertical patterns as calculated and plotted by the time-shared computer for a six-bay General Electric zig-zag antenna. The requirement is for ¾° beam tilt, 30 percent null fill with no nulls less than 4 percent field. Illustration A shows the starting point with experience dictating input data. Both

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reflected signal. A block diagram of the components is shown in Fig. C. Both signals are detected in equipment having an ideal receiver characteristic using the vestigial sideband transmission principle. The pulse rate is the same as the horizontal line frequency of about 15 kc, although this is not at all critical.

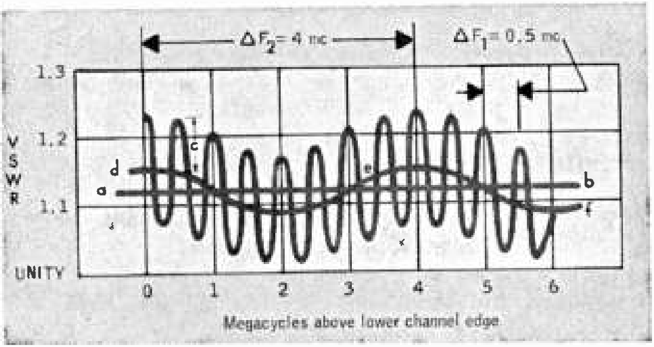

Fig. A. Two periodicity plots of VSWR vs frequency, one of 0.5 mc where the two discontinuities are separated about 980 feet, and another of 4 mc where they are separated about 120 feet. The VSWR values of the three discontinuities can be determined approximately. The separation between discontinuities can be calculated from the formula L = 491.5/F, where F is the frequency change in mc from peak to peak.

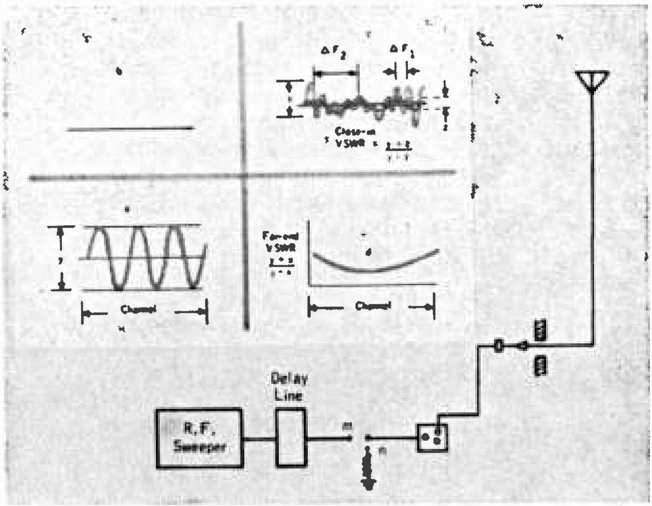

Fig. B. Using a delay line, the RF sweeper method provides far-end and close-in VSWR values as well as the distance between any discontinuities from the L = 491.5/F relationship.

Both incident and reflected signals are displayed on an oscilloscope, and an amplitude comparison of the two values is made. An oscilloscope trace with the reflectometer in the reflected position is shown in Fig. D. The phase of the carrier compared to the reflected sidebands is adjusted by a line stretcher or phasor so as to measure the maximum relative reflected

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voltage, thus representing the most pessimistic condition. The amount of reflection from the far-end components is specified as a percentage of the input pulse magnitude, 3% being a typical value.

Other reflections in the system, such as the transmission line, are specified for a lower value, typically 1%. Since the display on the oscilloscope is on a time base which corresponds to distance, the location of such reflections can be determined. For an 0.25-μs pulse, discontinuities occuring within a distance range of about 100 feet will appear as one reflected pulse. In special cases, such as a candelabra installation where an antenna system including all of the far-end elbow complexes may be located over a distance greater than 100 feet, a longer RF pulse should be used so as to summate these effects for the longer pulses that

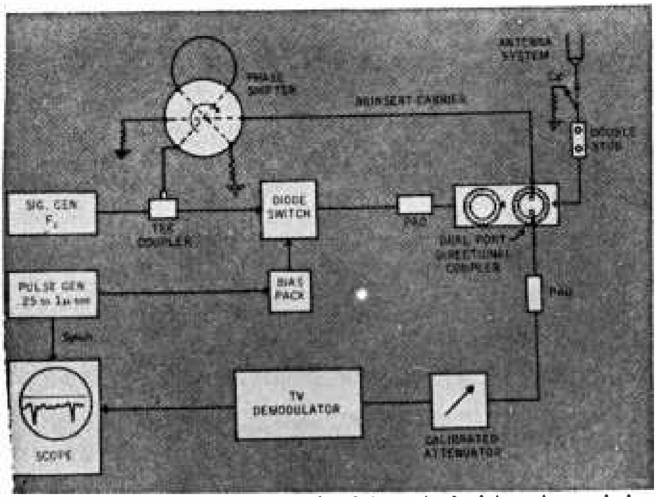

Fig. C. The RF pulse method simulates actual picture transmission and accurately measures the reflection from both the far-end components and the transmission line.

may appear in TV transmission. A longer RF pulse should also be used for any situation where an accumulation of reflections over a distance of greater than 100 feet is suspected.

The RF pulse method gives the best measure of actual system performance since it utilizes actual picture transmission methods. In the analysis, the most pessimistic conditions are sought by using line stretchers to adjust the phase for the maximum RF pulse reflection. The method fulfills the requirements for best analyzing the pertinent characteristics of the antenna system. It gives a clear, definite indication of the far-end reflection, which can be directly related to ghosting. It displays the transmission line run on a time base at the RF frequency used so that faults

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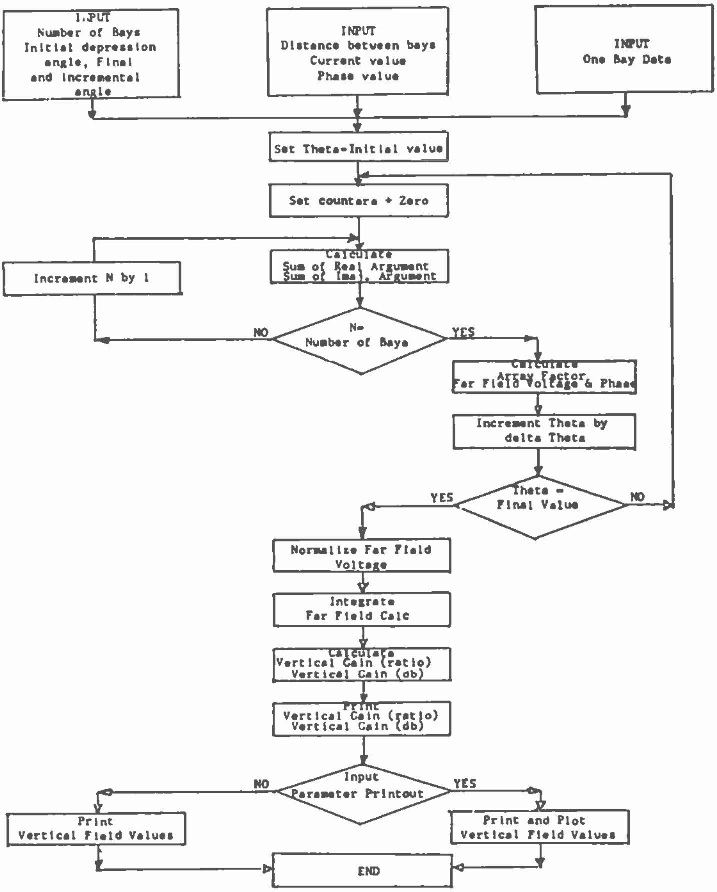

Fig. 1. Flow chart for solving vertical field patterns of antenna.

beam tilt and null fill have to be adjusted. By changing the phase of currents, illustration B shows that the beam tilt requirement is correct but that null fill is still below the required 30 percent. Illustration C is the next computer run with slight changes of data so that null fill and beam tilt are correct; a pattern that fulfills all specifications.

With the time sharing computer, the entire sequence takes less than ½ hour. With an ordinary computer, the calculating time is quite the same, but the logistics of supplying data to a

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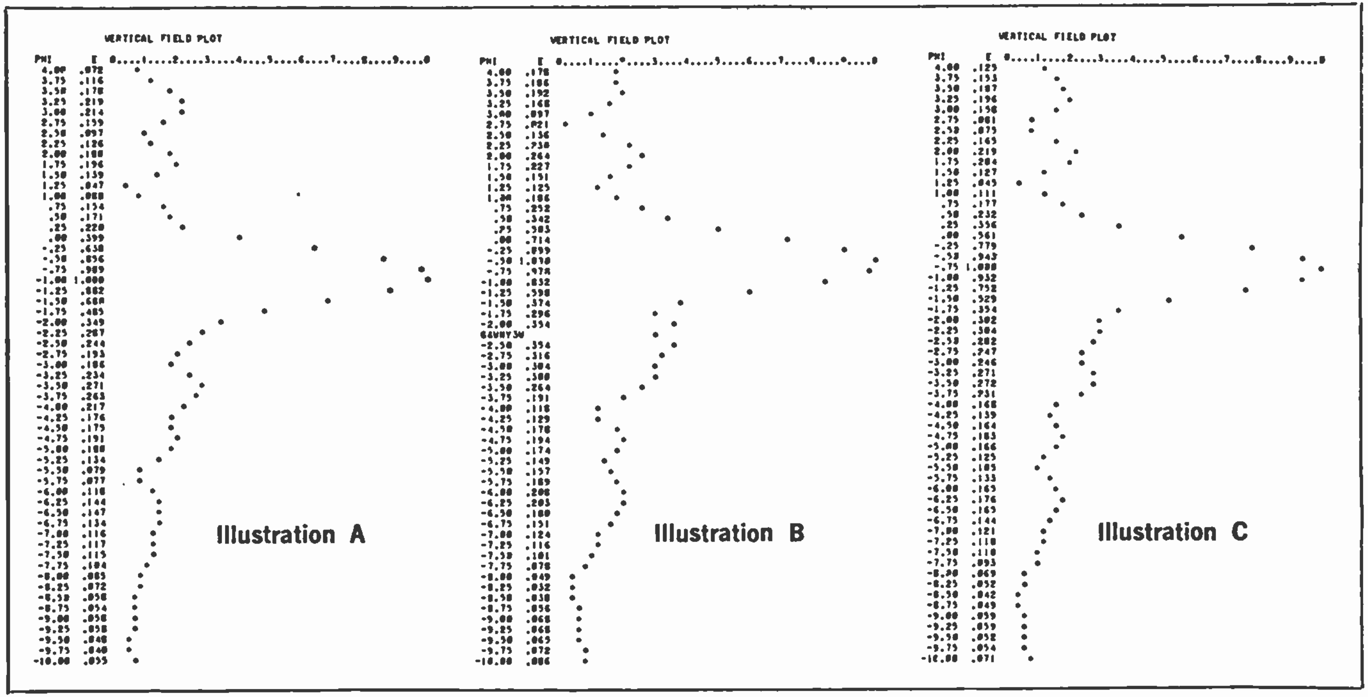

Fig. 2. Vertical field plots. Illustration A is based on experience data. Illustration B is the result after changing phase circuit once, and meets criteria more closely. One more change, illustration C, produces the desired plot.

programmer, having him batch-process it and return it to the designer, would probably take at least four days. Calculating mathematically or with vector plots would take approximately 32 hours.

Another area where the time-sharing computer is used to full benefit is in the actual production assembly of an antenna. Again a six-bay antenna is taken as an example. Once the parameters as in Illustration C of Fig. 2 have been fixed, the various subassemblies of the antenna are assembled and tested. The bottom bay is built and tested for proper moding, beamwidth, etc., and this one-bay data is compared to that one-bay data on which the entire array was originally computed. Minor differences are sometimes noted. In these cases, the new array is recalculated with the actual measured data to assure that the antenna will perform as specified. If so, assembly is continued; and if not, changes in the one bay are made until it does meet requirements. If time-sharing were not available, production delays could become impossible. Likewise, the bottom two-bay, bottom-three bay, top-bay, top-two-bay and top-three-bay patterns are computed and compared against measured results, so that when the assemblers and test men marry the complete antenna, they can have complete confidence that with only minor touch up, the antenna will meet both the specifications and shipping deadlines.

Horizontal Patterns

A few simple modifications of the basic vertical pattern program yields a program for computing the horizontal field of an antenna. Due to the ever increasing need for directionalized antennas, especially in the uhf area, the backlog of requests for pattern information could not have been met without the time-sharing computer or a great increase in experienced personnel. The flow chart for programming is much the same as that for the vertical pattern program except the designer must now account for the size of the tower or mast structure, number of panels, the azimuth and skew angles as well as the currents

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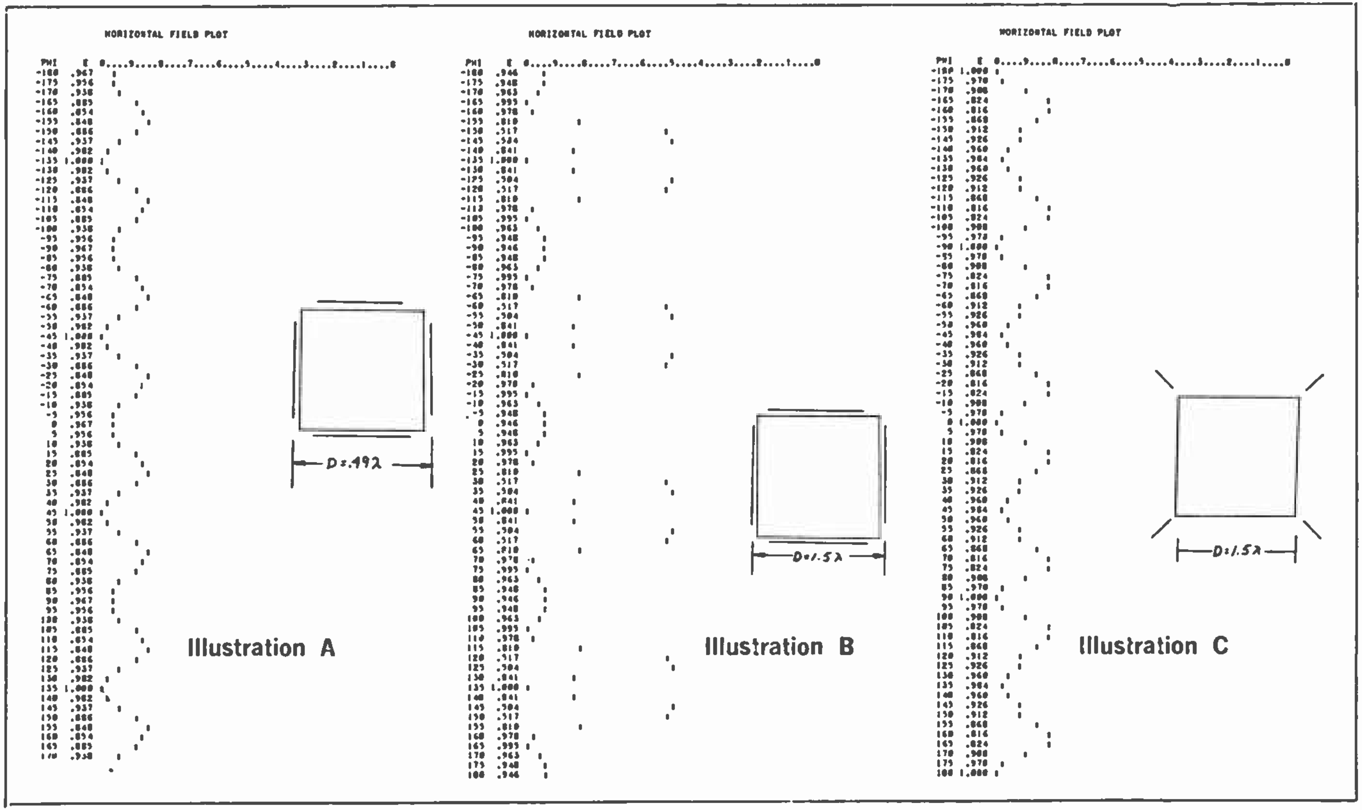

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              HORIZONTAL FIELD PLOT

