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THE FEEDBACK VIBRATING CAPACITOR FIELDMETER

by

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ABSTRACT

A redesign effort was undertaken starting in the fall of 1988 to replace our Models 1019A and 1019B fieldmeter probes resulting in greatly improved performance. Extensive testing was conducted to confirm performance of the new design and to evaluate outdoor atmospheric applicability. We will discuss theory of operation, design improvements, performance, proper use, maintenance, and applications for the new intrinsically safe design.

INTRODUCTION

The feedback vibrating capacitor fieldmeter was first developed in 1965 by Robert E. Vosteen [1], founder of Monroe Electronics, Inc., to address problems a manufacturer of coated film was having with its production lines during winter months when humidity is low and static events are more prevalent. The client did have field mills at the time. They were custom made in house for their own use.

The stator was made from copper clad glass epoxy printed circuit board material etched to 18 equal segments. The rotor was made from stainless steel. Regular calibration was required due to changes in impedance of the glass epoxy from surface contamination, possible charge holding characteristics of the glass epoxy and contact potential differences of the bare copper and stainless steel.

Bearing noise from motors of 25 years ago was also a problem and little was known about contact potential at the time. The calibration procedure was a real ordeal as remembered by one of their employees who used to do it.

By incorporating a feedback null seeking technique, calibration of the vibrating capacitor probe was made extremely stable over time being little affected by changes in impedance due to surface contamination of the electrode insulator or changes in modulator efficiency. Zero drift was about 2% due mostly to contact potential of the gold plated electrode and aperture plate.

Field mill design has improved immensely since those days. Much improved motors, better insulating materials, better knowledge of contact potentials and better mechanical and electronic design has resulted in extremely accurate and stable modern instruments.

Regular calibration is still required if the mill is used in an environment where the electrode stator insulators can get contaminated thereby changing their insulating properties and calibration.

The film manufacturer uses Monroe Electronics' vibrating capacitor fieldmeters exclusively and have units 20 years old still in use. They are presently embarking on a replacement program to take advantage of the increased performance and stability of the new design probes which we will proceed to describe. One of our goals in the redesign effort was to close certain performance gaps between our previous design and state of the art field mills.

PRINCIPLE OF OPERATION

The sensitive electrode "senses" the field to be measured through the aperture in the probe gradient cap. The A.C. signal induced on this electrode is proportional to its excursion path length and the strength of the ambient field. The polarity of this field determines phase. This signal and a reference signal from the oscillator are fed into a phase sensitive detector whose output feeds a D.C. integrating amplifier. The output of this amplifier is used to drive the electrode to a potential just sufficient to neutralize the net field at the sensitive electrode.

This feedback principle and null seeking operation combine to make a remarkably stable and highly accurate instrument.

DESIGN IMPROVEMENTS

A new patented low noise pre-amp [2] was employed which reduced noise by a factor of 10.

Electrode size was increased from 0.5 inch to 0.625 inch resulting in an approximate 50% increase in area which translates to conversion efficiency or gain. Alloy 304 stainless steel was used wherever possible for the electrode and for parts viewed by the electrode. Research [3] has shown stainless steel to be a superior material for reducing contact potential effect in fieldmeters.

If increased speed of response is deemed by the user to be more important than low noise then the pre-amp gain can be changed to increase speed 10% to 90% to a maximum of 50 milliseconds. A time of 250 milliseconds is typical in the low noise mode.

The gradient cap on the new design is at ground potential whereas the old one was at driven shield potential. This enhances the intrinsically safe design, hardens the unit to static discharge and may improve measurement accuracy in high fields.

Better purging is designed into the 1019E version for reliable performance under extremely dirty conditions. An air column surrounds the gradient cap as well as exiting through the gradient cap aperture. The old design purged through the aperture only and charge-carrying contamination could deposit on the gradient cap altering measurements being taken.

Applications

There are now three fieldmeter mainframes used to cover a range of application.

1. Model 245 is a single channel battery powered unit used for trouble shooting static hazards and taking of measurements where a.c. power is not available.
2. Model 273 is a single channel unit with 2 symmetrical alarm levels. Relays are supplied via barrier strip to allow automated control of chart recorder, external alarms or high voltage supplies, etc. Optional battery power is available.
3. Model 171 is a multichannel (2 to 16) unit for monitoring and alarming more than one site at a central location. Up to 1000 feet of probe cable may be used on all instruments.

All units are 1019E & F compatible. The E probe is designed with long term monitoring in mind and has better purging capabilities and better shielding of cables for noise reduction. The F probe is the same probe head but much smaller and is used for short term monitoring or where small size is of importance. These units are used in monitoring:

A. Charge accumulation

1. Fueling monitoring
2. Filling stations/processes
3. Painting operations
4. Explosives handling
5. Solid rocket manufacturing processes
6. Read-write head analysis
7. Mixing processes
8. Transport systems ducting, pipe lines, etc.

