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STATUS REPORT ON PHYSICS BRANCH LOW CURRENT DETECTOR PROGRAM

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BY

H. Z. REED

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GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

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Goddard Space Flight Center

Work to improve the methods and hardware used to detect currents in the range of 10^{-6} to 10^{-18} ampere was initiated about 2-1/2 years ago. At that time, the tentative approach was to construct vacuum tube electrometers of improved performance for spacecraft instrumentation. A limited survey of the literature soon gave convincing evidence that in order to construct vacuum tube electrometers of improved performance, the component parts themselves must be improved. A detailed literature review of journal articles and manufacturers sales bulletins presented a very confusing state of affairs, not by what they said, but by what was not mentioned or noted only briefly. At this point a thorough search of the technical literature was started to uncover much of the available information on methods and techniques of low current measurements used in the past as well as those currently in use.

A careful review of the literature collected revealed that many components did indeed require improvement. The following list includes most but not all the components which require improvement: high megohm resistors, electrometer tubes, flight quality vibrating capacitor modulators, solid state devices, electron multipliers, insulators, and high impedance switching devices.

The literature survey revealed the areas of greatest need permitting an orderly formulation of a research and development program the basic elements of which are as follows:

(a) A program to provide high megohm resistors, with reduced values of temperature and voltage coefficients, reduced physical dimensions, and with less polarization in values of 10^9 ohms and above.

(b) A program to improve the electrometer tubes currently being manufactured, such as 5886, 5889, 5800, 5803, VX-55, ME-1402, and ME-1403. Specifically attention was to be given to reducing the level of control grid current, reducing long term drift, and improving shock and vibration resistance.

(c) A development program to provide flight quality vibrating capacitor converters.

(d) A reading program to follow the progress of the various solid state devices that have been proposed for use in low current measurement.

(e) A low level effort to understand the basic principles of operation and deficiencies of electron multipliers and follow the current state-of-the-art.

(f) Development of accurate and convenient methods of calibration, less susceptible to error in the laboratory calibration of electrometers.

(g) Development of accurate, in-flight calibration systems which do not require the use of high megohm resistors, also to develop calibration procedures for flight instruments that would not require switching in the electrometer feedback or input circuits.

(h) Formulation of a specific program to design, build, and evaluate high impedance switching devices with low piezo-electric generated charges and with low shunt and series capacity for use in range change in flight electrometers and for multiple input devices such as the S-6 magnetic mass spectrometer.

(i) An overall program to design suitable instrumentation to test the components and complete electrometers that would flow from the development programs. Very little in the way of commercial test sets is available for the low current detector component field. All of the required test sets must be designed, breadboarded, de-bugged and built up in final form and certified for proper performance and calibration.

(j) A relatively close watch is to be maintained on the published literature to keep abreast of low current techniques in other laboratories.

A DETAILED LOOK AT THE DEVELOPMENT AREAS

ELECTROMETER TUBES

Electrometer tubes suffer from many defects in design, construction and testing. Perhaps the cause of most trouble is the low price to which they have been forced by the Office of Civil Defense and their large quantity purchases for use in portable RADIAC survey meters. Electrometer tubes inherently are a delicately balanced bundle of compromises, which can be upset by sloppy maunfacturing and testing procedures. The only electrometer tube currently in large quantity (10,000 or over annually) production is the Raytheon 5886. The design for this tube was derived from a hearing aid tube, it is not a ruggedized tube, it is not processed as a reliable tube, it was not designed for use in scientific research instruments, but due to the fact that a better tube is not now available it is used for this purpose with moderate success when all its shortcomings are noted.

First efforts to do something about the 5886 was to contact the Raytheon Company and inquire about a higher quality tube processed under controlled conditions. As a result, several sample 5886 tubes processed under controlled conditions were supplied and they did show a lower level of control grid current and increased insulation resistance.

Mr. Paul Keeler, Manager of the Industrial Products Division at Raytheon and two tube engineers visited Goddard to discuss the problem of electrometer tubes. During this visit they left a sample of a reduced size electrometer tube coded QV-220 to show what was being produced under terms of a small contract ($8K) with the Naval Research Laboratory to simply reduce the size of the 5886 and the filament power drain to 6.25 milliwatts. Mr. Paul Keeler was verbally requested to prepare a proposal for development work on electrometer tubes for a one year period. Prior to receiving this proposal, problems developed in the environmental testing of S-6 and EOGO subassemblies creating a severe problem. Raytheon supplied a quantity of the QV-220 tubes which would survive the environmental testing for S-6 and EOGO, providing a stop gap solution to this serious problem.

The first contract with Raytheon was for $29K with an extension in FY'64 of $58K and a further extension of $55K now in the process of negotiation.

A large number of experimental tubes have been designed and processed under the Raytheon contracts. All tests are given a specific number starting with W-12 and each of the tests is described briefly in Appendix A along with the purpose of the test and the results obtained. Many of these tests have not been evaluated at GSFC due to the lack of time.

The following test vehicles are at the present time being used to obtain data on electrometer tube construction, processing and testing.

QV-269

A double ended version of the CK-587 with the control grid brought out at the opposite end of the envelope from the flat press. This type of mechanical construction can ease the packaging problem and reduce the effect of normal contamination on the glass envelope insulation resistance. A small decrease in the time required for initial absorption current to fall to a steady value is noted. This version is available commercially as the CK-590.

QV-271

A very short active tube structure with a very low drain filament, rated 0.625 volts at 5.0 milliampere for a total filament power consumption of 3.25 milliwatts. Primary purpose of this tube was to determine if a tube structure of this length would be of practical value. Several further tests are planned for this structure to fully evaluate its potential as a flight type electrometer tube.

QV-290

Primary aim of the QV-290 is an attempt to retain the desirable characteristics of the 8520 electrometer tube in a version in which the change of static characteristics caused by shock and vibration are reduced to a minimum. The basic tube structure of the 8520 is retained, but utilizes mica spacers that lend themselves to roll crimping the T-3 glass envelope of the top mica spacers on the N-67 proximity fuze tube sealing-in machinery. It is hoped that many of the observed structural resonances present in the standard 8520 housed in the rectangular T - 1 × 1/2 bulb can be entirely eliminated and many others reduced in amplitude. There are several opinions as to whether this new structure will increase or decrease broadband microphonic noise output.

QV-291

An all metal envelope electrometer tube with a ceramic stem seal and internal alumina ceramic spacers for the tube element support. With this design it is hoped that it will be possible to outgas the entire tube structure and envelope at temperatures of 400-600°C and to seal off at residual pressures less than 10^{-8} torr by means of a copper pinch seal. A considerable advance in electrometer tube technology is expected from this test vehicle. Parts and materials are rapidly being assembled for a test lot early in the first quarter of 1965.

QV-292

A space charge grid electrometer tube in the FP-54 tradition in a subminiature T-3 glass envelope, but with the addition of a third grid to make it a true pentode rather than the tetrode arrangement as in the FP-54, VX-55, and ME-1402. To the best of my knowledge a true pentode space charge grid electrometer tube has not been built and evaluated. Several test lots with various changes will be built and evaluated. If the basic design does not reveal significant advantages it will be dropped.

QV-293

This is the Raytheon copy version of the German DC-760. Test lots identical as possible to the German prototypes are to be assembled and evaluated for characteristics. If the test lot characteristics duplicate the German prototype an attempt will then be made to design a ruggedized version for space flight use. The triode inverted structure offers many advantages over tetrode and pentode tubes of conventional construction. Input electrode current in the DC-760 is very low and the position of the control electrode outside of the wound anode places it in a favorable position as far as contamination due to metallic barium evaporated from the filament. The plate resistance of this tube is in the order of 5000 ohms allowing a proper impedance match to ultra low noise transistors.

