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FIELD-INTENSITY MEASUREMENTS

By Robert F. Field *

THE measurement of the intensity of the electromagnetic field produced by a transmitting station at a distant point has been a problem of considerable interest since the earliest radio-telegraphic transmission. In fact every reception of a radio signal constitutes a field-intensity measurement, provided an estimate of the strength of the audio signal is made and the approximate over-all sensitivity of the receiving set is known. These two conditions were, however, the stumbling blocks which until quite recently prevented all but qualitative results.

The earliest measurements of the strength of the received audio signal were made by shunting the head tele-

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FIGURE 1. Radio field intensity in millivolts per meter from a survey made by Bown and Gillett (see reference [7], page 3) for a transmitter located at 24 Walker Street in lower Manhattan, New York City. We reproduce the photograph with the kind permission of the authors, the American Telephone and Telegraph Company, and the Institute of Radio Engineers

phones, so that the signal was rendered either just intelligible or just audible. From the value of the shunting resistance and the impedance of the telephones, the amount of attenuation introduced could be calculated and thence the strength of the original unattenuated audio signal. This type of measurement depends on the existence of a threshold of audibility. This threshold is, however, a function of the audio frequency heard and of the physical condition of the listener, and varies considerably among different people. Many types of audibility meters were built which conveniently performed this shunting and indicated the ratio of the current producing the full signal to that necessary for the threshold value.

On the other hand, little was known concerning the sensitivity of the receiving set. A large antenna was used to give the maximum radio-frequency voltage. This could not be transported nor duplicated, so that the early field-intensity measurements were confined to the study of the variation of field strengths at one point throughout the day and year. A survey of the variation of field strengths with position around a transmitter was impossible.

The advent of the vacuum tube and its use as amplifier, oscillator, and detector, both non-regenerative and regenerative, greatly widened the scope of field-strength measurements. L. W. Austin[1] in 1917 described a method of measuring the sensitivity of the receiving set. An oscillating vacuum tube produced in a tuned circuit a radio-frequency current which was measured by a thermocouple and galvanometer. To this circuit was coupled the receiving set, whose output was measured with an audibility meter.

In the discussion of this paper, C. R. Englund[2] suggested that this sensitivity measurement be made for every field-strength observation, in such a way that the signal introduced into the receiver by the local oscillator produced in the telephones the same response as that obtained from the radio signal being measured. The voltage thus introduced into the receiver, as calculated from the reading of the thermocouple meter and the constants of the circuits, is equal to that similarly introduced from the antenna.

In order to obtain the voltage induced in the antenna by the electromagnetic wave, the constants of the antenna and its coupling to the receiver must be known. It is impossible to introduce the comparison voltage directly into the antenna, thus making the antenna system a part of the receiver, because generally the observer has no control over the transmitter and cannot shut it down when he wishes to make a comparison measurement. G. Vallauri[3] in 1919 described the use of two similar loop antennae, so oriented that one received the radio signal with maximum intensity, while the other was in the null position with reference to this signal, and so could have the comparison signal introduced into it at will.

C. R. Englund[4] in 1922 used a single loop which could be rotated through 90° from the maximum to null position. He used a **T**-section attenuator to control the voltage introduced into the loop instead of the more usual method of varying a mutual inductance. He

[1] L. W. Austin, "The Measurement of Radiotelegraphic Signals with the Oscillating Audion," *Proceedings of the I.R.E.*, Vol. 5, No. 4, August 1917, pp. 239–246.

[2] C. R. Englund, Discussion on L. W. Austin's Paper, *Proceedings of the I.R.E.*, Vol. 5, No. 4, August 1917, p. 248.

[3] G. Vallauri, "Measurement of the Electromagnetic Field of Waves Received during Transoceanic Radio Transmission," *Proceedings of the I. R. E.*, Vol. 8, No. 4, August 1920, pp. 286–296.

