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ORNL 191
PHYSICS-INSTRUMENTATION

INSTRUMENT DEPARTMENT

METHODS FOR REDUCING INSULATOR NOISE AND LEAKAGE

BY

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Report Number: ORNL-191

This document consists 20 pages.
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ABSTRACT

A recent study of the insulator problem involved in radiation detection instruments disclosed the fact that insulators, in high impedance input circuits,are the predominate source of background noise when subjected to high voltages and high humidities. Methods for eliminating this trouble in some of the commonly used circuit components and new and superior insulating materials were found.

METHODS FOR REDUCING INSULATOR NOISE AND LEAKAGE
October 19, 1948

Serious insulation problems have arisen with the advent of radiation detection instruments. In certain types of detection devices such as alpha chambers, proportional counters, and electrometers having high input impedances, the necessity for good insulators cannot be overemphasized. In many instances where background noise is of sufficient amplitude to make accurate counting difficult or impossible, the spurious counts can be traced to insulator noise. However, as a result of our experience with past applications of insulators in the electronic field, engineers are prone to take the quality of insulators for granted. We carefully select the best insulating materials available, and then overlook the fact that the insulator may be made into a constant source of trouble by improper milling or molding technique. It is the intent of this article to point out some of the insulator troubles encountered and to suggest some preventive measures.

Let us consider some of the common circuit components that are a potential source of trouble as a result of poor insulation. Figure 1 shows a conventional preamplifier for use with an alpha chamber or proportional counter. In the grid circuit we note that the filter condenser, C-1, the coupling condenser, C-2, and any other supporting insulators in the chamber or cable and cable connectors are subjected to high voltage. All these components are possible noise makers, especially in the presence of high humidity.

Since the humidity is not always a controllable factor in the use of radiation detection instruments, it is necessary to provide insulators which are noise free at humidities approaching saturation.

DESCRIPTION OF TEST

In order to determine the pulse characteristic, frequency and cause of insulator noise in such circuits as Figure 2, a series of tests were made under simulated operating conditions. The equipment used in these tests consisted of an Oak Ridge National Laboratory A-1 amplifier[1] and preamplifier with a combined voltage gain of 300,000, a 5,000V power supply, a 248 DuMont oscilloscope, a Higinbotham scaler[2], a Tobe line filter, and a humidity controlled test chamber (see Figure 2). The test chamber was constructed with two compartments. One of these contained the high voltage filter in dry air to prevent surface noise on the .01 mfd. 10,000V glassmike filter condenser. The other compartment, in which the insulator under test was placed, was humidity controlled. A special noise free feed through insulator that could take 5,000V at 96% humidity was used to feed the 5,000V through the partition. A hygrometer mounted on the side of the chamber and extending through the wall made it possible to keep a constant check on the humidity. The humidity was controlled by passing dry or saturated air through two valves provided for that purpose. A small fan motor on top of

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[1] W. H. Jordan and P. R. Bell R.S.I. 18, 703 (1947)

[2] W. A. Higinbotham, J. Gallagher and M. Sands R.S.I. 18, 706 (1947)

the chamber with the shaft extending through an air-tight seal drove a small fan which thoroughly mixed the incoming air. This arrangement provided a means for testing an insulator at any given humidity, and at the same time maintained a zero count background.

It was observed that all insulator noise could be traced to one of four sources. The first and most annoying source of noise in good insulators is surface noise resulting from high humidity. When the insulator is subjected to high voltage, random pulses are produced with characteristics so nearly like those from ionization chambers, and with amplitudes of such height as to make it impossible to discriminate against them, when counting pulses of low amplitude. These pulses have a rise time of 1/5 microsecond or less, and amplitudes as high as 300 microvolts. Since shot effect and thermal noise in well designed amplifiers may be as low as 3 microvolts rms or lower, depending on band width, it is quite obvious that defective or noisy insulators may well be the determining factor in the effective sensitivity of the amplifier.