B. Coating processes

1. Metal coating
2. Paper coating
3. Film coating
4. Solvent coating

C. Atmospheric monitoring

1. H V D C transmission lines
2. Research
3. Lightning hazard warning

Intrinsic Safety [4]

Probes have been certified Class I, Division 1, Groups C & D intrinsically safe by Factory Mutual Research Corporation when used with approved barriers. With purging and interlocks, Division 1, Groups A & B requirements can be met [5].

Sensitivity

Sensitivity is controlled by hole size in the gradient cap. Ranges from ±10 kV/m to 2MV/m are possible. The larger the hole size, the greater the sensitivity and the lower the full scale field strength.

It is recommended that the range of most interest to the user should be the approximate mid-range of full scale sensitivity.

Some degradation in speed of response will be noticed on the more sensitive ranges due to loss of feedback gain because of the larger aperture sizes.

Calibration

Calibration is done using the parallel plate method. The probe is placed flush with a grounded plane and a voltage is applied to a parallel plate a set distance from the probe. A minimum ratio of 5:1 width of plate to distance between plates is recommended [6]. Using this method, kV/M, kV/cm and kV/in sensitivities can be calibrated. Larger fixtures with greater distance (10cm) between plates are considered optimum but are not always practical and can be of some danger to the user due to high voltages required. Well made fixtures with spacings of 1cm to 1 inch have been found to correlate well with the larger fixtures.

Testing was performed to compare the 1cm fixture to the 10cm fixture and check linearity.

Equipment List

Calibration Fixture #1 (10cm)

Dimensions:	plates 58.7cm x 58.7cm insulators 10cm

Calibration Fixture #2 (1cm)

Dimensions:	plates 15.2cm x 15.2cm insulators 1cm

Monroe Electronics Model 152A ±10kV Coronaply
Monroe Electronics Model 241 ±3kV reference supply
Monroe Electronics Model 175-57 1000:1 divider
Data Precision 2540A1 digital voltmeter
Monroe Electronics Model 273 fieldmeter with 1019F-3 probe (1kV/cm or 100kV/M)

The Model 152A was used for the 2kV to 10kV range. Output was checked and adjusted using the 175-57 divider and 2540A1 meter. The Model 241 is a 0.05% instrument and no adjustments were required in the 1V to 1000V range.

The fixtures were placed on a cardboard box to isolate them from leakage to the benchtop. The fieldmeter was calibrated at full scale on the 10cm fixture. 10kV at 10cm = 100kV/m and 10.000 VDC output. Voltage applied was then reduced 1 decade at a time and fieldmeter output measurements taken. The last (mV) digit on output voltages flashed ±1 due to noise. The F model probes have a lesser degree of shielding on the probe cable and therefore may exhibit a greater degree of noise from local sources. As can be seen from the data, the output was linear within 0.05% and sensitive to 10V/m. When the same test was then performed on the 1cm fixture without re-calibration, full scale output started at 1000V at 1cm = 9.846VDC. This was noted to be about 1.5% difference. Some of this difference is attributed to variation in calibration distance. Other factors such as field convergence may be affecting calibration at the close spacing. The accuracy of your calibration is correlated directly to how well you know your plate spacing, flatness and adequate size as described earlier to insure straight field lines.

Cleaning

When cleaning is required (the probe is disassembled and) the gradient cap is removed. At this time, care must be taken not to drop the probe or allow the electrode to receive any blows or contact with anything but the solvent cleaner. It is fairly fragile and can be fractured from its insulator if exposed to excessive force. The electrode should not be pushed on as this can alter the magnetic set of the transducer possibly altering the performance. Recommended solvent for cleaning purposes is Miller Stephenson MS160/C02 or technical grade isopropyl alcohol. Any other solvent may attack conductive polymer used in manufacturing and render probe inoperable. Flush the electrode and transducer with a spray and dry with light application of Aero Duster (MS222) or clean dry low pressure air. Clean the gradient cap with same solvent and wipe dry with a lint free wipe. Re-assemble gradient cap to base making sure it is well seated. A short bake in an oven at 75°C will drive off any residue solvent and help to stabilize the probe.

Purging

Purging is highly recommended when any long term monitoring (more than 24 hours) is undertaken. The only place purging may not be required is in a clean room or other similar ultra clean environment. Due to the close spacings used in the probe particulate contamination will cause zero drift due to charge holding characteristics of contaminants.

Well filtered air is recommended and filtered inert gas such as argon or nitrogen can be used where air may not be compatible with the environment being monitored.