[4] C. R. Englund, "Note on the Measurement of Radio Signals," *Proceedings of the I. R. E.*, Vol. 11, No. 1, February 1923, pp. 26–33.

also used a plate-current meter in the detector-tube circuit, in place of telephones whenever possible. Englund's methods were thus identical with present practice. All of the early measurements were made on long-wave telegraphic transmitters. The dot and dash signals and heavy static interference were the factors that prolonged the use of head telephones and the audibility meter as instruments of comparison.

The advent of broadcasting on the frequency band, 500 kc.[5] to 1500 kc., stimulated the interest in field-intensity measurements and expanded the points at which measurement should be made to a large number scattered over the area around the transmitter and extending outward some hundreds of miles. A portable set built to meet the new conditions imposed by the higher frequencies involved was described by Bown, Englund, and Friis[6] in 1923. The most serious problems were those of shielding the loop from the local oscillator and of building an attenuator whose calibration would hold at a frequency of 1000 kc. The latter consideration caused a reversion to the old antenna practice of introducing the voltage from the local oscillator into the receiving set, that is, placing it across the grid of the first tube. This increased the magnitude of this voltage by the step-up ratio of the loop, perhaps a fifty-fold increase, and by that much reduced the severity of the demands on the attenuator, which took the simple form of a voltage divider.

Surveys of the field around certain transmitting stations in the larger cities followed. Bown and Gillett[7] in 1923 made surveys in New York and Washington. Expressing field strength as the millivolts per meter of height which would be induced in a vertical antenna,[8] they plotted contour lines of equal field strength around the transmitter ranging from 100 to 0.1 millivolts per meter. The shapes of these contours are determined in the densely populated city areas by the location of the tall buildings and in the outlying districts by the topography of the country, especially by river valleys and large water areas. Tall buildings cast shadows and cause rapid attenuation while water courses allow minimum attenuation.

Bown, Martin, and Potter[9] extended the New York City survey and discovered peculiarly shaped contours to the northeast of the city which suggested interference between waves which have traveled by slightly different paths to reach a given point.

Two recent surveys are those by McIlwain and Thompson[10] in Philadel-

[5] *kc.* is here used to mean kilocycles per second and *cps.* to mean cycles per second.

[6] R. Bown, C. R. Englund, H. T. Friis, "Radio Transmission Measurements," *Proceedings of the I. R. E.*, Vol. 11, No. 2, April 1923, pp. 115–152.

[7] R. Bown and G. D. Gillett, "Distribution of Radio Waves from Broadcasting Stations over City Districts," *Proceedings of the I. R. E.*, Vol. 12, No. 4, August 1924, pp. 395–409. A. G. Jensen, "Portable Receiving Sets for Measuring Field Strengths at Broadcasting Frequencies," *Proceedings of the I. R. E.*, Vol. 14, No. 3, June 1926, pp. 333–344.

[8] The relation between a field intensity e, expressed in microvolts per meter, and the total voltage E which it induces in a loop is

$$E = \frac{2\pi f A N}{v} e$$
$$= 2.09 \times 10^{-8} fANe$$
$$= he \quad \text{(microvolts)},$$

where f = frequency in cps.
A = area of loop in square meters
N = number of turns on loop
v = velocity of light in meters per second $= 3 \times 10^8$
h = the equivalent height of loop in meters $= 2.09 \times 10^{-8} fAN$.

[9] R. Bown, D. K. Martin, and R. K. Potter: "Some Studies in Radio Broadcast Transmission," *Proceedings of the I. R. E.*, Vol. 14, No. 1, February 1926, pp. 57–131.

[10] K. McIlwain and W. S. Thompson, "A Radio Field Strength Survey of Philadelphia," *Proceedings of the I. R. E.*, Vol. 16, No. 2, February 1928, pp. 181–192.

phia and by C. M. Jansky, Jr.,[11] in Minneapolis. McIlwain and Thompson made their receiving set into a direct-reading portable field-strength meter by calibrating it in the laboratory and by providing sufficient controls to assure the constancy of this calibration. While their work shows that this is an entirely feasible method, the consensus of opinion at the present time seems to favor the older comparison method. It is much easier to stabilize an oscillator and attenuator with their one thermocouple meter than a multistage radio-frequency amplifier having a voltage gain of a million fold at its maximum. The extra care necessary to insure the constancy of calibration of this multistage receiver certainly balances the time taken by the comparison measurement with the local signal generator, and the latter procedure removes the possibility that a whole day's work will be lost by a change in calibration, discovered only at the end of the day's run.

