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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Environmental Research Laboratories

A Rocket Borne Instrument to Measure Electric Fields Inside Electrified Clouds

L. H. RUHNKE

BOULDER, COLO.
MAY 1971

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A ROCKET BORNE INSTRUMENT TO MEASURE ELECTRIC FIELDS INSIDE ELECTRIFIED CLOUDS

L. H. Ruhnke

Development of a rocket borne instrument to measure electric fields in thunderstorms is described. Corona currents from a sharp needle atop a small rocket are used to sense the electric field. A high ohm resistor in series with the corona needle linearizes the relationship between corona current and electric field. The corona current feeds a relaxation oscillator, whose pulses trigger a transmitter which operates in the 395 to 410 MHz meteorological band. The instrument senses fields between 5 kV/m and 100 kV/m.

1. INTRODUCTION

During 1970, the Atmospheric Physics and Chemistry Laboratory of NOAA conducted a study of the problem of discharging electrified clouds by rocket triggered discharges (Kasemir, 1971). This program considered the basic theory that governs the mechanism of artificially triggering lightning discharges as well as pilot experiments. The concept is based on the fact that an elongated conductor, i.e., a small rocket, in an electric field enhances the electric field at the surface of the conductor at both its ends. If the electric field is strong enough, breakdown conditions will exist and a discharge may be triggered by the rocket. To test this method under field conditions, it is necessary to know the electric field component along the trajectory of the rocket. Such a measurement of the electric field will give information on the likelihood of triggering a discharge as well as assess the effect of triggered lightning on the electric field. With this information we can also estimate the magnitude of the remaining electrical charge of the cloud.

The electric field inside clouds, in particular thunderclouds, is difficult if not impossible to determine from ground based sensors. Airplanes equipped with electric field sensors have successfully measured and determined the distribution of electric charges inside clouds (Schumann, 1969); however, to infer from such measurements the distribution of electric fields, one must make assumptions about the distribution of charges in the neighborhood of charge centers. At present, not enough charge distributions in electrified clouds have been observed to specify these needed assumptions. Direct measurements of the electric field inside thunderstorms require that an aircraft penetrates the clouds at several levels. Such penetrations lead to safety problems because of dangers of high turbulence and possibly high lightning activity associated with these clouds. Balloons do not penetrate clouds fast enough and also do not have a flight path that can be predicted accurately.

For these reasons we decided to develop a rocket borne probe that uses the same or a similar rocket as used for the discharge triggering device. The rocket selected was the 2.75-inch folding-fin aircraft rocket (FFAR) named "Mighty Mouse." This rocket is readily available, costs less than $50.00, and has flight characteristics suitable to investigate thunderstorms. Winn (private communication) has successfully measured electric fields inside thunderstorms with this rocket. His instrument sensed the field component perpendicular to the flight path. The important component for triggering lightning by a rocket is, however, the component in flight direction.

The design criteria, the development procedure, and a description of an instrument to measure and telemeter the electric field of electrified clouds is discussed in this report.

2. DESIGN CRITERIA

The characteristics of the rocket as well as the needed information establish most of the design criteria. The rocket reaches burnout after about 2 sec at an altitude of about 1000 m. After burnout the rocket ballistically reaches an altitude of about 6000 m after 30 sec and impacts the ground after about 70 sec. The cloud base is reached after 10 sec at a velocity of 250 m/sec. This velocity decreases to about 25 m/sec at maximum altitude. The payload can weigh 3 kg and can have a volume of 2000 cm^3. During flight the rocket is probably never farther than 10 km from the launch pad. Maximum acceleration is 50 G. The payload cannot be recovered after the flight.

These characteristics will determine the instruments' size, weight, and immunity against acceleration. Also the transmitted power can be estimated from this information.

The electric field will vary strongly with position. Every 10 m along the trajectory at least one reading of the electric field should be made and telemetered to a ground station, if a charge pattern is to be derived from the data. Assuming a maximum velocity of 250 m/sec at cloud base and assuming that electric fields are of interest mainly inside of clouds, one needs a data point every 0.04 sec. This means that the sensor for the electric field must have a relatively fast response. The magnitude of the electric fields varies from 30 V/m in fair weather at cloud level to 300,000 V/m inside thunderstorms at conditions when lightning are initiated. This range, however, does not have to be covered by the instrument, since the objective is to survey electric fields only in the range of interest to artificially initiate lightning. A realistic estimate is that electric fields from 5000 V/m to 100,000 V/m should be measured. Because of a very high variability of the magnitude of electric fields inside clouds in space as well as in time, and because of the large uncertainties involved in predicting triggered lightning from theoretical considerations, there are no very high demands on the accuracy of the measurements. We considered an accuracy of 20 percent sufficient for the present series of tests.

The position of the sensor at any time during flight must be known to relate the measured electric field to the location of observation. Also here the accuracy required is not extreme. An accuracy of 20 percent of the altitude above ground is sufficient. It was anticipated to determine the trajectory of the rocket from a computer simulation after establishing a valid simulation model from the radar information.

3. PRELIMINARY TESTS AND DEVELOPMENT PROCEDURE

Several methods are available to sense the electric field. A field mill on a fast moving rocket for the vertical electric field component is mechanically too complex and too difficult to design under the present program. Radioactive probe circuits involve difficult logistic procedures (see safety manual AFETRM-127-1, page 6, 72). Such devices are also difficult to construct for high electric fields.

Because the sensed fields vary very rapidly in time during each flight, and because measurement times are short compared to the relaxation time of air, it is feasible to neglect the conductivity of air and consider electrostatic measurement methods. An exposed conductor, e.g., a small sphere, isolated from the body of the rocket and electrically connected to an amplifier with input time constants large compared with the flight time of the rocket will give readings proportional to the electric field, if the electric field at the start of the flight can be neglected. Unfortunately, such an exposed sphere can easily collect charges by impact with precipitation particles. Large measurement errors could occur and such errors should not be easily compensated for or identified.

In the present design, a corona probe is used to detect the vertical electric field. A sharp point in an electric field will initiate electrical breakdown in a small region and a semi-continuous current will flow from the sharp point. This current depends not only on the electric field but also on the geometry of the point, air pressure, temperature, wind velocity, and to a lesser degree the chemical composition of air. There also exists a nonlinear relationship between corona current and electric field. To eliminate the nonlinearity as well as the various factors that influence corona currents, the current from the sharp point (corona point) is fed through a high ohm resistor to bias the corona point against the instrument ground. If the voltage drop over the resistor is large compared with the voltage drop between corona point and environment, then the corona current measured is proportional to the electric field to a practical degree, if the electric field is higher than a certain threshold field.

Preliminary tests were conducted to predict the linearity that can be obtained and to determine the magnitude of the biasing resistor. The corona point used was made out of 1/16 inch tungsten steel rod about 4 inches long. The point was sharpened by a grinding machine at a 10° angle. The corona onset potential U_o measured with the setup in figure 1 was usually between 1000 V and 1500 V. One example of a corona probe characteristic is shown in figure 2. In this test the corona current I(amp) and its dependence on the voltage U(volts) could be approximated well by

$$\sqrt{I} = 0.95 \cdot 10^{-6} (U - U_o),$$

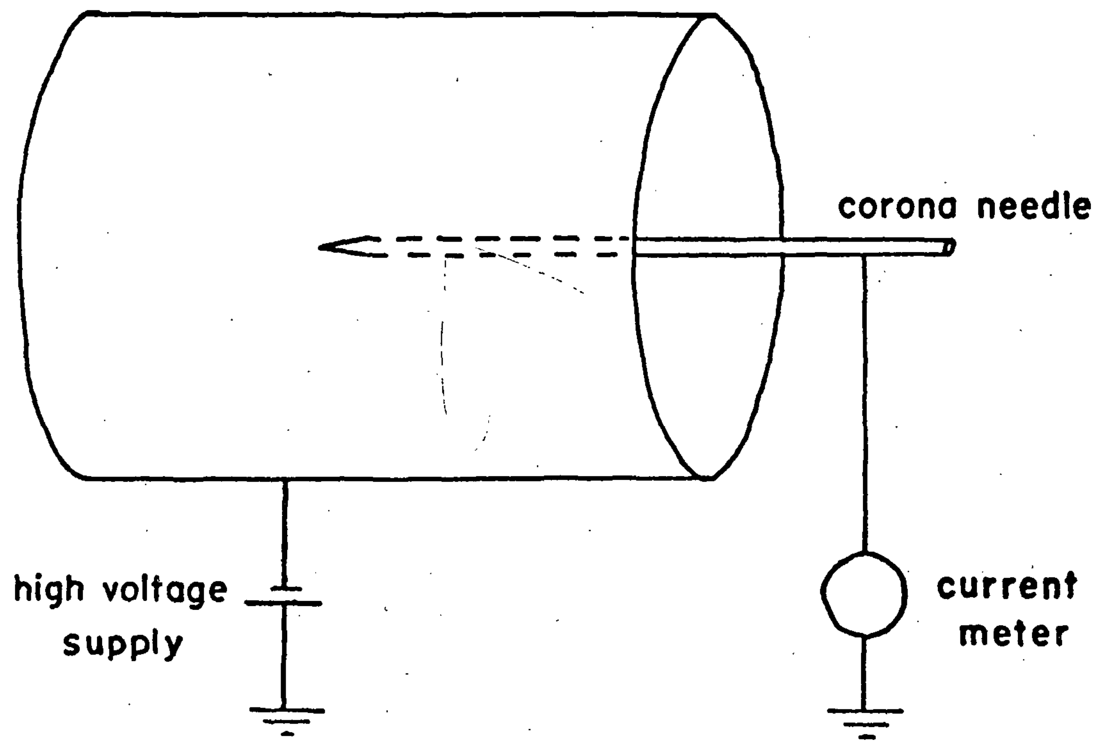


Figure 1. Experimental setup to measure onset potential of corona probe.

where U_o was 1150 V. One can now modify the circuit by including a linearizing resistor of 5000 MΩ, as shown in figure 3, and obtain the current-voltage relationship shown in figure 4. For voltages larger than twice the corona outset voltage the characteristic is linear and reproducible within 2 percent. Larger biasing resistors gave even better linearities. For operational use this resistor will determine the sensitivity of the instrument.