QV-309

This number identifies the Raytheon copy version of the DC-762 inverted triode electrometer tube. The primary difference between the DC-760 and DC-762 is in the Mu. The program for the QV-309 is the same as that for the QV-293.

It is possible that a QV number will be assigned to the development of a nonmagnetic electrometer tube. Primary construction material for such a tube would be Nichrome V, molybdenum and tungsten.

Some work also may be undertaken to explore the possibility of a unipotential heater cathode electrometer tube for laboratory use, in which conservation of heater power is not a prime requirement.

A LOOK AT UNSOLVED PROBLEMS OF ELECTROMETER TUBES

(A) Long Term Stability

Much has been written about long term drift in a vacuum tube electrometer, but little concrete information is available concerning drift in the tube itself. No test data or reports have been located on the stability of the tubes alone. Extensive inquiries have been made of various low current workers and manufacturers of electrometer tubes as to suitable methods of testing the stability of the tube alone. Distilling all the various comments it appears that the method of placing tubes in a test circuit with super-regulated potentials and low temperature coefficient wire wound plate load resistance, and measuring the potential appearing on the plate by a differential voltmeter, appears to be the method that will generate the largest quantity of useful information.

A group of tubes were placed on such a test about 4 months ago. Results from this preliminary test have not been entirely satisfactory owing to drift in the power supplies. Power supplies of several orders of magnitude better stability have been ordered for a continuation of this particular phase of long term drift testing.

A second test is to be run by placing a group of tubes, 10-15, in a temperature chamber and evaluating the tubes for their temperature coefficient of change and also their drift properties at other than room temperature. There is absolutely no data available on these two items.

(B) Short Term Stability (10 seconds to 48 hours)

There is a very large difference in the shortest to longest interval of time considered herein. Primary reason for the shortest interval is the short warm-up time available in some satellite experiments. The longest time is required for strain induced currents to decay to insignificant values; also, a long period of time is required for trapped electrostatic charges to decay.

A very large variety of tests can be devised to check various theories for their applicability to this area of instability. Perhaps the primary test would be to determine the magnitude and decay period of dielectric absorption in the tube envelope and other necessary dielectrics. Another test under this category is the time required for the tube filament not only to reach the proper operating temperature but for the emission to become stable.

(C) Changes in Tube Characteristics During Long Term Storage

It is known that the control grid current is a decade or more higher in tubes that have been in storage for several months than tubes from the same production lot operated continuously or intermittently. The zero set point of equipment placed in inoperative storage for several months undergoes a considerable shift owing to a rather large control grid current.

Perhaps the internal tube contact potentials also change but they have not been evaluated owing to other larger changes in characteristics, such as the previously mentioned control grid current. A rather large dielectric absorption current also will be observed for a considerable period of time when a completely discharged dielectric is again placed in service.

(D) Changes in Tube Characteristics Induced by Shock and Vibration

Electrometer tubes that are relatively immune to characteristic changes induced by shock and vibration are not available at this time. In many respects the construction requirements for high shock and vibration resistance are contradictory to the requirements for low grid current and minimum dielectric absorption. Much remains to be done in this area. Tests will begin very shortly to observe the mechanical resonances in various types of tube construction. Several items to reduce shock and vibration induced changes in characteristics are now underway; such as frame grids, stiffening filament tension spring mount, use of stronger filament wire and heavier filament tension springs, all for improved tube stability. Many other items in tube construction will require attention but we must eliminate or reduce the largest sources of trouble prior to evaluating the smaller but more numerous problems.

(E) High Temperature Sterilization

The requirement for electrometer tube sterilization is something of recent origin and very few tests have been conducted to determine the effect of relatively long periods of operation or storage at 150°C.

From previous information it is thought that failure of electrometer tubes at high temperatures is caused by release of water vapor and other gases from the 0120 high lead glass envelope and mica spacers. In many test samples it has been possible to "reactivate" cathodes poisoned by high temperature exposure. It is felt that significant progress cannot be obtained until glass and mica are eliminated from the tube structure and envelope.

At the time when metal envelope electrometer tubes using 99 plus aluminum oxide as insulation become available it will then be possible to pinpoint other possible sources of contamination which poison filamentary cathodes.

(F) Uniformity of Electrometer Tubes

It has been a characteristic of all electrometer tubes produced to this time that they differed widely in their operating characteristics from one sample to another. There are many possible causes for this behavior, many of which can be brought under control by the manufacturer's paying attention to the various manufacturing operations, seeing that all raw materials and processes are handled in an identical approved manner every day. Preparation and handling of component parts, length of time tube mounts are held after assembly prior to sealing-in and exhaust can cause wide variations in even a single lot of tubes. There are several areas in which new design techniques can contribute to tube uniformity, one example is frame grids for the presently easily deformed and damaged wound grid structure. By using frame grids it should be possible to improve tube uniformity.

Getter flashing as performed at the present time is thought to cause considerable variation in tube characteristics, due to the fact that barium metal is evaporated and deposits over the entire interior of the tube envelope and mount structure changing the effective work function of all the tube elements. Getter flashing is not a well controlled process, the amount of RF energy coupled into the getter pellet will determine the temperature of flash as well as the velocity with which it is expelled from the retainer cup which results in very large variations in the distribution of the barium flash within the vacuum envelope.

The so-called "Hot Shot" activation of the filamentary cathode also is believed to be a large source of variation in tube characteristics due to the fact that barium metal and possibly other metals and oxides are evaporated and are then deposited nonuniformly over the tube structure, changing the work functions of the various metal surfaces and reducing the insulation resistances.

Both items can be brought under control by proper attention to tube design and using improved tube processing technique.

(G) High Level of Microphonic Output

At the first glance, the requirements for a ruggedized tube structure to reduce microphonic noise output appear to be contradictory to the requirements for premium electrical performance as an electrometer tube.

A reduction of microphonic noise cannot be achieved by present tube assembly design and assembly techniques. New methods of fabrication and support of tube structural elements must be developed if this problem is to be brought under control.

The problem of filament resonance will still be present if all other sources of microphonic output are completely eliminated. But by using a short structure and a heavy filament tension spring the resonance can be placed somewhere between 8 to 11 kilocycles. There is no known practical method of reducing filament resonant "Q" at the present time. Filaments display "Q" values ranging from 10,000 to 100,000. This wide range of "Q" values can be reduced to a much narrower value by attention to assembly procedures.

(H) Reduction of Absorption Currents in Tube Dielectrics

A reduction in the magnitude of the troublesome long duration absorption and desorption of electric charges in the structural insulation of electrometer tubes can be achieved if proper attention is given to the voltage stress placed on the insulation present in the control grid or control electrode circuit.

The German DC-760 and DC-762 are examples of electrometer tube design in which this very important parameter received attention and a considerable reduction in dielectric absorption was achieved

(I) Piezoelectric Output from Strained Input Circuit Insulation

A reduction in piezoelectric generated charges within electrometer tubes can be achieved by proper attention to the selection and application of methods to secure input circuit insulators so as to not apply undue amounts of strain. Strain can be placed on insulators by improper tolerance, mismatch in the thermal coefficients of expansion and improper stress relief of brazed ceramic metal assemblies. It must be mentioned that trouble from piezoelectric charges do not become appreciable until attempts are made to measure currents less than 10^{-13} ampere. Glazed ceramic insulators are particularly bad as sources of piezoelectric potentials.