The second source of noise, although annoying, need not be a serious handicap. It is caused by a change in dielectric strain resulting from a sudden change in voltage across the insulator. This noise appears to be piezoelectric pulses resulting from discontinuity in the mechanical motion of the dielectric when seeking equilibrium. As a rule this phenomenon is more pronounced in materials of crystalline structure. However, ceramics, being comparatively free of this noise, are an exception. Only insulating materials considered suitable for radiation detection instruments were tested for this source of noise. Mica was found to produce the most pulses, while teflon, fluorothene, and polyethylene produced no pulses. This noise is relatively unimportant in any insulator if the high voltage is turned on one or two minutes before the instrument is put in use and if no sudden changes of voltage greater than 100V occur while in operation. (See Fig. 3)

The third source of noise may offer some difficulty unless a few simple precautions are taken. It is most pronounced in polystyrene or polystyrene substitutes, and results from stresses set up in machining. Annealing these materials at 65° C. for an hour or more will sufficiently relieve them of stresses set up in the machining processes. These stresses can be visually recognized by use of crossed polaroids. After the insulator has been annealed care should be exercised in mounting to prevent unnecessary mechanical strain. If these two precautions are taken the insulator will be free of noise as a result of mechanical stresses.

The fourth source of insulator noise results from leakage through the insulating material. The chief offender among frequently used insulating materials is mica-filled bakelite. This noise is not present in high grade insulating material such as polystyrene, mica, and teflon and fluorothene[3]. Since it is assumed the designer will use only good insulating materials, this article will carry no further discussion on this type of noise.

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[3]A fluoro-ethylene polymer, manufactured by Carbide and Carbon Chemicals Corporation, Oak Ridge, Tennessee.

CABLE CONNECTORS.

Cable connectors head the list of trouble makers. Many of the commercially available connectors were tested and none of them were found satisfactory for pulse work when subjected to high voltages and high humidities. The results of these tests are shown in Table 1. This table shows the average counting rate for five samples each of the connectors tested. Pulses were recorded over a period of ten minutes for each individual test. Each time the voltage was advanced, a two minute delay was made before starting the next count. This prevented the recording of counts as a result of change in dielectric strain.

As a result of these tests engineers at Amphenol, working with the O.R.N.L. developed a pulse fitting that is noise free at 5000V and 96% humidity. This cable connector has teflon insulation which can be successfully cleaned when it gets dirty. The minimum surface leakage path is ½". The shell has spring fingers for low impedance ground connections, and the center connector is designed to give corona free service. The Amphenol stock number on these connectors is #82-804 and #82-805.

COUPLING CONDENSERS

The data obtained from tests run on coupling condensers were even more discouraging than that obtained from the cable connector tests. However, the noise was eliminated without design changes. Only two of the many condensers tested showed any promise of being satisfactory. Centralab's type #850 high voltage ceramic series were by far the best condensers tested. They were found to be entirely satisfactory at low humidities but very unsatisfactory at high humidities. Table 2 shows some of the data obtained from this test. Since these condensers are noise free in dry air, a search was made for a method of surface treating the ceramic shell to make it less hygoscopic.

Silicones were discarded because the temperature necessary for baking exceeds the melting point for the soft solder used in the condenser assembly. Since it had already been demonstrated that a good polystyrene surface produced no pulses, several attempts were made to coat the ceramic shell with polystyrene. A successful method was finally worked out, and is described as follows:

1. The condenser is washed in petroleum ether, or benzene, then in 180 proof ethyl alcohol, and finally rinsed in distilled water.

2. It is then baked in a vacuum oven for about one hour at 100°C., after which time the oven is cooled to 60°C. and dry air admitted.

3. The condensers are removed from the oven and while still warm, dipped in Amphanol 912 coil dope that has been cut by adding an equal quantity of 916 thinner.

4. They are then air dried for 2 hours and baked at 60°C. for one hour. The condensers can then be soaked in water for several hours and tested at 90% humidity at 5000V and no pulsing will occur.

FILTER CONDENSERS

Another source of trouble has been filter condensers. The Glassmike, Plasticon ASG, silicon filled, made by Condenser Products Company, seems to be the most promising condenser for high voltage applications These condensers produce no pulsing internally, but give considerable trouble on the shell surface at high humidities, However, if the shell is properly cleaned, no trouble will be encountered below 3,000V at any humidity.

