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THE SUSCEPTIBILITIES OF ELECTRICAL AND MAGNETIC ANTENNAS TO PRECIPITATION STATIC NOISE (EXPERIMENTS IN AN ELECTROSTATIC WIND TUNNEL)

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Fort Monmouth, New Jersey

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The effects of precipitation static noise interference with the reception of radio-navigation and communications signals on aircraft flying through ice and snow clouds were generated with an electrostatic wind tunnel. Electrical type antennas, that is metal-rod and blade antennas, were found to be highly susceptible to precipitation static noise fields. Magnetic type ferrite loopstick antennas were found to be practically immune to these noise fields, if electrically conductive materials, such as wet or moist plastics or metal, were kept approximately 30 cm away from the antennas. This critical distance

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S U M M A R Y

An electrostatic wind tunnel for the generation of precipitation static radio noise by wind-driven styrofoam pellets has been constructed. This electrostatic wind tunnel was used to simulate precipitation static noise which interferes with the reception of radio navigation and communication signals on board aircraft flying through ice and snow clouds. Experiments with different types of antennas showed the electrical-type antennas to be the most sensitive to precipitation static noise fields. This noise blocks signal reception by nonlinear overload of conventional wide-band-antenna preamplifier circuits and covers up signal reception by narrow band receivers. Electrical-blade and electrical-rod antennas responded differently to the same "blizzard" of styrofoam pellets in the electrostatic wind tunnel. The noise voltage output from the blade antenna consisted of densely-spaced overlapping spikes; the noise output voltage from the rod antenna was characterized by more discrete spikes of much larger amplitudes. In contrast to these electrical-type antennas, a magnetic antenna in the form of a single ferrite loopstick by itself was found to *not* be susceptible to quasi-electrostatic (high impedance) type precipitation static noise fields. However in close proximity to conductive materials, such as wet or moist plastics or metal, the magnetic ferrite loopstick antenna loses its immunity to precipitation static noise. The intrinsic ability of electrically-balanced magnetic ferrite loopstick antennas to pick up LF radio signals clearly in the local precipitation static noise field was preserved when a separation of $\sim$30 cm was maintained between the ferrite loopstick antenna and a metal plate. This critical separation could be reduced to 10 cm when the single ferrite loopstick antenna was replaced by a pair of ferrite loopsticks in a magnetically orthogonal and electrically parallel arrangement.

CONTENTS

CONTENTS (Contd.)

FIGURES

RECORDINGS

THE SUSCEPTIBILITIES OF ELECTRICAL AND MAGNETIC ANTENNAS TO PRECIPITATION STATIC NOISE
(EXPERIMENTS IN AN ELECTROSTATIC WIND TUNNEL)

1. INTRODUCTION

The radio interference encountered during flight through snowstorms [1] is known as "precipitation static noise." It is also experienced during flight through snow and ice clouds, particularly through supercooled and aged cumulus clouds [2]. This interference, which is peculiar to aircraft in flight, tends to block the reception of LF and MF radio navigation signals on board aircraft when their reception is vital for flight safety.

The basic cause of this radio interference is triboelectric charging of ice and snow particles and of the aircraft, and the resultant transient charge transfer phenomena [3]. Three such phenomena contribute to the overall precipitation static noise:

(1) Corona discharge from metal parts of the aircraft to air;

(2) Streamer discharges from the plastic aircraft parts to the metal parts; and

(3) The influence of electrically-charged-particle motion in the vicinity of the aircraft and the impact of particles on the aircraft.

The corona noise can be reduced greatly by using electrostatic dischargers, which are decoupled from the RF field. Streamer noise is essentially eliminated by coating the exposed plastic parts of the aircraft with a conductive material [4], [5].

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[1] D. C. Pearce and B. W. Currie, "Some qualitative results on the electrification of snow," *Can. J. Res.*, vol. A27, Jan. 1949, pp. 1-8.

[2] YU. A. Bragin, "Production of ice crystals in slightly supercooled cumulus," *Nature*, vol. 245, Oct. 26, 1973, p. 451.

[3] Robert L. Tanner, "Precipitation particle impact noise in aircraft antennas," *IRE Trans. Ant. & Prop.*, vol. AP-5, April 1957, pp. 232-236.

[4] R. L. Tanner and J. E. Nanevicz, "An analysis of corona-generated interference in aircraft," *Proc. IEEE*, vol. 52, no. 1, January 1964, pp. 44-52.

[5] J. E. Nanevicz and R. L. Tanner, Some techniques for the elimination of corona discharge noise in aircraft antennas," *Proc. IEEE*, vol. 52, no. 1., January 1964, pp. 53-64.

However, RF noise from particle impact and from the influence of particle motion in the antenna field cannot be suppressed by electrostatic means. This kind of noise contribution to the precipitation static noise can be controlled by RF antenna design only.

2. THEORETICAL BACKGROUND

The susceptibility of an aircraft antenna to precipitation static noise can be described in terms of Carson's reciprocity theorem which relates the response of a linear multiport system to its excitation. The response at port N to an excitation induced into port M agrees with the response at port M to the same excitation at port N. In the precipitation static noise case, the system consists of the antenna (including its counterpoise, in the form of the aircraft body) and the ice and snow particles in the field space of the antenna. The ice and snow particles carry triboelectrically-generated charges, which are separated by the frictions and collisons among the particles and by particle impact on the aircraft body (and on the antenna). The effects of the time-like and space-like variations of the electrical charges on the snow or ice particles in the field space of the antenna constitute the precipitation-static-noise output from that antenna. The resulting noise-output current which flows through the short-circuited antenna port can be described by $I_{AS}(t)$. This short circuit antenna-output current then represents the total response at the "antenna port" of the excitations of the "particle ports" by electrical convection current filaments (charge times velocity), which arise from the motions of the charged particles in the antenna field space. Vice-versa, the excitation of the antenna port by an open circuit voltage $V_{OA}(t)$ produces as its response, an electric field $E(x,t)$ at the particle port locations x, in the field space at time t. Under the quasi-electrostatic conditions governing precipitation static noise pickup by the antenna, the field $E(x,t)$ represents the instantaneous near field. For simplicity, assume there is only one particle with the charge q and velocity $v(x,t)$ at location x, at time t. The system would then have only two ports: the antenna port and the particle port. The reciprocity theorem for this two-port system would then read as follows:

$$I_{AS} \cdot V_{OA} = q\, \bar{v}\cdot\bar{E}, \qquad (1)$$

and the short circuit current response at the antenna port due to the convection current excitation at $q\bar{v}$ at the particle port would become:

$$I_{AS} = \frac{|E|}{V_{OA}} \, , \, q|\bar{v}| \cdot \cos\alpha \, , \qquad (2)$$

where α is the angle between the velocity of the charged particle and the electric near field vector E. The factor $|E|/V_{OA}$ in Eq. (2) evidently represents a characteristic of the antenna. The reciprocal of this factor, i.e., $V_{OA}/|E|$, has the dimension of a length; and if E were a radiation field vector, this length would represent the effective height of the antenna, i.e., the ratio of the antenna output voltage to the strength of the electrical field being sensed by the antenna. However, in view of the low radio frequencies used and the corresponding long wavelengths of the signals which are being interfered with by precipitation static noise and in view of the quasi-electrostatic nature of the noise generating process, the E in Eqs. (1) and (2) represents here the electric near field of the antenna. Consequently, for a given $q\bar{v}$, the noise current output I_{AS} from an antenna will be very large when the antenna is characterized by a large $|E|/V_{OA}$ ratio. The fact that intense quasi-electrostatic field gradients arise at the tips and edges of the metal-whip and metal-blade antennas when small dc voltages are applied to their terminals suggests that these electrical antennas are highly susceptible to precipitation static noise by virtue of their large $|E|/V_{OA}$ at low radio frequencies. It was therefore evident that different antennas had to be used in the attempt to reduce or to eliminate the effects of precipitation static noise. These "different" antennas ought to be characterized by the absence of an electric field in the dc-limit case and by a relatively small electric near field for large driving voltages at low radio frequencies. It followed that these requirements could be fulfilled by an idealized magnetic antenna only. A practical approach to realize such a magnetic antenna is the use of an electrically balanced ferrite loopstick antenna. "Electrical balance" refers here to the wire windings of the loopstick which consist of left- and right-hand wound sections which are symmetrical with respect to the center of the ferrite core. The outer endings of these sections are joined at one antenna terminal, and their central endings are joined at the other antenna terminal. Consequently, the magnetic flux linkages reenforce each other, whereas electric voltage gradients along the left- and right-sections oppose each other. This opposition of the voltage gradients along the winding and the resulting electrical balance of the antenna is responsible for the relative insensitivity of ferrite loopstick antennas to quasi-static electric fields. However, it follows that a perturbation of this electrical balance of ferrite loopstick antennas destroys their intrinsic immunity to precipitation static noise fields.

3. SYNOPSIS OF THE ELECTROSTATIC WIND TUNNEL EXPERIMENTS

A. The Electrostatic Wind Tunnel

The electrostatic wind tunnel was designed and constructed to create "blizzards" of plastic styrofoam pellets in the laboratory (Figs. 1 and 2). This wind tunnel is a hollow ring-shaped lucite

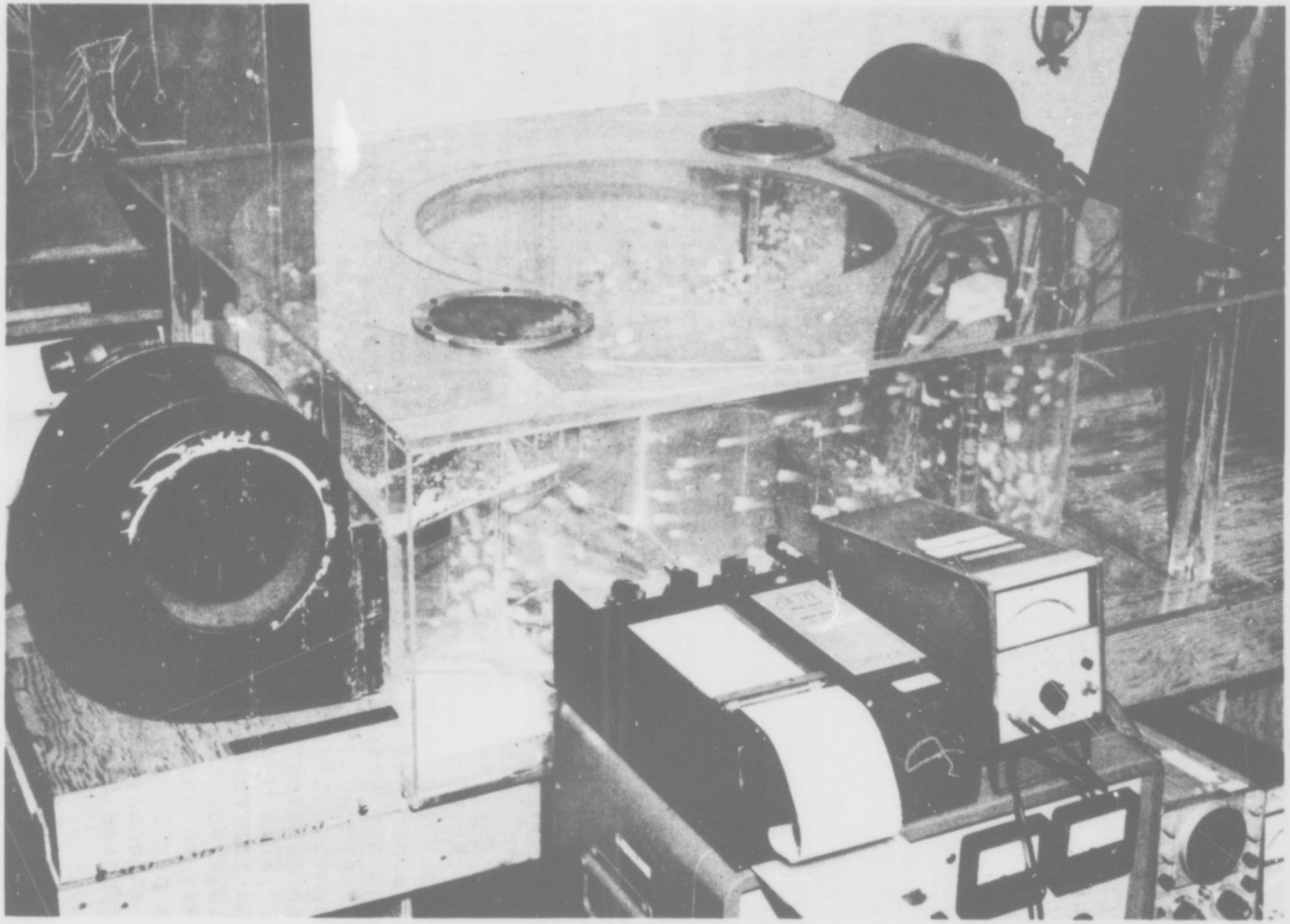

Fig. 1. Electrostatic wind tunnel (overall view).

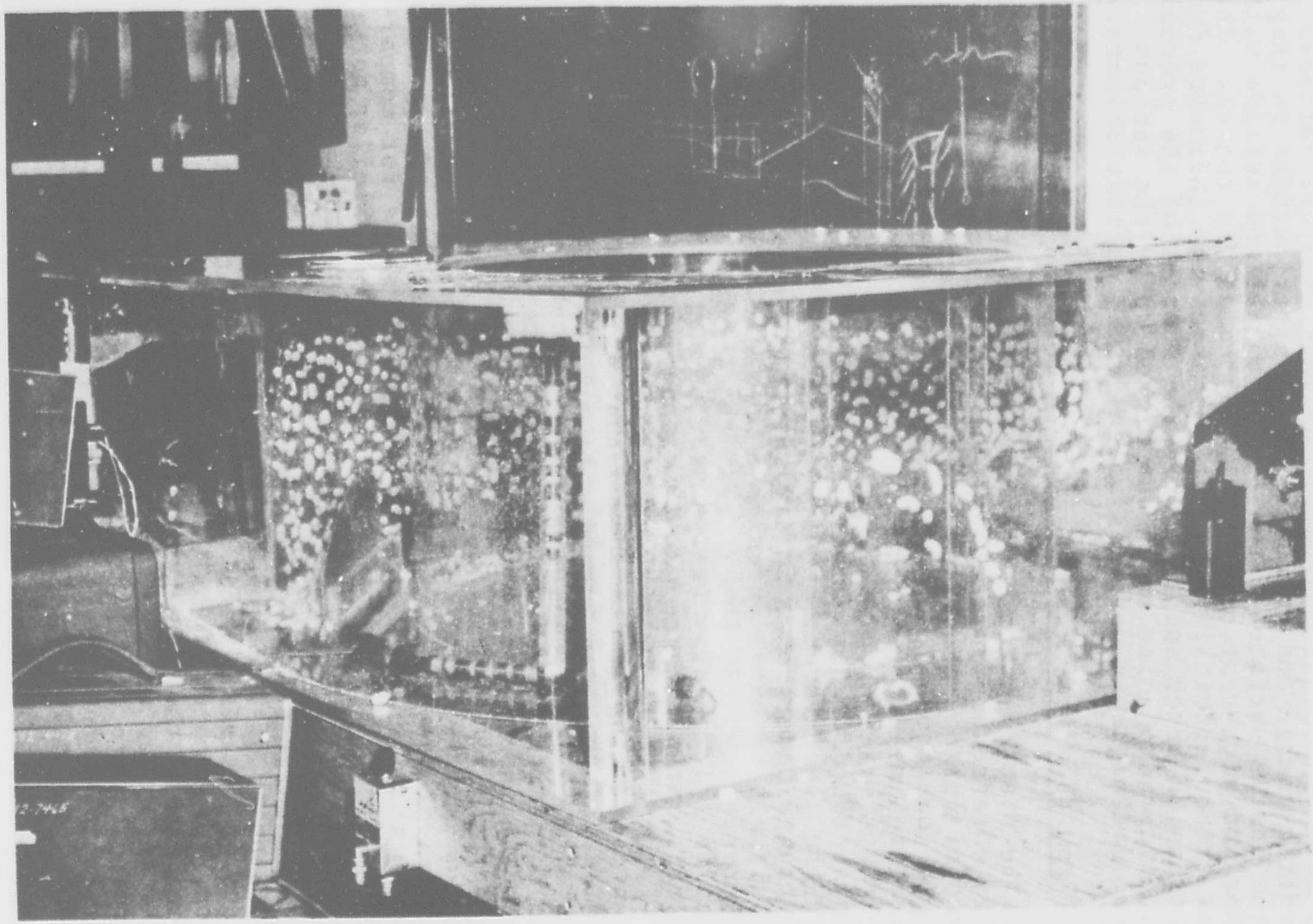

Fig. 2. Electrostatic wind tunnel with Metal-Blade Antenna and ferrite loopsticks inside (close-up view).

enclosure. Air is blown into it tangentially via apertures on its outside walls, and escapes through screened vents in its ceiling. The wind-driven styrofoam pellets generate variable triboelectric-charge and influence-field distributions as they rub on the inside surface of the lucite tunnel and collide with each other and with test objects placed inside the tunnel. The resultant triboelectrically generated charges and influence field distributions in space and time were the sources of the precipitation static radio noise which was picked up by the various electrical and magnetic antennas which served as test objects.

B. Results of the Experiments

The electrostatic wind tunnel experiments confirmed the previously observed differences in the performance of metal antennas and of ferrite loopstick antennas in precipitation static noise field environments. Compared to electric-type metal whip and blade antennas (Fig. 3), the magnetic-type ferrite loopstick antennas (Figs. 4 and 5) were practically immune to precipitation static noise fields. Consequently, the use of ferrite loopsticks permitted the clear reception of RF signals in the 100 to 200 kHz frequency range under noise conditions which made the reception of these signals by metal antennas impossible. However, as observed previously, the immunity of the ferrite loopsticks to precipitation static noise fields was lost in close proximity to metal objects, including the metal antennas and metal plates [6].

The present experiments showed that the precipitation static noise induced from a metal plate into a single ferrite loopstick (Fig. 6) is strongly dependent upon the distance between the loopstick and the metal plate (Recording Nos. 1 to 5). When a separation of 30 cm was used, the noise contributions from the metal plate became negligibly small. At separations of less than 15 cm, the noise contributions became extremely large, and approached the levels and the spiked wave shapes of the noise outputs from metal antennas. Recording No. 6 shows for comparison the noise output from a metal whip antenna. Similar noise effects were observed when the lucite insulation tube of the ferrite loopstick was removed (Fig. 7) such that the wind-blown, electrically-charged styrofoam pellets collided with the bare wire winding of the loopstick. (For a comparison of the differences in the noise conditions with and without the lucite insulation, see Recording Nos. 7 and 8, and 9 and 10.) The non-reproducibility of the results of experiments with the ferrite loopsticks insulated with polyurethane and styrofoam (Fig. 8 and Recordings 11 to 16) led to the discovery that dryness of these insulation materials is essential for noise-free performance of the ferrite loopsticks (Recording Nos. 17 to 24).

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[6] Kurt Ikrath, "Interference with aircraft radio navigation and communications by precipitation static from ice and snow clouds (Electrostatic wind tunnel experiments)," R&D Technical Report ECOM-4244, U. S. Army Electronics Command, Fort Monmouth, N. J., Aug. 1974 (AD 784623).

Fig. 3. Metal-Blade Antenna (close-up view).

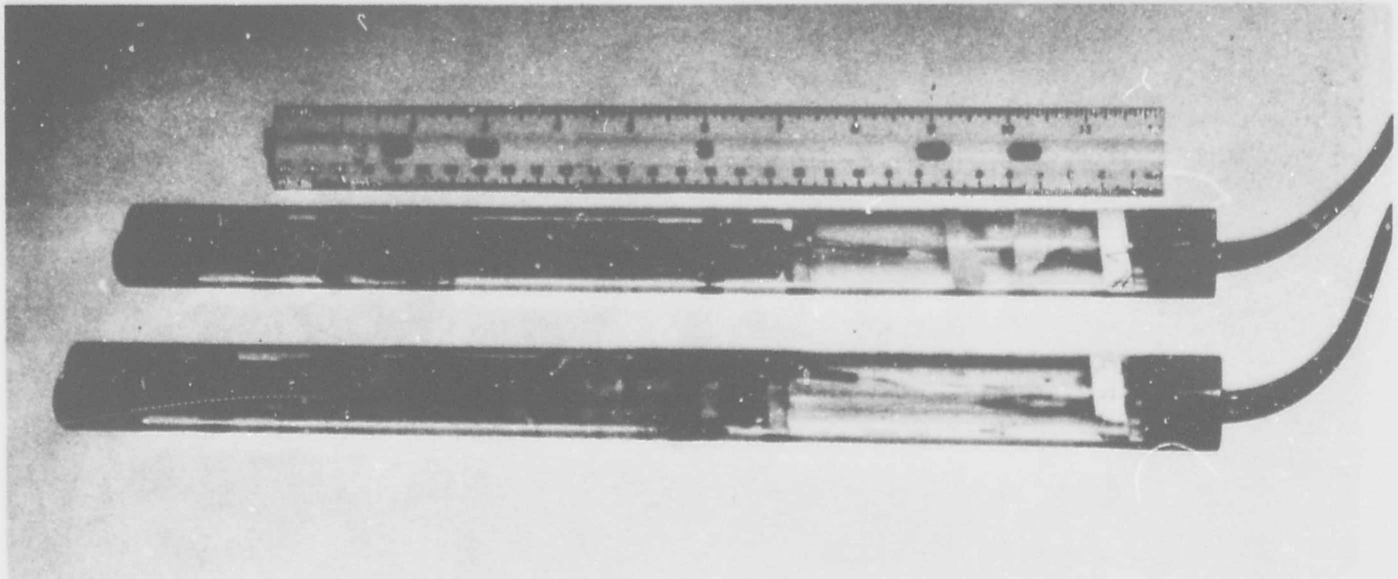

Fig. 4. Crossed Ferrite Loopsticks Antenna (sealed inside lucite insulation tubes).

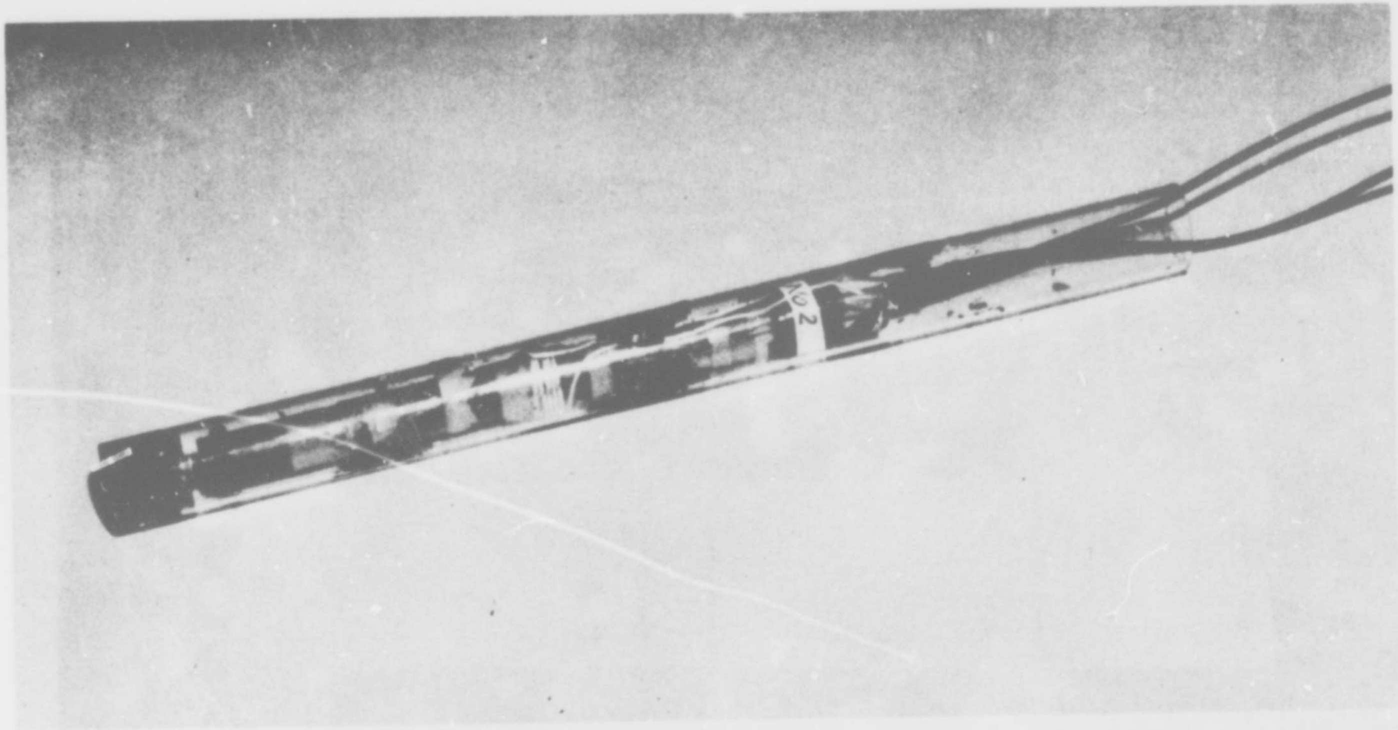

Fig. 5. Modified Ferrite Loopstick No. 2
inside lucite insulation tube.

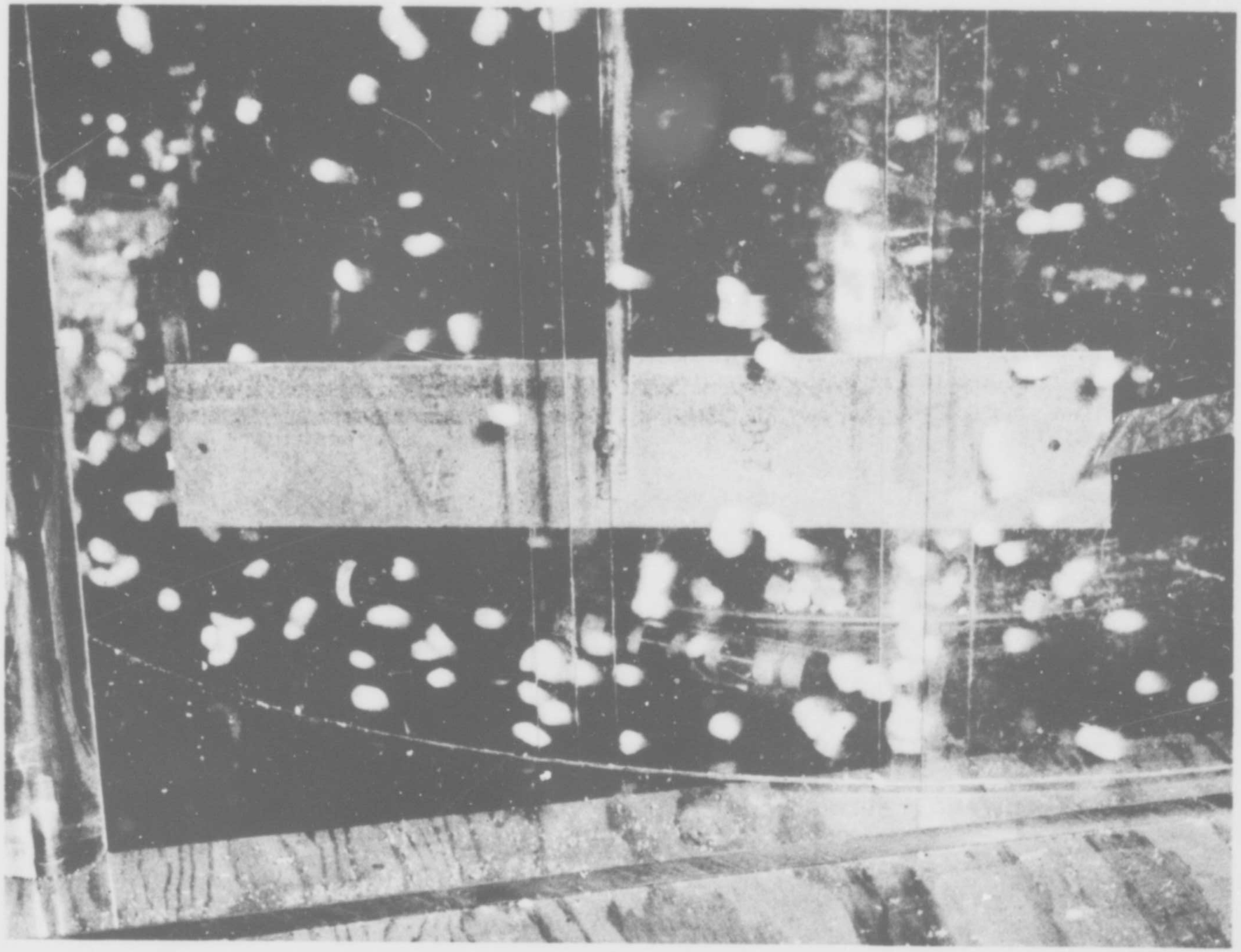

Fig. 6. Ferrite Loopstick No. 3 and metal plate inside electrostatic wind tunnel.

