A Static Recorder

By H. T. FRIIS

SYNOPSIS: This paper discusses different types of apparatus for recording static and also describes a new instrument in which the output of the set is kept constant by automatic control of the amplification, this amplification then being recorded as the relative measure of static. The set makes use of a fluxmeter with zero restoring torque by means of which the rectified output current arising from static interference is integrated over a period of ten seconds. The following five seconds are required to adjust the gain of the amplifier and record the change in gain from an arbitrary level. The gain is recorded in stops of 4 TU which correspond to a power amplification change by approximately a factor of 2.5. A record is shown during which the intensity of static changed by a factor of more than 10,000.

IN the following is given a general discussion of receiving sets for recording static and also a detailed description of a new instrument of this kind which is based upon the principle that the output of the set is kept constant by automatic control of the amplification, this amplification then being recorded as the relative measure of the static.

The literature on manual measurements of static is plentiful and for extensive references the reader may be referred to a paper on "Present Status of Atmospheric Disturbances," presented by L. W. Austin before the American Geophysical Union.[1] Many different methods of measuring static have been employed in obtaining the results given in this paper and it may further be added that we have found that the most reliable method of measuring the effect of static upon the intelligibility of speech signals is to introduce a local warbler signal[2] in the antenna. Unfortunately, however, all manual measurements require trained observers and therefore the cost of making continuous measurements will always be high, and besides, the human element introduced will decrease their reliability.

Very little has been published on automatic recording of static. The American Telephone and Telegraph Company and the Western Electric Company in 1923 developed an automatic static recorder which measured the high frequency currents induced in a loop antenna by amplifying them and passing them through a recording thermocouple meter. This apparatus was also equipped with a means of automatically measuring the gain of the entire receiving device so that the energy of the static could be evaluated directly. A popular account of this device was given under the caption "Getting Static's Autograph" by Austin Bailey in "Popular Radio," May, 1924. A recorder working at Aldershot, England, is mentioned in a paper by

---

[1] Will be published in the Proc. I. R. E. probably in the February, 1926, number.

[2] See "Radio Transmission Measurements," by Bown, Englund and Friis, Proc. I. R. E. Vol. 11, No. 2.

R. A. Watson Watt,[3] but it seems that this recorder is mainly an automatic counter of static crashes and it would therefore be of little value in U. S. A. where static is mostly a continuous rumble. The reason for the small advance which has been made to date in the automatic recording of static is probably due largely to the lack of suitable apparatus. Certainly there has never been any doubt that automatic records would be very valuable. It is just as important to know the static level as it is to know the strength of a radio signal because it is the static to signal ratio that determines the intelligibility of the signal. A static recorder connected to a rotating directional antenna system would tell us where static comes from and therefore enable the radio engineer to determine whether it is worth while to construct a directive antenna system. Also the connection between thunder-storm areas and static would make static recording valuable to the meteorological service. There is perhaps no reason why a suitable static recorder should not make it possible in a few years to obtain a daily static forecast just as we get our weather forecast now.

The question is then, what would be the best way of obtaining such a record of static? It would, of course, be very desirable to get a continuous record of the actual shape of the static wave, but we have no hope of ever realizing this and will have to be satisfied with the wave forms of a few typical static impulses as given by Watson Watt and E. V. Appleton.[4] Besides it would require a tremendous amount of labor to interpret such a record. The recorder described in this paper records the energy received within periods of 10 seconds. To be sure, such an energy curve of static does not tell the whole story due to the fact that the character of static is so variable. Thus, the same energy levels of a continuous rumbling static and of static consisting of separate clicks does not mean that these two types of static have the same effect upon the intelligibility of a speech signal. However, the shape of an energy record will indicate the general character of the static, but whether such an energy record will enable us to obtain absolute quantitative results with respect to the effect of static upon speech signals cannot yet be determined until further experimental results are available.

Requirements of an Energy Recorder

Let us take the case of recording the rectified current through the receiver of an ordinary receiving set supplied with a local carrier

---

[3] "Directional Observations of Atmospheric Disturbances," by R. A. Watson Watt, Proc. Royal Soc. A, Vol. 102, page 477.

[4] "On the Nature of Static," by Watson Watt and Appleton. Proc. Royal Soc. A, Vol. 103, page 84.

oscillator. This may, for instance, be accomplished by replacing the phone by a thermocouple connected to a standard recording galvanometer. Such a recorder would probably record the average of the current squared, but only for changes of energy received of not more than fifty times. The daily variation of the energy level of static (at 60 kilocycles) is, however, generally at least 100 times and sometimes even 10,000 times, so that this method of employing a receiving set with fixed amplification is unsatisfactory. Besides it would be very difficult to prevent overloading of the set if we limit ourselves to the use of 10-watt tubes.