(J) Control Grid Current Cross-over Voltage

This parameter has been mentioned often in the review of the current tests underway at GSFC and Raytheon. Primary benefit from a change in the cross-over point from near 1.7 - 1.8 volts at present in the 5886 CK-587 to 1.0 or 1.1 volts is a much larger plate current for a given cathode temperature. A further consideration is that a greater difference would then exist in the voltage between the negative bias and the cross-over voltage; this will cause a reduction of the initial current portion of the total control grid current at the normal bias point of 2.00 volts.

How to move the cross-over point is the subject of considerable debate at the present time. Several new tests are being prepared to check several different approaches to moving the cross-over voltage to 1.0 or 1.1 volts.

(K) Stabilization of Input Impedance at Resistance Values in Excess of 10^{16} Ohms

Stabilization of input electrode insulation resistance is perhaps one of the most difficult items to control in electrometer measurements. Building a tube to exhibit 10^{16} - 10^{17} ohms insulation resistance is difficult but possible, even in commercial manufacture. The environment in which tubes are placed by the user completely determines the effective insulation resistance. Other than reactive silicone coatings applied to the glass, nothing can be done in production to help the user when the tube is completely immersed in a dirty and moist environment.

(L) Response of Electrometer Tubes to Energetic Particle Radiation

The response of electrometer tubes to energetic particle radiation apparently has not received the amount of study that has been devoted to other problems inherent in the measurement of low currents utilizing electrometer tubes. Very little information on the subject has been published in the technical journals. A large amount of information perhaps is available in the various Atomic Energy Commission Laboratories, but the problem of locating and identifying the particular tests performed and under what conditions appears to be a formidable long term task. It would therefore appear to be prudent to devise and run tests according to the expected radiation environment of space.

(M) Thermoelectric Couples in Tube Structure as a Possible Cause of Zero Drift

Electrometer tubes of current manufacture are assembled from a large variety of pure metals and alloys in a rather confusing variety of metal to metal welds. In electrometer tubes at very low electrode potentials thermoelectric junctions can perhaps generate sufficiently large potentials when the temperature varies to cause offset from the desired operating point.

Nothing is known at the present time concerning the various possible junctions, their distribution in the tube structure or differences in their operating temperatures.

When many other larger sources of offset and drift are brought under control, a study of thermoelectric junctions in the electrometer tube structure should lead to a further reduction in zero offset and drift.

(N) Distribution of Thermal Energy from Tube Filament

A detailed knowledge of the thermal distribution of energy along the length of the filamentary cathode of electrometer tubes is not presently available. The electrometer filamentary cathodes operate at a sufficiently low temperature to place their radiation beyond the region visible to the human eye, therefore, a study of temperature variations are not possible with the optical pyrometer which is used extensively throughout the electron tube industry. New methods and equipment are needed to properly design and control the many parameters that are responsible for optimum filamentary cathode operation.

Infrared radiometers focusing on areas less than 0.0001 inch in diameter or less are needed to adequately define the temperature distribution accurately. Also studies of pictures obtained by use of long wavelength infrared film will add a great deal to our knowledge of temperature distribution along the filament and also of the supporting insulation.

(O) Electrostatic Shielding

With the all metal envelope tube design now being pursued a large part of this problem will be taken care of. With the currently available glass envelope electrometer tubes methods of shielding are still a problem.

Many of the methods currently in use introduce various other problems such as movement of the metal shield causing unwanted noise. Methods of applying electrostatic shields by dipping, spraying or vacuum evaporation must be investigated to provide shields as an integral part of the vacuum envelope.

(P) Magnetic Shielding

Electrometer tubes change their characteristics when immersed in a moderate to strong magnetic field. If the field is constant with time proper adjustments can usually be made to compensate for offsets. A changing magnetic field generates a replica of itself in the tube output circuit. Electrometer tubes operated in a magnetic field can and do generate excess noise, therefore, investigation should be undertaken to determine the magnitude and frequency distribution of such noise.

(Q) Optical Shielding

Radiation over a wide band of frequencies in the optical and adjacent regions cause unwanted offsets and excessively high and variable control grid currents. Construction methods and materials must be developed to shield the active tube structure from stray radiation in the band extending from 2000 to 25000 Å.

(R) Obtaining and Maintaining UHV Conditions in the Electrometer Tube Envelope

Obtaining and maintaining clean UHV in the electrometer tube envelope is the number one problem of electrometer tubes at the present time. Many of the present problems of variability from one tube structure to the next along with the greater portion of observed drifts should disappear when we can process electrometer tubes at high temperatures which will free the active elements of their absorbed films of the organic contaminants responsible for the large temperature coefficients of work function of the metal structural elements.

Grid currents due to ions and contaminated insulation within the envelope should virtually disappear under the UHV processing. Maintaining a UHV condition within the electrometer tube envelope will require considerable work as the presently available getters do not operate efficiently for most gases at the low cathode temperatures mandatory for electrometer tubes. Perhaps a miniature Titanium sublimation pump can be built into the tube to remove the last traces of gas after pinch off and the gases evolved during use. Also UHV conditions cannot be obtained in electrometer tubes using soft glass (0120) envelopes and mica, spacers, therefore, ceramic seals, ceramic spacers, and a metal envelope are necessary for UHV electrometer tubes.

(S) Reduction of 1/f and/or Flicker Noise

Many measurements of the 1/f noise component have been made on standard receiving tubes, but only one or two articles have appeared in the technical journals in 20 years concerning this problem in electrometer tubes.

A program to measure the specific noise generated by different electrometer tube designs incorporating different types of cathode construction can perhaps lead to a reduction in excess noise from this source.

(T) Problems in Mounting Electrometer Tubes

The fact that electrometer tubes must somehow be mounted in instruments whether laboratory or spacecraft, receives very little attention at the design or manufacturing level at the present time. In the future, thought and action must be given to the mounting problem to permit electrometer tubes to survive severe environmental testing.

(U) Trapped Charges on Glass Envelopes

Glass envelope electrometer tubes at the present time are treated with reactive chloro-silanes, which react with the silicon in the glass displacing the tightly bound surface moisture and creating a highly water repellant surface on the glass envelope, resulting in a higher and more stable insulation resistance of the control grid under most environmental conditions.

The reactive chloro-silane treatments have been applied and used for a period of over 10 years. Recent tests have shown that an undesirable reaction occurs when tubes are handled in a routine cautious manner, it appears that electrostatic charges of several hundred volts are trapped on the water repellant surface layer. The trapped charge results in a temporary change in the tube characteristics. This is referred to as a temporary change in characteristics since it is reversible by raising the ambient temperature or exposing the treated envelope to ultraviolet light of moderate intensity. If the trapped charge is not released by one of the above methods it can and does persist for many hours and several days leaking off at a very irregular rate causing noise and offsets.

Investigations should be undertaken to evaluate other reactive chloro-silanes of various chain lengths and perhaps the fluoro-silanes as potential water repellant surfaces which might not trap electrostatic charges.

Preliminary tests have not shown much promise. Materials with less charge retention are less efficient as water repellants.

HIGH MEGOHM RESISTORS

High value resistors for use in low current measurements have from the very beginning been unstable, troublesome devices. At the time low current detector research and development work started at Goddard, only two domestic companies were in the business of supplying, "precision", resistors in values greater than 1000 megohms: Resistance Products Company, Harrisburg, Pa. and Victoreen Instrument Company, Cleveland, Ohio, with Victoreen supplying approximately 90% of all so-called "precision" resistors in values above 1000 megohms. A third supplier placed a resistor on the market early in 1964—Pyrofilm Resistor Company, Cedar Knolls, New Jersey.

Conversations two years ago with Mr. Donald O. Ward, Victoreen Applications Engineer, left the impression that Victoreen believed that they were manufacturing as good a resistor as the present state-of-the-art permitted. My recent visit to the Victoreen plant again confirmed this view.

