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UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

To be presented at the American National Standards Institute Meeting, Subcommittee C82-1 on Fluorescent Lamp Ballasts, Chicago, IL, September 15-16, 1981

HIGH-FREQUENCY STARTING OF FLUORESCENT LAMPS

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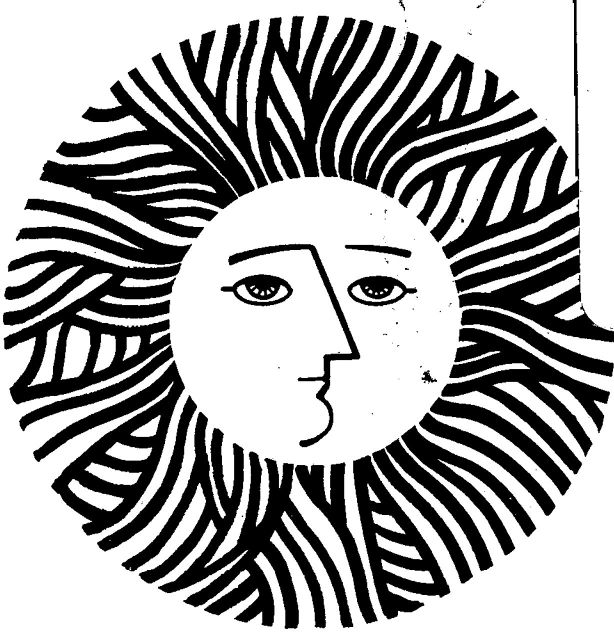

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HIGH-FREQUENCY STARTING OF FLUORESCENT LAMPS

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ABSTRACT

Lamp and ballast manufacturers have shown increasing interest in having a high-frequency testing procedure to determine the peak and rms starting voltages for fluorescent lamps. This, paper discusses a starting voltage procedure and typical test results for a single-lamp circuit. These peak/rms relationships are shown as a function of frequency, cathode voltage, and ambient temperature for three types of "F40" lamps (the standard F40, the F40 35-watt and the F40 35-watt without a conductive coating).

1.0 INTRODUCTION

E.E. Hammer[1] has recently done some experimental work to determine starting requirements for 60-Hz fluorescent lamps. He has measured two starting parameters, a peak voltage (Vp), (the high potential from cathode to the external starting aid), and an rms voltage (Va) requirement across the lamp. Electronic ballasts may present new starting requirements because they operate at between 20 kHz and 50 kHz. This study was made over a wider range of frequencies (60 Hz - 100 kHz), in the event other operating frequencies become more desirable. This paper describes an experiment with three types of "F40" lamps:

1. the standard F40, T-12 rapid-start lamp;

2. the F40 (35-watt) T-12 rapid-start lamp;

3. the F40 (35-watt) T-12 rapid-start lamp without internal starting aid (no internal conductive coating).

We will present data for the above frequency range in ambient temperatures of 10°C and 25°C.

2.0 PROCEDURES

2.1 Circuit

Figure 1 is a schematic of the electrical circuit used for measuring the peak breakdown voltage (Vp) of the lamps. The starting aid is 1" wide and is 1/2" from the lamp. Cathode heat is supplied at 60 Hz for all test frequencies because the error introduced was considered negligibly small and did not justify the logistical difficulties of supplying high-frequency cathode heat.

E.E. Hammer, 1981, "Peak and RMS Starting Voltage Procedure for Standard/Low Energy Fluorescent Lamps," Journal of the Illuminating Engineering Society 10(4):204.

2.2 Breakdown Observation

The nature of the breakdown phenomenon varies widely as a function of applied frequency and lamp type. At 60 Hz the admittance of the lamp is greater than that of the inherent capacitance between the lamp and the starting aid. Therefore, the entire length of the lamp glows when Vp is reached. At frequencies greater than 10 kHz, the capacitive admittance "shorts out" the voltage at the middle of the lamp, and only the ends glow.

At intermediate frequencies, both phenomena can occur at different voltages. The end glow occurs at lower voltages, and is extremely difficult to detect. The circuit depicted in Figure 1 includes a very sensitive bridge circuit that detects end glow. With applied voltage set well below Vp, R_1 and C_1 are adjusted for minimum signal on the oscilloscope. When breakdown occurs, the lamp becomes nonlinear, and distorts the current waveform in that leg of the bridge. At intermediate frequencies, the breakdown can be very subtle and gradual.