Existing gas supplies to be used for purging should be equipped with dedicated filtering for purging use only. Supply filters are available capable of removing 99.99% of 0.1 micron oil, water and dirt when properly maintained per manufacturer's instructions. Replaceable in line filters can also be used to further enhance filtering. Zero drift should be monitored and re-zeroed as required at intervals determined by the user to keep error within acceptable limits. If excessive zero drift is observed the probe should be disassembled, cleaned and recalibrated. Air filter maintenance should be done at this time also. Recalibration is required only after disassembly of the probe. Calibration is unaffected by contaminants.

Environmental Testing

Hundreds of hours of tests have been performed to establish working parameters of the probes.

A Tenney environmental chamber has been used for indoor testing of humidity and temperature effects. The probes have been found to work well in specified temperature ranges of -30°C to +100°C and 0 to 100% humidity (non-condensing). Temperature drift has been found to be about 0.5% from -30°C to 100°C. A test was performed to check performance at 10°C increments through the full temperature range. Data taken involved zero drift, calibration, speed of response (which equates with overall gain) and noise. A zero offset of around 2% is induced starting at around 80°C to 90°C. This only takes place on an initial ramp up to 100°C. The probe can then be re-zeroed and will hold within 0.5% zero drift over the temperature range. Calibration was found to hold within 0.05% through the full temperature range.

Speed of response is degraded starting at about 60°C to 70°C. A probe exhibiting a 10% to 90% speed of 250 milliseconds at room ambient will degrade to 500 milliseconds at these higher temperatures. This is probably due to loss in modulator efficiency. There is also some loss of performance at temperatures below 0°C although to a much smaller degree. Noise was found to remain stable through the temperature range varying only 2-3 mV peak to peak.

Drift Under Working Conditions

Our old design probe has a platinum/palladium/gold thick film over ceramic electrode viewing a gold plated stainless steel gradient cap. The use of stainless steel in these parts has greatly reduced observable drift rates. Contact potential and modulator efficiency are known to be the largest factors effecting drift. Modulator efficiency in field mills is vastly superior to that of the vibrating capacitor and greater spacings of electrode to vanes are possible with this combination greatly reducing contact potential effects. A larger more powerful modulator with a larger electrode could be used to enhance stability but intrinsic safety of the present design would most probably be lost.

Outdoor drift rates are probably a worst case due to changes in air pollution levels and the chemical cocktail always present in the atmosphere. Fluctuating temperature and humidity also will affect drift.

Observed zero drift outdoors usually runs less than 0.1% per day, <0.5% per week and <1% per month. These guideline parameters may be better or worse depending on air quality and weather conditions of a given location. The user would determine drift rates through checks and decide on a zeroing schedule compatible with the accuracy of measurements required.

Indoor drift rates are usually much lower. A probe was left running unpurged on a bench in the factory in a zero field and drift was less than 0.1% for a period of three weeks. In a clean room situation drift would probably be lower yet. Conversely, in extremely dirty conditions or chemically contaminated atmospheric drift may be enhanced. Attention to good purging practices will minimize drift under all conditions.

Development Of Outdoor Probe And Fixture

Feasibility testing was done at New Mexico Tech. Langmuir Laboratory in November - December 1988 with the help of Dr. William Rison [7]. We compared the signals of our Model 245/old 1019A with their E-100 field mill, which was designed for airborne applications by Dr. William P. Winn, for a period of six weeks. These mills are in use for ground level measurements at several research and military installations in New Mexico. Little attention was paid to getting absolute calibration of measurements. We were most interested in seeing how well the instruments would track under similar conditions. The signals on the chart recorder were nearly identical for the period. The main discrepancy noted was zero drift of the 1019A. It would quickly (within 48 hours) drift off about 2% of full scale or 200V/m and then stabilize. This made it impossible for accurate measurements of ambient E-field to be taken.

The outdoor fixture in use at the time was that of a downward facing probe viewing a grounded wire mesh grid. A probe height of approximately 14" gave the same reading as one facing upward flush with the ground. The NM Tech fixture was also downward facing but at a greater distance from ground and viewing ground. It was explained by Bill Winn that this arrangement works like an antenna enhancing the E-field by a factor determined by comparison with an upward facing flush mounted mill. The face of the mill is at approximately 1 meter, giving an enhancement factor of about 7:1, i.e. 60 kV/m at the face of the mill gave 8.4 kV/m in the fixture. It is felt that under most conditions, the earth itself is an adequate static ground. Unusual geological situations do exist where the earth is not a good ground. In this case a grounded wire mesh grid or plate should be provided for the fieldmeter to view.

