Efficiency and stroboscopic effect of fluorescent lamps as affected by circuit characteristics
by Ralph B Hammerstrom

A THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering
Montana State University

Abstract:
The purpose of this investigation was to determine the stroboscopic effect and efficiency of fluorescent lamps as affected by circuit characteristics* The tests were made on standard two-lamp circuits with a third lamp in series, using standard 15-watt and 20-watt, white fluorescent lamps* The efficiency of the 15-watt, lamp circuits increased from 3.38 relative-lumens per watt for the 15-watt, two-lamp circuit to 3.52 relative-lumens per watt for the three-lamp circuit. The efficiency of the 20-watt, lamp circuits increased from 3.36 relative-lumens per watt for the two-lamp circuit to 4.31 relative-lumens per watt for the 20 watt three-lamp circuit* The percentage of deviation of light output or stroboscopic effect were 6 and 11 per cent for the 15-watt and 20-watt, three-lamp circuits respectively. The percentage of deviation of light output of a two-lamp circuit is 16 per cent * A secondary consideration was the harmonic content of the line current. Harmonic content was 24 per cent of the fundamental for the 15-watt, three-lamp circuit and 16 per cent of the fundamental for the 20-watt, three-lamp circuit. The harmonic content of the line current of a two-lamp circuit is approximately 20 per cent of the fundamental.

EFFICIENCY AND STROBOSCOPIC EFFECT OF FLUORESCENT LAMPS AS AFFECTED BY CIRCUIT CHARACTERISTICS

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ABSTRACT

The purpose of this investigation was to determine the stroboscopic effect and efficiency of fluorescent lamps as affected by circuit characteristics.

The tests were made on standard two-lamp circuits with a third lamp in series, using standard 15-watt and 20-watt, white fluorescent lamps.

The efficiency of the 15-watt, lamp circuits increased from 3.38 relative-lumens per watt for the 15-watt, two-lamp circuit to 3.52 relative-lumens per watt for the three-lamp circuit. The efficiency of the 20-watt, lamp circuits increased from 3.36 relative-lumens per watt for the two-lamp circuit to 4.31 relative-lumens per watt for the 20 watt, three-lamp circuit.

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A secondary consideration was the harmonic content of the line current. Harmonic content was 24 per cent of the fundamental for the 15-watt, three-lamp circuit and 16 per cent of the fundamental for the 20-watt, three-lamp circuit. The harmonic content of the line current of a two-lamp circuit is approximately 20 per cent of the fundamental.

I INTRODUCTION

The purpose of this investigation was to determine the stroboscopic effect and efficiency of fluorescent lamps as affected by circuit characteristics.

The stroboscopic effect of fluorescent lamps is a matter of considerable discussion among illumination engineers, opthalmologists and optometrists. Morgan[1] states that Pacific Northwest opthalmologists and optometrists report that 20 to 33 1/3 per cent of all patients say eyestrain was first noticed when they started working under fluorescent lamps. Morgan[1] also wrote, "As to the stroboscopic effect, this is an obvious defect in fluorescent lighting."

The largest use of fluorescent lamps is on alternating current sources. The light output of fluorescent lamps follows the cyclic current variations. Therefore, the light output drops almost to zero, except for phosphorescent effects, when the current drops to zero. Such variations in the light output are termed the stroboscopic effect and are measured as the per cent of deviation of light output from the mean.

Commercial single-lamp installations have a per cent of deviation of 35 per cent for white fluorescent lamps and 55 per cent for daylight fluorescent lamps[2]. This has been improved by the use of two lamps operated in parallel; one leading the line voltage by 60 degrees, and one lagging by 60 degrees. The two-lamp installations reduced the stroboscopic effect to 25

per cent for daylight lamps and 16 per cent for white lamps. Operation of three daylight lamps on separate phases of a three-phase supply reduces the stroboscopic effect to 5 per cent, which is comparable to the 5 per cent deviation of 100-watt incandescent lamps and better than the 13 per cent deviation of 40-watt incandescent lamps[2]. Three white lamps on separate phases of a three-phase supply have a deviation of 3 per cent. Because of the equivalent three-phase light output of the experimental circuits, a 3 per cent deviation is theoretically possible. The three-lamps circuits investigated

