SIGNAL VARIATIONS OVER A FIVE-YEAR PERIOD

by Len Spencer, BE Consulting Author,
and Chief Engineer, CKAC,
Montreal, Quebec.—Daily recording of signal strength for five years has revealed large variations, apparently due to temperature changes.

In March, 1958, operation of CKAC's 730-kHz, 50-kw directional installation began. In keeping with approved practice, we took daily field-strength readings and recorded them, along with the temperature, at our downtown Montreal studio. This studio is within the 50 mv/m contour and is 18.5 miles from the antenna site. The purpose of the readings was, of course, to detect pattern shift. For the readings we used an RCA WX-2c field-strength meter permanently mounted inside the building.

As the first winter approached, a significant increase in field strength occurred until, on a day of bitter coldness (−14°F), the reading was 38 mv/m, compared to our proof reading of 24 mv/m.

By this time we were alarmed. Both transmitter and receiving-point meters were checked and found reasonably accurate. A trial proof was run, and all check points were found to be high in the same ratio as the daily check point at the studio. A thorough search of engineering texts, handbooks, and journals revealed no specific answer to our frustrating problem.

With the return of spring and higher temperatures, our readings returned to normal. By the third year of operation, a clear pattern of annual variation was evident; in winter our field strength in mv/m was more than half again that of summer. Effective propagation was clearly a matter of temperature.

In order to establish that temperature alone was the governing factor, we researched weather records and found no correlation of recorded field strength with such factors as rain, snow, sleet, cloudiness, or freedom from ambient moisture. Other variables given consideration were antenna common-point currents, leg currents, and phasing. The only variations found were directly related to line-voltage fluctuations. The maximum common-point current was 15.1 amps and the lowest, 14.8 amps. Temperature alone, therefore, appeared to be the controlling factor in our field-strength variation.

Our record keeping continued over a five-year period. Graphic representation of field strength vs time of year is shown in Fig. 1. Average extremes in field strength are shown for each month during the five year period, and the curve shows the mean average of monthly variations.

It can be seen from Fig. 1 that CKAC's effective radiated power was much higher in January than in June. Assuming that the June minimum of 21 mv/m represents nominal radiation of 50 kw, effective radiation of 164 kw in January can be developed in this manner:

Since field strength is proportional to the square root of the power[1],

$$F \alpha \sqrt{P} \qquad \text{(eq 1)}$$

Therefore,

$$P \alpha F^2 \qquad \text{(eq 2)}$$

where F = Field-strength in mv/m
P = Power in kw

Our next step is to establish a ratio between the maximum winter reading and the minimum summer reading; therefore,

$$\frac{P_w}{P_s} = \frac{F_w^2}{F_s^2} \qquad \text{(eq 3)}$$

where P_w = winter power in kw
P_s = summer power in kw
F_s = field strength in summer
F_w = field strength in winter

Developing for effective winter power, we arrive at the formula

$$P_w = P_s \left(\frac{F_w}{F_s}\right)^2 \qquad \text{(eq. 4)}$$

Substituting known values from Fig. 1.:

$$P_w = 50 \left(\frac{38}{21}\right)^2 = 164 \text{ kw}$$

The effects of temperature upon field strength can be seen in Fig. 2. Fig 3 is the result of 1,325 readings at the studio and over 32,000 at the transmitter. From it one can easily observe a definite cyclic pattern in field strength. During the investigation, required readings were taken at specified points on designated radials; in addition, readings were also taken at the null point at three-month intervals. These readings substantiated our studio monitor findings, but the variations were not so pronounced.

It is our intention to continue this investigation by taking measurements on at least two radials during the winter and summer months. These will be made at distances much closer to the antenna in order to determine whether the effect is as great at shorter distances.

