THE DESIGN OF A HIGH INTENSITY
STREET LIGHTING SYSTEM FOR A METROPOLITAN
BUSINESS DISTRICT

A thesis submitted to the faculties of
The School of Engineering and the Graduate School
The University of Kansas

For

THE DEGREE OF ELECTRICAL ENGINEER

By

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PREFACE

The problem which is submitted in this thesis has two general aspects,- the design or selection of the street lighting equipment proper and the selection and design of a distribution system to handle this load.

The choice of the equipment which is to perform the actual function of lighting is relatively simple. A particular lighting effect is desired and the problem is merely to choose the lamps and fixtures which will produce this effect. The standards or brackets, while of secondary importance as far as illumination is concerned, have complete bearing on the satisfactory daytime appearance of the system as seen from the street. The public is directly interested in this part of the problem.

The determination of a method or plan for supplying electrical energy to the lamps is by no means as simple a problem. The public has practically no knowledge and very little interest in this phase of the subject.

The distribution plan which is selected must be practical to build, successful to operate and economical from the standpoint of the energy losses and the investment required.

This thesis illustrates in particular the method of obtaining a solution to this latter part of the problem.

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A LIST OF ILLUSTRATIONS

A LIST OF DRAWINGS

I. INTRODUCTION

The increasing use of city streets at night, largely due to the automobile and the motion picture entertainment, is calling for better street illumination in all of our larger cities and towns.

The main business streets of any city are used the most and, consequently, require the greatest attention. The aim should be to make these streets as safe and as usable by night as by day. It has been observed that traffic accidents are less frequent on the well lighted streets.

The growing popularity of flood-lighting prominent buildings by night has combined with the need of more illumination on the street level. The merchants are demanding that their store fronts be brilliantly illuminated at night.

The artistic appearance of the lamp units by day is second in importance only to the lighting effect produced by night. This has brought about the design of fixtures and standards which will enhance the appearance of any street.

In accordance with the demand for more light it is proposed to install a modern, high intensity, illumination system on the streets of the downtown business district of Kansas City, Missouri.

GENERAL DESCRIPTION.

The section involved in the proposition extends in general from Fifth to Twenty-Fourth Streets north and south, and from Oak to Wyandotte Streets east and west. This is the main business district of the city. New lamps and appropriate fixtures are to be installed on the north and south streets and arranged as shown on the accompanying lamp layout plan.

The load which will be added to the lines of the power company will amount to approximately 50 per cent of the present street lighting load of the entire city. This increase may possibly be extended over a period of several years.

PRESENT LOAD IN THE DISTRICT.

The present street lights in this district on the east and west streets will not be increased but will be included in the new system. This load consists of 181, 6,000-lumen lamps and 80, 15,000-lumen lamps, a total load of 125 kilowatts. All of the lamps on the north and south streets will be changed. There are at present on these streets 63, 4,000-lumen and 653, 6,000-lumen lamps, which make a total load of 233 kilowatts.

ULTIMATE LOAD IN THE DISTRICT.

The present lamps on the north and south streets will be replaced by 1,216, 15,000-lumen lamps on the narrow streets and by 414, 25,000-lumen lamps on the wider streets --Oak Street and Grand Avenue--which will make a total load of 1,510 kilowatts. This added to the load of 125 kilowatts on the east and west streets will make an ultimate load of 1,635 kilowatts which must be handled by the distribution system. The load center falls at Fourteenth and Walnut Streets.

By the removal of the present lamps on the north and south streets and the transfer of those on the east and west streets to the new system, 23 series, street lighting circuits will be cut off from the present street lighting feeders. Each of these series circuits is fed from a 20-kilowatt, 2,300-volt, constant-current transformer. The primary current of each transformer is 12.5 amperes. Ten of the circuits to be removed are supplied from Substation "A". This substation, therefore, will lose 125 amperes or 300 kilovolt-amperes of load, based on an average primary, phase-to-neutral voltage of 2,400 volts at the substation. Substation "D" will lose 4 circuits or 120 kilovolt-amperes and Substation "P" will lose 9 circuits or 270 kilovolt-amperes of load.

METHOD OF CONSIDERATION.

It appears that the present system of operating street lighting circuits in Kansas City if merely expanded to provide for this new load, will be uneconomical, cumbersome and impractical. In order to determine a more desirable method of operation, four additional plans will be investigated and compared in this discussion with the present method.

The design of the lamp system in itself will be the same for all of the plans, but the manner of supplying the lamps will be totally different.

The five plans for supplying the lamp circuits to be considered are as follows--

No. 1 - A series-multiple plan using 20-kilowatt, 2300-volt, pole type, constant-current transformers. This plan would be an extension of the present method of operating the street lighting circuits.

No. 2 - A 115/230-volt multiple plan whereby the lamps in the direct-current district would be supplied from the Edison, three-wire, direct-current system. Outside of the direct-current district the lamps would be connected to 115/230-volt secondary lines from 2300-volt distribution transformers.

No. 3 - A series-multiple plan using 70-kilowatt, 13,200-volt, station-type, constant-current transformers.

No. 4 - A series-multiple plan whereby the lamps are to be operated in series directly from the 2300/4000-volt feeders with fuse protection but without the constant-current transformer.

No.5 - A series-multiple plan for operating the lamps in series on 4000-volt secondaries from 13,200/4,000-volt constant-potential, station transformers.

The incoming 13,200-volt lines supplying the substations are considered as the final source of supply in each plan. The calculations are carried back to these feeders.

The typical layouts of the electrical circuits of each plan show the method of operation and suggest the advantages and disadvantages of each.

The annual fixed investment charge and the cost of the lost energy will show which plan is the most economical to install and to operate.

II. LIGHTING SYSTEM

The streets which run north and south in the down-town business district range in width from 36 to 70 feet from curb to curb as shown below-

Oak Street	60 feet
McGee Street	40 feet
Grand Avenue	70 feet
Walnut Street	56 feet
Main Street	48 feet
Baltimore Avenue	37 feet
Wyandotte Street	36 feet

The average distance parallel to the street between the lamp standards will be 100 feet. They will be located opposite each other except in a few places along the edges of the district. There will be two lamps on each standard or pole. A lamp rated at 25,000-lumens was proposed for Oak Street and for Grand Avenue. For the other streets a 15,000-lumen lamp was chosen on a trial basis.

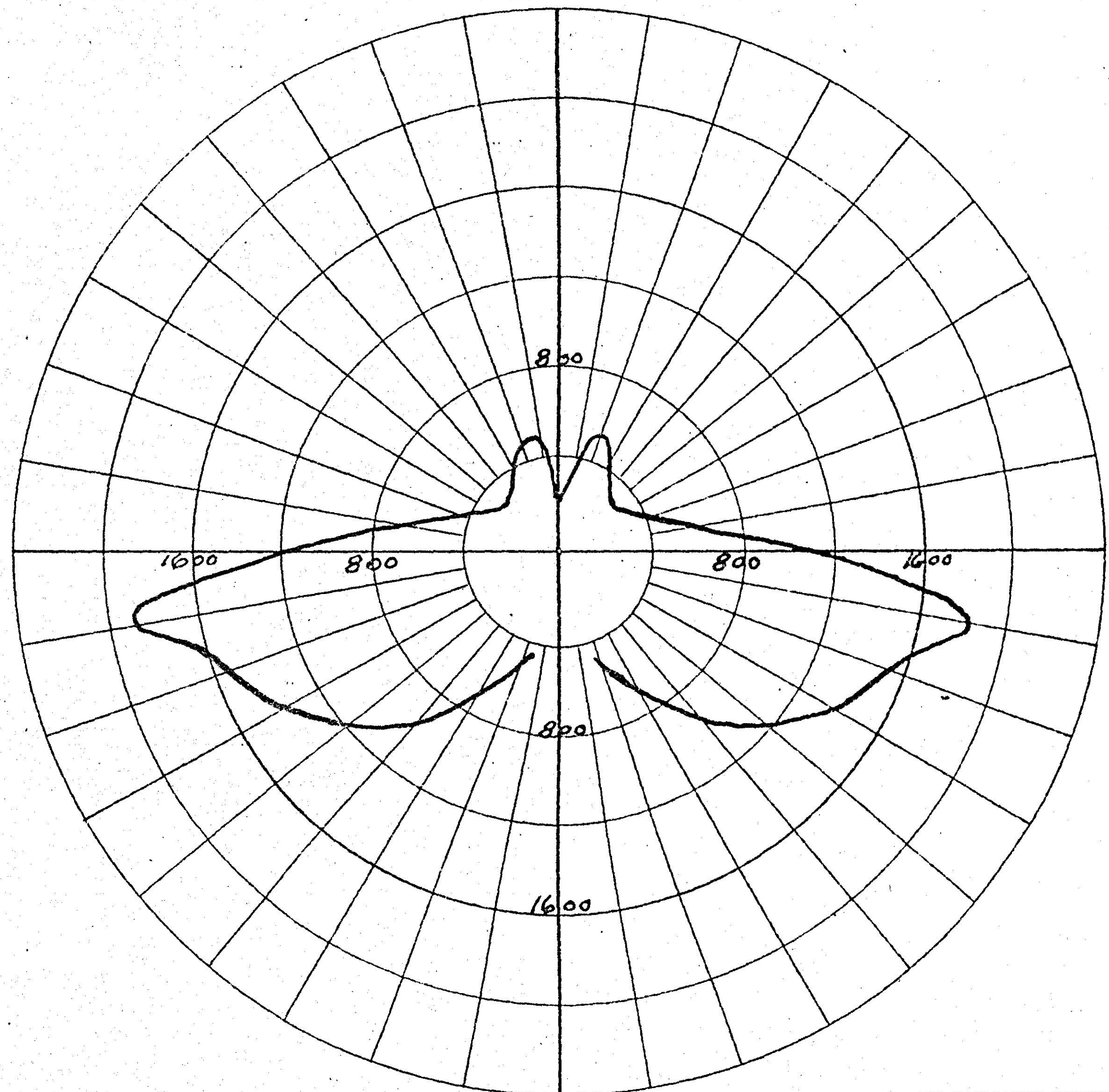
The manufacturers suggest illumination values of from 300 to 800 lumens per lineal foot on the main business streets. With a spacing of 100 feet between the lamps on the streets in this district there will be 600 generated lumens per foot on the narrow streets and 1000 generated lumens per foot on Oak Street and on Grand Avenue.