One important requirement of a static recorder is therefore that the *output level of the receiving set be kept constant*, or more correctly, within certain narrow limits. In the receiver here described, the amplification of the receiving set is varied so as to satisfy this requirement, i.e., the gain is automatically cut down when the output level reaches its upper limit, and vice versa.

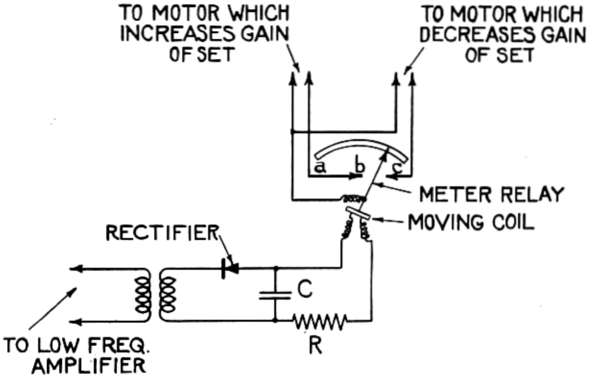

Fig. 1—Continuous recording system

The output level of the set may be kept constant either by a continuously or by a discontinuously working system. The first method is mentioned here for comparison purposes only and is illustrated in Fig. 1. The figure shows that the rectified output current is sent through a moving coil relay whose pointer can only move between the contact points *b* and *c* while its real zero position is at *a*. Nothing happens if the pointer is between *b* and *c* but at the moment it touches *b* a motor will start, to increase the gain of the receiving set and will continue until the pointer is free again. Correspondingly the gain will be decreased if the pointer touches *c*. The purpose of the large resistance *R* and the condenser *C* is to prevent quick movements of the pointer caused by the individual static crashes. The time constant RC of the circuit would probably have to be at least five seconds and the speed at which the gain of the set is changed must be correspondingly slow. This system will, therefore, react very slowly for great changes in static level. Ordinarily static does not change very fast but if the recorder is working with a directive antenna system that is rotated say 360° in 20 minutes, then a fairly fast working recorder is desirable. The main disadvantage of the continuous system is that it will be difficult to make the meter give a true indication of the average energy level.

The method employed is therefore based upon a discontinuous system and will be described in connection with Fig. 2. The rectified output current of the set is integrated over a period of 10 seconds by means of a fluxmeter.[5] If, after these ten seconds the fluxmeter deflection is below a certain mark, then the gain of the set is increased *one* step and, vice versa, if the deflection is above a certain mark the gain is decreased *one* step. For deflections in between these marks the gain remains unchanged. To change the gain one step and to bring the fluxmeter needle back to zero takes approximately 5 seconds after which the whole process is repeated. The output energy due to static received during ten-second periods is here kept within two *definite limits.* The gain can be changed only one step after each period, but since each step corresponds to a change of 4 TU (1.58 times) in voltage gain it will take only one minute and a quarter for the recorder to adjust itself to a sudden change of 100 times in the energy level of static.

THE APPARATUS OF THE RECORDER

The receiving set is shown schematically in Fig. 2. It is an ordinary double detection set that requires altogether ten tubes, of which the last low frequency amplifier tube must be able to handle 10 watts in order to prevent overloading. The power supply may be rectified AC.

The gain control is inserted in the first intermediate frequency amplifier in order to be sure that no tubes are overloaded. The local oscillator shown is used for amplification calibration of the set and

---

[5] A galvanometer with negligible restoring torque, whose deflection is proportional to the coulombs sent through it. Its use for the present purpose was suggested by Mr. L. J. Sivian of the Bell Telephone Laboratories. He has employed the instrument for measurements of rectified speech and noise currents on telephone circuits. The use of a fluxmeter for similar purposes has been independently reported by Dr. E. M. Terry, of the University of Wisconsin, at the December 30, 1924, meeting of the U. R. S. I. at Washington, D. C.

requires no special shielding as its input voltage induced into the loop is comparatively large.

The selectivity of the set is determined by three separate units, viz., the antenna circuits, the intermediate frequency filter and the low frequency filter, each of which has a specific use. Carson and Zobel[6] have made the following statement.

"In filters designed to select a band of frequencies of width w, the ratio of energy transmitted through the network by the signal and by random interference is inversely proportional to the band width and increases inappreciably when the number of sections is increased beyond two."