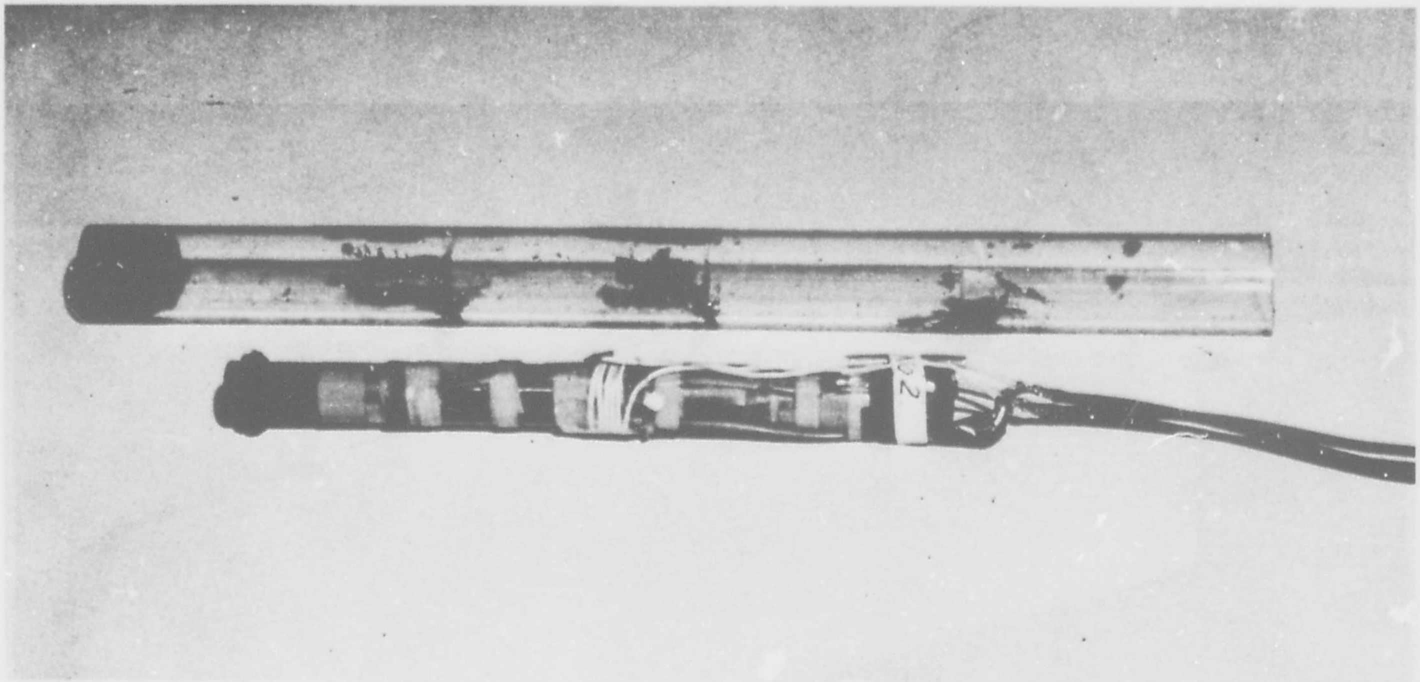

Fig. 7. Modified Ferrite Loopstick No. 2 with insulation tube removed.

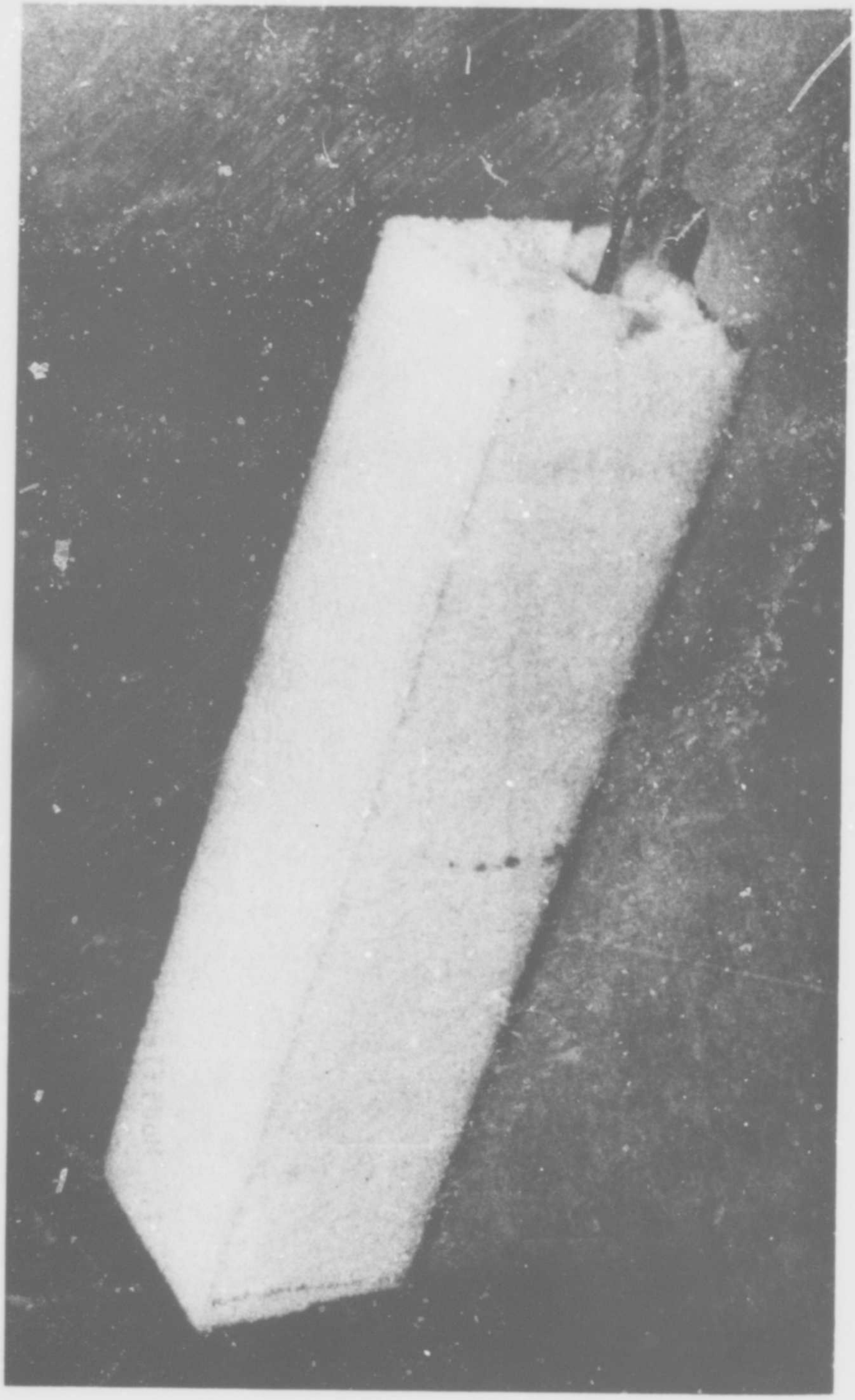

Fig. 8. Modified Ferrite Loopstick No. 2 insulated by lucite tube and plastic foam.

Moisture absorbed by the styrofoam insulation material as well as a wet outer surface of the lucite insulation caused drastic increases in the noise pickup and output from the ferrite loopsticks. This noise was similar to that encountered in close proximity to metal. These noise-generating proximity effects were apparently caused by the disturbance in the electrical balance of the ferrite loopstick when it was situated in the vicinity of electrically conductive materials and objects. Consequently, an attempt was made to compensate for the noise-generating stray capacitance between the single ferrite loopstick and the metal plate by using the stray capacitance between a second ferrite loopstick and the same metal plate. The first and second ferrite loopsticks were connected electrically in parallel to short out their mutual capacitance. They were then oriented perpendicular to each other to minimize their mutual inductive coupling. It was then possible to separate the resultant pair of Crossed Ferrite Loopsticks (Fig. 9) at a distance of less than 10 cm from a large metal plate (Fig. 10) without serious signal degradation by the precipitation static noise generated on the surface of the metal plate (Recording Nos. 25 to 29). Furthermore, when narrow band LF radio receivers R-389 (Fig. 11) were used for the reception of RF signals degraded by precipitation static noise, it was found that the nonlinear response of the receivers to the spike-shaped precipitation static noise enhanced the differences in the performance of the metal whip and blade antennas and of the ferrite loopstick antennas (Recording Nos. 30 and 31). For example, the nonlinear response of the receiver to noise led to the capture of the receiver by the noise and the suppression of a 100-microvolt 162 kHz RF signal which was delivered to the receiver from a metal blade antenna (Recording No. 32). Yet the same RF signal output from the Crossed Ferrite Loopsticks was able to capture the receiver and to suppress the noise when the ferrite loopsticks were used in the same noise field environment as the Metal-Blade Antenna (Recording No. 33). These capture effects and the associated critical RF signal levels were used to quantify the performance of the Metal-Blade Antenna (Fig. 3) and of the Crossed Ferrite Loopsticks Antenna (Fig. 10) in the same noise field environment. The critical signal level for the Metal-Blade Antenna in this case was 170 microvolts, and that for the Crossed Ferrite Loopsticks was 40 microvolts (Recording Nos. 34 and 35), respectively.

4. CONCLUSIONS

(a) Electrical-type metal whip and blade antennas are highly susceptible to precipitation static noise fields. Electrically balanced, magnetic-type ferrite loopstick antennas are essentially immune to these fields.

(b) The immunity of ferrite loopstick antennas to precipitation static noise fields is lost in close proximity to metal surfaces.

(c) The noise-generating influence of a metal plate on the

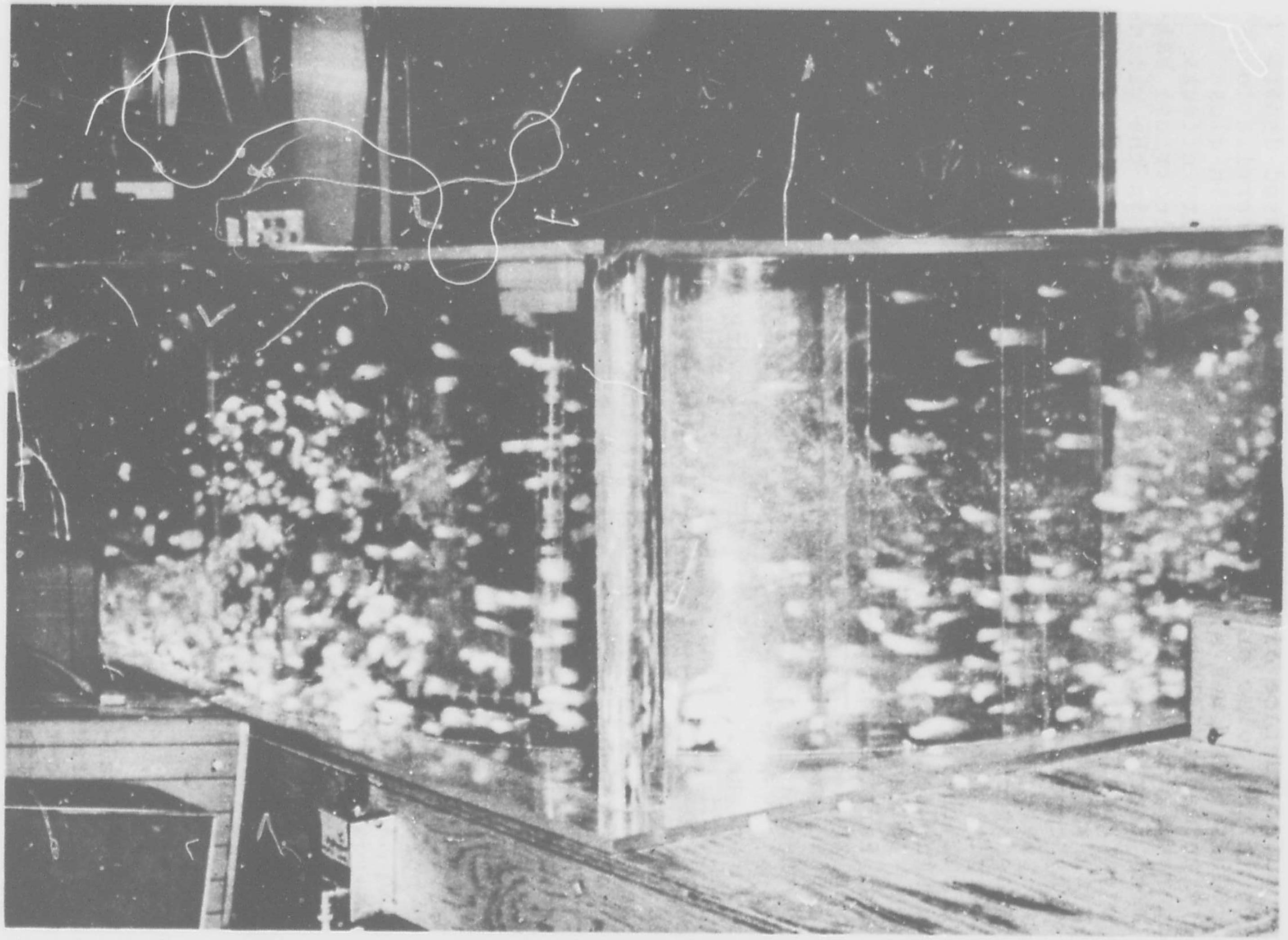

Fig. 9. Crossed Ferrite Loopsticks (Nos. 1 and 3) and Metal-Blade Antenna inside wind tunnel.

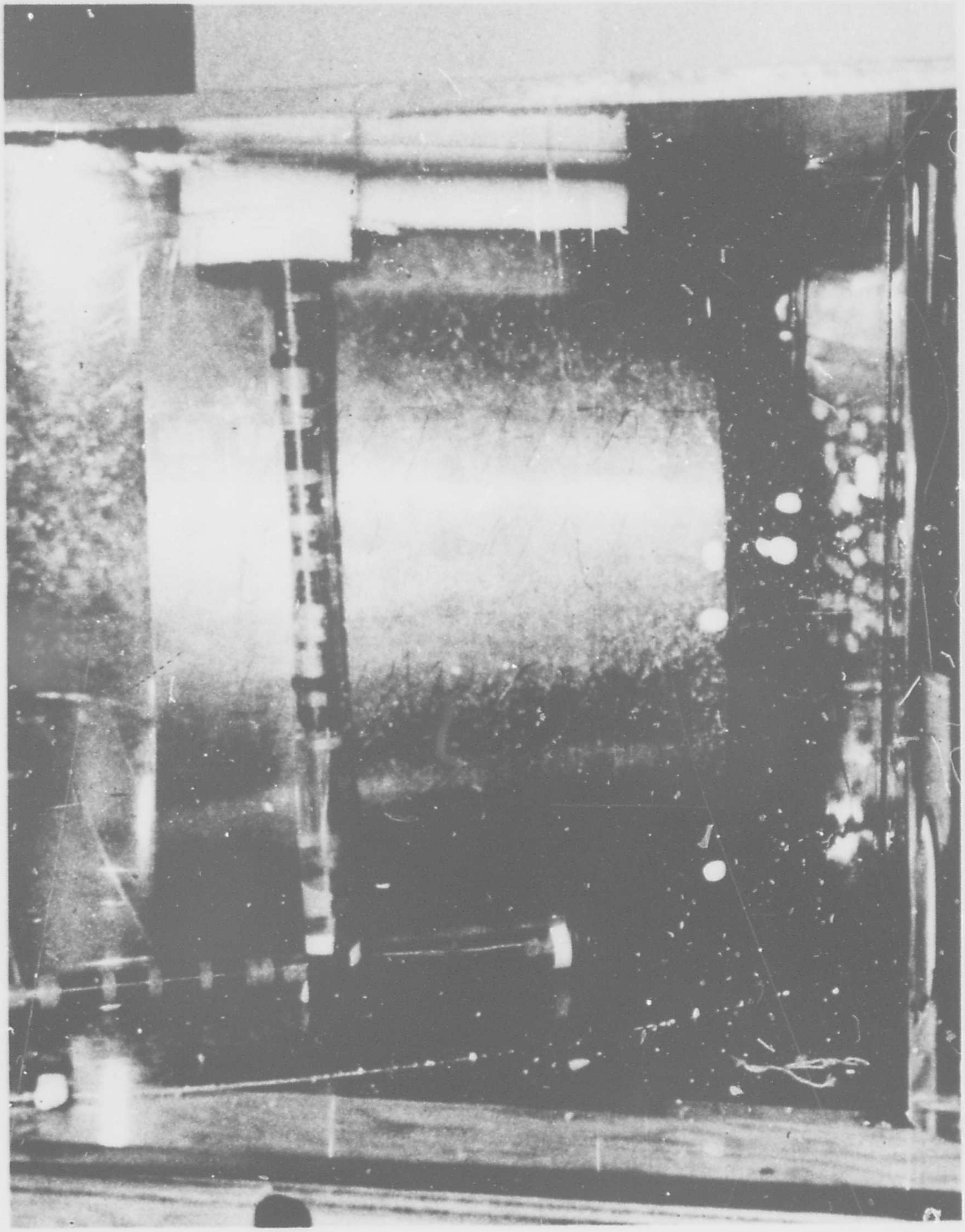

Fig. 10. Crossed Ferrite Loopsticks (Nos. 1 and 3) next to large metal plate.

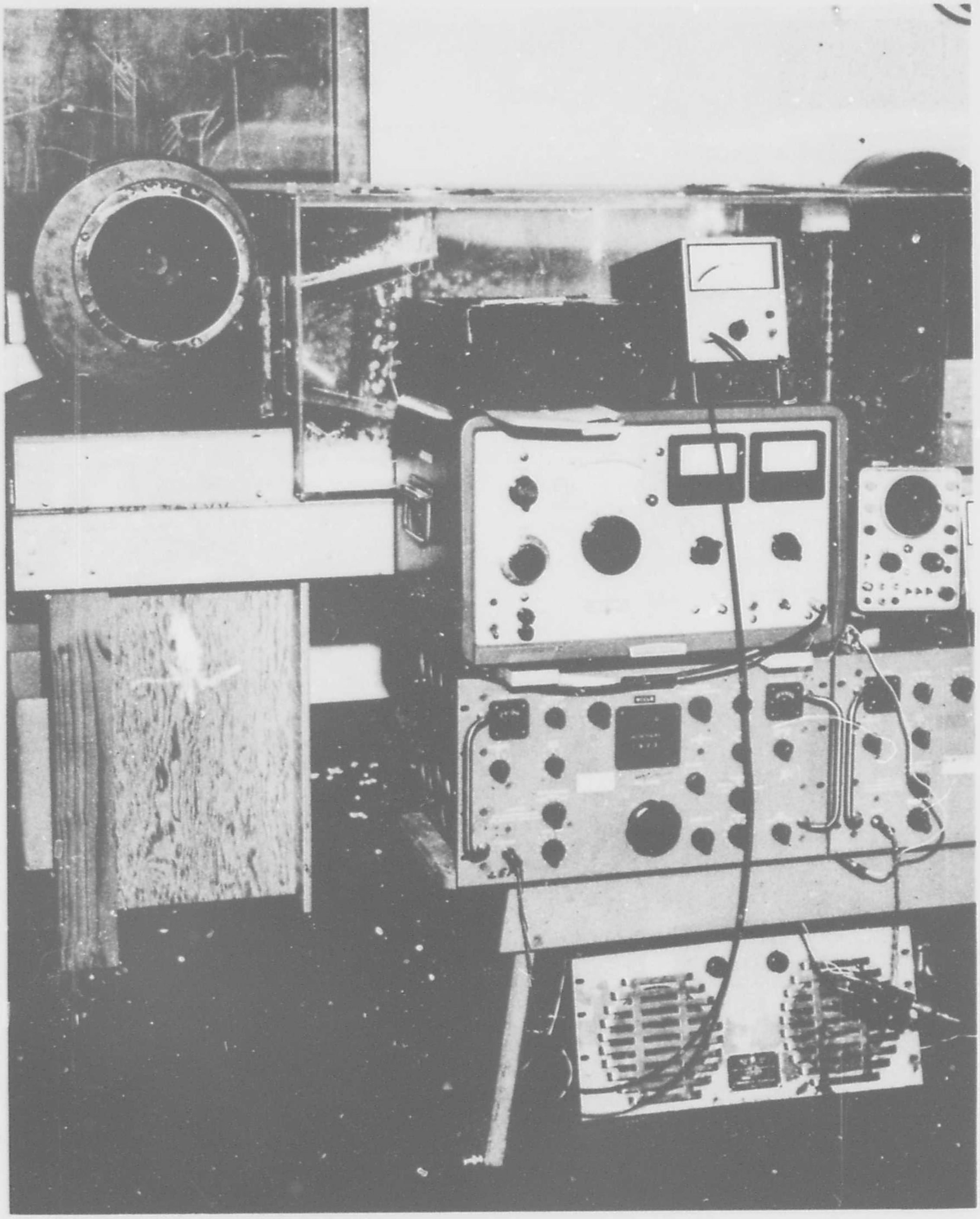

Fig. 11. R-389 Radio Receivers, HP 606-A Signal Generator setup for reception and calibration of received signals and noise.

reception of 150 to 200 kHz signals by ferrite loopstick antennas becomes negligibly small for a spacing of 30 cm between the metal plate and the ferrite loopstick.

(d) This critical separation of 30 cm can be reduced to 10 cm for a pair of ferrite loopsticks oriented orthogonally and connected electrically in parallel.

(e) Ferrite loopsticks must be insulated electrically to prevent the generation of noise by random galvanic contacts between the windings of the loopsticks and triboelectrically charged particles.

(f) Moist or wet insulations of ferrite loopsticks create precipitation static noise which in many respects is similar to the noise created by the close proximity of metal to the ferrite loopsticks.

(g) The nonlinear response of narrow band LF radio receivers (R-389) to the precipitation static noise can manifest itself in either of two ways: (a) when the RF signal exceeds a certain critical level, the receiver is captured by the signal and the noise is suppressed, and (b) vice versa, when the RF signal level is lower than the critical level, the receiver is captured by the noise and the signal is suppressed.

5. RECOMMENDATIONS

Install a magnetic ferrite loopstick antenna in the form of a pair of orthogonal loopsticks on an aircraft. Keep at least a 30 cm spacing between the metal skin of the aircraft and the ferrite loopsticks. Protect the ferrite loopstick antenna mechanically and insulate it electrically from snow and ice by means of a plastic enclosure. Maintain a 30 cm spacing between the inside wall of this enclosure and the ferrite loopsticks. Prevent the penetration and accumulation of moisture inside the protective plastic and on the ferrite loopsticks.

Test and compare the performance of this magnetic ferrite loopstick antenna with that of a conventional electrical aircraft antenna by receiving LF signals in the 100 to 200 kHz range when flying through ice and snow clouds.

APPENDIX

DETAILED DESCRIPTION OF EXPERIMENTS

1. DESIGN OF EXPERIMENTS

Exploratory experiments with (a) metal electrical whip and blade antennas and (b) magnetic ferrite loopstick antennas placed in an electrostatic wind tunnel [7] have shown that, in contrast to the former antennas, the latter antennas are intrinsically insensitive to precipitation static noise fields. This insensitivity was lost when the magnetic ferrite loopstick was placed next to the metal electrical antenna or on a metal baseplate. The subsequently described experiments were designed to quantify these proximity effects, and in particular, to find metal-surface to ferrite-loopstick separations at which the pickup of precipitation static noise from the metal surfaces becomes negligibly small.

In these experiments, three ferrite loopsticks were used. These loopsticks were originally identical in their construction and each was sealed in a lucite tube. To ascertain the effects of moisture on the insulation of direct galvanic contacts between the loopstick windings and the charged particles, one of the original loopsticks was changed. This changed loopstick is referred to in the recordings as "New Loopstick No. 2"; it was removed from its sealed lucite tube insulation and packaged in lucite, in styrofoam insulation, or in polyurethane insulation. It was also used bare, with no insulation whatever. Subsequently, the New Loopstick No. 2 was modified by placing a low impedance secondary winding over its high impedance primary winding. In this form it is referred to as "Modified Loopstick No. 2." This modification was made to achieve a match between the loopstick output impedance and the nominal 50-ohm input impedance of conventional radio receivers. A similar match was achieved between Loopstick Nos. 1 and 3 by means of capacitive voltage divider circuits.

2. METAL PROXIMITY EFFECTS

A. Measurement Setup

The experimental setup used to quantify the metal-to-loopstick proximity effects with regard to precipitation-static-noise pickup is shown in Fig. 6. Ferrite Loopstick No. 1 was placed inside the electrostatic wind tunnel and connected by a 30 cm long RG-58 Cable to an HP 450-A Amplifier outside the wind tunnel. The input of this amplifier was shunted by a tuning capacitor (10 to 100 pF) which was adjusted

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[7] Ikrath, op. cit., p. 6.

to resonate the ferrite loopstick inductance at 145 kHz. The HP 450-A Amplifier was set to 20 dB gain and its output was connected to a HP 3400-A RMS Voltmeter that drove a TR-722 Recorder. This setup was used to record the precipitation static noise generated by styrofoam pellets being blown through the wind tunnel, where they impinged on the lucite insulation of Ferrite Loopstick No. 1 and on a metal plate (ℓ = 44 cm, h = 8 cm, t = 4 mm) mounted next to the ferrite loopstick. The separation "d" between the ferrite loopstick and the metal plate was adjusted by means of a fiber glass insulation rod to which the metal plate was attached (Fig. 6).

B. Metal-Proximity Induced Precipitation Static Noise

Recording Nos. 2 to 5 show the precipitation static noise spike levels obtained when the ferrite loopstick and the metal plate were separated by d = 0, 5, 10, and 15 cm. Notice the disappearance of the precipitation static noise spikes at a separation of d = 15 cm. This performance of the magnetic ferrite loopstick is in contrast to the performance of the short (26 cm long) electrical whip antenna connected to the same amplifier-meter-recorder system (see Recording 6). These recordings obtained with Ferrite Loopstick No. 1 (Recording Nos. 1 to 5) and with the whip antenna (Recording No. 6) verify similar recordings obtained previously [8].

On November 7, 1974, several recordings were made with a new ferrite loopstick, hereafter referred to as "New Ferrite Loopstick No. 2." In contrast to Ferrite Loopstick No. 1 which was sealed in a lucite tube (ℓ = 35 cm, d = 2.5 cm, and t = 2.5 mm), this new ferrite loopstick was packed in polyfoam insulation. Otherwise, Ferrite Loopstick No. 1 and the New Ferrite Loopstick No. 2 were identical with regard to material and construction.

The overall smaller dimensions of the polyfoam insulation package (ℓ = 20 cm; h = w = 4 cm) permitted the rotation of the package perpendicular to the wind- and charged-particle velocity in the 20 cm wide electrostatic wind tunnel. The results are shown in Recording Nos. 11 and 12. It is evident again from a comparison of these recordings that close proximity of the metal plate induced precipitation static noise into the ferrite loopstick. However, in contrast to the previous recordings (Nos. 1 to 5), the precipitation static noise did not disappear completely when the metal plate was moved as far away as 30 cm from the new Ferrite Loopstick (No. 2 - polyfoam package, Recording No. 12). The new ferrite loopstick-polyfoam package was then oriented perpendicular to the wind and charged particle velocity. Yet the possibly greater coupling to the precipitation static noise field in the perpendicular orientation of the ferrite loopstick should have been compensated for by the larger (d = 30 cm)

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[8] Ikrath, op. cit., p. 6.

separation between the metal plate and the loopstick. Consequently, it was suspected that the plastic polyfoam insulation was responsible for the residual noise (Recording No. 12). To verify this, the metal plate was removed from the wind tunnel. The subsequent results obtained with the New Ferrite Loopstick No. 2 by itself in the polyfoam package are seen in Recording Nos. 13 to 16. For these recordings, the New Ferrite Loopstick No. 2 in the polyfoam package was oriented both parallel to, i.e., longitudinal orientation (Recording Nos. 13 and 15) and perpendicular to (Recording Nos. 14 and 16) the wind- and charged-particle velocity. The results of these recordings were consistent: the noise spikes were much larger for the longitudinal orientation than for the perpendicular orientation. Yet this result conflicts with the magnetic field geometry associated with the wind-blown charged particle currents as sensed by the ferrite loopstick. On the other hand, the results agree with the different exposures of the length (20 cm) and width (4 cm) of the polyfoam surface of the loopsticks insulation package to triboelectric charging and discharging. Thus it became evident that the noise created by the plastic insulation surrounding the ferrite loopsticks should be investigated more closely.