The survey reported by Jansky covered a greater rural area than the earlier urban surveys and in it is discussed the quality of reception accorded large farming districts in a sparsely settled community. It appears that the field strengths of 5 to 30 millivolts per meter, which are usually considered necessary in urban areas to raise the signal level sufficiently above the high static level (mostly man-made) existing there, are unnecessary for the rural dweller. Artificial interference is much less in the country, and the demands for continuous service are perhaps not as exacting. At any rate, a field strength of 100 microvolts per meter is an acceptable lower level. This report is typical of recent surveys in its emphasis on the economics of broadcasting and on the general principles which must govern the allocation of broadcasting stations in this country.

Edwards and Brown[12] in two recent papers have discussed the coverage in city and suburban areas which may reasonably be expected from transmitters of different power ratings. The latest equipment used by the Radio Division of the United States Department of Commerce is also described. It is a refinement of the sets described by Friis and Bruce[13] and has a frequency range of 200 kc. to 6000 kc. and a field-strength range of 10 microvolts per meter to 4 volts per meter. These large ranges are obtained by introducing into the loop a voltage from the local signal generator large enough to be measured by a vacuum-tube voltmeter and attenuating this large signal in the intermediate-frequency amplifier of the superheterodyne receiver. This transfers the difficulties attendant on the design of an attenuator giving 110 db attenuation at these frequencies to those arising from the design and calibration of a detector which may operate linearly over an equal voltage range. This method is applicable only where the signal generator, attenuator, and receiver are constructed and calibrated as a unit.

The older method, where the signal generator and attenuator are a unit independent of the receiver and indicating instruments, is illustrated schematically in Figure 2. The signal generator produces a radio-frequency

[11] C. M. Jansky, Jr., "Some Studies of Radio Broadcast Coverage in the Middle West," *Proceedings of the I. R. E.*, Vol. 11, No. 10, October 1928, pp. 1356–1367.

[12] S. W. Edwards and J. E. Brown, "The Use of Radio Field Intensities as a Means of Rating the Outputs of Radio Transmitters," *Proceedings of the I. R. E.*, Vol. 16, No. 9, September 1928, pp. 1173–1193. "The Problems Centering about the Measurement of Field Intensity," *Proceedings of the I. R. E.*, Vol. 17, No. 8, August 1929, pp. 1377–1384.

[13] H. T. Friis and E. Bruce, "A Radio Field Strength Measuring System for Frequencies up to Forty Megacycles," *Proceedings of the I. R. E.*, Vol. 14, No. 4, August 1926, pp. 507–519

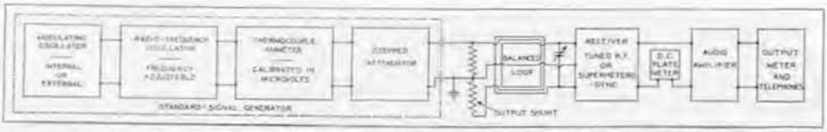

Figure 2. Schematic arrangement of apparatus for measuring radio field intensity by the comparison method described in this article