2.3 Peak Voltage

To determine Vp, the Vp voltage source was gradually increased until a change in the waveshape occurred. For intermediate frequencies a subtle change occurred at a lower voltage (end glow) and at a higher voltage, a much more obvious change occurred. Both voltages were recorded.

2.4 Rms Voltage

Figure 2 shows the circuit for finding the rms breakdown voltage V_A. This circuit permits independent control of all three voltage sources, V_k, V_p, and V_A where V_k is the cathode voltage. The phase-lock generator is not necessary at 60 Hz because the power mains are of one coherent frequency. At other frequencies, the phase-lock generator is necessary to make the Vp and Va sources coherent.

The ballast resistor was adjusted for a lamp current of 0.43 A with 236 volts applied to the lamp and ballast in series. This is similar to the ANSI 236-volt reference circuit except that a resistor is used instead of an inductor. The impedance of the resistor is relatively constant over the frequency range of interest.

To find the rms breakdown voltage Va, first apply at least twice the value of Vp between the high-potential cathode and the starting aid. Gradually increase the Va voltage source, carefully monitor the voltage across the lamp, and note when the lamp voltage reaches a maximum, then starts to decrease. This maximum lamp voltage is Va, at which the transition from abnormal glow to arc mode occurs.

3.0 RESULTS

Figures 3 through 6 show the values of V_p and V_A for the three types of lamps at 10^oC and 25^oC ambient. Although data for cathode heat voltages of 2.5, 3.6, and 4.0 were obtained, only that for 3.6V is presented here because there was little change in results for the other two values of cathode heat voltages. Experimental 60 Hz data by Hammer[1] is included on the graphs where possible.

4.0 DISCUSSION

The most salient results of this experiment are the high V_p requirements of uncoated 35-watt lamps at 60 Hz and the high V_A requirements of coated 35-watt lamps at high frequencies. The internal conductive coating, which was furnished for improving 60-Hz starting, turns out to be detrimental at high frequencies.

The peak breakdown voltage, V_p, between the high potential cathode and the external starting aid varies significantly as a function of lamp type, frequency, and ambient temperature. At 60 Hz, the uncoated 35-watt lamp requires 370 volts versus 160 volts for the internally coated lamp. The internal coating intensifies the electric field near the ends of the lamp, thereby permitting a lower overall applied starting voltage. At higher frequencies, the internal starting aid still reduces the V_p requirement, but to a lesser extent. For the 40-watt lamp, the V_p versus frequency graphs are confusing between 1 kHz and 8 kHz. It was difficult to observe breakdown phenomena in this range on the 40-

watt lamp. End glow was obscured by the cathode heat glow, and could only be inferred from the change of waveshape on the oscilloscope.

The internal conductive coating on the 35-watt lamp increased the rms breakdown voltage, V_A, from 125 volts to 200 volts at 60 Hz, and from 100 volts to 270 volts at 30 kHz. The conductive coating is capacitively coupled to the arc, and tends to short out the voltage across the lamp. The higher the frequency, the greater the capacitive coupling and accompanying increase in V_A requirements. The V_A requirements are relatively independent of frequency for the 40-watt lamp.

An increase in ambient temperature lowered the V_p and V_A requirements in most cases. The overall frequency range of operation is of interest for future designs when ballasts can be made efficiently for operation at higher frequencies. The three potential frequency ranges in use today are 50-60 Hz (power mains), 400 Hz (aircraft), and 20 - 50 kHz (solid-state ballasts). Frequencies between 400 Hz and 20 kHz are undesirable because of audible noise.

Data were taken for cathode heat voltages of 2.5, 3.6, and 4.0 volts. These voltages are minimum, rated, and maximum voltages per ANSI. There was so little variation in the results over this range of cathode voltage that only the data for 3.6 volts have been measured. Experimental results by Hammer[1] also show very little change for this range of cathode voltages.

5.0 CONCLUSIONS

The starting peak voltage requirement is lower at frequencies above 10 kHz for the F40-watt lamps. The conductive coating for the F40 (35-watt) lamps is needed so that the 60-Hz ballast will start the lamps at a reasonable voltage. The rms starting voltage increases with frequency for the coated F40 (35-watt) lamps. At high frequency the peak and rms voltage requirements are least for an uncoated F40 (35-watt) lamp.

