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The Measurement of FM and TV Field Strengths (54-890 MHz)

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The coverage of a broadcasting station and the technical quality of the service provided are determined by the received signal and field strengths. Presently available methods of estimating field strengths within the service ranges of FM and television stations are only approximate, and even the best methods of calculating field strengths often fail to take into account variations due to important local conditions. For operating stations the best determination of station coverage is provided by properly made field-strength measurements.

This part describes equipment and techniques for measuring field strengths over the frequency ranges employed for FM and television broadcasting. These services are assigned to several bands between 54 and 890 MHz as shown in Table 1.

TABLE 1

Frequencies Employed for FM and Television Broadcasting

Service	Frequencies, MHz	Channel Nos.	Channel Bandwidth
TV	54–72	2–4	6 MHz
TV	76–88	5–6	6 MHz
FM	88–108	201–300	200 kHz
TV	174–216	7–13	6 MHz
TV	470–809	14–69	6 MHz

The quality of service is related to the field strength by considerations of receiver sensitivity and noise figure, receiving antenna gain and transmission-line loss, and tolerable signal-to-noise ratios. The required fields vary with the class of service and frequency assignment. Interfering signals from other transmitters on the same or adjacent channels may limit service to higher values of field strength. Table 2 lists values of median field strength required for various grades of FM and television service in the absence of interfering signals as established by the Federal Communications Commission's Technical Standards.[1] There are also included revised estimates of the fields required in the television bands to provide acceptable grades of service based on the practical experience of operating stations and the findings of the Television Allocations Study Organization (TASO).[2] These latter have not as of the present date (Sept. 1, 1974) been officially adopted by the Commission.

Note: Superscript numbers refer to References at end of the chapter.

TABLE 2

Median Field Strengths Required for Various Grades of Service in the Absence of Interfering Signals

FM Broadcasting (All Channels)

Grade of service	μv/m	dbu[a]
Principal city	3,160	70
Urban	1,000	60

Television Broadcasting (FCC Technical Standards)

Grade of service	Ch. 2–6		Ch. 7–13		Ch. 14–83	
	μv/m	dbu	μv/m	dbu	μv/m	dbu
Principal city	5,000	74	7,000	77	10,000	80
Grade A	2,500	68	3,500	71	5,000	74
Grade B	225	47	630	56	1,600	64
(Based on TASO Data)						
Primary	250	48	1,400	63	7,500	75
Secondary	50	34	200	46	630	56
Fringe	20	26	55	35	180	45

[a]This abbreviation was coined by the FCC for television service and signifies the field strength in decibels above 1 μv/m. 0 dbu = 1 μv/m.

Service is defined in Table 2 in terms of the median field at a receiving antenna at a height of 30 ft. above ground. In these frequency bands, the field usually varies appreciably with antenna height, generally tending to increase with increasing antenna height. However, the variation in field with height may not follow simple laws, as discussed more fully in subsequent paragraphs.

The presence of trees, buildings, and terrain irregularities[3-7] often results in considerable variation in the signal from one location to another, even within relatively small areas. The variation in field strength with location must be taken into account in measuring the field strengths as well as in specifying service. Service is usually defined in terms of the *median value* of field strength, which is the value exceeded for at least 50 percent of the time at the best 50 percent of the receiving locations.

The results of field-strength-coverage surveys are customarily presented as contour maps, showing lines of constant median field strength which represent the outer limits of various grades of service. A typical map of measured television-station coverage is shown in Fig. 1. Methods of preparing contour maps are described in detail under the heading "FCC Standard Method."

Much of the present knowledge of wave propagation in these frequency bands has been derived from field-strength-coverage surveys on operational FM and television stations. The information gained from these commercial coverage surveys has added to the body of scientific knowledge, but field-strength-measurement surveys employing special techniques are often needed to supply data for special propagation problems. Examples of such special techniques are discussed under "Recommended TASO Method for Special Studies."