PHI      E 0....9....8....7....6....5....4....3....2....1....0
-180  .967   I
-175  .956   I
-170  .938    I
-165  .885       I
-160  .854        I
-155  .840         I
-150  .886       I
-145  .937    I
-140  .982  I
-135 1.000 I
-130  .982  I
-125  .937    I
-120  .886       I
-115  .840         I
-110  .854        I
-105  .885       I
-100  .938    I
 -95  .956   I
 -90  .967   I
 -85  .956   I
 -80  .938    I
 -75  .885       I
 -70  .854        I
 -65  .840         I
 -60  .886       I
 -55  .937    I
 -50  .982  I
 -45 1.000 I
 -40  .982  I
 -35  .937    I
 -30  .886       I
 -25  .840         I
 -20  .854        I
 -15  .885       I
 -10  .938    I
  -5  .956   I
   0  .967   I
   5  .956   I
  10  .938    I
  15  .885       I
  20  .854        I
  25  .840         I
  30  .886       I
  35  .937    I
  40  .982  I
  45 1.000 I
  50  .982  I
  55  .937    I
  60  .886       I
  65  .840         I
  70  .854        I
  75  .885       I
  80  .938    I
  85  .956   I
  90  .967   I
  95  .956   I
 100  .938    I
 105  .885       I
 110  .854        I
 115  .840         I
 120  .886       I
 125  .937    I
 130  .982  I
 135 1.000 I
 140  .982  I
 145  .937    I
 150  .886       I
 155  .840         I
 160  .854        I
 165  .885       I
 170  .938    I
             .
```

```
              HORIZONTAL FIELD PLOT

PHI      E 0....9....8....7....6....5....4....3....2....1....0
-180  .946    I
-175  .948    I
-170  .963   I
-165  .995 I
-160  .978  I
-155  .810          I
-150  .517                         I
-145  .504                          I
-140  .841         I
-135 1.000 I
-130  .841         I
-125  .504                          I
-120  .517                         I
-115  .810          I
-110  .978  I
-105  .995 I
-100  .963   I
 -95  .948    I
 -90  .946    I
 -85  .948    I
 -80  .963   I
 -75  .995 I
 -70  .978  I
 -65  .810          I
 -60  .517                         I
 -55  .504                          I
 -50  .841         I
 -45 1.000 I
 -40  .841         I
 -35  .504                          I
 -30  .517                         I
 -25  .810          I
 -20  .978  I
 -15  .995 I
 -10  .963   I
  -5  .948    I
   0  .946    I
   5  .948    I
  10  .963   I
  15  .995 I
  20  .978  I
  25  .810          I
  30  .517                         I
  35  .504                          I
  40  .841         I
  45 1.000 I
  50  .841         I
  55  .504                          I
  60  .517                         I
  65  .810          I
  70  .978  I
  75  .995 I
  80  .963   I
  85  .948    I
  90  .946    I
  95  .948    I
 100  .963   I
 105  .995 I
 110  .978  I
 115  .810          I
 120  .517                         I
 125  .504                          I
 130  .841         I
 135 1.000 I
 140  .841         I
 145  .504                          I
 150  .517                         I
 155  .810          I
 160  .978  I
 165  .995 I
 170  .963   I
 175  .948    I
 180  .946    I
```

```
              HORIZONTAL FIELD PLOT

PHI      E 0....9....8....7....6....5....4....3....2....1....0
-180 1.000 I
-175  .970  I
-170  .908      I
-165  .824          I
-160  .816          I
-155  .868        I
-150  .912     I
-145  .926     I
-140  .960   I
-135  .984  I
-130  .960   I
-125  .926     I
-120  .912     I
-115  .868        I
-110  .816          I
-105  .824          I
-100  .908      I
 -95  .970  I
 -90 1.000 I
 -85  .970  I
 -80  .908      I
 -75  .824          I
 -70  .816          I
 -65  .868        I
 -60  .912     I
 -55  .926     I
 -50  .960   I
 -45  .984  I
 -40  .960   I
 -35  .926     I
 -30  .912     I
 -25  .868        I
 -20  .816          I
 -15  .824          I
 -10  .908      I
  -5  .970  I
   0 1.000 I
   5  .970  I
  10  .908      I
  15  .824          I
  20  .816          I
  25  .868        I
  30  .912     I
  35  .926     I
  40  .960   I
  45  .984  I
  50  .960   I
  55  .926     I
  60  .912     I
  65  .868        I
  70  .816          I
  75  .824          I
  80  .908      I
  85  .970  I
  90 1.000 I
  95  .970  I
 100  .908      I
 105  .824          I
 110  .816          I
 115  .868        I
 120  .912     I
 125  .926     I
 130  .960   I
 135  .984  I
 140  .960   I
 145  .926     I
 150  .912     I
 155  .868        I
 160  .816          I
 165  .824          I
 170  .908      I
 175  .970  I
 180 1.000 I
```

Fig. 3. Horizontal plot for various tower sizes.

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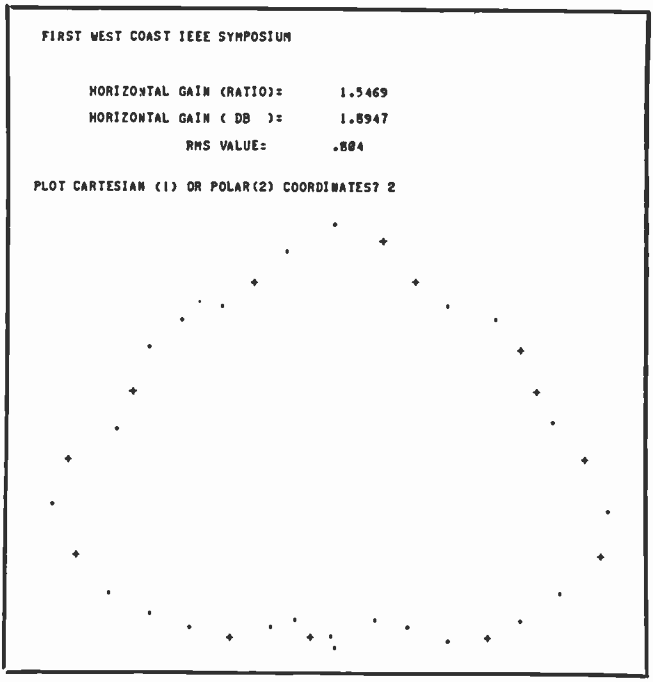
as phases to each panel. Fig. 3, A & B illustrates the effect of two otherwise equal antennas mounted on different size tower sections. Illustration C will show that even with such a large tower as in B, other parameters, such as azimuth and skew angle can be changed to bring the antenna back to tolerable limits. Again, this process would take the designer less than an hour with time-sharing with no interruption in his logical approach to problem-solving.

As an extension of the horizontal pattern program, the output may be plotted in more easily visualized polar coordinates rather than Cartesian co-ordinates as seen in Fig. 4. This polar plot may be then transferred directly to a translucent overlay and, when used with topographic maps of the area to be served, provides a very powerful tool in designing a directional pattern with a minimum of tradeoffs.



```
FIRST WEST COAST IEEE SYMPOSIUM


     HORIZONTAL GAIN (RATIO)=      1.5469
     HORIZONTAL GAIN ( DB  )=      1.8947
                RMS VALUE=        .804

PLOT CARTESIAN (1) OR POLAR(2) COORDINATES? 2
```

```
PWR GN     16:54   £  SAT 11/04/67
```

Fig. 4. Polar co-ordinates quickly produced by computer.

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```
       N       D          PHI        THETA        A        ALPHA
       1         .72      45.00      45.00       .50        .00
       2         .72     135.00     135.00      1.00        .00
       3         .72    -135.00    -135.00      1.00        .00
       4         .72     -45.00     -45.00      1.00        .00
HORIZONTAL GAIN(RATIO)=        1.5688   HORIZ GAIN (DB)        1.9557
RMS VALUE:          .7984
POWER GAIN COMPUTED ON VERTICAL GAIN OF       30.92
VERTICAL GAIN AT 0 DEGREES:        19.56
ERP CALCULATION BASED ON PWR INPUT TO ANTENNA(KW)=       27.50


                    MAXIMUM     MAXIMUM    HORIZON     HORIZON
·AZIMUTH  RELATIVE  PWR GAIN    PWR GAIN   PWR GAIN    PWR GAIN     ERP
 ANGLE    FIELD      (RATIO)     (DB)       (RATIO)     (DB)       (KW)
======================================================================
-180        1.000     48.507     16.858     30.686     14.869     1334.
-175         .963     44.976     16.530     28.452     14.541     1237.
-170         .868     36.548     15.629     23.121     13.640     1005.
-165         .770     28.784     14.592     18.209     12.603      792.
-160         .725     25.470     14.060     16.112     12.072      700.
-155         .776     29.186     14.652     18.463     12.663      803.
-150         .855     35.486     15.501     22.449     13.512      976.
-145         .939     42.784     16.313     27.065     14.324     1177.
-140         .966     45.272     16.558     28.639     14.570     1245.

- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----

  50          .479     11.110     10.457      7.028      8.468      306.
  55          .461     10.297     10.127      6.514      8.138      283.
  60          .396      7.604      8.810      4.810      6.822      209.
  65          .342      5.658      7.550      3.598      5.561      156.
  70          .341      5.645      7.516      3.571      5.528      155.
  75          .439      9.335      9.701      5.906      7.713      257.
  80          .574     15.990     12.039     10.115     10.050      440.
  85          .691     23.134     13.643     14.635     11.654      636.
  90          .759     27.910     14.458     17.656     12.469      768.
  95          .775     29.145     14.646     18.437     12.657      801.
 100          .760     28.032     14.477     17.733     12.488      771.
 105          .752     27.412     14.379     17.341     12.391      754.
 110          .766     28.426     14.537     17.982     12.548      782.
 115          .826     33.084     15.196     20.929     13.207      910.
 120          .890     38.429     15.847     24.310     13.858     1057.
 125          .951     43.834     16.418     27.729     14.429     1205.
 130          .972     45.827     16.611     28.990     14.622     1260.
 135          .981     46.663     16.690     29.519     14.701     1283.
 140          .963     45.013     16.533     28.475     14.545     1238.
 145          .933     42.260     16.259     26.734     14.271     1162.
 150          .848     34.861     15.423     22.053     13.435      959.
 155          .768     28.592     14.562     18.087     12.574      786.
 160          .718     24.989     13.978     15.808     11.989      687.
 165          .765     28.411     14.535     17.973     12.546      781.
 170          .865     36.290     15.598     22.957     13.609      999.
 175          .961     44.838     16.516     28.365     14.528     1233.
 180         1.000     48.507     16.858     30.686     14.869     1334.
```

Fig. 5. Antenna gain at all radial angles.

```
            COVERAGE AS PREDICTED BY FCC(50,50)CURVES
                        CHANNELS 7-13

                         316 KW ERP


AZIMUTH    HEIGHT ABOVE          DISTANCE    DISTANCE        DISTANCE
 ANGLE     AVE TERRAIN           PRINC CITY  GRADE A         GRADE B
 (DEG)        (FT)                 (MI)        (MI)            (MI)
---------------------------------------------------------------------
   0          1000                 38.98       45.99           63.76
  45           800                 35.05       42.79           60.12
  90           500                 27.10       35.03           51.97
 135           700                 32.71       40.67           57.83
 180          1100                 40.64       47.23           65.23
 235          1500                 46.10       51.52           70.36
 270          2000                 53.00       61.00           80.02
 315          1830                 49.98       56.13           75.26
```

Fig. 6. Computer plot of FCC (50/50) curve.

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Other Applications

Once the immediate problem of programming for a specific application and the language of the computer is at least familiar, many other applications come to mind. For instance, having calculated the vertical pattern and the vertical gain of the antenna, a modification of the horizontal pattern program will compute the antenna gain at all radial angles as in Fig. 5. Not only is the power gain ratio computed, but the ratio converted to dB and the necessary information for FCC filing such as the gain at the horizon (0 degrees) and the associated field at 0 degrees. The effective radiated power at all radials is also computed.

It is quite a simple but menial task to hand calculate the familiar FCC (50/50) curve, for the principal city, Grade A and Grade B contours for a specified erp. The time-sharing computer does this in 4 seconds, as in Fig. 6. With such instant response, it becomes a simple matter to calculate the contours at reduced erp such as in an emergency condition, and thus formulate plans for redundancy in transmitting equipment to insure an economic level of operation. The program for these calculations would take approximately half an hour to write; at least less time than it would take to plot contours at a single value of radiated power.

Computer Basics

The language of the computer is covered quite thoroughly in the literature; however, a brief review is worthwhile to demonstrate its capability.

A program is a set of directions, a recipe, that is used to provide an answer to some problem. Any problem must fulfill two requirements before it can be carried out. The first is that it must be presented in a language that is understood by the "computer." The second requirement is that it must be completely and precisely stated. This requirement

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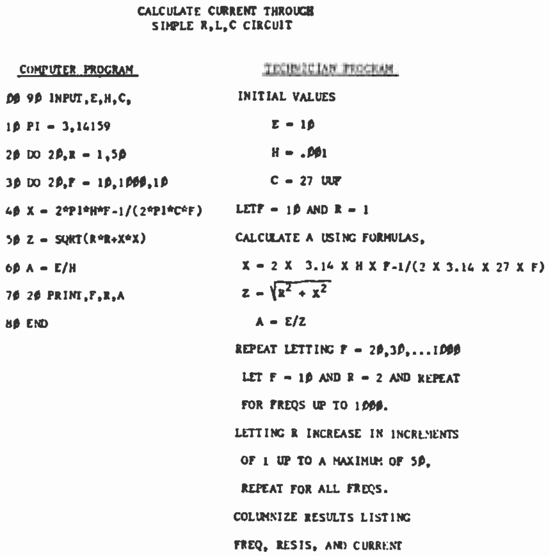

```
                 CALCULATE CURRENT THROUGH
                  SIMPLE R,L,C CIRCUIT

 COMPUTER PROGRAM                  TECHNICIAN PROGRAM

00 90 INPUT,E,H,C,                INITIAL VALUES
10 PI = 3,14159                         E = 10
20 DO 20,R = 1,50                       H = .001
30 DO 20,F = 10,1000,10                 C = 27 UUF
40 X = 2*PI*H*F-1/(2*PI*C*F)      LETF = 10 AND R = 1
50 Z = SQRT(R*R+X*X)              CALCULATE A USING FORMULAS,
60 A = E/H                         X = 2 X  3.14 X H X F-1/(2 X 3.14 X 27 X F)
70 20 PRINT,F,R,A                  Z = √R² + X²
80 END                               A = E/Z
                                  REPEAT LETTING F = 20,30,...1000
                                   LET F = 10 AND R = 2 AND REPEAT
                                   FOR FREQS UP TO 1000.
                                  LETTING R INCREASE IN INCREMENTS
                                   OF 1 UP TO A MAXIMUM OF 50,
                                   REPEAT FOR ALL FREQS.
                                  COLUMNIZE RESULTS LISTING
                                  FREQ, RESIS, AND CURRENT
```

Fig. A. Program for computing current in RLC circuit.

is crucial when dealing with a digital computer, which has no ability to infer what you mean. The computer can act only upon what you actually present to it.

The general logical steps used in solving a problem are usually formulated before writing a specific program. This is called flowcharting. Fig. A shows two programs, one that a computer could follow, another that an average technician could wade through. The problem is to solve the current flowing through a simple R-L-C series circuit with different values of resistance from 1 to 50 ohms at frequencies between 10 and 1000 Hz. It may be noted that the computer language and directions written in Fortran are even simpler for the technician to understand and manipulate.

The flow chart for such a problem is shown in Fig. B. Here the logic is formalized even though specifics (such as formulas) are not. Once a logical approach can be made to a problem, the computer detail language can be mastered. It becomes quite evident that the DO LOOP is the most powerful tool in the computer language. A range of variables

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can be set and the computer will calculate the results swiftly and accurately. A computer must be given explicit instructions for each step toward the solution. You need to know the numerical methods as well as a computer language.

The time-sharing computer—the type used in the applications discussed in this article—is a relatively new concept in computer service. Time-sharing, or the simultaneous access to a central computer system from many remote locations, is ideally suited for solutions of problems and for program updating and editing.