3. PLASTIC INSULATION PROXIMITY EFFECTS

A. Exploratory Experiments

The investigation of proximity effects was initiated with the originally used Ferrite Loopstick No. 1 sealed in the lucite tube (Fig. 4). For this recording (No. 7), the originally used shunt tuning capacitor across the input of the HP 450-A Amplifier was removed, so that the ferrite loopstick (and its connecting cable) could be operated at its self-resonance frequency of 196 kHz. A keyed 196 kHz CW signal was generated with a signal generator (GR 1330-A Bridge Oscillator) and a relay keyer (laboratory constructed). The signal was emitted by a wire antenna inside the laboratory. Recording No. 7 shows the wave shape of the keyed 196 kHz CW signal as picked up by Ferrite Loopstick No. 1 and recorded by the same amplifier (HP 450-A), RMS voltmeter (HP 3400-A), and Recorder (TR-722). As expected from the previous recordings with Loopstick No. 1, the signal wave shape and amplitude (50 mV) remained unchanged by the wind-blown charged particles, i.e., during the time interval between "Blower No. 1 ON" and "OFF" on Recording No. 7. The next recording was made with New Ferrite Loopstick No. 2 which had been used previously inside the polyfoam insulation package (Recording Nos. 11 to 16). However, for Recording No. 8, the polyfoam insulation was removed and Ferrite Loopstick No. 2 was used uninsulated (Fig. 7) such that the wind-blown charged particles impinged on the ferrite core and the wire windings of the loopstick. The results in Recording No. 8 are self-evident: the precipitation static noise peaks thus induced into the ferrite loopstick exceeded the received keyed CW 190 kHz signal amplitude (50 mV) and completely distorted the original keyed signal wave shape. The next recordings (Nos. 36 and 37) were made with a third loopstick (No. 3), which like Loopstick No. 1 was sealed inside a lucite tube (Fig. 4). The recordings obtained with Loopstick No. 3 (Recording Nos. 36 and 37) are similar to those obtained with

Loopstick No. 1. As in the Loopstick No. 1 case (Recording No. 7), reception of the keyed CW 190 kHz (self-resonance) signal by Loopstick No. 3 was not affected by precipitation static noise. Thus it seems evident that insulating the ferrite loopstick by means of the lucite tube inhibited the noise produced by galvanic transfer of charges to the loopstick windings from the charged styrofoam particles which were impinging on the windings in the case of Recording No. 8. Proof of this noise-inhibiting action of the lucite tube is confirmed by Recording Nos. 9 and 10. These recordings were made with Loopstick No. 2 placed first inside a lucite tube (Recording No. 9) and then bare, again without the protective shield of a lucite tube (Recording No. 10). The self-resonance frequency of the loopstick and the corresponding signal frequency used for these recordings (Recording Nos. 9 and 10) was 184 kHz instead of the previously used 190 kHz (Recording No. 8). This decrease in the self-resonance frequency was caused by a connector which had been added to the loopstick cable circuit to facilitate the insertion and removal of Loopstick No. 2 into and out of, the lucite tube. Recording Nos. 9 and 10 demonstrate the noise inhibiting effect of the lucite tube insulation. Yet the previous recordings (Nos. 12 to 16) provide evidence that plastic insulation (polyfoam) can also be detrimental rather than helpful in suppressing precipitation static noise pickup by ferrite loopsticks. The reason why plastic foam insulation of of ferrite loopsticks may become the source of precipitation static noise is revealed in the following section.

B. <u>The Effects of Moist Plastic Insulation</u>

In these experiments, Loopstick No. 2 and the same amplifier, meter, and recorder circuit as described before were used. Results of the initial experiments are shown in Recording Nos. 17 and 18. For Recording No. 17, Ferrite Loopstick No. 2 was enclosed in a lucite tube and then embedded in a styrofoam insulation package (ℓ = 35 cm, h = w = 7.5 cm, Fig. 8). This styrofoam insulation package was removed for Recording No. 18. Comparison of these two recordings (Nos. 17 and 18) shows clearly the noise-generating role of the styrofoam insulation package. In Recording No. 17, reception of the keyed 184 kHz CW signal was completely covered up by the precipitation static noise caused by the styrofoam insulation package. When the styrofoam package was removed and only the lucite tube used as insulation, the signal came through clearly and undistorted, as seen in Recording No. 18.

The mysterious noise-generating role of the styrofoam insulation became even more mysterious when Loopstick No. 2 in its lucite insulation tube was put back into the styrofoam insulation package for a rerun of the test shown by Recording No. 17. However, instead of duplicating this record, a less noisey Recording was obtained (No. 19). Considering the evidently diminished noise level, the following question arose: Could it be that the styrofoam insulation package had been moist originally (Recording No. 17) and that it dried somewhat when exposed to the wind inside the tunnel? Recording Nos. 17 to 19 were made on 12 Nov. 1974 after a humid and rainy night, when the styrofoam insulation had probably absorbed moisture and would therefore act like a metal conductor rather than like a plastic insulator.

This theory was confirmed by the experiments carried out on the succeeding day, 13 Nov. 1974. These experiments were prepared for by blowing heated air through the wind tunnel. Ferrite Loopstick No. 2 enclosed in a lucite tube and embedded in the styrofoam insulation package was then placed inside the wind tunnel. After more than one-half hour of drying by the heated air, the styrofoam insulation package was no longer a source of precipitation static noise (see noise-free Recording No. 20). But to make certain that it really was the moisture in the styrofoam insulation package that had produced the precipitation static noise (Recording Nos. 17 and 19), a few drops of water were sprinkled on the surface of the styrofoam insulation package before the next recording was made. This recording (No. 21) shows that the few drops of water sprinkled on the surface of the styrofoam package created a few noise spikes. The styrofoam package was then soaked with water to drastically increase the pickup by the ferrite loopstick of the precipitation static noise. The expected noise-generating role of the moisture was confirmed, as can be seen in Recording No. 22. In fact, with the styrofoam insulation package soaking wet, the precipitation static noise became so severe that it blocked and overloaded the receiver-recorder circuit. Keeping the blower on for the next half-hour helped dry the styrofoam package, and now again only a few noise spikes interfered with the signal reception. Since the blower motor of the wind tunnel tends to run hot from constant operation, no attempt was made to continue drying the styrofoam insulation inside the wind tunnel. Instead, the still slightly-moist styrofoam insulation was removed and Recording No. 23 was made with the loopstick insulated by only the lucite tube. The noise-free performance of the loopstick in the lucite insulation tube was self-evident in this case.

In practice also, the lucite insulation may become wet, at least on the surface. Recording No. 24 shows the differences in signal reception resulting from dry-surface and wet-surface conditions of the lucite insulation tube. Loopstick No. 1 was used for these recordings since it was sealed in the lucite tube such that no water could seep into its interior. This loopstick in its lucite tube enclosure was then taped to a drinking glass. The glue on the paper tape was apparently still moist, and produced a few noise spikes, as seen in the "dry-surface condition" recording (No. 24a). [The drinking-glass mount was used to prevent water drops from falling into the wind tunnel bottom when the lucite tube surface was being soaked with a wet sponge in preparation for Recording No. 24b and during the recording.] The wet surface of the lucite insulation tube produced the precipitation static noise shown in Recording No. 24b. This noise was so intense that it completely covered up reception of the keyed 190 kHz signal. Thus, it is evident from these experimental results that with regard to the generation of precipitation static noise, wet or moist plastic insulation behaves like conductive metal in close proximity to ferrite loopstick antennas. Consequently, the investigation of metal proximity effects was resumed.

4. METAL PROXIMITY EFFECTS (Resumed)

After having segregated and understood the effects of the proximity of metal and of moist insulation on the antennas, experiments were resumed to quantify the influence of noise generation resulting from the proximity of metal.

A. Experimental Setup

The HP 450-A Amplifier used in the test setup previously was replaced by an R-389 Radio Receiver. The circuit characteristics of this standard Army receiver are typical for LF receiver-detector circuits used for communication and navigation in the LF bands. The audio output of the R-389 Receiver was connected to the HP 3400-A RMS Voltmeter, which drove the TR-772 Recorder. To produce an audio output signal from the R-389 Receiver, the subsequently described experiments were made with 400 Hz amplitude-modulated and slowly-keyed RF carrier signals which were emitted from the wire antenna in the laboratory. Furthermore, Ferrite Loopstick No. 2 was modified to match its output impedance to the R-389 Receiver RF input. This match was achieved empirically by placing a 6-turn secondary winding over the high impedance primary winding of the ferrite loopstick (Fig. 7). The terminals of this primary winding were connected by a 45 cm long RG-174/U Cable to a variable tuning capacitor in a shielded enclosure. The terminals of the low-impedance secondary winding were connected by a 1-meter long RG-174/U Cable to the RF input of the R-389 Radio Receiver.

In the subsequently described experiments, Modified Ferrite Loopstick No. 2 was used inside a lucite insulation tube. The loopstick was then placed inside the wind tunnel in a horizontal position and oriented 45° relative to the wind and particle velocity. The bandwidth control of the R-389 Radio Receiver was set at 2 kHz, and its RF gain control was set at 10. The local gain control of the receiver was initially set at six (Recording No. 38) and subsequently changed to seven (Recording Nos. 39 to 42). In each case, the RF gain of the R-389 Receiver and the meter-recorder system was calibrated by substituting an HP606-A Signal Generator (Fig. 11) for the ferrite loopstick. Calibration was carried out by using the same RF signal as emitted by the wire antenna.

The metal proximity effects for these experiments were created with the same metal plate used for Recording Nos. 1 to 5.

B. Experiments with Insulated Metal-Whip Antenna and Modified Ferrite Loopstick No. 2, Using R-389 Radio Reciver (Ser. 479)

These ferrite loopstick experiments were initiated by using the Insulated Whip Antenna for the reception of 28-, 100-, and 220-microvolt signals. The resulting noise-perturbated recordings (Nos. 43 to 45) served as a reference for the subsequently described experiments with Modified Ferrite Loopstick No. 2. The first experiment involved the reception and recording of a slowly-keyed 165 kHz and 400 Hz modulated signal when the metal plate and loopstick were separated by d = 30 cm. The resulting signal record (No. 38) was practically undisturbed by precipitation static noise. Calibration of this signal record showed that the tuned ferrite loopstick circuit had delivered a 200-microvolt signal level to the R-389 Receiver input. For subsequent experiments, the output from the GR 1330-A Bridge Oscillator into the wire transmitting antenna was reduced to deliver a 100-microvolt signal output from the ferrite loopstick in the wind tunnel. Consequently, the corresponding signal wave shape (seen in Recording No. 39) was slightly more perturbated (Recording No. 38) by precipitation static noise. Perturbation of the 100-microvolt signal wave shape became more severe after the separation between the ferrite loopstick and the metal plate was reduced to d = 20 cm (Recording No. 40). Reducing the loopstick-to-metal separation further to d = 10 cm yielded Recording No. 41; here the original signal wave shape was completely lost in noise. After a further reduction in the separation between the loopstick and metal to d = 0 cm, i.e., the metal plate touching the lucite insulation of the ferrite loopstick, the loopstick circuit had to be retuned in order to receive the same 165 kHz signal frequency. However, the resultant recording (No. 42) showed that the signal was again lost in precipitation static noise. In fact, the noise was now so strong that it overloaded the dynamic range of the receiver-recorder system in spite of the AGC on the receiver. Thus, these experiments with the R-389 Radio Receiver and Modified Ferrite Loopstick No. 2 proved once more, the detrimental noise-generating effects as a function of the proximity of metal to ferrite loopsticks. Yet, they also showed that a separation of 30 cm between the metal plate and the lucite-tube-insulated loopstick is sufficient to permit practically undisturbed reception with a R-389 Radio Receiver of a 100-microvolt 165 kHz signal. The question, "Can this critical separation be further reduced by the use of more than one ferrite loopstick?" then became the motive for the experiments described next.

5. EXPERIMENTS WITH A PAIR OF CROSSED (ORTHOGONAL) FERRITE LOOPSTICKS

A. Concept

The wire windings of a ferrite loopstick antenna consist of a left-hand wound and a right-hand wound section. These sections are wound symmetrical relative to the center of the ferrite core. Electrically, these sections are connected in parallel such that one antenna terminal is formed by joining the outer ends of the left- and right-hand wound sections; the other terminal is formed by joining the inner ends of these sections. Magnetically, the left-hand and right-hand sections of the winding are connected in series. The purpose of this type of winding is the suppression of the electrical influence of quasi-static electrical fields. Such an electrical field, i.e., the electrical precipitation static noise field, was generated triboelectrically in the electrostatic wind tunnel. Consequently, the ferrite loopstick was immune to precipitation static noise fields as long as the electrical balance between the left- and right-hand wound sections was not disturbed by the proximity of a conductive object. Once this balance became disturbed by the proximity of the metal plate or by the proximity of the wet or moist insulation, or by random mechanical contacts between the bare winding and impinging charged particles, the existing electrical precipitation static field was sensed by the ferrite loopstick antenna; it then manifested itself as a noise output voltage across the loopstick terminal. In the metal-plate proximity case, the electrical unbalance was created by the stray coupling capacitance between the ferrite loopstick and the metal plate. Consequently, it should be possible to reduce or to eliminate precipitation static noise pickup caused by this electrical unbalance by restoring the balance artificially with the aid of a second stray coupling capacitance. In practice, this can be accomplished by using two, instead of one, ferrite loopsticks in relatively close proximity to metal surfaces. However, the use of two ferrite loopsticks introduces problems with their mutual electrical and magnetic coupling. The electrical coupling problem was solved by simply shorting their mutual electrical capacitance, i.e., by connecting the two loopsticks electrically in parallel. Their mutual magnetic coupling was minimized by perpendicular orientation of the loopsticks. The resultant pair of orthogonal loopsticks consisting of Loopsticks Nos. 1 and 3 (Fig. 9) is referred to in the subsequently described recordings as "Crossed Ferrite Loopsticks (Nos. 1 and 3)." Each ferrite loopstick was sealed in a lucite insulation tube.

B. Experimental Setup

Since Crossed Ferrite Loopsticks (Nos. 1 and 3) were sealed in lucite insulation tubes, it was impossible to put a secondary low impedance winding over their primary windings without breaking the sealed tubes. Consequently, the coupling of the Crossed Ferrite Loopsticks to the R-389 Receiver and tuning of their outputs was accomplished with a variable shunt tuning capacitor and a fixed series capacitor. Otherwise, the receiver, meter, and recorder circuit were identical to those used in conjunction with the previous ferrite loopstick experiments.

C. Performance of Crossed Ferrite Loopsticks in Precipitation Static Noise Fields

As in the single loopstick experiments, the first recordings of a keyed 163 kHz and 400 Hz modulated signal were made without the metal plate in the electrostatic wind tunnel. The results are shown in Recording Nos. 25 and 26. The clean, unperturbated wave shape of the 150-microvolt keyed RF signal in these recordings again confirmed the intrinsic immunity of the lucite-insulated ferrite loopsticks to precipitation static noise fields. In the following experiment, the metal plate was placed such that one of its vertical edges was d = 10 cm away from the vertical loopstick of the Crossed Ferrite Loopstick pair. These proximity relations are sketched on Recording No. 26. The completely undisturbed wave shape recorded in this case was unexpected on the basis of the noise levels experienced previously (Recording No. 41) for the same separation (d = 10 cm) between the metal plate and the single loopstick. Therefore, an attempt was made next to increase the pickup of the precipitation static noise by the Crossed Ferrite Loopsticks. For this purpose, the previously used metal plate (44 × 8 cm^2) was replaced by a larger plate (44 × 28 cm^2). This larger plate was wedged in the wind tunnel at a distance of 8 cm from the Crossed Ferrite Loopsticks. The corresponding proximity relations are sketched on Recording No. 27. This recording showed again that the 150-microvolt signal was not perturbated by precipitation static noise in spite of the close proximity (d = 8 cm) of the antenna to this large metal plate. In order to obtain at least a discernable noise effect, the signal level emitted from the wire antenna in the laboratory was reduced by readjusting the output control of the signal generator which fed the wire antenna. Recording No. 28 showed that the precipitation static noise effects became discernable at the 50-microvolt level of the signal. The resulting distortions of the signal by noise became more severe when the separation between the Crossed Ferrite Loopsticks and the metal plate was reduced further, such that the lucite insulation tube enclosing the horizontal loopstick touched the metal plate. After retuning the loopstick circuit for maximal signal pickup, Recording No. 29 was obtained. The perturbations of the signal by noise were increased, but not as drastically as in the single ferrite loopstick case (Recording Nos. 39 and 42). It seemed, therefore, that use of the Crossed Ferrite Loopsticks had significantly improved the electrical balance conditions in the proximity of metal surfaces and reduced accordingly, the interference from precipitation static noise. Therefore, one would expect similar performance of the Crossed Ferrite Loopsticks in the proximity of the Metal-Blade Antenna which had previously spoiled the performance of single ferrite loopsticks [9].

D. Crossed Ferrite Loopsticks versus Metal-Blade Antenna

The subsequent experiments were carried out with the pair of Crossed Ferrite Loopsticks and the Metal-Blade Antenna placed inside the wind tunnel and separated from each other by d = 20 cm. The Metal-Blade Antenna was connected to the R-389 Radio Receiver (Ser. 479) and to the RMS Voltmeter (HP 3400-A) which were used before in conjunction with the Crossed Ferrite Loopsticks. A second R-389 Radio Receiver (Ser. 5) and a second RMS HP 3400-A Voltmeter were connected to the Crossed Ferrite Loopsticks. The left- and right-channels of Recording No. 31

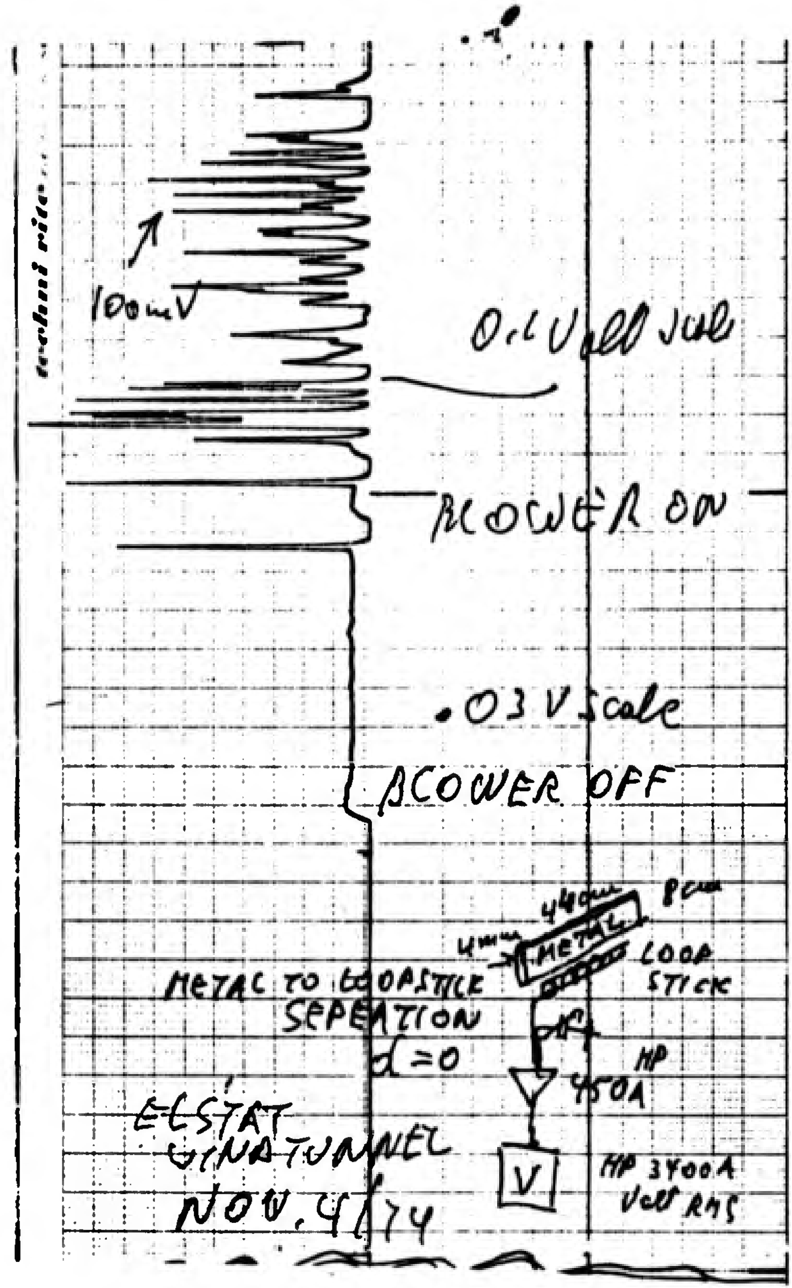
[9] Ikrath, op. cit., p. 6.

(using the TR-722) showed the effects of the same precipitation static noise field environment with respect to a 34-microvolt RF signal as sensed by the Metal-Blade Antenna and with respect to a 54-microvolt signal as sensed by the Crossed Ferrite Loopsticks: reception by the Metal-Blade Antenna of the keyed 163 kHz and 400 Hz modulated signal was blocked completely by the noise. The same signal was received only slightly impaired by noise when the Crossed Ferrite Loopsticks were used. In the latter case, the influence of noise was indicated by the small variations in the null level of the signal record. This indicated that the noise appeared only during the signal-off keying periods and that the signal was controlling the AGC of the R-389 Radio Receiver. In the Metal-Blade Antenna case (Recording No. 31, left channel), the situation was reversed: the noise saturated the AGC of the receiver and thus blocked signal detection. These nonlinear detection phenomena are referred to as "capture" of the receiver by the signal or by the noise. The associated critical signal- and noise-levels were deduced from the subsequently described experiments.

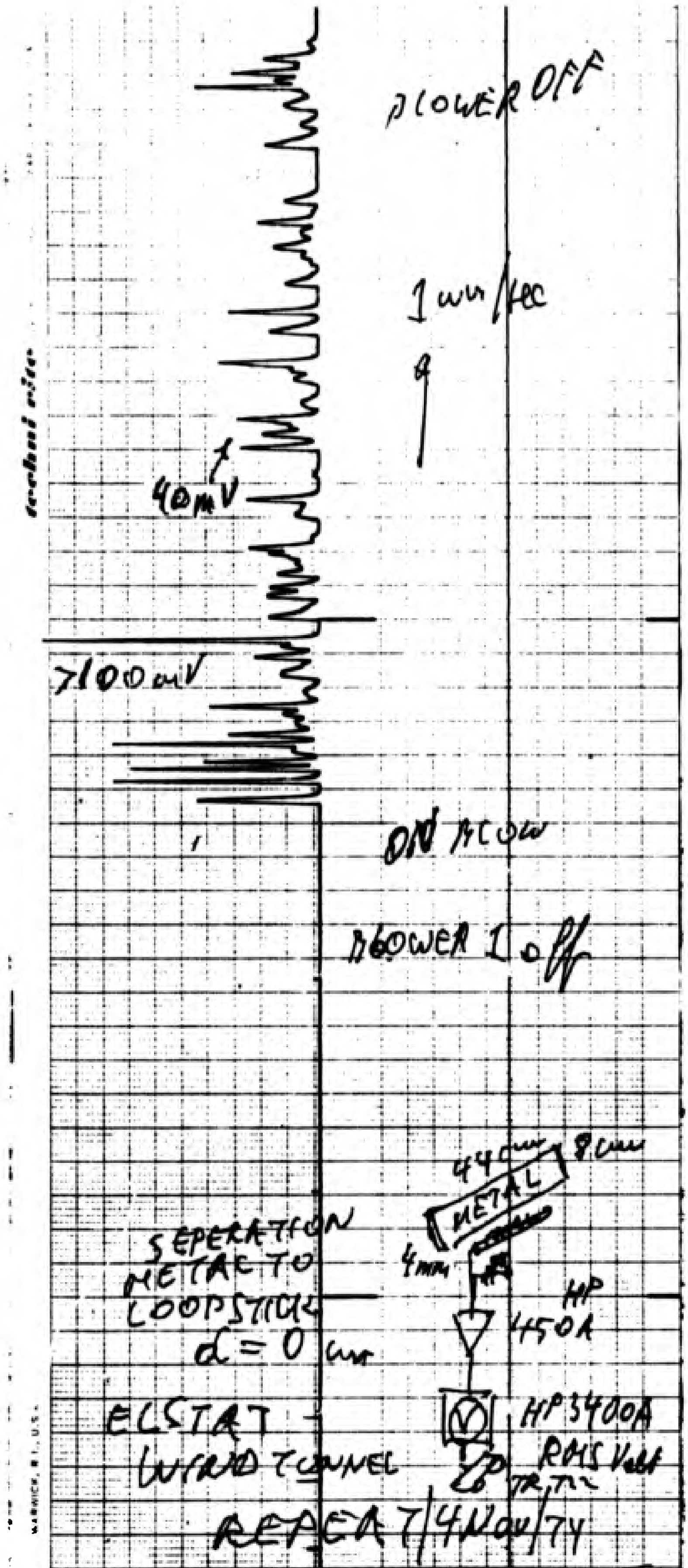
E. Critical Signal and Noise Levels

The increase in precipitation static noise output from the ferrite loopstick antennas in the proximity of metal, and in particular the increased density of the noise spikes tended to enhance the capture of the receiver by noise. The subsequently described recordings of interference with the reception of the keyed 162 kHz and 400 Hz modulated signal resulting from precipitation static noise, revealed the critical signal- and noise levels which govern capture effects. Recording No. 46 shows the wave shape of a slowly-keyed signal as received by the Crossed Ferrite Loopsticks (Nos. 1 and 3) and the R-389 Radio Receiver (Ser. 479). In this recording of a 100-microvolt RF signal, noise interference was hardly noticeable, in spite of the close proximity (d = 3 to 6 cm) of the large metal plate (40×28 cm^2) to the ferrite loopsticks. The noise-free quality of the received signal changed drastically after the vertical loopstick (No. 1) was disconnected, and the signal was picked up by the horizontal loopstick alone (Recording No. 47). Disconnecting the vertical loopstick reduced the signal level (from 100 to 25 microvolts), but did not produce a corresponding reduction in the noise level, in spite of retuning the circuit. Instead, the strength of the noise increased such that it covered up the received signal, i.e., captured the receiver. Yet the reduction in the signal from the 100-microvolt RF input and 1.6-volt audio output level of the R-389 Receiver (Recording No. 46) to the 25-microvolt RF and 0.3-volt audio level (Recording No. 47) suggests that the response of the receiver to the signal reduction was essentially linear. The next recording (No. 48) was made with the horizontal loopstick disconnected and the vertical loopstick connected. The results are similar to those shown in Recording No. 47. Evidently, the lower sensitivity of the single loopstick relative to the pair of Crossed Ferrite Loopsticks with regard to the signal field did not apply to the noise field.

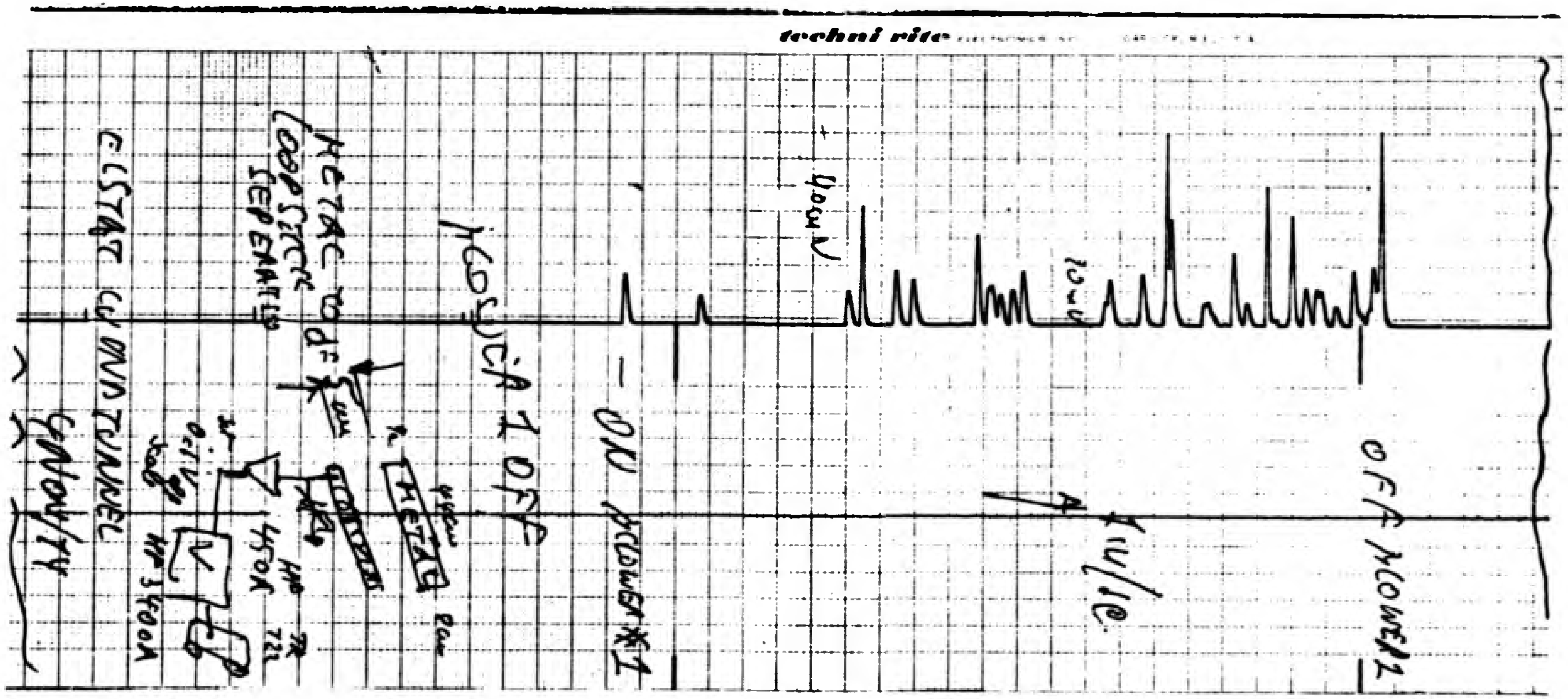
Increased noise due to the increased electrical unbalance of the ferrite loopstick relative to the metal plate led to the capture of the receiver by the noise. To find the critical RF signal level at which the Crossed Ferrite Loopsticks and R-389 Receiver system would fail to deliver a recognizable audio output signal, the horizontal loopstick was again connected and the circuit retuned for optimal reception of an RF signal level lowered to only 40 microvolts. The resulting recording (No. 49) showed that this signal was too low to overcome the precipitation noise produced by the large metal plate. However, after the metal plate was removed from the wind tunnel, dominance of the 40-microvolt RF signal became recognizable in the audio output (Recording No. 35). Therefore, the critical signal level at which neither the signal nor the precipitation static noise were able to capture the receiver was approximately 40 microvolts; a 50-microvolt signal level produced good signal quality, as seen in Recording No. 29. Next, the emitted signal strength was increased to again produce a 100-microvolt RF signal output from the Crossed Ferrite Loopsticks (see perfect signal in Recording No. 33). The clear signal in Recording No. 33 (without the metal plate) and in Recording No. 47 (with the metal plate) showed that a 100-microvolt RF signal level was sufficient to capture the receiver and to suppress the precipitation static noise when the Crossed Ferrite Loopsticks were used as antennas. The next recording (No. 32) was obtained after the Crossed Ferrite Loopsticks had been replaced by the Metal-Blade Antenna. Using the Metal-Blade Antenna for reception of the same signal, the noise captured the receiver and suppressed the 100-microvolt RF signal. The next recording (No. 34) showed that under the same conditions, a 170-microvolt RF signal level was necessary to obtain a recognizable audio signal output. Thus it is apparent that the critical signal level was approximately 170 microvolts in the Metal-Blade Antenna case, in contrast to 40 microvolts for the Crossed Ferrite Loopsticks.