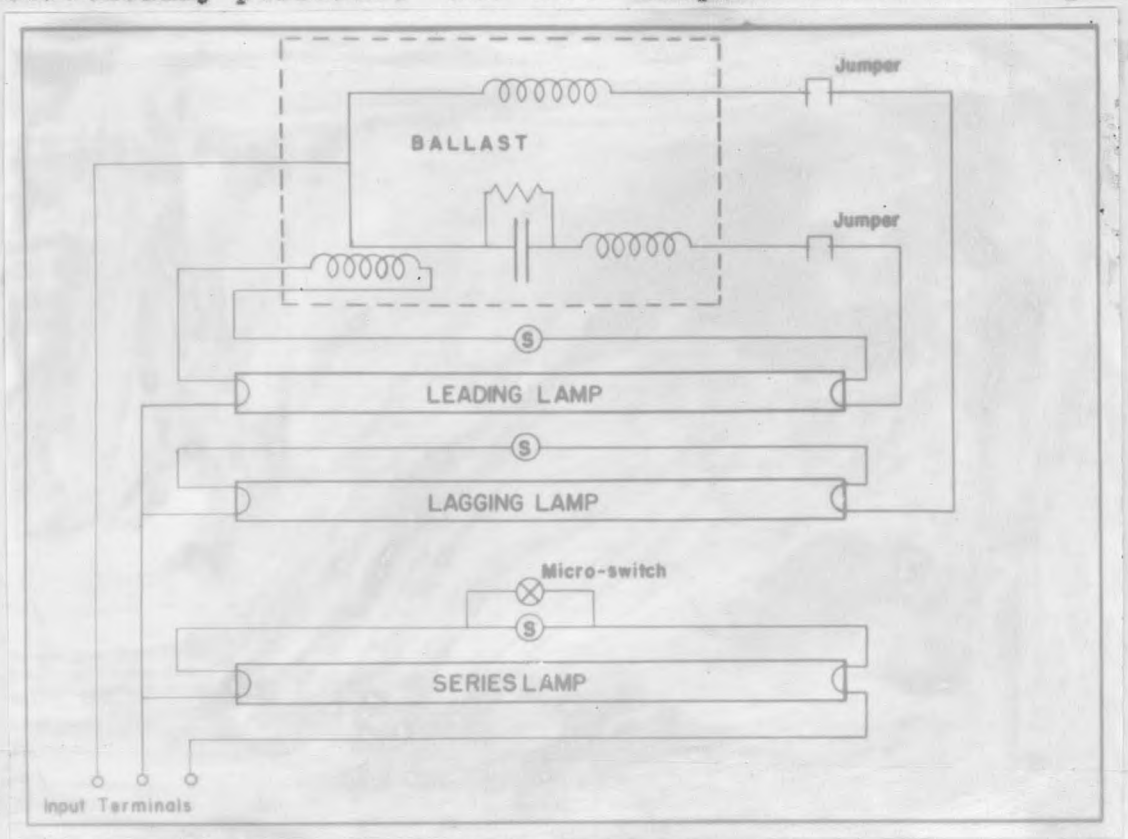


Figure 1. The schematic circuit diagram of the lamp circuits

had deviations of 6 per cent for the 15-watt circuit and 11 per cent for the 20-watt circuit.

Three-phase supply is not available at the majority of fluorescent lamp installations. Therefore, for a reduced stroboscopic effect on single-phase supply, some method of phasing lamps properly must be employed. A complicated circuit could be designed to operate satisfactorily but the primary consideration of this investigation was the use of commercially available equipment. The circuit investigated was a commercial two-lamp installation with a third lamp connected in series with the line supply and the two-lamp installation. The schematic circuit diagram is shown in Fig. 1 and the vector diagram of currents and line voltage in Fig. 2.