During the period of this investigation, parallel discoveries were made by Mr. Donald W. Howe, Jr., at WORC[2] and by Mr. Robert A. Jones at WIMS and WFRL[3]. From the data supplied by Mr. Howe, the curves in Fig. 4 have been developed for this article. Again the tempera-

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[1] Terman, F. E., *Radio Engineering* (McGraw-Hill Book Company, Inc. New York 3rd ed. 1947), p. 611.

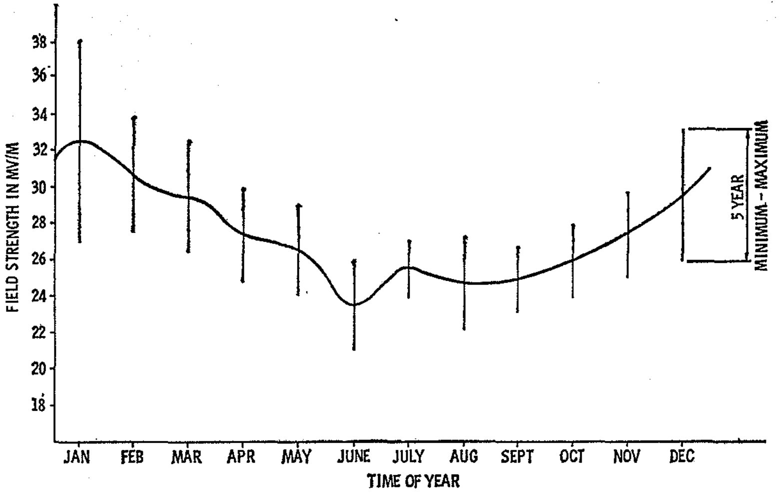

Fig. 1. Measured field strength at various times of year shows extremes of variation.

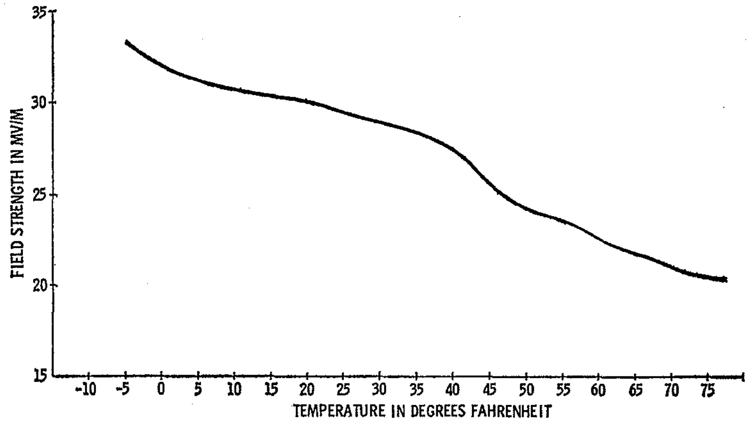

Fig. 2. Calculations indicate a relationship between signal strength and temperature.

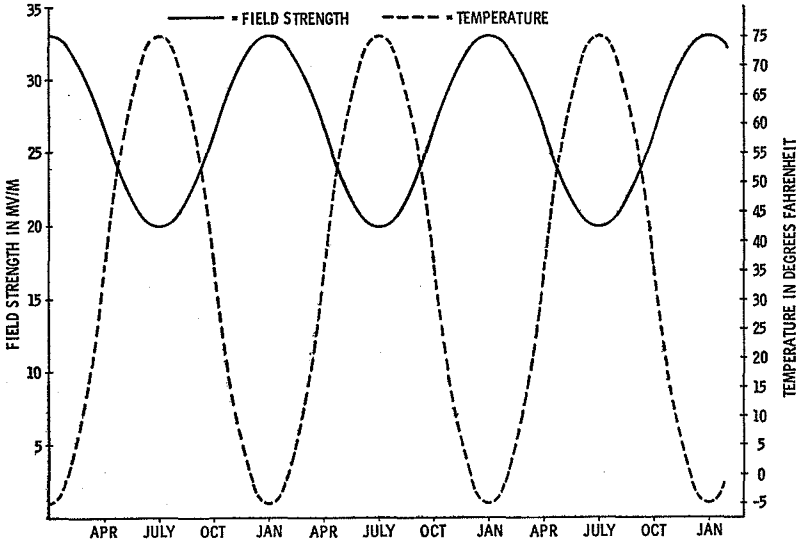

Fig. 3. Cyclic nature of variations reveals correlation with annual temperature changes.