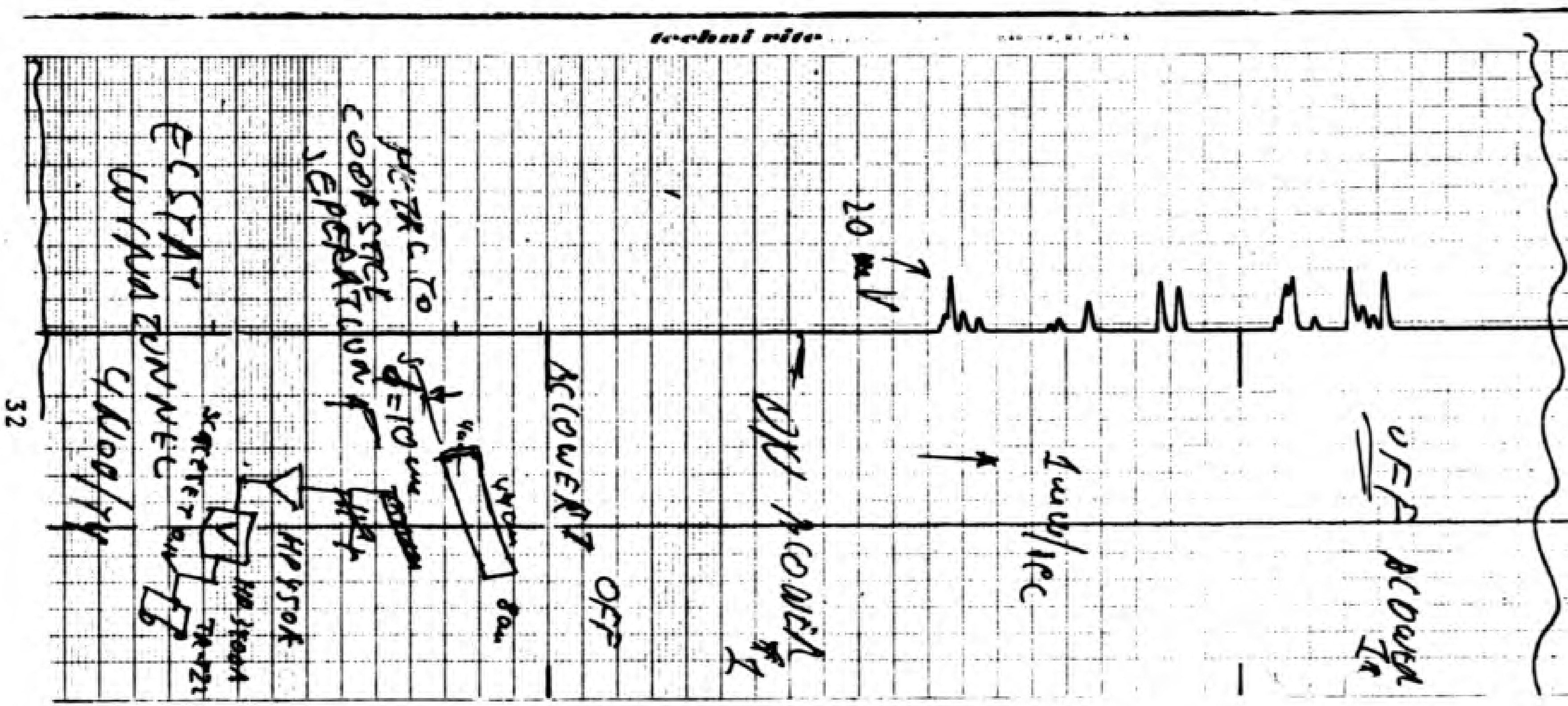
Recording No. 1. Noise output from Ferrite Loopstick No. 1 touching metal plate (d = 0 cm), 4 Nov 1974.



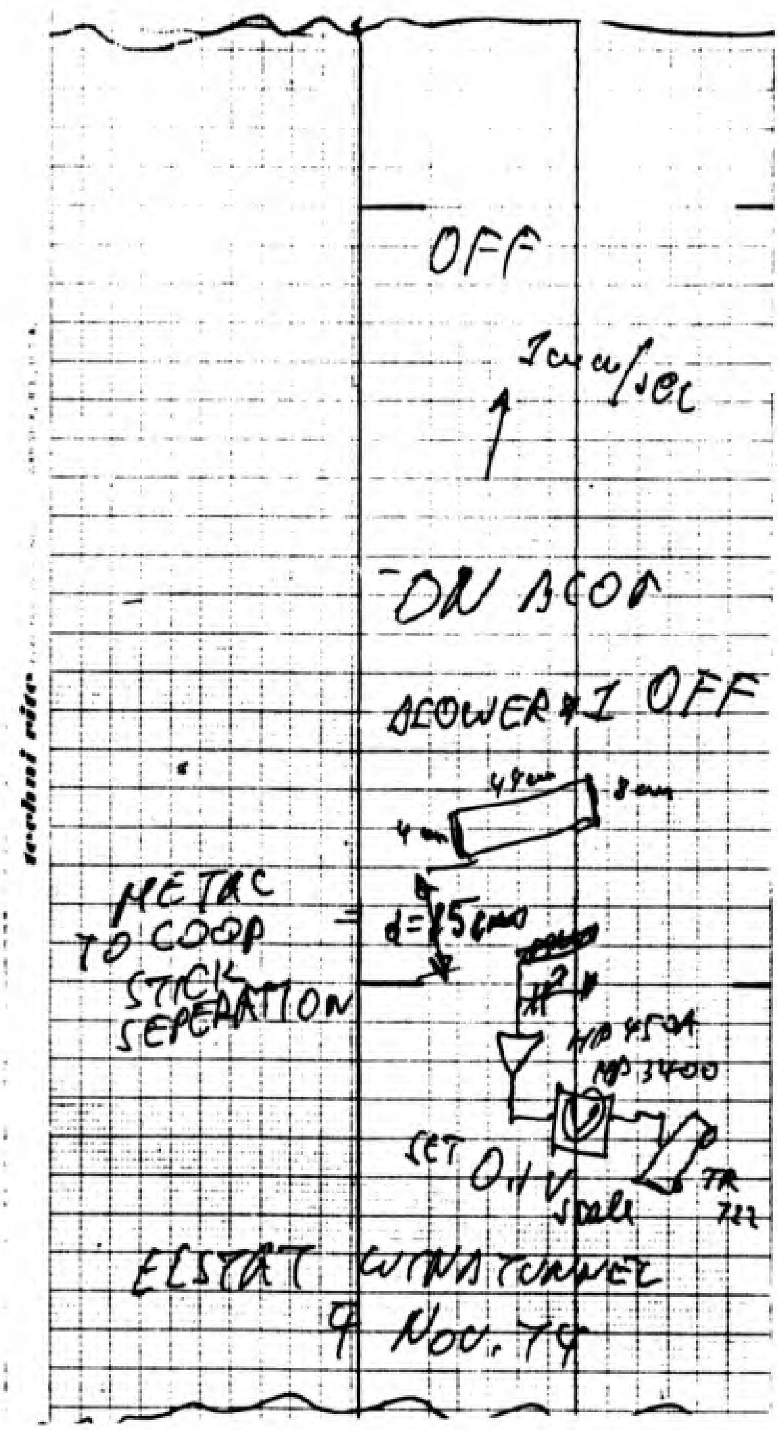
Recording No. 2. Noise output from Ferrite Loopstick No. 1 touching metal plate (d = 0 cm), 4 Nov 1974.



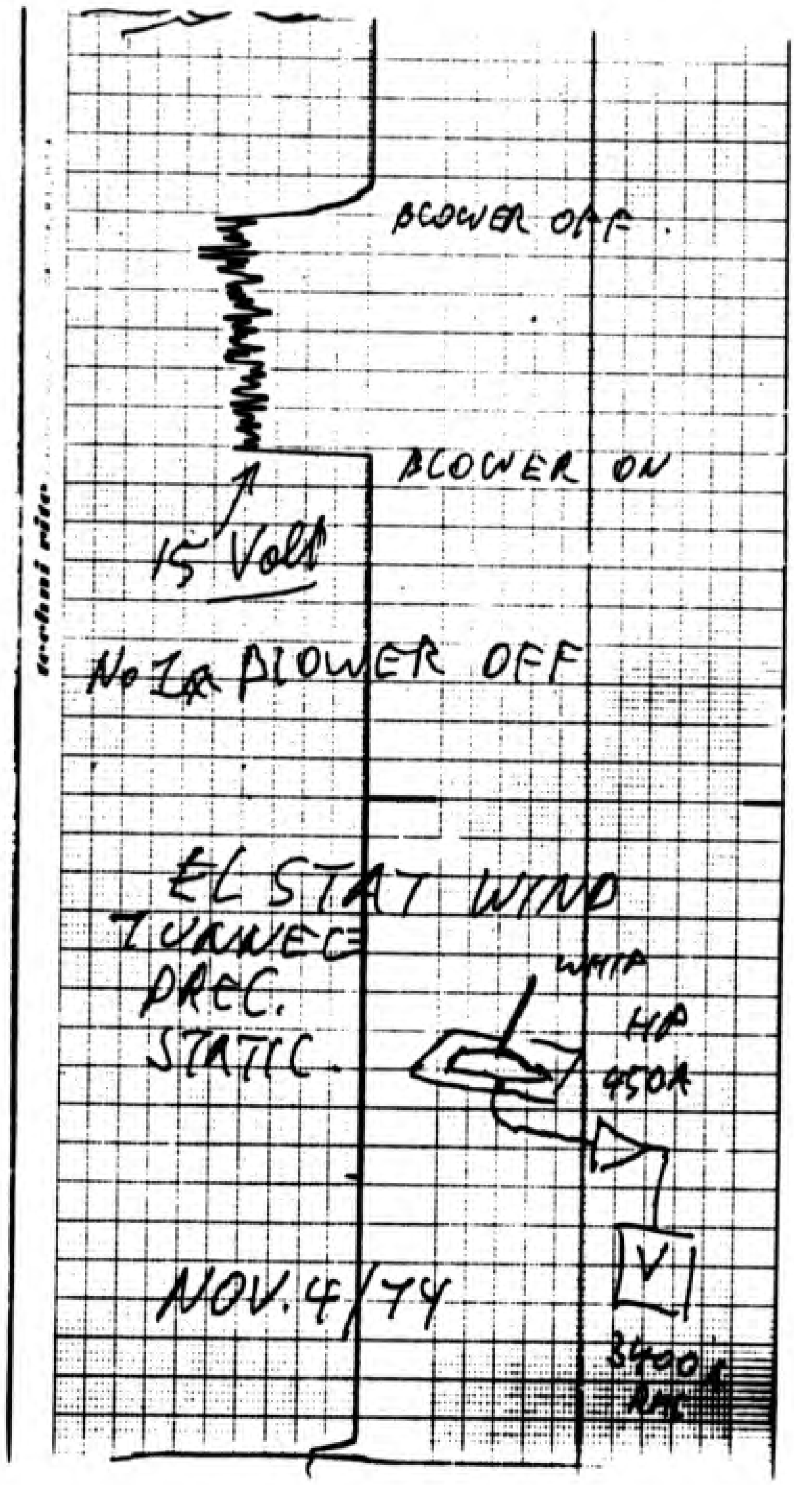
Recording No. 3. Noise output from Ferrite Loopstick No. 1 at d = 5 cm from the metal plate, 4 Nov 1974.



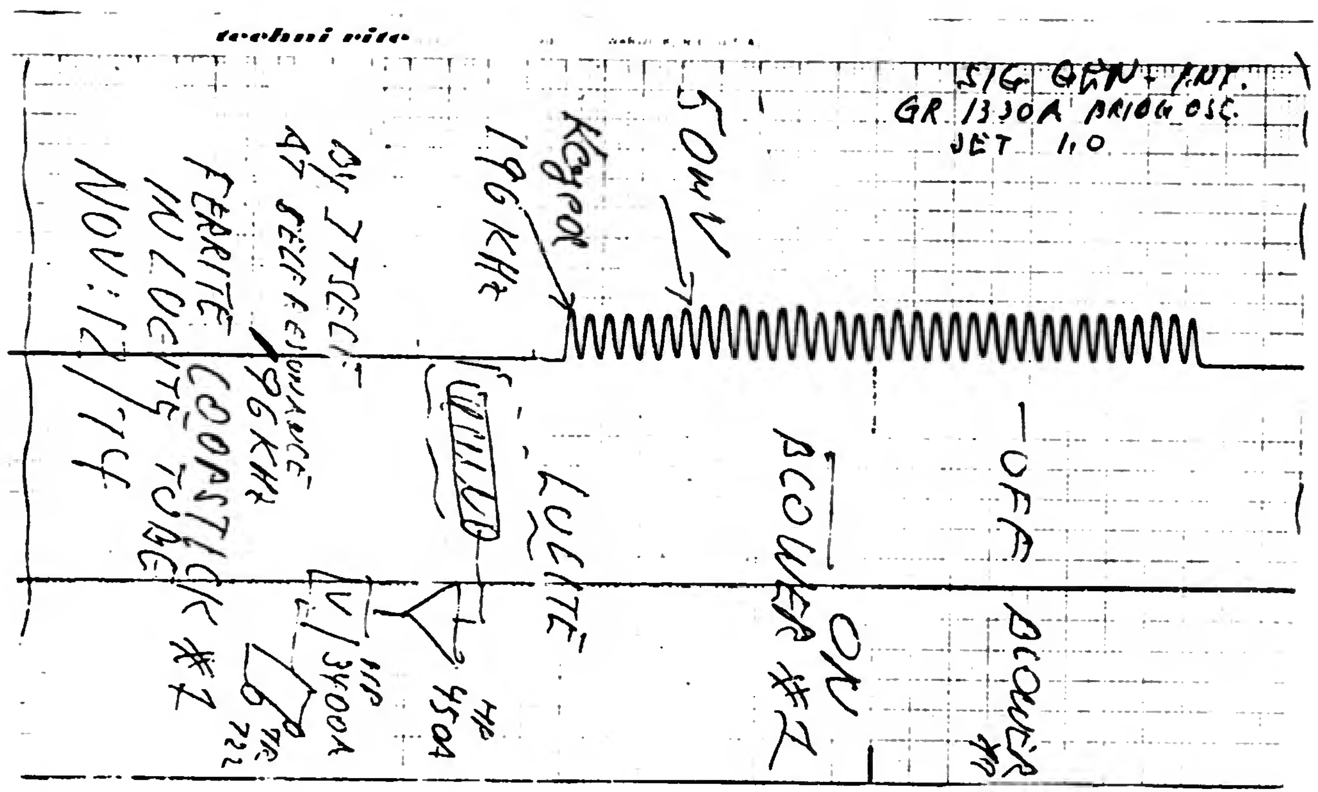
Recording No. 4. Noise output from Ferrite Loopstick No. 1 at d = 10 cm from the metal plate, 4 Nov 1974.



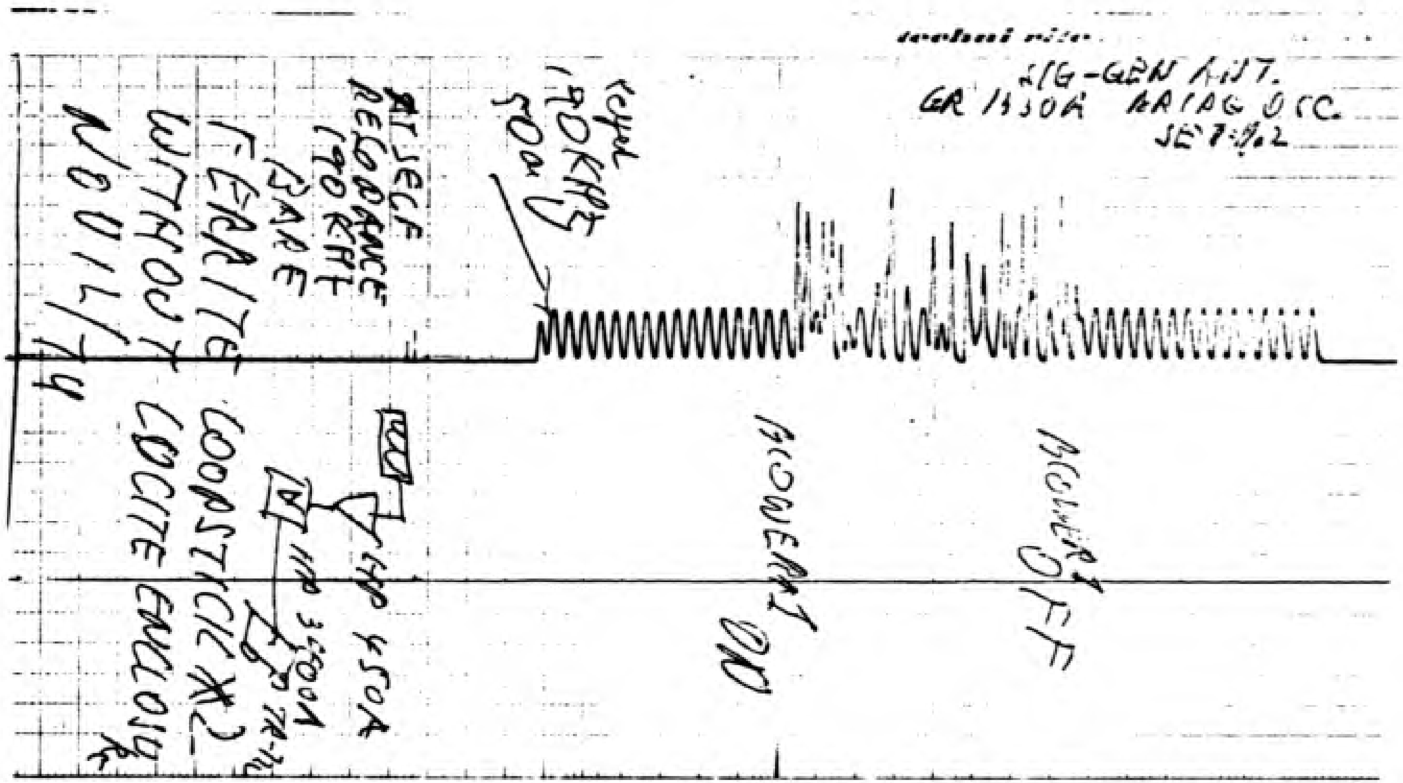
Recording No. 5. Zero noise output from Ferrite Loopstick No. 1 at d = 15 cm from the metal plate, 4 Nov 1974.



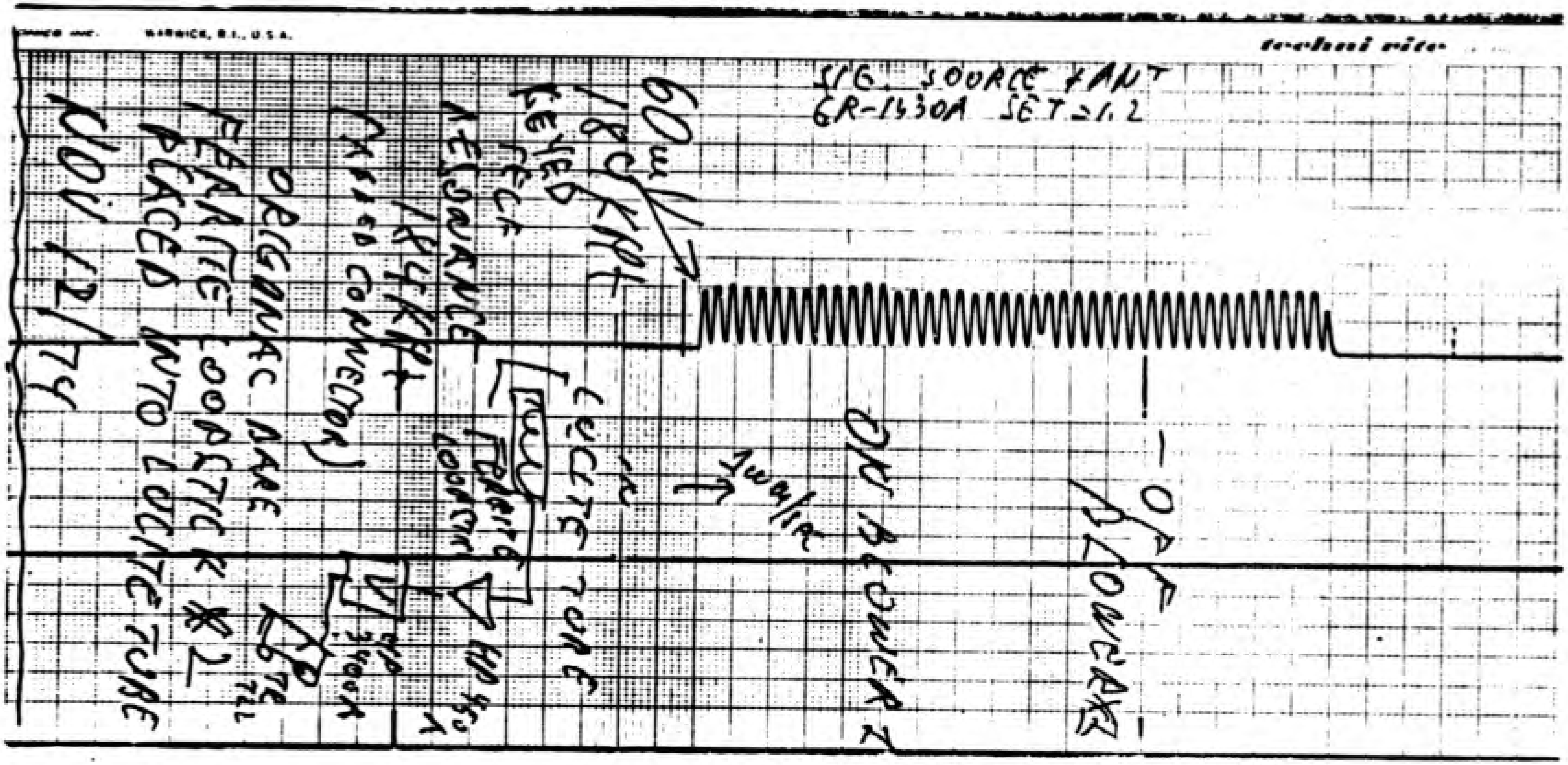
Recording No. 6. Noise output (15 volts) from metal whip antenna (h = 26 cm, w = 6 mm), 4 Nov 1974.



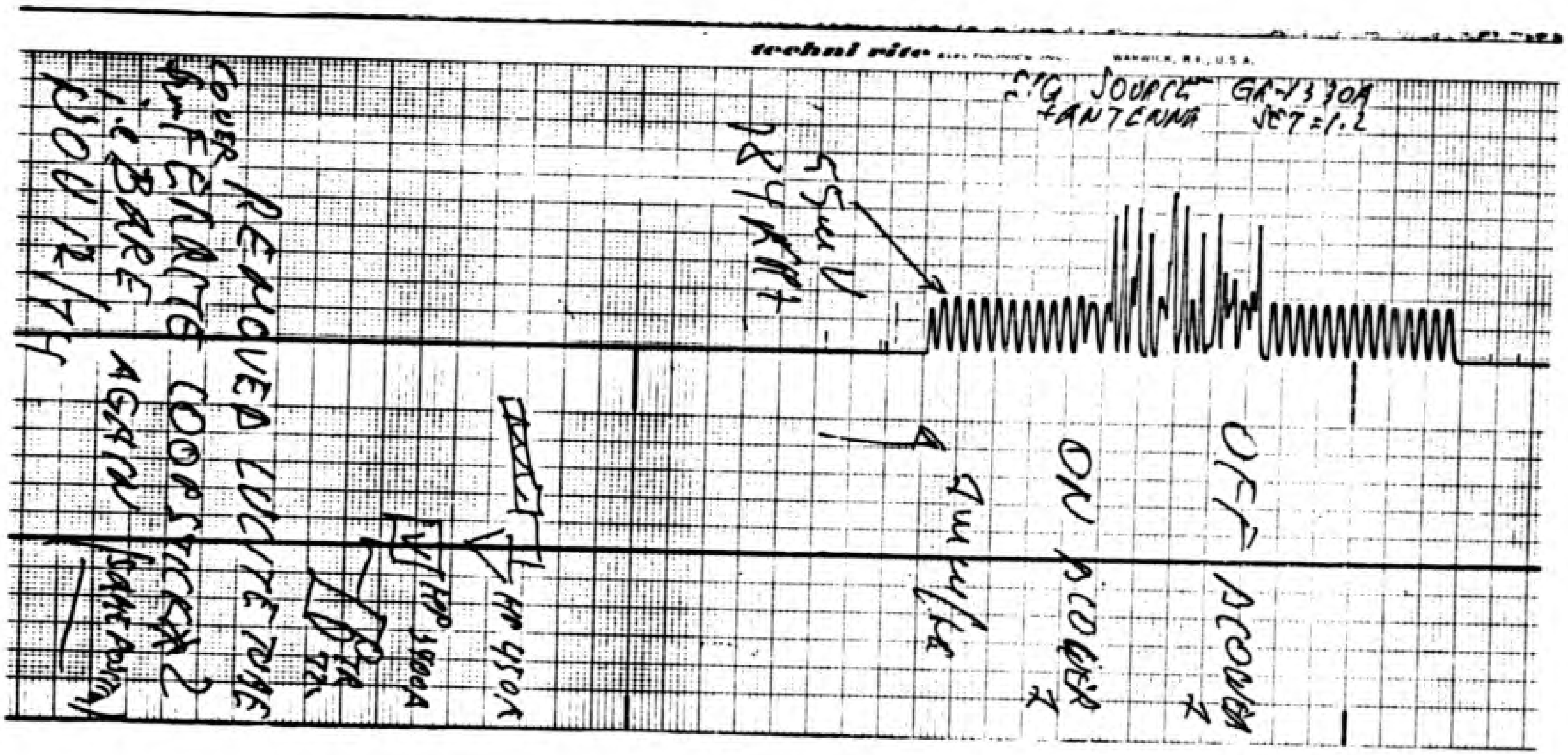
Recording No. 7. Signal (196 kHz keyed CW) received unperturbated by noise with Ferrite Loopstick No. 1 sealed in lucite insulation tube, 12 Nov 1974.