As a next task it was considered how this corona current could be used to modulate a transmitter for recording the data at a ground station. For simplicity and economy we converted the corona current into pulses with a frequency which is proportional to the current. Drifts of gain or frequency in the electronics for telemetering and recording should not affect the accuracy of the electric field meter. Several

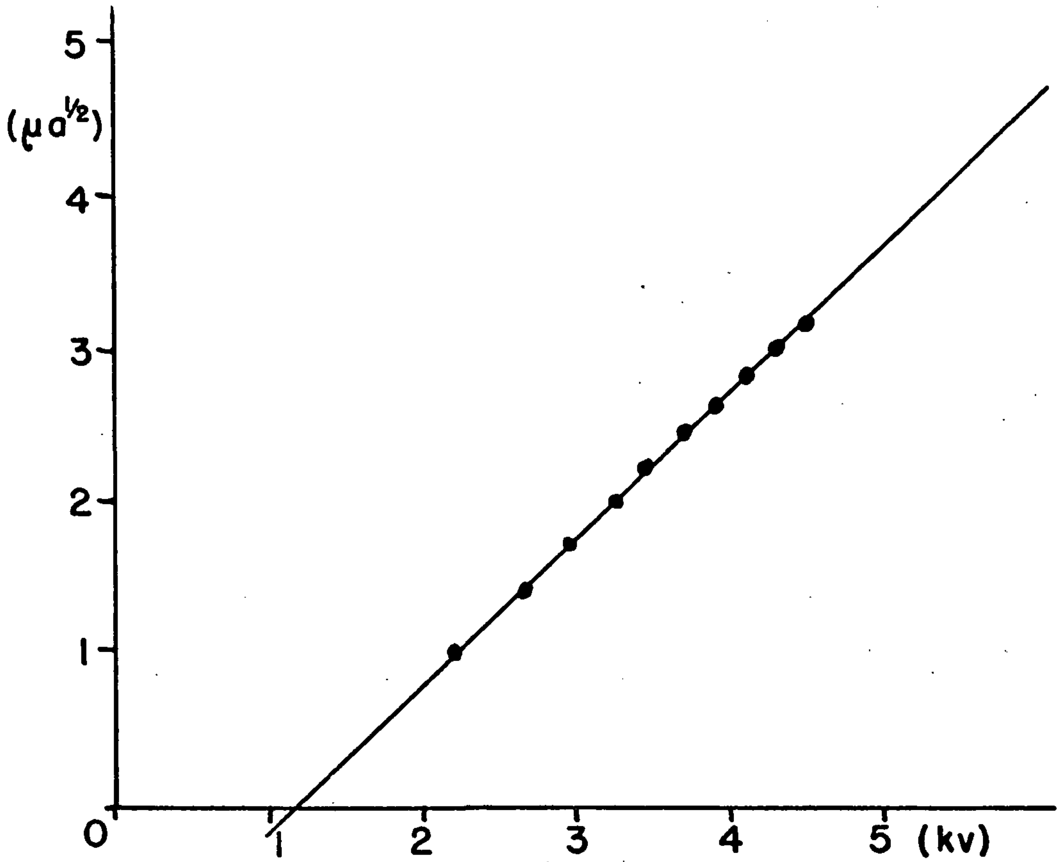


Figure 2. Voltage-current characteristics of corona probe.

electronic devices were tested for converting the corona current into pulses. Relaxation oscillators were built using neon bulbs, unijunction transistors, and four-layer avalanche diodes. Neon bulbs type NE-81 proved to be by far the most sensitive device. A current of 0.02 μA was sufficient to start oscillations. The corresponding current was 0.5 μA for unijunction transistors and 2 μA for the four-layer diodes. Neon-bulb oscillators usually have a highest frequency of 5 kHz because of the sluggishness of the device, but with a minimum of 25 Hz needed for proper resolution at cloud levels, a ratio of 1:250 can be achieved. This is sufficient to cover the range of electric fields of interest to the discharge triggering program. The circuit diagram of

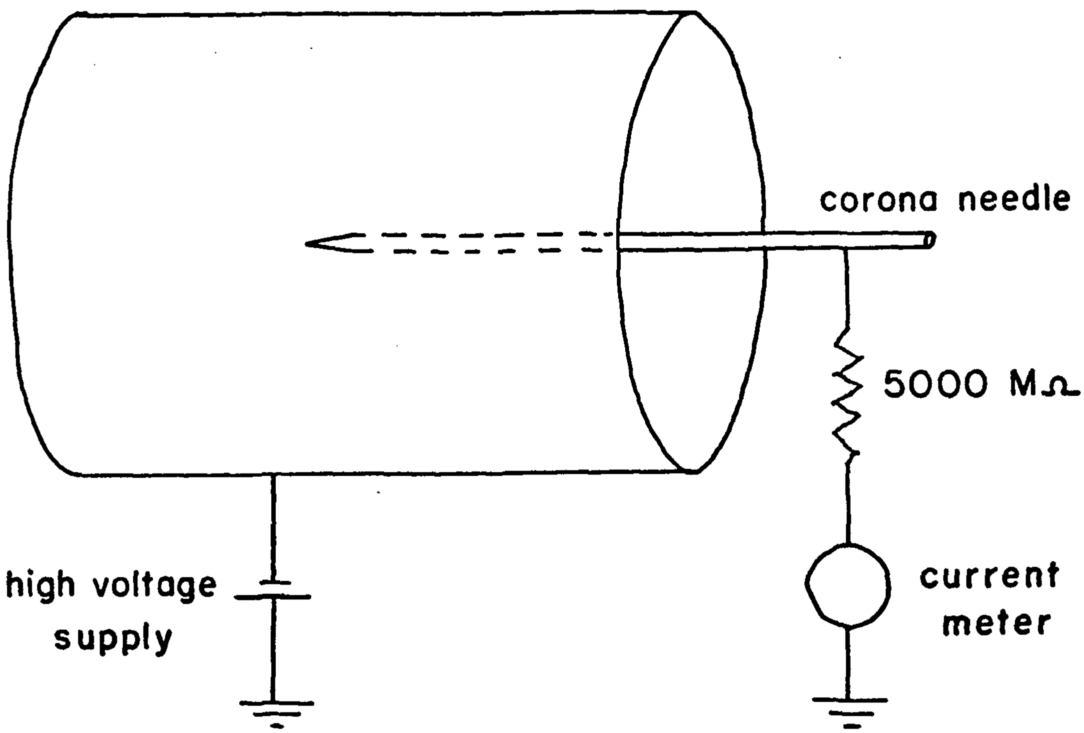


Figure 3. Experimental set-up with 5000 MΩ linearizing resistor.

the relaxation oscillators used in the field measuring instrument is shown in figure 5 together with a test. There is a difference in the frequency characteristics if positive or negative currents are used. This difference varies widely from one neon bulb to another. Proper selection of units can considerably minimize this difference.

The pulses available are several volts. We considered the possibility of using this voltage to drive a small transmitter. Pulses of 100 mW and 50 μsec duration are available. A proper circuit would convert this power into radio frequency power. No extra power supplies would be needed. A feasibility test was successful using a 400 MHz transmitting circuit. This concept was given up, however, because of the marginal power available and because no signal would be