Alcohol alone will not do the job, as it is not a good solvent for the flux that is used in soft soldering the ends on the glass case. To properly clean these condensers, carbon tetrachloride should be used first to remove the flux. Then they should be washed thoroughly in alcohol. If voltages higher than 3,000V are used the surface can be further improved, temporarily, by applying a very thin coat of ceresin wax. This is accomplished by dissolving a piece of ceresin the size of a pea in about four ounces of benzene and dipping the condenser in the solution. The condenser will then stand 5,000V at 90% humidity without pulsing. This surface, if not protected from dust, will soon be inferior to the plain glass surface that has been well cleaned. Therefore, if voltages lower than 3,000V are used, it is strongly recommended that no ceresin be applied.

STAND-OFF INSULATORS.

At the present there are no stand-off or feed-through insulators on the market that are noise free. They should be machined from teflon, or flourothene, or molded from polystyrene, if possible. If molded from polystyrene the molds should be so constructed that the use of wax is not required for unloading the mold. The mold should have an optical finish, and be kept immaculately clean. From the standpoint of surface noise the insulator cannot be any better than any foreign materials that might be deposited on the surface. If teflon or fluorothene is used, it can be easily machined, and no polishing is required. The only precautions necessary are to use a clean cutting tool and to prevent the finished insulator from coming in contact with the hands or anything dirty or greasy. When machining and polishing polystyrene the following techniques will produce good insulators.

1. When turning on a lathe, as little chuck pressure as possible should be employed, and the stock material within one-half inch of the chuck is not considered usuable. With a milling machine one must use as little clamp pressure as possible and take only light cuts to prevent setting up mechanical stresses.

2. A sharp cutting tool that has been thoroughly cleaned with alcohol must be used. Sapphire cutting tools are recommended.

3. Polishing is done slowly with emerald or diamond powder and distilled water using a clean lint-free rag. Chamois is not used as there is always some oil present. Slow polishing speeds are required to prevent surface heating and consequent imbedding of the polishing agent. Powdered carborundum may be used with extreme care to prevent overheating. <u>Note</u>: It is almost impossible to get a pulse free surface using metallic oxide polishing agents.

4. The insulator is then polished with talc until an optically polished surface is obtained.

5. The insulator is then removed from the lathe with clean padded tongs and dropped in a container of distilled water until ready for use. The hands should never come in contact with the insulator during the milling or polishing process. Once dirty, no satisfactory method of cleaning polystyrene insulators has been found.

6. When the insulator is ready for installation it should be removed from the jar of distilled water and rinsed thoroughly in fresh distilled water and dried in a vacuum oven.

<u>Note</u>: Almost all surface leakage is a result of poor polishing technique or mishandling the insulator after it leaves the machine shop.

SELECTOR SWITCHES.

High input impedance electrometers place the same exacting demands on insulators as do the input circuits of high gain amplifiers. In addition to the circuit components already mentioned as sources of trouble, we have the problem of procuring a good selector switch for changing input resistors to the electrometer. These switches often must have a D.C. leakage resistance exceeding 10^{15} ohms at humidities as high as 90%. They must be comparatively free of contact and stress potentials. It is also often desirable that they be compact for use in portable test equipment. Efforts to obtain these switches commercially have been unsuccessful. Therefore an intensive study of the commercially available switches was made to determine the feasibility of altering or surface treating the most promising of these so that they would fulfill our needs. Centralab's ceramic series, being the most promising of the commercially available switches, was studied first. These switches were found to be very good from the standpoint of contact and stress potentials. Tests were then run on leakage resistance, and very discouraging results obtained. Tests in a humidity controlled test chamber showed the resistance to vary from 5 X 10^{14} ohms at 2% humidity to 8 X 10^{12} ohms at 90% humidity. This indicated that if the switch were properly cleaned and sealed against moisture, the insulating properties of the ceramic would be satisfactory for our present needs. Other minor changes in the switch assembly made further improvement by lengthening the shorter leakage paths. After these switches had been treated according to the following process, the leakage resistance exceeded 10^{15} ohms, and were independent of humidity.

1. The switch assembly should be removed from the indexing assembly and cleaned thoroughly with carbon tetrachloride and a stiff brush, then rinsed thoroughly in ethyl alcohol, followed by a distilled water rinse.