6.0 ACKNOWLEDGEMENTS

The author would like to thank E.E. Hammer of the General Electric Company for helpful advise and for providing the uncoated 35-watt lamps.

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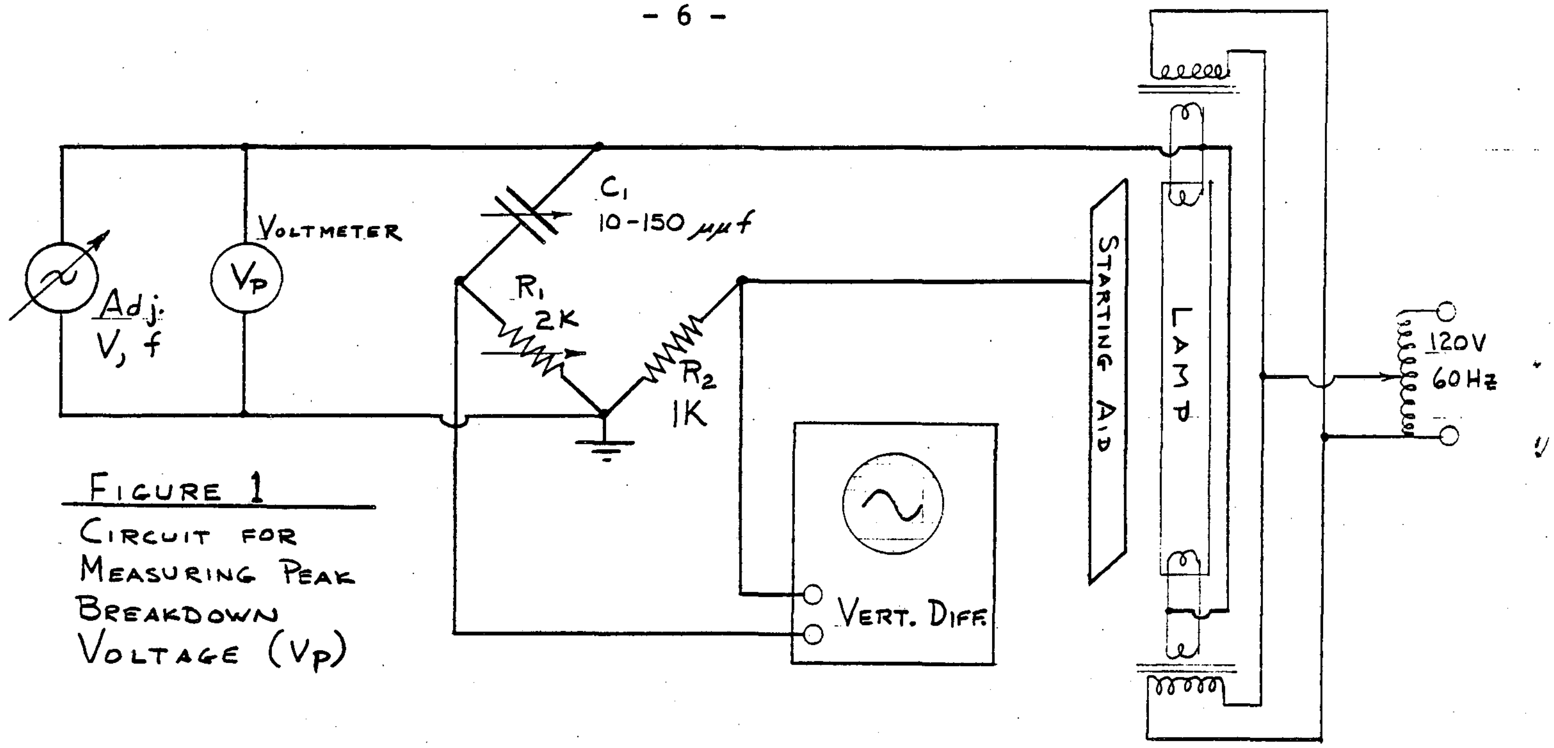


Figure 1

Circuit for Measuring Peak Breakdown Voltage (Vp)