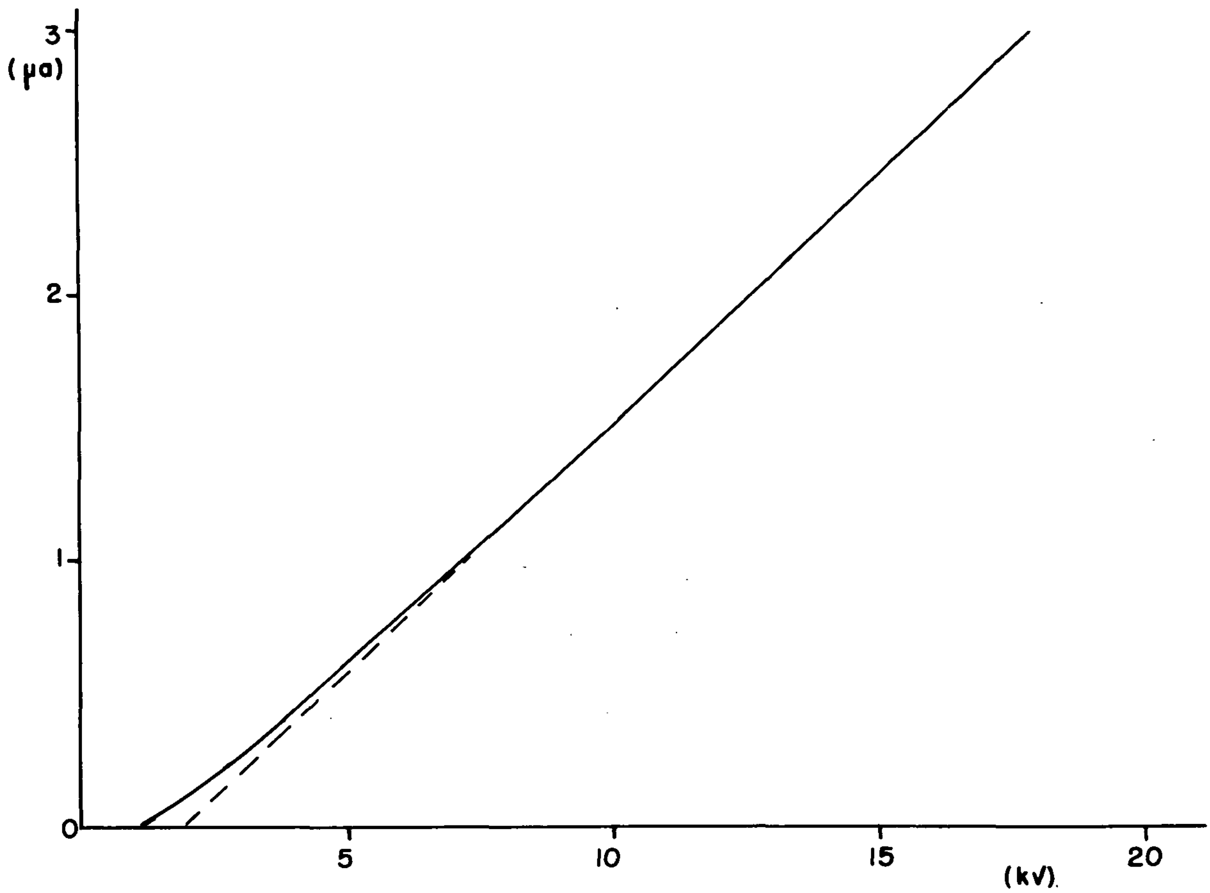


Figure 4. Voltage-circuit characteristic of linearized circuit.

available if the electric field were below a certain threshold value. This latter reason would make it difficult to test the unit before flight and to test the proper functioning of the transmitter during flight under conditions of low electric fields. This problem also exists if the pulses from the relaxation oscillator are used to modulate a 1 W transmitter, as used in the final design. Therefore, a second relaxation oscillator was designed that was powered by the power supply of the transmitter and gave pulses at a fixed rate of about 20 Hz. These pulses were used to monitor proper functioning of the transmitter.

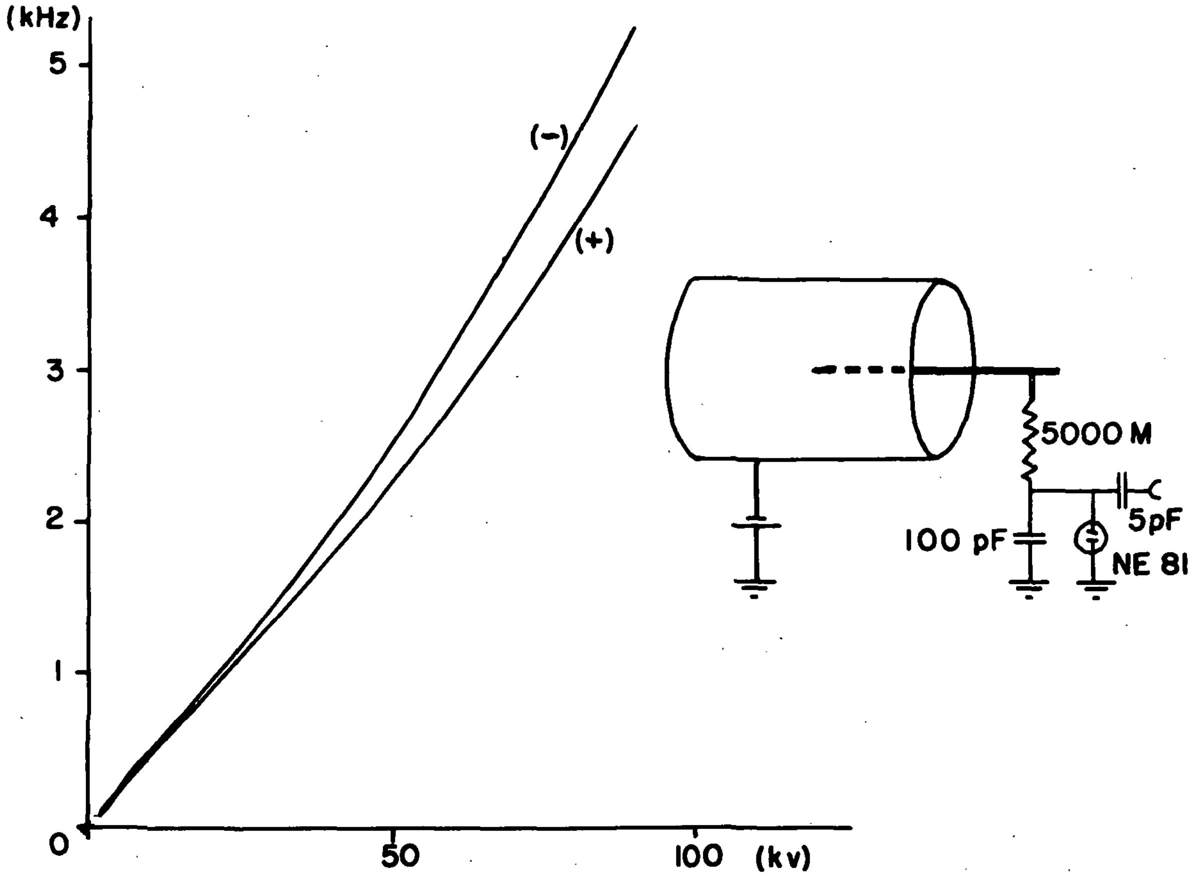


Figure 5. Circuit diagram of relaxation oscillator and frequency-voltage characteristic.

Because of time restrictions no attempt was made to develop a transmitter circuit. The possibility was explored to use equipment commercially available. A transponder type BT20 of Metrodata Systems, Inc., Norman, Oklahoma, was suitable after some modifications. This instrument contains a transmitting circuit for the meteorological frequency band of 395 to 410 MHz. Output pulses of 1 W power of about 1 μsec duration can be triggered from the pulses available at the relaxation oscillator output.

Difficulties did arise when increasing the average output power through increasing the pulse length from 1 μsec to 10 μsec. For a second generation of instruments, it is advisable to develop a new radio frequency circuit that takes into account special requirements of input and output characteristics. In this first-generation series, the pulse length was increased by changing the time constant of a coupling transformer and in the preamplifier circuitry.

Further difficulties did arise in the construction of a proper antenna that neither interfered with the corona point field sensor, nor interfered with the flight performance of the rocket at highest speeds (Mach 2). Tests were made to use a slot antenna in the nose cone. With proper matching the radiated power was 70 percent of that radiated from a $\lambda/4$ dipole antenna. The matching, however, was very critical to adjust and required two variable capacitors. After several weeks of testing, this approach was given up, and a $\lambda/4$ radiator on top of the rocket and connected in series with the high-ohm biasing resistor was tested. In this approach the sensor input current and rf output current are flowing through the same conductor. No trouble developed because of this in the first few test models; however, later tests showed signs that radio frequencies were influencing the performance of the neon-bulb relaxation oscillator. We recommend that in a second generation series this influence be studied further and eliminated.

The receiving station did not need any particular development. For testing, a commercially available receiver type MR-17 of Metrodata Systems, Inc., Norman, Oklahoma, was used in connection with a helical antenna of 18 dB gain. With this setup the transmitted signal could be received well up to 30 km over flat ground.

The output of the receiver was fed over a frequency-to-analog converter into a strip chart recorder. For actual operations, we intended to use operational receiving stations at the Kennedy Space Center and use our test setup only as back-up equipment.

4. INSTRUMENT DESCRIPTION

A direct current in the order of 1 μA flows from the corona point over a 5000 MΩ resistor, over the rf antenna, through the circuitry, and through the relaxation oscillator to the main body of the rocket. Corona currents on the sharp edges of the rocket fins keep the potential of the rocket body close to the potential of the atmosphere at the level of the fins. The corona current I through the biasing resistor R depends approximately on the potential calculated by the product of the electric field E and the length of the antenna d. More appropriate, but still with considerable mathematical simplifications, it holds

$$I = (E \cdot d - U_1 - U_2)/R.$$

Here U_1 and U_2 are voltage drops over the corona point and sharp edges of the fins at the corona current I. For electric fields larger than 10 kV/m, terms U_1 and U_2 can be neglected. For a more accurate assessment of the electric field, it is either necessary to consider the potential distribution in the neighborhood of the rocket by a theoretical analysis or necessary to use an experimental calibration procedure.

The circuit diagram of the transmitter is shown in figure 6. It shows, in essence, the circuit of the transporter type BT-20 with all modifications and additions. Pulses from the relaxation oscillator are coupled out through a full wave rectifier bridge, such that pulses of either polarity trigger the transmitter. The information on the polarity of the electric field is lost by this procedure. We found no simple way to preserve the sign with the pulse transmission mode used. The pulses from the neon-bulb oscillator are coupled over a 100 pF capacitor in series with a 47 kΩ resistor to the first amplifier stage.