BASIC EQUIPMENT PRINCIPLES

Field strengths in the VHF and UHF bands (30 to 3,000 MHz) are ordinarily measured by determining the voltage which the field induces in a half-wave dipole. The basic relationships can be expressed in several forms. The power transferred between two half-wave dipoles in free space separated by a distance d is given by

$$\frac{P_r}{P_t} = \left(\frac{1.64\lambda}{4\pi d}\right)^2 \qquad [1]$$

where P_r = received power
P_t = transmitted power
λ = wavelength in same units as d

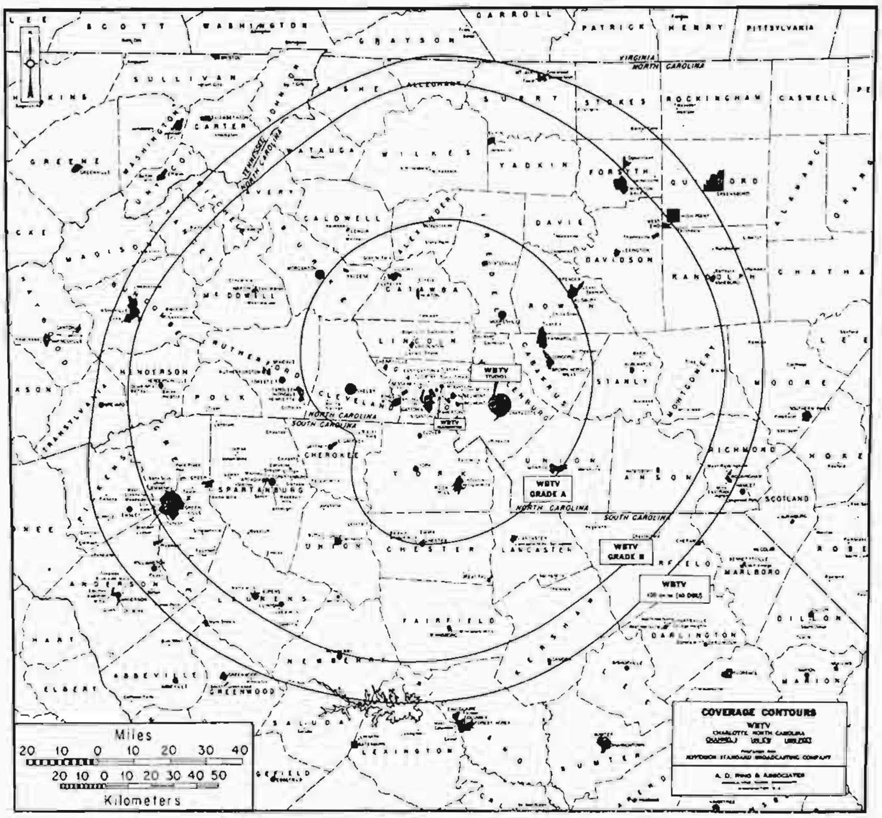

Fig. 1. Map showing measured service contours for an operation television station. (Courtesy of Jefferson Standard Broadcasting Company.)

In terms of the field at the receiving dipole, the power delivered to a matched load by a half-wave dipole in a field of E volts/m is

$$P_r = (0.186E\lambda)^2 \quad \text{watts} \qquad [2]$$

where λ is expressed in meters. For a resistive load of R ohms, the voltage V developed across a matched load by a dipole in a field E is

$$V = \frac{E\lambda\sqrt{R}}{53.7} \qquad [3]$$

The fundamental problem presented, therefore, is that of measuring the developed RF voltage by a practical instrument of acceptable accuracy.

Fig. 2 is a graph showing the available power and voltage developed across a matched 50-ohm load as a function of frequency for a half-wave dipole in a uniform field of 1 volt/m at the frequency indicated. This graph summarizes the relationships shown in Eqs. 2 and 3.