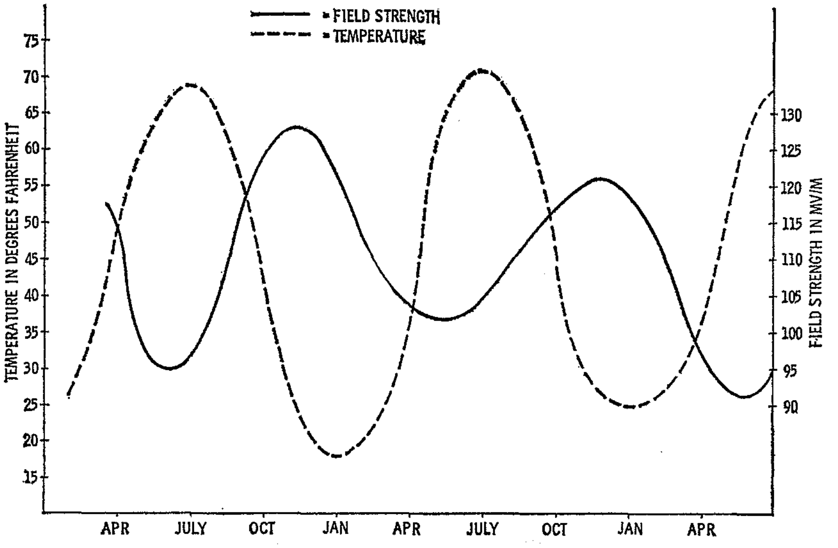

FIG. 4

Fig. 4. Curves of field strength and temperature developed from information for WORC.

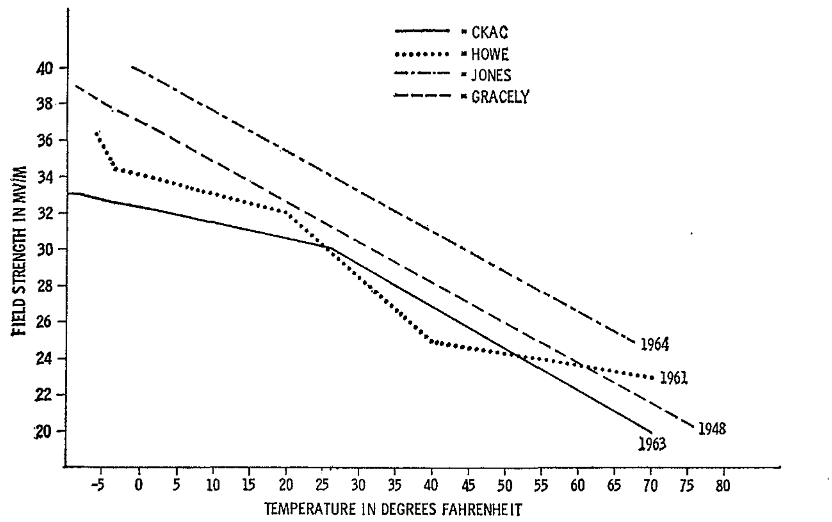

Fig. 5. Variation measurements from four sources over a seventeen year period.

ture/seasonal variation in field strength is evident. Observations of signal variation were published as early as 1949 by F. R. Gracely.[4] In each instance the temperature/seasonal variation in field strength is evident.

Fig. 5 is a comparative evaluation of each recorded report of seasonal variations. The phenomenon is consistent over a number of years, but variations in the degree of the effect would indicate that geographical location may be significant in assigning the cause.