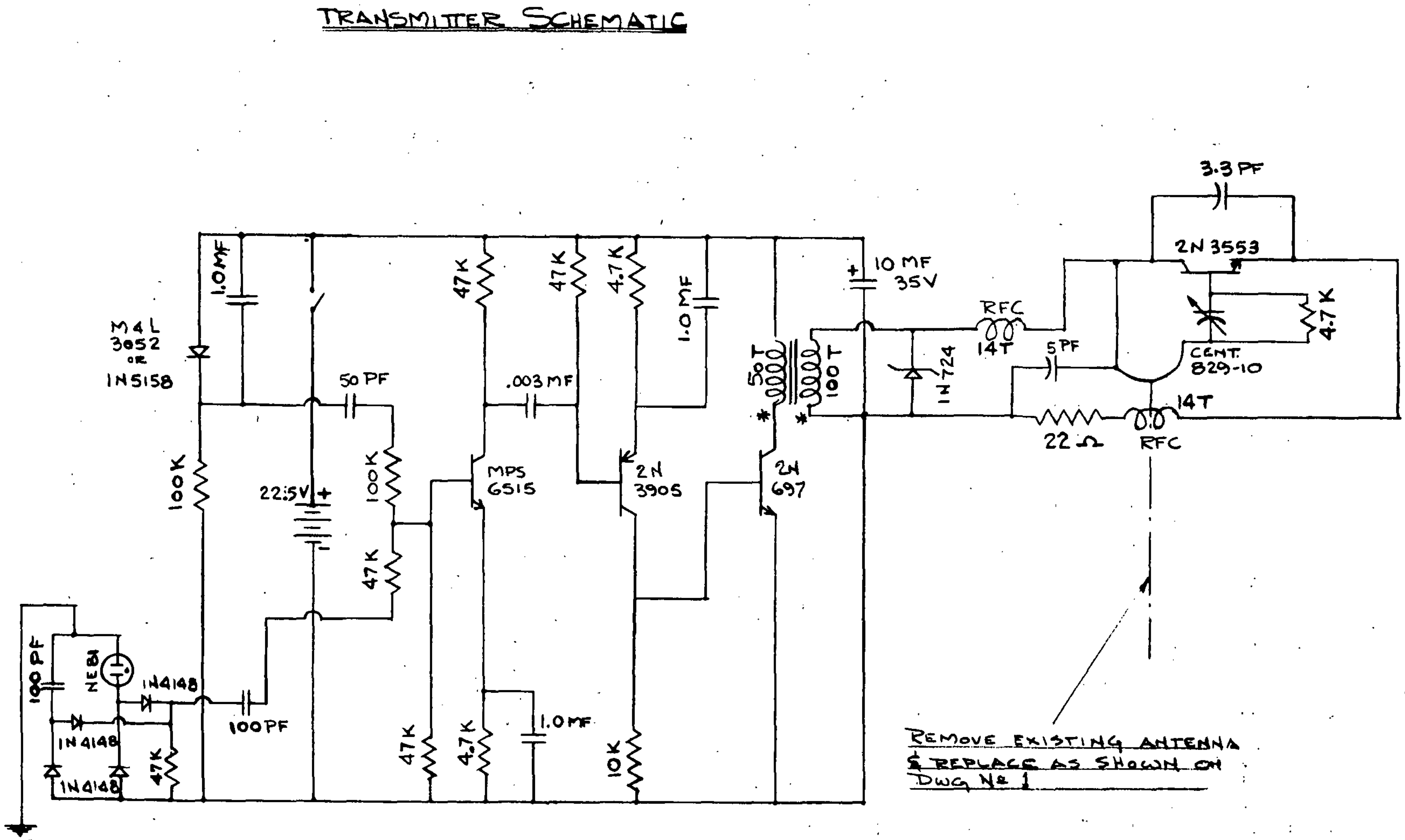


Figure 6. Transmitter circuit diagram.

A similar relaxation oscillator for the reference pulses consists of a 100 kΩ resistor, a four-layer diode type 1N5158, and a 1 μF capacitor. The produced pulses are also coupled over 50 pF and 100 kΩ to the first amplifier stage. After two-stage amplification, a switching transistor 2N697 is switched on by the pulse. In the collector circuit a pulse transformer produces a 45 V pulse, which is available to drive the radio frequency transistor 2N3553. A variable capacitor Cent. 8 29-10 provides a means to vary the frequency from 395 to 405 MHz. Radio frequency is coupled out to the antenna from the midpoint of the U-shaped resonance circuit. An acceleration switch is provided to connect the 22.5 V battery to the circuit. This switch is adjusted to 20 G's. Detailed drawings of the rocket borne electric field sensor are shown in figures 7 through 17. For instruction on checking and preparing the rocket for flight see Appendix.

Figure 18 is a block diagram of the receiving system. A modification made at the model MR-17 receiver is explained in figure 19. This receiver is designed for use with weather radar instrumentation. A special network shapes the output pulses, and very short pulses (≈ 0.1 μsec) appear at the output terminal. For our use it is advantageous to have an output available without waveform modification. One coaxial connector type BNC was, therefore, added which connects the video output of the IF amplifier to the output terminal. A second additional output connector type BNC was added with an integrating circuit and a peak voltage rectifier. This circuit has the effect that the pulses are stretched such that they are easier to display on an oscilliscope. Furthermore, the integrating network has such a time constant that pulses shorter than 10 μsec are reduced in amplitude at the output. The effect is that noise pulses of short durations are surpressed to some degree, thus increasing the signal-to-noise ratio.

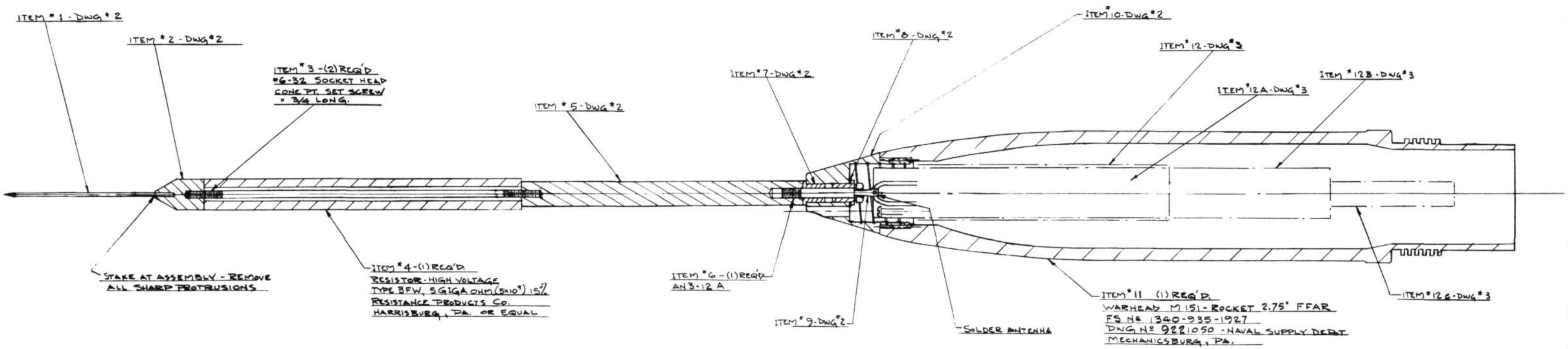


Figure 7. Payload for rocket.

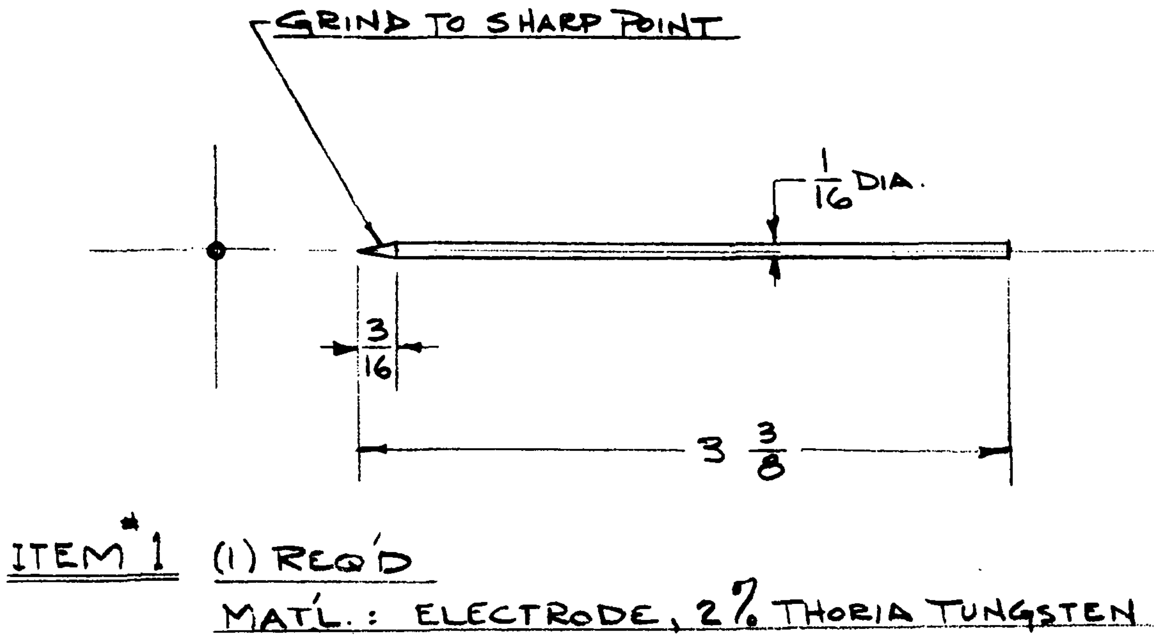


Figure 8. Corona needle.