The master control console and remote consoles are connected to the computer system through telephone lines—either private, PBX extensions or public facilities—using

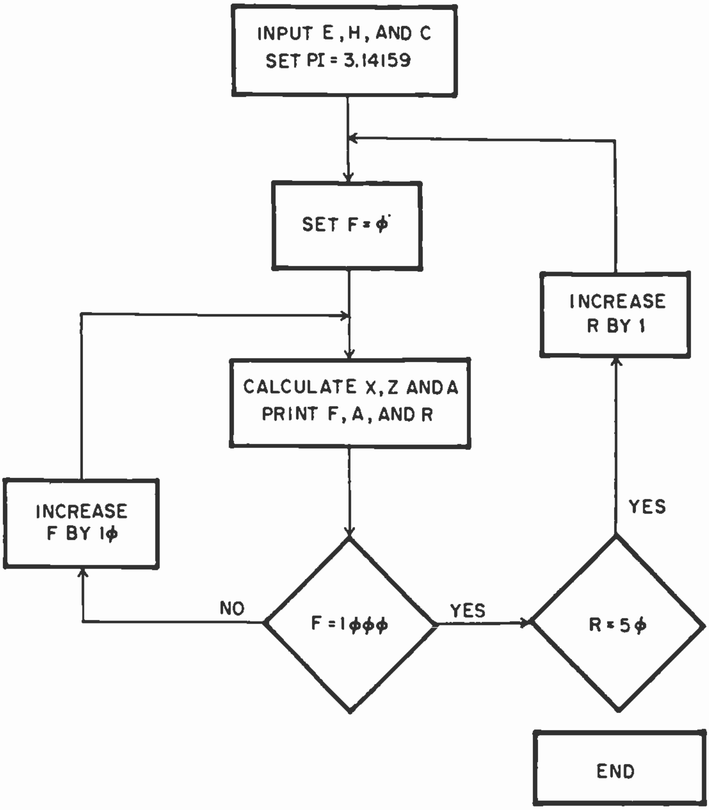

Fig. B. Flow chart for solving current in RLC circuit.

Data-Phone service or TWX service on a dialup basis. Up to 40 remote consoles can be accommodated simultaneously through the automatic switching system. This is possible because the response of the computer and the response of the printing units have at least one order of magnitude time differential. The computer assigns priority to all sequences so that even with all consoles in use, delays are nominal. A typical sequence for an engineering program might be 25 seconds of computer time, 3 minutes for data printout and a maximum of 30 seconds "holding" time while the computer is time-shared to a different problem.

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DA Antenna Systems for FM

John H. Battison

THE FCC has long permitted AM broadcasters to use directional antennas, but prior to the FM freeze during the early 60s, very few FM stations were allowed this privilege.

Before a station manager decides to use a directional antenna, he should become familiar with the pertinent parts of the FCC Rules. Two deal specifically with such antennas and their uses (see box). A typical application under the classification of improving service might be a situation where the proposed principal city is close to a mountain or similar shadowed area and there is no advantage in radiating toward the blank mountain side. The other approved application is for the purpose of using a specific antenna site. If an applicant owns an existing tower or high building, or even another class of broadcast station, and wishes to use this as the supporting structure, a directional antenna might be required in order to limit the combination of height and power in a specific direction to conform with the Rule regarding power and height combinations.

Technical Requirements

Technical requirements are spelled out in detail in FCC Rule 73.316(c),(d) subparagraphs 1 through 3. Certain portions are particularly noteworthy.

In most cases where a directional FM antenna is used, the engineering portion of FCC Form 301 will be completed by the applicant's consulting engineer.

However, sometimes a well qualified chief engineer can handle this work. If this is the case, these points should be observed. The application must completely describe the antenna and explain the method of obtaining directivity. You must provide a radiation pattern showing free space field intensity at one mile in mv/m for the horizontal plane[1] and data on vertical radiation between plus

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[1] The FCC prefers to have all data in dbk. rather than kw. See Fig. 6.

and minus 10° above the horizontal plane. This data must not show any undesirable radiation in the vertical plane between these limits. Finally, the name, address and qualifications of the engineer making the calculations must be given. The antenna information required above may be computed or measured, but you must include a full description of your computations and methods of measurement.

Station managers with experience in AM directional antennas will notice a big difference—a consulting engineer must provide the technical data supporting the directional antenna system. This is because there are so many variations in AM DA patterns that every installation is different. The limits of radiation are very rigid in FM DA systems; therefore, it is possible for a manufacturer to have FCC required technical data for his whole line of FM antennas. There may be the exception, of course, where an exotic pattern is required—and can be justified—but this will be rare. The manufacturer will furnish complete engineering data for paragraph (d) of this Rule.

Condensation of FCC Rules Governing FM DAs

Rule 72.213 (c): In the case of short-spaced stations, maximum radiation may be used—provided that the maximum power radiated in the short-spaced direction is not in excess of the amount allowed non-directionally. No more than the maximum permissible power for the class of station concerned may be radiated in any direction, and the power increase off the radial separating the two stations must not be greater than 2 db for every 10° of change in azimuth. (See Fig. 1.)

Rule 73.316 (c): A directional antenna is considered to be any antenna that obtains a deliberate non-circular pattern for the purpose of improving coverage or using a particular site. It may not be used to circumvent the minimum mileage separation requirements. A ratio of 15 db maximum to minimum radiation will not be accepted. The hypothetical patterns in Fig. 1 comply with this rule.

Operating Directional Antennas Systems

The horizontal field patterns for three operating FM DA systems are shown in Figs. 2, 3, and 4. WJZZ, Bridgeport, Conn., Fig. 2 uses a Jampro J 6b/6V/DA; WGIR-FM, Manchester, N. H., Fig 3, plans to use a Collins 37M-DA and WTFM, Lake Success, N. Y., Fig. 4, will use an Alford 7615.

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These DA's are shown because they represent a cross section of new stations; there are many older operations, but they were installed before the present DA regulations went into effect, and as a result do not have to conform with the new Rules.

Engineering Considerations

The application procedure for an FM directional antenna system is far simpler than that for an AM directional. This is due to the difference in physical arrangement. Because of the small size and often one-piece construction of an FM antenna, it can be adjusted and tuned at the factory for its desired

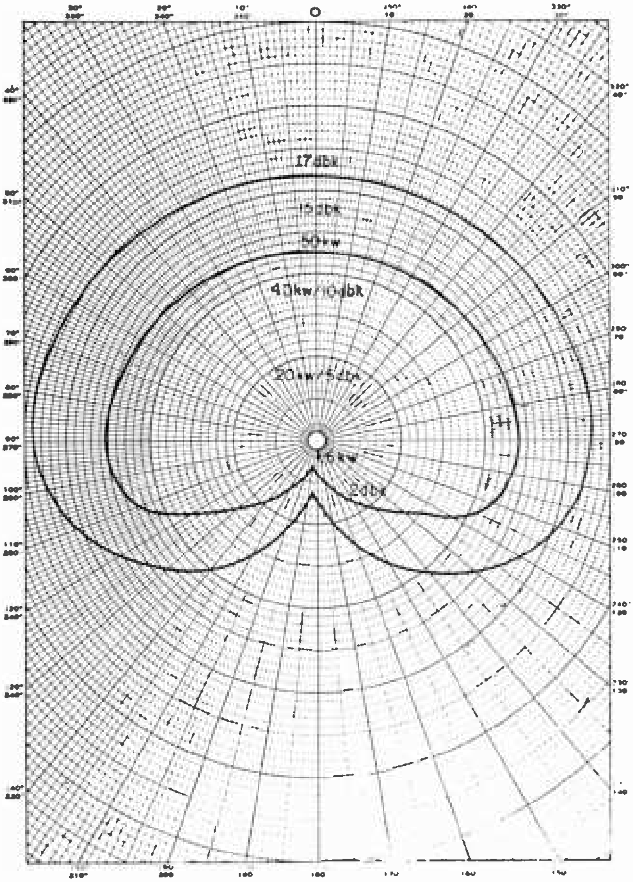

Fig. 1. An illustration of the relationship between power in kw and dbk for a given pattern.

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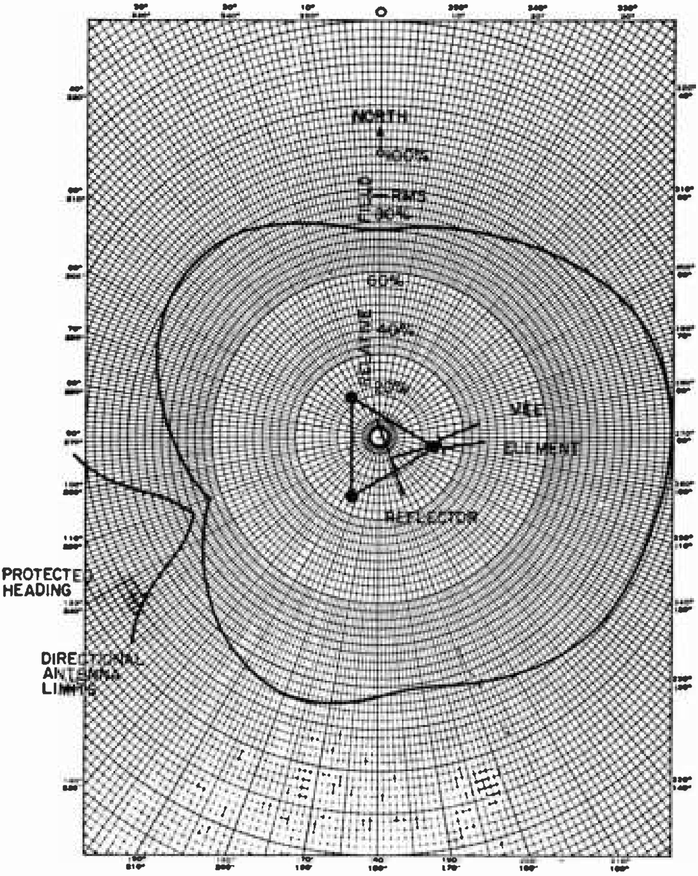

Fig. 2. Predicted antenna horizontal field plot for WJZZ, Bridgeport, Conn.

directional pattern, and installed in the field with reasonable certainty that the pattern will be correct—provided that the antenna is properly oriented.

The FCC has inserted into the Rules a provision that might go unnoticed by many readers. It says "a submission must be made by a qualified surveyor that the antenna has been properly oriented at the time of installation." This means that a surveyor must measure the azimuth of the antenna when it is installed, probably by means of a mark on the base of the antenna as it is being mounted on the tower, or in a manner which will assure the Commission that the antenna is properly oriented.

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Proof of Performance

Measurements are required in the horizontal as well as the vertical plane. The 360° horizontal radiation pattern must be shown. There is no formal way in which the FCC requires the proof to be measured or submitted, provided the material is there and is correct.

The Rules call for a proof to be made in the field, or by the manufacturer. The latter is far easier and less expensive for the applicant, although such activities do tend to remove the bread from the mouths of consulting engineers. However, the Commission requires that the manufacturer make his measurements with the antenna mounted on the actual tower, or a replica thereof, together with all lines, ladders,

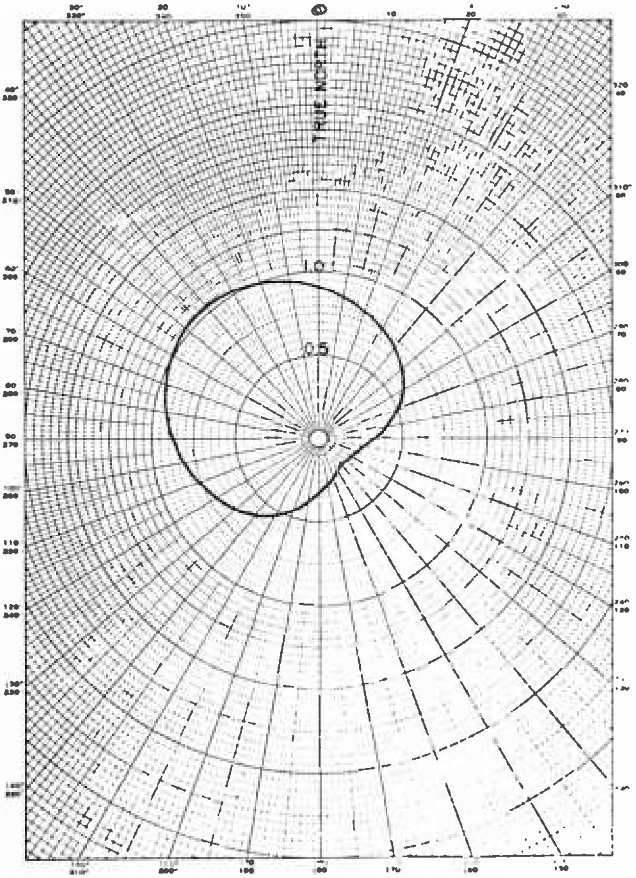

Fig. 3. DA horizontal pattern for WGIR-FM, Manchester.

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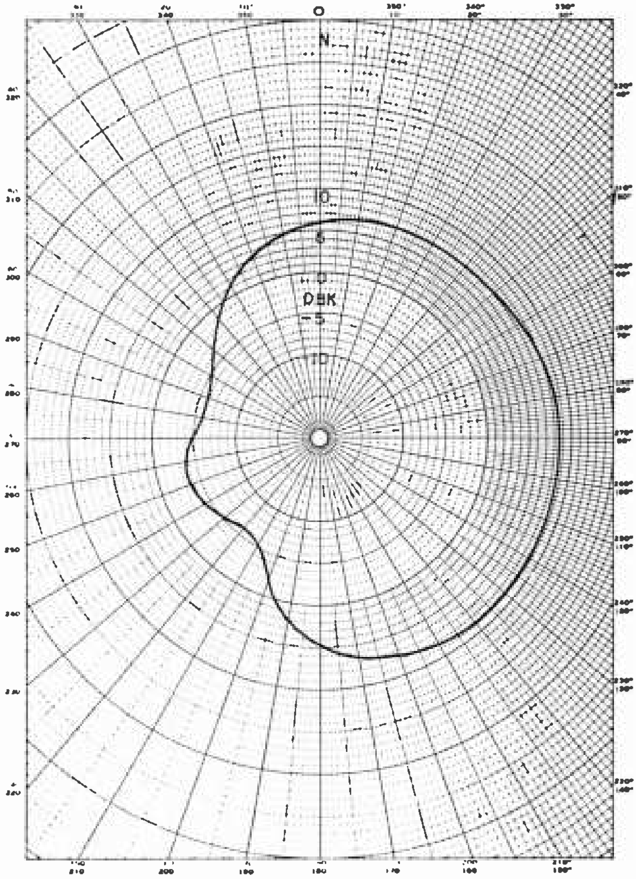

Fig. 4. DA horizontal pattern for WTFM, Lake Success.

lights, etc., that will be used in the final installation. The reasoning behind this is obvious. However, the word *tower* should not be taken to mean the 300-foot high mounting structure, but to a section of tower or pole on which the antenna is secured prior to mounting on the actual tall tower. The old rule which required measurements along eight radials with a pen recorder is out! Today, directional antennas for FM use are as simple to specify and use as non-directional antennas.

Management Considerations

FM directional antenna costs should not be more than 10% of general equipment costs. Their construc-

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tion is simple and, in many cases, undetectable from non-directional antennas. DA arrays are as simple to install as non-directionals, except for proper orientation. Unlike AM DAs only one tower or supporting structure is needed.

The average FM station now operating at full power, will not have to consider directional operation. One application of the FM directional is in the case of a short-spaced station which wants to increase power. Then it may be necessary to use a directional antenna to control radiation in the short-spaced direction. Occasionally an operating FM station will discover that coverage in a given direction is not what it might be for various reasons such as terrain. In

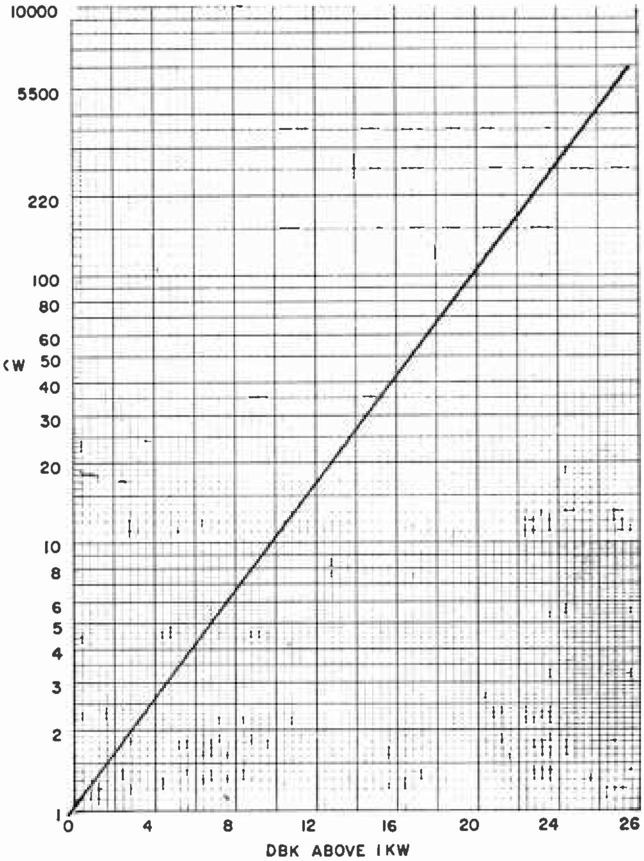

Fig. 5. Graph showing relationship between power and dbk above 1 kw.