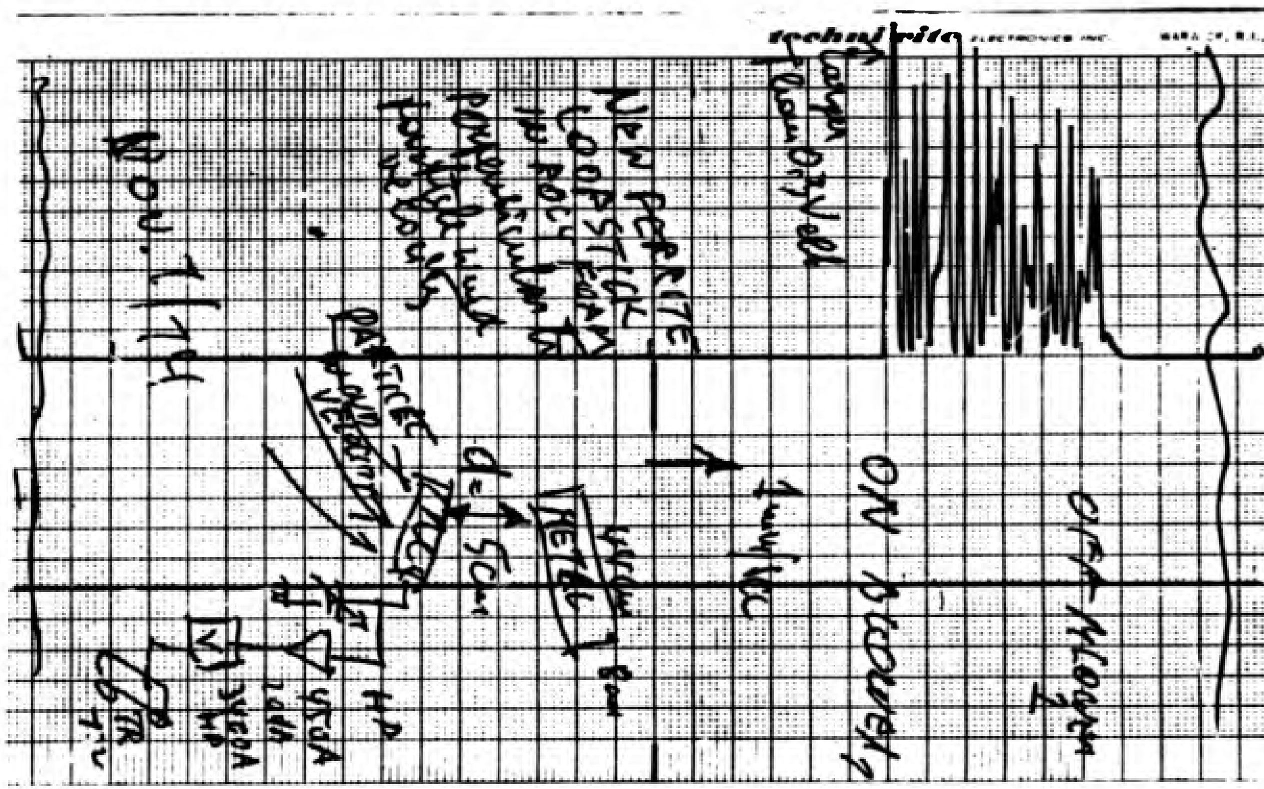
Recording No. 8. Signal (190 kHz keyed CW) covered up by noise as received by Ferrite Loopstick No. 2 bare, without lucite insulation, 12 Nov 1974.



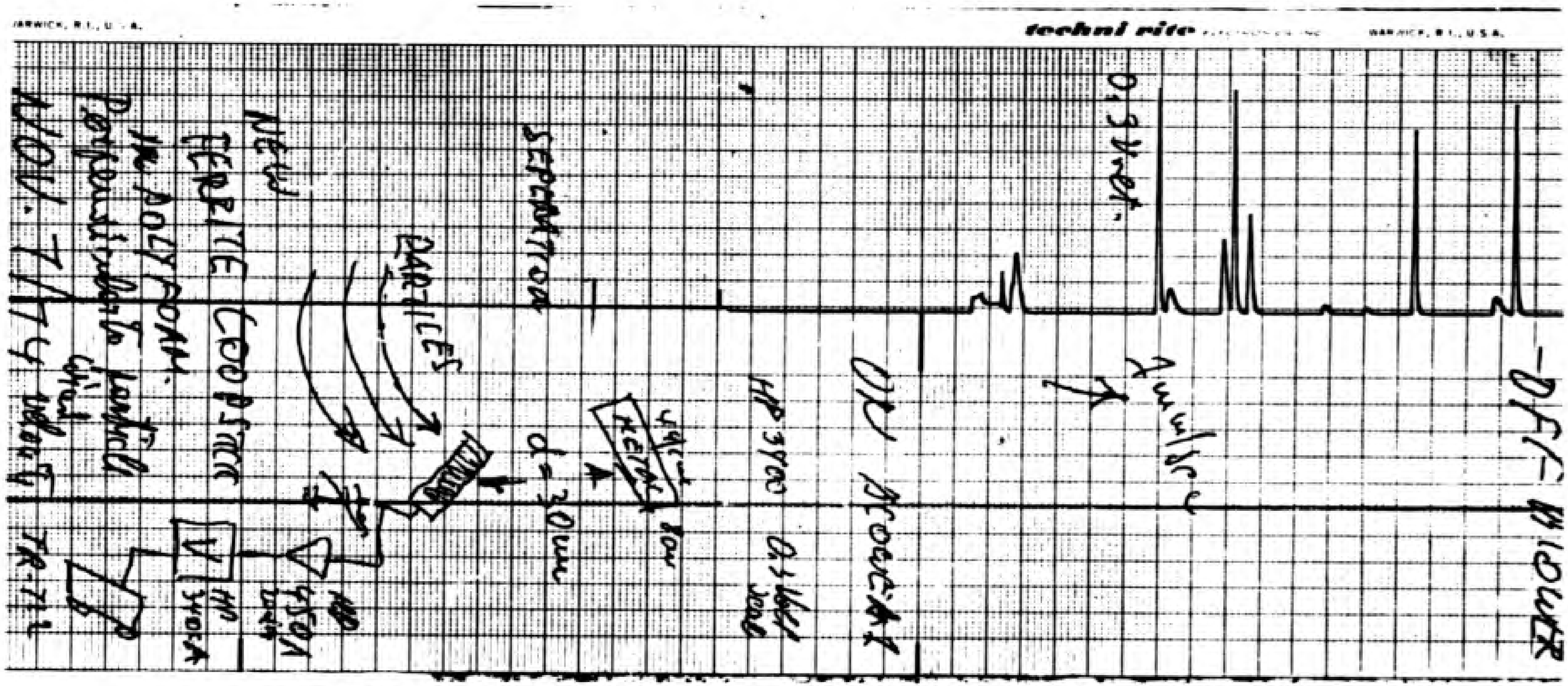
Recording No. 9. Signal (184 kHz keyed CW) received unperturbated by noise with Ferrite Loopstick No. 2 placed inside lucite insultation tube, 12 Nov 1974.



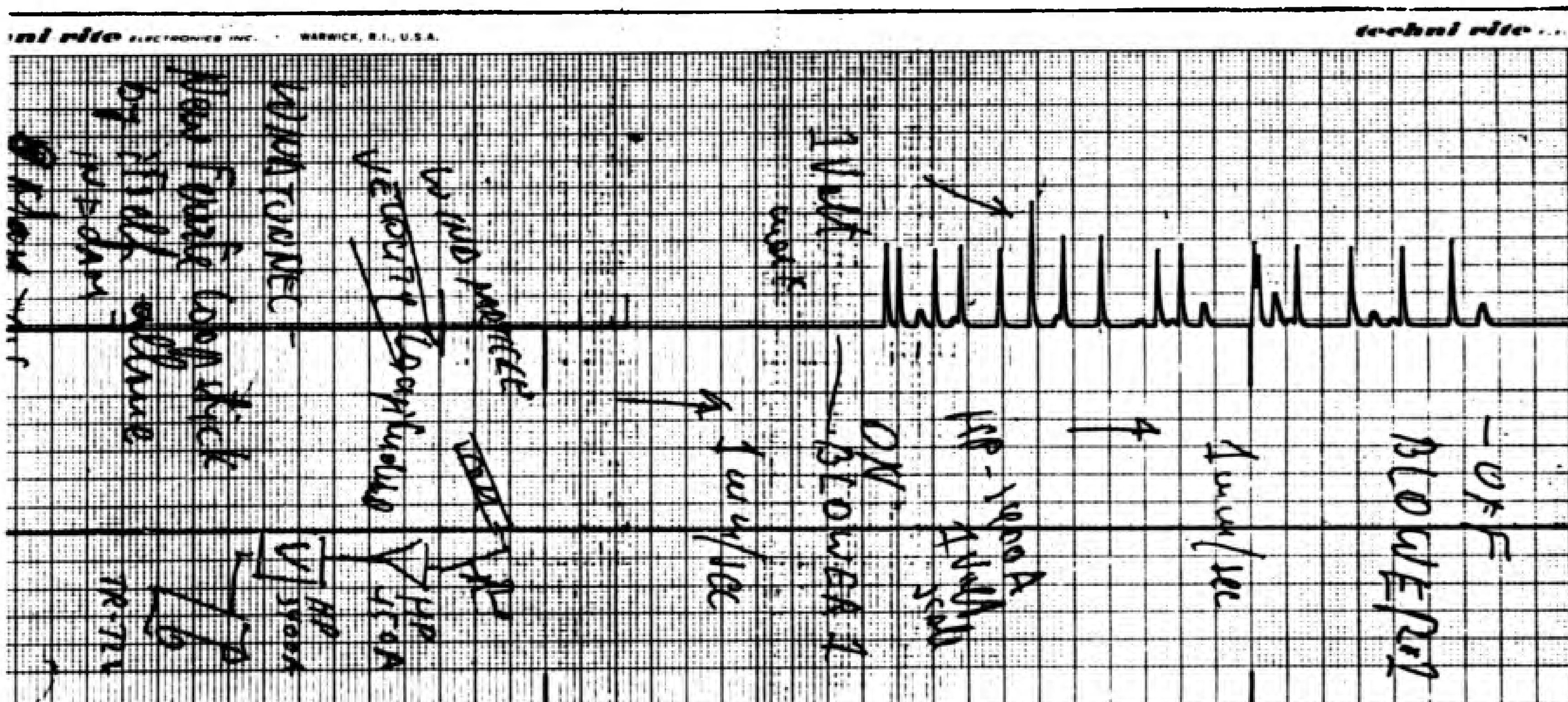
Recording No. 10. Signal (184 kHz keyed CW) covered up by noise as received with Ferrite Loopstick No. 2 bare, without lucite insulation, 12 Nov 1974.



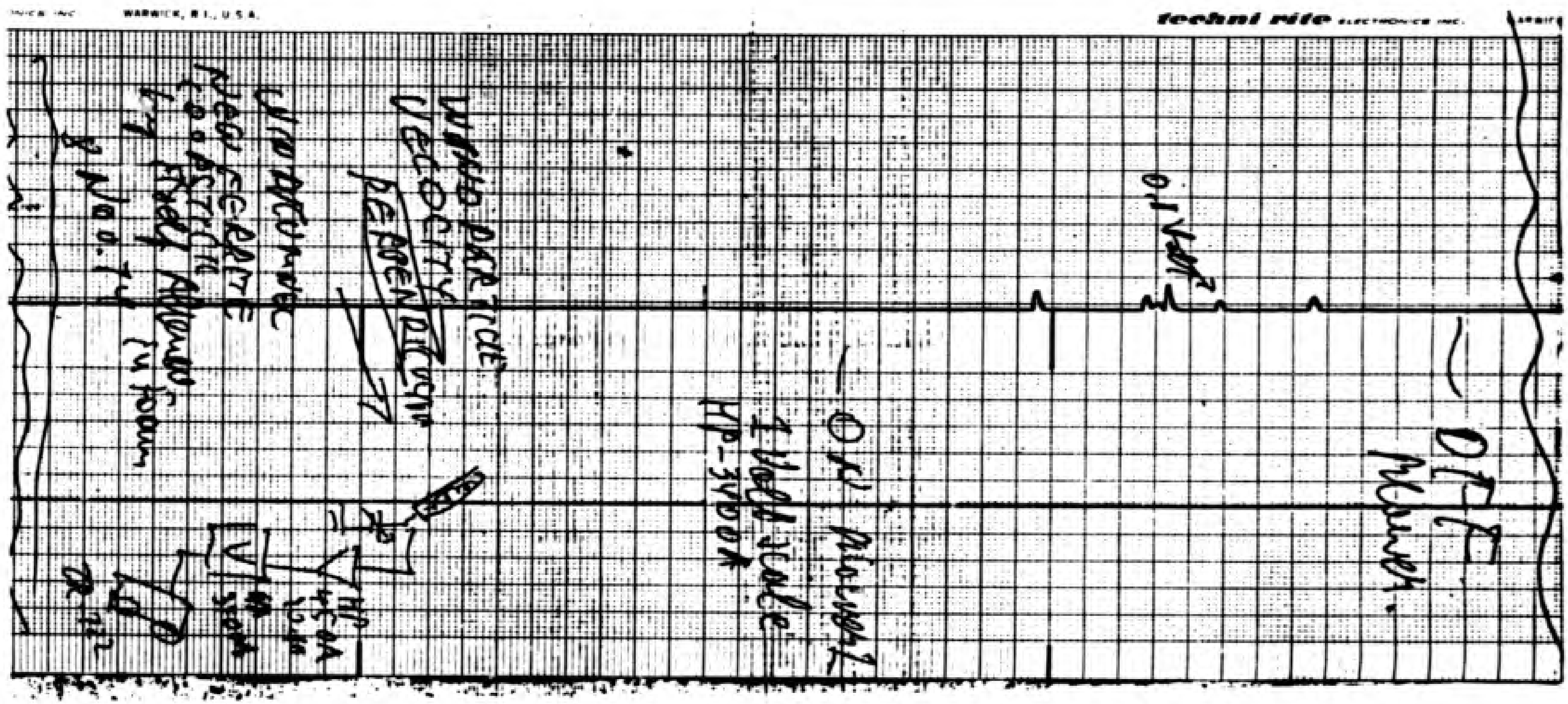
Recording No. 11. Noise output from Ferrite Loopstick No. 2 inserted in lucite tube and embedded in polyfoam insulation, mounted perpendicular to the particle and wind velocity and at d = 5 cm from the metal plate, 7 Nov 1974.



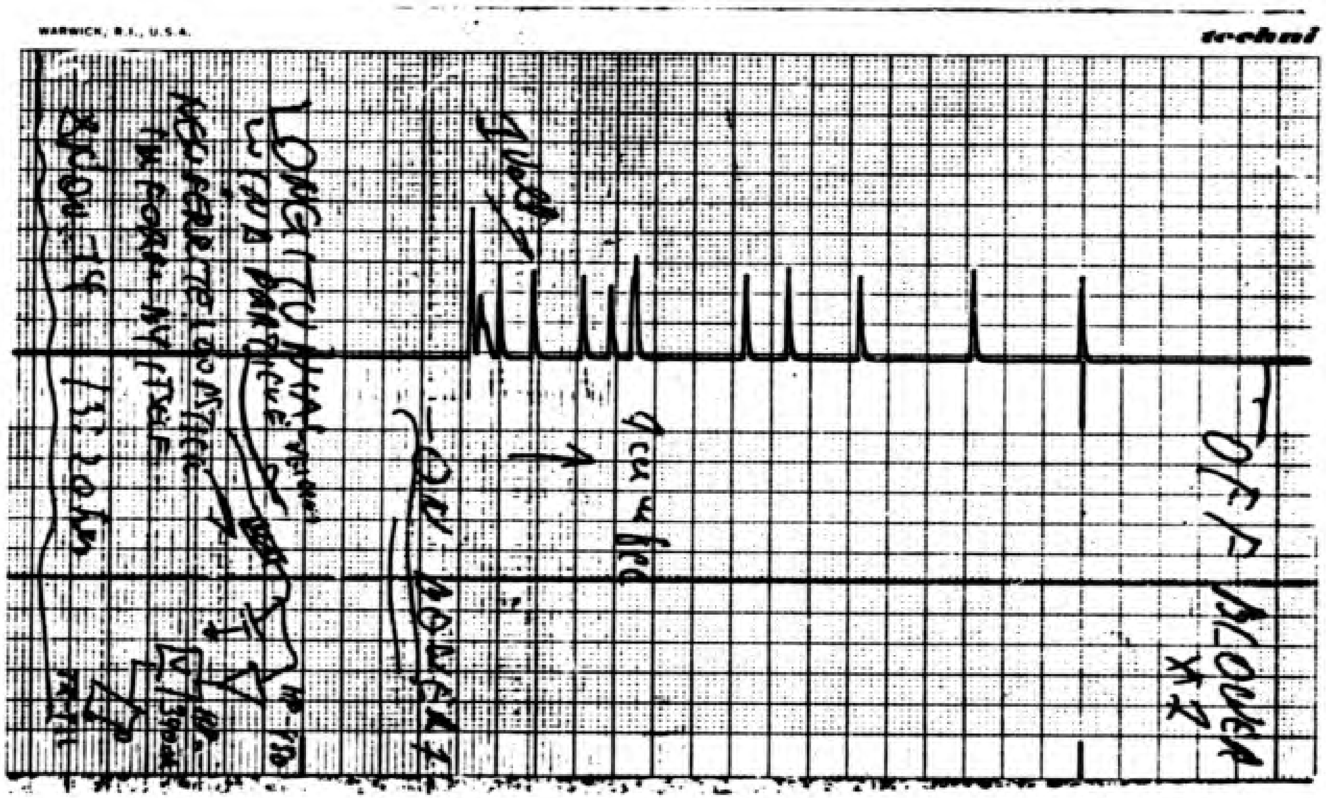
Recording No. 12. Noise output from Ferrite Loopstick No. 2 in lucite tube embedded in polyfoam insulation, mounted perpendicular to the particle and wind velocity and at d = 30 cm from the metal plate, 7 Nov 1974.



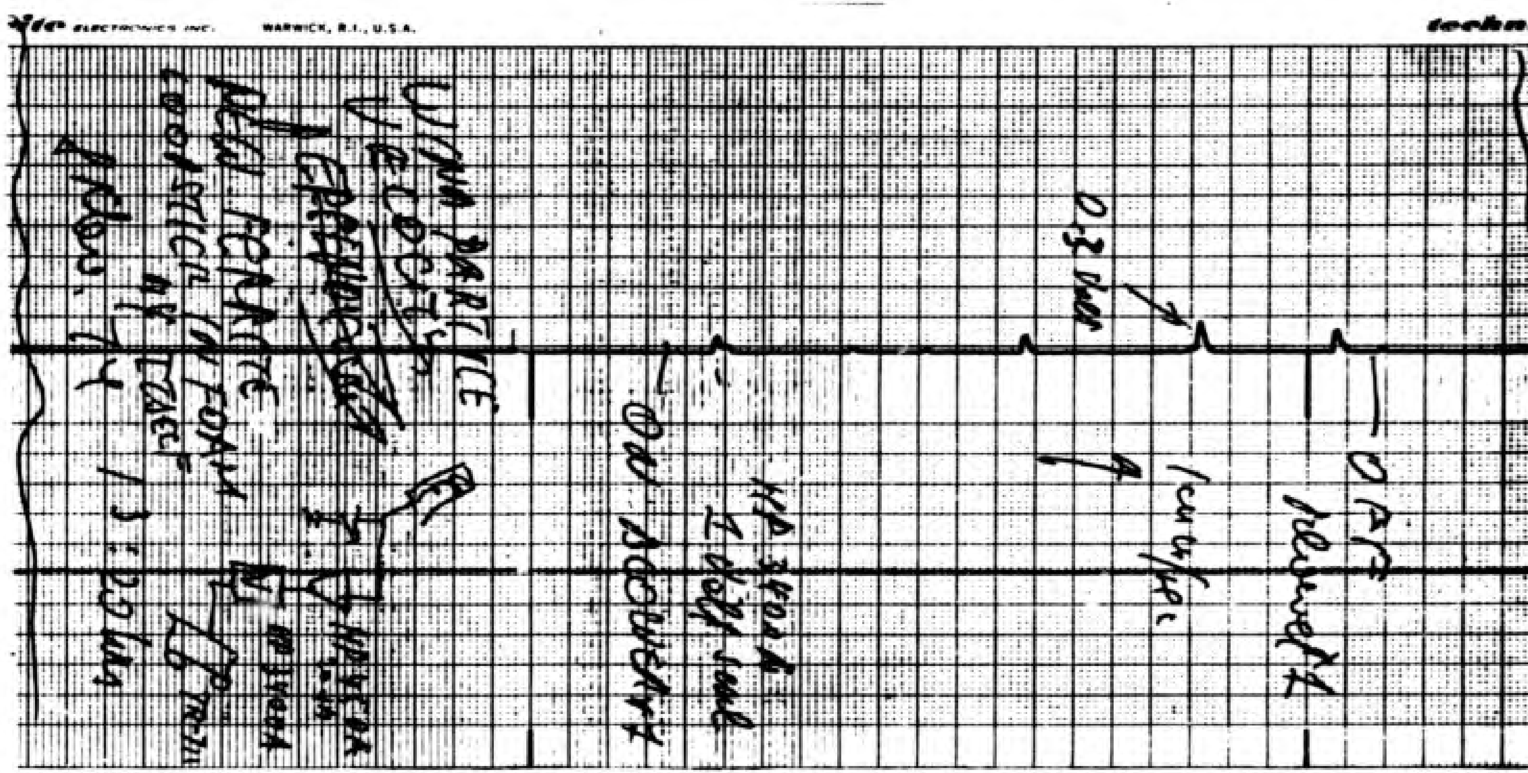
Recording No. 13. Noise output from Ferrite Loopstick No. 2 in lucite tube embedded in polyfoam insulation, mounted logitudinal relative to the particle and wind velocity, 8 Nov 1974.



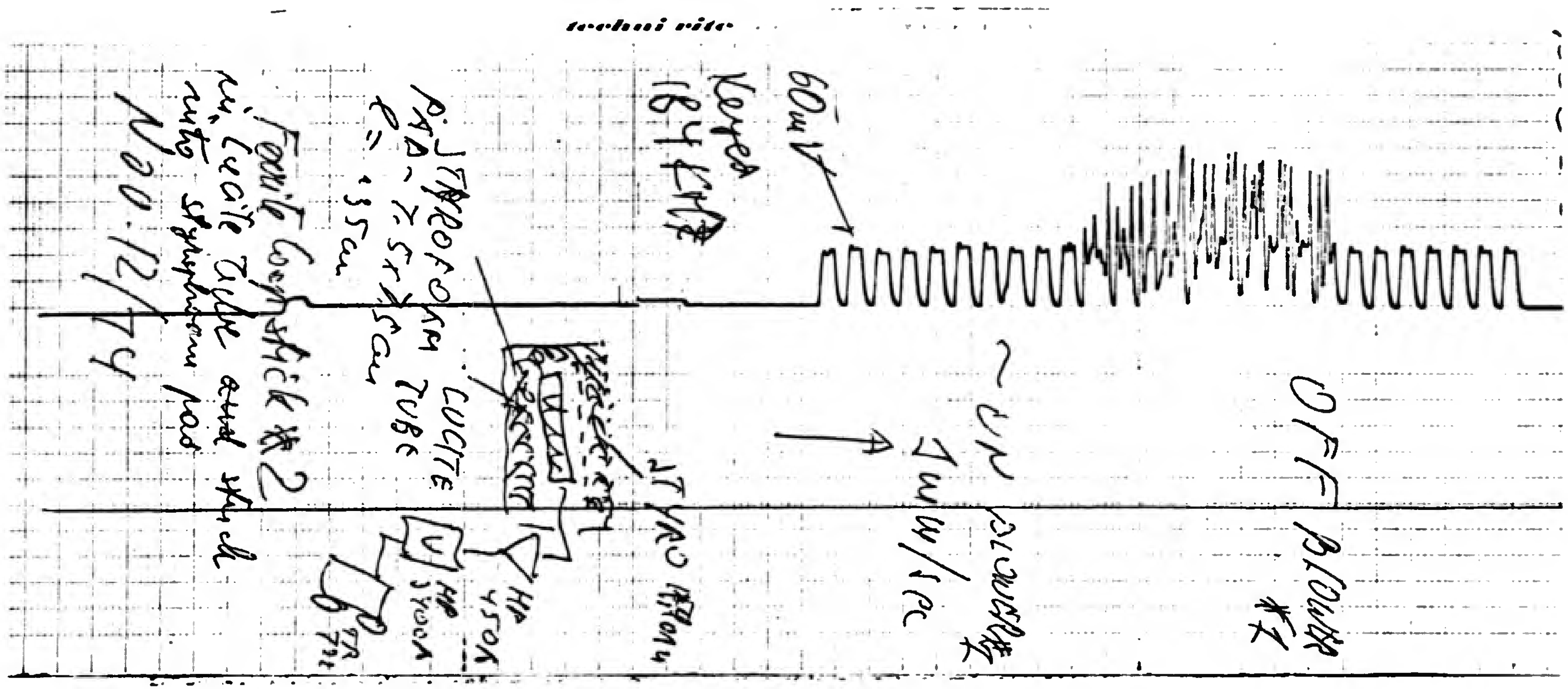
Recording No. 14. Noise output from Ferrite Loopstick No. 2 in lucite tube embedded in polyfoam insulation, mounted perpendicular to the particle and wind velocity, 8 Nov 1974.



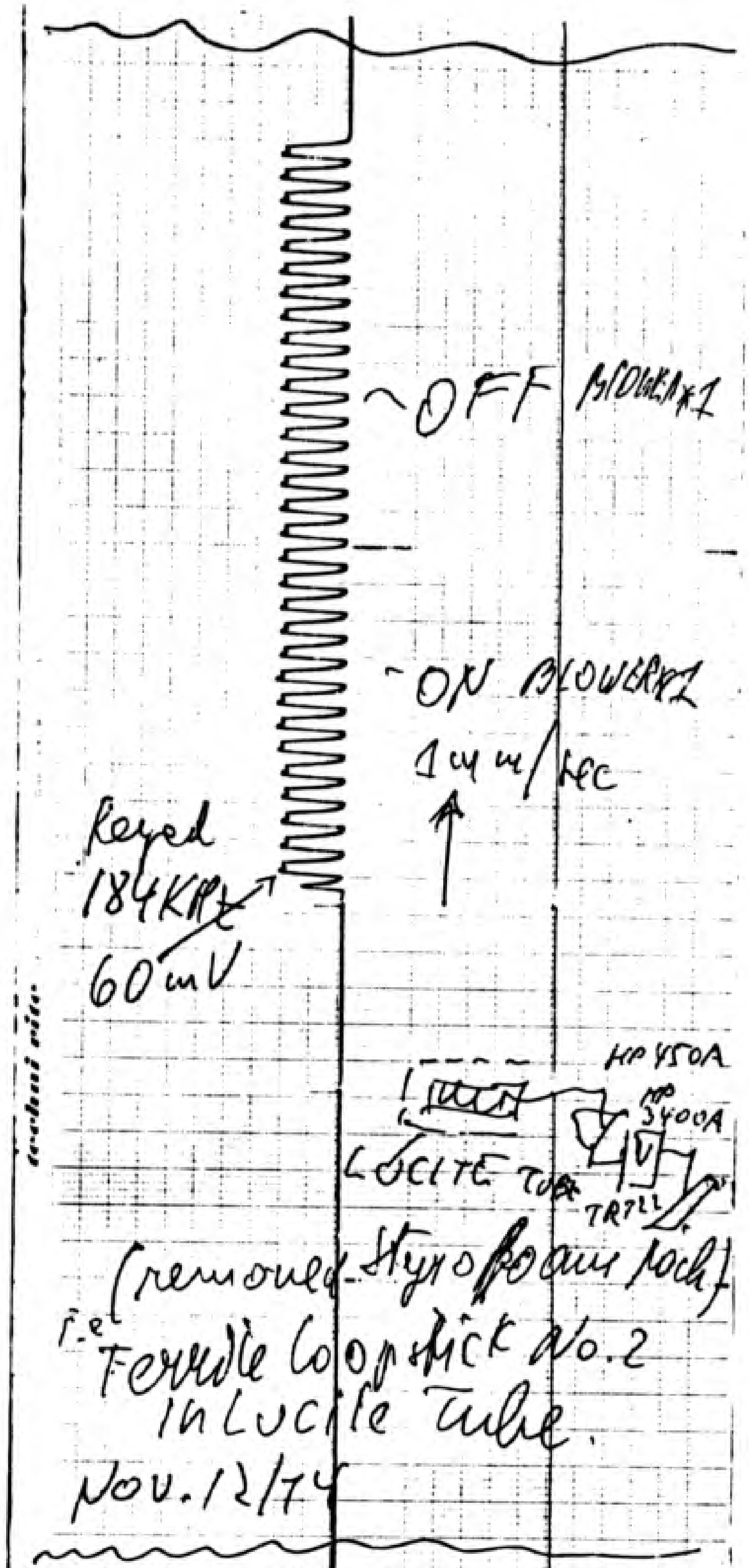
Recording No. 15. Noise output from Ferrite Loopstick No. 2 in lucite tube embedded in polyfoam insulation, mounted longitudinal relative to the particle and wind velocity, 8 Nov 1974.