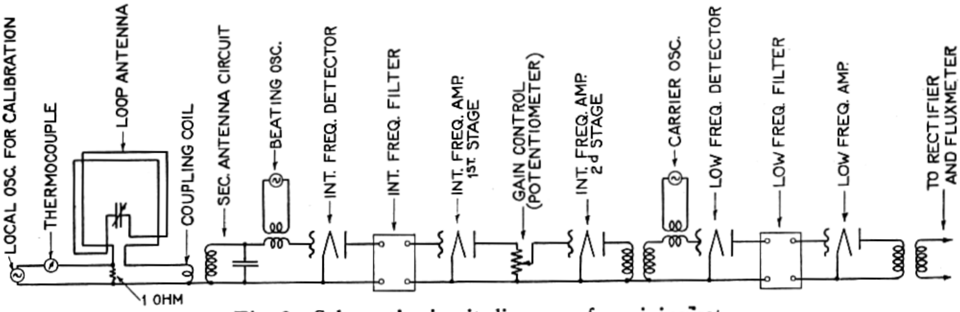

Fig. 2—Schematic circuit diagram of receiving set

The main purpose of the filters is therefore not to define the frequency band of the set insofar as static is concerned, but to exclude continuous wave interference. It is hoped that 500 cycles wide frequency bands[7] can be maintained free of *c.w.* interference for static measurements and the simplest way to obtain such a band in the receiver is to make the low frequency filter an efficient low pass filter that cuts off every frequency above 600 cycles. More than two coupled circuits are hardly required in the antenna circuits, but the intermediate frequency filter ought to have sharper cut-off points than two coupled circuits will give. The selection of filters naturally depends upon the *c.w.* interference and it may in some cases be possible to reduce the number of filters and thereby make the recorder cheaper. The records shown later correspond to a frequency band of 2000 cycles—between 57.5 and 59.5 *k.c.*,—but it will probably not be long before *c.w.* interference makes it necessary to reduce this band

---

[6] "Transient Oscillators in Electric Wave-Filters"—John R. Carson and Otto J. Zobel, Bell System Technical Journal, Vol. II, No. 3, p. 27.

[7] Bands at 15, 30, 60, 120 . . . kilocycles would probably be satisfactory.

width. It is desirable to have a loud speaker connected to the output of the set and occasionally listen for *c.w.* interference.

The constant output control apparatus is shown in Fig. 3. The fluxmeter is seen in the upper right corner. Full deflection corresponds to 2 x 10^{-4} coulomb. The needle is normally free to move except when the cam *Z* presses the needle down until its point touches the scale *OS*. The shaft carrying the cam *Z* and the disc *N* is rotated one complete turn in 15 seconds by a clock motor. The different elements are explained in the figure and the whole action may be understood by studying this carefully. However, it is probably worth while to go through a complete 15 second period and explain in detail the purpose of each part.

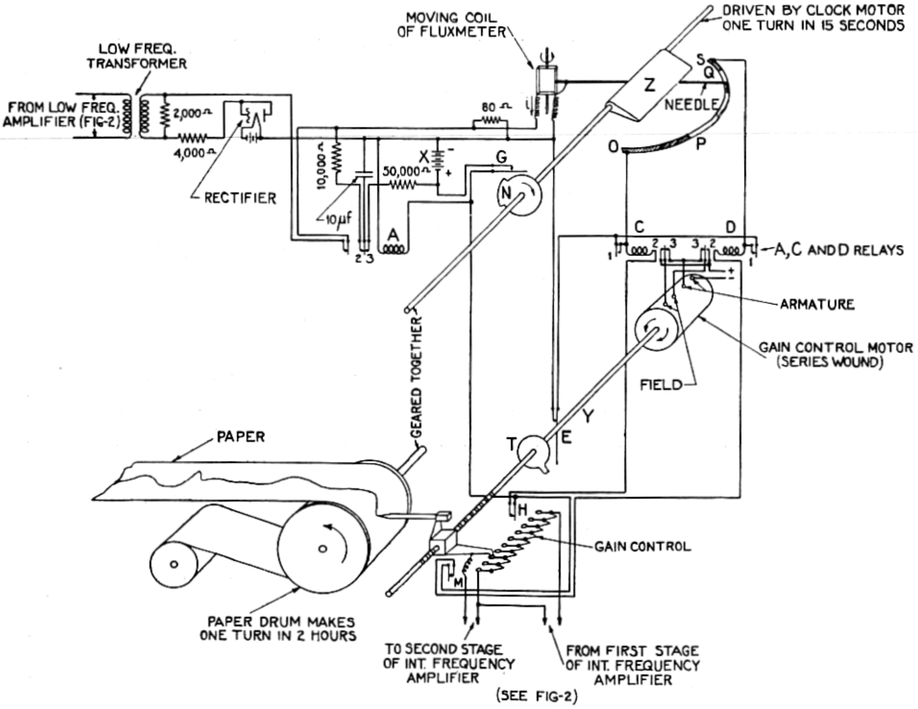

Fig. 3—Schematic circuit of constant output control apparatus

Time in Seconds—0–10:

Switch *G* is open, therefore relay *A* is open and no current can pass through the windings of relays *C* and *D*. (These relays start the gain control motor, which is therefore shut off.)

Contact 1 of relay *A* is closed and closes the circuit consisting of the secondary winding of the low frequency output transformer, the rectifier for the static currents and the fluxmeter. The 2000 and 4000 ohm resistances in this circuit insure distortionless input voltage to the rectifier. The fluxmeter is damped by an 80 ohm shunt. The needle, which was initially at zero, will therefore move, its deflection being proportional to $\int idt$.

Time in Seconds—10–14:

Switch G is closed by the cam on the revolving disc N and locks relay A.

Contact 1 of relay A is opened and opens the rectifier fluxmeter circuit, thereby bringing the fluxmeter needle to a stop.

Contact 3 of relay A is closed and makes the battery X charge the 10 μf condenser through the 50,000 ohm resistance.

Time in Seconds—11–14:

The cam Z presses the needle point down on the scale OS. Now, one of three things will happen.

1. Static has decreased since the last period, so that the needle point will make contact with the metal strip OP and close the following circuit: Battery X, needle of fluxmeter, winding of relay C, switch H and switch G to battery X. Relay C is therefore closed and its closed contact 2, together with contact 3 of the open relay D will start the gain control motor. After approximately half a turn of the gain control or motor shaft Y the needle point is lifted from OP by the rotation of the cam Z, but relay C stays closed due to the fact that it is self-locking through its contact 1, so that the shaft Y continues turning until the switch E is opened by the disc T. This opens the self-locking circuit of relay C. Relay C therefore opens and the gain control motor stops after the shaft Y has made exactly one complete turn and increased the gain of the set one step (4 Transmission Units or 1.58 times). Notice that the opening of the needle point contact does not break any current, due to the use of self-locking relays. This preserves the needle point contact.
2. Static has not changed since the last period. The needle point will now touch the insulating strip PQ and nothing else will happen, i.e., the gain of the set remains unchanged.
3. Static has increased since the last period so that the needle point now will make contact with the metal strip QS and close relay D and as in case 1 the motor will start and turn the shaft Y one turn, but this time in the opposite direction, i.e., the gain of the set is decreased one step.

Time in Seconds—14:

Switch G is opened again by the revolving disc N and opens relay A. Contact 2 of relay A is closed and will discharge the 10 μf condenser through the fluxmeter, thereby bringing the needle back to zero. (Notice that the time constant of this discharge circuit is $10000 \text{ x } 10\text{x}10^{-6} = 1/10$ seconds.)

Time in Seconds—15:

A new period has started.

The purpose of the switches M and H is to stop the motor when the gain control switch arm has reached the end of the scale.

The recorder is of such recent development that no comprehensive data are yet available.

Fig. 4 shows part of an actual record of static received on a set tuned to $57.5-59.5$ kilocycles. The ordinates represent the attenuation of the gain control of the set and it is to be remembered that the gain of the rest of the set is constant. The curve shows that the static power on the morning of October 30 changed more than 10,000 times. The point B on the curve gives the effect of inducing a local