From the data on CKAC, WFRL, WIMS, WORC, and Gracely, Table 1 has been prepared to show the variations in effective radiated power experienced at different locations over a period of time. Effective power has been computed from appropriate field-strength readings and the formula of Equation 4. Since information with respect to recorded temperatures was not available, a direct correlation between temperature and field strength could not be established.

Assigning the specific cause of this apparent phenomenon is difficult because very little research has been made, or at least, is available. Among serious hypotheses are temperature-coefficient factors in ground and air conductivity, and radio-wave absorption by heavy runs of tree sap in heavily forested areas.

One study of this apparent phenomenon was undertaken by Frederick R. Gracely. In his summary he notes that variations of ground-wave signal intensity at standard-broadcast frequencies appear to be more closely related to changes in temperature than to any other single commonly observed meteorological measurement. Mr. Gracely's conclusions were based on an analysis of signal intensties and weather conditions over six paths between 30° and 45° north latitude, and at distances from 76 to 558 miles from respective radiation centers.

The distances involved in this study tend to indicate that ionospheric transmission is involved, but the CKAC observations were made at 18.5 miles and consistently between 9 and 10 a.m. These facts and the similarity of observations would seem to indicate that the ground wave is the more influential in producing the variations in signal strength.

At CKAC the question of the effect of changes in the character of vegetation was raised, because the difference of absorption or attenuation by tree foliage is quite marked in the 30 to 300 mHz range. It was suggested that low signal strength during the summer months could be attributed to this effect. This suggestion was discarded with the discovery that during January and February thaws and causal high temperatures, signal strength decreased to values obtained in early fall and spring.

This effect was also noted by Gracely, ". . . when an attempt was made to obtain correlations seasonally with vegetations, signal intensities at the same or similar temperature in various seasons were compared, but no appreciable trend or tendency toward grouping was apparent. Furthermore, there were short periods of high atmospheric temperature on a few winter days when signal intensities corresponding to the same temperatures in summer were closely duplicated, although presumably the vegetation would have been in a condition much different from that of summer. Two points should be further emphasized in this connection: The survey reported below consists of a large number of observations distributed over a range of frequencies, path locations, and path lengths; and the main bodies of the data in the two reports were in substantial agreement concerning the intensity versus temperature relationship."

"Probably the most promising data, next to temperatures, are those on precipitation," Gracely continues. "On most of the paths there were frequent instances of marked increases in signal intensity during, and for a few days following, periods, some of them with equally heavy rainfall, when no such increase occurred."

This was also observed at CKAC, but in nearly all of the observations the rainfall was also accompanied by a drop in temperature. This tends to support the first hypothesis, that temperature alone is the predominant factor in signal variations. No apparent correlation with barometric pressure appears in either study.

The 1949 paper corroborates the temperature theory: "Comparisons of intensities with atmospheric pressure, dew point, and vapor pressure were, in general, inconclusive. A few highly localized coincidences with humidity were observed: but

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[2] Howe, Donald W. Jr. "Letters to the Editor" *Broadcast Engineering*, Sept 1964, p. 6.

[3] Jones, Robert A. "Winter-to-Summer Conductivity Effects," *Broadcast Engiing*, Sept 1964, p. 12.

[4] Gracely, F. R., "Temperature Variations of Ground-Wave Signal Intensity at Standard Broadcast Frequency," *Proc IRE*, April 1949, Vol. 37, No. 4, p. 360.

not enough to form a basis for generalized results."