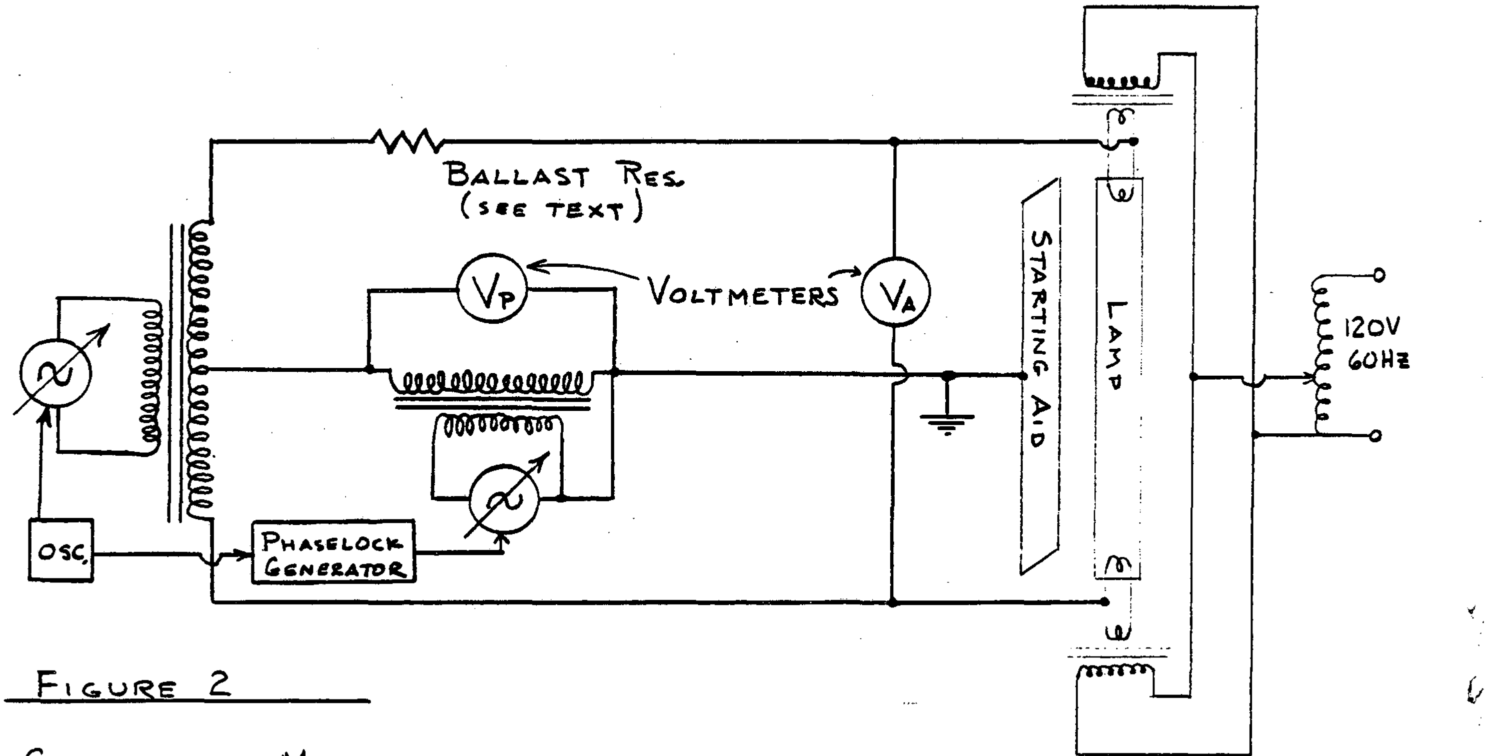


Figure 2

Circuit for Measuring RMS Breakdown Voltage (VA)