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this case a directional antenna will achieve the desired coverage. FCC Rules governing the proposed operation must be adhered to. Often an existing FM antenna can be modified, depending on the design, to give a directional pattern by means of fairly simple phasing alternations. When this is done, field pattern measurements will have to be made with the antenna mounted on the station's tower, and this can run into several thousand dollars, depending on the complexity of the measurements. Generally, if the antenna in use has been amortized, and the station is about ready for a new one it would be better and cost less in the long run to install a new one that has been factory-tuned, adjusted, and furnished with a proof of performance.

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Dual Antenna Polarization Tests

During the past decade there has been a great deal of interest directed toward achieving more uniform coverage from FM broadcast stations through the use of dual polarized antennas. Tests conducted using facilities at WNHC-FM, New Haven, Conn. were reported in CCIR Study Group X, Document USPC-BC 22, dated Dec. 15, 1964. The antenna feed system was modified to provide for radiation of horizontally polarized signals only, vertically polarized signals only, or a combination of the two. Extensive measurements were made in both Hartford and New Haven to determine the effects of dual polarization on reception in the service area, and also upon the interference potential of dual polarized transmissions.

Transmitting Equipment Used

The transmitting antenna consisted of a Jampro 8-bay horizontally polarized section mounted on one leg of a 100-meter self-supporting tower and an 8-bay vertically polarized section mounted on an adjacent leg. The two sections were separated by approximately 4 meters, and fed through a 50/50 power splitter with individual feed lines originating from separate junction boxes. A coaxial switch was installed between the power splitter and the vertically polarized antenna junction box so that power could be switched into a dummy load. It was therefore possible to make field intensity measurements with horizontally polarized antenna excitation only or both horizontally and vertically polarized antenna excitation. The effective radiated power in the horizontal plane was 10 kw, and in the vertical plane 9.5 kw. (The gain of the vertically polarized antenna was slightly lower, thus accounting for the difference.) The VSWR of the system was 1.15, and remained the same for all modes of operations.

During the latter portion of the tests, the coaxial switch was moved to permit power to be switched from the horizontally polarized antenna to a dummy load. Thus, it was possible to make measurements resulting from vertically polarized radiation alone.

Receiving Equipment Used

To assure accuracy of the measured fields, it was necessary to design a dual polarized receiving antenna that would measure the horizontal and vertical fields simultaneously. The design of this antenna consisted of a horizontal balanced dipole mounted on the bottom skirt of a coaxial vertical dipole. It was necessary to bring the coaxial cables from the dipole down through the bottom skirt of the vertical antenna to eliminate radiation from currents flowing in the coaxial sheath. Tests on this antenna indicated 37 db decoupling between the horizontal and vertical sections.

Simultaneous horizontal and vertical fields were recorded by using two VHF field intensity meters to feed two chart recorders. The antenna was raised to a height of 10 meters during all measurements. To assure a homogeneous field, measurements were recorded by making runs varying in length from 30 to 150 meters, depending upon available clearances.

Measurements of the service area field were made with the same equipment, except that four spot measurements were made at each location, instead of a continuous chart recording, because of limited clearances in populated areas.

Close-in Measurements

A number of close-in measurements (2 to 5 miles) were made to determine the extent of vertical component radiation from the horizontally polarized antenna. Line-of-sight locations, which had Fresnel clearance, were chosen for these measurements. The vertically polarized component measured from 14.9 to 32.0 db below the horizontally polarized component. The average of these locations showed the vertical field to be 22.2 db below the horizontal field. (See Table I).

TABLE I—Vertically Polarized Component Transmitted From The Horizontally Polarized Antenna

Measurement No.	Horizontal Field (mv/m)	Vertical Field (mv/m)	DB Difference
1	83.0	2.5	32.0
2	79.0	2.8	29.0
3	72.0	2.2	30.3
4	84.0	3.8	26.9
5	78.0	14.0	14.9
6	90.0	12.0	17.5
7	120.0	11.5	20.3
8	38.5	5.0	17.8
9	37.5	2.7	22.9
10	47.0	4.0	21.4
11	54.0	7.0	17.8

A second set of measurements was made at these same points to determine the extent of horizontal component radiation from the vertically polarized antenna. It is interesting to note that the horizontally polarized component measured from 13.8 to 38.8 db below the vertically polarized component, and the average of these locations showed the horizontal field to be 23.0 db below the vertical field. (See Table II.)

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TABLE II—Horizontally Polarized Component Transmitted From The Vertically Polarized Antenna

Measurement No.	Horizontal Field (mv/m)	Vertical Field (mv/m)	DB Difference
1	4.3	60.0	32.1
2	3.5	59.0	36.6
3	7.4	53.0	17.2
4	3.5	54.0	34.6
5	8.6	43.0	14.0
6	4.0	38.0	19.6
7	2.3	43.0	38.8
8	6.2	52.0	18.4
9	3.0	39.0	29.6
10	5.8	40.0	16.8
11	7.2	34.0	13.8
12	8.8	48.0	14.6

Far Field Measurements

Far field measurements were made starting at the 1-mv/m contour to determine the effect on the horizontal field when equal amounts of power were fed to the horizontally and vertically polarized sections. At each of the eight locations chosen, chart recordings were made of the horizontally and vertically polarized fields being radiated from the dually polarized antenna, from the horizontally polarized antenna only, and from the vertically polarized antenna only. The fields were recorded while the receiving vehicle was moved over a distance of from 50 to 150 meters with the receiving antenna at a height of 10 meters. The most distant recordings were made at a location where the horizontal field measured approximately 70 microvolts. (See Table III.)

Service Field Measurements

To determine the effect of the addition of the vertically polar-

TABLE III—Far Field Measurements

		DUAL ANTENNA		HORIZONTAL ANT.		VERTICAL ANT.	
Point No.	Distance (miles)	Horizontal Field (mv/m)	Vertical Field (mv/m)	Horizontal Field (mv/m)	Vertical Field (mv/m)	Horizontal Field (mv/m)	Vertical Field (mv/m)
1	27.0	.980	.750	.940	.110	.120	.860
2	33.4	.850	.300	.820	.110	.045	.360
3	42.3	.320	.170	.350	.065	.032	.185
4	46.9	.260	.090	.270	.030	.024	.100
5	52.3	.310	.150	.280	.040	.018	.180
6	55.6	.070	.038	.080	.028	.007	.031
7	57.4	.080	.034	.080	.012	.010	.036
8	61.5	.070	.030	.070	.010	.008	.030

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TABLE IV—Hartford Area Measurements

	DUAL ANTENNA		HORIZ. ANTENNA		VERT. ANTENNA	
Point No.	Horizontal Field (mv/m)	Vertical Field (mv/m)	Horizontal Field (mv/m)	Vertical Field (mv/m)	Horizontal Field (mv/m)	Vertical Field (mv/m)
A1	.360	.720	.330	.095	.079	.740
B1	.960	.995	.935	.140	.290	1.100
D1	.260	.245	.235	.038	.032	.235
F1	.370	.190	.280	.034	.070	.210
G1	.730	.360	.650	.090	.086	.340
B2	.580	.370	.510	.060	.130	.300
E2	.750	.890	.780	.190	.280	.770
A3	.280	.190	.240	.040	.064	.110
B3	.250	.240	.220	.050	.090	.180
C3	.960	.720	.900	.140	.130	.455
D3	.260	.089	.170	.038	.090	.120
E3	.740	.530	.670	.112	.180	.490
G3	.295	.215	.240	.029	.070	.250
A4	.560	.420	.560	.104	.057	.340
B4	.120	.160	.138	.036	.044	.120
C4	.160	.130	.150	.026	.032	.100
D4	.210	.190	.190	.022	.064	.160
E4	.500	.400	.490	.120	.150	.330
G4	.745	.320	.650	.093	.120	.230
A5	.350	.300	.300	.078	.045	.180
B5	.490	.590	.480	.080	.083	.525
F5	.360	.335	.330	.073	.045	.298
G5	.395	.420	.350	.047	.110	.370
C6	.350	.610	.370	.057	.095	.570
D6	.430	.390	.400	.065	.080	.355
A7	1.640	1.100	1.630	.050	.140	1.240
B7	.820	.510	.850	.150	.093	.360
F7	.380	.400	.420	.065	.100	.340
G7	.200	.205	.180	.018	.056	.210

ized field in the service areas of WNHC-FM, a number of measurements were made in the Hartford and New Haven areas. The Hartford area is approximately 25 miles from the transmitting site. The transmission path is over terrain which produces varying degrees of shadowing starting with practically line-of-sight in West Hartford to moderate shadowing in East Hartford. The dual polarized antenna is mounted on the north face of the tower, toward the city of Hartford.

A grid system was laid over a city map of the Hartford area so that most of the 49 grid points fell in the populated area shown on Map No. 1. Measurements were recorded at 29 of these grid points, with the greatest concentration in the downtown area. The locations were chosen by going to the grid point and then finding the nearest site where the measuring antenna could be raised to 10 meters with sufficient clearance to

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TABLE V—New Haven Area Measurements

	DUAL ANTENNA		HORIZ. ANTENNA		VERT. ANTENNA	
Point No.	Horizontal Field (mv/m)	Vertical Field (mv/m)	Horizontal Field (mv/m)	Vertical Field (mv/m)	Vertical Field (mv/m)	Horizontal Field (mv/m)
A1	1.950	3.100	2.500	0.210	1.360	2.900
B1	3.100	5.250	2.375	0.420	1.160	5.200
C1	2.650	10.900	1.900	0.450	1.310	8.400
D1	0.960	0.890	0.415	0.110	0.810	1.230
E1	6.600	20.250	6.100	0.460	5.600	20.750
F1	1.600	6.180	0.865	0.103	1.500	6.230
C2	3.100	11.300	1.640	0.320	2.180	10.750
D2	1.250	3.500	0.680	0.135	0.790	4.500
E2	2.560	8.750	1.425	0.265	1.850	10.200
B3	4.450	6.600	4.300	0.480	1.880	10.100
C3	1.650	4.480	0.850	0.131	0.990	5.730
F3	1.100	5.100	0.280	0.056	1.000	5.650
A4	1.950	1.950	1.900	0.150	0.360	2.350
B4	1.100	4.330	0.805	0.110	0.695	4.880
E4	6.150	13.500	5.500	0.580	0.800	15.100
F4	2.080	5.300	0.640	0.070	1.650	5.620
A5	6.430	4.280	4.850	0.370	1.230	3.730
B5	4.180	4.150	1.100	0.080	2.350	4.130
E5	1.060	7.930	1.710	0.130	0.980	7.930
F5	2.100	15.480	1.450	0.115	2.200	17.150

move the vehicle approximately 20 meters. At each of these locations, four spot measurements were recorded with the vehicle being moved about 5 meters between spots. Measurements were recorded while transmitting with the horizontal and vertical antenna, the horizontal antenna only, and vertical antenna only. The four spot measurements at each location were averaged and tabulated in Table IV.

Similar measurements were made in the New Haven area, approximately 9 miles from the transmitting site, as shown on Map No. 2. New Haven is located at the base of a number of mountains which end abruptly and almost immediately before entering Long Island Sound; thus, the transmission path from WNHC is over very rough terrain. Severe shadowing is evident in some areas, while in some parts of the city farther south, line-of-sight paths were obtained. The transmitting antenna, however, is mounted on the opposite side of the tower from New Haven. A map system with 30 grid points was used. Measurements recorded at 20 points in populated areas appear in Table V.

Summary of Results

As shown in Table III, measurements made at distances from 27 to 61.5 miles from the transmitter, using alternately dual polarization and horizontal polarization, show very little improvement in the horizontally polarized compo-

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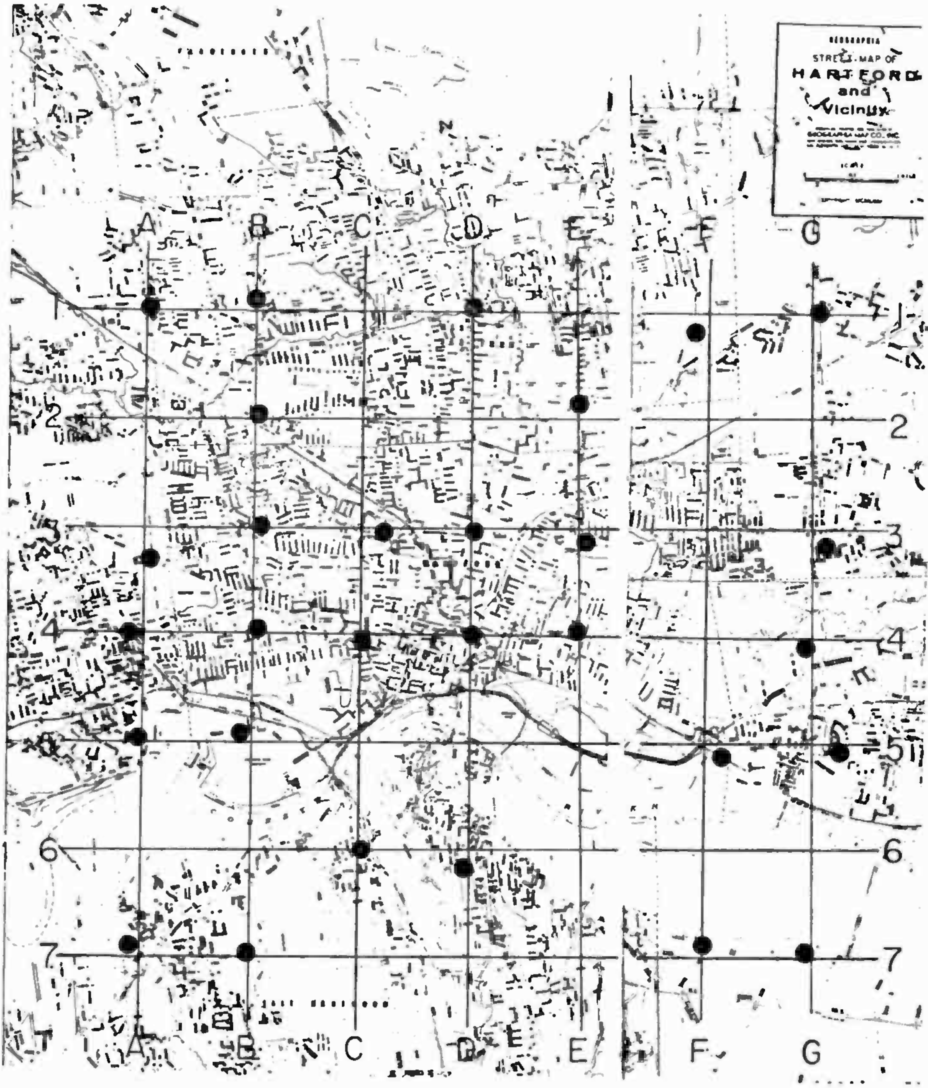

Map. 1. Locations of Measurement Points in Hartford area.