A contract was negotiated with the Physical Science Laboratory of Melpar, Inc. to explore a technique for depositing rhenium metal films over evaporated dielectric films on quartz substrates which were thought to increase the total ohms per square without destroying the low temperature coefficient or its ohmic properties. This work was to be an extension of work carried on by Dr. Charles Feldman at the University of Paris, from 1950-1955.

The net result of this one year contract for $29K can be summed up as follows: A dielectric layer, rough on the atomic scale, does increase the ohms per square by a factor of 5 to approximately 25; from Dr. Feldman's previous work using platinum it was thought that ratios as great as 10^3 or 10^4 were possible without destroying the low temperature coefficient and ohmic behavior of the metal films deposited on a dielectric, rough on the atomic scale. The dielectric films used in this work were magnesium fluoride and calcium fluoride, with primary emphasis on the calcium fluoride. Rhenium thin films deposited over calcium fluoride react at room temperature giving rise to a drift in resistance value with time.

This technique holds promise of a low temperature and voltage coefficient resistor if a dielectric layer of the proper crystalline structure and stability coupled with high insulation resistance can be found or formulated for this specific purpose.

As a long term research project it should be continued at an educational institution. This could be carried out on a rather low level of funding.

Problem Areas High Megohm Resistors

Many problems exist in the measurement and use of high megohm resistors. Some of the problems have been mentioned previously but will now be discussed in greater detail.

Voltage Coefficient

All of the presently available high megohm resistors suffer from this non-ohmic behavior to a greater or lesser degree. Measurement of voltage coefficient is usually made at 20 and 120 volts impressed on the resistor under test and the result computed as a percentage change per volt. This choice of test voltages is above the range in which most electrometer input and feedback resistors operate. At the present time little if anything is known about the non-ohmic behavior of high megohm resistors in the 10 millivolt to 10 volt range. Test methods and equipment must be designed, breadboarded, debugged and built up as standard test sets of high accuracy, to obtain this information.

There is some indication that the voltage coefficient changes with time but data to support this is not available.

Temperature Coefficient

All presently available high megohm resistors have relatively large temperature coefficients. Pyrofilm type HR-1250 high megohm resistors have a temperature coefficient of 5000 parts per million per degree C or 0.5% per degree C, this value of temperature coefficient holds for all values of resistors from 10^9 to 10^{15} ohms and apparently shows little variation from one resistor to another. The Victoreen RX-1 high megohm resistor shows quite different behavior in that the magnitude of the temperature coefficient changes from one resistance decade to the next and individual resistors show wide variations in their temperature coefficients even at temperatures near 26°C. Type RX-1 resistors display a negative temperature coefficient of resistance at the maximum storage and use temperature of 100°C, ranging from 2 to 8 percent below their 26°C values. Such changes are to be found in a large percentage of RX-1 resistors manufactured.

Temperatures coefficient of resistance cannot be read from the "average" temperature coefficient curves published by Victoreen. Every resistor manufactured is different and must be measured if high accuracy data are required.

A further complication in the RX-1 temperature coefficient curve is that at temperatures below 26°C it undergoes a rather sharp break in the percentage change per degree centigrade, so that at minus 10° C positive increases in resistance of 5 to 10 percent above the 26°C resistance are rather common.

Measurement of the temperature coefficient of resistance above 26°C is time consuming but can be accomplished without major problems. Below 0°C all sorts of problems are encountered in the measurement. To obtain reliable data is a very time consuming operation. Because of the time and problems involved in measuring high megohm resistors below room temperature, very few measurements have been made that can be accepted as reliable and of reasonable accuracy.

Temperature Range

Victoreen type RX-1 high megohm resistors are limited to a maximum storage and use temperature of 100°C. Storage or operational temperatures in excess of 100°C will result in changes of the resistance value, temperature coefficient and voltage coefficient. A rather large change in resistance value will be accompanied by a long term uncontrolled drift of an unpredictable duration. This behavior places a severe limitation on several scientific experiments which are required to be sterilized at temperatures of 145°C for 36 hours on several separate occasions, the last just prior to launch.

The Pyrofilm Resistor Company type RH-1250 high megohm resistor can be exposed to 150°C for extended periods of time, with little or no change in resistance value, according to data generated by the manufacturer. It must be kept in mind that this particular model resistor has a very large temperature coefficient of resistance, 5000 parts per million or 0.5% per degree centigrade. This large temperature coefficient could be a problem in many experiments.

No data is available on changes in temperature or voltage coefficient or drift characteristics of HR-1250 resistors stored or used at 150°C.

Shock and Vibration Resistance

The Victoreen and Pyrofilm glass encapsulated high megohm resistors as now manufactured are of a marginal design when used in applications subjecting them to relatively high levels of shock and vibration. Much work remains to be done to improve the shock and vibration characteristics without destroying the basic electrical characteristics.

Long Term Stability

Victoreen type RX-1 high megohm resistors are not stable with time. As a general rule this type of resistor will drift to lower resistance values at a rate of between 1 and 2 percent per year for an indefinite length of time. This is a general rule, occasionally a maverick resistor will be found that does not drift or if it does at a very slow rate, but they are very rare.

Pyrofilm type HR-1250 high megohm resistors have been available only 1 or 2 years and no data exists on which to base a reliable drift figure. Data taken by Pyrofilm shows very low drift rates over a period of 2 years.

Excess and 1/f Noise

All electrometers using high value resistors are limited in sensitivity by 1/f excess noise and/or Johnson noise generated in the resistor. Therefore, measurement and control of this particular item should receive considerable attention, but it has received very little in the way of methods to measure and sort out those resistors with excessive amounts of noise. The only method I have been able to uncover is that of installing it in your "pet" electrometer of unknown bandwidth and measuring the noise output on a RMS indicating vacuum tube voltmeter; such voltmeters usually have a low frequency cutoff in the range of 15 to 50 cycles and therefore do not measure the larger 1/f component near DC. A better method is sometimes used, that of viewing the output of the electrometer on a direct coupled oscilloscope.

Test sets should be designed, debugged and built up to compare the performance of resistors.

Dielectric Polarization

Dielectric polarization of high megohm resistors becomes significant at values of greater than 10^{10} ohms. Polarization can be mistaken for short term electrometer tube drift or dielectric absorption and suspected changes of the input insulation resistance if its specific effect is not clearly understood. Considerable work needs to be done to evaluate its contribution to electrometer short term drift and instability. When this phenomena is better understood by low current researchers and its specific effects in high megohm resistors determined, perhaps methods can be devised to reduce it to an insignificant value.

Resistor Measurements

All measurements on high megohm resistors, such as voltage and temperature coefficient and absolute resistance value are time-consuming operations, requiring a large investment in test sets, standards, and mechanically refrigerated environmental test chambers. CO_2 cooled environmental test chambers are absolutely useless due to the large amount of water contained in commercially bottled CO_2 which freezes on the resistor body and insulator surfaces and changes the measured resistance value. A side effect is that the growing ice crystals add a large erratic noise component making it almost impossible to determine null points accurately.

Resistor Low Frequency Complex Impedance

At the present time there are no commercially available impedance bridges for use in the frequency range of .001 to 200 cycles per second covering the impedance range of 10^7 to 10^{15} ohms. Such a bridge was built at the National Bureau of Standards and was very successful. To evaluate the complex impedance of high megohm resistors it will be necessary to construct and calibrate such a bridge. This is not a simple task but one requiring considerable knowledge, skill and equipment.