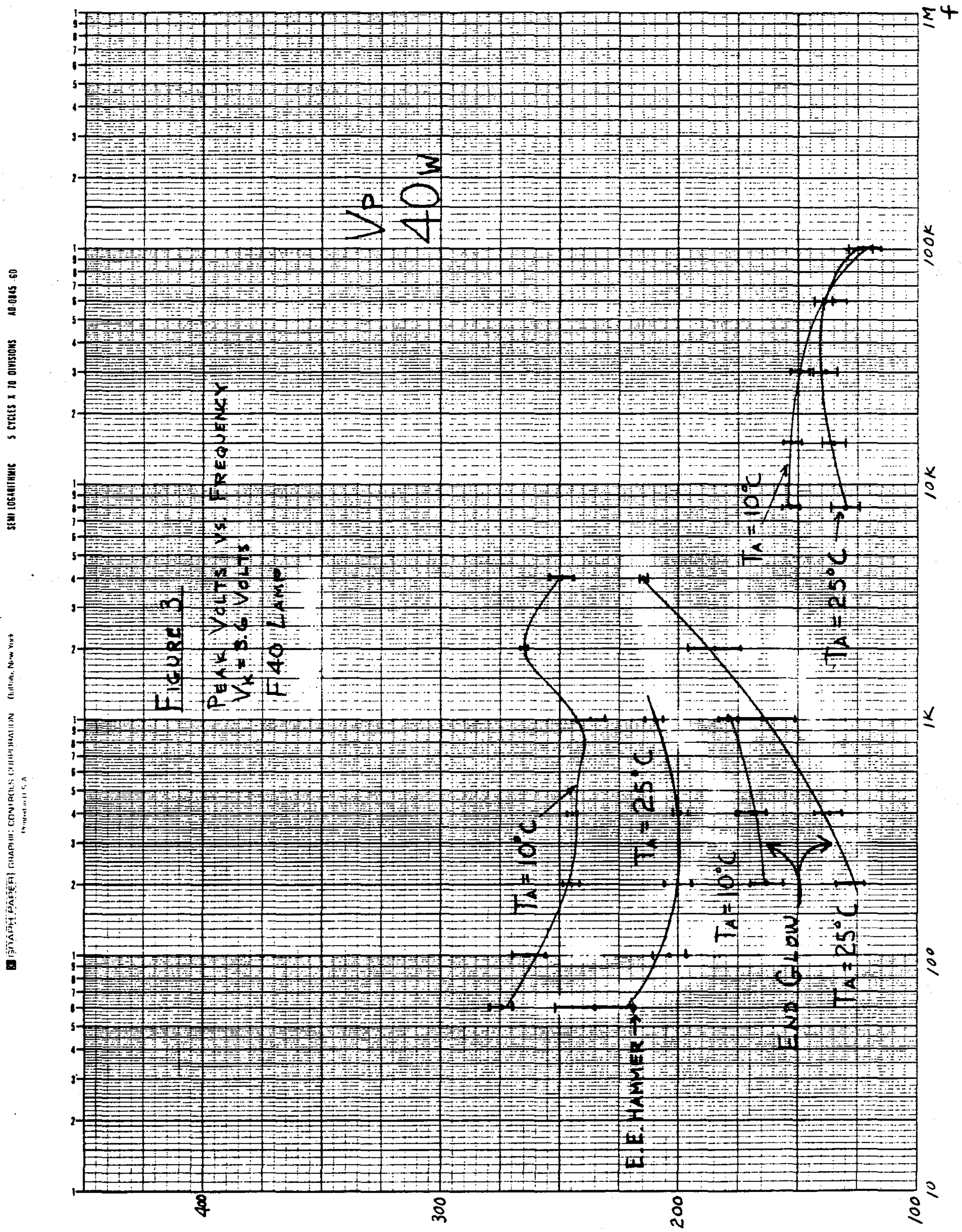