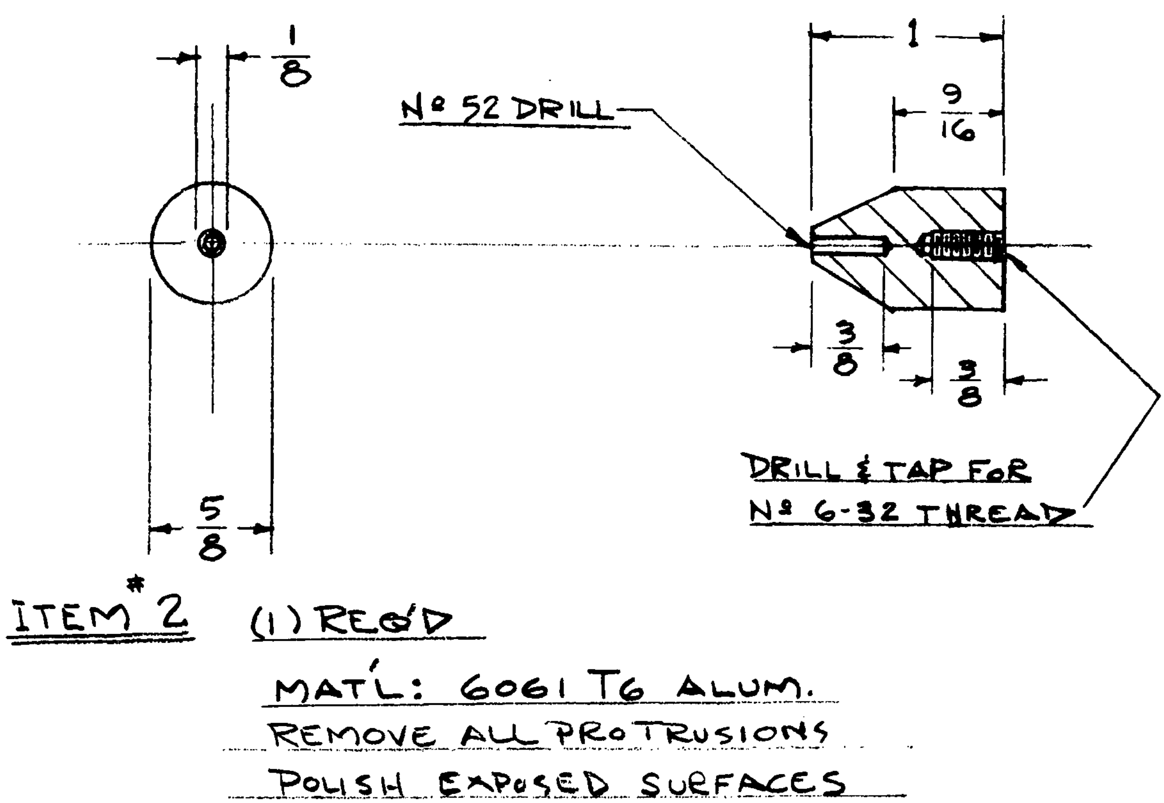


Figure 9. Needle holder.

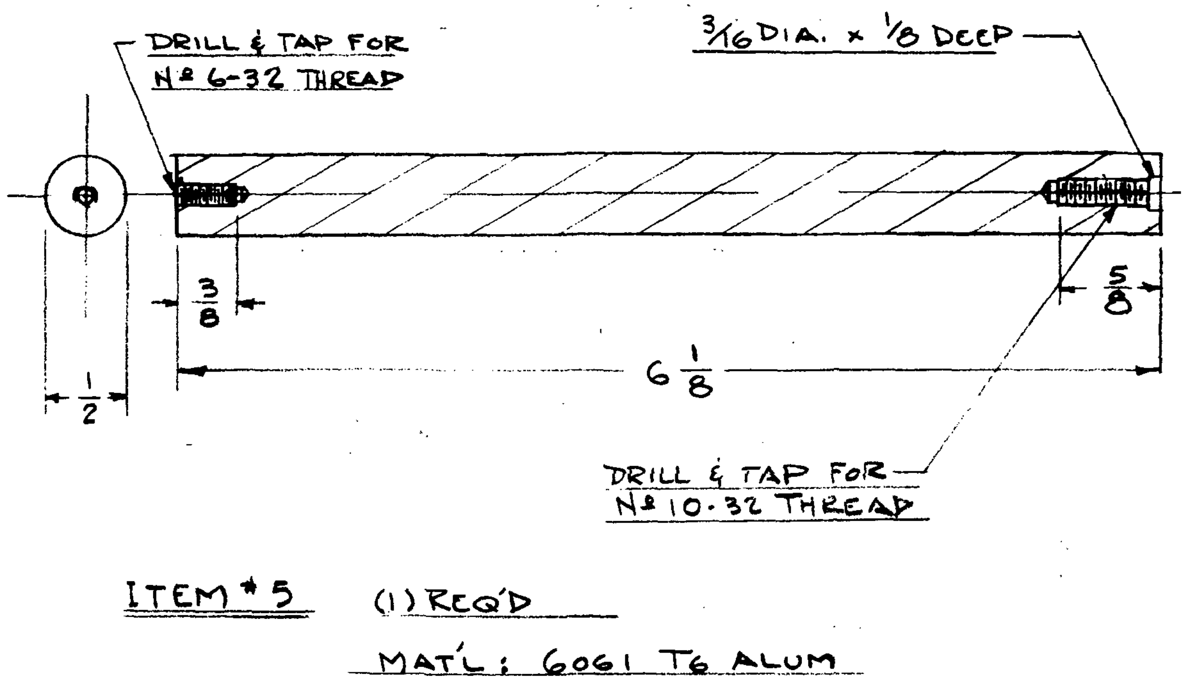


Figure 10. 400 MHz antenna rod.

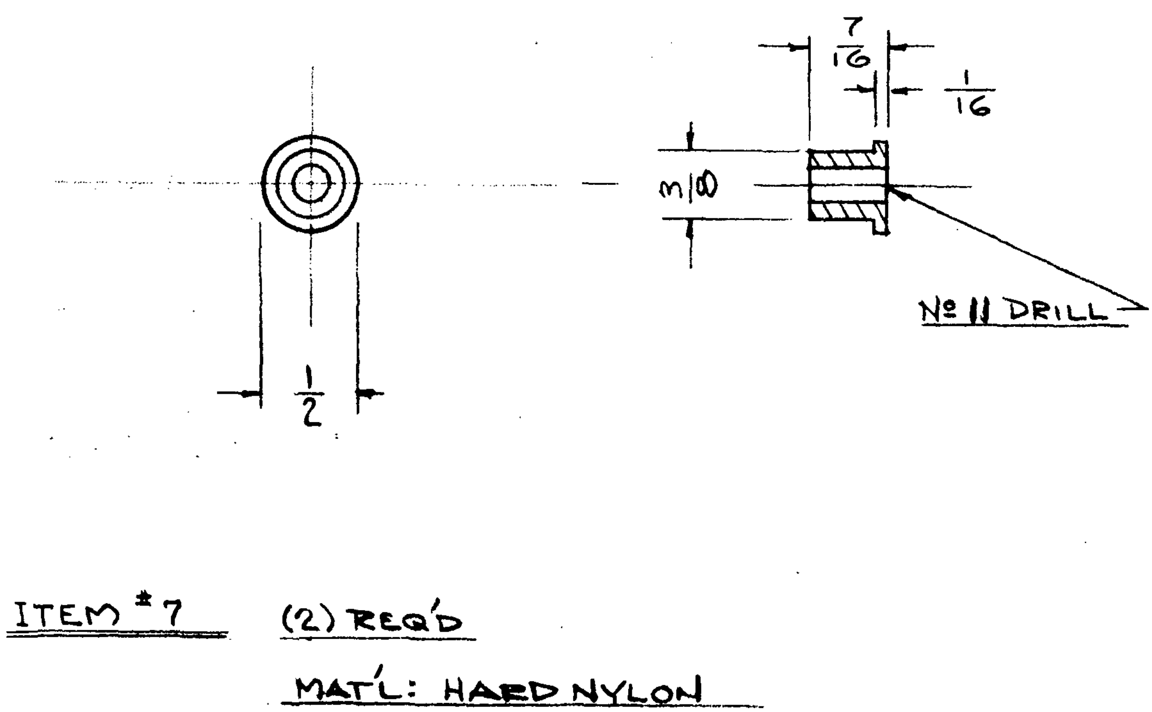


Figure 11. Insulator for antenna mount.