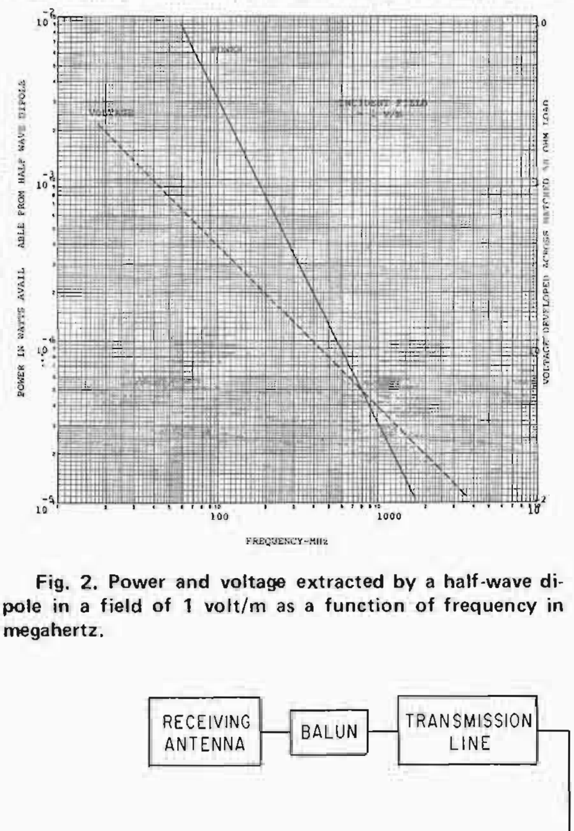

Fig. 2. Power and voltage extracted by a half-wave dipole in a field of 1 volt/m as a function of frequency in megahertz.

The voltage-measuring device is ordinarily separated from the antenna by a length of cable. The cable may introduce losses, and any impedance mismatch must be sufficiently small that calibration errors are not introduced by differences between the antenna and cable impedance and the internal impedance of the calibrating oscillator.

PRACTICAL FIELD-STRENGTH METERS

Fig. 3 is a block diagram of a practical field-strength meter. The antenna delivers its received power to a transmission line leading to the receiver input. If the receiver input is unbalanced to ground, a balance-to-unbalance transformer ("balun") is required. The transmission line between the antenna and the receiver is shielded to avoid stray pickup.

The RF attenuator shown serves two purposes: to avoid overloading of the receiver input on strong signals and to improve the impedance match when the receiver input impedance is substantially different from the characteristic impedance of the transmission line. It is frequently omitted when not required for either of these purposes.

The signal at the receiver input is amplified and converted to the intermediate frequency. Amplification and attenuation at the intermediate frequency permit operation over a wide range of field strengths; further range is provided by the receiver gain control. The rectified receiver output operates the indicating meter.

In operation, the attenuators and gain control are adjusted to provide an on-scale reading of the

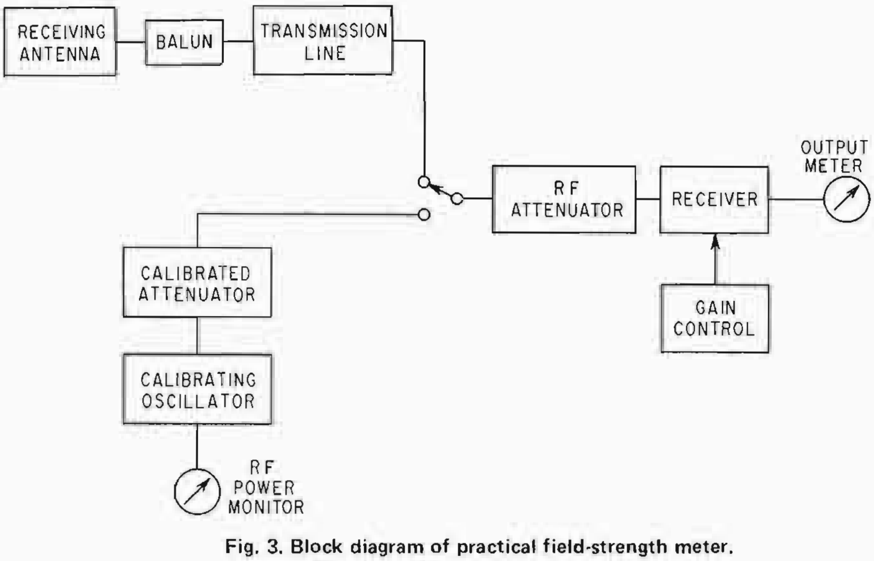

Fig. 3. Block diagram of practical field-strength meter.