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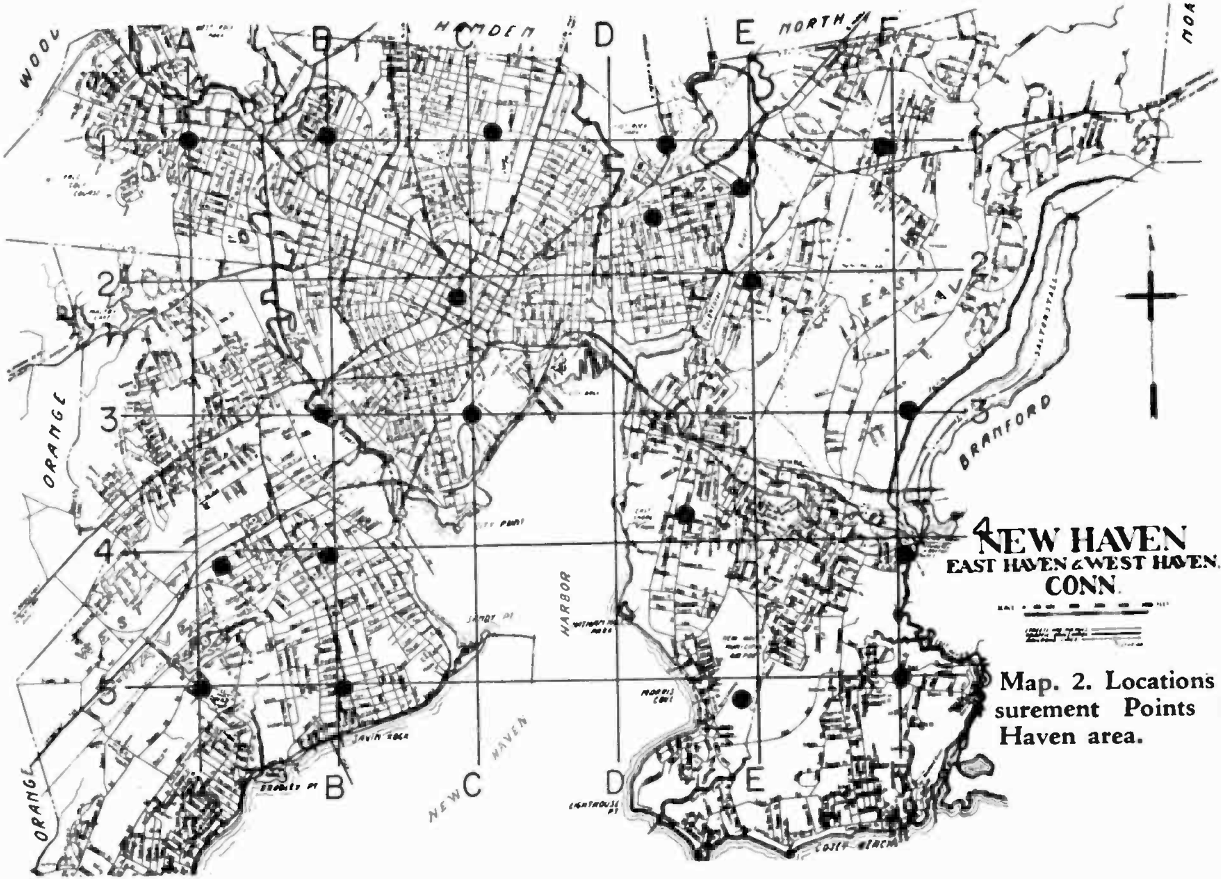

Map. 2. Locations of Measurement Points in New Haven area.

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nent received at the eight monitoring points. At distances greater than 55 miles, very little change is observed. Up to 50 miles, on the other hand, a vertically polarized component on the order of 100 microvolts or better is established. This signal would be of considerable advantage to listeners employing automobile FM receivers with a whip antenna.

The measurements given in Table IV, while not made in areas which are line of sight from the transmitter, were not substantially affected by shadowing. Consequently, the plane of polarization of the received signal should be substantially the same as transmitted. This, apparently, is the case. Although the relative magnitudes of the dually transmitted vertical and horizontal components appear to be about equal, there was little increase in the horizontally polarized field over that measured when the horizontal antenna alone was in use. This, of course, would be the case if no rotation of the plane of polarization were to occur. At the same time, there is a substantial vertically polarized field throughout the Hartford area, which would indicate that car radios employing whip antennas or home radios that employ so-called "rabbit ear" antennas, should receive a substantially better signal due to the presence of the vertical component.

Table III presents a different picture, however. The measurements, in general, were made in areas shaded to a greater or lesser degree by the rocky formations which lie between the transmitting antenna and New Haven. In 90% of the locations the dual antenna provides a horizontally polarized field measurably improved over that received when using the horizontal transmitting antenna alone. This improvement is most noticeable in those areas where the magnitude of the fields indicates substantial shadowing—for example, points D2, D1 and C2 on map No. 2.

Reference to the New Haven measurements shows that at 18 out of the 20 locations measured, the *horizontal* component of the field *increased* when vertical polariza-

Conclusions Drawn From Tests

1. In the absence of shadowing or diffraction effects, transmission of a vertically polarized component adds very little to the signal received on a horizontally polarized receiving antenna.
2. When receiving antennas having a substantial vertical component are employed, a correspondingly substantial improvement in overall service can be expected.
3. The vertical component appears to have substantial value for users of automobile FM radios, both in town and at distances up to 50 miles from the transmitter.
4. In the presence of shadowing or diffraction effects (see New Haven measurements), shadowed areas which have very low signal strength during horizontally polarized transmissions receive substantially improved horizontally polarized components when dual polarization is employed.

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tion was added. At 7 of the 20 locations, the *vertical* field *increased* with the addition of horizontally polarized radiation. It should also be noted that at 10 of the 20 locations, the horizontally polarized field measured with only the vertical transmitting antenna operating, was of higher intensity than the horizontally polarized field measured when only the horizontal antenna was excited. At 16 of the 20 locations, the vertical component of the measured field was of higher intensity than the horizontal component when radiating with both vertical and horizontal antenna sections. In New Haven, as in Hartford, the presence of the strong vertically polarized field would substantially improve the service rendered to FM receivers with indoor, or "rabbit ear," antennas.

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Improve FM Coverage with Dual Polarization

Harry A. Etkin

FM stations radiating a horizontally polarized signal experience a definite loss in transmission effectiveness because of the vertically polarized whip or line cord receiving antennas used with many modern FM sets. Transmission of a vertically polarized signal, in combination with a horizontal signal, will considerably improve coverage of the authorized service area. The advantages of a dual polarized FM antenna system are:

1. Increased signal pickup by vertical car whip antennas.
2. More signal into home FM receivers with line cord and built-in antennas. (These antennas are widely used in console FM combination radios.)
3. More signal into transistor portable FM receivers with whip antennas.
4. Increased signal level in the null areas of the horizontal antenna.
5. Improved reception in multipath areas; more listeners in hilly terrain.
6. Improved reception of monaural, stereo, and SCA signals.

This article will provide the FM broadcaster with detailed electrical and performance characteristics for the proper installations of a dual polarized antenna system.

Technical Considerations

The addition of vertical polarization is not a cure-all in providing increased coverage. In some cases the addition of vertical antennas will not increase signal in a deadspot for the horizontal system. Vertical radiation will not cure the multipath effect, but used in conjunction with the horizontal system, improved reception in areas with multipath problems often results. The dual system also does not increase signal pickup of a horizontally polarized receiving antenna.

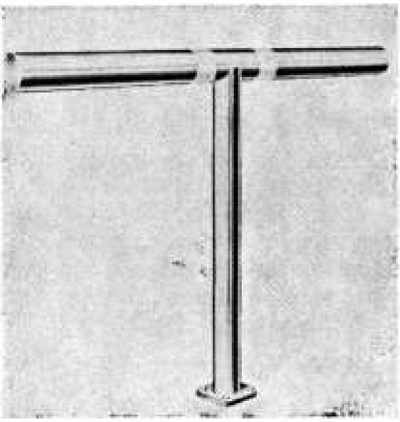

Fig. 1. Basic folded dipole.

Broadcast engineers should note that operation of both types of

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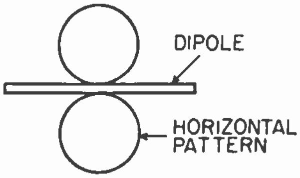

Fig. 2. Pattern for a half-wave horizontal dipole.

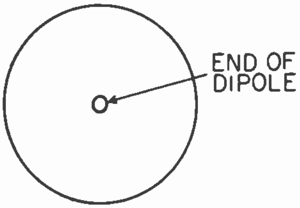

Fig. 3. End view pattern of a half-wave horizontal dipole.

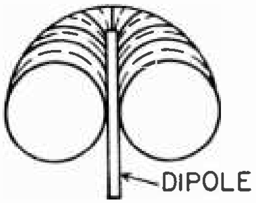

Fig. 4. Pictorial radiation pattern for a vertical dipole (doughnut pattern).

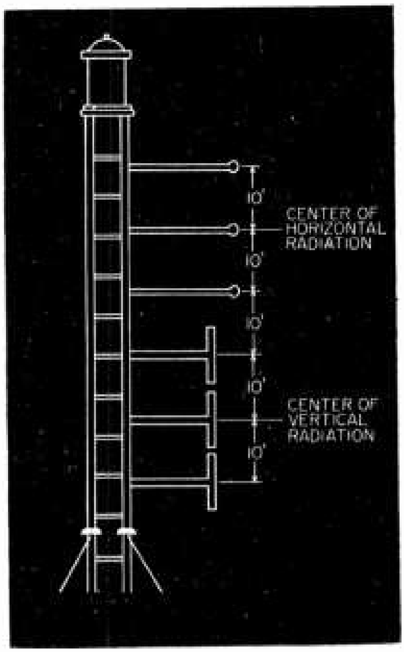

Fig. 5. Drawing of stacked dual polarized antenna system.

antenna systems does not degrade the horizontally polarized ERP when the vertically polarized antenna is installed. Existing FCC Rules authorize radiation of the same amount of power in the vertical mode. For example, a Class B station having a 10-kw transmitter and a 4-bay horizontally polarized antenna with a gain of 4 will radiate a horizontal ERP of approximately ~~30~~ 40 kw. A vertical antenna system could therefore radiate an equal 30 kw in the vertical mode. 40

Horizontaly polarized vee, ring, and circular shaped radiating antenna elements have earned an excellent reputation, and their technical characteristics are well known. The vertically polarized antenna is basically a folded dipole, usually constructed of copper tubing or transmission line copper (see Fig. 1).

These dipole elements, or bays, are spaced approximately one wave-length apart. The bays in some makes of antenna are then fed in phase along a transmission line that will support from one to sixteen elements connected in parallel. The impedance of each dipole is made greater than the transmission line impedance by the number of elements. Thus, the input impedance of the antenna must be 50 ohms to match the transmission line impedance following the standard Ohms Law formula for parallel impedance ($1/Zin = 1/Z_1 + 1/Z_2 + \ldots\ldots 1/Z_n$).

The standard FM antenna is a modified half-wave horizontal dipole. Fig. 2 shows the horizontal radiation pattern, the typical figure 8. According to the position of the antenna it is possible to radiate a signal which is either vertically or horizontally polarized. When the dipole is horizontal, the signal is horizontally polarized; when the dipole is in a vertical plane the radiated signal is vertically polarized.

To produce a circular horizontal radiation pattern, the most common antennas in use today are the circular ring and vee type. These antennas will radiate a uniform omnidirectional circular horizontal polarized pattern. The circular dipole is usually end-loaded to provide a more uniform current along its length. The appearance of the radiation pattern, when viewed from an end of the dipole, is shown in Fig. 3. The circular or ring antenna is simply a folded dipole bent in a circular shape, which gives a circular horizontal

FCC RULES ON DUAL POLARIZATION

The FCC Rules and Regulations, Volume III—January, 1964, Part 73—Radio Broadcast Services, designates in Paragraph 73. 310 FM technical standards that the definition for effective radiated power is as follows:

> The term "Effective Radiated Power" means the product of the antenna power (transmitter output power less transmission line loss) times (1) the antenna power gain, or (2) the antenna field gain squared. When circular or elliptical polarization is employed, the term "effective radiated power" is applied separately in the horizontal and vertical components of radiation. For allocation purposes, the effective radiated power authorized is the horizontally polarized component of radiation only.

It should also be noted that Paragraph 73. 316, Antenna Systems, sub-paragraph (a) specifies that:

> It shall be standard to employ horizontal polarization; however, circular or elliptical polarization may be employed if desired. Clockwise or counterclockwise rotation may be used. The supplemental vertically polarized effective radiated power required for circular or elliptical polarization shall in no event exceed the effective radiated power authorized. The rules therefore provide that the amount of power authorized for horizontally polarized radiation may also be radiated in the vertical mode. Under Paragraph 73. 257, FM broadcast stations are required to apply to the FCC for a construction permit, requesting authority to install a vertically polarized antenna as addition to the existing horizontally polarized system.

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field pattern. The vee antenna is a folded dipole formed into a truncated vee shape. As the number of horizontal bays is increased, the vertical radiation beamwidth is decreased or "squeezed down." To step up the vertical radiation pattern, vertical antenna elements must be used in combination with the horizontal elements.

Using a half-wave dipole in the vertical mode, the horizontal becomes the vertical and the radiation pattern is circular, like the doughnut pattern in Fig. 4.

Installation Details

There are three basic configurations to be considered in the installation of dual polarized antenna systems. The first, shown in Fig. 5, is the stacked arrangement, with the horizontal elements mounted above the vertical elements. Notice that the center of vertical radiation is lower than the center of horizontal radiation. A large tower section must be used for mounting the complete antenna system.

The second method, shown in Fig. 6, is the "back to back" mounting, which distributes the weight of the dipoles equally. The vertical antenna elements are mounted on one side of the tower and the horizontal elements on the opposite side, at the same height above ground.

The third method is interposing or interlacing. This system of mounting places the vertical antenna in the same plane as the horizontal antenna with the vertical elements between the horizontal antenna sections (see Fig. 7). Notice that less tower mounting space is required than for the stacked system in Fig. 5.

Interlaced or Interposed System

Of the three described mounting methods, the interlaced or interposed system is the most effective in improving the station's coverage area. In this system the pole mounted antenna does not affect the pattern circularity.

Back-to-Back System

Some engineers prefer the "back to back" system, since this arrangement tends to balance the pole or tower load distribution. However, because the vertical and horizontal elements are facing in opposite directions, the horizontal pattern distribution of their respective signals may be affected.

Stacked System

Many recent installations are of the stacked antenna type. These are popular because advantage is taken of the existing FM horizontal antenna. The vertical antenna bays are usually installed directly below the horizontal bays.

The difference in height of the antenna elements in the stacked configuration may affect the line of sight distance to the horizon. When tower-side or tower-leg mounted, the antenna pattern will be somewhat affected by the supporting structure. The extent of deviation from a circular pattern will vary with the type and size of the structure.

Power Distribution

Since normally one transmitter feeds both antennas, the recommended type of installation is a single transmission line from the transmitter output to the antenna. Therefore, to operate with the same horizontal and vertical ERP, a power divider or splitting

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"tee" with a power division ratio of 50/50, 60/40, or 70/30 can be used to feed both the horizontal and vertical assemblies (see Fig. 8). An adjustable transformer may be used between the power splitter and the antenna elements to adjust for proper matching and power distribution.

As noted previously, the maximum allowable ERP of vertical polarized radiation is limited to the licensed horizontal radiated ERP power. The power available to the antenna can be determined by multiplying the transmitter power output by the transmission line loss (efficiency). For example, the total available power of a 10-kw transmitter is equal to 10 kw (transmitter output) multiplied by the transmission line efficiency of 90%, the result is 9 kw of available power. If the horizontal polarized antenna is a 3-stacked array with a gain of 3.0, and the station's licensed ERP is 24 kw, then the transmitter will be operating at less than full power output of approximately 8.0 kw.

Since the total available power is 9 kw and we want to operate with same horizontal and vertical power, using one transmission line, we must use a 50/50 power split to feed 4.5 kw to each antenna. A 6-bay horizontal polarized antenna with a power gain of 6.3 would be required to obtain the licensed ERP of 24 kw with a power input of 3.8 kw for each antenna feed line.

If a 6-bay horizontal polarized antenna is used, a 5-bay vertical polarized antenna should be interlaced between the horizontal elements. One manufacturer's vertically polarized antenna has the same gain as their horizontally polarized elements; thus, an equal number of horizontal and vertical bays may be used. The vertical polarized ERP for this combination would be 20.2 kw. (5.31 power gain × 3.8 kw power input = 20.2 kw ERP). Thus the dual polarized FM antenna combination would therefore comply with the FCC regulations. The gain of the horizontal and vertical antennas increases with the number of stacked bays used; Table I contains the figures for determining the appropriate number of horizontal and vertical antenna elements.

Vertical Pattern

The vertical pattern shows how the radiated energy is distributed and its proper choice is an important factor in good coverage. The vertical pattern is a plot of the relative field strength versus the vertical angle transmitted in a given vertical plane. Fig. 9 illustrates typical patterns for low, medium, and high gain antennas.

Choice of System

In the examples given here, only vertical and horizontal plane radiation has been discussed. Elliptically polarized radiation results from a dipole whose axis is 45 degrees to the earth. Unfortunately, this condition holds true in two general directions only. Circularly polarized radiation occurs from a combination of vertically and horizontally polarized radiators with the same center of radiation and with power 90 electrical degrees displaced. Circularly polarized FM antennas are practical in interposed arrays if the power to the vertical (or horizontal) elements are delayed 90 degrees. There appears to be no particular advantage of circular polarization over

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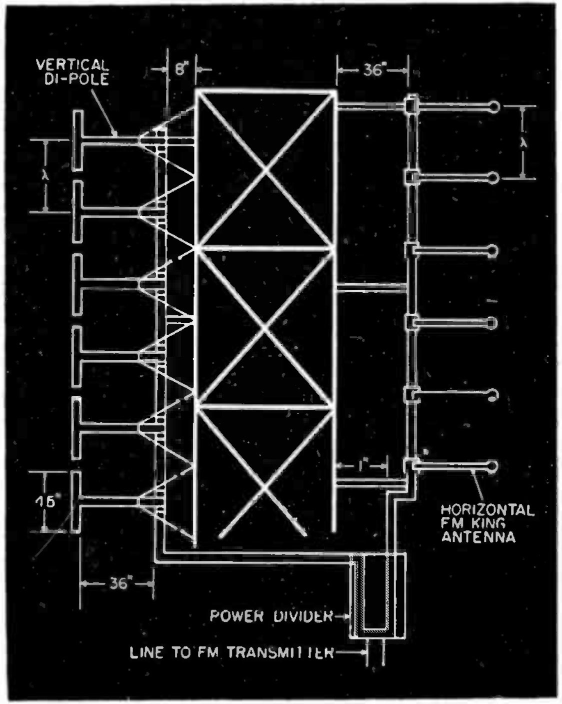

Fig. 6. "Back-to-back" dual polarized antenna system.