Our latest design outdoor fixture 1019G is patterned after the New Mexico Tech design. There are several advantages:

1. Reasonable manufacturing cost
2. Good portability
3. Stable in high wind conditions
4. Works well in adverse conditions (rain, snow, etc.)
5. Enhances performance factors of the fieldmeter used
6. Excellent for long term monitoring at fixed sites

The probe faces downward at a height of approximately 1 meter. The full scale sensitivity of the probe is 20kV/m which becomes 5kV/m when used on the fixture. Our enhancement factor is 4:1 where the Tech fixture is 7:1 at approximately the same height. Our probe is equipped with a round 6 inch diameter field normalization plate which also works as a roof keeping rain from the probe aperture. This plate allows less of the E-field converging on the fixture to reach the electrode therefore making the enhancement factor less. Each design of fieldmeter will have its own enhancement factor when used in this downward facing mode.

A rain proof NEMA enclosure is attached to the fixture for permanent installations. This contains a small air pump with filters for purging, an electrical box for AC connections and a dry place for probe connections. It is recommended that all wiring to a permanent installation be run in buried conduit and be well grounded.

The probe is equipped with a self regulating heater which will enhance performance at low temperature and keep the probe free from condensation which can deposit contaminants over time and degrade performance. Temperature inside the probe is raised about 20°C at -30°C and stops working completely at about +50°C. At +20°C the temperature inside is about +33°C; at +30°C, it is about +36°C and at +40°C, about +41°C.

The ±5kV/m full scale range was selected because the range of most interest in lightning hazard warning is in the ±3kV/m range. Bill Rison suggested that an adequate speed of response for the probe would be around 200 milliseconds. This will allow the user to detect lightning discharge in the range of 3 - 5km radius with use of a chart recorder. The spikes seen at this distance would be on the order of the ambient field at 100 to

200V/m. Gain was added at the pre-amp to reach this speed with some increase in noise to about 10 - 12 mV peak to peak. This level still allows for a maximum sensitivity of less than 5V/m. The gradient cap can be changed for wider range measurements should they be desired, the 4:1 enhancement factor being constant.

Many months of outdoor year around testing have been done. No probe failures have been noted. They have survived normal and severe weather conditions well.

At present we are doing a final evaluation with the help of Bill Jafferies at NASA atmospheric science laboratory. Initial results look promising. The unit tracks well with the on-site field mills in ambient E-fields. As of this writing no storms have passed by and outputs need to be compared under higher fields. We also plan to check fixture calibration with a flush mounted mill and adjust it if required.

Conclusion

This new design has proven itself to be a significant improvement over the old design. Further studies are needed in material selection and mechanical design considerations to minimize contact potential effects.

Acknowledgments

The authors wish to thank (in alphabetical order) Bill Jafferis, Launa Maier, Charlie Moore, Bill Rison, and Bill Winn for all their help and cooperation in the development of the outdoor fixture.

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6. *A Review of Current Electrostatic Measurement Techniques And Their Limitations* by William E. Vosteen, Monroe Electronics, Inc., Lyndonville, NY 14098.