Water Repellant Treatment of Glass Housing

All high megohm resistor glass surfaces receive a water repellant treatment prior to shipment to the customer. Present water repellant treatments are all based on some form of treatment using methyldichlorosilane. This treatment provides a durable water repellant surface of high electrical resistance, but the surface silicone film becomes charged by handling and this electrostatic charge can be retained for an indefinite period, in some cases, several days. It may be possible to obtain a moisture repellant film which does not exhibit this electrostatic charge storage effect.

The Effect of Energetic Particle Radiation on the Characteristics of High Megohm Resistors

To the best of my knowledge no data exists as to any possible temporary or permanent change in resistance value caused by exposure to energetic particle radiation. There is possibly such data buried in the mountains of data generated by the Atomic Energy Commission but I have not been able to find even a single journal reference to any such test data. Until such data is available high megohm resistors must be used with caution in experiments orbiting in or traversing the Van Allen belts. The primary reason for such a view is that the "binder" in the Victoreen RX-1 resistors is of an organic nature and subject to damage by energetic particle radiation. It must be remembered that thermal radiation also degrades this organic binder resulting in significant changes in resistance. Planning for such tests should be started very soon so that test results can be made available at a early date.

VIBRATING CAPACITOR MODULATED ELECTROMETERS

The program for development of a flight quality capacity modulated electrometer started in early 1961. During a visit to the Applied Physics Corporation, Monrovia, California, I was informed of a proprietary experimental 5 kilocycle capacity modulator that was being developed as a company research project.

I requested the company to quote on a breadboard electrometer which would incorporate the 5 kilocycle converter. Sensitivity of this electrometer was to be 5×10^{-16} ampere, with a time constant of 1 second full scale, weight of components not to exceed 1000 grams and a power consumption of less than 1.0 watt. The breadboard did meet the specifications, and, in some cases, exceeded the performance requirements.

Several frustrating months were spent trying to negotiate a contract with Applied Physics Corporation to develop 5 flight model electrometers based on the first breadboard model. A fixed price contract of $66K was awarded to Applied Physics in October 1963 with delivery to be completed in 300 days.

Three flight type electrometers have been delivered and laboratory testing is proceeding at a rather slow pace, due primarily to the length of time required to get special adapters designed.

Preliminary tests show excellent stability, accuracy and acceptably low power consumption. One feature of the design is that the +18 volt and -18 volts required for operation need not be regulated to better than ±2.0 volts, such variations do not degrade the performance or accuracy. Two separate outputs are provided thru small operational amplifiers. One output is 0-5 volts from one amplifier which serves as an isolation stage with a gain of one. The other output amplifier also serves as an isolation amplifier and is set for a gain 50, to expand the 0 to 50 millivolt output, so that low resolution PCM telemetry systems can telemeter this portion of the electrometer output.

Total expenditures to date on the program at Applied Physics is $71K.

It is my personal opinion that this unit could be subjected to the 36 hours at 145°C for 3 to 6 cycles required for thermal sterilization and still provide accurate and reliable performance in the range to 1×10^{-15} ampere. However, no tests have been run, nor are any scheduled in the near future unless an urgent need arises.

A request has been made for Applied Physics to look into follow-on work to the present 5 units, but with several specific improvements as follows:

(A) Reduce overall volume to one half the present 70 cubic inches.

(B) Provide automatic range change.

(C) Provide digital output to telemetry with provision to identify range in use.

(D) Improve the performance of the present standardize circuits (the electrical rezero).

(E) Provide in-flight calibrations not requiring switching in the input or feedback circuits operating at high impedance levels. Such calibrations should not use high megohm resistors.

(F) Look into increasing bandwidth to 50-100 cycles at 10^{-13} ampere and thereby sacrificing minimum detectable signals.

(G) Reduce the total amount of high permeability material in the entire circuit including the capacity modulator.

Funds to pursue this phase of the work at Applied Physics are not available in the low current detector budget for FY'65.

The vibrating capacitor electrometer offers very high accuracy and stability, with moderate frequency response. I believe that this work should be pursued at an accelerated pace for upcoming experiments being designed to refine our present knowledge of the earth and planets.

Goddard Space Flight Center should also sponsor development of capacity modulated converters outside of Applied Physics Corporation, this because Applied Physics insist that they retain all patent rights to research findings, and their reluctance to move at an accelerated pace as is required in space hardware development. At Phillips in Holland the recent development of a capacity modulator built entirely of glass appears to be a very profitable line of research to follow. From Phillips preliminary reports, it appears that they are coming very close to achieving close control of the temperature coefficient of the contact potential as a source of drift. Perhaps a development could be undertaken by a company with optical facilities and instrument production capabilities such as Texas Instruments.

I believe that a contract should be negotiated as early as possible in FY'65 to obtain sample converters for testing not later than January or February 1966.

Preliminary work on wideband capacity modulated electrometers indicate that it may be possible to build electrometers limited in sensitivity only by the 1/f and Johnson noise originating in the input resistors. Offsets and drifts as low as 10-15 microvolts per degree centigrade appear within reason.

SOLID STATE DEVICES

The first solid state device used for electrometers was the unipolar or field effect transistor. Field effect devices exhibit input gate leakage currents in the range 10^{-11} to 10^{-12} ampere at 20°C which is very sensitive to temperature. Commercial field effect transistors are processed for purposes other than electrometers, therefore, the performance is spotty and variable. Some groups report glowing success and others complete failure. This device is degraded very little by energetic particle radiation.

Parametric diodes as choppers and modulators have been used to some extent but do not provide response to direct current inputs. Junction leakage of 10^{-11} to 10^{-12} ampere at 20°C limits the useful measurement range of such devices.

Metal oxide semiconductor devices have been fabricated with very high input insulation resistance, by several groups and some success has been reported as electrometer input devices. A very serious limitation is their sensitivity to burn out by static charges in normal handling, and spikes of 10 to 15 volts at the input to electrometers using such devices usually will destroy the device.

Several metal oxide semiconductor transistors have become available during the last year. They are fabricated using N or P channels with depletion and enhancement modes of operation. Units are currently being fabricated using germanium, silicon, gallium arsenide, or cadmium sulphide. In the case of polycrystalline cadmium sulphide I believe it was used as a low energy electron detector in the S-46, therefore, it could possibly be very sensitive to Van Allen belt particles generating pulse type noise. The present state-of-the-art on MOS transistors is such that the performance is very erratic with shorts and many cases of long term drift when DC potentials are applied for extended periods of time.

Test data obtained by Roland Van Allen at Goddard using the Cobalt-60 gamma source show considerable change in device characteristics. Such changes can be tolerated in computer flip-flops but result in very large shifts in the operating points of DC analog electrometers.

Burn out due to normal handling procedures is a problem in the MOS transistor. Spike noise at the input of the MOS electrometer very frequently cause burn-out rendering the electrometer useless.

Excess noise also is a problem with MOS transistors currently available. It is reported to be 20 to 26 DB higher than that generated by standard electrometer tubes.

Further development work can possibly reduce the burnout problem and improve the noise figure, but money must be made available to channel the development effort toward a high quality analog device with stage gains of 2 to 10. Present research is pointed strictly at the digital computer market with its loose tolerances and low cost per device as the paramount aim.

I would recommend that GSFC sponsor development of a high quality MOS analog device in FY'66.

AREAS FOR FUTURE CONSIDERATION

ELECTRON MULTIPLIERS

I believe we should not ignore the capabilities of the electron multiplier in particular situations where very fast response at very low current levels is required by the physics of the proposed experiment. The use of the electron multiplier is limited to experiments in which a beam of particles can be arranged to impinge upon the first dynode of the multiplier string. However, these are the very experiments that require very fast response at very low current levels to operate at high efficiency and accuracy in data collection.