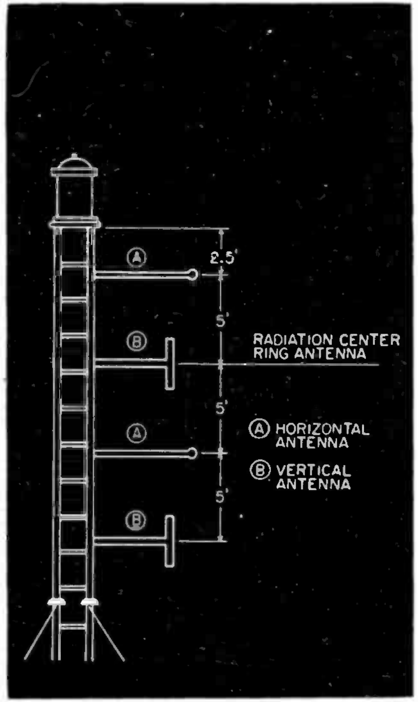

Fig. 7. Intermingled or interlaced dual polarized antenna system.

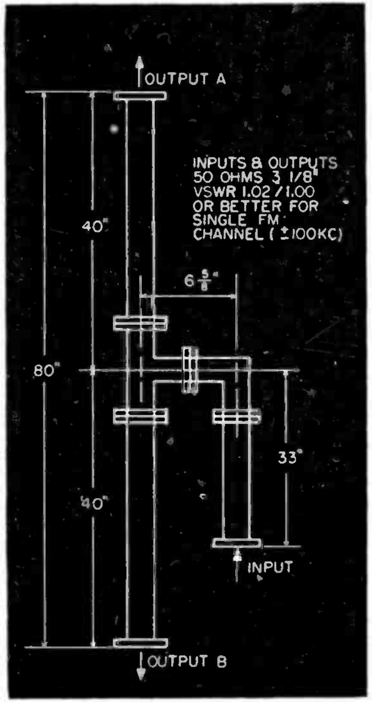

Fig. 8. A typical FM power dividing tee.

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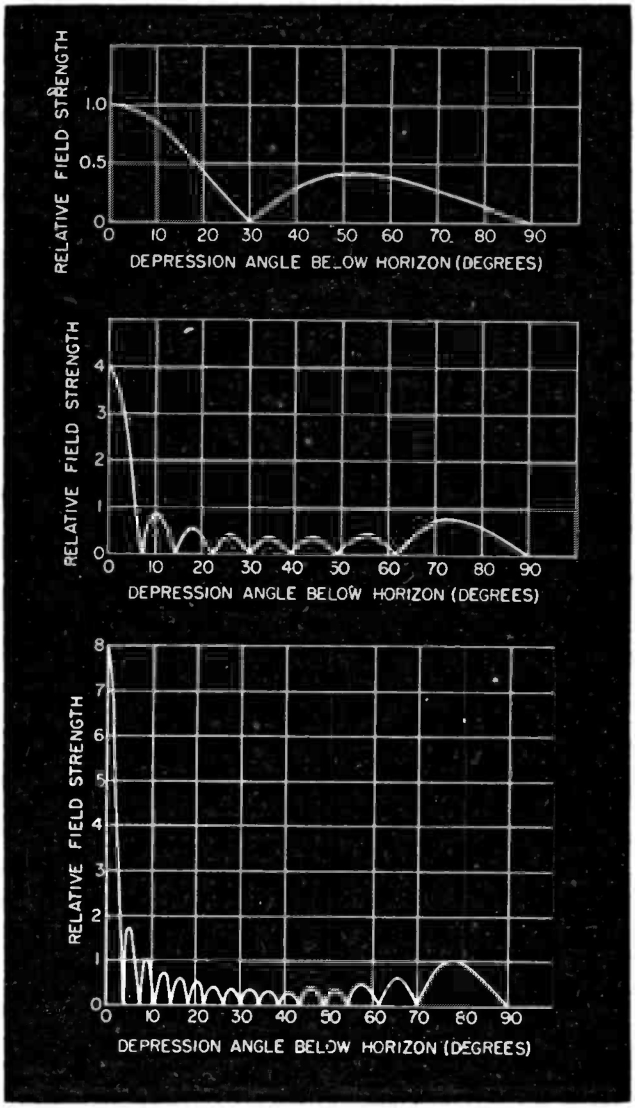

Fig. 9. (top) 2-bay vertically polarized antenna. Power gain: 1.969, db gain: 2.942. (center) 8-bay vertically polarized antenna. Power gain: 8.571, db gain: 9.330. (bottom) 16-bay vertically polarized antenna. Power gain: 17.483, db gain: 12.426.

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HORIZONTAL					VERTICAL				
No. Of Dipoles	Gain		Input Power Rating		No. Of Dipoles	Gain		Input Power Rating	
	Power	DB.	KW	DBK		Power	DB.	KW	DBK
1	0.9	0.5	3	4.8	1	.95	.002	3	4.8
2	1.0	2.8	6	7.8	2	1.97	2.942	6	7.8
3	3.0	4.8	9	9.5	3	3.12	4.942	9	9.5
4	4.0	6.0	12	10.8	4	4.2	6.230	12	10.8
5	5.1	7.1	15	11.8	5	5.31	7.251	15	11.8
6	6.3	8.0	18	12.6	6	6.39	8.057	18	12.6
7	7.3	8.6	21	13.2	7	7.5	8.751	21	13.2
8	8.4	9.2	24	13.8	8	8.57	9.330	24	13.8
10	10.5	10.2	30	14.8	10	10.96	10.398	30	14.8
12	12.5	11.0	36	15.6	12	13.19	11.204	36	15.6
14	14.5	11.62	42	16.4	14	15.3	11.844	36	15.6
16	16.5	12.18	48	17.2	16	17.48	12.426	36	15.6

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straight horizontal and vertical polarization.

Selecting the desired dual polarized antenna system can only be made by evaluating a particular station's requirements. Consideration must be made of the inter-effects of these factors:

1. Available transmitter power.
2. Transmission line losses.
3. Existing antenna and tower structure.
4. Terrain of area coverage.
5. FCC rules.

The proper choice will result in vastly improved service to an existing FM audience.

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Directional Dual Polarized FM Antennas

Harry A. Etkin

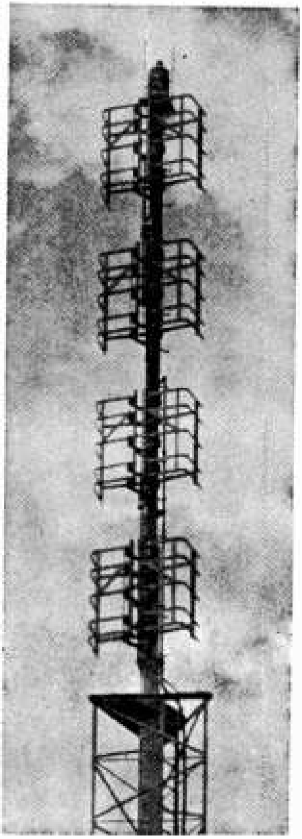
IN 1965, THE FCC authorized the use of directional FM transmitting antennas for the purpose of improving service, for the use of a particular transmitting site, and for the protection of another FM station's service contour. The Rules specify that the maximum to minimum radiation in the horizontal plane should not exceed 15 db, which is a power ratio of 31.62 to 1 for both the horizontal and vertical antennas. The Rules further state that the maximum attenuation change between any 10° azimuth shall not exceed 2 db.

FM DA Technology

Modern FM antenna technology allows unprecedented control of the transmitted signal. Arrays are available in horizontal and vertical combinations. In addition, the elements may be arranged so that the bulk of the transmitter signal is aimed almost directly at the location of greatest audience concentration.

The combination of horizontal and vertical antenna arrays allows doubling the effective radiated power, improves the coverage and, in addition, increases available signal strength to portable, auto, and home receivers with line cord and built-in an-

Slotted ring horizontally polarized antenna using reflector-type directionalization.



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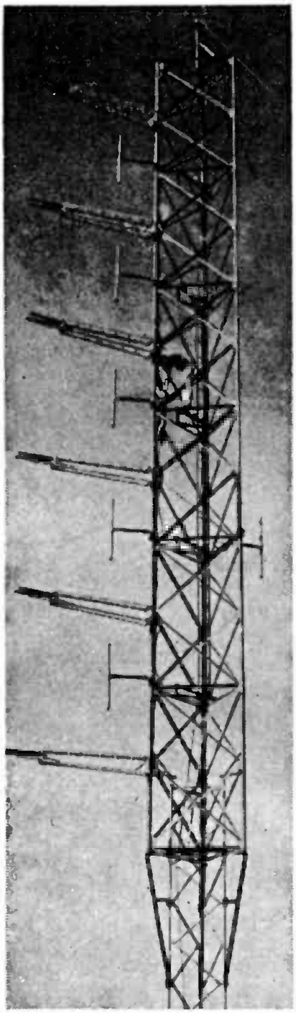
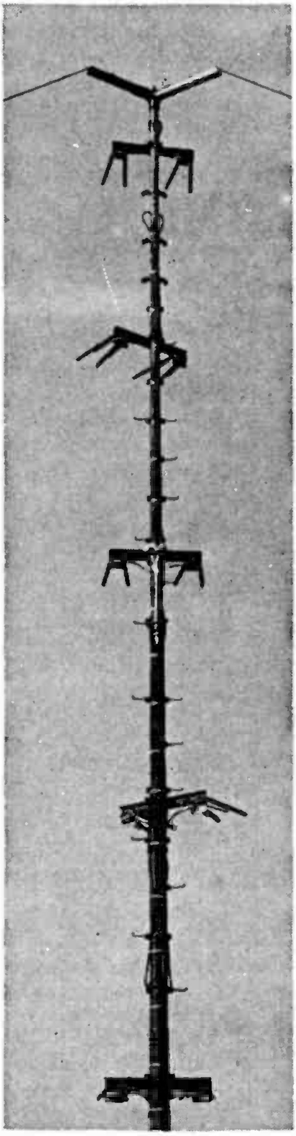


Dual polarized directional antenna fabricated for WJZZ-FM Trumbull, Conn. The lone vertical dipole mounted on the right side of the tower was installed to fill in the back of the pattern. Horizontal elements protrude 72" from the tower in order to obtain desired pattern. Effect of 6-foot wide steel tower, tower bracing, inside ladder lighting conduits, and coax cable are used to achieve the desired pattern.



Horizontally polarized phased array directional antenna.

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tennas. By directionalizing a dual polarized system, signals are radiated only in the direction or directions of the service area with the greatest population. As the directional antenna dispenses with wasted coverage, there is some increase in transmitter operating economy.

Installation Methods

Directional horizontal and vertical antenna arrays are usually arranged in one of three forms: back-to-back, stacked, and interlaced or interleaved. From a coverage standpoint, the interlaced system is best because the radiation patterns of the two arrays are concentric. With the back-to-back arrangement, the horizontal array is located on one side of the tower and the vertical array on the opposite side; in the stacked arrangement one antenna system is located above the other on the same side of the tower. The latter two arrangements, although not quite as good as the interlaced system from a coverage standpoint, distribute tower loading more effectively. Any of the three arrangements can be used for in directional dual polarized antenna system; standard patterns obtained are bidirectional and cardioid.

Types of Antennas

Directional dual polarized FM antennas are available for use in any given application, depending on the type of horizontal coverage pattern desired. The reflector type antenna is generally used where large areas are to be protected. Where small areas are to be protected, the phased antenna array may be used. Figs. 1 and 2 illustrate typical horizontal polar patterns. Various power gains are available; gain is provided at the expense of attenuated signal in some direction. Both types of antenna elements or bays are spaced approximately one wavelength apart.

The two types of FM directional antennas can be arranged in two basic designs, one resulting in a bidirectional or "peanut" pattern and the other a cardioid pattern. The bidirectional pattern may be obtained by various methods of mounting two omnidirectional radiators spaced in the same horizontal plane and fed equal power with a certain amount of phase delay to one of the radiators, or by mounting the radiators on opposite sides of the transmission line and fed in phase. Nulls of up to 10 db on each side can be obtained with power gains of up to 2.2 per bay. This may be achieved by the ring, cycloid, "V", and slotted-ring type antennas. The cardioid pattern may also be obtained by either placing a reflector in the front or back of the radiators. Nulls of up to 30 db can be obtained with power gains of up to 2.5 per bay. The vertically polarized antenna is usually directionalized by using parasitic reflectors, feeding greatly different amounts of power to the dipoles, or a combination of both. By using variations of these two combinations, many pattern types can be obtained and tailored for almost any requirement. Examples of typical patterns, shown in Fig. 3, show extreme conditions that can be achieved.

Various combinations of the bidirectional and cardioid pattern designs have been fabricated, ad-

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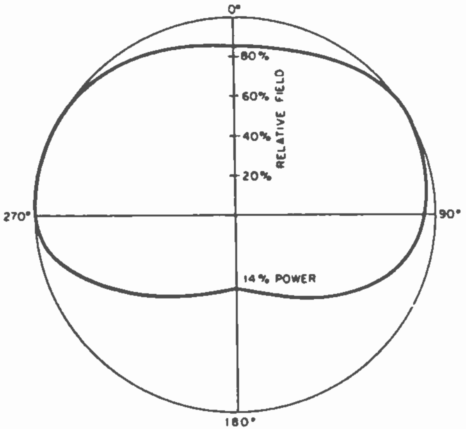

Fig. 1

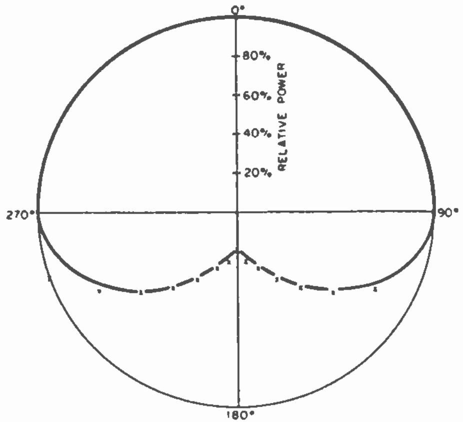

Fig. 2

Fig. 1. Typical horizontal pattern using phased array directionalization.

Fig. 2. Typical horizontal pattern using reflector array directionalization. Pattern cannot change more than 2 db from azimuth to azimuth, indicated by "X" marks.

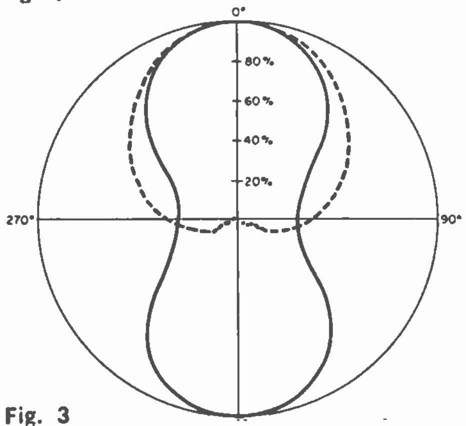

Fig. 3

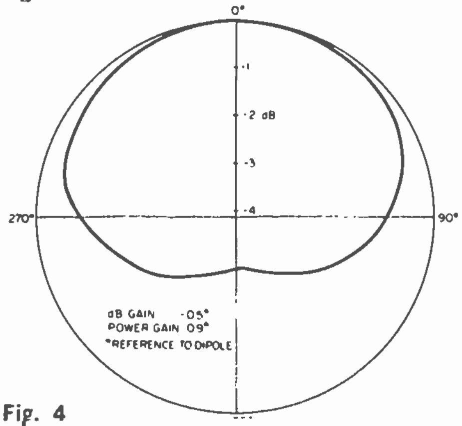

Fig. 4

Fig. 3. Typical bidirectional (solid line) and cardioid (broken line) patterns.