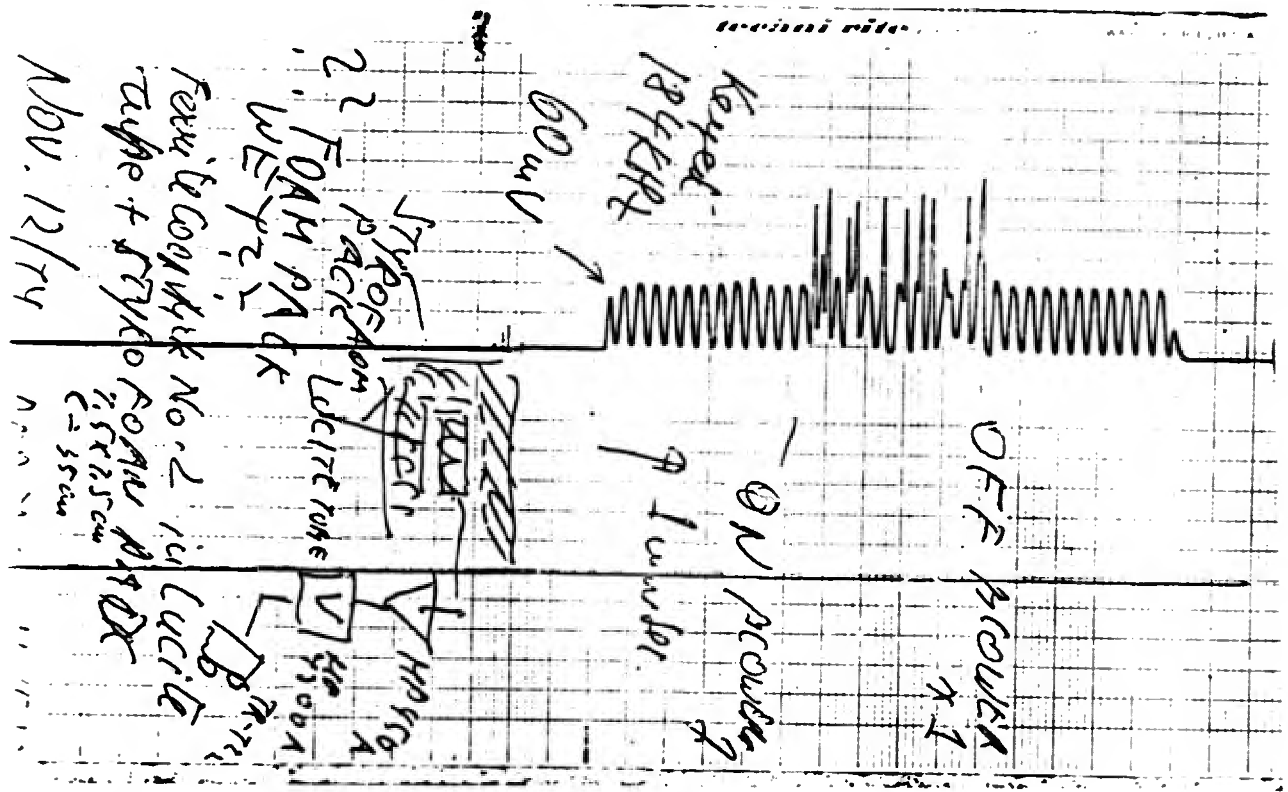
Recording No. 16. Noise output from Ferrite Loopstick No. 2 in lucite tube embedded in polyfoam insulation, mounted perpendicular to the particle and wind velocity, 8 Nov 1974.



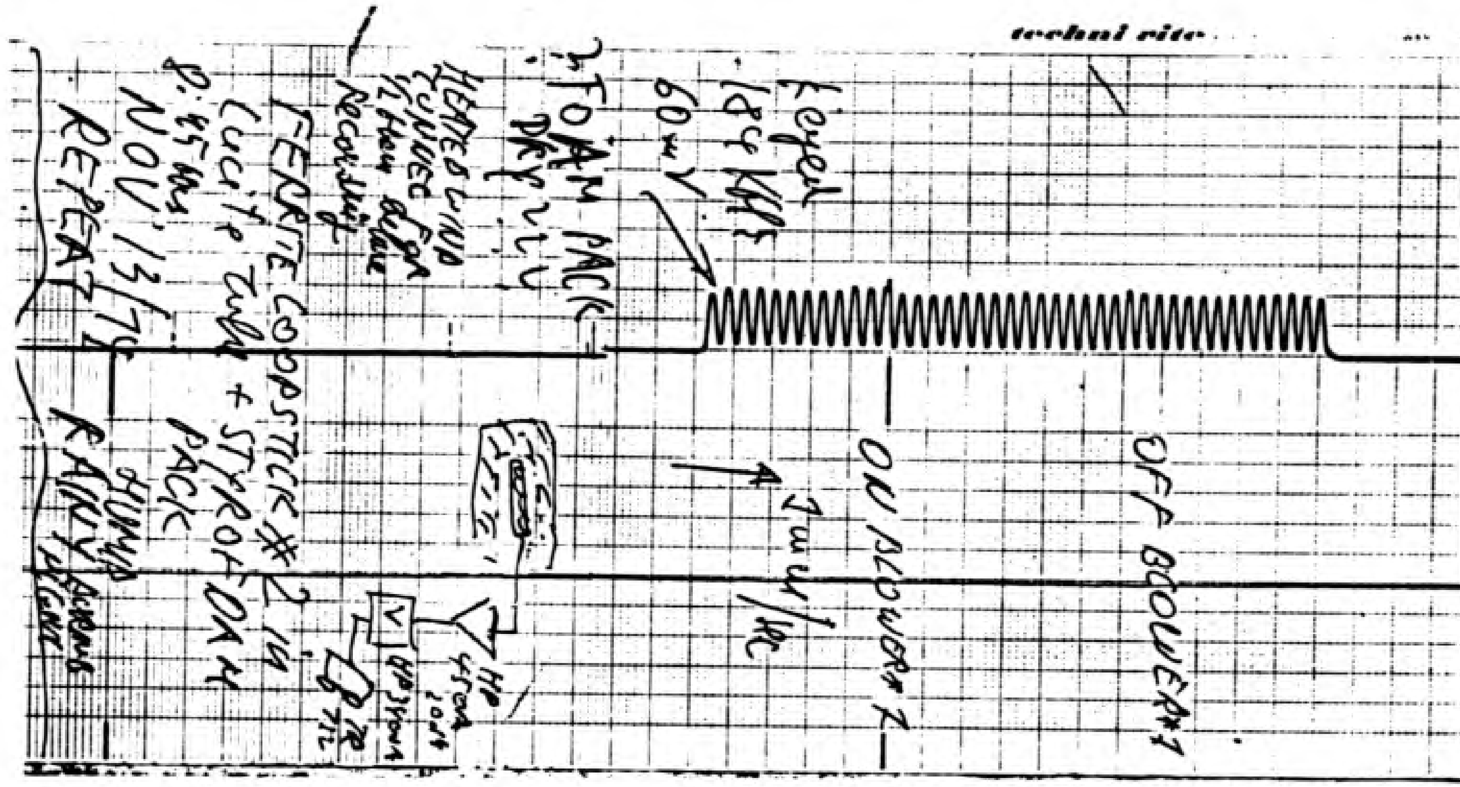
Recording No. 17. Signal, 184 kHz keyed CW, covered up by Noise as received with Ferrite Loopstick No. 2 inserted in lucite tube and embedded in styrofoam, 12 Nov 1974.



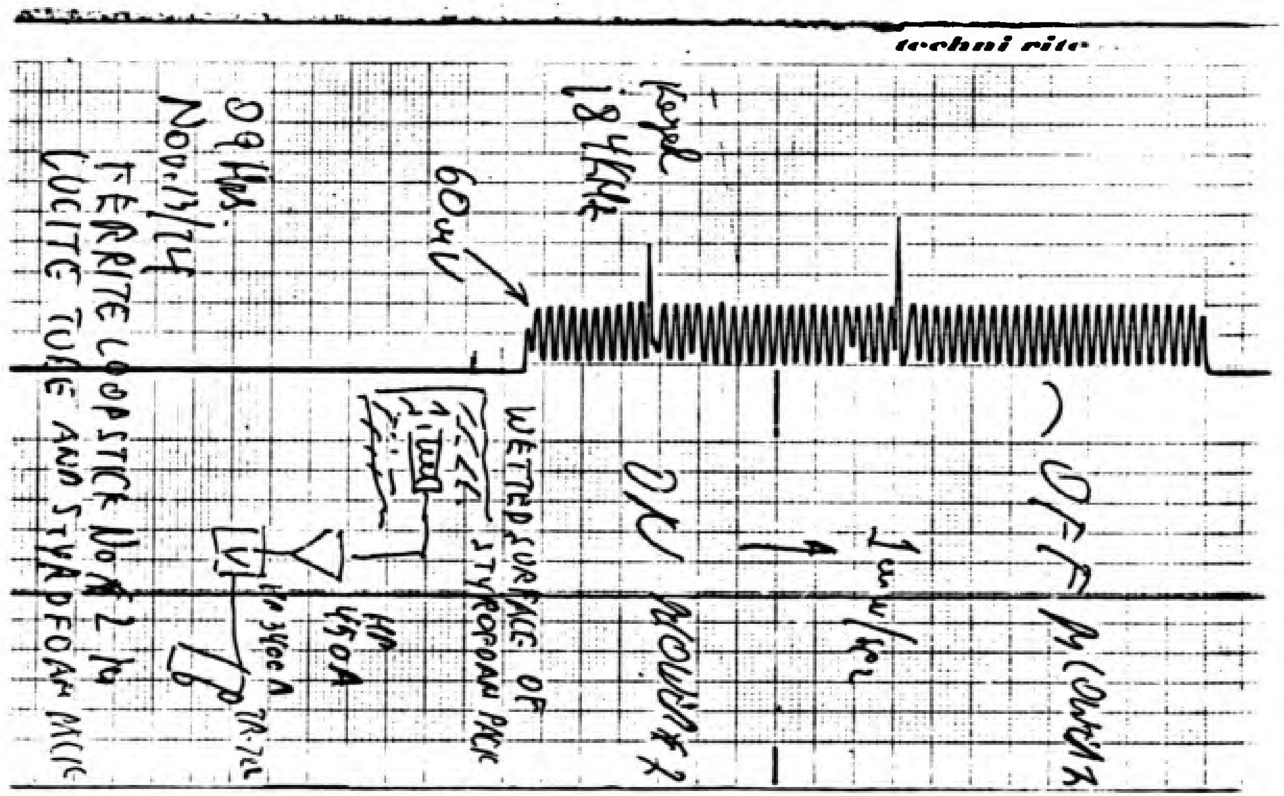
Recording No. 18. Signal, 184 kHz keyed CW, received unperturbated by noise with Ferrite Loopstick No. 2 insulated by lucite tube (styrofoam removed), 12 Nov 1974.



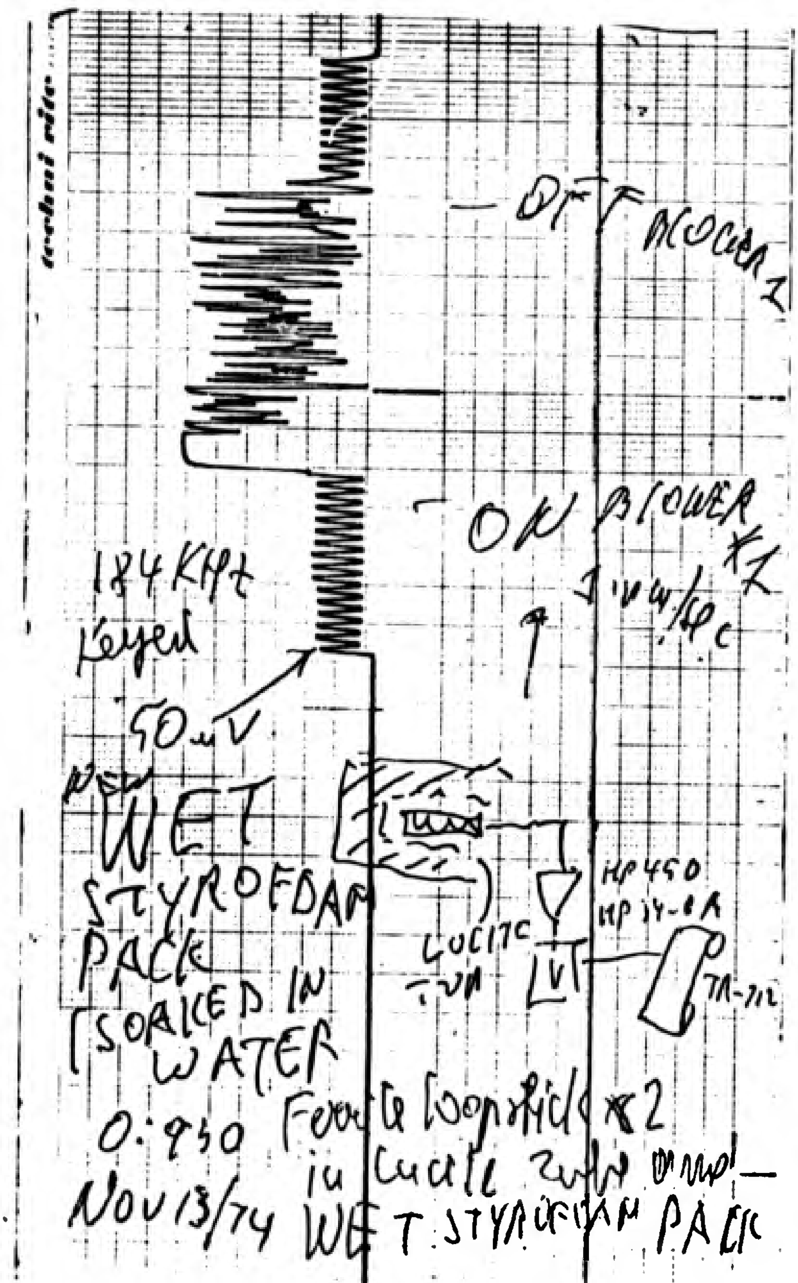
Recording No. 19. Signal, 184 kHz keyed CW, covered up by noise as received with Ferrite Loopstick No. 2 insulated by lucite tube and by styrofoam, 12 Nov 1974.



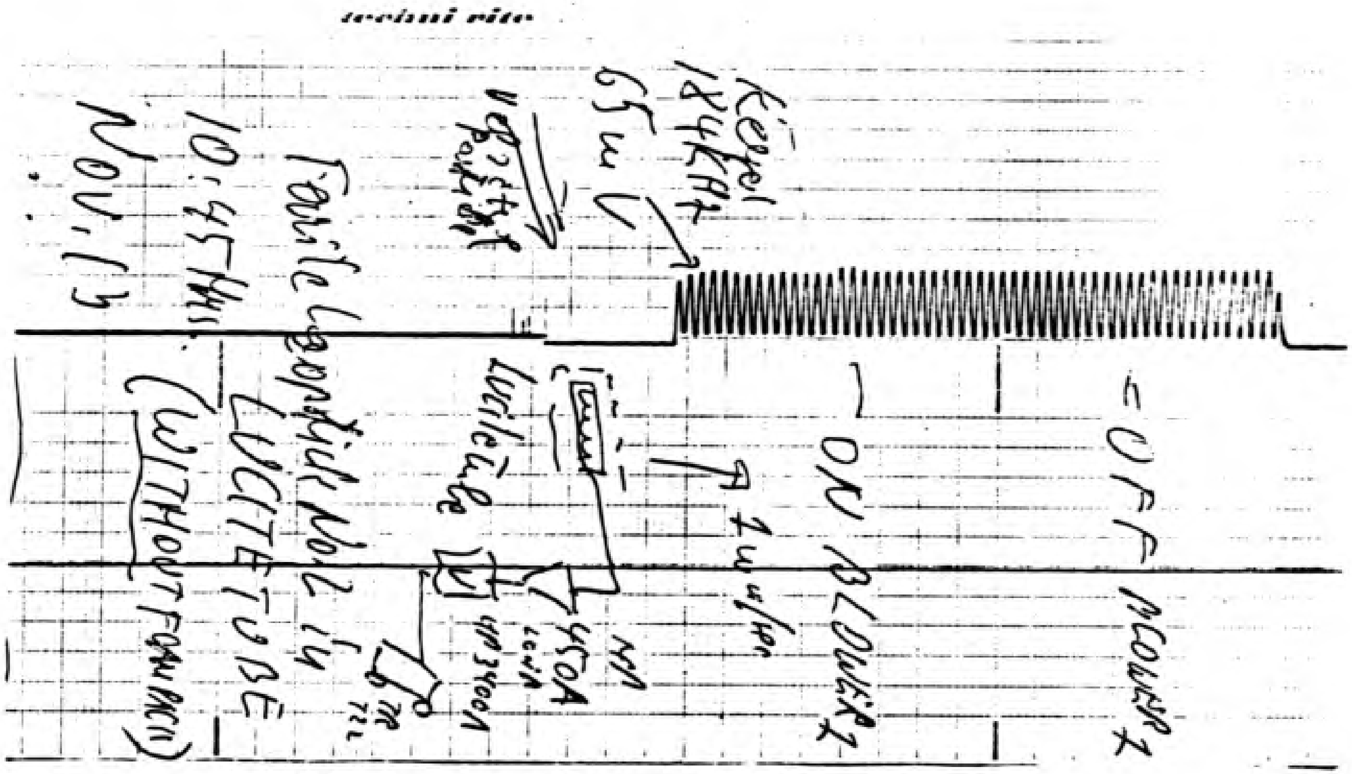
Recording No. 20. Signal, 184 kHz keyed CW, received unperturbated by noise with Ferrite Loopstick No. 2 insulated by lucite tube and by styrofoam after heating the wind tunnel by hot air for > 1/2 hour, 13 Nov 1974.



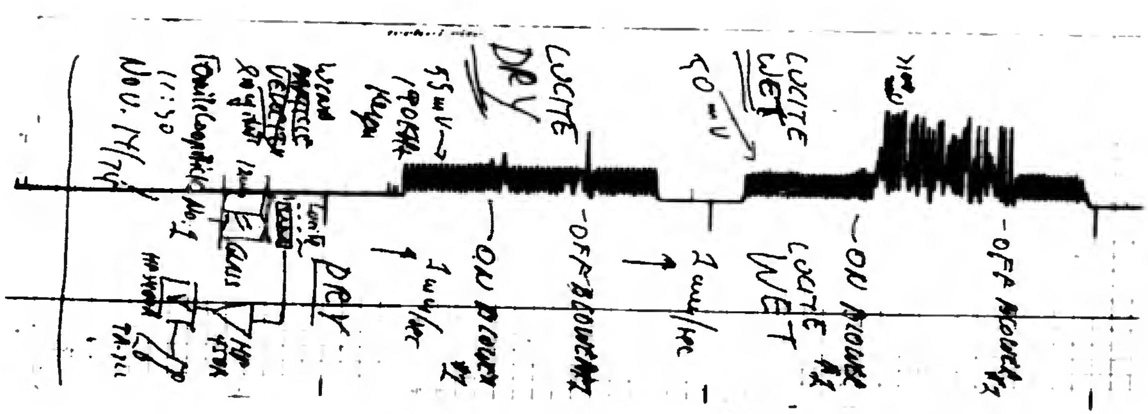
Recording No. 21. Signal, 184 kHz keyed CW, slightly perturbated by two noise spikes as received with Ferrite Loopstick No. 2 insulated by lucite tube and by styrofoam after a few drops of water were sprinkled on the surface of the styrofoam, 13 Nov 1974.



Recording No. 22. Signal, 184 kHz keyed CW, blocked by noise, as received with Ferrite Loopstick No. 2 insulated by lucite tube, and embedded in styrofoam soaked with water, 13 Nov 1974.

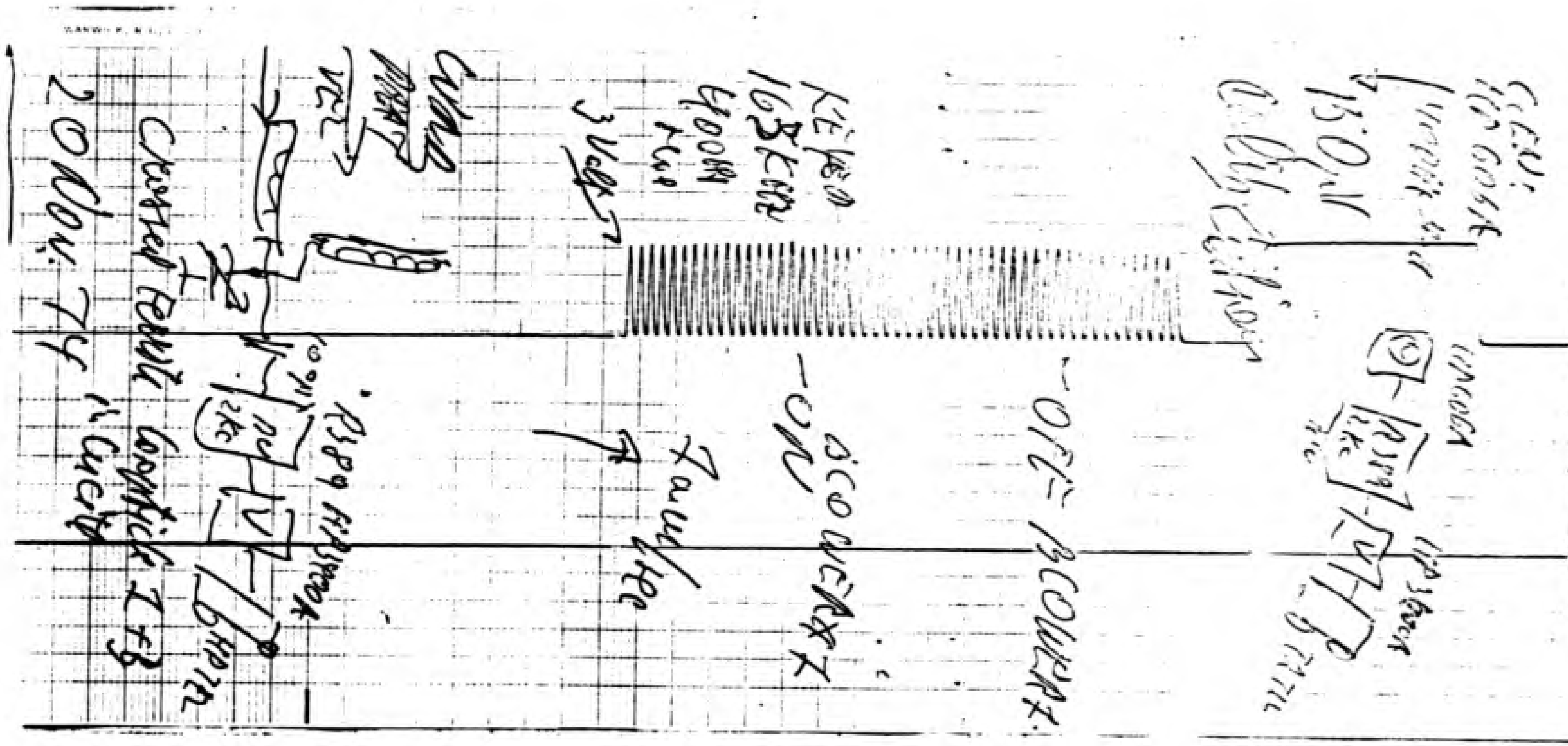


Recording No. 23. Signal, 184 kHz keyed CW, unperturbated by noise, as received with Ferrite Loopstick No. 2 insulated by lucite tube (styrofoam removed), 13 Nov 1974.

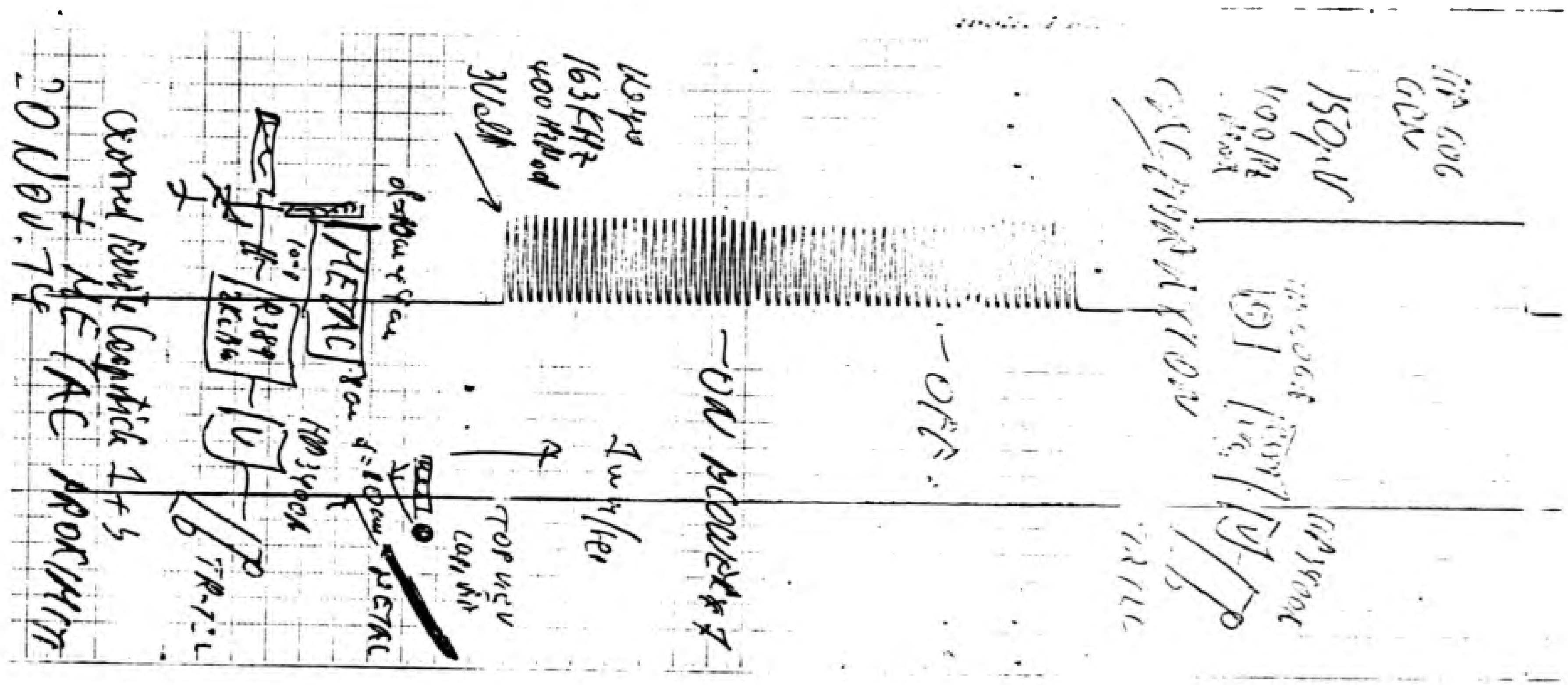


(a) (b)

Recording No. 24. Signal, 190 kHz keyed CW, as received by Ferrite Loopstick No. 1: (a) clearly, with dry lucite insulation tube, and (b) covered up by noise with wet lucite insulation tube, 14 Nov 1974.

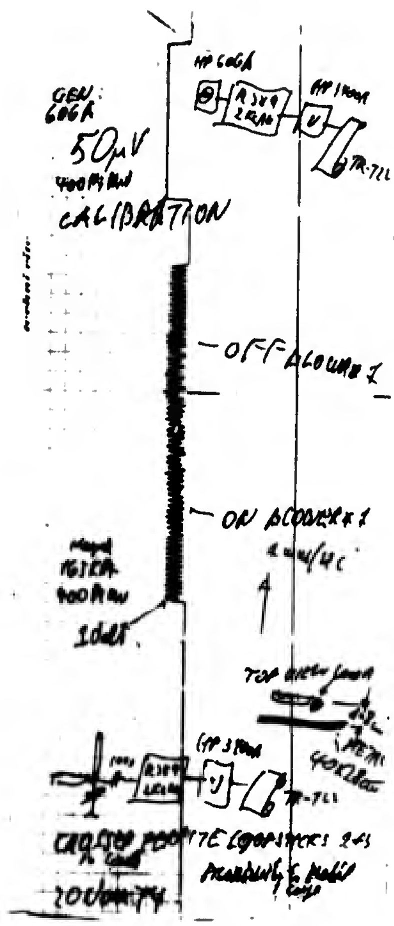


Recording No. 25. Signal, 163 kHz keyed 400 Hz, mod. CW, 150 µV RF, unperturbated by noise as received with Crossed Ferrite Loopsticks (Nos. 1 and 3), and using R-389 Radio Receiver, 20 Nov 1974.

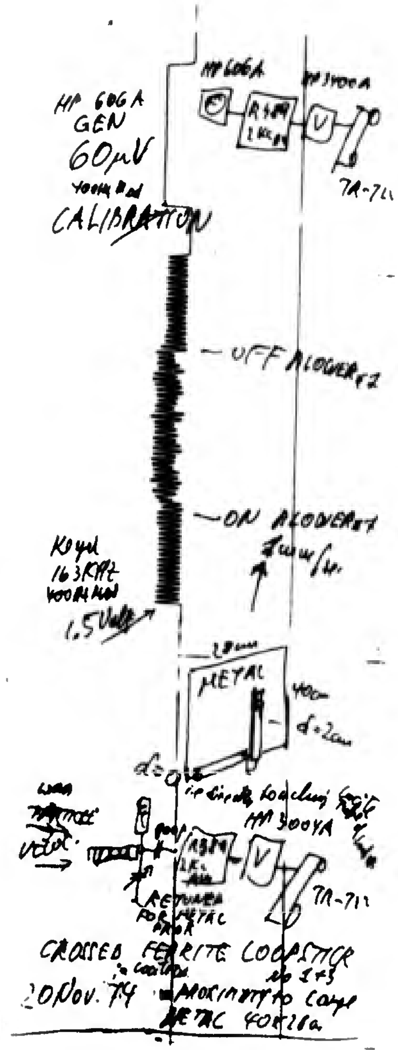


Recording No. 26. Signal, 163 kHz keyed 400 Hz, mod. CW, 150 μV RF, unperturbated by noise as received with Crossed Ferrite Loopsticks (Nos. 1 and 3) at d = 10 cm from metal plate, and using R-389 Radio Receiver, 20 Nov 1974.