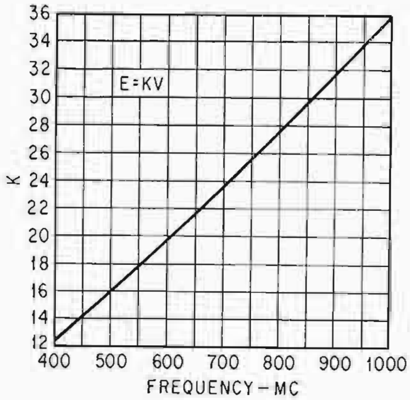

Fig. 4. Graph of K for typical UHF field-strength meter. $E = KV$

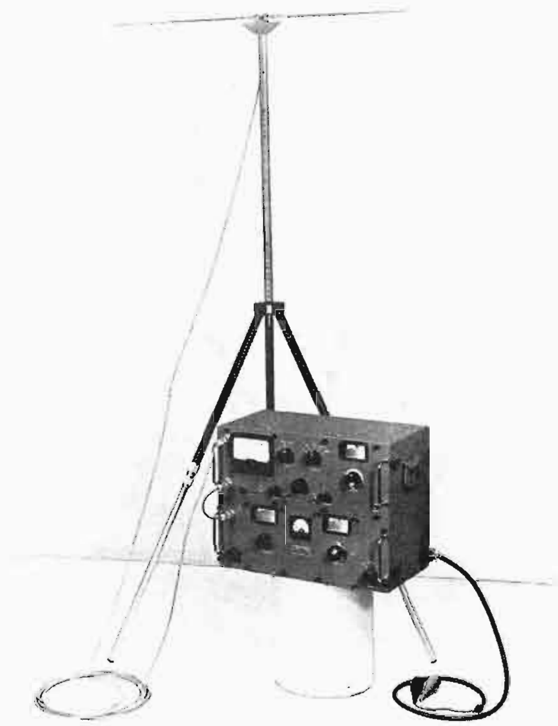

Fig. 5. A VHF field-strength meter of professional quality. (Courtesy of Nems-Clarke Company.)

indicating meter. The receiver input is then switched between the output of the transmission line and the output of the calibrating oscillator, which is tuned to the frequency being measured. The output of the calibrating oscillator is adjusted to a predetermined fixed value using the RF power monitor, and the calibrated attenuator is adjusted until the indicating meter deflection is the same as that obtained from the antenna and transmission line.

For this condition, the voltage at the output of the calibrated attenuator is the same as that from the antenna and transmission line. By taking line and balun losses into account and applying Eq. 3 above, the field at the antenna required to produce this voltage can be determined. The relationship between field strength and receiver input voltage is usually expressed as $E = KV$, where K is a function of frequency. Fig. 4 is a typical graph showing values of K for a UHF field-strength meter.

A typical commercial field-strength meter of professional quality is shown in Fig. 5. The instrument shown is a Nems-Clarke type 107-A, covering the VHF FM and television band from 54 to 216 MHz. A companion instrument, similar in appearance, covers the UHF television band from 470 to 890 MHz.

Accurate instrument calibration is essential in measuring RF fields. During use, the calibration of the instrument described is provided by the calibrating RF voltage source, which is usually an integral part of the field-strength meter (see Fig. 5). The calibration of the oscillator and the over-all calibration of the instrument as a whole must in turn be established and maintained by reference to laboratory standards.

The most direct laboratory calibration of the complete field-strength meter is established by generating a known standard field in which the receiving antenna is placed. Standard-field ranges have been developed and constructed at both UHF and VHF[8] and are sometimes used in primary calibration of field-strength meters. Most commercial laboratory calibrations, however, are made by removing the dipole elements from the standard antenna and applying a known RF voltage at the proper frequency to the dipole terminals in series with an impedance equal to the receiving-antenna impedance. The calibration of the balun, line, and receiver is established in terms of this applied voltage, which is then related to field strength through Eq. 3.

The calibration of the internal reference oscillator section includes the calibration of both the oscillator proper and the variable-output attenuator. The attenuator is usually of the inductively coupled piston type,[9] which depends only on its dimensions for proper functioning; this can be checked against the correct dimensions or against a laboratory standard attenuator. The oscillator can be compared with a standard oscillator, or its output can be measured with a laboratory standard such as a bolometer bridge.[10] This calibration is normally performed only by the manufacturer.

If measurements are made on the visual carrier of a television station, the difference between the peak and average powers of the transmission must be taken into account. This can be done by establishing a calibration in terms of average power for a still scene (such as test pattern or black picture), or a peak-reading voltmeter can be employed to indicate the level of the synchronizing peaks. Such peak-reading voltmeters are an integral part of many of the commercial field-strength meters such as the one illustrated in Fig.