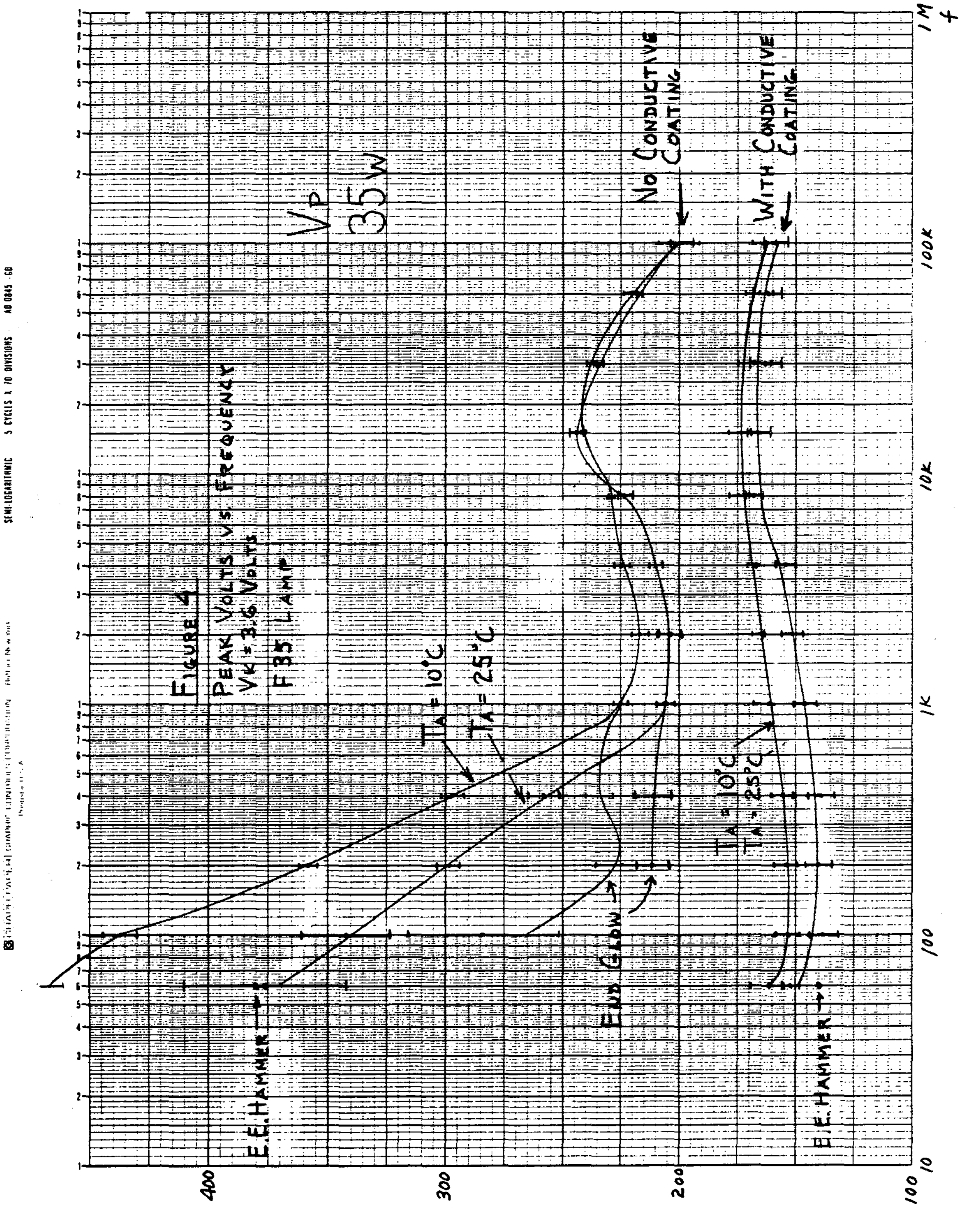