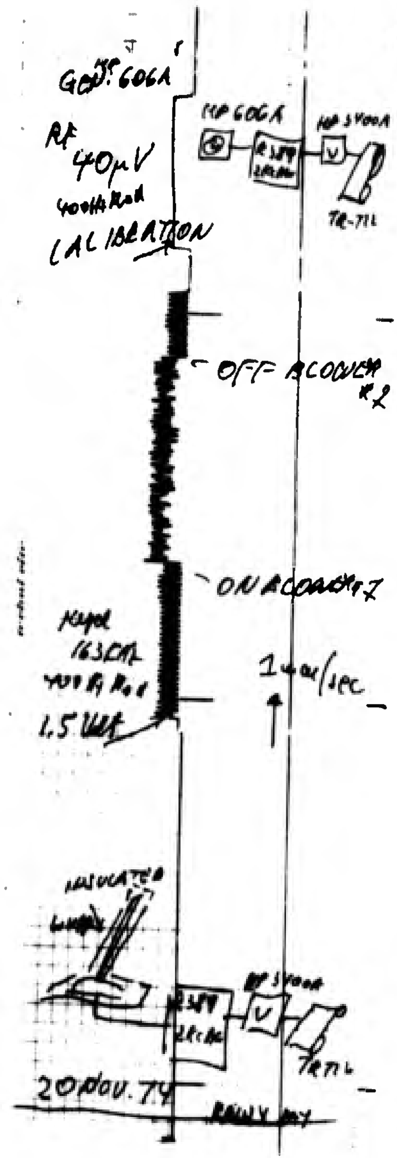
Recording No. 27. Signal, 163 kHz keyed 400 Hz, modulated CW, 150 µV RF, unperturbated by noise as received with Crossed Ferrite Loopsticks (Nos. 1 and 3) at d = 8 cm parallel to large metal plate, and using R-389 Radio Receiver, 20 Nov 1974.



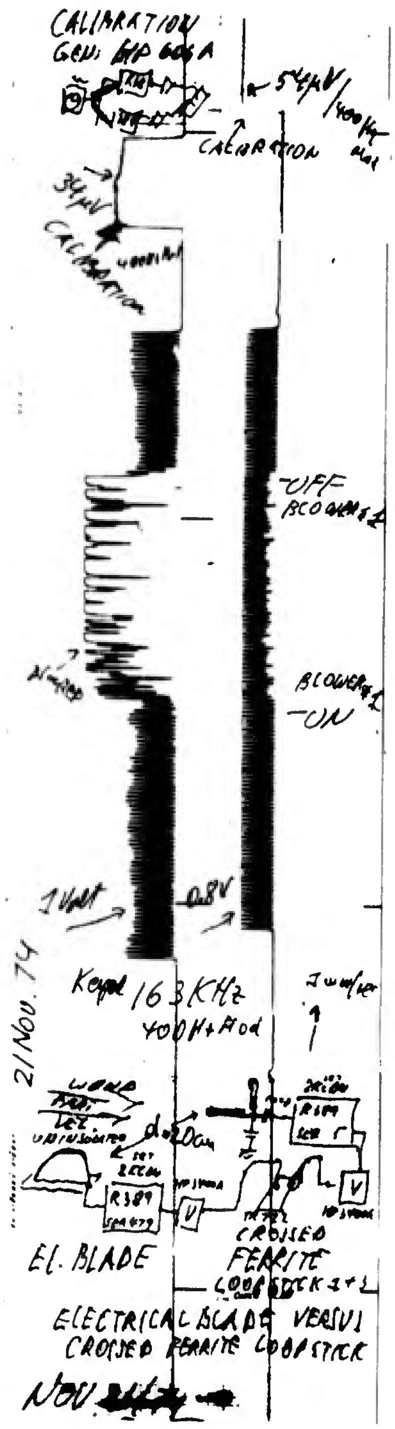
Recording No. 28. Signal, 163 kHz keyed 400 Hz, modulated CW, 50 μV RF, slightly perturbated by noise as received with Crossed Ferrite Loopsticks (Nos. 1 and 3) at d = 8 cm parallel to large metal plate, and using R-389 Radio Receiver, 20 Nov 1974.



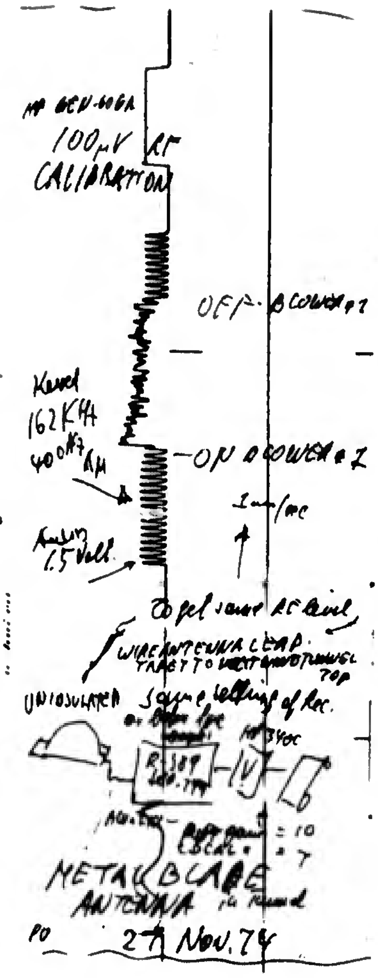
Recording No. 29. Signal, 163 kHz keyed 400 Hz, modulated CW, 60 μV RF, perturbated by noise as received with Crossed Ferrite Loopsticks (Nos. 1 and 3) at d = 2 cm parallel to large metal plate, and using R-389 Radio Receiver (20 Nov 1974).



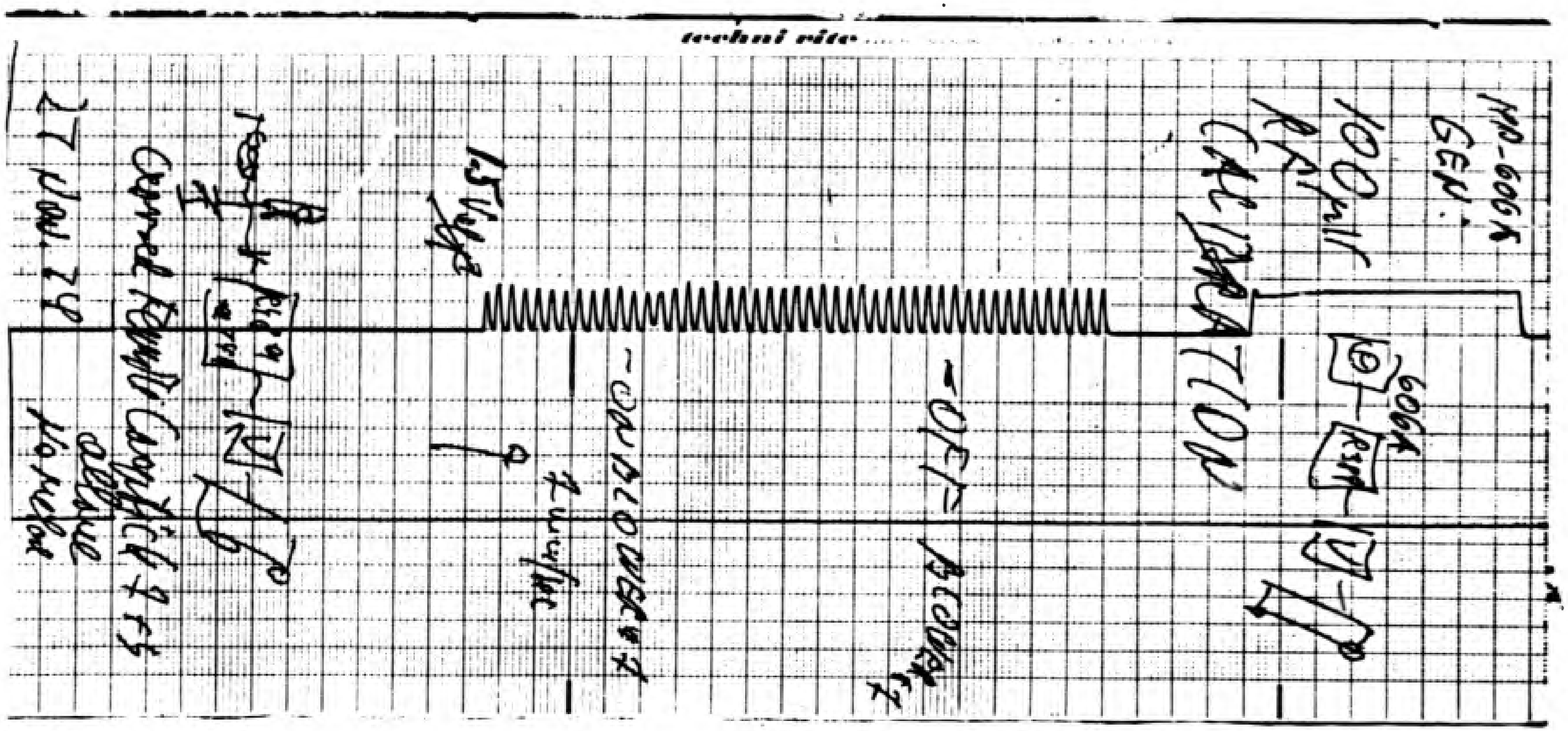
Recording No. 30. Signal, 163 kHz keyed 400 Hz, modulated CW, 40 μV RF, covered up by noise as received with insulated whip antenna and R-389 Radio Receiver, 20 Nov 1974.



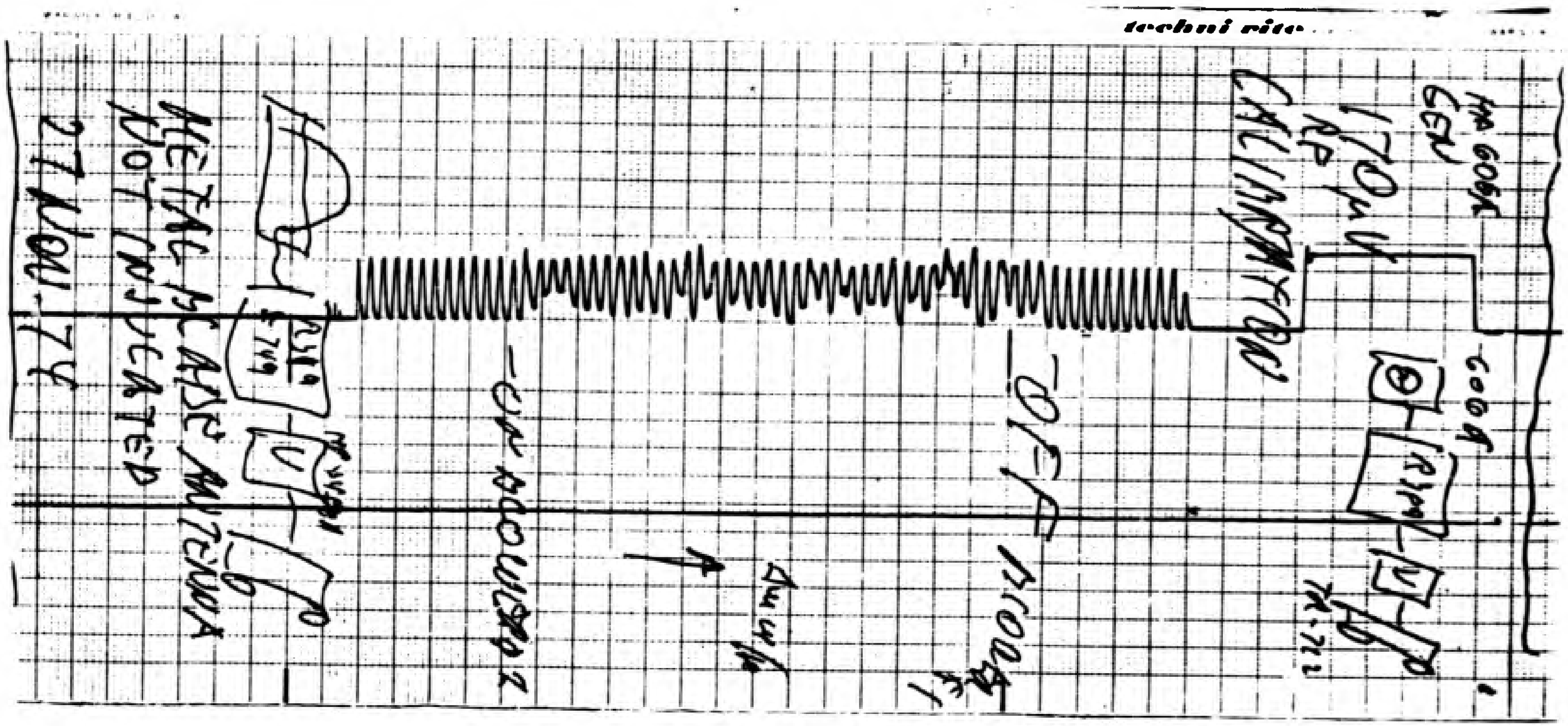
Recording No. 31. Signal, 163 kHz keyed 400 Hz, modulated CW, 34 μV RF, blocked by noise as received by Metal-Blade Antenna and R-389 Radio Receiver (Ser. 479). Same signal, 54 μV RF, only slightly distorted by noise as received simultaneously with Crossed Ferrite Loopsticks (Nos. 1 and 3) at a distance of d = 20 cm from Metal-Blade Antenna, using a second R-389 Radio Receiver (Ser. 5), 21 Nov 1974.



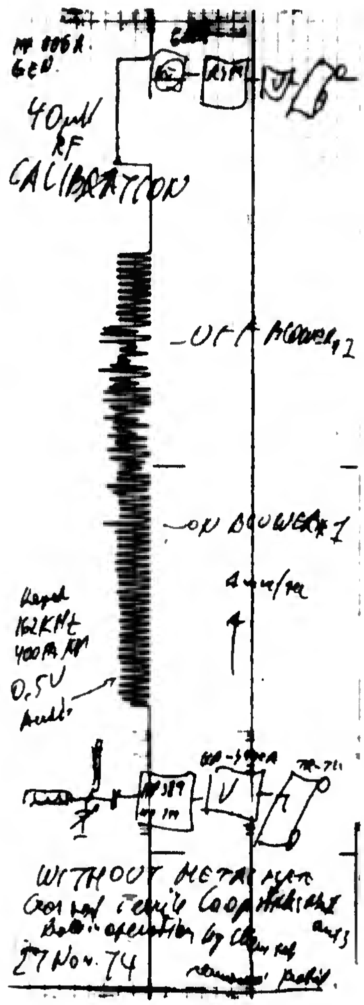
Recording No. 32. Signal, 162 kHz keyed 400 Hz, modulated CW, 100 μV RF, blocked by noise as received with Metal-Blade Antenna and R-389 Radio Receiver (Ser. 479), 27 Nov 1974.



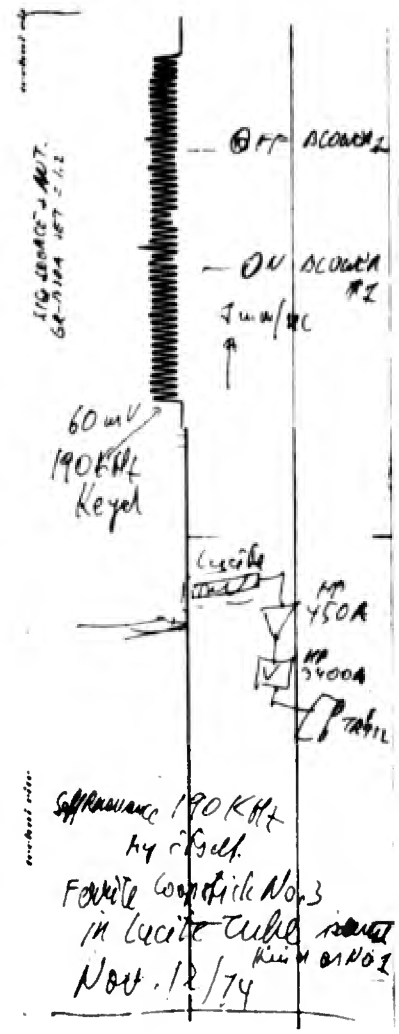
Recording No. 33. Signal, 162 kHz keyed 400 Hz, mod. CW, 100 µV RF, unperturbated by noise as received with Crossed Ferrite Loopsticks (Nos. 1 and 3), and using R-389 Radio Receiver (Ser. 479), 27 Nov 1974.



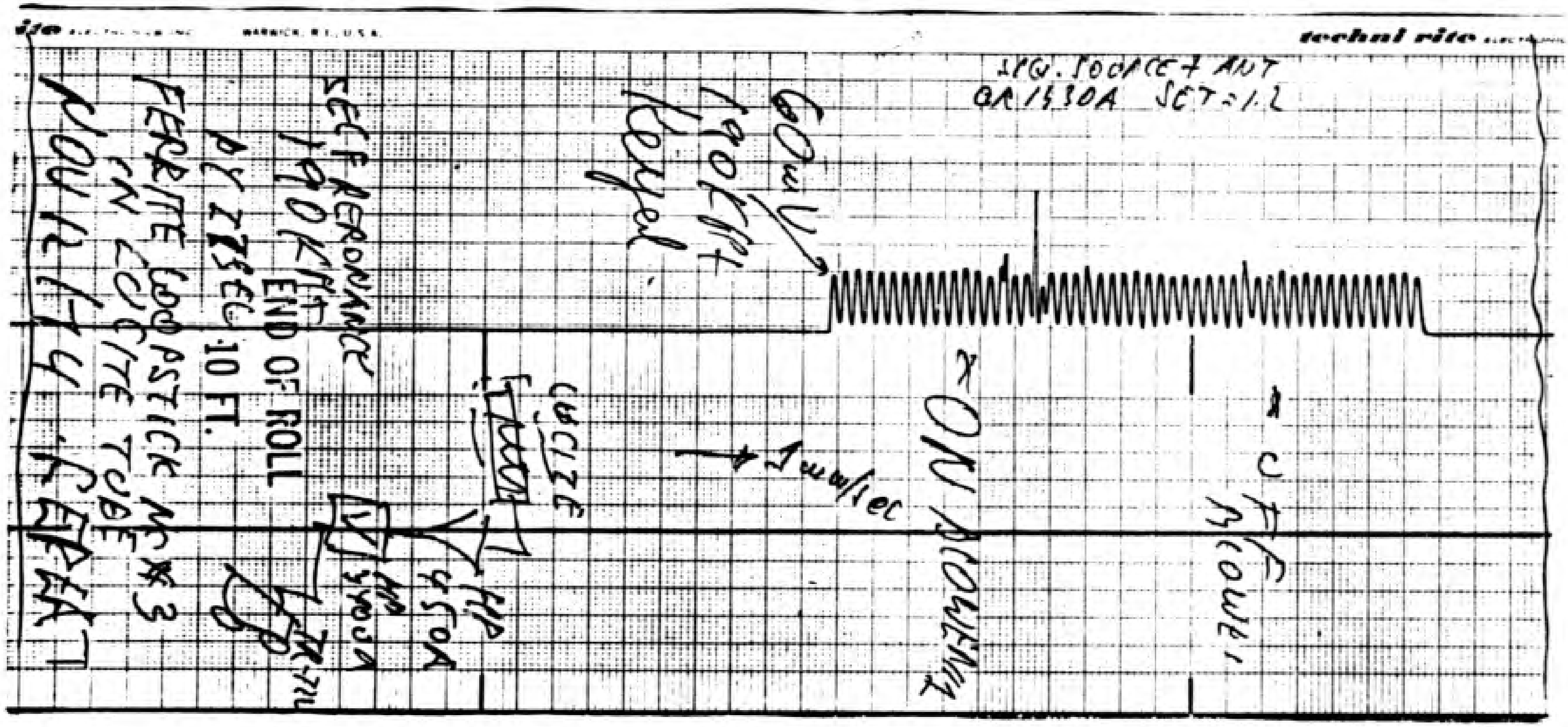
Recording No. 34. Signal, 162 kHz keyed 400 Hz, mod. CW, 170 µV RF, distorted by noise as received by metal blade antenna and R-389 Radio Receiver (Ser. 479).



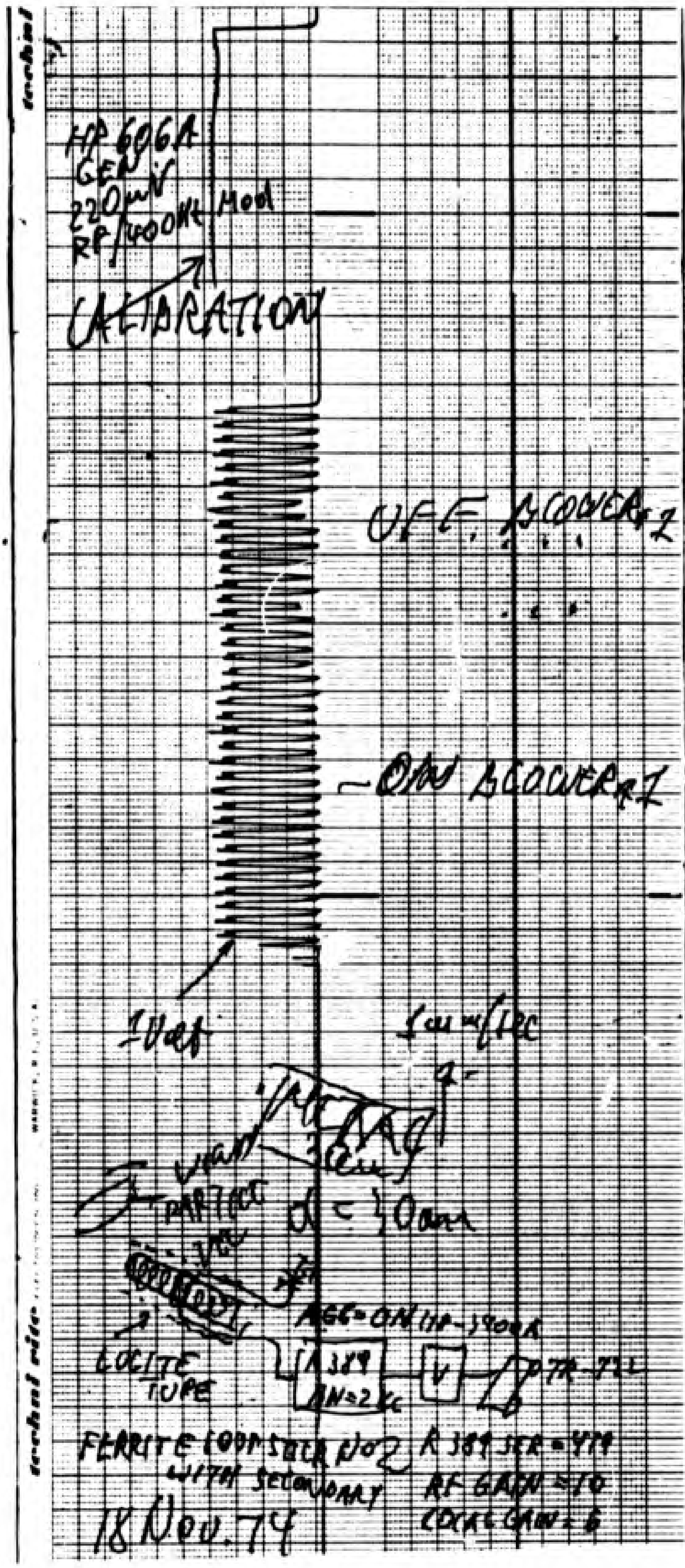
Recording No. 35. Signal, 162 kHz keyed 400 Hz, modulated CW, 40 µV RF, perturbated by noise as received with Crossed Ferrite Loopsticks (Nos. 1 and 3), and using R-389 Radio Receiver (metal plate removed), 27 Nov 1974.



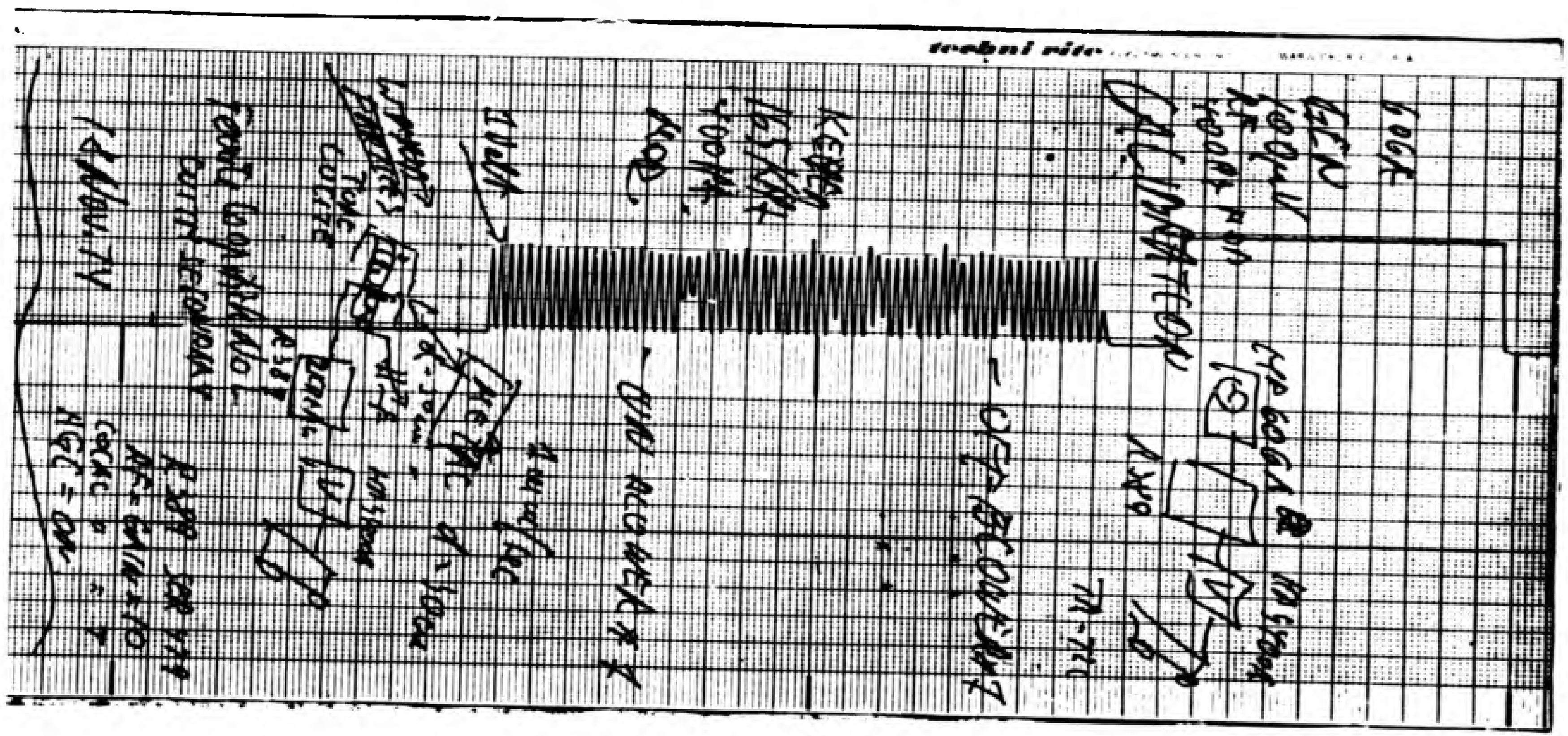
Recording No. 36. Signal, 190 kHz keyed CW, received almost free of noise with Ferrite Loopstick No. 3 sealed in lucite insulation tube, 12 Nov 1974 12 Nov 1974.