voltage at the input terminals of the attenuator which is adjusted so that there is introduced into the loop the same voltage as that induced by the incoming signal. The attenuator is set at zero when the incoming signal is observed, with the loop turned for maximum response, while the loop is set at its null with respect to the incoming signal when the local signal is used. The attenuator may be shunted, if the resistance which it introduces into the loop is comparable to that of the loop, thereby increasing the selectivity and sensitivity of the receiver. This shunt is usually so chosen as to decrease the resistance of the attenuator and also the induced voltage by a power of ten. It should have a balancing resistance if the loop is balanced. The receiver may have either a multiple-stage radio-frequency amplifier, or a detector, oscillator, and intermediate-frequency amplifier. Its low-frequency detector is used as an uncalibrated vacuum-tube voltmeter. The direct-current meter in the plate circuit of this detector indicates by the equality of its deflections when the local signal has been made equal to the incoming signal. Its reading is independent of whether the carrier is modulated or not, except as the modulation affects the output of the transmitter. Thus, field-intensity measurements may be made at any time that the transmitter is operating without interruption of its regular schedule.

Some audio amplification is usually added to make easy the finding and identifying of any incoming signal with head telephones. With an output meter replacing the head telephones, the response produced by a modulated radio signal may be observed. The variations in the fractional modulation of the transmitter may be observed qualitatively. When the field strength produced by any two transmitters has been measured in the manner just described, using the direct-current meter, the audio-frequency responses produced by their modulations may be compared by noting the corresponding deflections produced on the output meter and correcting for any difference in field strength between the two stations. These readings indicate the degree to which these stations utilize their respective carriers.

If the signal generator can be modulated, the fractional modulation of the incoming signal may be estimated. A field-strength measurement is made and the attenuator set to give equality of carriers of local and incoming signal. The fractional modulation of the signal generator is then varied until equal response is indicated on the output meter for the local and incoming signal.

The following equipment is necessary for making field-strength measurements by the method schematically illustrated in Figure 2. A Type 403-C Standard-Signal Generator[14] with 400 cps. internal modulation and self-contained attenuator feeds a balanced loop through a Type 403-P10 Output Shunt, which shunts the attenuator to one-tenth its normal resistance and inserts one ohm into each side of the

[14] Charles T. Burke, "The Standard-Signal Method of Measuring Receiver Characteristics," *General Radio Experimenter*, IV, 10, March 1930. Also General Radio Company, Catalog F, pp. 88–90.

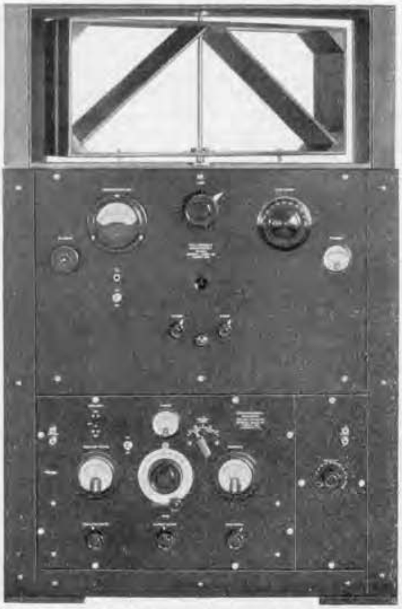

FIGURE 3. A field-strength measuring set making use of a TYPE 403-C Standard-Signal Generator. See accompanying description

loop. The normal frequency range of the signal generator is that of the broadcast band, 500 kc. to 1500 kc. The voltage range extends from 5 microvolts to 50,000 microvolts used directly or from 0.5 to 5000 microvolts using the output shunt.

A receiver having, with one stage of audio amplification, a sensitivity of 10 microvolts per meter will give satisfactory results. The better grade of present-day broadcast receivers meets this requirement. The greatest drawback to their use is the large capacity low-voltage storage battery needed to heat their alternating-current tubes. A micro-ammeter is inserted in the plate circuit of the low-frequency detector. The head telephones and a TYPE 486 Output Meter[15] are connected in the output circuit of the audio amplifier, which must be so arranged that there is no direct-current voltage across the output meter.

The design of the attenuator in the TYPE 403-C Standard-Signal Generator is such that its maximum error at maximum attenuation is less than 15 per cent. The shielding of the signal generator as built at present[16] is such that at no point more than six inches away from the case is the effect of the magnetic field on a loop greater than that of an electromagnetic field of 50 microvolts per meter. At a distance of 2 feet above the generator, the equivalent field is less than 2 microvolts per meter.