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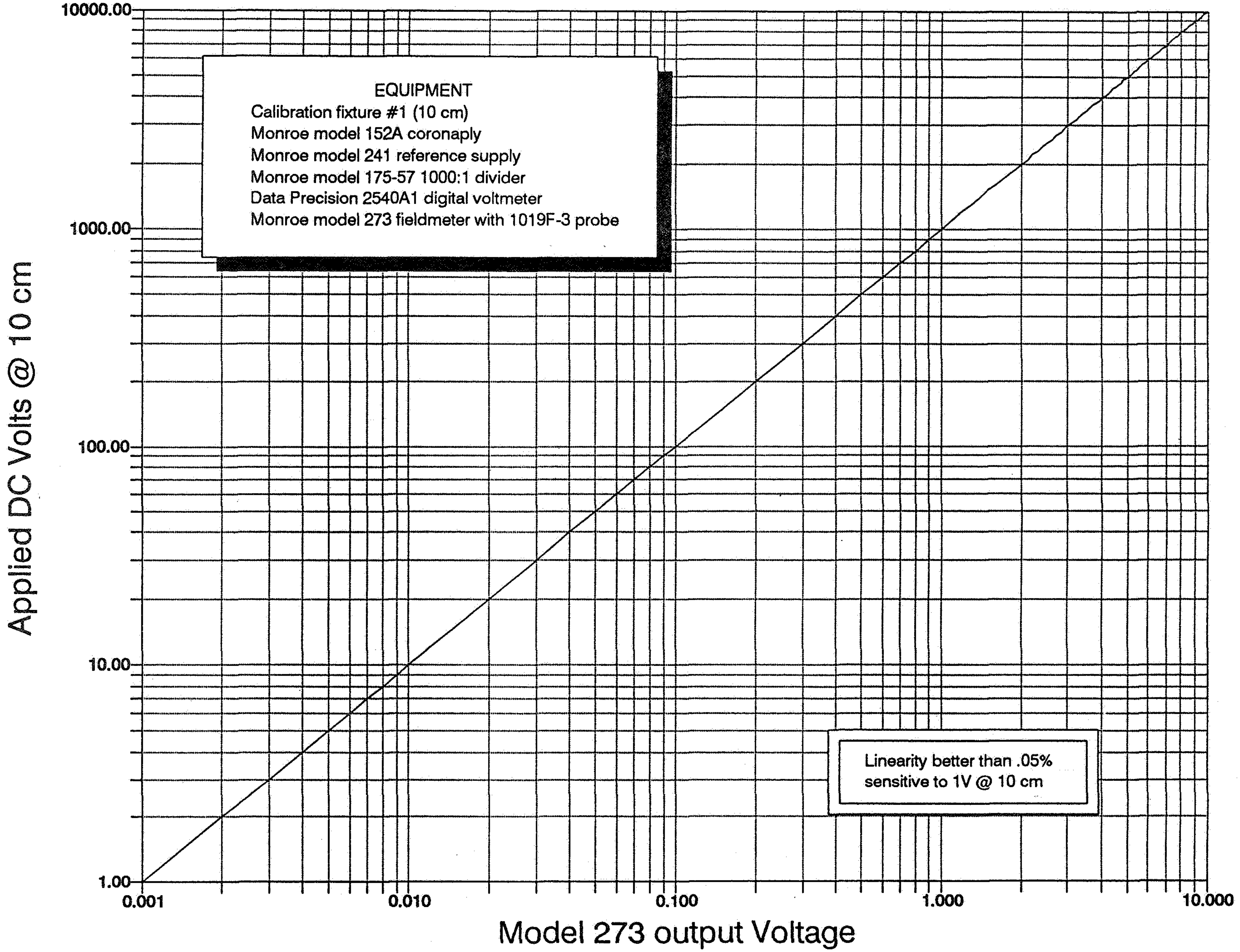
Calibration Linearity and Sensitivity