The distribution curves of these lamps and fixtures, Figures 1 and 2, show that the total light from them will be 11000 and 18300 lumens. This is 440 and 772 lumens per lineal foot on the street which is well within the recommendations.

The manufacturers suggest an average of between 1.3 and 3.0 foot candles intensity of illumination on the streets. The curves, Figures 3 and 4, show the point-to-point and the average foot-candle intensity of illumination on the streets in this district both with the 15,000-lumen lamps and with the 25,000-lumen lamps. In view of the recommendations of the manufacturers the 25,000-lumen lamp was then definitely selected for Oak Street and for Grand Avenue, and the 15,000-lumen lamp for the other streets. The arrangement and location of the lamps is shown on the Map, Fig. 5.

The lamp on the street side of the standard or pole will burn all night. The one next to the building will be turned off at one o'clock in the morning. The street lighting schedule calls for a total of 4000 hours burning of the all-night lamps and for 2000 hours burning of the one-o'clock lamps.

TRANSFORMER	II
LAMP	CLEAR
VOLTS	122
AMPERES	6.6-20.
WATTS (INCLUDES TRANS. LOSS)	806
DOWNWARD LUMENS	7920
MEAN SPHERICAL CANDLE POWER	876
TOTAL LUMENS	11000



PHOTOMETRIC TEST

DISTRIBUTION OF CANDLE POWER IN 2 VERTICAL PLANES

READINGS TAKEN AT 25 FT. RADIUS

CLEAR LAMP OPERATED AT 15000 TOTAL LUMENS

NO. 124 LIGHT ALABASTER RIPPLED GLASS GLOBE

NO. 1124 LIGHT ALABASTER RIPPLED GLASS CANOPY

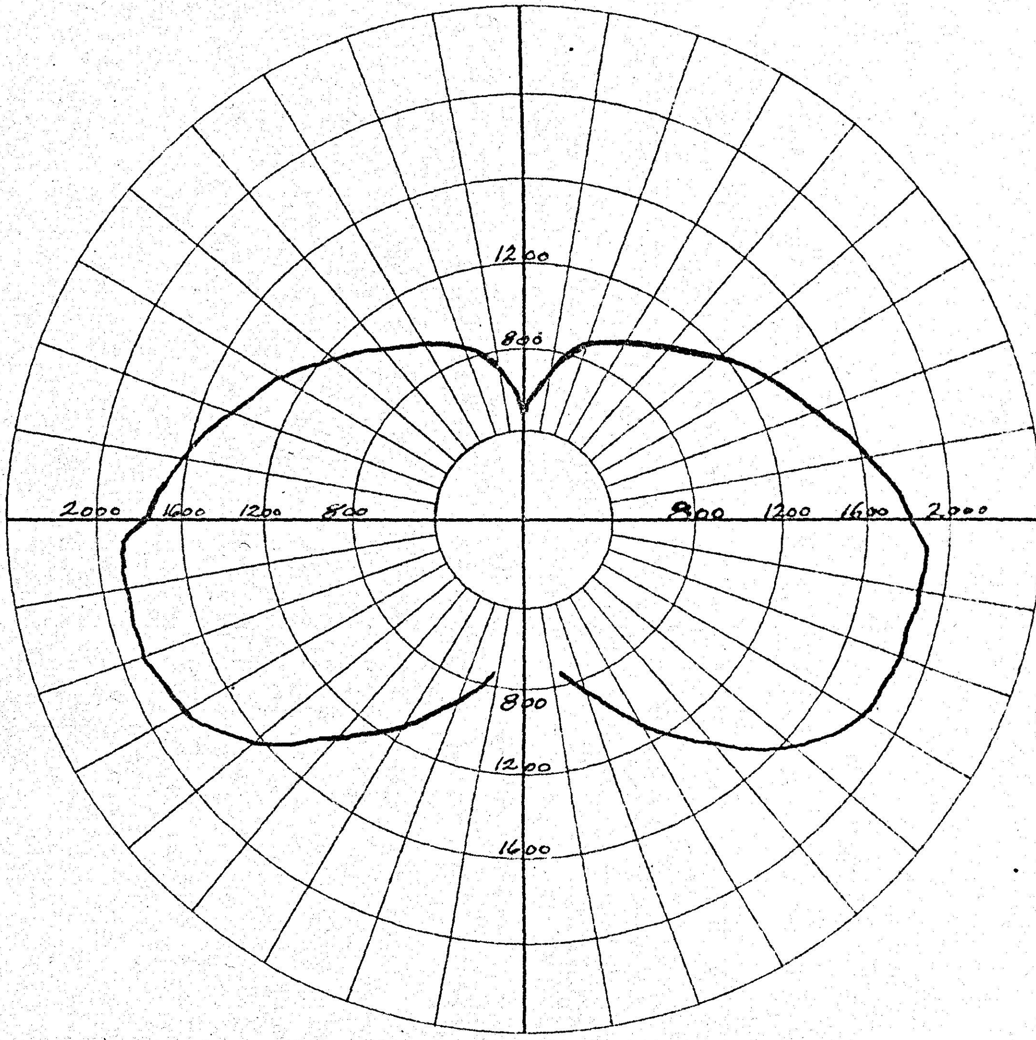
8½" HOLOPHANE PRISMATIC DOME REFRACTOR

FIG. 1.

ZONE 0 TO	LUMENS
10	
20	
30	289
40	830
50	1700
60	2860
70	4340
80	6230
90	7920

DRN. BY- [illegible]

TRANSFORMER	IL
LAMP	CLEAR
VOLTS	122
AMPERES	6.6 - 20
WATTS (INCLUDES TRANS. LOSS)	1277
DOWNWARD LUMENS	8850
MEAN SPHERICAL CANDLE POWER	1320
TOTAL LUMENS	18300



PHOTOMETRIC TEST

DISTRIBUTION OF CANDLE POWER IN TWO VERTICAL PLANES

READINGS TAKEN AT 25 FT. RADIUS

CLEAR LAMP OPERATED AT 25000 TOTAL LUMENS

NO. 124 LIGHT ALABASTER RIPPLED GLASS GLOBE

NO. 1124 LIGHT ALABASTER RIPPLED GLASS CANOPY

FIG. 2.

ZONE 0 TO	LUMENS
10	
20	
30	408
40	1110
50	2160
60	3540
70	5220
80	6980
90	8850

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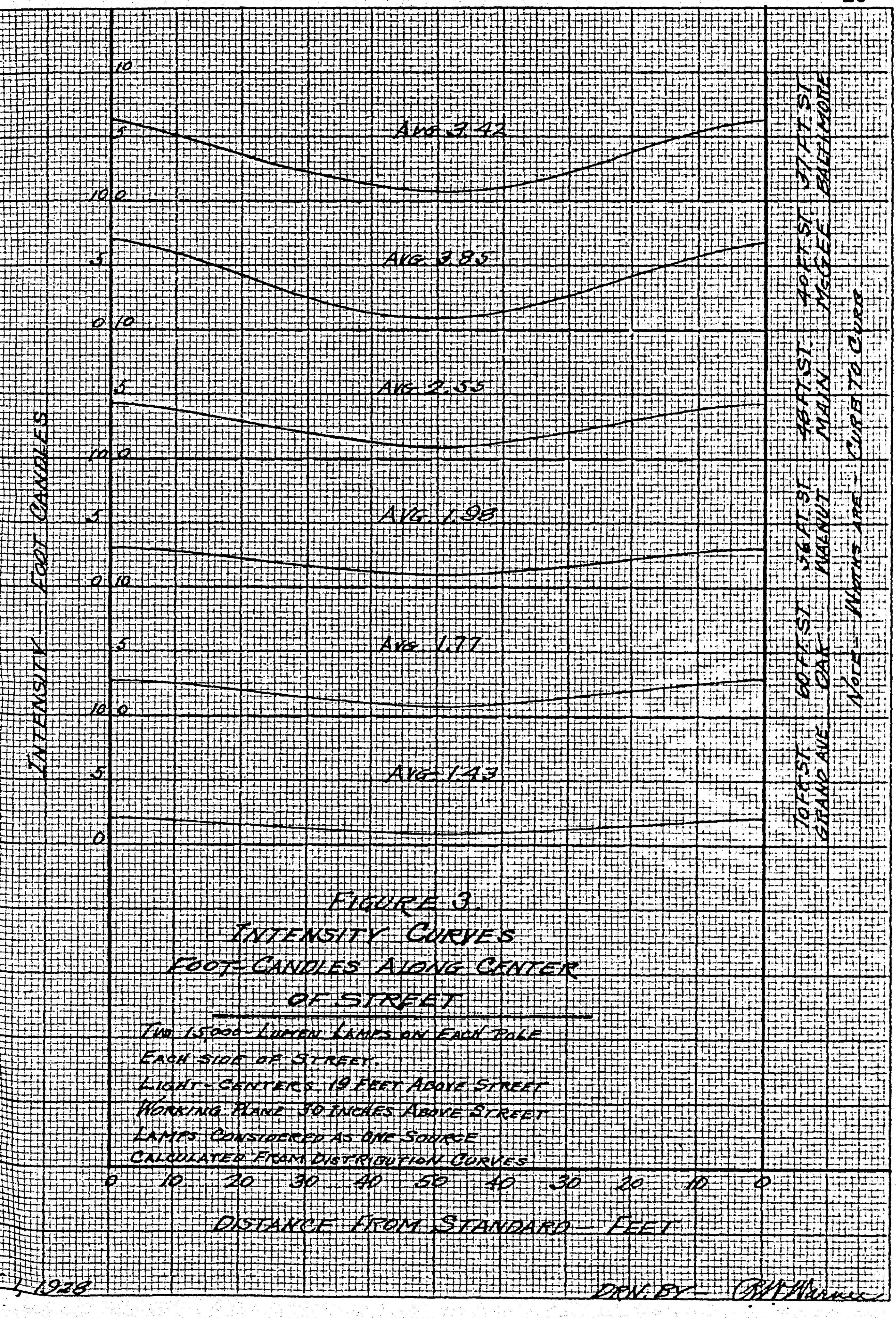