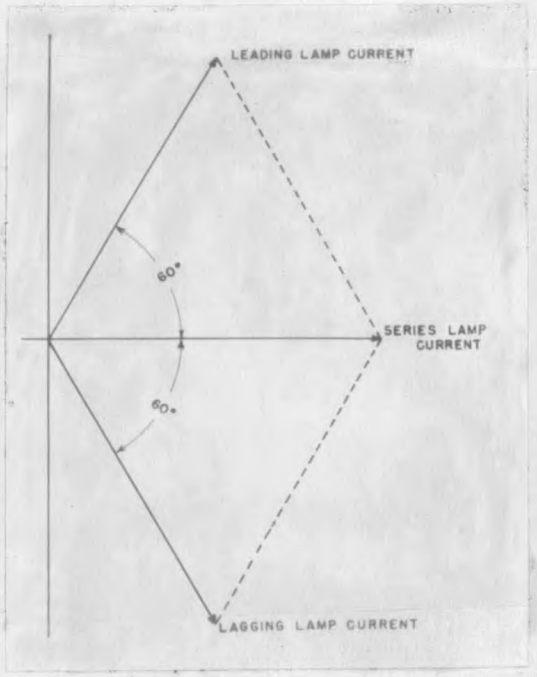


Figure 2. Vector diagram of lamp currents

The efficiency determination of the circuit that was used for this study is not a complete analysis of energy distribution. A complete analysis would involve equipment that was

not available. Factors such as the conduction and convection of heat, lumen output, radiated heat and ultra-violet conversion would have to be considered for a complete analysis[2]. Therefore, an efficiency comparison of the three-lamp circuit with a commercial two-lamp circuit using white lamps constituted the efficiency study.

Because of the effect of a distorted current wave upon the efficiency and light output, a secondary consideration of this investigation is the distortion factor of the current waves. The distortion factor is a ratio of the effective value of the harmonic content of a wave to the effective value of the total wave[3]. Peterson and Blakeslee[3] say that the distortion factor should be 0.25 or less. Using the Fourier graphical method of wave analysis, distortion factors of 0.24 for the 15-watt, three-lamp circuit and 0.16 for the 20-watt, three-lamp circuit were determined.

II EQUIPMENT AND PROCEDURES

A. Equipment

The equipment used in this investigation consisted of the following: two, three-lamp chassis shown in Fig. 3; one single-lamp chassis; a variable auto-transformer; three a-c ammeters; an a-c voltmeter; a wattmeter; a vacuum-tube voltmeter; an electronic phototube circuit; a three-stage amplifier; an icosohedron photometer; a Macbeth illuminometer;