Low Current Calibration of Detectors

A program to develop more accurate electrometer calibration techniques has been foremost and is now bearing fruit. The long-in-use method of a battery and high megohm resistor perhaps was adequate 5 years ago but is less acceptable today and certainly will not be adequate in the future. Generation of long linear ramp voltages of accurately known dv/dt are possible. By using such ramps and 3-terminal guarded air dielectric capacitors, electrometers can be calibrated from 10^{-8} to 10^{-15} ampere to an accuracy of better than $\pm 1/2\%$ or perhaps with sufficient attention to detail to $\pm 1/4\%$ of absolute value.

The 3-terminal guarded air dielectric capacitors developed for use in current calibration also can be used to determine the frequency response of electrometers. This method makes use of a variable frequency triangular wave applied to the electrometer input by using a guarded air dielectric capacitor to integrate the triangular wave into a square wave input to the electrometer. Common capacitors frequently used for this purpose have leakage currents as large as 10^{-13} ampere. Dielectric absorption and polarization effects become a large portion of the calibration signal at 10^{-12} to 10^{-15} ampere level.

Excess Noise Measurement in Resistors

Methods to measure the 1/f excess noise in high megohm resistors are not now available. The only method is to install a resistor in some wideband electrometer and check to see if it generates more or less noise than some reference resistors. This is a most unsatisfactory procedure as resistor noise changes with time. A procedure to measure noise using a wideband sensitive capacity modulated electrometer with a very large feedback factor is the most promising method at the present time.

Accurate Determination of High Megohm Resistor Values

Measurement of resistor absolute value at 10^{12} ohms is still not better than 0.25% even at the National Bureau of Standards. Something must be done to improve this deplorable situation. Victoreen Instrument Company, engineering personnel do not believe that their standards and measurement methods are better than ±1.0% of absolute values at 10^{12} ohms.

In-flight Calibration of Electrometers

If we are to be certain of our in-flight data from low current detectors, accurate reliable methods must be found to insert currents of high accuracy into our flight electrometers on each current measurement range. The most common method is to use another high megohm resistor in series with a "known" voltage to derive a "standard calibration current" to be switched into the electrometer input. This method suffers from many defects.

(1) Change of calibration resistor value with time.

(2) Calibration resistor temperature coefficient.

(3) Change of input resistance of the electrometer by the switching devices used to apply the "known" voltage to the electrometer input can and does degrade overall system accuracy and performance.

Small ramp generators with 1.0 or 10 pf coupling capacitors permanently connected to the electrometer input can provide very accurate low level currents for calibration in the range of 10^{-10} to 10^{-15} ampere. This is possible because the input coupling capacities, if properly designed, will present insulation resistances of over 10^{16} ohms to the electrometer input circuit. All switching in a ramp calibration system can be by conventional relays or silicon controlled switches, in the low impedance portion of the circuit.

Radioactive ionization chambers of about one cubic inch in volume are under development as current calibration sources. Tritium adsorbed on tantalum provides an alpha source of long half life and a minimum amount of statistical noise in the output calibration current.

HIGH IMPEDANCE SWITCHING

Transfer switches for use in high impedance systems are needed which do not generate excess piezoelectric charges when the insulation is mechanically strained or by thermally induced strain due to difference in the coefficients of expansion of metals, glass, or high polymers used for insulation. TEFLON is a particular bad actor in the generation of piezoelectric charges due to the fact that TEFLON undergoes a crystalline phase change just above room temperature at 26°C. A TEFLON insulator confined in a metal chassis mount keeps itself pumped up to a very erratic current in the 10^{-13} - 10^{-15} ampere region just by normal changes in the room ambient temperature.

In very low level measurements at less than 1×10^{-14} ampere charges generated by separation of charged contacts during switching, the so-called charge transfer becomes a problem.

There is a need for switching systems with a minimum amount of insulation to be strained and absorb charges which are released in a very erratic manner over extended periods of time. In high resistivity insulators such effects persist for several hours, sometimes even longer.

Laboratory Test Sets

Due to the nature of the low current detector program a great variety of test sets have been designed, breadboarded, debugged and proper parts and materials ordered so that stable reliable test sets can be built to perform measurements on the various components under development.

In most cases commercial instruments of the highest possible accuracy have been purchased to be certain that progress is being achieved. Gains in the stability and accuracy of components are measured in fractions of one percent for each modification or change in processing methods.

Literature Survey

A continuous search of the literature is a must if the low current detector program is to take advantage of recent developments in low current detection technique at other laboratories. Publication of a bibliography of electrometer low current technical articles would be of great benefit to all workers in the low current field.

APPENDIX A

SUMMARY OF THE VARIOUS TESTS UNDERWAY AT RAYTHEON AS OF JANUARY 1, 1965

W-12 Dumet leads only sealed in the regular CK-587 envelope of 0120 high lead glass and exhausted and sealed without a getter.
Purpose: To determine the magnitude and duration of the dielectric absorption current of the CK-587 glass press as it affects early turn-on drift of the CK-587 electrometer tube.
Results: A large portion of the early turn-on drift in electrometer tubes does consist of dielectric absorption in the glass press. This test also confirmed that if the glass is not properly annealed the insulation resistance can be as much as a factor of 3 lower than a properly annealed press.

W-13 Standard CK-587, but with the control grid gold plated.
Purpose: Determine the effect of a gold plated control grid on G_m and total observed control grid current and the I_{c_1} cross-over voltage.
Results: The only results of such a nature that they could be identified was a small reduction in the average G_m for the test lot, although a large spread in G_m values was observed as it is in tubes with regular production HB nickel control grids.

W-14 Regular CK-587, but using control grids plated with platinum.
Purpose: Determine the effect of a platinum plated control grid on G_m and total observed control grid current and the I_{c_1} cross-over voltage.
Results: The observable results were very much the same as in test W-13. There is a possibility that sealing-in fires contaminated the tube structure. The test will be repeated.

W-15 FIRST HALF Regular CK-587, structure processed without flashing getters.
Purpose: Determine the effect of getter splash on tube insulation resistance and the total observed control grid current.
Results: Preliminary tests show that the tube insulation resistance is somewhat greater with the unflashed getter. Total control grid currents were no higher than in standard production tubes with flashed getters. A slight difference in control grid current cross-over voltage was observed leading to the conclusion that flashing the getter changes the work function of the tube elements.

W-15 SECOND HALF Regular CK-587 with glass envelope collapsed on the top mica spacer.
Purpose: Determine the effect of a very tight spacer to bulb fit on vibration induced noise output, and changes in static characteristics after shock.

W-15 Results: No tests have been run to this time. Other work with higher priority has prevented action on this item.

W-16 Regular CK-587, with an additional getter "splash shield" mica.
Purpose: Determine the effect of getter splash micas.
Results: No significant change of insulation resistance or lower control grid current levels were observed. Apparently when barium containing getters are flashed they deposit on all the cooler portions of the tube structure and envelope, with the greatest concentration near the getter pellet. No observable change in control grid cross-over point is found when comparing this lot to standard production tubes. This leads to the conclusion that barium does deposit on all tube elements to a greater or lesser degree and that the amount of barium required to change the work function of the tube elements is very small. A small variation in the time and temperature of getter flashing does result in wide variations in tube characteristics.

W-17 Regular CK-587, with a flashless bulk getter. Composition, 85% zirconium and 10% aluminum.
Purpose: To evaluate insulation resistance of tubes with flashless getters. To observe the effect on the control grid current and the cross-over point of I_{c_1}.
Results: Insulation resistance was measurably higher on this lot of tubes. Total observed control grid current was also somewhat lower than with regular flash type getter. Cross-over voltage was shifted slightly to a higher voltage showing that tube elements are contaminated by barium from flash type getters, lowering their work functions in standard production tubes.