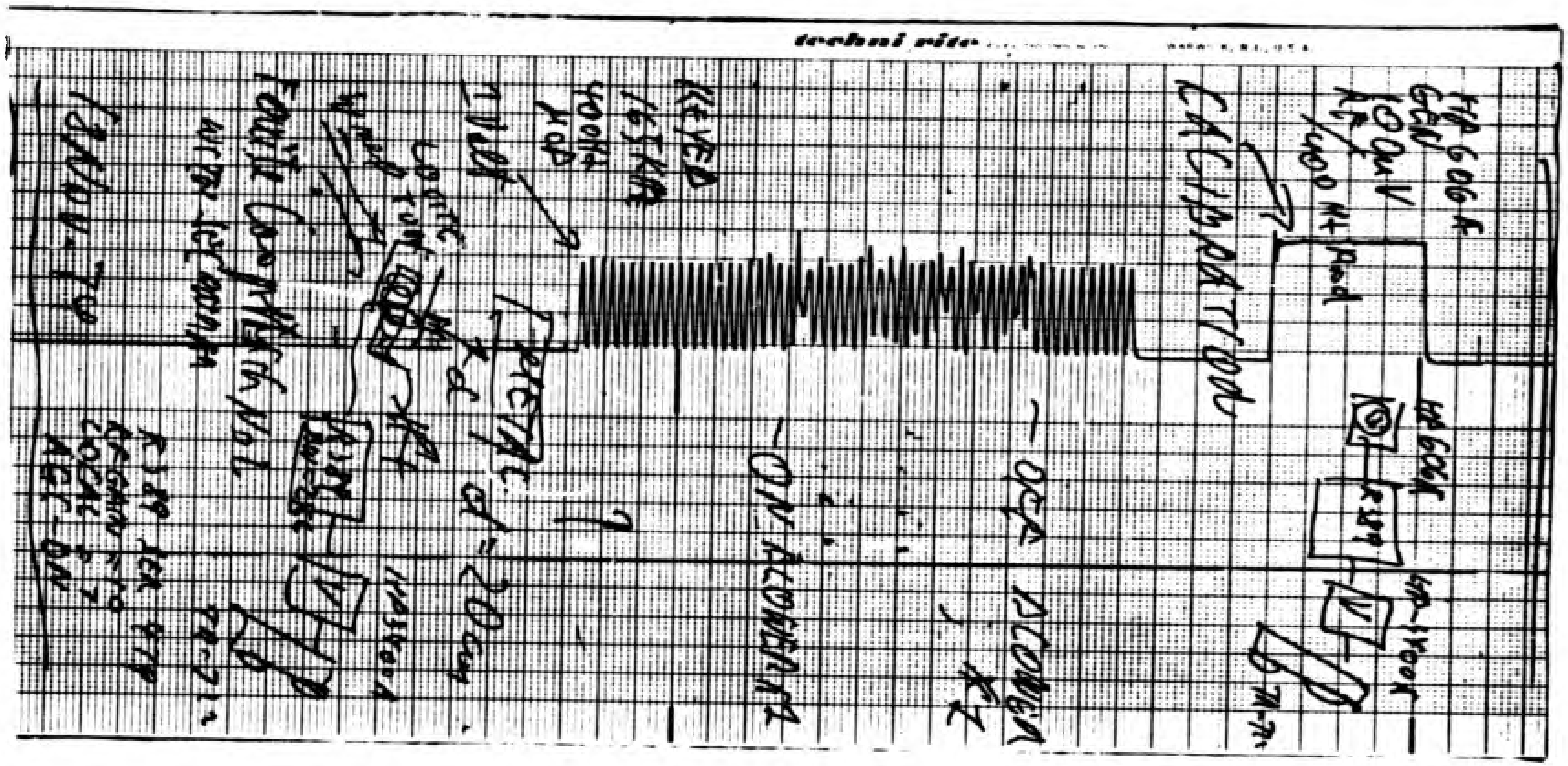
Recording No. 37. Signal, 190 kHz, keyed CW, received almost free of noise with Ferrite Loopstick No. 3 sealed in lucite insulation tube, 12 Nov 1974.



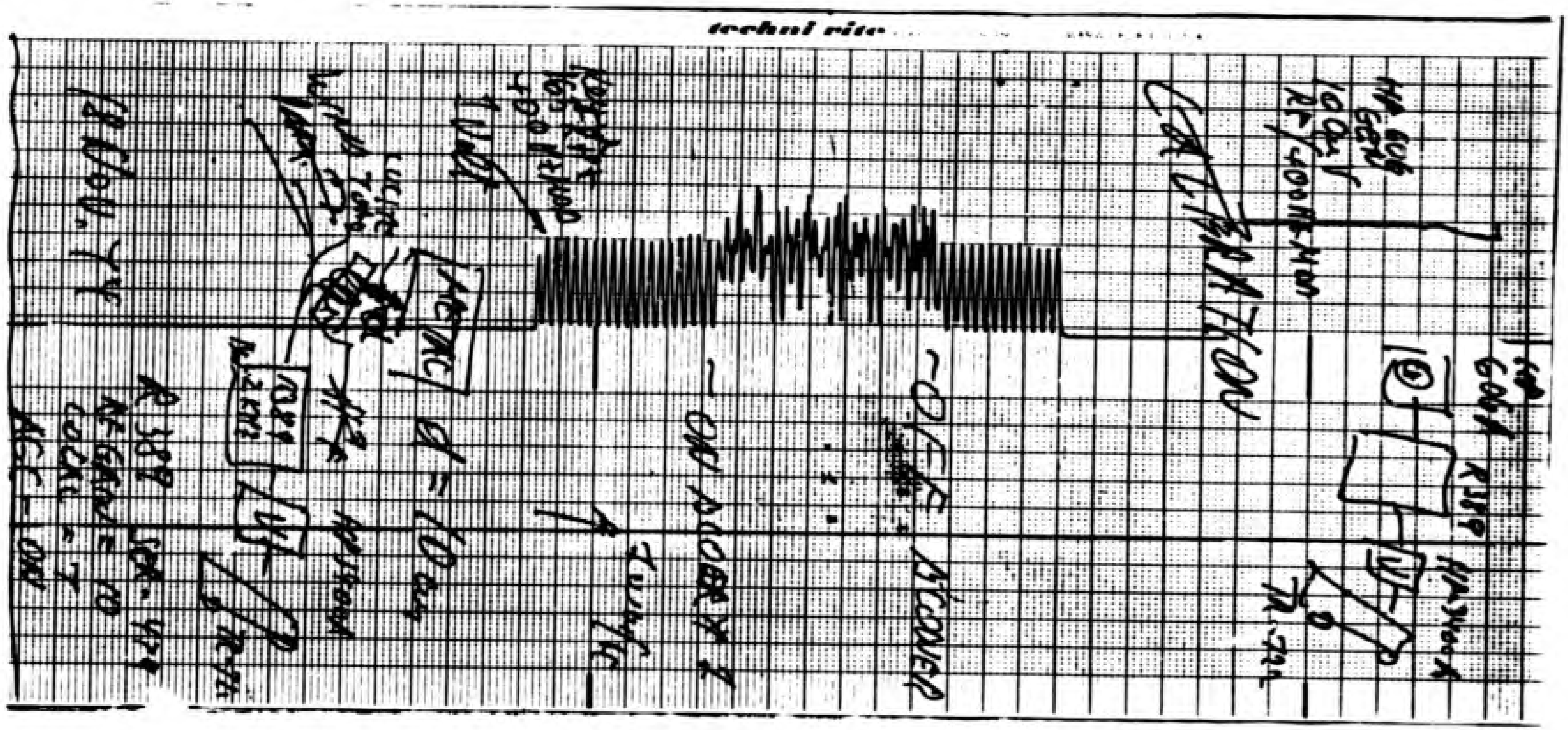
Recording No. 38. Signal, 165 kHz keyed 400 Hz, mod. CW, 220 μV RF, unperturbated by noise as received with Modified Ferrite Loopstick No. 2 in lucite insulation tube at d = 30 cm from metal plate, and using R-389 Radio Receiver, 18 Nov 1974.



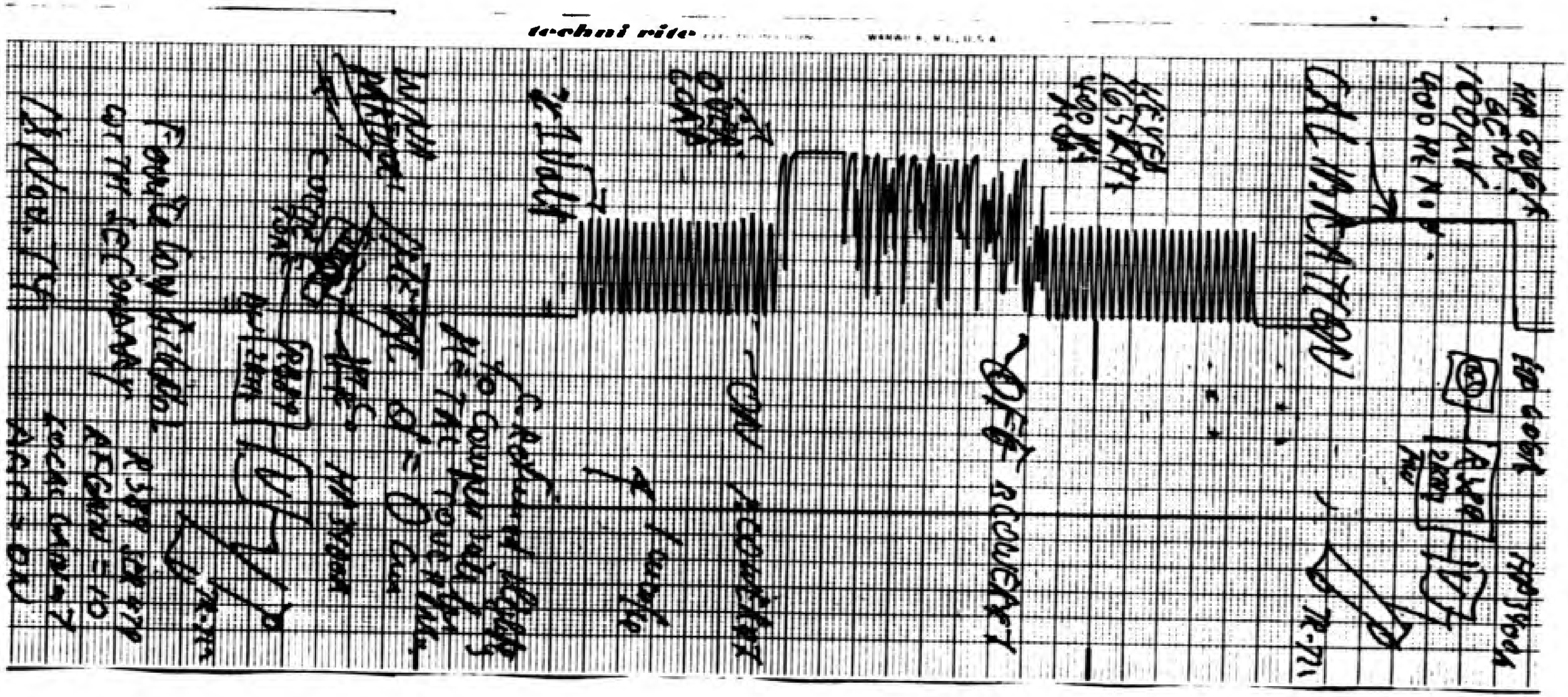
Recording No. 39. Signal, 165 kHz keyed 400 Hz, mod. CW, 100 μV RF, slightly perturbated by noise as received with Modified Ferrite Loopstick No. 2 in lucite insulation tube at d = 30 cm from metal plate, and using R-389 Radio Receiver, 18 Nov 1974.



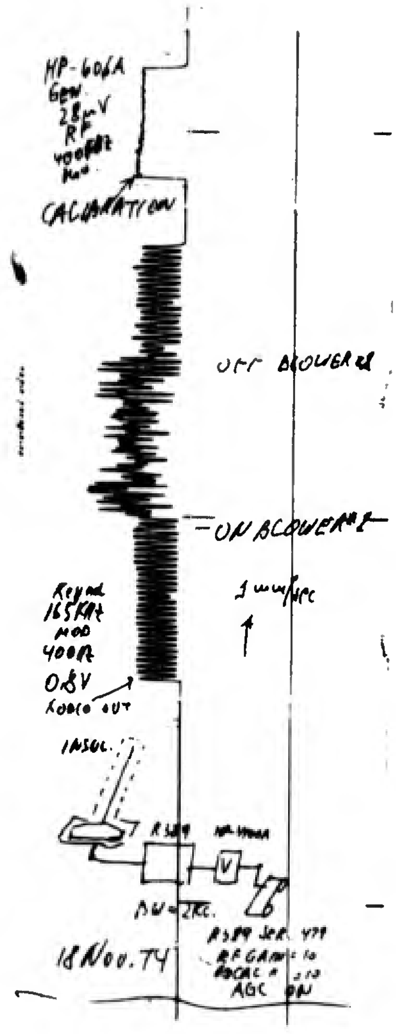
Recording No. 40. Signal, 165 kHz keyed 400 Hz, mod. CW, 100 μV RF, somewhat more perturbated by noise as received with Modified Ferrite Loopstick No. 2 in lucite insulation tube at d = 20 cm from metal plate, and using R-389 Radio Receiver, 18 Nov 1974.



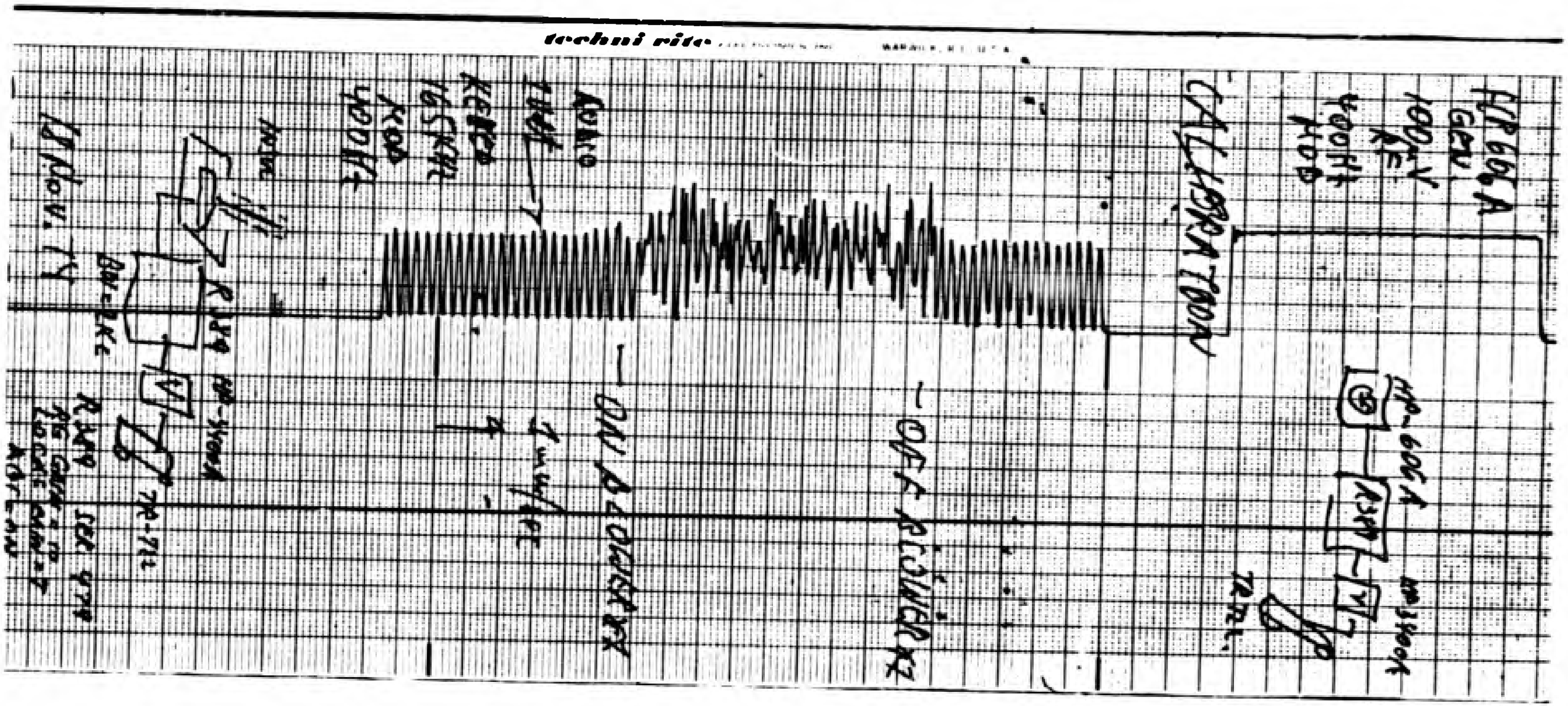
Recording No. 41. Signal, 165 kHz keyed 400 Hz, mod. CW, 100 μV RF, covered up by noise as received with Modified Ferrite Loopstick No. 2 in lucite insulation tube at d = 10 cm from metal plate, and using R-389 Radio Receiver, 18 Nov 1974.



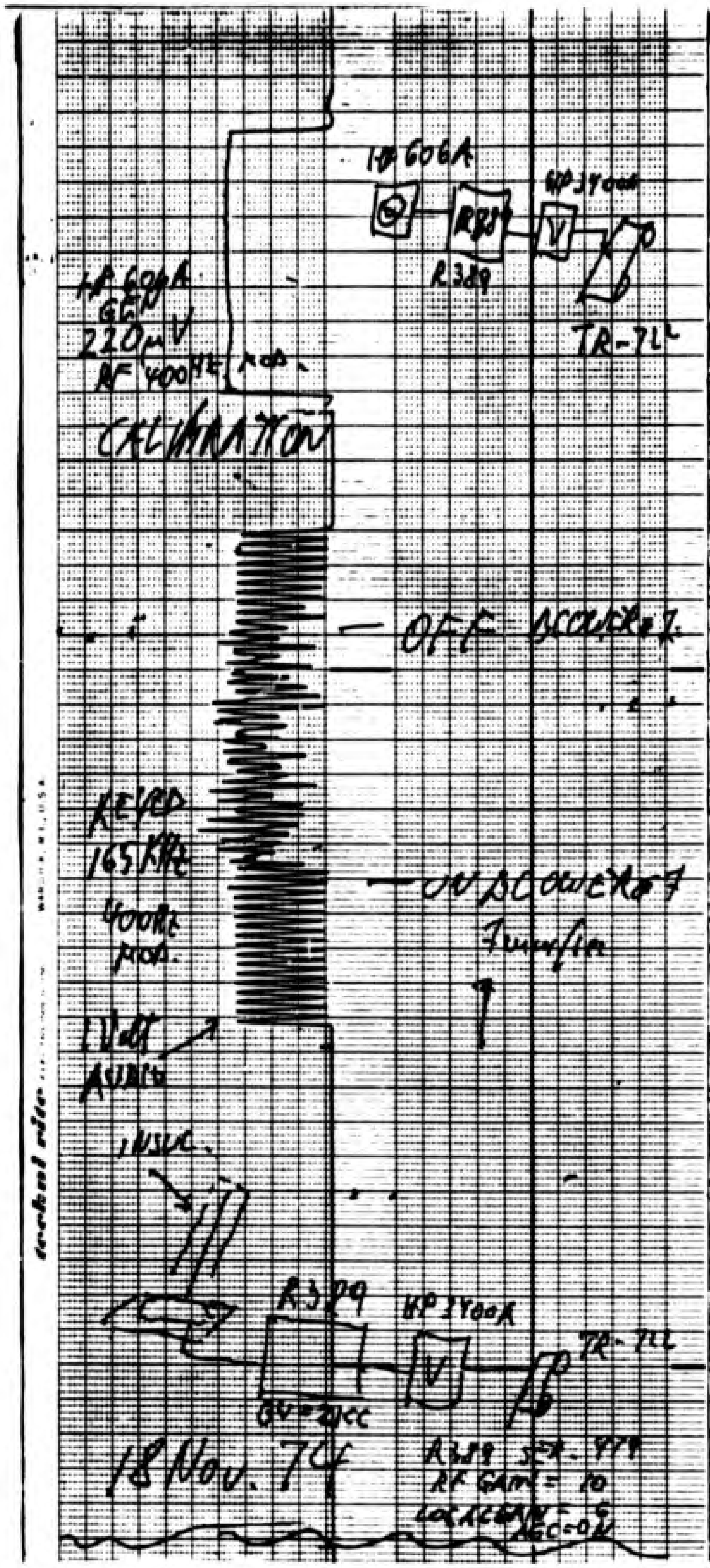
Recording No. 42. Signal, 165 kHz keyed 400 Hz, mod. CW, 100 µV RF, blocked by noise as received with Modified Ferrite Loopstick No. 2 in lucite insulation tube at d = 0 cm from metal plate, and using R-389 Radio Receiver, 18 Nov 1974.



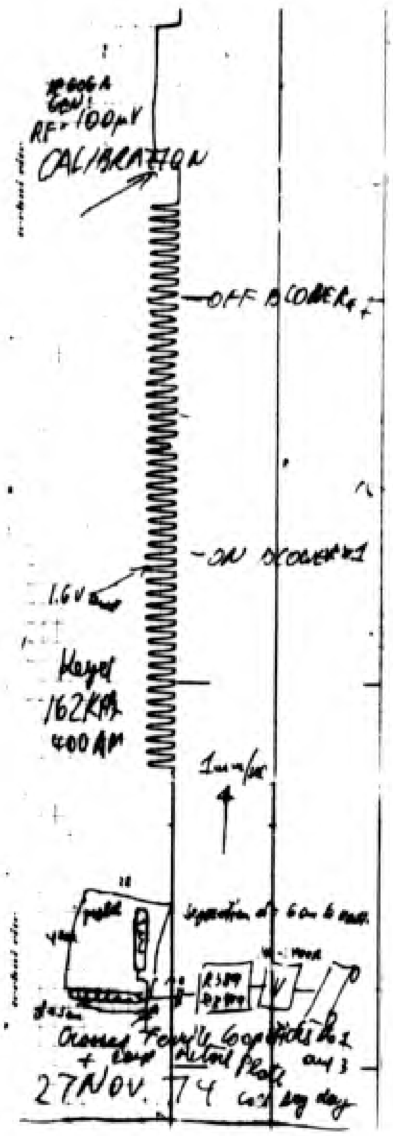
Recording No. 43. Signal, 165 kHz keyed 400 Hz, modulated CW, 28 μV RF, covered up by noise as received by Insulated-Whip Antenna and R-389 Radio Receiver, 18 Nov 1974



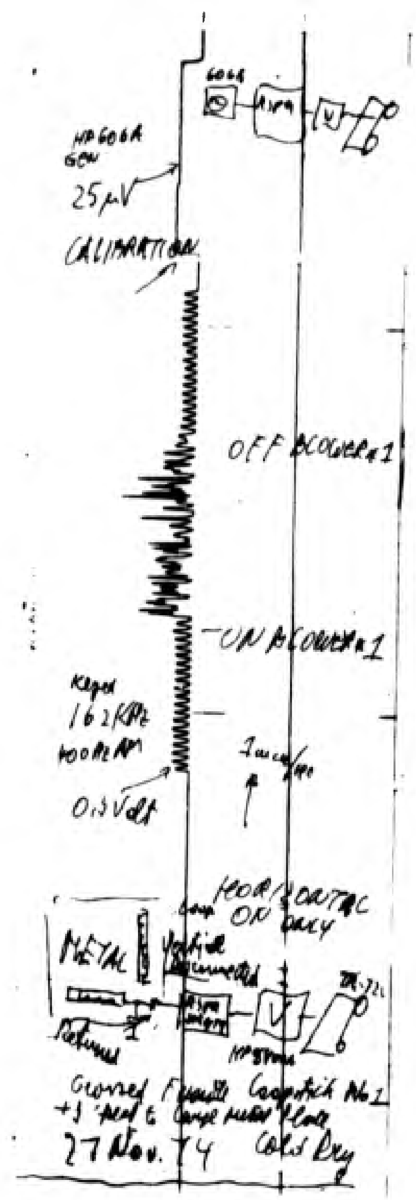
Recording No. 44. Signal, 165 kHz keyed 400 Hz Mod. CW, 100 µV RF, covered up by noise as received by insulated whip antenna and R-389 Radio Receiver, 18 Nov 1974.



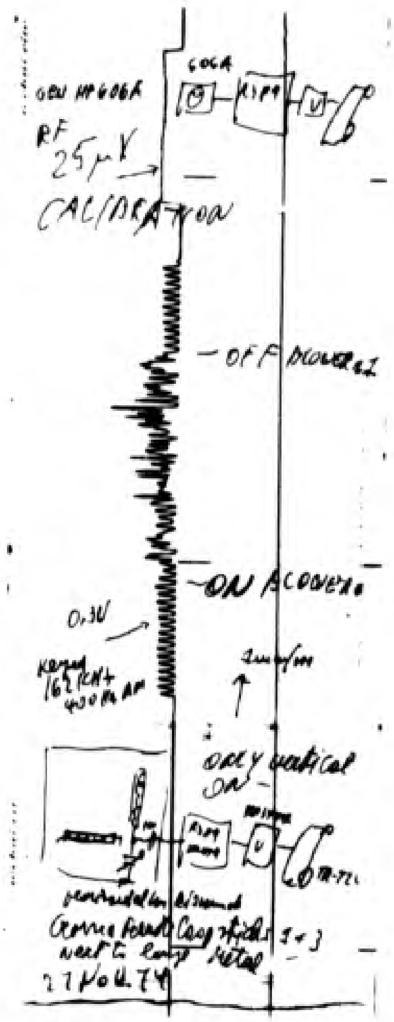
Recording No. 45. Signal, 165 kHz keyed 400 Hz, Mod. CW, 220 μV RF, covered up by noise as received by insulated whip antenna and R-389 Radio Receiver, 18 Nov 1974.



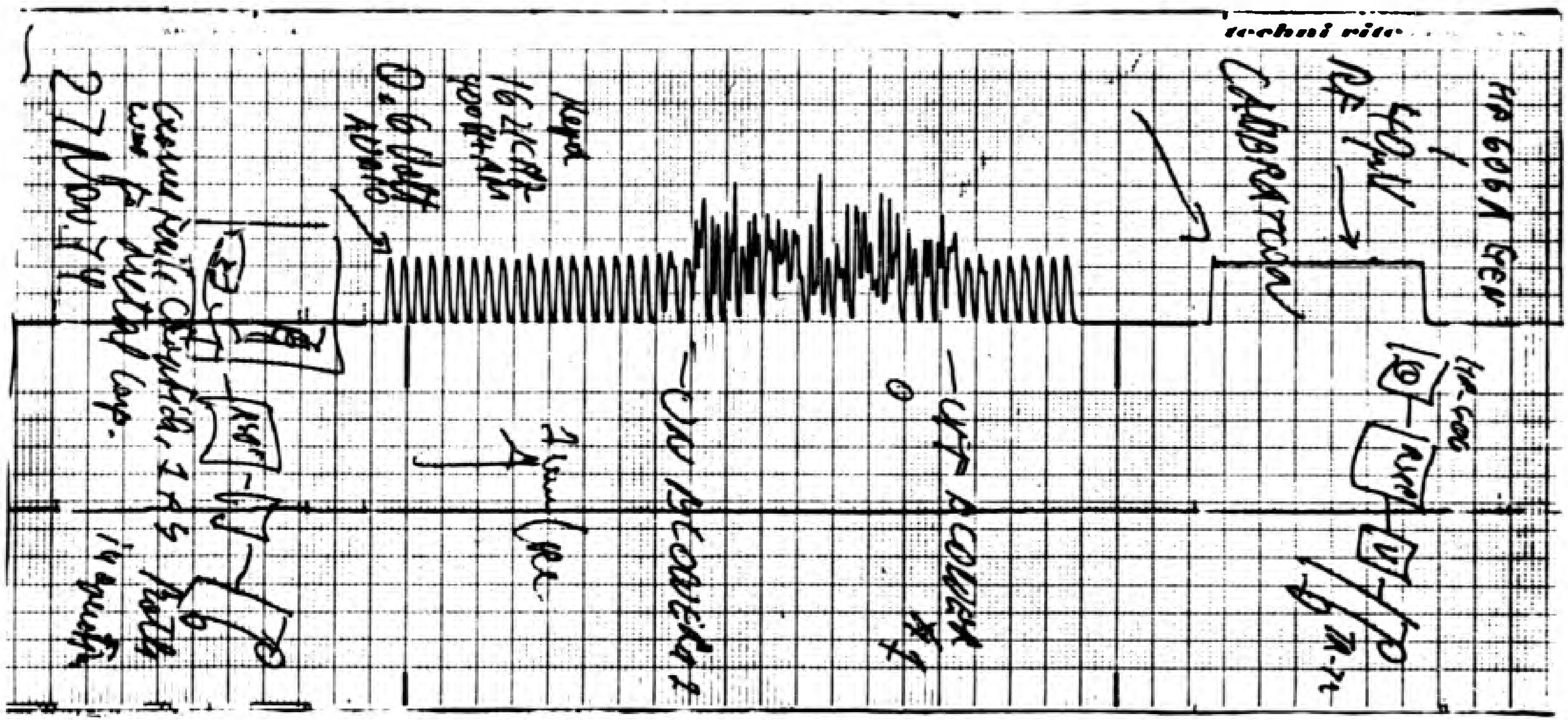
Recording No. 46. Signal, 162 kHz keyed 400 Hz, modulated CW, 100 μV RF, unperturbated by noise as received by Crossed Ferrite Loopsticks (Nos. 1 and 3) at d = 3 cm parallel to large metal plate, and using R-389 Radio Receiver, 27 Nov 1974.



Recording No. 47. Signal, 162 kHz keyed 400 Hz, modulated CW, 25 µV RF covered up by noise as received with horizontal loopstick only (vertical disconnected) of Crossed Ferrite Loopsticks (Nos. 1 and 3) at d = 3 cm parallel to large metal plate, and using R-389 Radio Receiver, 27 Nov 1974



Recording No. 48. Signal, 162 kHz keyed 400 Hz, modulated CW, 25 μV RF, covered up by noise as received with vertical loopstick only (horizontal disconnected) of Crossed Ferrite Loopsticks (Nos. 1 and 3) at d = 3 cm parallel to large metal plate, and using R-389 Radio Receiver, 27 Nov 1974.



Recording No. 49. Signal, 162 kHz keyed 400 Hz, mod. CW, 40 μV RF, covered up by noise as received with Crossed Ferrite Loopsticks (Nos. 1 and 3) at d = 3 cm parallel to large metal plate, and using R-389 Radio Receiver, 27 Nov 1974.