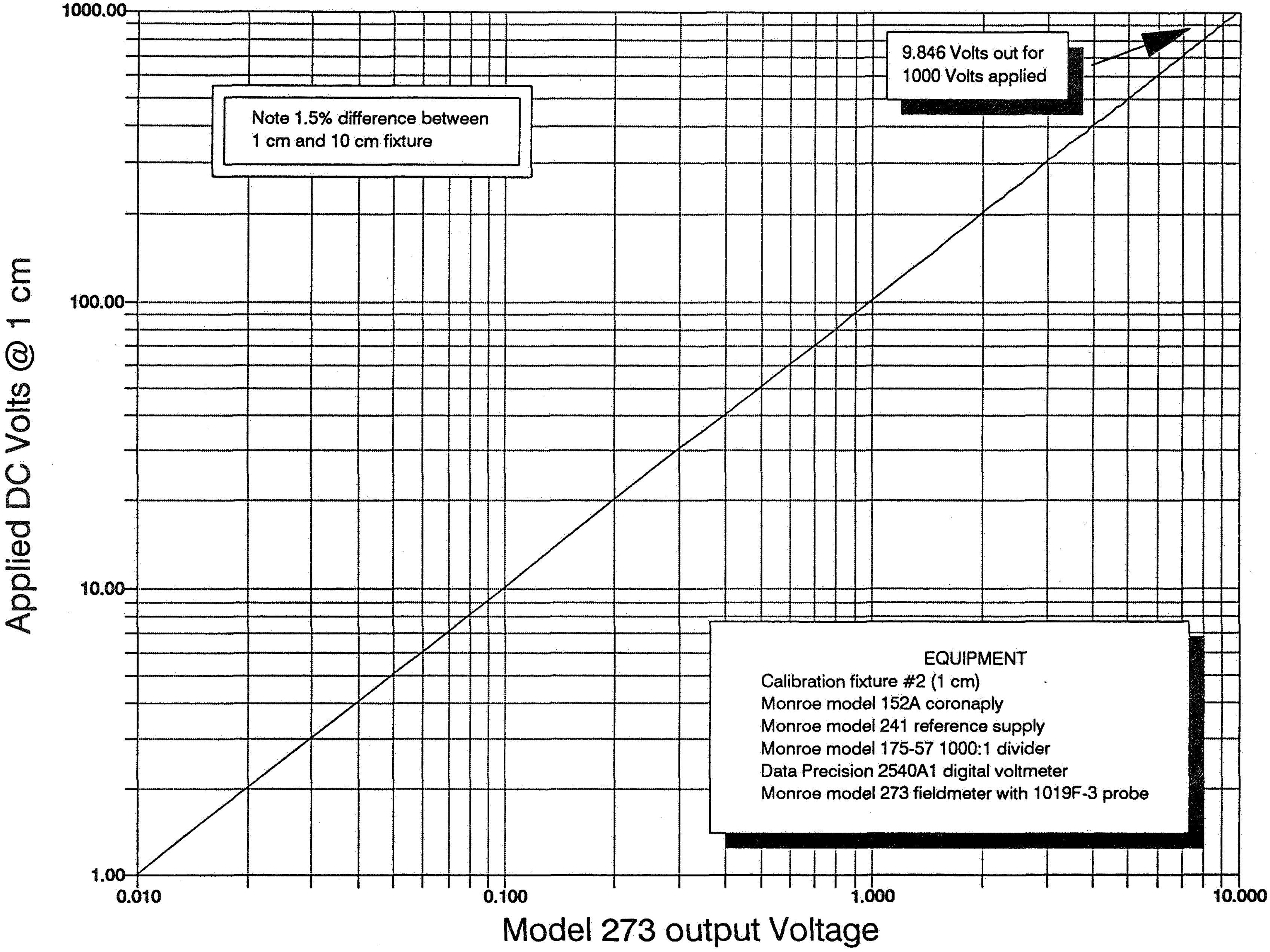


EQUIPMENT
Calibration fixture #1 (10 cm)
Monroe model 152A coronaply
Monroe model 241 reference supply
Monroe model 175-57 1000:1 divider
Data Precision 2540A1 digital voltmeter
Monroe model 273 fieldmeter with 1019F-3 probe

Linearity better than .05%
sensitive to 1V @ 10 cm

1 cm Fixture with Probe cal at 10 cm

273 Fieldmeter with 1019F-3 Probe



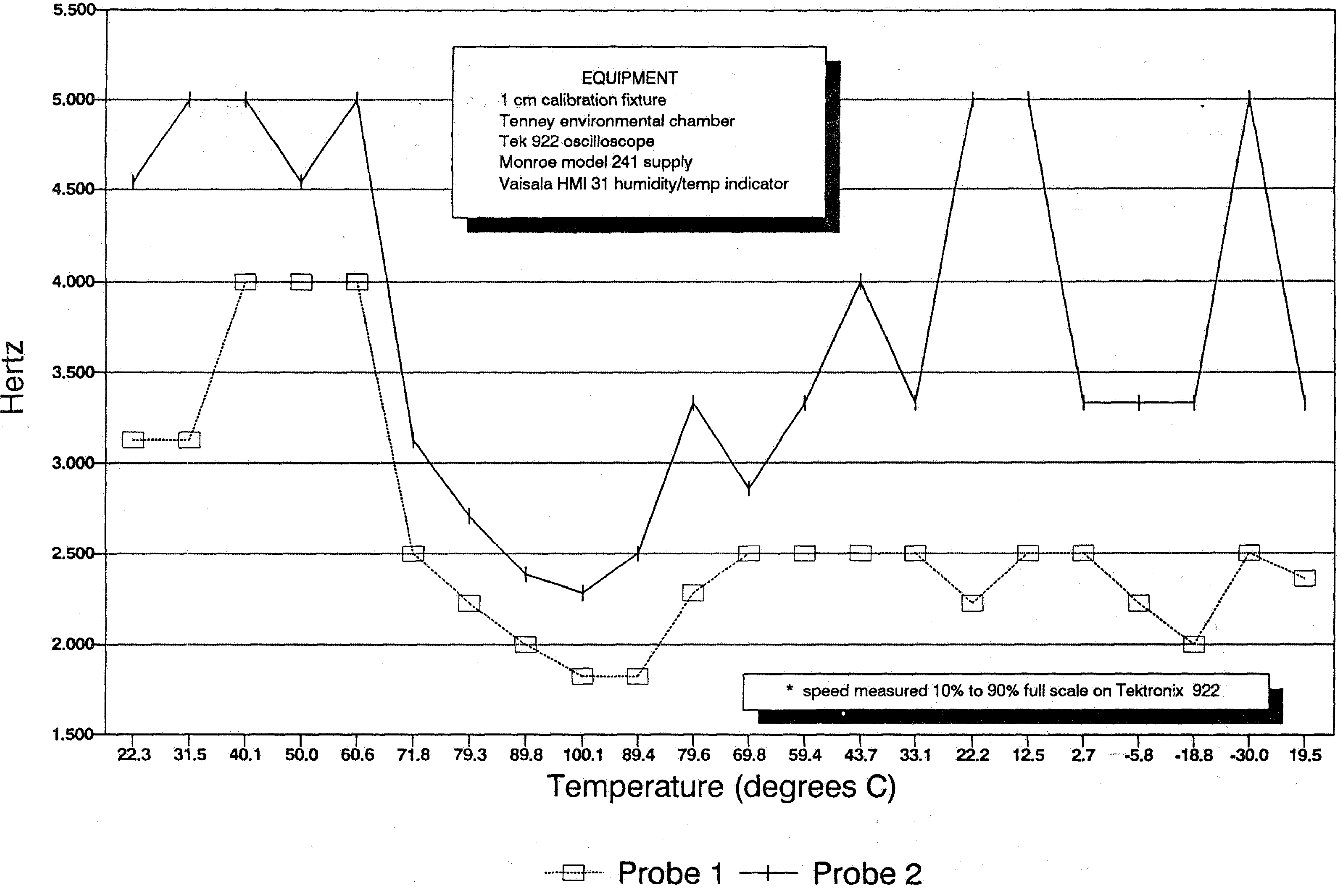
Note 1.5% difference between 1 cm and 10 cm fixture