W-18 A dummy tube with 4 leads sealed in the flat press and one lead in opposite end to give a double ended structure such as is used on the 5889, QV-269 and CK-590.
Purpose: To evaluate the decay time of the dielectric absorption current with the control grid located at the opposite end of the tube envelope from the flat press leads. The specific effect of an external silver guard electrode applied to the glass was also to be studied.
Results: A preliminary evaluation has been made of this test lot. Tests conducted with one or two samples show a somewhat faster decay of the dielectric absorption current, which also appears to be of lesser magnitude than with the control grid lead in the flat press. The effect of the external guard electrodes do not seem to play a marked role in either shortening or lengthening the dielectric absorption current. Further tests must be performed, but since they require a great amount of time (24-30 hours per test) and equipment they have been delayed.

W-19 Regular CK-587, but with less mass on the top filament tab to coil spring support.
Purpose: Determine the effect of reducing and controlling the mass of filament tab left during tube assembly.
Results: Filament resonance tests have been run using a magnetic field test procedure. Results from this type of testing were not conclusive. It appears that it will be necessary to mount tubes on the MB shaker and optically observe the filament resonances to fully evaluate this test lot of tubes.

W-19 Regular CK-587 with more mass on top filament tab to coil tension spring.
Purpose: Same as test W-18.
Results: Same as test W-18.

W-20 Test made to determine the feasibility of making the CK-587 with the control grid brought out at the opposite end from flat press. This construction was later coded QV-269 developmental type and CK-590 commercial type.

W-22 Regular CK-587 construction, but all parts except the filament gold plated.
Purpose: To determine the changes in tube characteristics with gold plated surfaces. To be compared with standard HB nickel construction.
Results: Tubes have been placed on burning, but no further evaluation has been undertaken.

W-23 Regular CK-587 structure modified to bring control grid out at end opposite flat press. All internal parts except filament were gold plated as in test W-22.
Purpose: To determine the changes in tube characteristics with gold plated surfaces. To study dielectric absorption currents and the effect of longer external leakage paths to control grid.
Results: Placed on burning rack, no tests run to this time.

W-24 Repeat of test W-13, except mounts were sealed in longer envelopes.
Purpose: This was an attempt to eliminate the suspected sealing-in fires contamination of the gold plated grids.
Results: Placed on burning rack. No evaluation to date.

W-25 Repeat of test W-14 except mounts were sealed in longer envelopes.
Purpose: This was an attempt to eliminate the suspected sealing-in fires contamination of the platinum plated grids.
Results: Placed on burning rack. No evaluation to date.

W-26 5886 with filament supported at the ends only, not touching mica spacers as in regular production tubes.

Purpose: Primary information to be gained from this test was to be a comparison of turn-on stabilization time to that in regular 5886. A secondary test objective was to check and see if there was a reduction in the control grid current.

Results: Filament resonant frequencies have been checked using the magnetic field method and the resonant frequencies average about 20% lower than regular production tubes. This lot has not been evaluated for turn-on drift or control grid current.

W-27 Regular CK-587 mount with external metal shield, sealed in a standard miniature T-5-1/2 envelope.

Purpose: Determine the effect on all tube characteristics of a metal shield enclosing the mount structure to the maximum extent possible.

Results: Tubes are on hand at GSFC but drafting and slow machine shop response are holding up the special test fixtures.

W-28 Regular CK-587 with 3-D filament wire and heavier than normal filament tension springs.

Purpose: To evaluate a 3% addition of Rhenium to the tungsten filament wire. To determine the effect of heavier than normal filament tension springs on tube stability, filament resonant frequency, and "Q". Also to determine the effect on cathode emission of 3% rhenium in the tungsten filament.

Results: Tubes are still at Raytheon, expect shipment during January.

W-29 Regular CK-587, with filaments clear of mica spacers.

Purpose: Determine turn-on stabilization time and drift characteristics of this type of filament suspension.

Results: Preliminary results of tests run to date have not been conclusive as to whether freeing filament from the mica spacers has any effect on the turn-on stabilization period. A refined test procedure will be required to determine if any change in turn-on properties occur with this type of filament suspension.

W-30 Regular QV-269 (Standard CK-587 mount with control grid brought out end opposite from flat press) with an overall external silver envelope shield terminated in a ground lead in flat press.

Purpose: To evaluate an external envelope shield as to its effect on control grid current. To determine if an external shield interposed between control grid and other element connections has any effect on dielectric absorption amplitude and duration.

Results: No tests run on this group of tubes.

W-31 Tubes from several domestic and foreign manufacturers measured by Raytheon for G_m, etc. for initial current velocity test samples at GSFC.
Purpose: To evaluate reverse control grid current flowing at various bias voltages applied to control grid. This test is aimed at a correlation of observed levels of control grid current to the initial velocity current in many tubes of different design and construction.
Results: Preliminary results on another group of tubes did show a correlation between control grid current and the initial velocity currents. Specifically, tubes with high initial velocity currents at -2.0 volts control grid bias also have high control grid currents. This was true in all tubes measured to this time. Final test samples are ready but other work of higher priority has prevented further tests. A period of 4 to 6 weeks will be required to bring this work to a conclusion.

W-32 CK-587 tests samples assembled in a round mica spacer for sealing in T-3 bulbs. A preliminary test lot of QV-290 tubes.
Purpose: To evaluate paper design and the ability to assemble tube mount. Also to provide test hardware for the N-67 proximity fuze tube sealing-in machine used to roll crimp glass around top mica spacer.
Results: One or two electrical samples were obtained, but primary emphasis was on N-67 machine setup and mount operator assembly procedures.

W-33 Regular CK-587 with uncoated tungsten filament.
Purpose: To test the possiblitiy of a very small tube with low voltages as an ionization gauge.
Results: Tubes are at GSFC - time to evaluate has not been available.

W-34 Regular CK-587 complete tubes with envelope sealed in an external T-5-1/2 envelope with exhaust tubulation.
Purpose: To test the effect of helium permeating of the tube glass envelope and entering the tube vacuum.
Results: Now waiting for a manifold system to be designed and built. Tubes are on hand at GSFC.

W-35 Regular CK-587 structure less grids one and two.
Purpose: To be able to observe the filament and study the temperature variations along the length of the filament by the infrared radiometers and infrared photographs.
Results: Tubes are on hand, camera is on hand, infrared calibration cathodes are on hand, but the time to evaluate and an area of low infrared background radiation has not been available.

W-36 This test number was used to identify an order for 100 QV-269 tubes, which have been delivered to GSFC.

W-37 Regular 5886 tube mount, except oxide coated tungsten filament, replaced with an oxide coated nickel filament.
Purpose: Determine the effect of oxide coated filament core metal on control grid cross-over voltage.
Results: Tubes are still in process at Raytheon.

W-38 Regular 5886, except for use of a flashless bulk getter.
Purpose: To determine the effect of flashless getter on the following parameters: control grid current, 1/f noise spectrum, control grid current cross-over voltage, and control grid insulation resistance.
Results: Tubes have been tested for noise at 100 and 1000 cycles. No other tests have been run to date.

W-39 Nippon Electric 5886 samples tubes measured for G_m, R_p, etc. by Raytheon and returned to GSFC as part of the initial velocity current test series.
Results: No test have been made.

W-40 Regular CK-587, except for a double carbonate filament coating containing 3% calcium, 97% strontium.
Purpose: Determine the effect of eliminating metallic barium from the tube structure and the specific effect on the control grid insulation resistance, total observed control grid current, control grid current cross-over point and the effect of long term drift.
Results: Tubes are still in process at Raytheon.