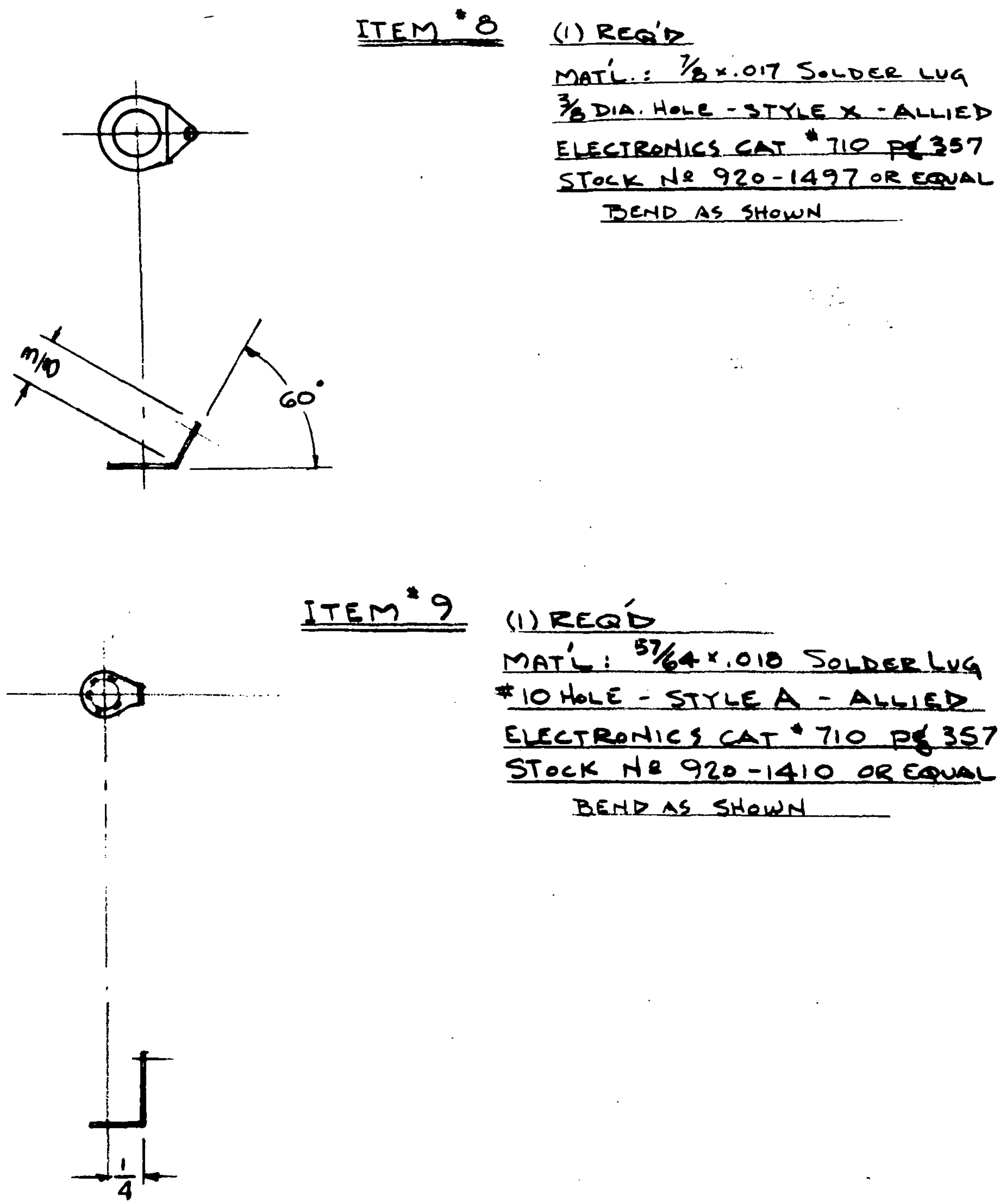
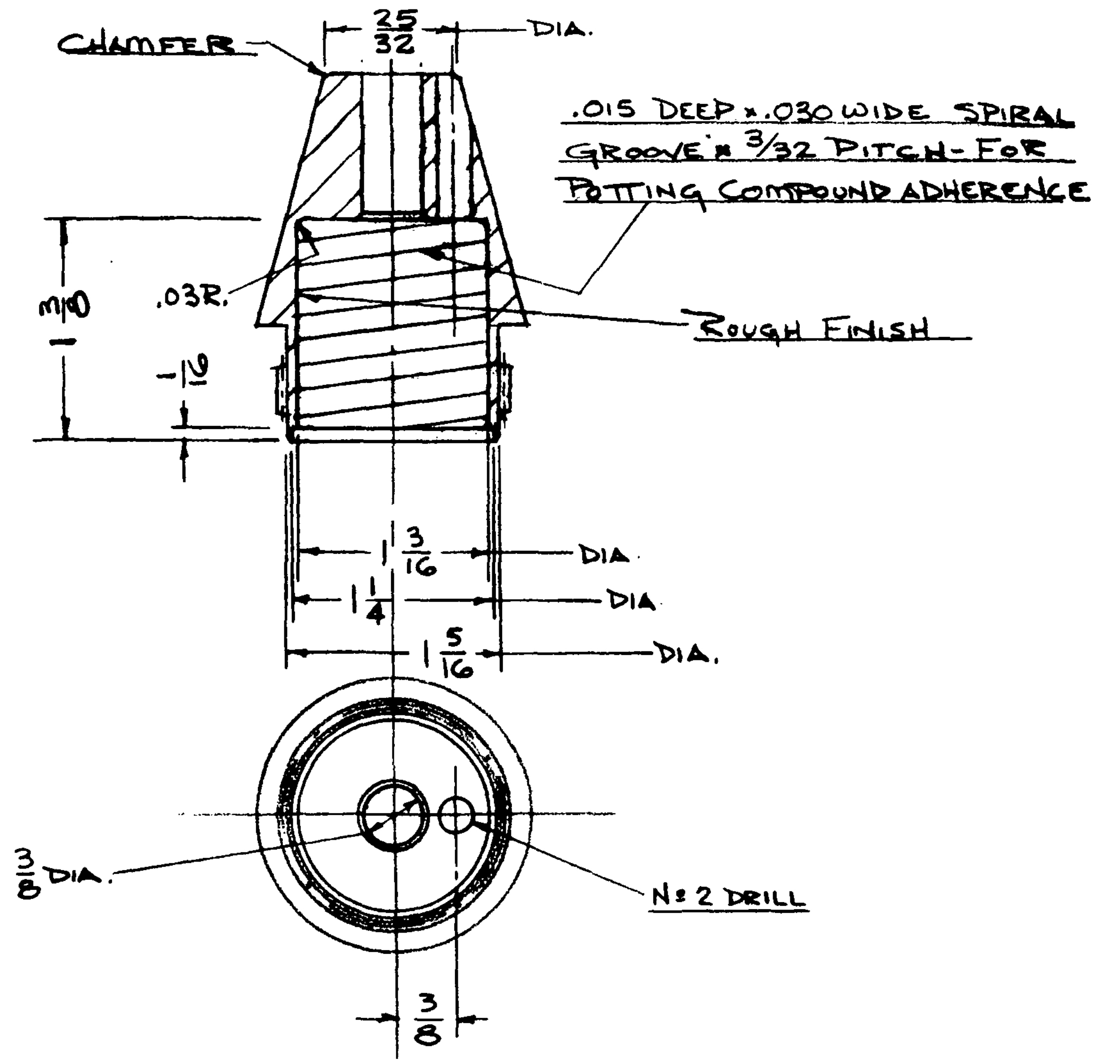


Figure 12. Solder lugs for antenna mount.



ITEM * 10 (1) REQ'D

MAT'L: FUSE, ROCKET, PRACTICE DUMMY, INERT FOR 2.75 INCH ROCKET WARHEAD F.S. No 1340-738-1994, NAVAL SUPPLY DEPOT, MECHANICSBURG, PA.
REWORK AS SHOWN

Figure 13. Antenna mount.

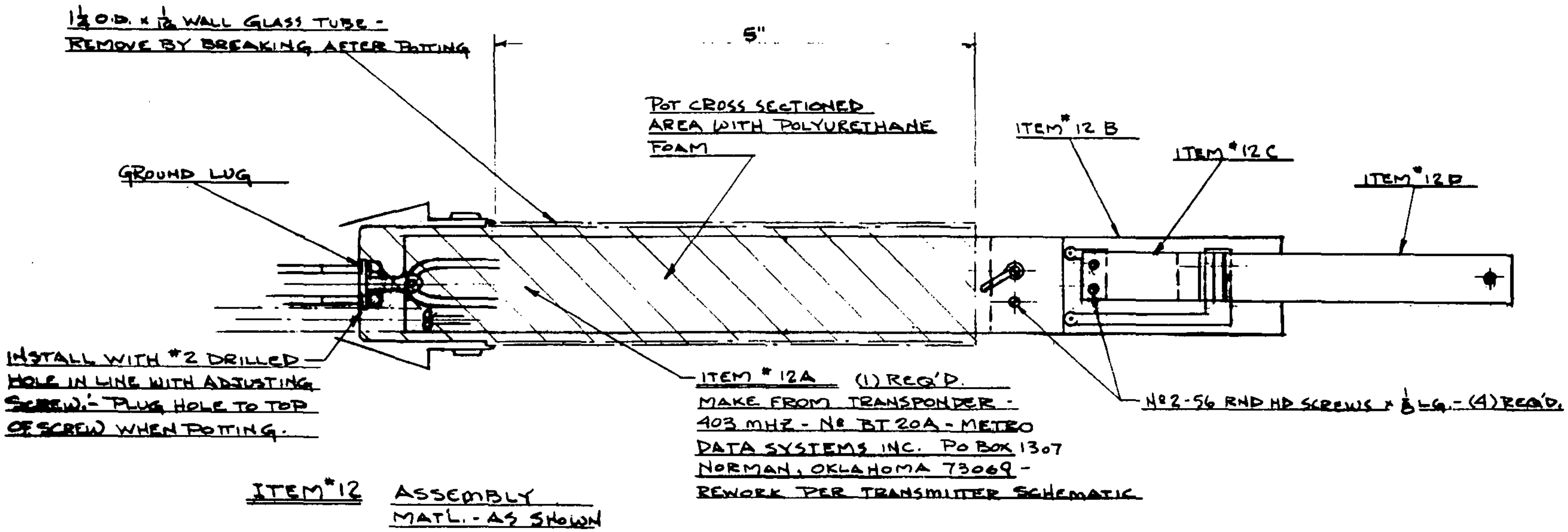


Figure 14. Assembly instructions for transmitter.