9.846 Volts out for 1000 Volts applied

EQUIPMENT

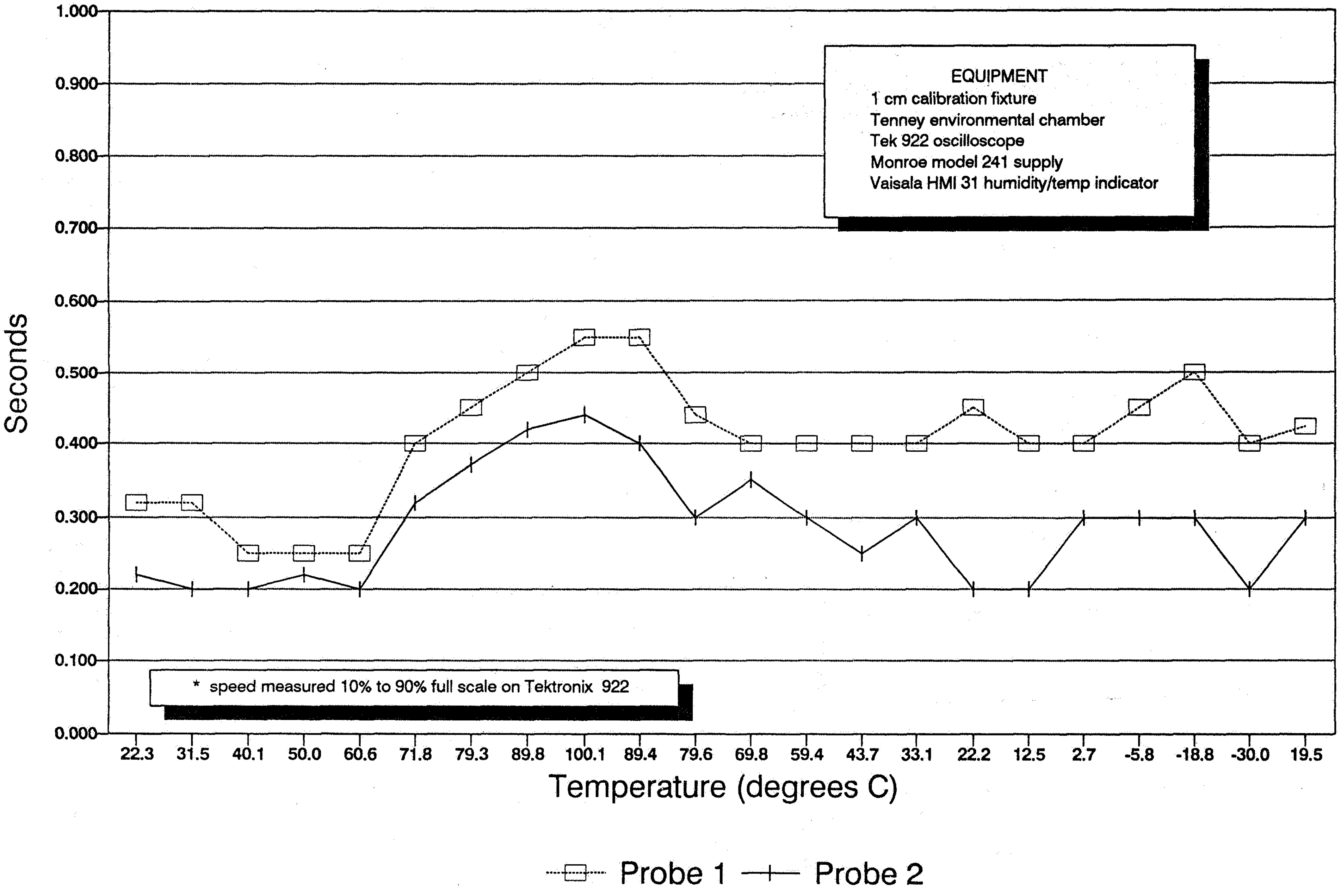
Calibration fixture #2 (1 cm)
Monroe model 152A coronaply
Monroe model 241 reference supply
Monroe model 175-57 1000:1 divider
Data Precision 2540A1 digital voltmeter
Monroe model 273 fieldmeter with 1019F-3 probe