A recent installation of a TYPE 403-C Standard-Signal Generator in a portable field-strength set for use by the Shepard Broadcasting Service of Boston, Massachusetts, is shown in Figure 3. Here a rack-type mounting is used with the loop and signal generator separated by the receiver. The loop is turned by the handle at the center top of the panel through bevel gears. The leads from the loop pass down through the hollow shaft and then in shielded cable, one pair to the receiver and one pair to the output shunt mounted on the signal generator. The receiver is a Radiola Superheterodyne, Model 80, with the alternating-current tubes supplied from a large storage battery (not shown). Their control rheostat and switch are shown at the left on the receiver panel. Near them is the 200-

[15] John D. Crawford, "A Rectifier-Type Meter for Power Output Measurements at Audio Frequencies," *General Radio Experimenter*, IV, 2–3, July-August 1929. Also General Radio Company, Catalog F, p. 106; Bulletin 932, p. 40.

[16] The recent improvements in shielding consist in: doubling the thickness of copper on the top over the oscillator coil; soldering all parts of the box lining; encasing the modulation and output voltmeters in copper shields; and placing an L-shaped shield along the upper front edge. These changes may be made on the older TYPE 403-C Standard-Signal Generator at a cost of $22.00. All signal generators ordered on or after January 24 have the new shielding.

micro-ampere Weston meter in the plate circuit of the low-frequency detector. The dial at the right tunes the loop. This unit is mounted immediately behind the driver's seat in a Ford truck.

Figure 4 shows the field-strength measuring set mounted in the truck. The passenger's seat has been tipped forward to give a full view of the panel.

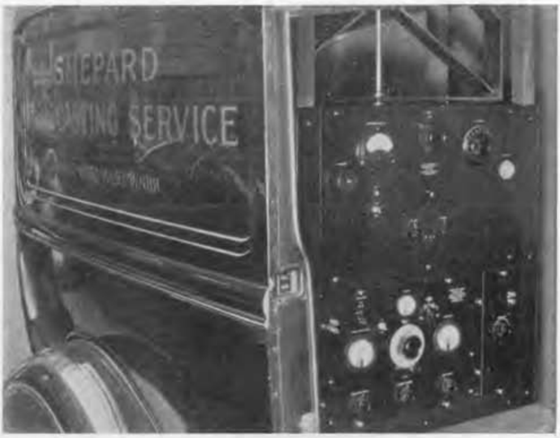

Figure 4. The measuring set in position

Miscellany

Since the publication of the anniversary number of the *Experimenter* last June, two new members have been added to our Engineering Department. They are William N. Tuttle and Roy L. Steinberger.

Mr. Tuttle received his doctor's degree for work in physics at Harvard University last year. He is specializing in problems pertaining to acoustics.

Mr. Steinberger is also from Harvard. He has completed the necessary work for his doctor's degree and, after a year and a half of part-time work, is now able to devote all of his time with us. During this period, he has been working on special applications of magnetostriction, particularly those relating to subaqueous communication. This work has been carried on under the direction of Dr. G. W. Pierce of Cruft Laboratory at Harvard, with whom we have just executed a patent license which will permit us to investigate the subaqueous field in an active manner.

* * * *

The Type 403-P10 Output Shunt is obtainable for a price of $4.00. It is fitted with plugs for connecting to the output terminals of the standard-signal generator and with three binding posts for connecting to the loop. We are prepared, on request, to supply it without extra charge in place of the Type 418 Dummy Antenna usually supplied with the Type 403-C Standard-Signal Generator.

The General Radio *Experimenter* is published monthly to furnish useful information about the radio and electrical laboratory apparatus manufactured by the General Radio Company. It is sent without charge to interested persons. Requests should be addressed to the

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Field-strength measurements are described in the January, 1931, issue of the *General Radio Experimenter*. Extra copies are available on request. Please address Section X, Engineering Department, for further information.

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