2. The assembly is then baked for 2 hours at 100° C. under vacuum, after which dry air should be admitted.

3. The switch is then removed from the vacuum oven and dipped while still hot in Amphenol 912 coil dope that has been thinned with two parts of Amphenol 916 thinner, agitating it until all the bubbles which form on the ceramic surface are gone. After dipping it will be necessary to sling off all excess coil dope.

4. After allowing the switch to dry for 20 minutes in clean, dust-free air, the rotor should be rotated with a clean screw driver to remove the coil dope from the contacts.

5. After the switch has dried for three additional hours the switch may be assembled using a polystyrene connecting link or shaft between the indexing assembly and the switch assembly. The metal spacers should also be replaced by spacers made from ¼" polystyrene dowels 5/8" in length, drilled and tapped for 5-40 screws. Caution: Do not drill all the way through the dowel or spacer as this provides another surface leakage path. Surfaces should be well polished. Also, the hands or anything that is greasy or dirty must not be allowed to come in contact with the ceramic insulation at any time after starting the cleaning process. Switches should be kept in dust proof containers until such time as they are used. If these instructions are followed carefully these switches will be found to have a leakage resistance exceeding 10^{15} ohms regardless of humidity. Some of these switches have been in service for eight months, and still appear to be satisfactory.

METAL-TO-GLASS SEALS

Other insulators that play an important part in many detection devices are metal-to-glass (Kovar) seals. They are often used in metallic chambers to support the center electrode. Fortunately this type of glass is free of noise if properly cleaned and installed. One successful method of cleaning is to remove all traces of flux from the surface with Zapon #5 thinner, then wash in alcohol and rinse in distilled water. If available, dry in a vacuum oven. If the chamber is to be operated with voltages exceeding 1500V, seals having a flash-over voltage rating of 13 KV or higher should be used. If these precautions are taken, no trouble should be encountered with these insulators.

CONCLUSTIONS

Insulator noise presents a difficult problem. Especially is this true when the counter voltage exceeds 1500V and the humidity is above 60%. Under such conditions the problem becomes extremely difficult when counting pulses of amplitudes less than 150 microvolts. When accurate counting at low rates is required, it should preferably be done in an air conditioned room, with a humidity not exceeding 50%. The insulators should be designed to offer a minimum surface leakage path of ½". The number of parallel leakage paths should be held to a minimum. From the standpoint of economy and performance teflon or fluorothene insulation should be used. The labor cost for machining teflon or fluorothene is about 10% of that required for machining and polishing polystyrene. These materials produce fewer pulses as a result of mechanical or dielectric strain and produce far less surface noise at high humidity. If a polystyrene insulator is accidently touched by the hand it is ruined. Teflon and flrorothene, on the other hand, may be successfully cleaned many times. Neither type of insulator should be dried by rubbing with a cloth as this charges the insulator causing it to attract dust. Only extreme care and patience will solve the insulator problem in radiation detection instruments.

The author takes this opportunity to thank Mr. P. R. Bell of O. R. N. L. for bringing to the author's attention the need for this investigation and for the many helpful suggestions which he contributed.

SAMPLE	VOLTAGE	COUNTS/MIN. AT 5% HUMIDITY	60%	90%
Amphenol 93-C & 93-M	1500	0	0	7
	3000	0	0.2	420
	5000	0	2.5	>60,000
Amphenol -P. L. 259	1500	0	0.2	420
	3000	0	64	>60,000
	5000	0	498	>60,000
Cannon Q-1-22C & Q-1-SL	1500	0	0	68
	3000	0	0	>60,000
Q-1-22C With Polystyrene insulation installed in place of original insulation	5000	0	>60,000	>60,000
Amphenol A.N. #UG-58U	1500	0	0	4,470
	3000	>60,000	>60,000	>60,000
	5000	>60,000	>60,000	>60,000
Amphenol 83-1SPY	1500	0	0	>60,000
	3000	8	8	>60,000
	5000	51	81	>60,000
Amphenol 83-1SPN with phenolic insulation	1500	50	571	704
	3000	25,600	>60,000	>60,000
	5000	>60,000	>60,000	>60,000

Table 1

Table shows pulse repetition rate of cable connectors as a function of voltage and humidity.