FIGURE 3.
INTENSITY CURVES
FOOT-CANDLES ALONG CENTER OF STREET

TWO 15000-LUMEN LAMPS ON EACH POLE
EACH SIDE OF STREET.
LIGHT-CENTERS 19 FEET ABOVE STREET
WORKING PLANE 30 INCHES ABOVE STREET
LAMPS CONSIDERED AS ONE SOURCE
CALCULATED FROM DISTRIBUTION CURVES

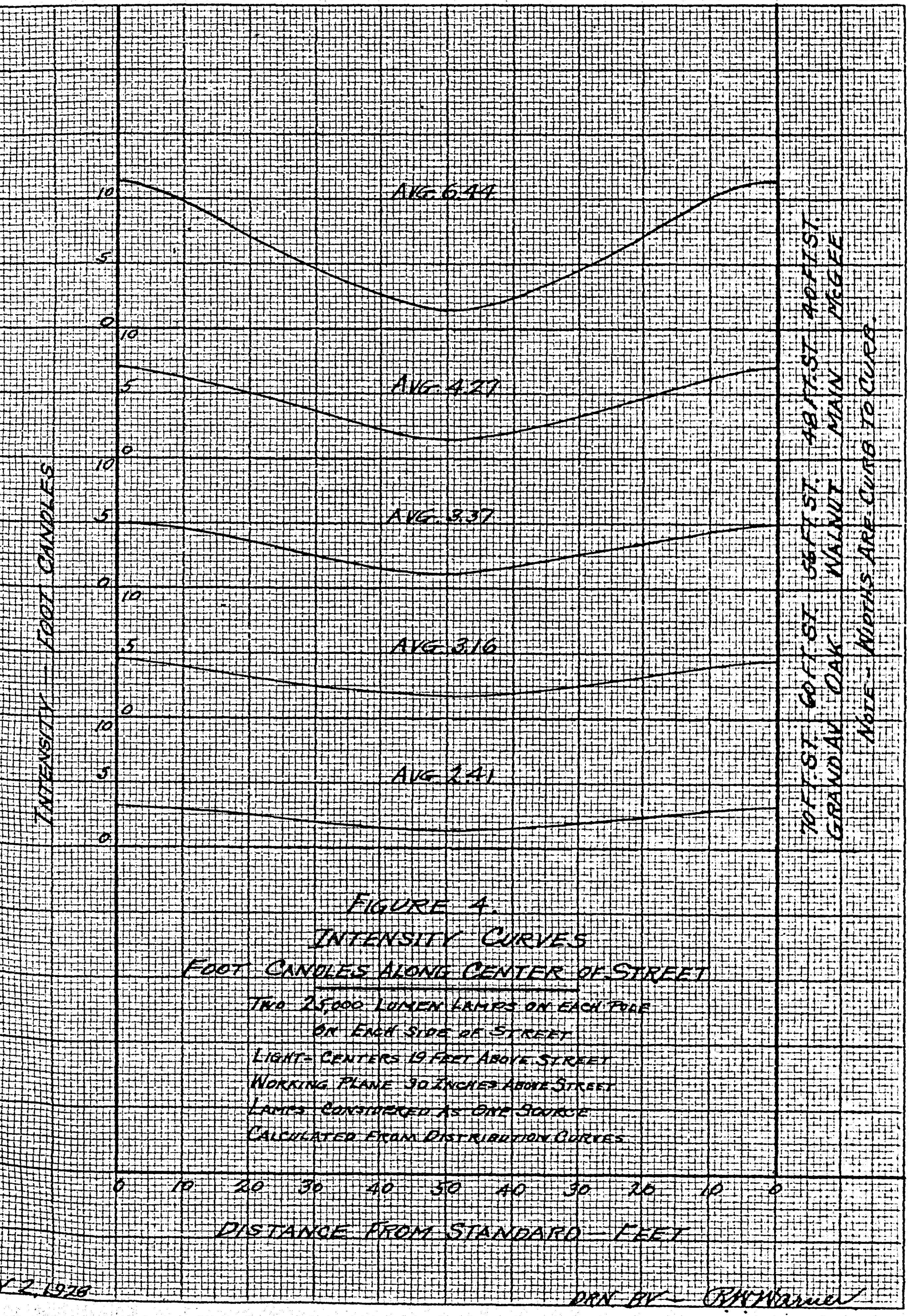
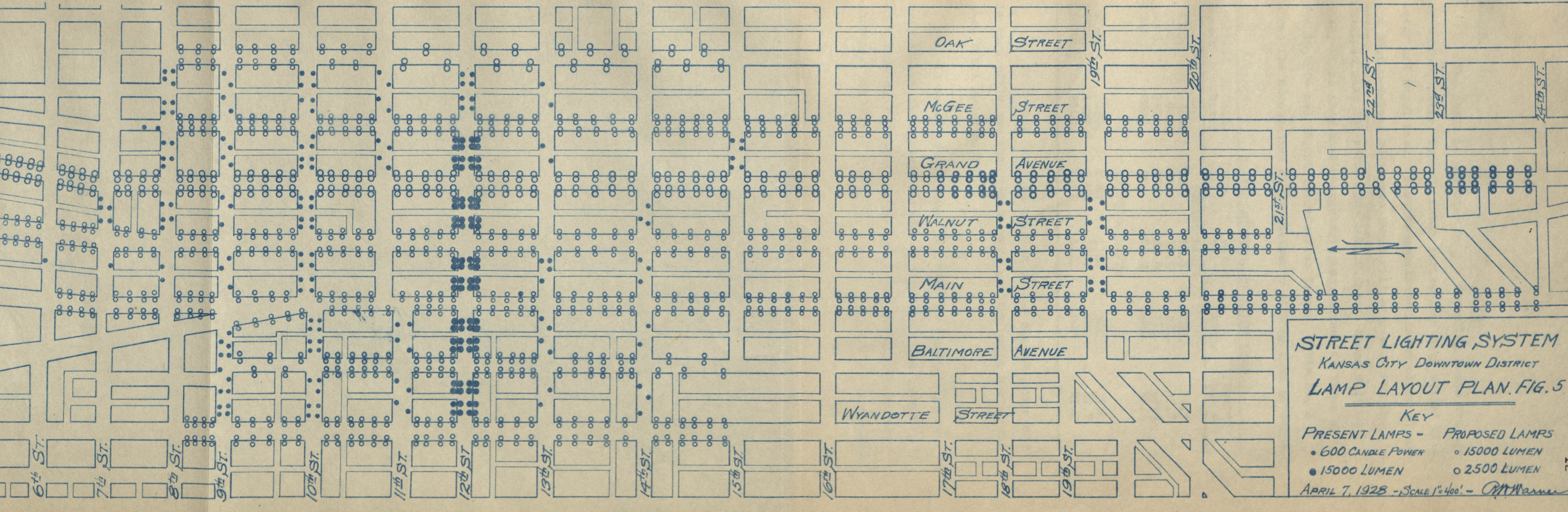


FIGURE 4.
INTENSITY CURVES
FOOT CANDLES ALONG CENTER OF STREET

TWO 25,000 LUMEN LAMPS ON EACH POLE
ON EACH SIDE OF STREET
LIGHT CENTERS 19 FEET ABOVE STREET
WORKING PLANE 30 INCHES ABOVE STREET
LAMPS CONSIDERED AS ONE SOURCE
CALCULATED FROM DISTRIBUTION CURVES



OAK STREET
McGEE STREET
GRAND AVENUE
WALNUT STREET
MAIN STREET
BALTIMORE AVENUE
WYANDOTTE STREET
6th ST.
7th ST.
8th ST.
9th ST.
10th ST.
11th ST.
12th ST.
13th ST.
14th ST.
15th ST.
16th ST.
17th ST.
18th ST.
19th ST.
20th ST.
21st ST.
22nd ST.
23rd ST.
24th ST.
STREET LIGHTING SYSTEM
KANSAS CITY DOWNTOWN DISTRICT
LAMP LAYOUT PLAN. FIG. 5
KEY
PRESENT LAMPS -
• 600 CANDLE POWER
• 15000 LUMEN
PROPOSED LAMPS
◦ 15000 LUMEN
◦ 2500 LUMEN
APRIL 7, 1928 - SCALE 1" = 400'.