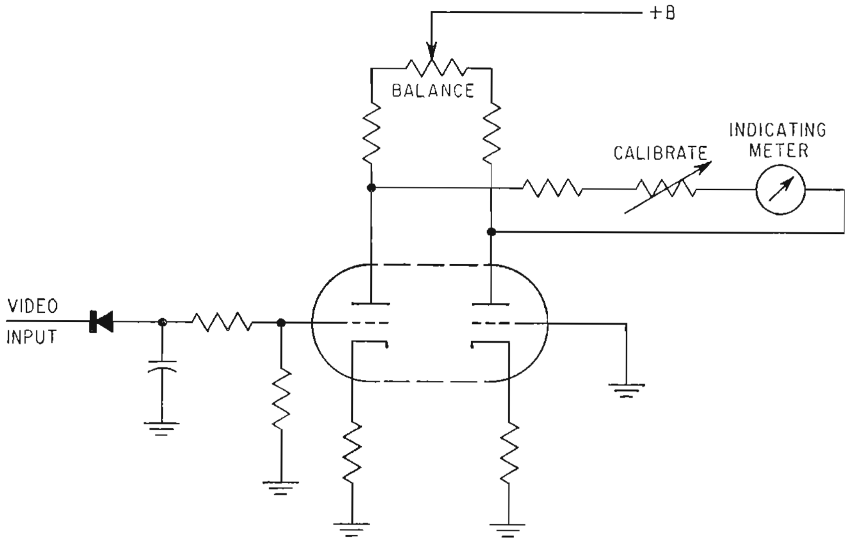

Fig. 6. Schematic diagram of bridge circuit for reading voltage corresponding to synchronizing peaks. The component values in the grid circuit are chosen to provide a long time constant.

5. A schematic diagram of a typical peak-reading voltmeter is shown in Fig. 6.

In addition to the field-strength meter, several accessory items are needed in making a field-strength survey. The principal items and their use are described in the following paragraphs and include (*a*) a special receiving antenna, (*b*) an antenna-supporting mast, (*c*) a chart recorder, and (*d*) power supplies. The size and weight of the equipment usually dictate that it be mounted in an automobile or light truck. Fig. 7 shows a large station wagon containing permanently mounted equipment for field-strength surveys.

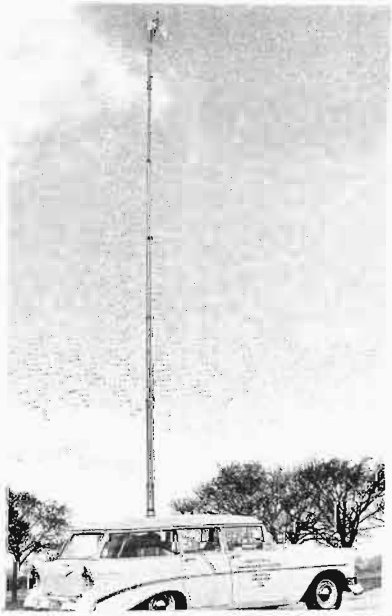

Fig. 7. Station wagon equipped for making field-strength-coverage measurements showing 30-ft hydraulic mast. A UHF receiving antenna is mounted on the mast. (Courtesy of Association of Maximum Service Telecasters, Inc.)

RECEIVING ANTENNAS

The measurement survey can be made by employing the standard dipole antenna furnished with the field-strength meter, or other antennas can be utilized. An antenna which is essentially omnidirectional in the horizontal plane does not require orientation as the vehicle is moved. Fig. 8 shows a typical nondirectional receiving antenna designed for this purpose. Directional receiving antennas can be employed when their gain is needed (principally for UHF measurements) or when their rejection is desired to eliminate unwanted signals from sources other than the transmitter being measured.