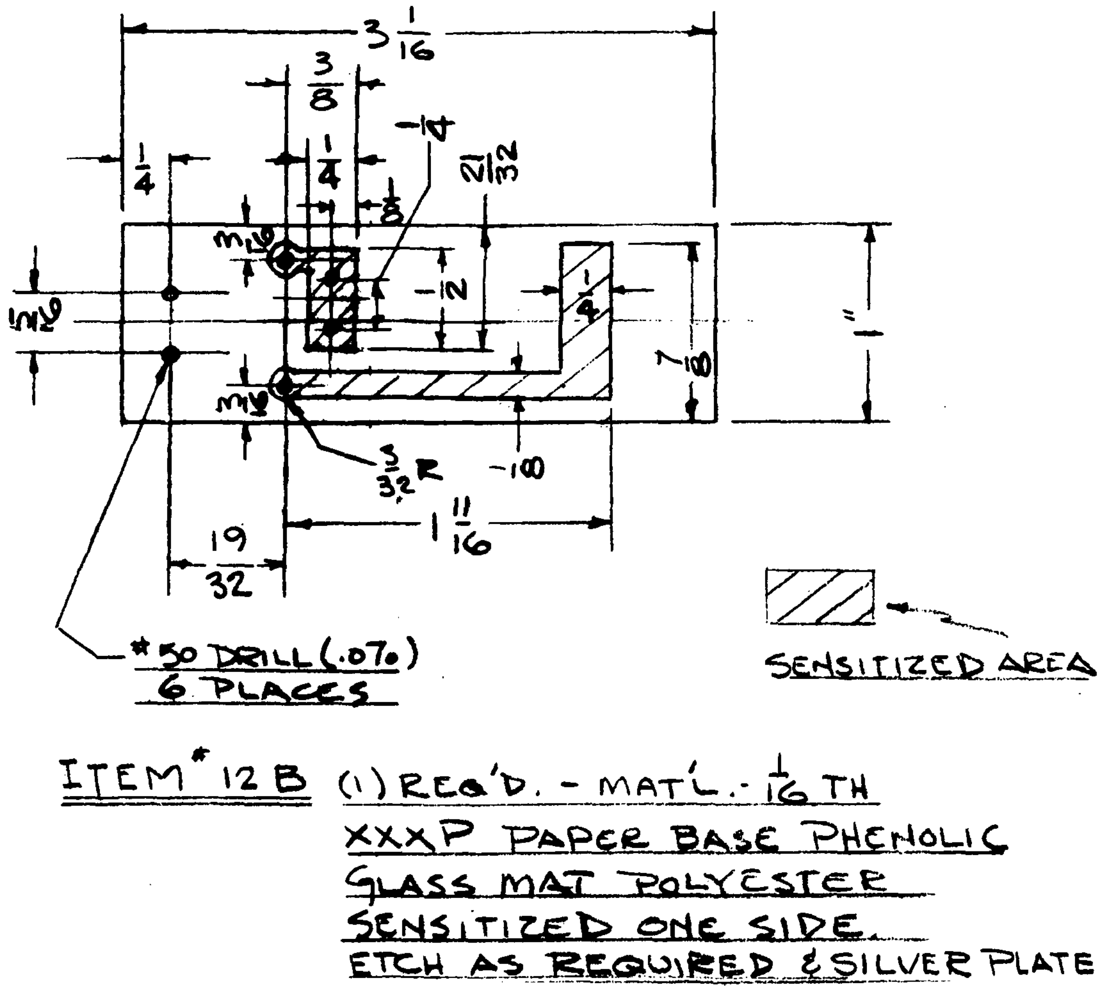


Figure 15. Details of acceleration switch.

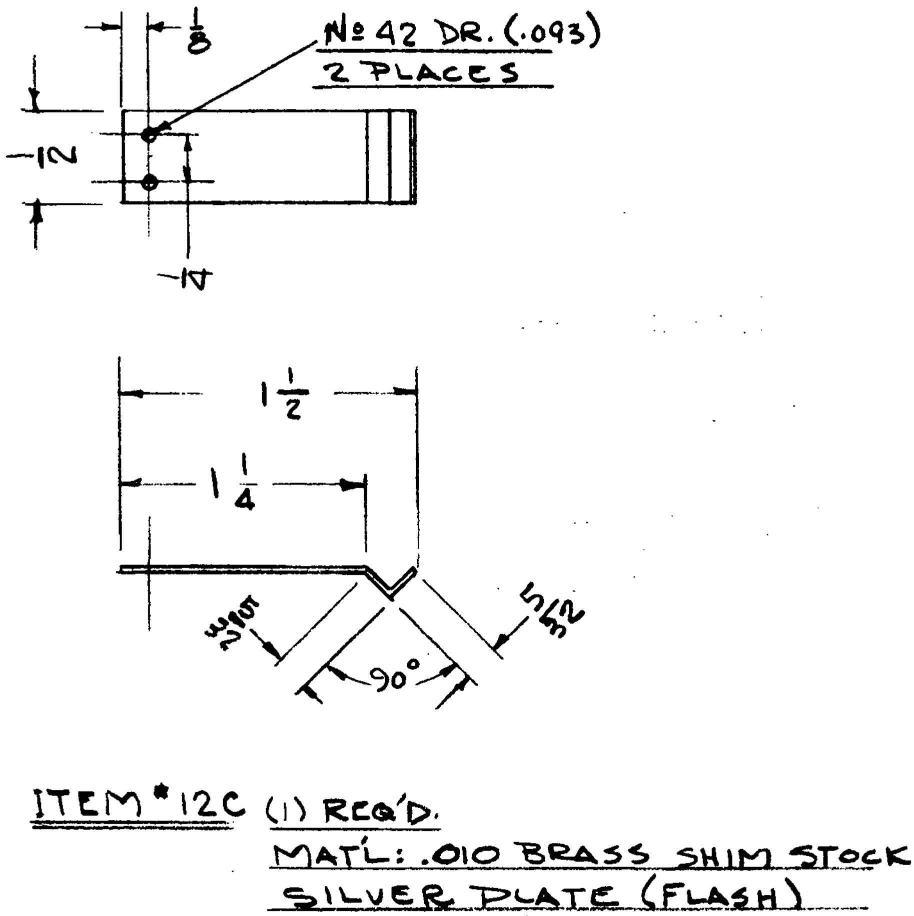


Figure 16. Acceleration switch spring.

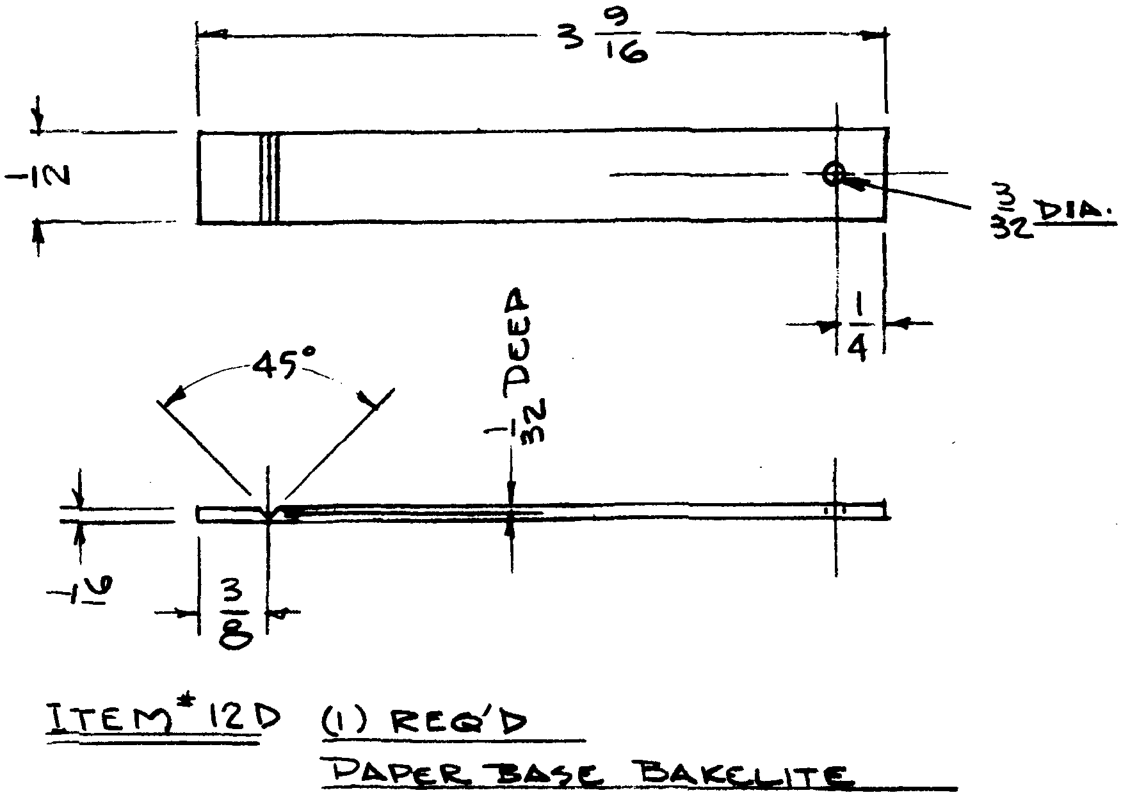


Figure 17. Acceleration switch tongue.