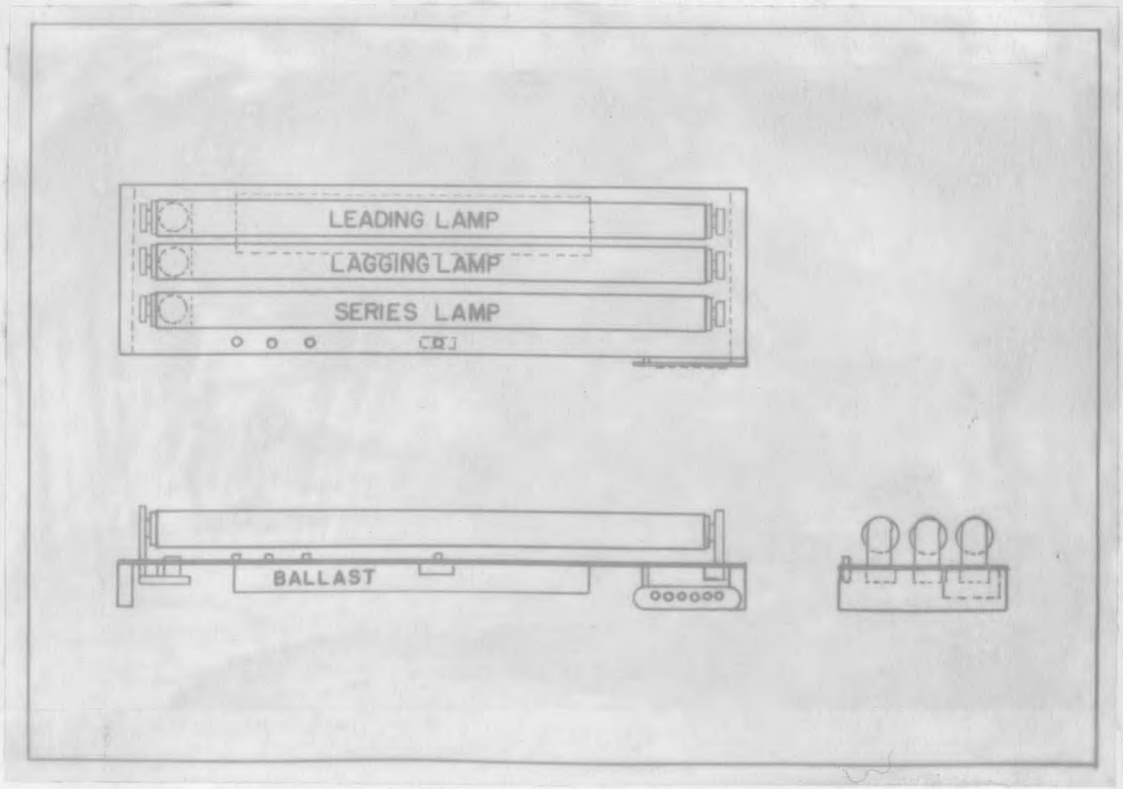


Figure 3. Lamp chassis assembly

three one-ohm shunts; and a magnetic oscillograph.

The lamp chassis were cut from masonite with wooden supports at each end. The circuit components necessary for operation were mounted on the lamp chassis as shown in Fig. 3.

General Electric TU-Lamp ballasts were used in the two, three-lamp circuits. The 20-watt lamp ballast is rated 0.45 line amperes at 118 line voltage, 60 cycle, with a full-load loss of 9 watts and a full-load power factor of over 90 per cent. The Catalog Number of the 20-watt, two-lamp ballast is 58G678. The 15-watt-lamp ballast is rated 0.35 line amperes at 118 line volts, 60-cycle, with a full-load loss of 9 watts. The Catalog Number of the 15-watt, two-lamp ballast is 58G679. The single-lamp circuit used a Jefferson Electric Corporation, 15-watt-lamp ballast. The ballast is rated at 0.16 line amperes at 118 line volts. The ballast is 218752.

The two, three-lamp chassis were supplied with three power-input terminals. One is common, and is connected to the line input of the ballast. The other two terminals are connected so that either the three-lamp series circuit or the conventional two-lamp circuit may be used. Other terminals on the lamp boards are jumper connection terminals between the ballast and lamps. FS-2, glow-type starters were installed for starting the two parallel lamps. A microswitch was installed for starting the series lamp. Provision was also made for the use

of a glow starter with the series tube. For the complete schematic circuit diagram of the three-lamp chassis, see Fig. 1.