The antenna employed for the measurements must be calibrated on the measurement vehicle.[11] The received field is first measured using the standard dipole antenna removed from the vehicle. The antenna to be used in making the survey is then mounted on the vehicle at the height to be employed in making the survey, and the receiver input voltage determined with the receiving antenna at the same spot in the field. If an omni-

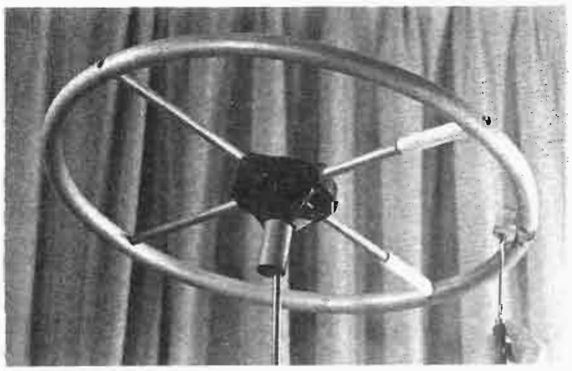

Fig. 8. Nondirectional VHF receiving antenna for making coverage surveys.

directional receiving antenna is employed, the circularity of the pattern of the antenna as mounted on the vehicle must be determined. Unless the vehicle can be rotated, this can be done by driving the vehicle in a small circle in an area of uniform field and recording the received signal.

The gain of the service antenna can be established relative to the dipole antenna by means of measurements with the antennas stationary, but more consistent results are often obtained by making short mobile runs over identical paths and recording the signals from the two antennas. For either procedure, the voltage gain of the service antenna G_s relative to the standard dipole antenna G_d is $G_s/G_d = V_s/V_d$, where V_s and V_d are the voltages delivered to the receiver input using the service and standard dipole antennas, respectively.

If the transmission line or balun between the antenna and receiver is different from the standard cable and balun supplied with the instrument, the antenna calibration must include the cables and baluns.

ANTENNA-SUPPORTING MAST

The receiving antenna is ordinarily supported at a height of 10 to 30 ft. above ground, depending on the measuring technique employed. For the 10-ft. height, a simple mast of metal tubing can be used. For the 30-ft. height, a special mast is required to raise and lower the antenna, and the mast arrangement should permit the vehicle to move over limited distances with the mast elevated.

The measuring unit shown in Fig. 7 employs a telescoping mast of five sections of aluminum tubing[a] elevated by low-viscosity oil forced in under pressure; the mast descends under gravity when the pressure is relieved. A handle inside the vehicle permits the mast to be rotated to orient the receiving antenna.

CHART RECORDER

For measurements made with the vehicle in motion, a chart recorder is employed. The chart can be driven from the vehicle speedometer or a drive motor. The pen element of the chart recorder is driven by a galvanometer coil; excitation of the galvanometer is provided by a dc amplifier, which may be built into the field-strength meter or may be a separate accessory.

When the chart recorder is employed, the recorder pen element must be calibrated against the receiver output indicator of the field-strength meter. The d-c amplifier is adjusted for balance at the ends of the meter scale, and a calibration curve is prepared for intermediate values.

Power Supplies

The power drain of the measuring equipment can be fairly substantial, especially if much accessory equipment is employed. It is usually preferable to provide a power source for the measuring equipment separate from the vehicle battery. This may consist of a separate battery bank to operate the meter and accessories, or a separate 115-v. ac generator may be mounted in the vehicle.

MEASURING PROCEDURES AND TECHNIQUES

The FCC FM and TV Technical Standards prescribe measuring methods to be employed in making measurements to be submitted to the Commission. These methods are also usually employed in making station-coverage surveys, although variations from the official procedure are frequently taken. The Television Allocations Study Organization report recommends a number of changes in the FCC procedure and also recommends the testing of a radically new measurement technique. The following paragraphs summarize the present requirements of the Commission's Standards and indicate the changes recommented by TASO. The proposed revised method is also described.

FCC STANDARD METHOD[12]

The Commission's Technical Standards require field-strength-measurement surveys to be made with mobile equipment along roads following as closely as possible to radial lines from the transmitter, laid out along bearings separated by 45° beginning with true North. Measurements are required out to a point in each direction somewhat beyond the field-strength contour which it is desired to establish. Continuous recordings of the field strength are made along the roads employing the chart recorder. A minimum chart speed of 3 in. per mile is required. Fig. 9 shows a sample of a typical chart recording obtained by this method.

The completed recorder charts are divided into not less than 15 sections in each direction. Each section of the chart is analyzed to determine the median (50 percent) field for each section. The chart median values are then converted to received field strength by combining the individual calibrations of the antenna, transmission line, field-strength meter, dc amplifier, and chart recorder as discussed above.