LAMPS.

The lamps as selected on the foregoing basis are the 20-ampere, clear, type C, Mazda series lamp with coiled filament and mogul base. For the constant-current plans 15,000- and 25,000-lumen, 20-ampere lamps will be used. For the multiple plan 115-volt, 750- and 1000-watt lamps will be used, since they have characteristics nearest to those of the 15,000- and 25,000-lumen series lamps. Table No. I shows the comparative characteristics of both kind of lamps.

TABLE I. CHARACTERISTICS OF MAZDA LAMPS.

Initial Lumens	Candle Power	Lamp Current	Lamp Voltage	Watts	Lumens per Watt
		SERIES	LAMPS		
4000.	400.	15.	15.1	226.	17.7
6000.	600.	20.	16.0	321.	18.7
15000.	1500.	20.	38.6	773.	19.4
25000.	2500.	20.	61.3	1225.	20.4
		MULTIPLE	LAMPS		
5280.	528.	2.61	115.	300	17.6
14775.	1477.5	6.52	115.	750	19.7
21000.	2100.	8.70	115.	1000	21.0

From this table it is seen that a single large unit is more efficient than two or more smaller units having the same total power rating.

It is extremely important that the Mazda lamps be operated at the correct current or voltage. The operating of a lamp at a current or voltage above the normal greatly shortens its life. If the current or voltage is below normal the illumination is greatly reduced.

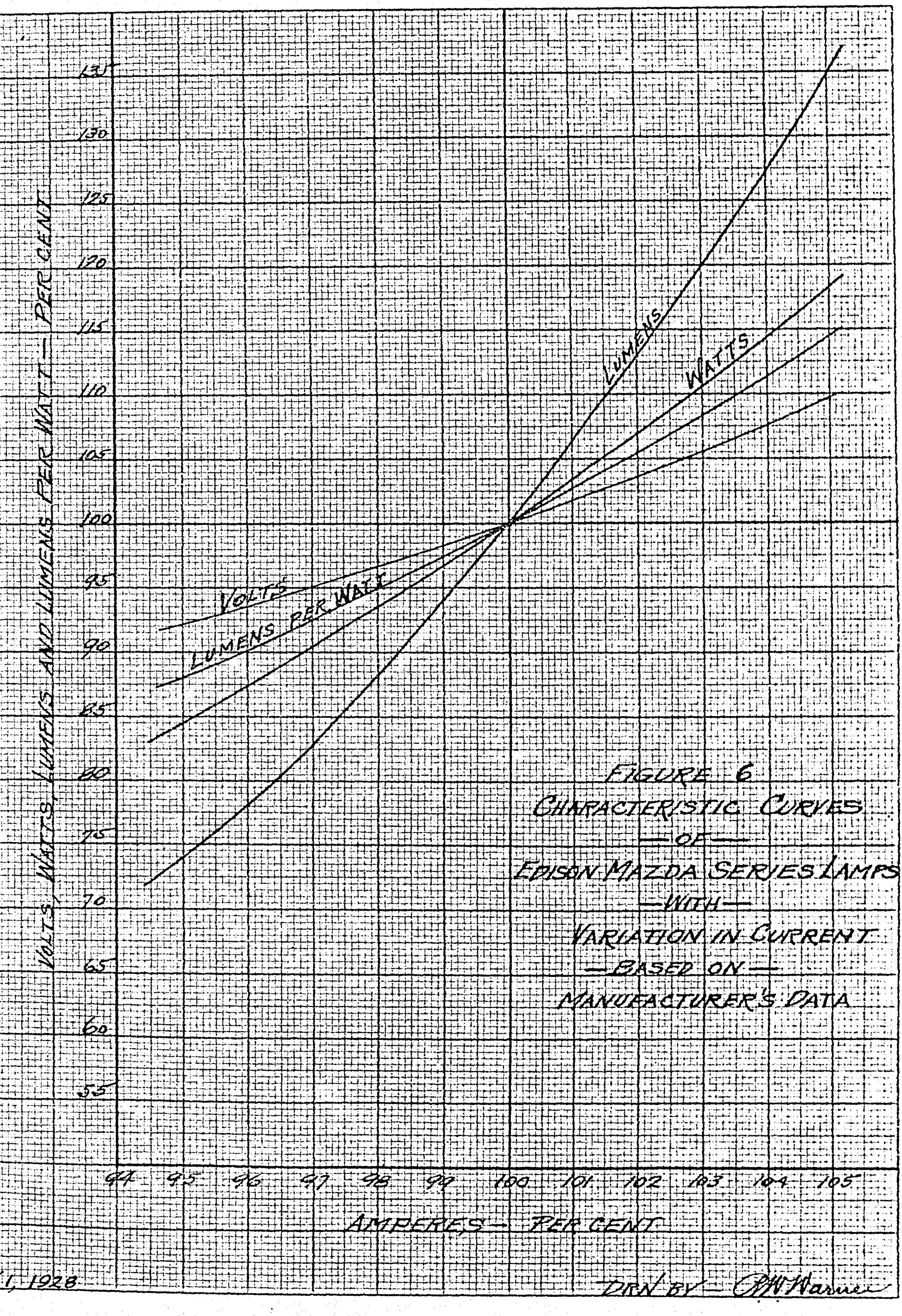
Curves, Figures 6 and 7 show these and other characteristics of the Mazda lamps.

FIXTURES.

The fixture chosen for this lighting system is the Form No.12, Novalux unit having a light alabaster, rippled glass globe and canopy, See Fig. 8. The 15,000-lumen unit is supplied with an 8 1/2-inch Holophane prismatic dome refractor to increase the downward illumination. A sectional view of this unit is shown in Fig. 9. A guard ring is used around the bottom of the globe to prevent the danger of breakage when tightening the screws of the holder. The fixtures will be the same for all of the plans under consideration.

STANDARDS.

The standard chosen for Oak Street and Baltimore Avenue, where there are no street car lines, is the "French Design," twin-lamp, style D, Fig. 10. The light-center will be 20 feet above the top of the curb. The centers of the lamps will be 27 inches apart and the center line of the standard will be 2 feet back of the edge of the curb. A small door in the base gives access to the insulating transformer and to the disconnecting pot-heads of the underground cables. A 3 1/2-inch iron pipe extends 4 feet below



VOLTS, WATTS, LUMENS AND LUMENS PER WATT — PER CENT
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
LUMENS
WATTS
VOLTS
LUMENS PER WATT
FIGURE 6
CHARACTERISTIC CURVES
—OF—
EDISON MAZDA SERIES LAMPS
—WITH—
VARIATION IN CURRENT
—BASED ON—
MANUFACTURER'S DATA
94
95
96
97
98
99
100
101
102
103
104
105
AMPERES — PER CENT
1, 1928
DRN BY