SAMPLE	VOLTAGE	PULSES / MIN. AT 5% HUMIDITY	60%	90%
50 uuf. Centralab ceramic not treated	1000	0	0	128
	3000	0	28	*
	5000	0	578	*
50 uuf. Centralab ceramic condenser with shell sealed	1000	0	0	0
	3000	0	0	0
	5000	0	0	0
.0001 microfarad 2500V Sangamo silver-mica condenser	500	0	1	16
	1000	0	2	8167
	1500	0	11	>60,000
	2000	6	122	>60,000
.01 microfarad 5000V Glassmike condenser	1500	0	0	0
	3000	0	0	0
	5000	0	0	1

Table 2

Table shows pulse repetition rate of condensers as a function of voltage and humidity.

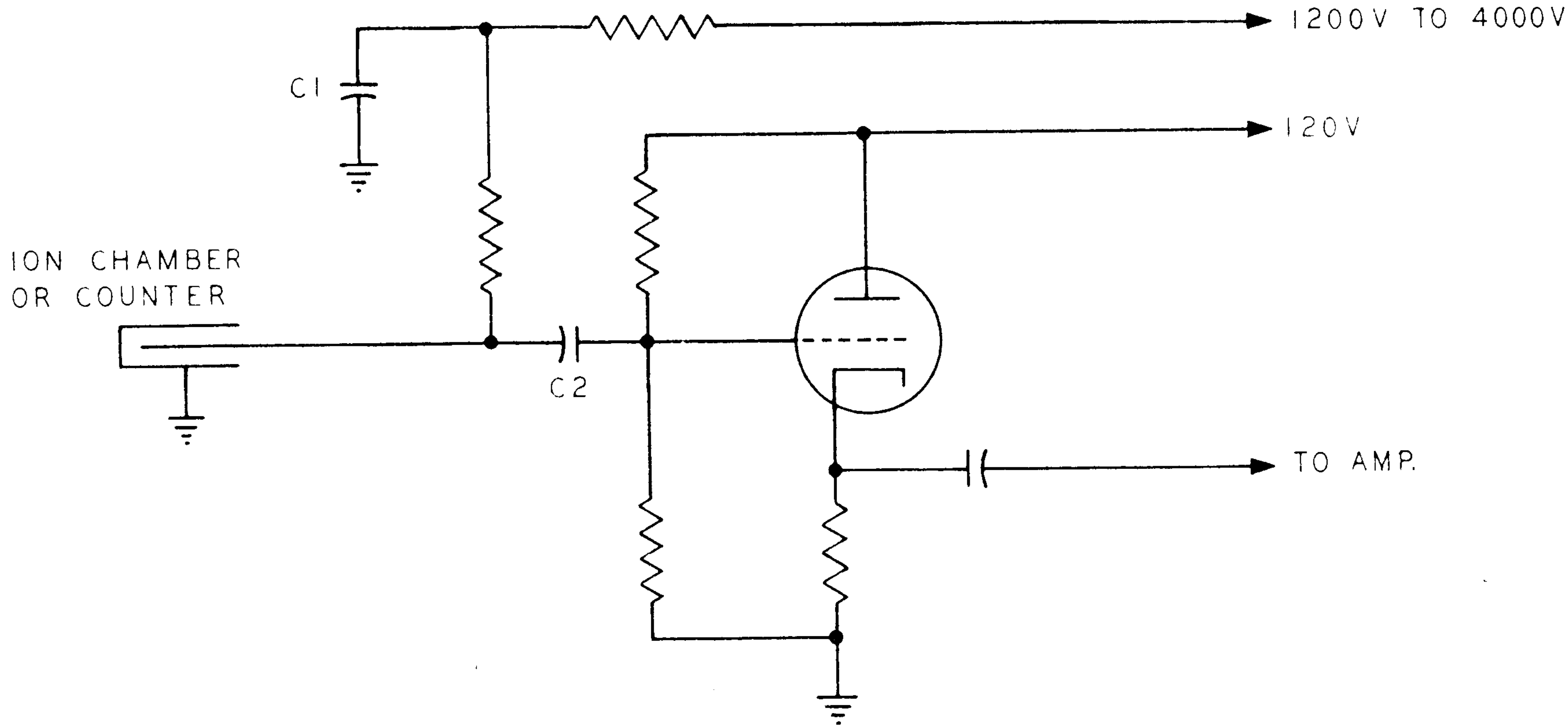

FIG. 1

CONVENTIONAL PREAMPLIFIER CIRCUIT FOR RADIATION COUNTERS