FIGURE 3
PEAK VOLTS VS. FREQUENCY
V_K = 3.6 VOLTS
F40 LAMP
Vp
40W
T_A = 10°C
T_A = 25°C
T_A = 10°C
T_A = 25°C
T_A = 10°C
T_A = 25°C
E.E. HAMMER
END GLOW
400
300
200
100
10
100
1K
10K
100K
1M
f
SEMI LOGARITHMIC
5 CYCLES X 70 DIVISIONS


SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS AD 0845 GO
FIGURE 4
PEAK VOLTS VS FREQUENCY
VK = 3.6 VOLTS
F35 LAMP
VP
35 W
TA = 10°C
TA = 25°C
END GLOW
NO CONDUCTIVE COATING
WITH CONDUCTIVE COATING
TA = 10°C
TA = 25°C
E.E. HAMMER
E.E. HAMMER
400
300
200
100
10
100
1K
10K
100K
1M

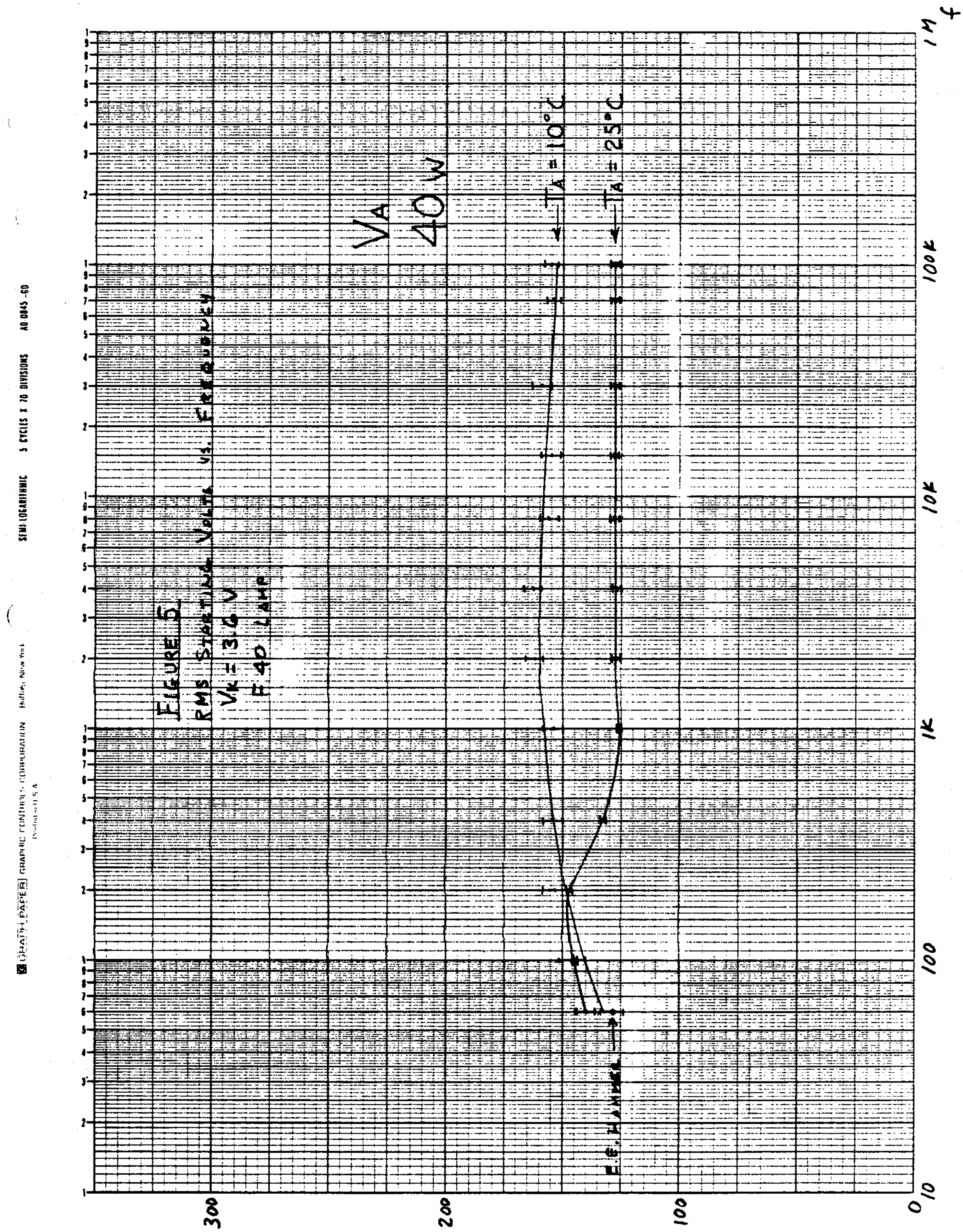


FIGURE 5
RMS STARTING VOLTS VS. FREQUENCY
VK = 3.6 V
F 40 LAMP
VA
40 W
TA = 10°C
TA = 25°C
E.E. HAMMER
300
200
100
0
10
100
1K
10K
100K
1M
f
SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
GRAPHIC CONTROLS CORPORATION