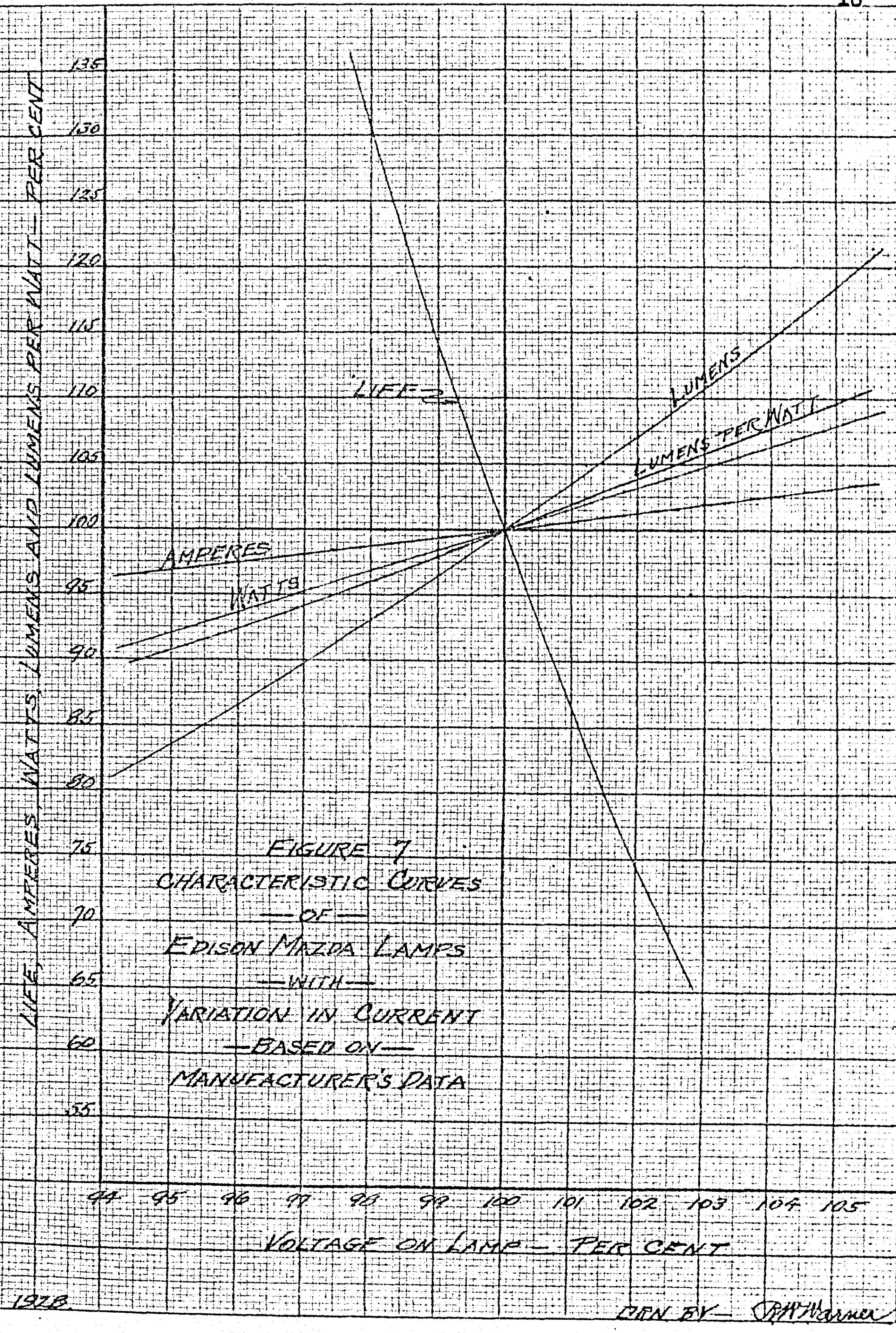


FIGURE 7
CHARACTERISTIC CURVES
— OF —
EDISON MAZDA LAMPS
— WITH —
VARIATION IN CURRENT
— BASED ON —
MANUFACTURER'S DATA

Fig. 8. Form 12, Novalux Lamp Unit.

Fig. 9. Sectional View of Form 12 Lamp Unit,
Showing Holophane Prismatic Refractor.

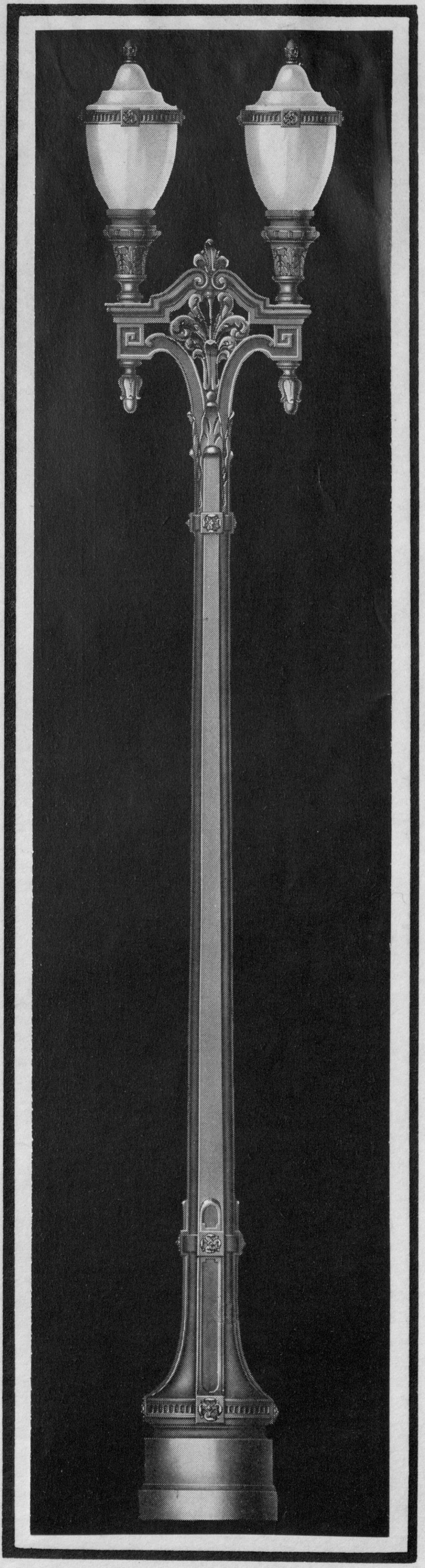


Fig. 10. Boulevard Standard.

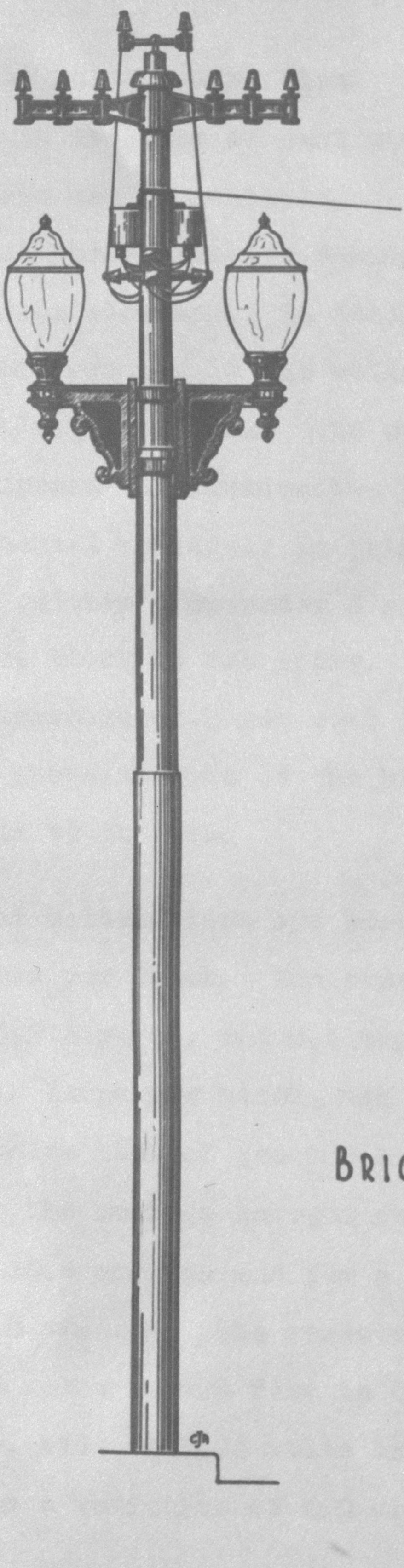
the bottom of the standard to give it stability.

There are street car lines and iron trolley poles available on the other north and south streets in the district. Here the lamp fixtures will be mounted in pairs on brackets supported by the trolley poles. The light centers will be 20 feet above the curb and 41 inches apart. The lines to these lamps will be carried on wood or iron cross-arms on the top of the pole. A typical installation is shown, see Fig. 11.

LAMP CIRCUIT.

The immediate circuit feeding the lamps consists of two parts, the wire and the insulating current transformer, which is required only for constant-current circuits. For the series multiple plans, No.6 weatherproof wire on 15,000-volt insulators will be used where the lamps are mounted on trolley poles. For the underground standards of the same plans, No.6, 5000-volt, underground parkway cable will be used. This cable is merely buried in the ground approximately two feet below the surface without any conduit protection. There will be two circuits at each standard or pole -- one for the all-night lamps and one for the one-o'clock lamps.

The multiple plan will require three circuits at each standard or pole in order to care for the lamps



BRIGHTWAY FIXTURES

Fig. 11.

on the two burning schedules. Individual lamp fuses will be required in the base of each underground standard. Since these lamps are in multiple, No.0 weatherproof wire will be required. Three wires or cables of this size will be necessary at each standard. In determining this wire size the chief consideration is the voltage drop from one lamp to another along the block. The curves, Fig. 7, show the rapid decrease in illumination when lamps are operated below a normal voltage. In this design it is planned to keep the voltage drop under 2 per cent per wire from one end of the block to the other. A drop of 2 per cent would cause a decrease of 7 per cent in the illumination of the lamps at opposite ends of the block, which would not be noticeable to the eye.

The calculations are based on having a maximum of seven lamps per block. The current taken by one 25000-lumen lamp is 8.7 amperes, and 6.5 amperes by the 15000-lumen lamp. With seven lamps per block, six of them will operate at a voltage below that of the one at the source end of the circuit. The average current for a block of 25,000-lumen lamps is 30.5 amperes and for a block of 15,000-lumen lamps it is 22.8 amperes. The resistance of No.0 wire for a circuit of 6 spans or 600 feet is 0.06 ohms. The voltage drop, therefore, will be 1.83 volts or 1.37 volts per wire. This will cause a variation of 5.0 or 4.0 per cent in the illumination from one end of the block to the other for the 25,000-lumen and 15,000-lumen lamps respectively. In blocks of less than 7 lamps per circuit the voltage and illumination regulation will be even better.

Investigation of the economy of using the No. 0 wire shows that the annual energy losses per block will be 550 and 306 kilowatt-hours. A block containing 7 lamps per circuit or a total of 14 lamps will require 1800 feet of wire. The cost of this is $42.00. Based on 15 per cent, the annual fixed investment charges will be $6.30. The energy losses capitalized at $0.01 per kilowatt-hour represent $5.50 per block for the 25,000-lumen lamp and $3.06 per block for the 15,000-lumen lamp circuits. Minimum total annual charges occur when the annual fixed investment charge equals the cost of the annual lost energy. It is seen that a smaller wire would be more economical, especially for the 15,000-lumen lamp circuits. However, a smaller size would be impossible on account of the greater voltage drop.