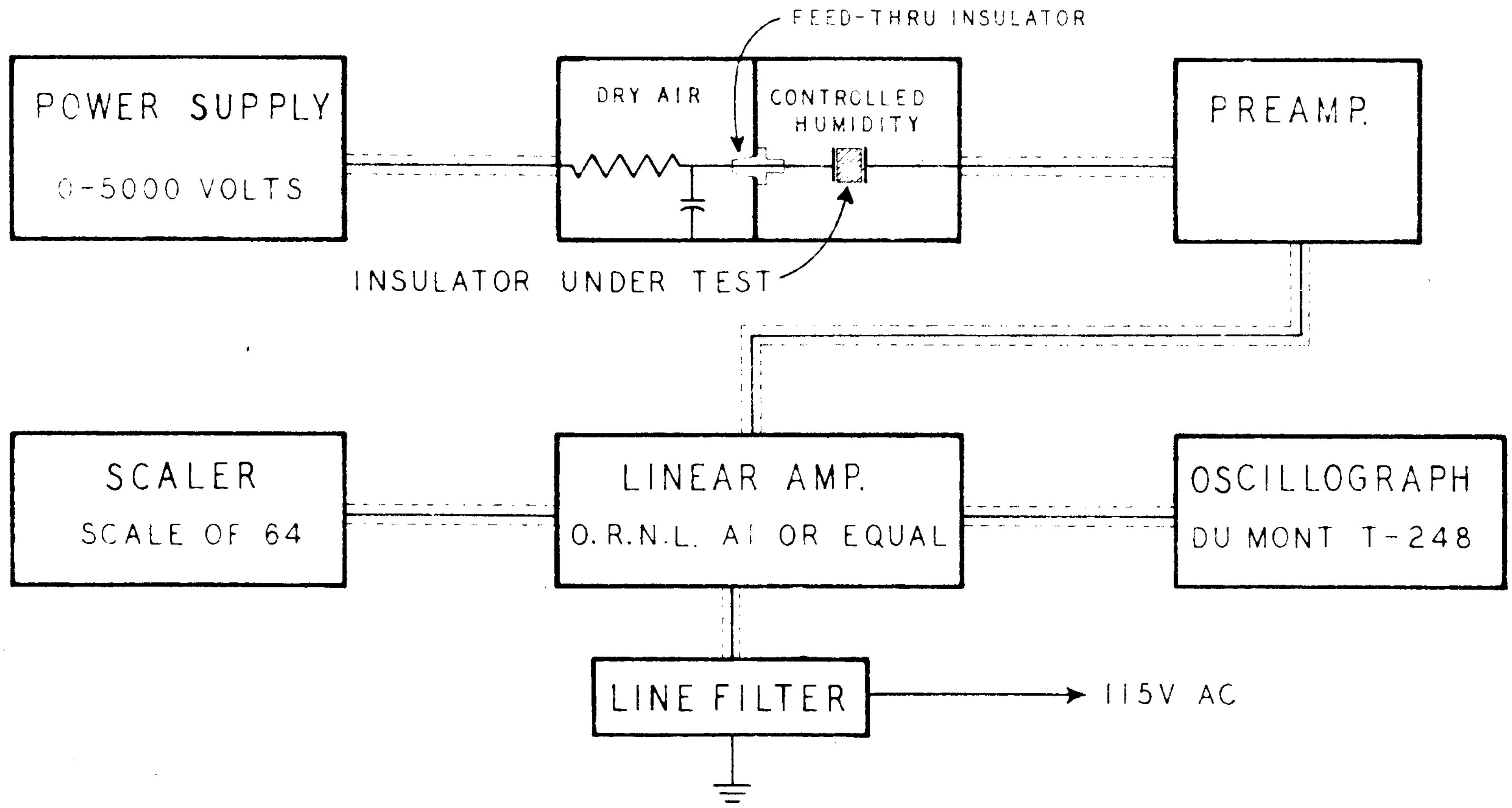

FIG. 2 - BLOCK DIAGRAM OF EQUIPMENT USED IN NOISE TESTS

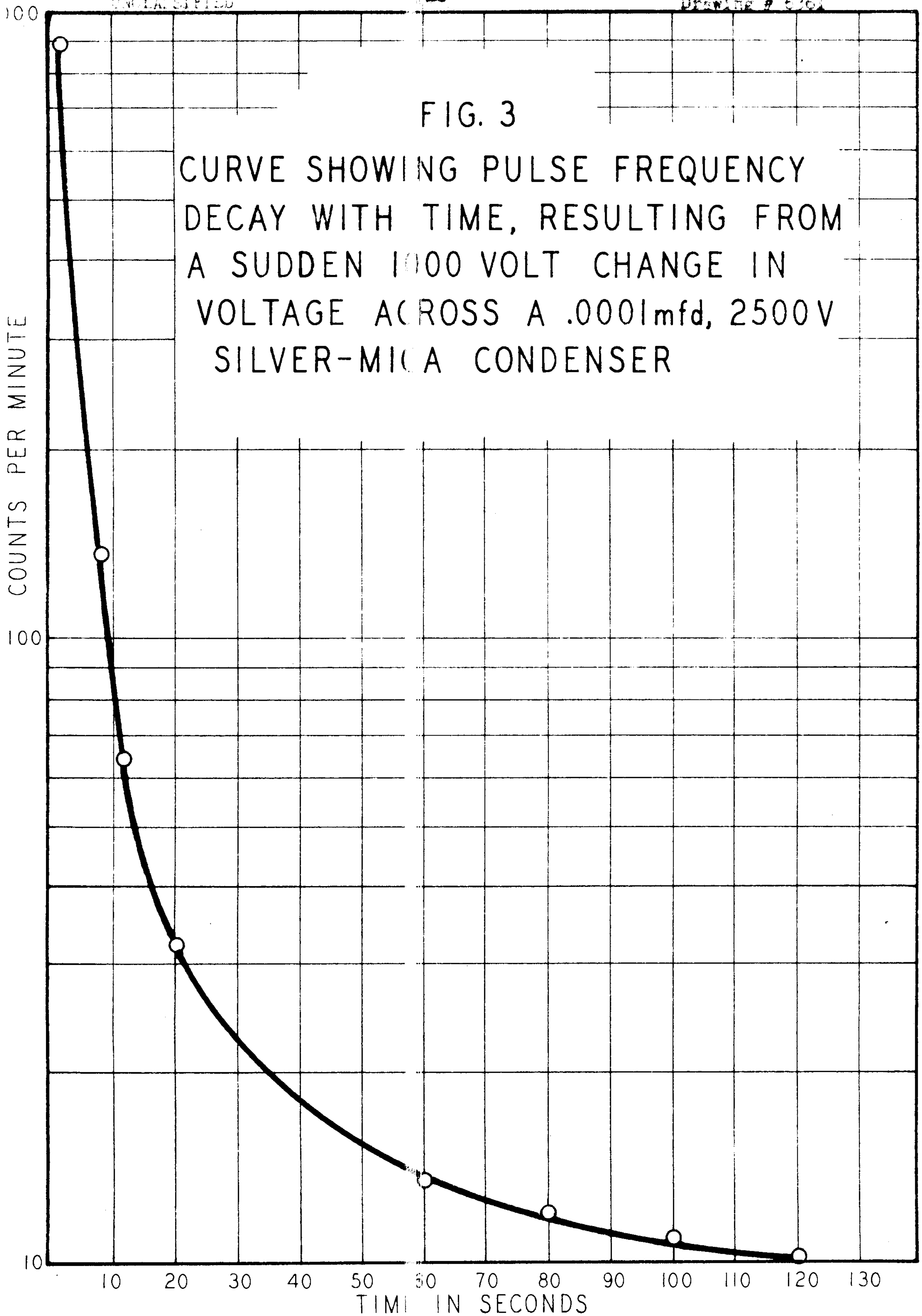

FIG. 3

CURVE SHOWING PULSE FREQUENCY DECAY WITH TIME, RESULTING FROM A SUDDEN 1000 VOLT CHANGE IN VOLTAGE ACROSS A .0001mfd, 2500V SILVER-MICA CONDENSER