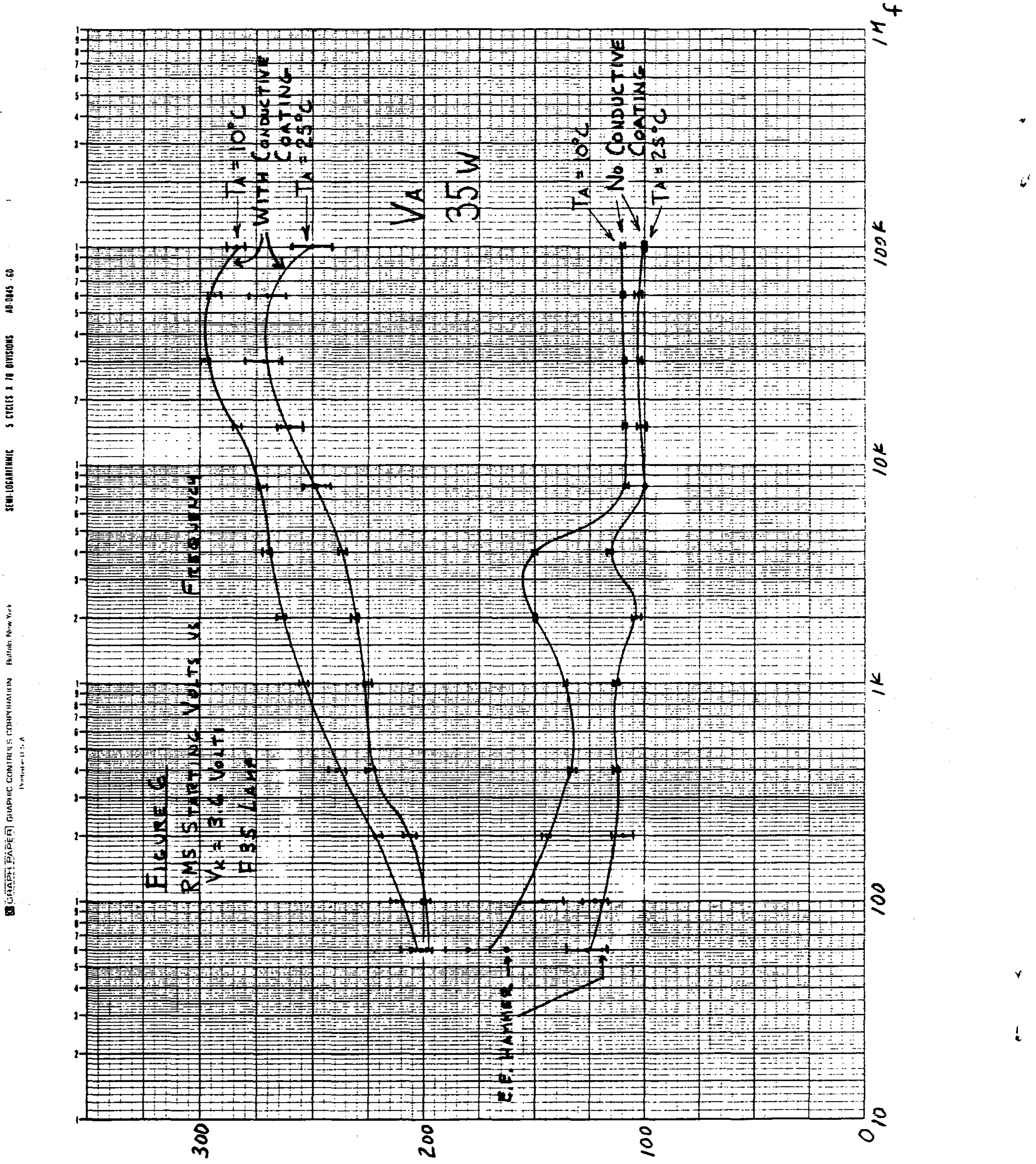


FIGURE 6
RMS STARTING VOLTS vs FREQUENCY
Vk = 3.6 VOLTS
F35 LAMP
VA
35W
TA = 10°C
WITH CONDUCTIVE COATING
TA = 25°C
TA = 10°C
NO CONDUCTIVE COATING
TA = 25°C
E.P. HAMMER
300
200
100
0
10
100
1K
10K
100K
1M
f
GRAPH PAPER GRAPHIC CONTROLS CORPORATION Buffalo, New York
SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS AB-0845-60

APPENDIX 1

Apparatus

Mfr.	Apparatus	Application
ENI	EGR-1600 Watt Amplifier	V_A Source 8 kHz -100 kHz
ENI	EGR-800 Watt Amplifier	V_p Source 8 kHz -100 kHz
Dynaco	Mark III 60 Watt Amplifier	V_A Source 100 Hz - 4kHz
Newcomb	E-10B 10 Watt Amplifier	V_p Source 100 Hz - 4kHz
Wavetek	186 Phase Lock Generator	Phase Lock, 100 Hz - 100 kHz
Tektronix	7623A Oscilloscope	Monitor
Clarke-Hess	255 V-A-W Meter (2 ea)	V_A and V_p Monitor

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