INSULATING TRANSFORMER.

In all series street lighting circuits it is desirable from a safety standpoint to keep the high voltage of the series circuit away from the lamp socket. For this purpose a series current transformer will be used at each lamp. It performs two functions: first, to insulate the individual lamp from the series circuit and second, to increase or step up the current in the lamp itself. It has been found that high intensity lamps operate with the best efficiency at high current and low voltage. The lamps used in the series-multiple plans are the 20-ampere type. The series transformer steps up the current from the 6.6 amperes of the primary circuit to 20 amperes in the secondary or lamp circuit. The voltage across the lamp is reduced correspondingly.

The Type-I L, insulating, current-transformer will be used for this installation. This transformer has characteristics such that any current variation in the primary circuit causes a lesser percentage of variation in the secondary current. This is a feature that will prolong the life of the lamps and will tend to reduce the number of burnouts due to current swings in the series circuit.

TABLE II. TYPE-IL TRANSFORMER CHARACTERISTICS

LAMP LUMENS	Primary Voltage Closed Circuit	Primary Voltage Open Circuit	Secondary Volts	Secondary Amperes
6,000	56	117.0	16.0	20.0
15,000	122	170.0	38.6	20.0
25,000	193	225.0	61.3	20.0

The normal primary current of all of these transformers is 6.6 amperes. The power factor is 98.5 per cent and the efficiency is 96.0 per cent.

From the above, Table II, it is seen that the open-circuit voltage is considerably higher than the closed-circuit voltage. No film cut-out is required at the lamp. If a lamp burns out the secondary of the Type-IL transformer is open-circuited. The voltage drop across the primary immediately increases to the open-circuit value. This reduces the current flowing in the primary series circuit and acts as a protective feature for the lamps which are still burning. A disconnecting, pothead-type cut-out is used for removing the individual transformer and the lamp without breaking the main series circuit.

The insulating transformers for the lamps on the trolley poles will be hung on the pole just above the lamps. See Fig. 11. The transformers for the boulevard standards will be mounted within the enlarged base of the standard.

III. SUPPLY FOR THE SYSTEM

The pedestrian, the motorist and the storekeeper are interested only in the illuminating effect produced on the streets by night and the artistic, or lack of artistic, effect to be observed by day. The operating power company, in addition to this, is vitally concerned with the part of the system which lies back of the lamps, between the lamp circuit and the power house. This part of the system serves only as an intermediate supplying link between the lamps and the generating station, but the economy of operation and the continuity of service depend greatly upon it.

Except in the case of the 115/230-volt multiple system the lamps, fixtures, insulating transformers, and lamp circuits will be identical. However, beyond this point there is a wide divergence in all of the schemes so that it will be necessary to take up each plan in detail.

PLAN NO. 1 - SERIES-MULTIPLE.

This plan is an expansion of the present method of operating the street lighting circuits at constant-current in this city. A typical diagram, Fig. 12, shows the schematic, electrical circuit from the lamps to the substation.

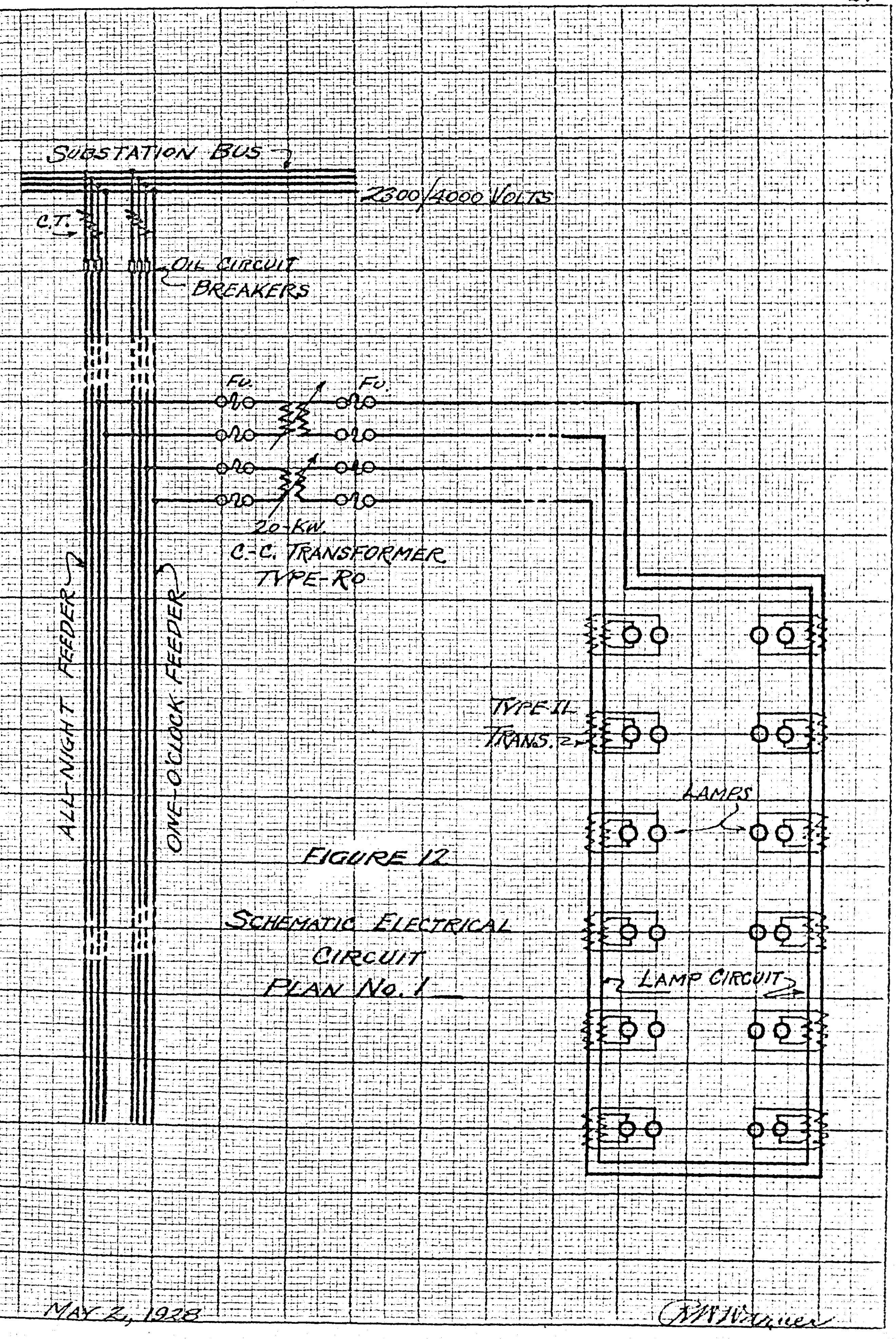


FIGURE 12

SCHEMATIC ELECTRICAL CIRCUIT

PLAN NO. 1

The primary series circuit is run overhead from the lamp circuit to a convenient location for the constant-current transformer. For this plan the Type-RO. constant-current transformer will be used.

This is a pole mounted, oil insulated, high reactance transformer which automatically regulates for constant secondary current within one per cent from full load to short circuit. After the transformer is installed the current is adjusted to 6.6 amperes. No further attention is required except occasional inspection and checking of the secondary current at intervals of from 60 to 90 days. The high reactance of the transformer protects the lamps at starting and acts as a buffer against any surges on the primary feeder.

The transformer to be used is rated at 20 kilowatts, 2,300 volts primary. The secondary voltage with normal load on the transformer is 3,030 volts. With an open-circuit on the secondary side this increasesto 4,150 volts. The primary input is 28.8 kilovolt-amperes, 12.52 amperes at any load. The efficiency and power factor at different loads are as shown in Table III.