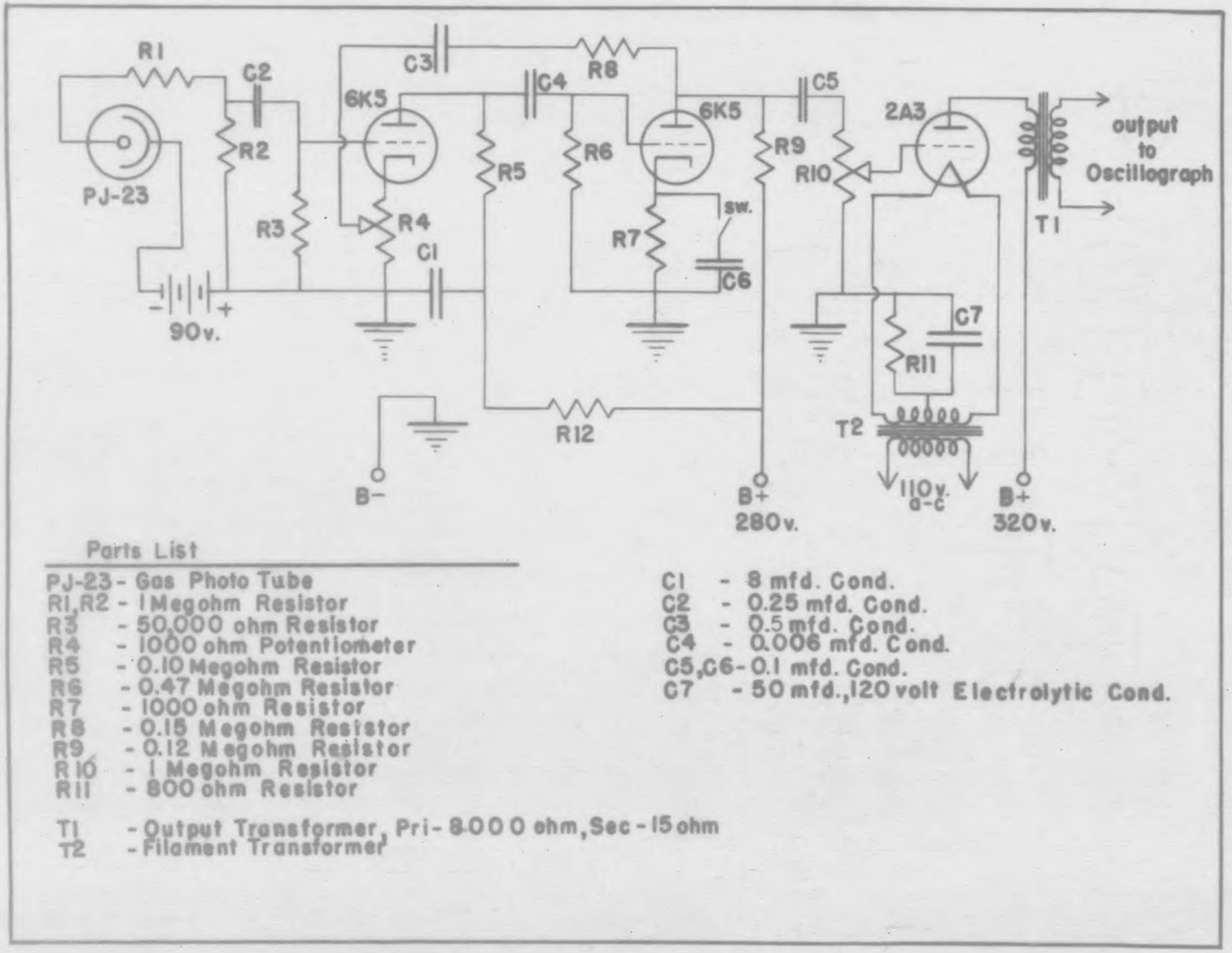
The single-lamp circuit was constructed in a similar manner as the preceding three-lamp circuits. Two line-input terminals and a jumper connection between the lamp and ballast were provided. The single, fluorescent lamp was supplied with a microswitch and a glow starter connection for starting.

The variable auto-transformer was a 220-volt, three-phase, open-delta variac.

The a-c ammeters used had a range of 0-1 amperes. Standards for calibrating the ammeters were not available, but the ammeters were checked with several available ammeters and the deviation was found to be one per cent or less from the average of all ammeter readings.

The a-c voltmeter used had two voltage ranges. The two scales were 0-150 volts and 0-300 volts. The voltmeter was calibrated with a standard and was found to have less than 0.5 per cent error per reading.

The a-c wattmeter used had two voltage ranges and two current ranges. The two voltage ranges were 0-100 volts and 0-200 volts. The two current ranges were 0-0.5 amperes and 0-1 amperes. The wattmeter was checked against a standard. Reading errors of three per cent were found. On the basis



Parts List

PJ-23 - Gas Photo Tube
R1,R2 - 1 Megohm Resistor
R3 - 50,000 ohm Resistor
R4 - 1000 ohm Potentiometer
R5 - 0.10 Megohm Resistor
R6 - 0.47 Megohm Resistor
R7 - 1000 ohm Resistor
R8 - 0.15 Megohm Resistor
R9 - 0.12 Megohm Resistor
R10 - 1 Megohm Resistor
R11 - 800 ohm Resistor

T1 - Output Transformer, Pri - 8000 ohm, Sec - 15 ohm
T2 - Filament Transformer

C1 - 8 mfd. Cond.
C2 - 0.25 mfd. Cond.
C3 - 0.5 mfd. Cond.
C4 - 0.006 mfd. Cond.
C5,C6 - 0.1 mfd. Cond.
C7 - 50 mfd., 120 volt Electrolytic Cond.