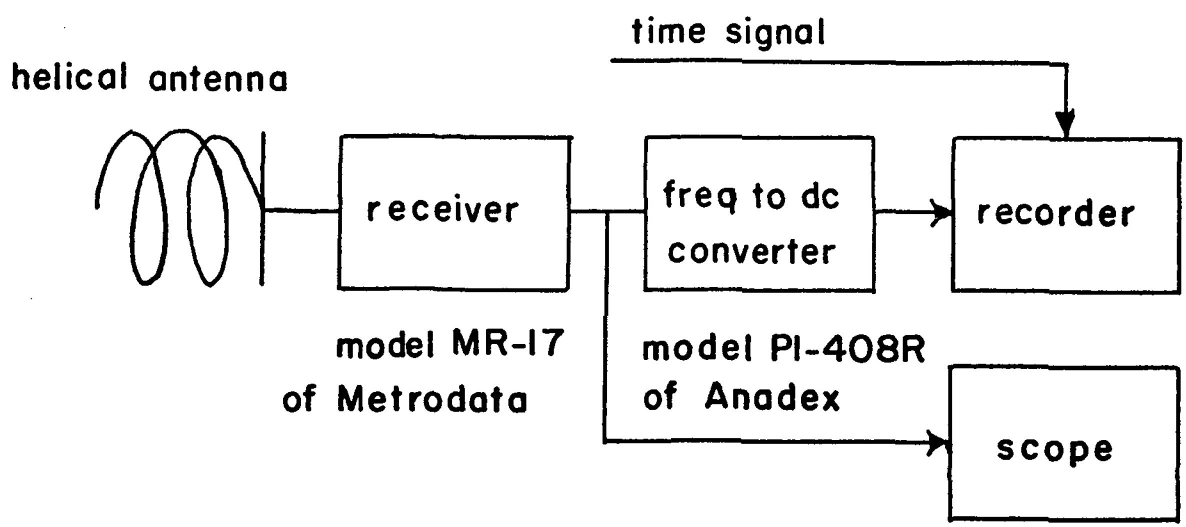


Figure 18. Receiving station block diagram.

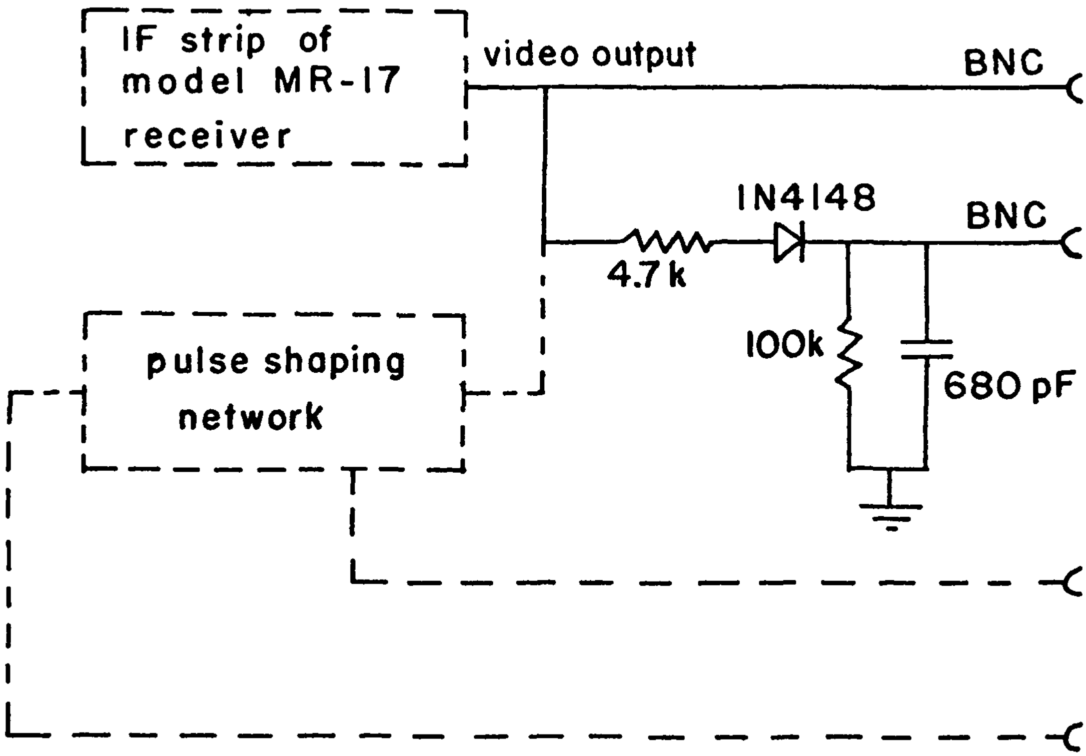


Figure 19. Modifications on receiver output.

5. TESTS FLIGHTS

Several test flights were made at Kennedy Space Center during the summer of 1970. Most were aimed at testing the needed power of the transmitter. One flight penetrated the edge of a thunderstorm and is summarized in Table 1. Between 3000 m altitude and apogee of the rocket during ascent a record of the electric field with good resolution was obtained. On descent the threshold field was exceeded in a 400 m thick layer at 2500 m above ground. These preliminary tests have helped to gain confidence in the developed device, but many more test flights are necessary to establish its value in thunderstorm research and, in particular, its value to the lightning triggering project.

Table 1. Field Strength Measurements on a Rocket Trajectory

Time (T + sec)	Altitude (m)	Field Strength (kV/m)
0	0	1.5
1.547	510	1.5 (Burnout)
5	2021	1.5
6.5	2423	1.5
9.5	3140	45.0
11.5	3566	12.5
13.5	3917	45.0
19	4587	15.0
23	4892	20.0
24.5	4968	1.5
27.8	5073	1.5 (Apogee)
30	5069	1.5
40	4496	1.5
50	3094	1.5
52.5	2598	40.0
54	2286	30.0
54.5	2179	45.0
54.6	2156	1.5
63.97	0	1.5 (Impact)

6. ACKNOWLEDGMENTS

This work was sponsored under NASA Contract No. CC-88025. Considerable efforts were spent by personnel of the Kennedy Space Center to assist in the field test phase of this program. In particular Mr. Fred J. Stevens of the NASA Test Support Office used considerable personal initiative to organize the test program. Mr. W. W. Bailey of DD-EDD-22 monitored the project and guided our efforts, and he showed great understanding for the many delays, and unforeseen difficulties that we encountered.

7. REFERENCES

Kasemir, H. W. (1971), Basic theory and pilot experiments to the problem of triggering lightning discharges by rockets (unpublished report). NOAA Tech. Memo TMERL APCL-12, NOAA Atmospheric Physics and Chemistry Lab., Boulder, Colorado.

Schumann, E. (1969), The inference of the charge distribution in thunderstorms from airborne measurements of the electric field. J. Appl. Met., 8, No. 5, 820-824.

APPENDIX

CHECKING PROCEDURE FOR THE FIELD MEASURING ROCKET

A. The electronics of the measuring rocket comes packed with the acceleration switch taped, to avoid accidental turn-on of the transmitter during transport. Carefully remove the tape without bending the spring of the switch more than necessary.

B. Test the force necessary to pull the switch to the "on" position. Use a spring scale that can measure 150 g mass to measure the necessary weight to pull the switch. It should require between 40 g and 60 g. Adjustments to the spring can be made carefully with a pair of pliers.

C. Attach a 5 GΩ resistor to the antenna and the corona point. Inspect the setup for possible mechanical damage during transport. An alignment of the antenna is not considered necessary.

D. Attach the transmitter package to a nose cone after the switch is pulled out. The transmitter should now transmit on a frequency within the meteorological band (395 MHz to 410 MHz). The frequency will be adjusted in the laboratory to 403 MHz or as close as possible. The frequency can be adjusted with the screw located close to the upper end at the antenna. A clockwise turn will decrease the frequency. The use of an insulated screwdriver is recommended.

E. The output of the transmitter gives pulses 7 to 12 μsec wide with a repetition rate of about 25 Hz. Very short pulse width (1 μsec) is indicative of damaged electronics.

F. The battery voltage can be checked by attaching a voltmeter between switch (+) and a solder lug (-) which is located closeby. The voltage should not drop below 18 V in the switched-on position.

G. A high voltage can be supplied between corona point and rocket body, 25 kV will produce 1000 Hz modulation frequency.

H. The operation at 100 G can be tested by reducing the length of the item No. 12D to 1/5 of its weight or length. With this switch inserted one can bounce the rocket head on a concrete ground. At 100 G acceleration the unit will switch on if it withstood this acceleration.

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