It is assumed that ground conductivity and inductivity play a significant part in seasonal field-strength variations. Both are related to the material involved. Conductivity can vary considerably; sea water has conductivity of 4.64 × 10^{-11} emu, and a typical Pennsylvania countryside has conductivity of 6 × 10^{-14} emu, according to available tables. Translating this to terms of resistivity, we apply the formula

$$R = \frac{1}{G} \qquad \text{(eq 5)}$$

where R = resistivity in ohms/cm^3 and G = conductivity in mhos/cm^3 But first emu must be converted to mhos/cm^3. This is accomplished by multiplying by the factor 10^9.

$$G = (\text{emu})\,10^9 \qquad \text{(Eq 6)}$$

Therefore

$$R = \frac{1}{(\text{emu})10^9}$$

For sea water

$$R = \frac{1}{(4.64 \times 10^{-11})10^9}$$

$$= 22 \text{ ohms/cm}^3\text{, approximately}$$

For the ground of Pennsylvania, the answer is approximately 17,000 ohms/cm^3. The resistivity of pure water would be approximately one-seventh that of the earth. It can be seen that the introduction of moisture into the ground can affect its resistivity considerably.

Table 1

Station	Frequency	Licensed Power	Season	Field Strength in mv/m	Maximum Effective Power
CKAC	730 kHz	50 kw	Winter	38.0	164.0 kw
			Summer	21.0	
WFRL	1570 kHz	5 kw	Winter	8.8	14.9 kw
			Summer	5.1	
WIMS	1420 kHz	5 kw	Winter	12.5	16.0 kw
			Summer	7.0	
WORC	1310 kHz	5 kw	Winter	130.0	10.0 kw
			Summer	92.0	
Gracely	—	50 kw	Winter	47.0	364.5 kw
			Summer	17.5	

The preceding can also be applied to inductivity, which is measured in terms of dielectric. The dielectric values of sea water, fresh water, and the described countryside are: 81, 80, and 13, respectively, in esu units. The entrance of moisture in excess of normal can also affect the dielectric of the ground through which a signal must pass. The effect which conductivity and resistivity have on signal strength can be ana-

• *Please turn to page 38*

SIGNAL VARIATIONS RESEARCH PROJECT

During the past few years a number of observations have been made at broadcast stations throughout the country which corroborate the experience of CKAC, Montreal, Quebec, presented in this issue of Broadcast Engineering. Other items and articles of the same nature have appeared in previous issues.

In substance, it appears that there are seasonal variations in radiated signal strength which may or may not be the result of long-range, seasonal, temperature variations. In some cases the variations have resulted in extremes of radiation in excess of three times the licensed strength (in the case of CKAC, from 50 kw to 164 kw, effective). The consequences of these variations could theoretically result in any one of the following violations of engineering requirements: interference, pattern distortion (depending on how extensive the proof-of performance has been), failure to meet minimum contour strength, and retrogressive signal strength in normally fringe service areas.

In order to provide science with sufficient data to fully explore and act upon the problem, Broadcast Engineering is prepared to serve as the control agent in a major world-wide research project.

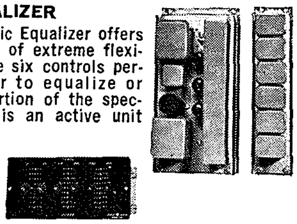
This will require the cooperation of a large number of our subscribers over a reasonably long period of time. As envisioned, the project should encompass all of the communications spectrum from the low to super-high frequencies, and at various points within each of the bands. Consideration should also be given to geographic distribution, normal weather patterns, radiated power, and the natural conductivity of soils at different radials in each pattern radiated.

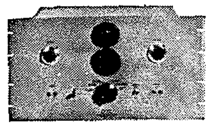
At the conclusion of the project (which should take at least two years in order to establish cyclic patterns) Broadcast Engineering will accumulate, assess, and report at length upon the findings obtained from the project.

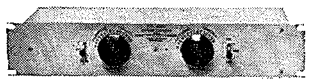
If your or your station is interested in becoming a part of this project, please write to

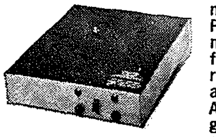
The Editor
Broadcast Engineering
4300 West 62nd Street
Indianapolis, Indiana 46206

In your correspondence, please include the call letters of the station participating, day and night power, exact geographic coordinates of the antenna site, appropriate contours (for AM stations 25, 5, and 1 mv/m), and if appropriate, for both day and night patterns; for FM and TV, city grade, and A and B; for microwave, normal receiving-point strength and degree of directivity, and an indication of whether appropriate instruments for reading field strentgh are available.