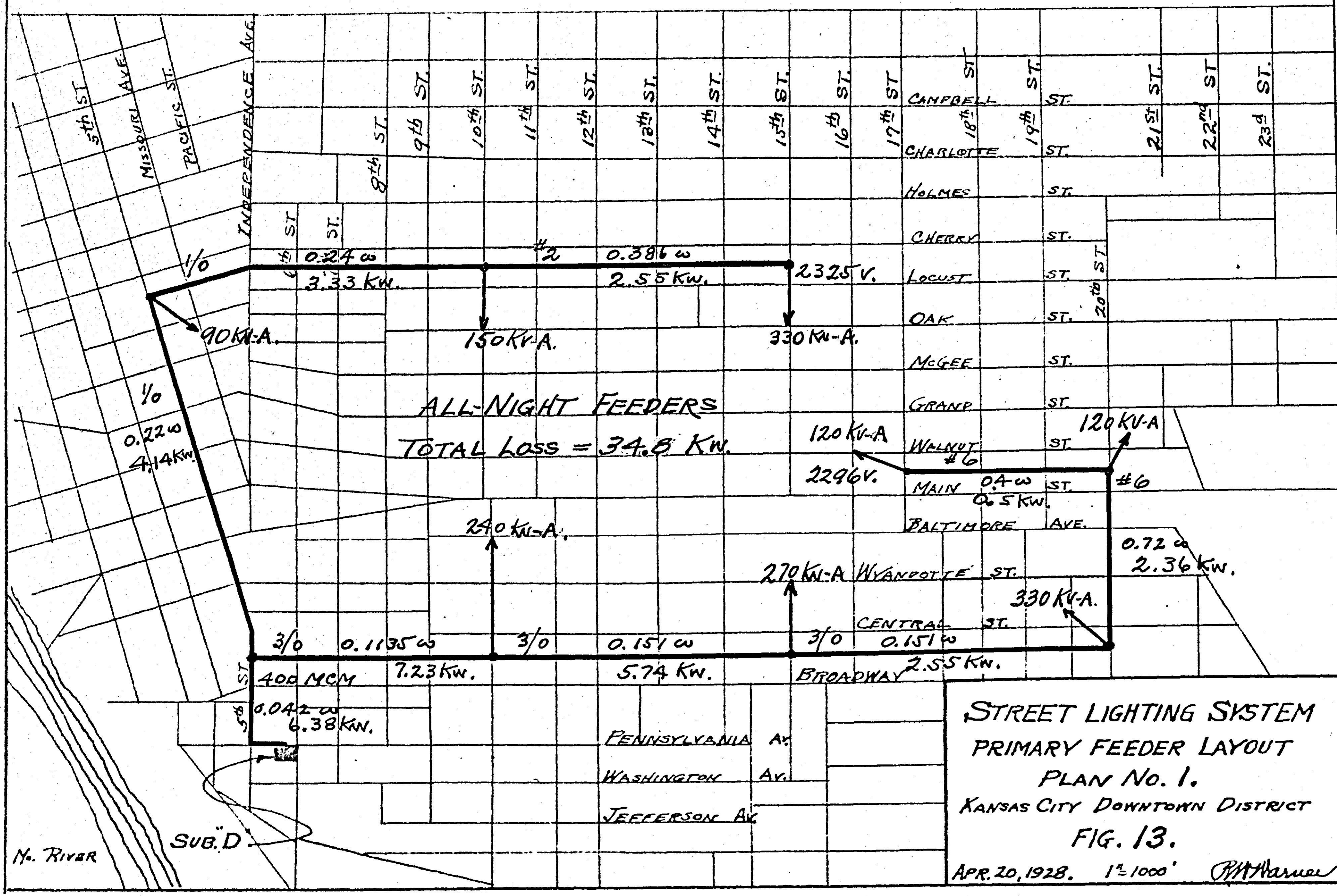
TABLE III. TYPE-RO TRANSFORMER CHARACTERISTICS

Capacity Kw.	Per Cent Load	Per Cent Efficiency	Per Cent Primary Power Factor
20	100	95.5	80
20	75	94.5	60
20	50	92.0	40
20	25	86.0	22

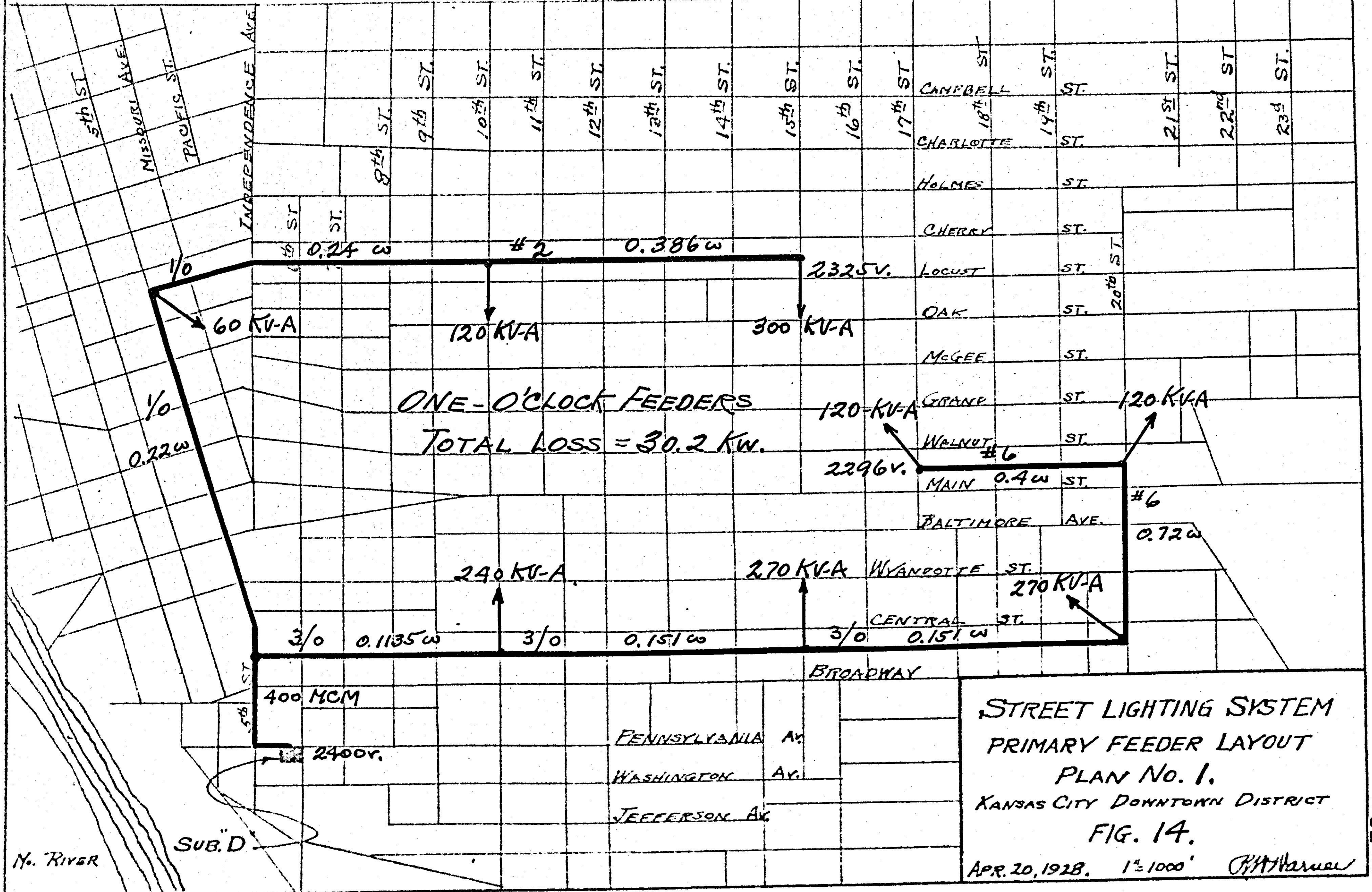
The 20-kilowatt transformer is recommended to carry 12, 25,000-lumen lamps, 20, 15,000-lumen lamps, or 46, 6,000-lumen lamps, with the corresponding Type-IL transformers. Any combination of these lamp sizes may be made as long as the total equivalent load is not exceeded.

The primary side of the constant-current transformer is connected to a 2300-volt feeder from an automatic, alternating-current, distribution, transformer substation which in turn is supplied by 13,200-volt feeders from the generating station.

The addition of a new load of this volume will require the rebuilding of the present feeder from the substation as well as the building of a new four-wire line for the one-o'clock load. The schematic layout of the 4000-volt feeders for the all-night circuits is shown on Fig. 13, the one-o'clock circuits on Fig. 14. The voltage drop and losses in each section are shown. The maximum voltage drop is 4.3 per cent which is well within the limits of good operation.



STREET LIGHTING SYSTEM
PRIMARY FEEDER LAYOUT
PLAN NO. 1.
KANSAS CITY DOWNTOWN DISTRICT
FIG. 13.
APR. 20, 1928. 1" = 1000' [signature]



STREET LIGHTING SYSTEM
PRIMARY FEEDER LAYOUT
PLAN NO. 1.
KANSAS CITY DOWNTOWN DISTRICT
FIG. 14.
APR. 20, 1928. 1" = 1000'

The total losses in the all-night feeder are 34.8 kilowatts, and in the one-o'clock feeder they are 30.2 kilowatts. The all-night feeder operates 4,000 hours per year and the one-o'clock feeder 2,000 hours. The annual losses are 199,540 kilowatt-hours. Capitalized at $0.01 per kilowatt-hour the annual cost of lost energy is $1,995.40. The total cost of the copper for both feeders is $13,737.00. The annual investment charge based on 15 per cent is $2,060.40. The total annual charges will be $4,055.80. This shows the line to be designed very closely for highest economy.

LOAD INVOLVED.

A total of 54 complete circuits will be required for the lamps which are to burn all night. Fifty circuits will be required for the lamps which are to be turned off at one o'clock. Since the primary current of the transformer for each circuit is 12.52 amperes, the total all-night load will be 676 amperes or 1,622 kilovolt-amperes, based on 2,400 volts, phase-to-neutral, at the substation bus. The one-o'clock load will be 626 amperes or 1,502 kilovolt-amperes. The total load will be 3,124 kilovolt-amperes.

As has been shown previously, the total lamp load with Type-IL transformers is 1,635 kilowatts. The constant-current transformer losses are 87 kilowatts and the line losses 69 kilowatts, making a total load of 1,791 kilowatts at the substation for an output of 3,124 kilovolt-amperes. The power-factor of the system will be 57.3 per cent. Power-factor tests made in the past on the street lighting feeders of the city check this calculated value within 5 per cent.

Under this plan it is expected to handle the street lighting load of the entire downtown district from Substation "D" since it is the station located nearest to the load center. The present all-night load on the street lighting circuit from Substation "D" is 170 amperes on a single-phase basis. This will be reduced by 50 amperes as previously explained, leaving 120 amperes or 288 kilovolt-amperes. The new downtown load of 676 amperes added to this will make 796 amperes or 1,910 kilovolt-amperes. The line leaving the substation is a 4-conductor 400-MCM cable with normal capacity of 2,000 kilovolt-amperes.