Speed of response over temperature *
273 Fieldmeter with 1019E-4



Speed of response over temperature *

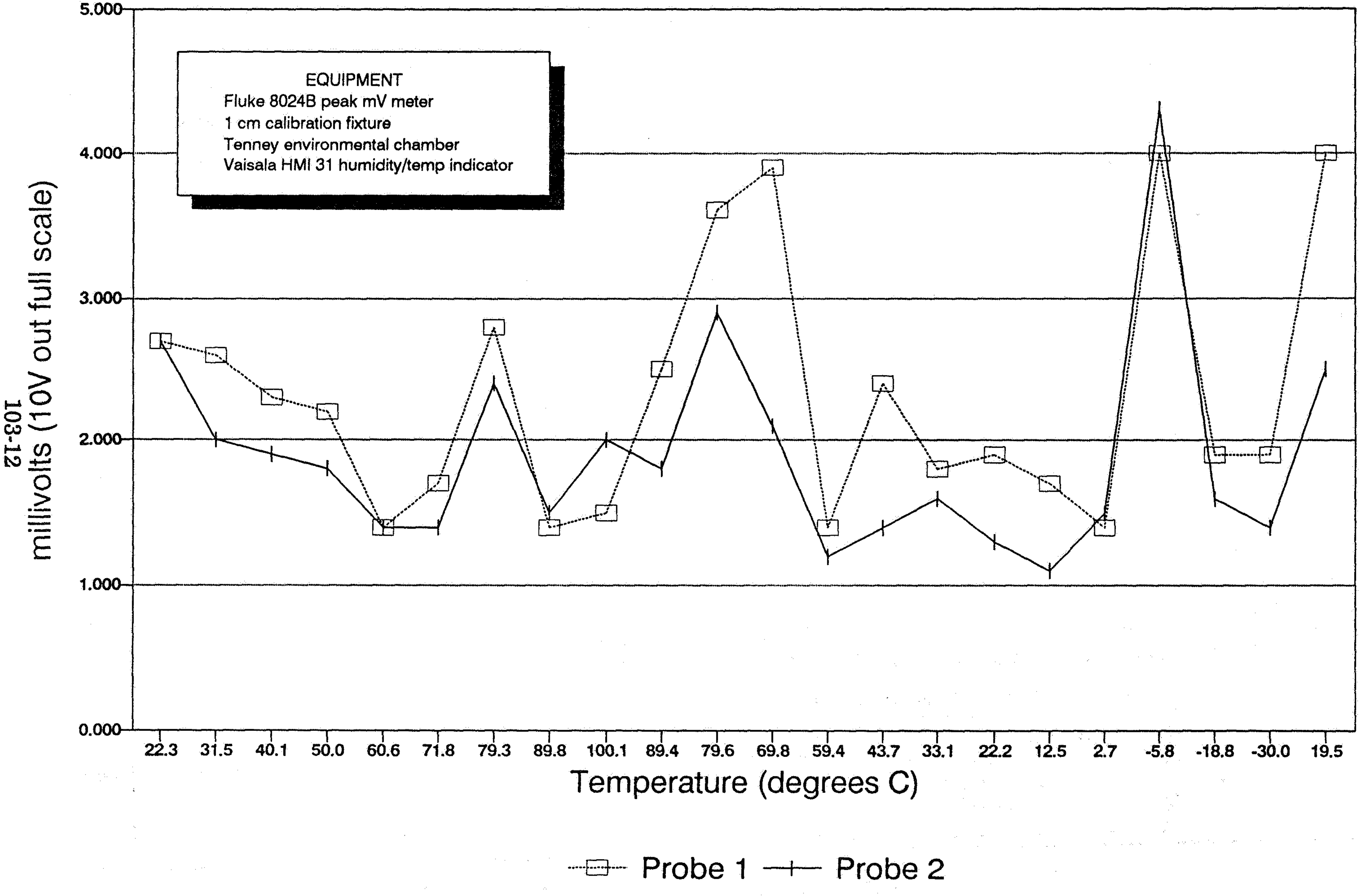
273 Fieldmeter with 1019E-4



EQUIPMENT
1 cm calibration fixture
Tenney environmental chamber
Tek 922 oscilloscope
Monroe model 241 supply
Vaisala HMI 31 humidity/temp indicator

* speed measured 10% to 90% full scale on Tektronix 922

Noise over temperature
273 Fieldmeter with 1019E-4



Zero drift/calibration over temperature *

273 Fieldmeter with 1019E-4