Signal Variation

(Continued from Page 19)

lyzed by imagining an infinite number of capacitors in series, with an infinite number of resistors across the capacitors. If the dielectric constant increases and the resistance decreases, conductivity is considerably increased.

There are two additional factors which must also be given consideration in a study of the problem. The first is skin effect, wherein the depth of signal penetration into the earth is dependent on the frequency of the transmitted signal. In substance this means the lower the frequency, the greater distance into the earth the signal goes. Terman gives 20 feet at 10mHz.[5] This is developed from the maxim that the depth of penetration varies inversely as the square root of the frequency. The other factor is dependent upon the "skin-effect" and is called "tilt." As a wave front crosses the earth, the lower part of the wave strikes the earth and is absorbed into it. This absorption causes the upper portion of the wave to fall forward in an attempt to compensate for the signal loss. This results in a "tilt" in the forward direction. This tilt, however, never exceeds 15°, and like skin effect, is a product of the frequency.

There was a belief that the crystalline formation in frozen earth might be responsible for the signal variations, but a National Research Council of Canada Bulletin (June, 1965) reported the work of M. Khalifa and R. M. Morris on "Transmission Line Insulators Under Rime Ice." In this report it is stated that ice is a good insulator with a conductivity of 1×10^{-8} μmho per cm^3 at 10° F. The average conductivity between the transmitter and monitoring point at CKAC is 6×10^{-5} mho per cm^3. Thus it appears that reducing the temperature of water would tend to reduce signal during the winter months.

This was confirmed by some kitchen-variety experiments with a home-type freezer. A cubic inch of water changed in resistance from 9,000 ohms in the liquid state to 1.5 megohms as ice. Next, a one cubic-inch container of moist earth was frozen, and the results were as follows:

Time	Resistance
0 minutes	25 k
10 minutes	35 k
30 minutes	100 k
1 hour	2 meg
2 hours	2 meg

A strange occurrence was noted during the experiments; when breath was blown across the frozen earth, resistance decreased sharply and after a short time returned to its previous value. The experiment was repeated at short intervals, and after about five minutes the effect ceased, the resistance remaining constant. The same experiment with ice produced similar results, but it could be observed that the film of water between the electrodes froze immediately after the breath air ceased to flow across it.

With dry earth, resistance was 60,000 ohms at room temperature and 20 megohms when reduced to freezing temperatures. Again the breath experiment achieved reduction of resistance.

It appears that summertime low-signal complaints from listeners are justified, at least in relation to maximum signal strength in the winter. To this time only the Northeast, East, and Central regions have reported the phenomenon. It would be of interest to know whether other regions are also affected, and to what extent. In their presentations neither Mr. Howe nor Mr. Jones indicated whether ice was present during the periods of high conductivity. It has been assumed, because of their locations, that this was the case.

For the CKAC data supplied in this paper, the sincerest gratitude is extended to G. Champagne and P. Smith for their faithful reporting and recording over a long period of time. ▲

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[5] Terman, F. E., *Radio Engineers Handbook* (McCraw-Hill Book Company, Inc. New York 1943) p. 697.