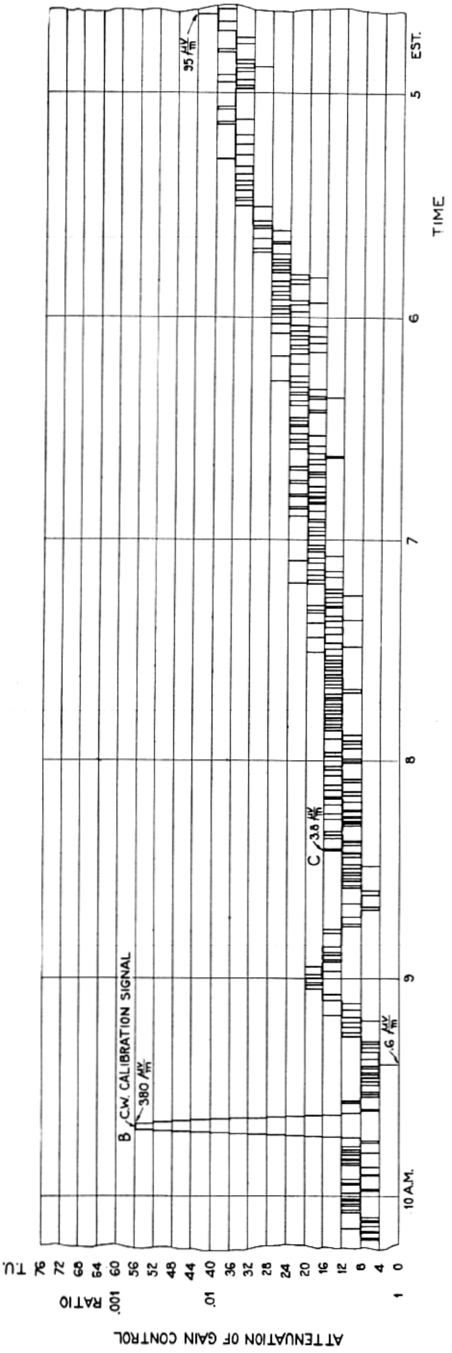

Fig. 4—Static record, morning of Oct. 30, 1925, Cliffwood, N. J., U. S. A.

signal of strength 380 $\mu v/m$ in the loop.[8] The point C on the curve shows that at 8:25 A.M. the static intensity received on a 2000 cycle wide frequency band corresponded to the energy received from a *c.w.* signal of strength 3.8 $\mu v/m$. It would be practical always to relate static to such a *c.w.* signal. Experiments are now being conducted to determine whether the energy received from static is proportional to the width of the frequency band of the receiving set and if such is found to be the case then it is proposed to have the data relate to a 1000 cycle wide band. That static is, say, 7 microvolts per meter per kilocycle (7 $\mu v/mkc$) would then mean that the energy of the static received on a 1000 cycle wide frequency band is the same as the energy received from a *c.w.* signal of strength 7 $\mu v/m$.

Attempts have been made to calibrate the set by inducing in the loop, voltages of the shape shown in Fig. 5. Relating static to such signals would have the advantage of being independent of the band width of the set. Such signals were obtained by closing and opening a mercury switch, but one signal per second, or 10 impulses per period, would overload the set (the tubes) very much. At least 10 impulses per second would be required if the set should not be overloaded by each individual impulse, but this would be a difficult task to accomplish and it is therefore recommended that static be measured as explained above, by inducing a local *c.w.* singal into the loop. The fact that five static crashes in the course of 10 seconds—one period—does not overload the set while 100 impulses of the shape shown in Fig. 5 are required to prevent overloading gives us some interesting information on static. It shows that a single static crash is not a single sudden change of the field in the ether and that it cannot be represented by less than 20 consecutive impulses.

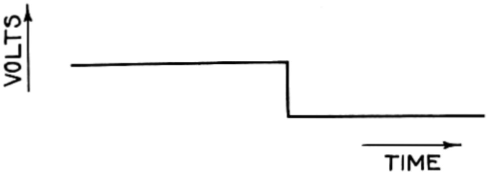

Fig. 5—Shape of impulse voltage

The record of Fig. 4 shows that each step on the gain control potentiometer is 4 TU and the selection of such steps and of 15 seconds will now be discussed. To decrease the 4 TU step to a 1 TU step would

---

[8] It may be worth while to have such a calibration signal introduced automatically for instance once every two hours.

decrease the speed of the set, i.e., it would take four times longer for the recorder to register a sudden change in the static level which is particularly a disadvantage when the recorder is connected to a rotating directional antenna. On the other hand a step larger than 4 *TU* would not give the static level with sufficient accuracy. If the time periods are changed from 15 to 10 seconds, then the "speed" of the set is increased, but the set is then inoperative over a larger part of the period since it takes 5 seconds to change the gain of the set and bring the fluxmeter needle back to zero. Besides, such a decrease in time period would increase the probability of overloading and also it would make the energy received per period vary more irregularly especially if static consisted of separate crashes.

Directional Static Recording

The usefulness of a static recorder will naturally be increased many times if it is able to indicate the general direction from which the static comes. A rotating loop antenna would give some results, but it would be still better to combine the rotating loop with an ordinary open antenna so as to obtain the well-known heart-shape directional characteristic. The loop should be rotated by the clock-motor of the set (see Fig. 3), say 2 complete turns in one hour, and the abscissa on the record would then require a direction scale in addition to the time scale.