The received fields must be corrected for the field expected at a receiving antenna height of 30 ft. above ground. The Commission's Standards do not specify the conversion factor to be employed, but it has been common practice to assume the field strengths to increase linearly with antenna

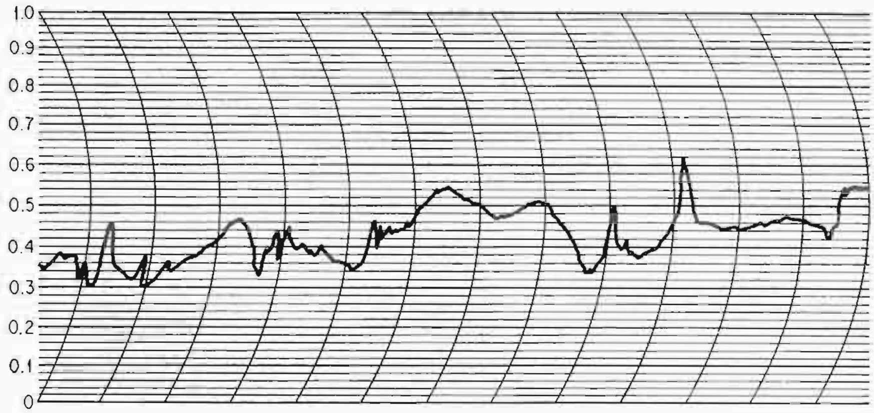

Fig. 9. Sample of typical recording chart showing the chart record obtained in making mobile field-strength recordings.

height, as indicated by classical propagation theory. For this assumption the relationship between the field E_{30} which would be expected at 30 ft. and the field measured at a receiving antenna height H_r is $E_{30}/E_H = 30/H_r$. For example, the ratio of the field at 30 ft. to the field at 10 ft. is 30/10 = 3.0, or 9.5 db.

The median fields as established in accordance with the procedure described above are plotted as a function of distance from the transmitter, and a smooth curve is drawn through the plotted points. Fig. 10 is a typical graph showing the plotted field strengths as a function of distance from the transmitter, together with the smooth curve through the plotted points. The dashed curve in Fig. 10 is the predicted field strength calculated using the propagation curves and prediction methods specified in the FCC Television Broadcast Technical Standards.[13]

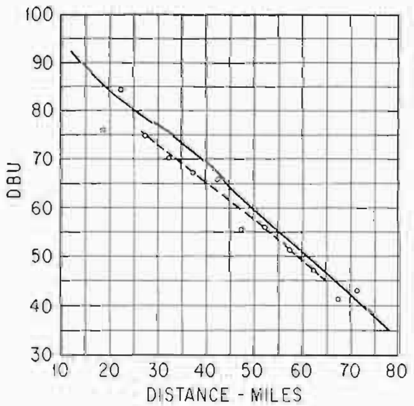

Fig. 10. Graph of measured field strength vs. distance for a typical radial route series of measurements. Each circle represents the median value of field strength for a 5-mile recording interval. The dashed line is a best-fit curve through the points. The solid line is the expected field strength computed using the FCC F(50,50) curves.

Individual graphs of median field strength versus distance as shown in Fig. 10 are prepared for each of the directions along which the measurements were made; the distances to the desired field strength contours, selected from Table 2, are determined in each direction. These distances are then plotted on a suitable map, and contours are drawn to produce a finished map such as shown in Fig. 1.

TASO RECOMMENDED CHANGES IN FCC PROCEDURE

TASO has recommended that the radial route-measuring pattern be modified to permit wider discretion in the selection of the measuring routes. A minimum of eight routes is recommended, selected to encounter representative terrain and to permit reasonable interpolation between adjoining radials. Additional routes, including branch routes, are recommended where needed.

In the analysis of the recorder tapes, TASO has recommended that the sections of the route chosen for analysis be as uniform as possible, with a minimum length of 2 miles.

One of the most important changes recommended by TASO in the present procedure is in the antenna height-gain correction factor. The application of the linear height-gain function discussed above is recommended only in relatively flat terrain, and in rolling or rough terrain the following height-gain factors (in decibels) are recommended to convert from 10- to 30-ft. fields:

Channel	*Smooth Unobstructed Terrain*	*Rolling Hilly Terrain*	*Rough Terrain*
2–6	9.5 dB	8 dB	7 dB
7–13	9.5	7	5
14–83	9.5	5	2

NEW METHOD RECOMMENDED BY TASO FOR FIELD TRIALS

TASO has also recommended field trials of a radically new method of measurement. The measuring pattern for this method is laid out as a series of five concentric circles centered on the transmitter rather than along eight radial lines as now employed. Four hundred measuring points are established on these five circles distributed in approximate proportion to the square root of the radii of the circles.