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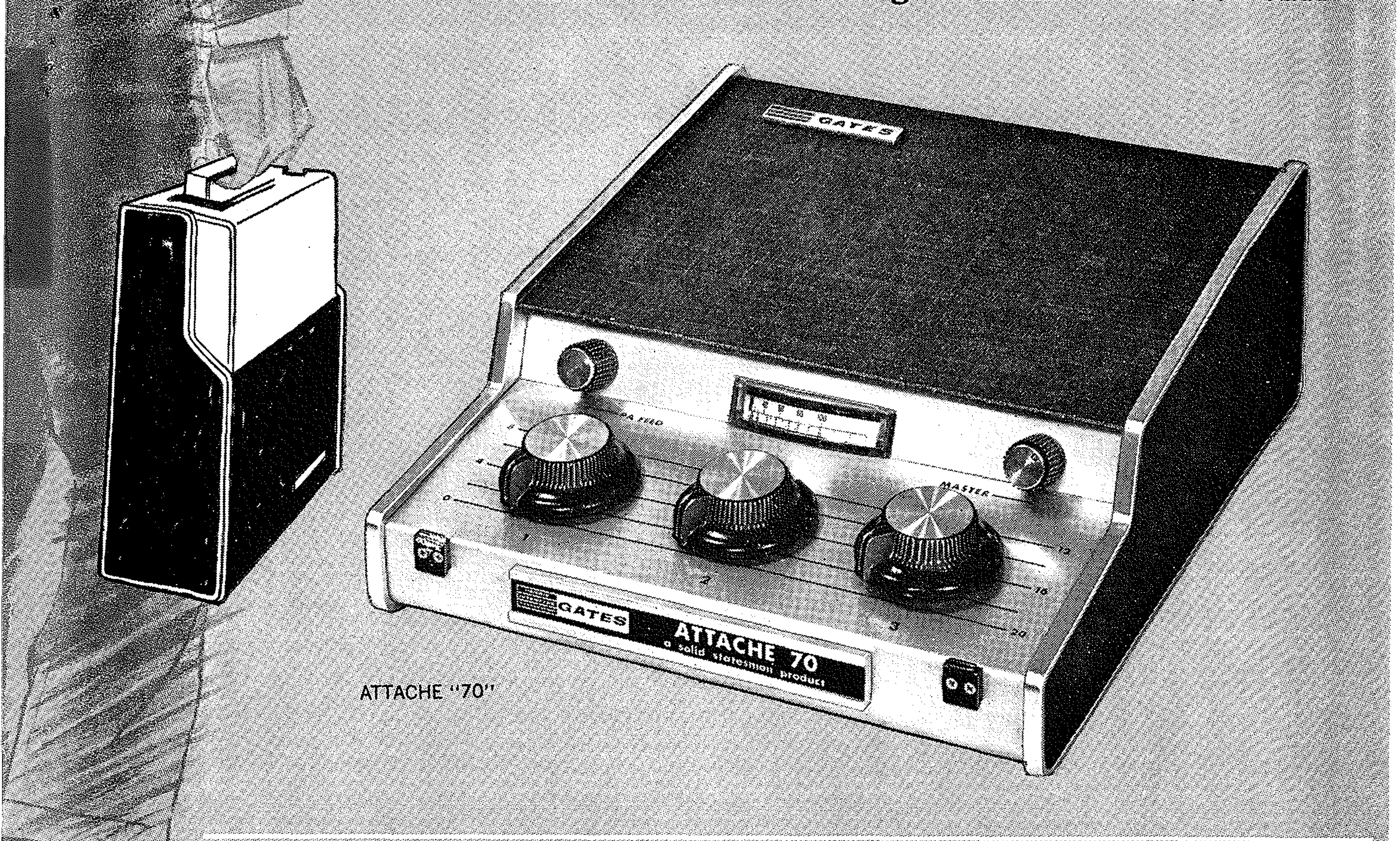

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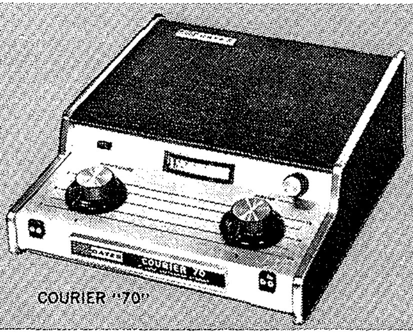

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