W-41 Regular CK-587 with a baked-on General Electric "Dri-Film", silicone water repellant treatment.
Purpose: To evaluate a much more durable water repellant surface treatment, and its effect on total observed control grid current. Also determine its electrostatic charge retention properties.
Results: Tubes were received at GSFC on 10/26/64 but no evaluation has been undertaken at this time.

W-42 Regular CK-587 with glass envelope collapsed on both top and bottom spacer micas, prior to exhaust.
Purpose: To evaluate the vibration induced noise response of tube with very tight envelope to mica spacer fit.
Results: Still in production at Raytheon.

W-43 Regular CK-587, without "HOT SHOT", during filament activation process.

Purpose: To determine the after affects of the so-called "Hot Shot" during filament activation. This so-called "Hot Shot" is a type of filament activation in which AC of approximately 4 times the normal operating filament voltage is applied for 10 seconds to 1.0 minute depending upon tube type. This is to convert the alkali earth carbonates to oxides and perhaps a small quantity of free barium metal. During this processing step a small amount of barium metal is evaporated onto the tube elements changing their work functions in an erratic manner. Processing is possible without this "Hot Shot", but consumes considerable time and additional effort.
Results: Tubes have been processed and are still at Raytheon.

W-44 Regular CK-587, except the entire getter assembly has been left out and the tube processing to be performed at lower than normal temperatures.
Purpose: Determine the effect on control grid current, control grid current cross-over point and the control grid insulation resistance.
Results: Tubes are in manufacturing process.

W-45, W-46, W-47 This group of tests were designed to gather information on the inverted triode. Tests were cancelled when the inverted triode from Germany were received.

W-48 Regular CK-587 in Corning 0120 glass bulbs, that had been baked for 12 hours at 400°C and given a post bake wash in a 15% KOH solution prior to sealing in mounts.
Purpose: To determine if a 12 hour 400°C bake with a post bake wash in KOH did, in fact, remove certain contaminants which poisoned cathode emission during 150°C, 150 hour sterilization tests.
Results: Several tubes from this lot have been run through the 150°C, 150 hour sterilization test and the change in characteristics have been less than any other tubes tested to date.
A new lot of tubes is scheduled to be made at Raytheon's Quincy, Massachusetts plant under another test number to be certain that the results were true and not a chance occurrence.

W-49 Regular 5886 mount with the top filament support strengthened.
Purpose: An attempt to reduce the amplitude of filament resonances in the 5886 structure.
Results: Tubes are still at Raytheon.

W-50 Regular CK-587 with RCA triple carbonate on the 3-D filament wire.
Purpose: Determine emission level and stability of RCA coating on 3-D filament wire.
Results: Still in production at Raytheon.

W-51 CK-587 mount with the control grid replaced by a narrow slit, rather than the conventional wound grid.

Purpose: Determine if a slit of approximately the turn to turn spacing of the regular wound grid would function as a control grid. This construction should help to reduce microphonic output from the control grid.

Results: Tubes have been read for G_m plate and screen currents at Raytheon. The results were comparable to regular CK-587 with the regular wound grid. Evaluation for microphonic output and control grid current will be undertaken when tubes are received at GSFC.

W-52 This test number was assigned to all data taken by Machlett on the studies of residual gas in subminiature electrometer tubes.

Purpose: To determine if any contaminants other than the well-known gases were contributing to failure of emission of electrometer tubes in the 150°C, 150 hour sterilization tests.

Results: No new information was gained by this test. It confirmed what was already known.

W-53 Regular CK-587 mounts except platinum - 10% iridium oxide coated filaments.

Purpose: Compare emission level and stability of platinum-iridium filaments. Determine if there is any effect on the control grid current cross-over point, also to determine if there is any significant change in total observed control grid current.

Results: Tubes are ready for aging and burning at Raytheon; due to be shipped to GSFC next week.

W-54 Regular CK-587 mounts with regular tungsten filament wire with heavier than normal triple carbonate coatings.

Purpose: Determine if the present filament coating weight is adequate to sustain emission over period of several thousand hours at a relatively constant level.

Results: Filament wire has been coated and tabbed but the holidays and the move to Quincy have delayed start on this item. I have instructed Raytheon not to start test lots during holiday season due to poor performance by mount operators.

W-55 Regular CK-587 mounts, except filament coating is a binary coating containing 50% calcium and 50% barium.

Purpose: In the standard triple carbonate coating barium is evaporated preferentially during tube life changing the work function of the filamentary cathode. The work function of the barium-calcium system changes by a very small amount for a very large change in the ratio of

W-55 barium to calcium. Therefore, if adequate emission can be obtained from this coating a reduction in overall long term drift should result.
Results: Filament wire has been coated and tabbed. No tubes built to date. Will be started early in January, 1965.

W-56 Regular CK-587 except filaments are to be coated with barium-strontium carbonate.
Purpose: To determine long term drift characteristics, emission level and effect on control grid current and the effect on control grid cross-over voltage.
Results: Filaments wire has been coated and tabbed. Tubes will be started early in January, 1965.

W-57 This is a 100 tube lot of the type QV-290, essentially the CK-587 metal parts but with a new mica for the T-3 round bulb.
Purpose: To evaluate the CK-587 tube design in a T-3 bulb which should be less microphonic than the regular CK-587 in the T-1 × 1/2 bulb.
Results: The N-67 proximity fuze tube sealing in machinery is still not in proper operating condition after the move to Quincy from Newton. It is expected to be ready early in January, 1965.

W-58 Large area triple carbonate indirectly heated cathode sealed in the 0120 glass envelope used for the CK-587.
Purpose: To provide large area infrared sources for infrared radiometer and infrared film calibration. These sources are to be used as comparisons to standard electrometer tube filaments.
Results: Tubes are at GSFC, no work undertaken at this time.

W-59 Regular production 5886 except a baked-on silicone water repellant treatment prior to final exhaust.
Purpose: To compare with regular reactive type silicone water repellant treatment.
Results: Tubes are awaiting shipment at Raytheon.

W-60 A regular lot of CK-587 mounted at the same time as tests W-50, W-54, W-55, W-56.
Purpose: To be used as a production control on the above mentioned tests.

W-61 Regular CK-587 except the number one grid is of the frame type construction.
Purpose: To determine if the frame type contsruction will result in better lot uniformity of tubes.

W-61 Results: Tubes have been tested for G_m, plate and screen currents, and they show a distribution of characteristics nearly the same as with regular production type wound grids. No explanation for this behavior is available. The test will be repeated with very careful control of all processing parameters. Evaluation of control grid current and other tests such as microphonic output will be performed as time permits.

W-62 All data taken on several DC-760 and DC-762 German inverted triode electrometer tubes are being collected under this test number.
Purpose: To bring together sufficient data from the analysis of the DC-760 and DC-762 to permit manufacture of sample lots by Raytheon.

W-63 Data taken on 200 CK-587 tubes for the GSFC high reliability specification for purchase of electrometer tubes.

W-64 QV-290 mount with Coors ceramic spacers in T-3 glass bulbs, using SAES 85% zirconium - 15% aluminum flashless bulk getter.
Purpose: To obtain several samples of this construction for 150°C sterilization tests at an early date. This would be the first tubes checked at 150°C using ceramic spacers rather than mica.
Results: None to date.

W-65 QV-290 mount with mica spacers in metal envelopes with ceramic headers.
Purpose: To obtain samples of this construction for 150°C sterilization tests.
Results: Still waiting for delivery of ceramic headers.

W-66 QV-290 metal envelope, ceramic header and ceramic mount spacers.
Purpose: Provide first samples of a clean tube using all metal ceramic construction to determine if elimination of glass and mica removes the source of cathode poisoning during 150°C sterilization testing.
Results: Waiting for several parts.