Field-strength measurements are to be made at each of the 400 points so located. If the designated point is inaccessible, the measurement should be made at a location as close to the designated spot as possible and as nearly as possible at the same ground elevation. Each of the 400 measurements is to consist of a single spot measurement made with the receiving antenna at a height of 30 ft. above ground.

The data collected are to be analyzed by dividing the area surveyed into eight or more sectors not exceeding 45° in width. These sectors are to be chosen so as to include reasonably homogeneous terrain insofar as possible. For each constant-radius arc within each sector, the mean value of the spot measurements is determined.[b] This analysis provides five values of field strength as a function of distance in the direction of each section, from which curves of mean field strength versus distance for the sector can be drawn. Linear interpolation can be employed for intermediate distances between adjoining circles.

RECOMMENDED TASO METHOD FOR SPECIAL STUDIES

For purposes of scientific investigation of field-strength behavior, measurements are often required employing special techniques. One such method, recommended by TASO in making measurements to be analyzed in terms of the terrain profiles between the transmitting and receiving antennas, is briefly outlined in the following paragraphs.

A precise radial line is laid out from the transmitter on topographic maps to the distance to which measurements are to be made.[c] Along this radial line, measuring locations are marked at exact 2-mile intervals, beginning at exactly 10 miles from the transmitting antenna. The actual measurements are made precisely on the radial, at locations as close as possible to the exact 2-mile marks established as described.

The individual measurements consist of short mobile runs (100 ft. along the road) at each location so chosen, with the receiving antenna at the 30-ft. height. The chart recorder is used, and the median, minimum, and maximum values of the field for each recording are determined from the chart recording.

PRACTICAL PROBLEMS ENCOUNTERED IN MAKING FIELD-STRENGTH SURVEYS

Before any field-strength-measurement survey is undertaken, the radiated power of the transmitting installation must be established as closely as possible. The transmitter output power should be determined by means of the dummy load and maintained as closely as possible to the proper value throughout the survey. The radiated power is established from the measured transmitter output power, taking into account the antenna power gain and the transmission line and diplexer losses.

The use of a 30-ft. receiving antenna mounted on a vehicle requires special permission from police or highway authorities in most states. These requirements vary among the individual states, but full details can be obtained from the state police or highway headquarters in the various state capitals.

The operation of a 30-ft. mast presents safety hazards which require the exercise of utmost caution in the use of an elevated mast. The TASO field-strength measuring specification includes a special appendix dealing with safety requirements. When measurements are made with an elevated antenna, the need for caution must be borne in mind at all times.

FADING OF SIGNALS NEAR THE RADIO HORIZON

Fairly substantial variations in field strength with time are frequently noted near and beyond the radio horizon. These variations may be relatively rapid, occurring over a period of a few minutes, or slow variations may appear over periods of several hours. Average field strengths in this region are usually lowest during winter afternoons, and higher average fields may be observed during the evening hours and during summer. The variations in field strengths with the passage of time must be taken into account in planning and making field-strength-coverage surveys.

The observed fluctuation of the field near the horizon is believed to be due principally to variations in the refractivity gradient of the lower atmosphere, which in turn is determined by the temperature, humidity, and barometric-pressure gradients. Measurements for coverage surveys should not be made beyond the radio horizon during periods when unusual conditions of temperature, humidity, and barometric pressure are believed to prevail. In particular, such measurements should not be made during changing weather conditions or if weather fronts are known to be in the area.

The variations in field with time often result from causes which are not readily apparent, and it is frequently difficult to determine whether typical propagation conditions prevail. One method which has been proposed and tried with some success is that of establishing fixed recording stations in one or more directions, at locations near the expected outer limit service, and recording the received signal over a period of several days. These recordings will give an indication of the signal to be expected under average conditions; the coverage survey measurements beyond the horizon can be made during a period when the recordings indicate propagation conditions to be typical. Measurements should not be made on days when these recordings indicate excessively high or excessively low field strengths.

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