Fig. 4. Horizontal pattern with 3 db front-to-back ratio.

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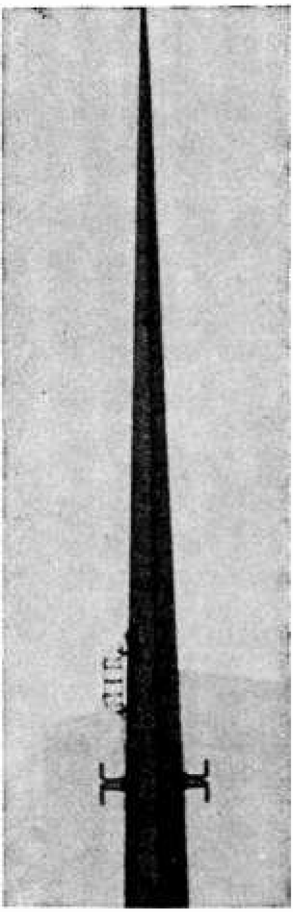
justed, and tested. Measured patterns are illustrated for 3, 4, 7, 10 and 15 db nulls in Figs. 4 through 8. Measured patterns for bidirectional and cardioid antenna designs are shown in Fig. 4 to illustrate the magnitude of protection obtainable if conditions warrant the attenuation. These horizontal field patterns could be achieved by either the horizontally or vertically polarized directional radiator elements.

Phased Arrays

The phased array consists of two omnidirectional radiator elements spaced in the same horizontal plane and fed equal power with a certain amount of phase delay added in the feed to one of the radiators. In other phased arrays, the radiator elements are mounted on opposite sides of the line and fed in phase. Many concepts of phased array systems are available, and combining them in a system multiplies their effectiveness. These types of directional antennas are quarter-wave vertical radiators and are usually easy to design.

Patterns can be controlled by radiator spacing and phase delay. As an example, in a 4-bay phased directional array, the north radiators may be fed 50% of the total power and they may be used as the reference radiator. The south radiators may be fed the other 50%, and their phase delayed by any desired amount. Phased array antennas are also designed in which the power ratio between the two sets of radiators are varied by any predetermined amount. This type of antenna system complicates physical construction, but may be desirable to meet certain requirements.

Antenna fabricators offer power dividers with variable power splitting; power division is performed by power splits through



This dual polarized directional FM antenna, used by WTFM, is mounted on the finial of New York City's Chrysler Building. Two slotted ring horizontally polarized antennas are directionalized by beam-shaping members. Two vertical dipoles are fed different amount of power for directionalization.

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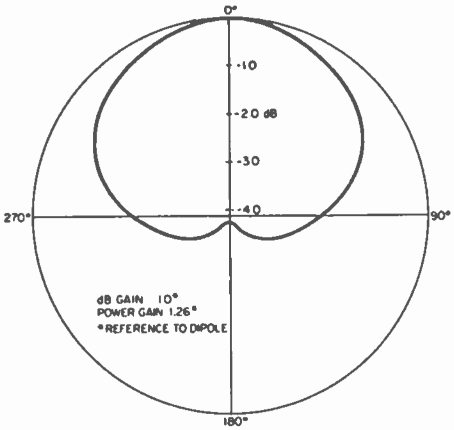

Fig. 5

Fig. 5. Horizontal pattern with 4 db front-to-back ratio.

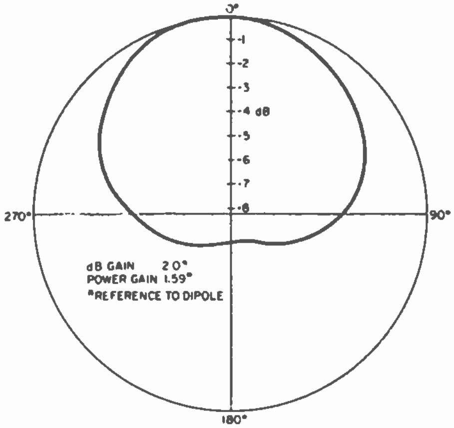

Fig. 6

Fig. 6. Horizontal pattern with 7 db front-to-back ratio.

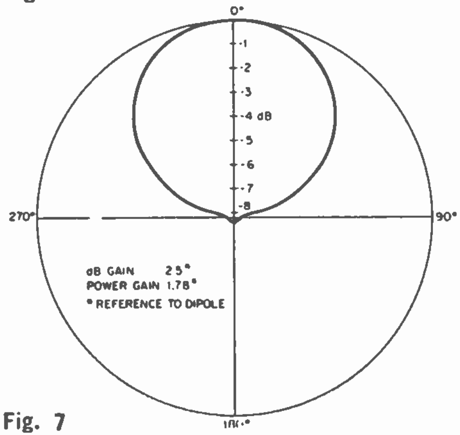

Fig. 7

Fig. 7. Horizontal pattern with 10 db front-to-back ratio.

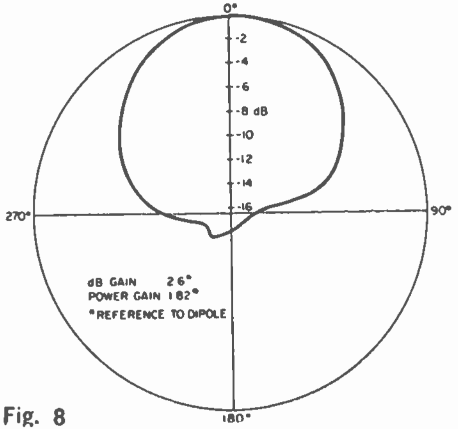

Fig. 8

Fig. 8. Horizontal pattern with 15 db front-to back ratio.

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impedance transformation. Each power divider feeds its own set of radiators, in the same manner as some TV antenna systems. By varying the length of the transmission line between power dividers, the phase of the currents are changed. For example, in an equal power division 5-bay array, the power divider has ten 50-ohm outputs. Five of these go in one direction and the other five in another direction. By varying the length of cable to one set of radiators, their phase is changed. The cardioid pattern with a deep null can readily be obtained. Some manufacturers can supply a cardioid pattern with a null at least 30 db below peak power. For illustrative purposes, Fig. 9 shows a horizontally polarized directional phased antenna array. This photograph indicates the complexity of the directional array in comparison to the conventional omnidirectional FM antenna.

Reflector-Type Arrays

A directional pattern may be obtained by placing a reflector, consisting of horizontal rods or a screen, behind or in front of a conventional vertically-stacked, horizontally-polarized FM antenna. The principle of operation is based on energy reflection. Pattern shape depends on the size of the reflector, the electrical efficiency, and the distance between the radiators and the reflector. Many patterns can be obtained, including bidirectional, by vertically stacking one set of bays to the north and another set to the south. The gain in each direction is one-fourth that obtained when both bays are pointing north. Nulls can be obtained in two different directions by adjusting one set of radiators and reflectors around the supporting tower. Since the far field voltages are in phase, there will be a field voltage addition in the acute null point.

In the reflector type installation, forward gain is much greater than that from the phased array. Forward gains as high as 20 can be achieved from a 5-bay installation using screen reflectors. The suppressed radiation using a reflector type of antenna array can be over 180°. In this type of installation, beam tilt and first null fill-in may be necessary, and can be accomplished by utilizing phase delay in the lower bays. In some antennas the feed lines connecting the bays between the power divider and the radiators are lengthened to achieve the desired phase delay.

The vertically polarized antenna is directionalized by using parasitic reflectors .55 wavelengths long and spaced from .2 to .4 wavelengths behind the dipoles. However, the antenna is usually designed to use the tower as a suppression element in directionalizing both the vertical dipoles and the horizontally polarized antenna elements. Fig. 10 shows the application of a slotted ring reflector type horizontally polarized directional antenna array.

The FCC requires that either the manufacturer adjust or certify the final pattern, or that this be accomplished by the station consulting or engineering personnel after installation. Antenna manufacturers prefer in-plant certification and require that the simulated supporting

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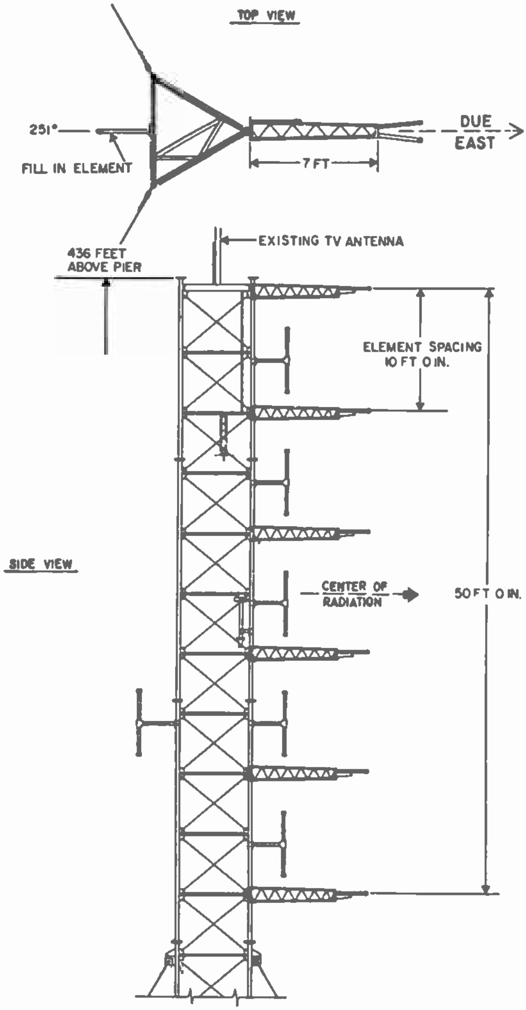

Antenna mounting configuration for WJZZ-FM.

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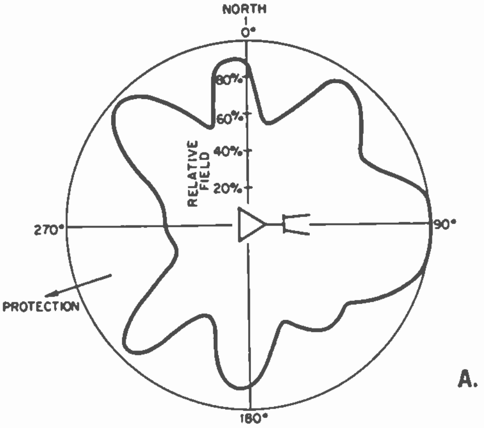

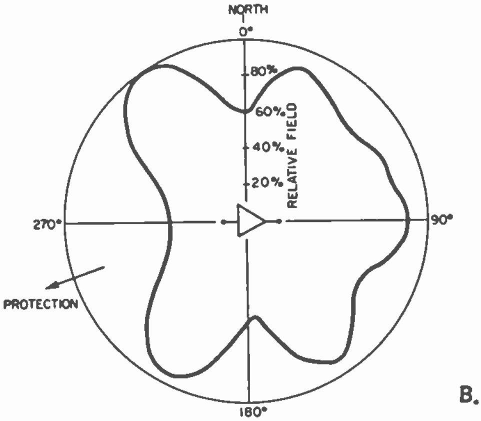

WJZZ-FM horizontal (A) and vertical (B) patterns. Major lobe gain, in both cases, is 8.89 (9.4 db); RMS gain is 5.

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tower or pole specified for mounting the antenna be used to support the antenna during the measurements of the final pattern. This pattern will be representative of the installed horizontal pattern. The FCC also requires that a surveyor certify the orientation of the antenna array.

Most manufacturers have a test range which allows their design engineers to erect, test, and adjust every antenna to conform to specific horizontal and vertical pattern requirements before shipment is made. Since the mounting pole and tower affect the radiation pattern, the engineers can actually duplicate the mounting specifications when adjusting the directional antenna at the test site. Such items as phasing and spacing are adjusted for the dual bays, which is usually a requirement in tight or multiple null patterns. As the power gain of an array increases, the vertical beam narrows and beam tilt and/or null fill-in may be required in high gain antennas to assure desired coverage. These two factors are included in the antenna during fabrication. Dual polarized directional antennas can be obtained for 1 through 8, 10, 12, 14 and 16 bays to satisfy vertical gain requirements.

New Technology

Never content to stand still, antenna engineers have been working behind the scenes on a development program to further improve the design and performance of dual polarized directional antennas.

A dual polarized directional FM antenna, consisting of a vertical and horizontal dipole making a cross with each other, will provide circular polarization in all directions of azimuth. It will perform as an equivalent helical side-fired TV antenna with the vertical component not squelched but adjusted by design to compare equally to the horizontal component.

FCC Rules Governing Dual Polarized Directional FM Antennas

Paragraph 73.213 specifies maximum values of radiation between short-spaced stations for specific conditions. Table I indicates that values of db attenuation of 1.86, 3.0, 3.97, 4.78, 6.98 and 10 db will satisfy all the conditions listed in the Rules. Paragraph 73.213 and 73.316 further state that the antenna pattern must not change more than 2 db for each 10° of azimuth and that directional antennas with a ratio of maximum to minimum radiation in the horizontal plane of more than 15 db will not be permitted. (See BM/E January and August 1965.) An analysis of Table 1 indicates that horizontal patterns of 2, 3, 4, 5, 7 and 10 db values satisfy all the above conditions.

Costs

Because of the many possible design configurations, tower, radiation elements, and combinations available for any specific requirement, the cost factor becomes a widely variable item in the construction and installation of dual polarized directional FM antenna arrays. Since each is designed for a particular need, combining the design features into an operating system multiplies

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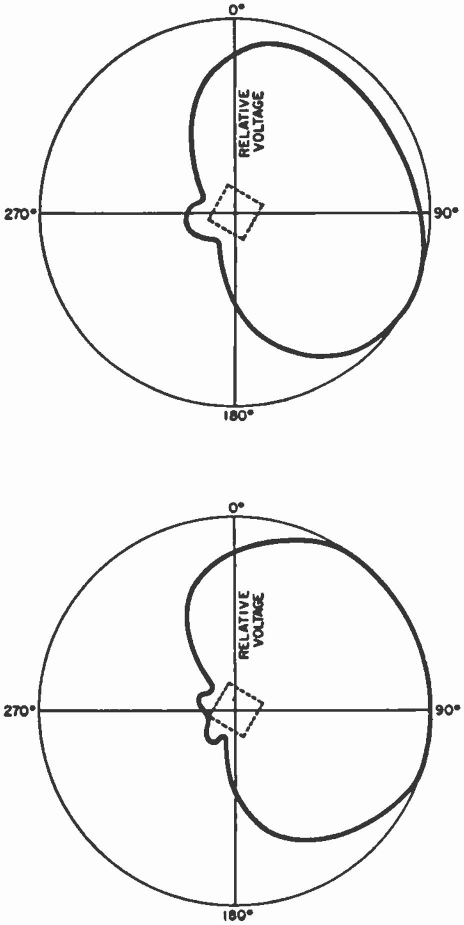
their effectiveness and makes possible individually tailored antenna arrays.

The approximate cost for directionalizing dual polarized antenna systems is as follows:

1. The basic antenna price, with either horizontal or dual polarization.

2. To this price add $300 per bay for directionalizing the FM radiators.

3. Add fixed charges of $2,500 for adjustments, pattern tests, and certification. The fixed charges remain the same from one through 10 bays. Above 10 bays, add $3,000. This charge



Field radiation pattern of WTFM. Note similarity of horizontally (top) and vertically (bottom) polarized patterns.

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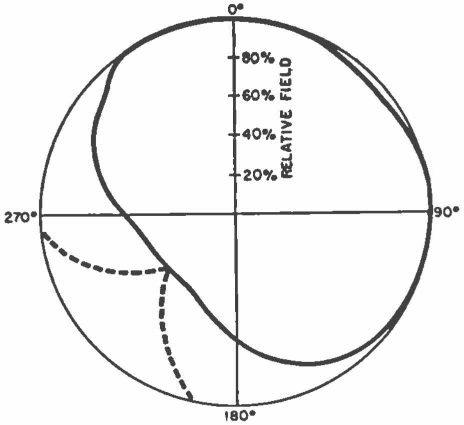

Predicted horizontal pattern of antenna system designed for WVNJ-FM Newark, N.J. Broken line is FCC 2 db per azimuth maximum change.

also includes the cost for manufacturing towers suitable to simulate the customer's supporting structure.

4. If a referenced dipole antenna is required, add $800. For example, the cost to directionalize a 4-bay horizontal FM antenna is:

(a) Cost of antenna—$2,075
(b) $300 x 4 = $1,200 for directionalizing radiating elements.
(c) Fixed charge of $2,500 for pattern tests, adjustments, and certification.
(d) Total price for this antenna would be $5,775. If a referenced dipole was required, add $800. If a dual polarized directional antenna was required, cost for items (a) and (b) would be approximately double.