Figure 4. Schematic circuit diagram of the electronic phototube and amplifier.

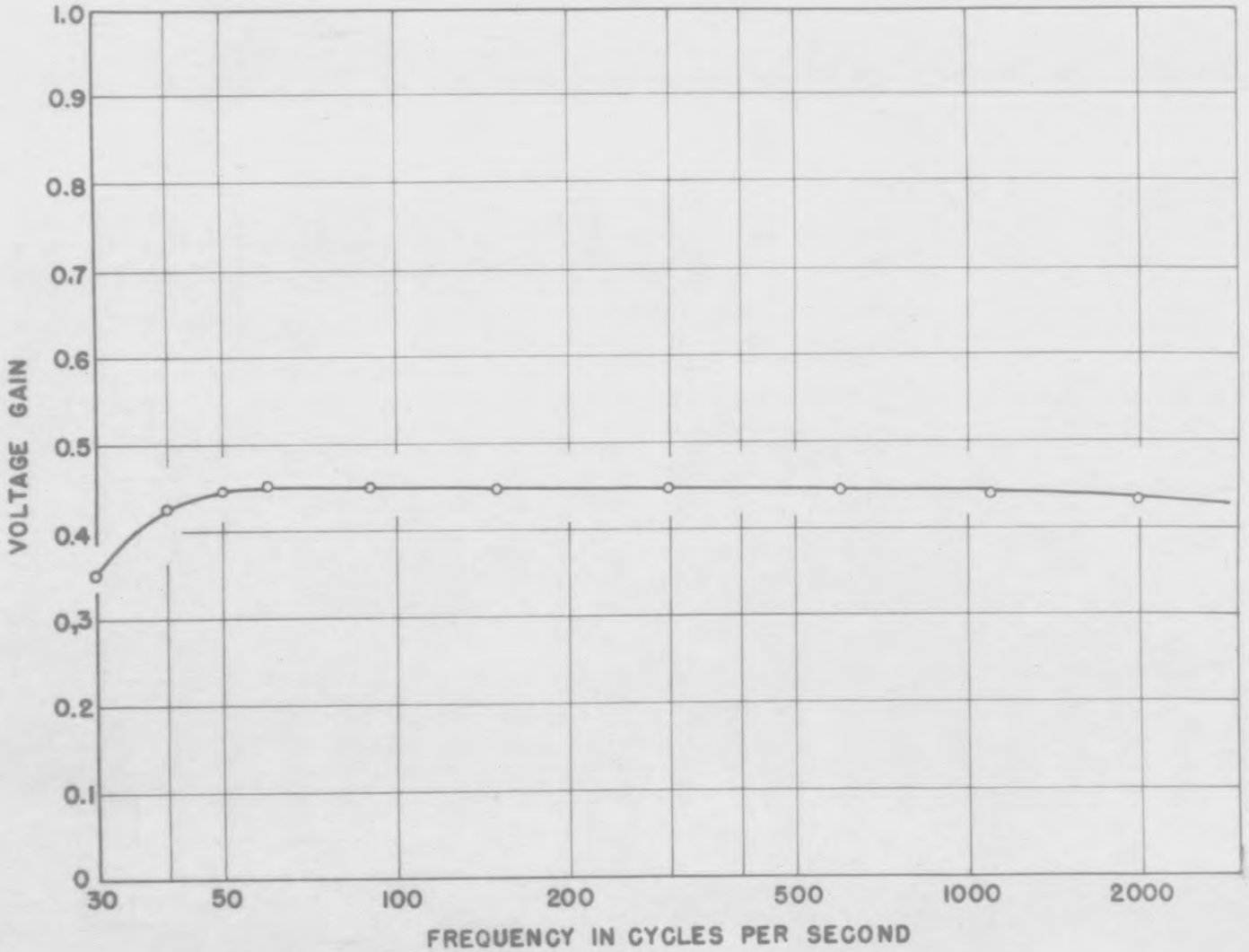


Figure 5. Frequency characteristic of the amplifier.