Conclusion

New developments and technology offer a wider choice of improved dual polarized FM directional antenna arrays. These antennas can be used to advantage in providing higher ERP values, when used in compliance with current FCC Rules, which requires protection to certain power levels in certain directions. It is recommended that manufacturers fabricate, adjust and test the directional dual polarized antenna array. This will insure correct installation on the customer's tower and it will be safe to conclude that the final installed antenna array will have a pattern equal to that measured

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under test conditions. Beam tilt and null fill-in may be incorporated to assure desired coverage. A directionalized and dual polarized FM antenna array is a symbol of deluxe programming aimed in the direction of maximum service coverage.

Photographs courtesy of Jampro Antenna Co., Sacramento, Cal., and Alford Manufacturing Co., Boston, Mass.

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FM Antenna System Care & Maintenance

Lewis D. Wetzel

THE ANTENNA SYSTEM is ofen the part of the station's equipment which receives the least attention, even though it is left to weather everything Mother Nature can dream up. The initial cost of the antenna system is usually a quarter to half the cost of the transmitter which receives daily attention. Some simple guidelines may be useful in maintaining an existing antenna system or choosing a new one.

A key meter in the transmitter system which can give the operator some indication of how the antenna is performing is the reflectometer, or VSWR meter. Unfortunately, this measuring device is 1) often installed at the wrong place; 2) not designed to give the needed accuracy; or 3) not supplied with the transmitter.

Let's take a look at the reflectometer which should really be considered a part of the antenna system. It is a device which should be inserted into the transmission line after the harmonic filter. It should have a directivity of about 35 dB and a coupling factor which is proper for the associated meter. The reflected or reverse power probe should preferably have 6 to 10 dB more coupling, but this again must be coordinated with the meter scale. The proper adjustment of these probes is made at the factory. No attempt to alter the adjustment in the field should be made unless fairly elaborate test equipment is available to assure knowledge of results.

Calibration of the reflectometer, however, is a function which the engineer must perform at the station whenever a proof-of-performance is made. To assure accuracy, the transmitter should be operated into a dummy load and the reflectometer adjusted to indicate the operating power level. By re-

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versing the leads from the directional coupler and switching the reflectometer to the reflected position, the calibration in this position may be checked taking into consideration the reflected coupling factor.

VSWR should be below 1.3

If the VSWR on your antenna system is above 1.3 under normal conditions, an effort should be made to determine the reason. Some of the things to check are: the accuracy of the reflectometer; the correct placement of the reflectometer in the system; uniform temperature along the transmission line; no presence of moisture in the system; good contact of all connectors; and proper antenna installation.

Let's take a look at some of these trouble indicators in addition to the aforementioned problems concerning the reflectometer. A discontinuity will cause hot spots every half wavelength along the transmission line—until the reflected energy has been dissipated. It is, therefore, necessary to get within a few wavelengths of the trouble or the hot spots will not be apparent.

Moisture in the system is difficult to determine, so the easiest remedy is to purge the system periodically with dry air or dry nitrogen. Be sure the dehydrator is delivering dry air. For convenience in purging the system, an eight to ten pound pop-off valve can be installed in place of the bleeder plug on the antenna.

A periodic resistance measurement of the transmission system using a bridge is a good way to detect or anticipate connector problems in the transmission line. The value of this reading will, of course, depend upon the length of line in the system but it should be in the 50 to 500 milliohm region. If a high resistance reading is obtained, a time domain reflectometer or pulse measuring equipment can be used to locate the fault.

Refer to the installation instructions and drawings to assure yourself that the ground straps are in place and that the antenna radiating elements are intact. Falling ice and careless riggers can cause troublesome damage.

If the antenna transmission system does not hold pressure, find the leak. A system without pressure invites moisture to accumulate and the voltage

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breakdown point of the system decreases drastically. To check each element of the antenna, have your antenna man hold a 15-watt flourescent tube at a similar position from each element to check for equal radiation. Bad connectors or mistuned elements within the antenna may be located in this manner.

Use the right antenna size

When an antenna system is being designed for a new station, or an existing system is being replaced, several factors should govern the type and size of antenna and transmission line. Conservative ratings for a transmission line which allow for a rise in VSWR without damage to the line are as follows: 8 kw for 1⅝ in. line, 30 kw for 3⅛ in. line, 60 kw for 4⅜ in. line, and 120 kw for 6⅛ in. line. Bear in mind that the ratings given in the catalogs are for unity VSWR with dry air in the line. Laboratory conditions are seldom met in the field.

How much gain should the antenna have? The FCC limits the Effective Radiated Power of FM stations by class of station. The ERP for a station can be achieved by a high-power transmitter and a low-gain antenna or, conversely, by a low-power transmitter and high-gain antenna—or something in between. With any combination, the maximum radiation in the main beam has to be the same. How high the antenna is mounted, how near the antenna is to the desired coverage area, and how rugged the terrain is in the coverage area are some of the factors which should be considered in selecting the power/gain combination. Null fill and/or beam tilt can be built into the antenna to tailor the radiation pattern to provide the desired coverage. With about a 15% reduction in gain, a high-gain antenna can be designed to give close-in coverage similar to a low gain antenna.

Pick a broadband antenna

Broadbanding of an antenna system is something not well understood by non-technical people. An analogy is the garage door built with only an inch to spare on either side of the automobile. One would have difficulty driving through the door. If, however, the garage door is built with two feet to spare on

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either side of the automobile, there should be no difficulty in passing through the door. With all the extras riding on the FM carrier today, i.e., stereo and SCA, it is important to have a broadband antenna to insure undistorted stereo and SCA service. Normally the measure of broadbanding is the VSWR of the antenna over the FM channel. This does not present the total picture since the VSWR could be flat across the channel while the impedence varied across the channel. A better measure of broadbanding would be to specify the percentage change of impedance over the channel.

A word of caution on circularly-polarized antennas

Circularity of an antenna can only be specified for free space. Unfortunately a supporting structure must be used to mount the antenna. The size of the supporting structure will determine the circularity of the radiation pattern. For large towers, the radiation pattern becomes rather directional. If coverage in all directions is important and the supporting structure is large, special attention should be paid to the antenna supports and their effect on the pattern. Possibly a special antenna which surrounds the tower should be used.

True circular polarization is rarely achieved except in a free space measurement. As soon as the antenna is mounted on the supporting structure, the amplitude and/or phase of the horizontal and vertical fields will change, producing elliptical polarization. This change in polarization is not important, however, since nearly all receiving antennas are other than circularly polarized.

Because each station's coverage area presents unique propagation problems, the best results from your station can be obtained when the transmitting system is designed for your market.

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Charge Dissipation Lightning Protection for Towers

To THE BROADCAST INDUSTRY, as to many others, lightning has always been an unpredictable and uncontrollable force, the dangers of which could be lessened by careful design and prudent procedures. But lightning could not be prevented from breaking through human defenses from time to time, especially at high-altitude installations. As is well known, a direct hit is not at all necessary to the production of plenty of damage. The induced current from a nearby lightning bolt can destroy any current-carrying device, the power line, the antenna transmission line, etc.

A startling development by a firm calling itself Lightning Elimination Associates of Downey, California, has apparently opened the era of *lightning prevention* in a protected area. The station operator who has had repeated lightning trouble can look forward to total relief, at small cost, if the new technique lives up to its promise. Such a development obviously represents, for *every* kind of human installation and enterprise, an historic shift away from the purely defensive response to lightning.

The basic idea is most simple. The lower part of a thunder cloud becomes highly charged, usually negatively. As the cloud moves, it carries beneath it along the earth's surface an area of induced opposite charge (below). If the potential between cloud and earth gets higher than the breakdown point of the air between, there is a lightning stroke. High structures make lightning more likely by shortening the air path from cloud to earth.

If the difference in potential could be substantially reduced by a dissipation of charge across the air gap, the chance of lightning occurring should be

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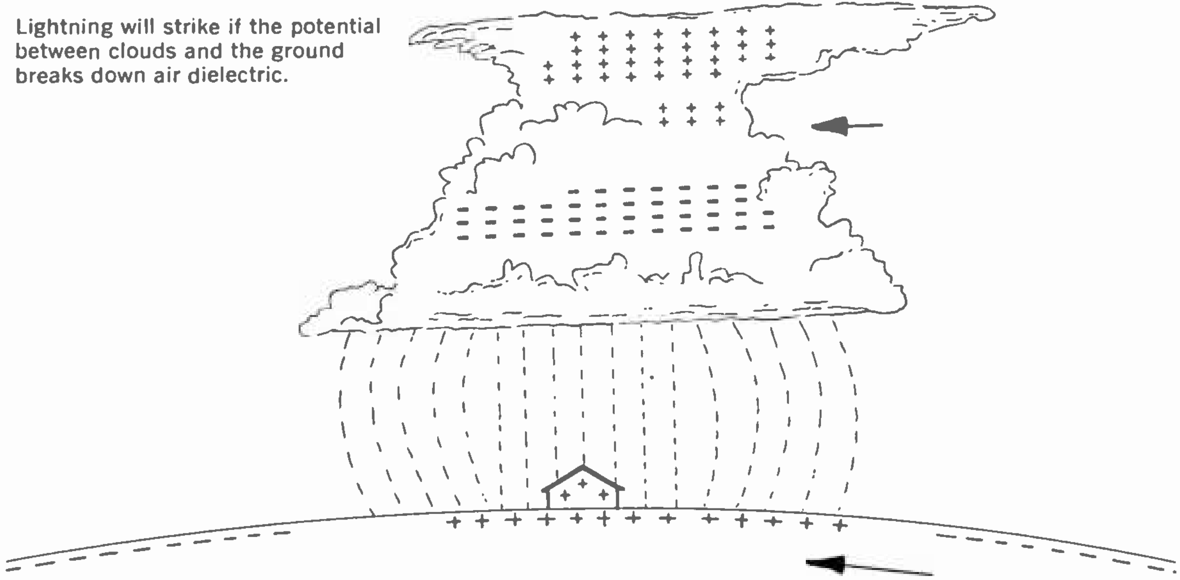

Lightning will strike if the potential between clouds and the ground breaks down air dielectric.

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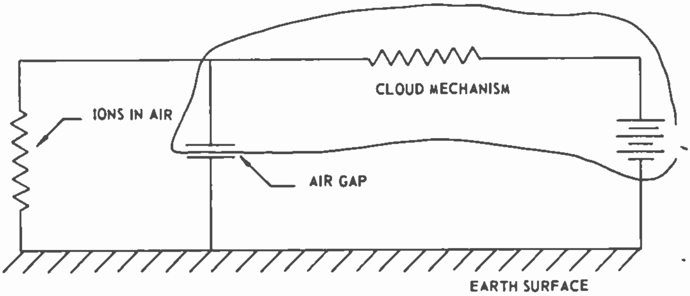
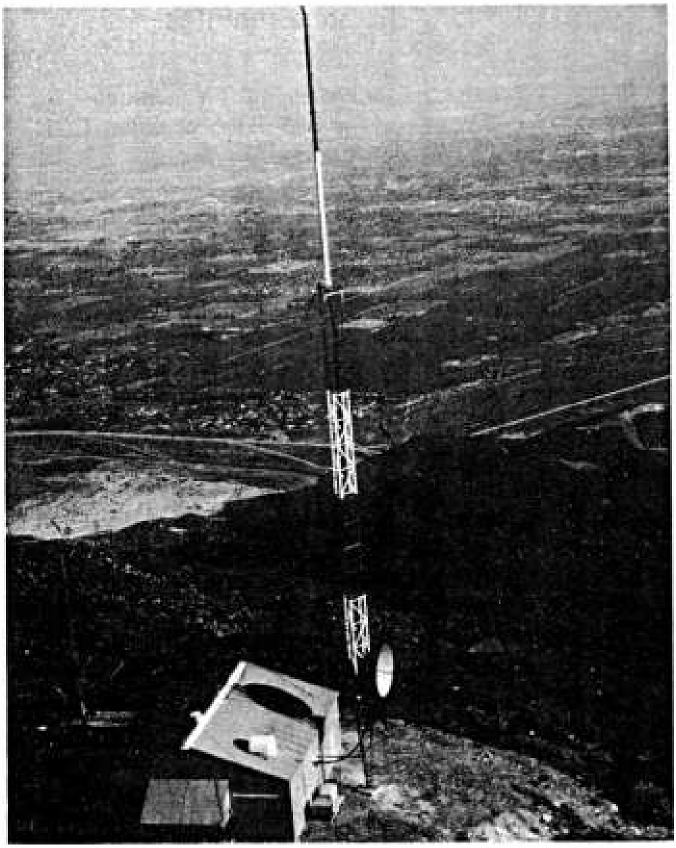


The equivalent electrical diagram. The LEA dissipation wires start a current flowing through ions to reduce the cloud-to-ground potential.



Antenna of station KHOF-TV supports a series of radial dissipation wires (almost invisible in photo).

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substantially reduced. This is just what the LEA system sets out to do, with an array of very many sharp metal points, connected to the ground and pointing upward. The ability of a sharp point in a strong voltage gradient in air to start a current across the gradient has been known since Ben Franklin flew his kite. The LEA dissipation array "leaks" the charge across the air gap.

The number of points in a given installation can be many thousands. The array in which they are mounted may have a variety of shapes, the particular configuration being chosen to suit the structures being protected. The antenna in the photograph supports a series of radial dissipation wires (barely visible).

Is a device of these comparatively modest dimensions up to the job of preventing lightning, one of Nature's truly outsize phenomena? Apparently so. LEA cites, among others, the case of the transmitter of station KHOF-TV, on a peak 5500 feet high near Los Angeles. The station and the incoming power line had been knocked out repeatedly by lightning. The station engineer had even been knocked off the

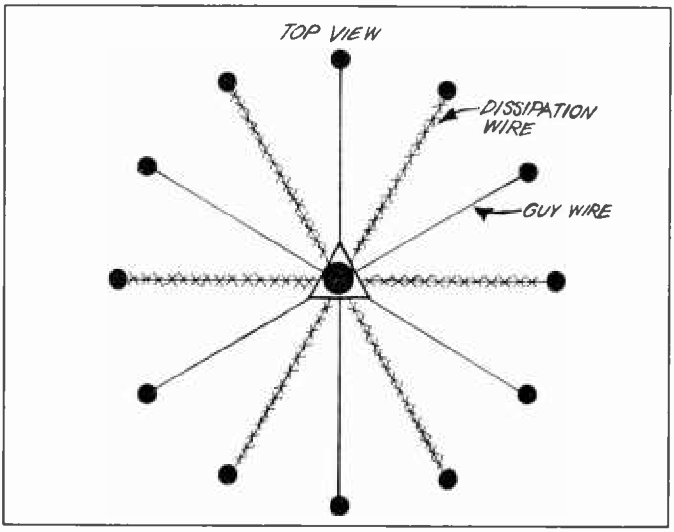

Diagram shows six dissipation wire radials strung from antenna (held up by guy wires). Antenna height is 225 feet. Dissipation wires are insulated from the tower and form angle of 35 degrees with respect to the ground.

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roof, with only one small black cloud in the area. One of LEA's dissipation arrays, installed last year, got KHOF through the lightning season without a single hit.

It seems a terrible loss that this relief from lightning's ancient danger has been stuck on the back burner for more than 40 years. The idea occurred about 1926 to Willard Starr, a young California engineer, after he saw lightning start a fire in an oil-refinery tank (the oil industry is one of the heaviest losers to lightning). After some experiments, he convinced himself that the idea was sound. A trial installation at an oil refinery was virtually forgotten when the executive who sponsored Starr died. No one else could be interested until the 1960s, when another engineer finally noticed that the tanks protected by Starr's arrays had never been hit by lightning. Starr was called back into lightning prevention after a long career as a consultant to the movie sound studios. He is now a principal in LEA, along with R. B. Carpenter, an engineering executive with much experience.

Broadcast engineers will be interested in the parameters of the array operation. LEA reports tests and calculations that indicate sustained currents through a typical array ranging up to more than 200 amperes. Lightning bolts, of course, often exhibit hundreds of thousands—or millions—of amperes of current, but over very short time intervals, measured in milliseconds. Evidently the system works by spreading the discharge between cloud and earth over a very longer, safe interval.

LEA says that operation is critically dependent on size, shape, material, and distribution of the points, and on many other factors, all of which they have thoroughly investigated. Each installation must be custom-made to fit the requirements of the structure to be protected. Prices have ranged from about $3800 to about $6800 for a complete installation. LEA looks forward to cost reductions that would put many broadcast installations in the neighborhood of $3000.

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