The lamp load to be turned off at one o'clock will require a new, 4,000-volt, three-phase, four-wire feeder from the substation. It will have a load of 1,502 kilovolt-amperes.

The supplying of the entire load from the one substation greatly simplifies the control and insures all of the lamps being turned on or off simultaneously throughout the entire district.

COMPARATIVE CHARACTERISTICS.

The chief advantages of this plan are--

1. Flexibility in the number of the lamps required in each circuit.

2. The constant-current transformer will regulate for the correct current for any number of lamps up to full load.

3. A single ground on the series circuit will not cause any immediate trouble. A second ground will put out only the lamps between the grounded points. The other lamps will not be affected.

4. Only two relatively small wires (No.6) are required from pole to pole.

5. The lamps are protected from primary line surges by the constant-current transformer.

The chief disadvantages are--

1. A large number of circuits are required on account of the large size of the lamps and small number that can be handled on one circuit.

2. The power-factor of the system is low.

3. The feeder copper loss is high.

4. Frequent tests and adjustments of the constant-current transformer are necessary.

5. There will be a congestion of the overhead wires leading from the constant-current transformers to the lamp circuits.

6. New 4,000-volt, substation equipment will be required. The present tendency is to put all load blocks of this size on the 13,200-volt system.

PLAN NO. 2 - MULTIPLE.

This plan considers the placing of the street lighting load of the new downtown system on the 115/230-volt direct-current Edison system.

The connections to the direct-current network system will be made at the manholes in the street and alley intersections. A total of 22 such tap locations will be required. Control contactors will be located in the manholes and cables will run to the multiple circuit at the lamp poles or standards. These cables are designed to have not more than 0.5 volt drop between the network and the beginning of the lamp circuit. Junction boxes and fuses will be required at each tap leading to a block circuit.

The load which lies outside of the territory served by the Edison system will be placed on 115-volt, alternating-current secondary lines from constant-potential, power transformers connected to the present, 2300-volt, street lighting feeders.

The typical layout of a block circuit for both direct- and alternating-current is shown in Fig. 15. The manner of controlling the all-night and one-o'clock circuits is also shown.

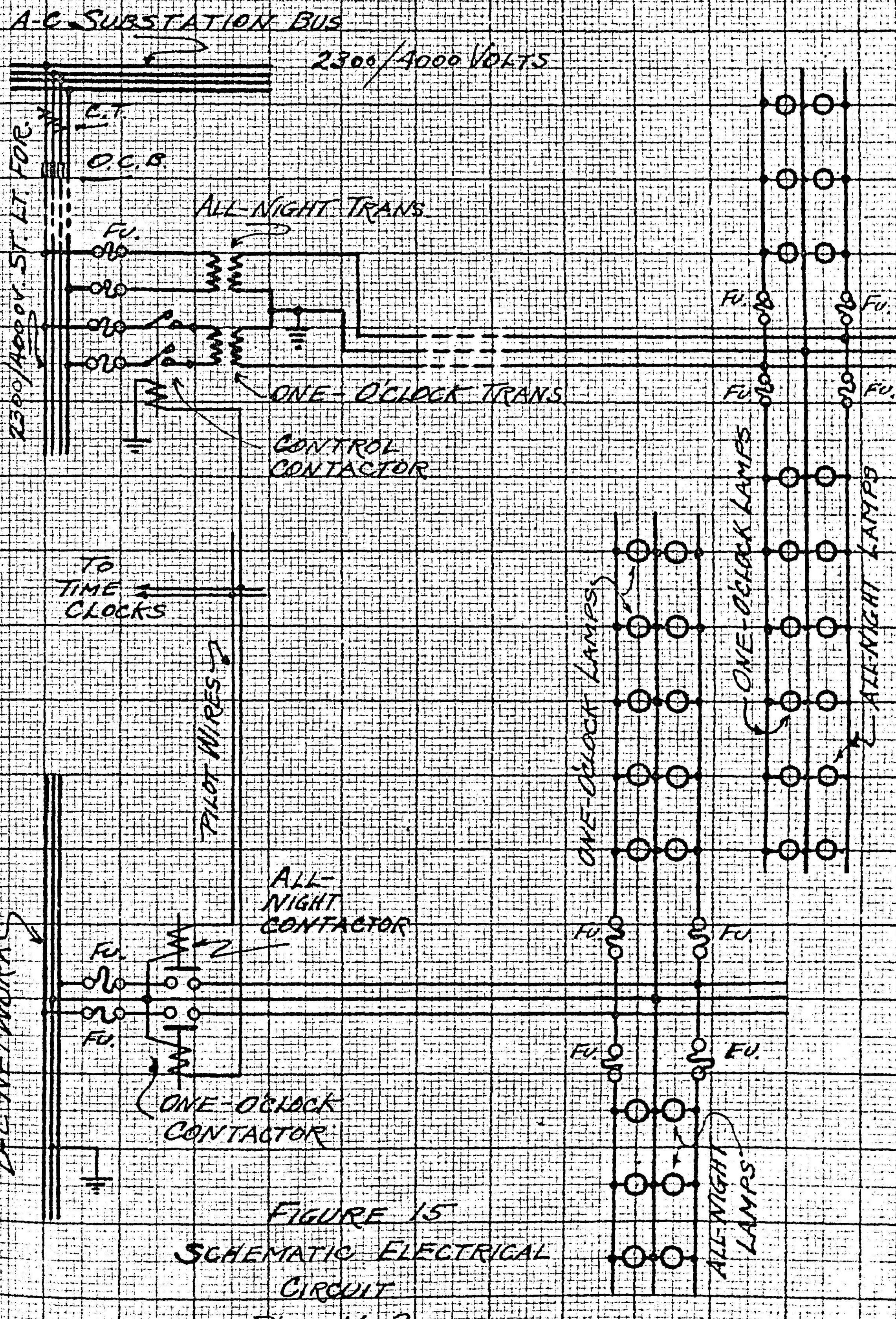


FIGURE 15
SCHEMATIC ELECTRICAL CIRCUIT
PLAN NO 2

MAY 4, 1928

R.W. Warner

METHOD OF CONTROL.

Two low-voltage contactors will be required in each manhole where connection is made to the direct-current network. A 2300-volt contactor will be required for each power transformer. Two No.6 pilot wires will run to each manhole tap and transformer location. The contactors will be of the magnetic type which open their contacts when de-energized. Time-clocks in the load-dispatcher's office will operate the contactors simultaneously through the pilot wires. One time-clock will control the all-night lamps and a second clock will control the one-o'clock lamps.

LOAD INVOLVED.

The load lying within the boundaries of the Edison district consists of 153, 6,000-lumen, 860, 15,000-lumen and 226, 25,000-lumen lamps, a total of 917 kilowatts with the load-center at Twelfth and Walnut Streets. South of the Edison district, which ends at Fifteenth Street, are 28, 6,000-lumen, 436, 15,000-lumen and 188, 25,000-lumen lamps or a total load of 523 kilowatts with the load-center at Nineteenth and Walnut Streets. Based on 95 per cent transformer efficiency and 95 per cent power-factor, this represents 580 kilovolt- amperes on the primary feeders.

A total of 18 distribution transformers will be required, rated as follows-- 4 at 50 kilovolt-amperes, 6 at 37.5 kilovolt-amperes and 8 at 25 kilovolt-amperes; a total rated capacity of 625 kilovolt-amperes.

The present street lighting feeder for this district is from Substation A. It is carrying 1,380 kilovolt-amperes. This will be reduced to 1,080 kilovolt-amperes on account of the loss of circuits which were absorbed in the new system. The new load of the alternating-current district if added to this feeder will make a total of 1,660 kilovolt-amperes. The full-load rating of this feeder is 2,000 kilovolt-amperes.

COMPARATIVE CHARACTERISTICS.

The chief advantages of this plan are--

1. There is plenty of spare capacity on the Edison system available for this load.

2. The power-factor of alternating-current part of the system will be high, 93 to 96 per cent.

3. It will be easy to add or subtract lamps because they will be connected in multiple.

The chief disadvantages are--

1. The three large wires running from pole to pole will detract from the appearance of the system.

2. A very large amount of copper will be required.

3. A large amount of expensive underground work will be required.

4. The lamps used in the territory adjacent to the downtown section will be of a series type. This will tend to produce confusion when lamps are being replaced.

5. A system of control contactors will be necessary to turn the circuits on and off. They will be a source of trouble.

6. A larger reserve stock of lamps will be required.

7. The life of multiple lamps is only 1000 hours as compared with 1350 hours for the series-type lamps. This will cause a higher annual cost for lamps as well as an increased maintenance expense for replacing the burned out lamps.

PLAN NO. 3 - SERIES-MULTIPLE.

Under this plan the lamps on the streets will be operated in series at constant-current with Type-IL insulating transformers in a way similar to that of PLAN No. 1 except at a higher voltage. The series lamp circuit will be run overhead on trolley poles and underground in cable on the streets where there are no street car lines.

High tension cables will be run underground from the lamp circuits to the constant-current transformers.

A typical layout, Fig. 16, shows the schematic electrical circuit from the lamps to the substation. The manner of controlling the all-night and the one-o'clock circuits is also shown.

The Type-RF constant-current transformer will be used in this plan. This is an air-cooled, station-type

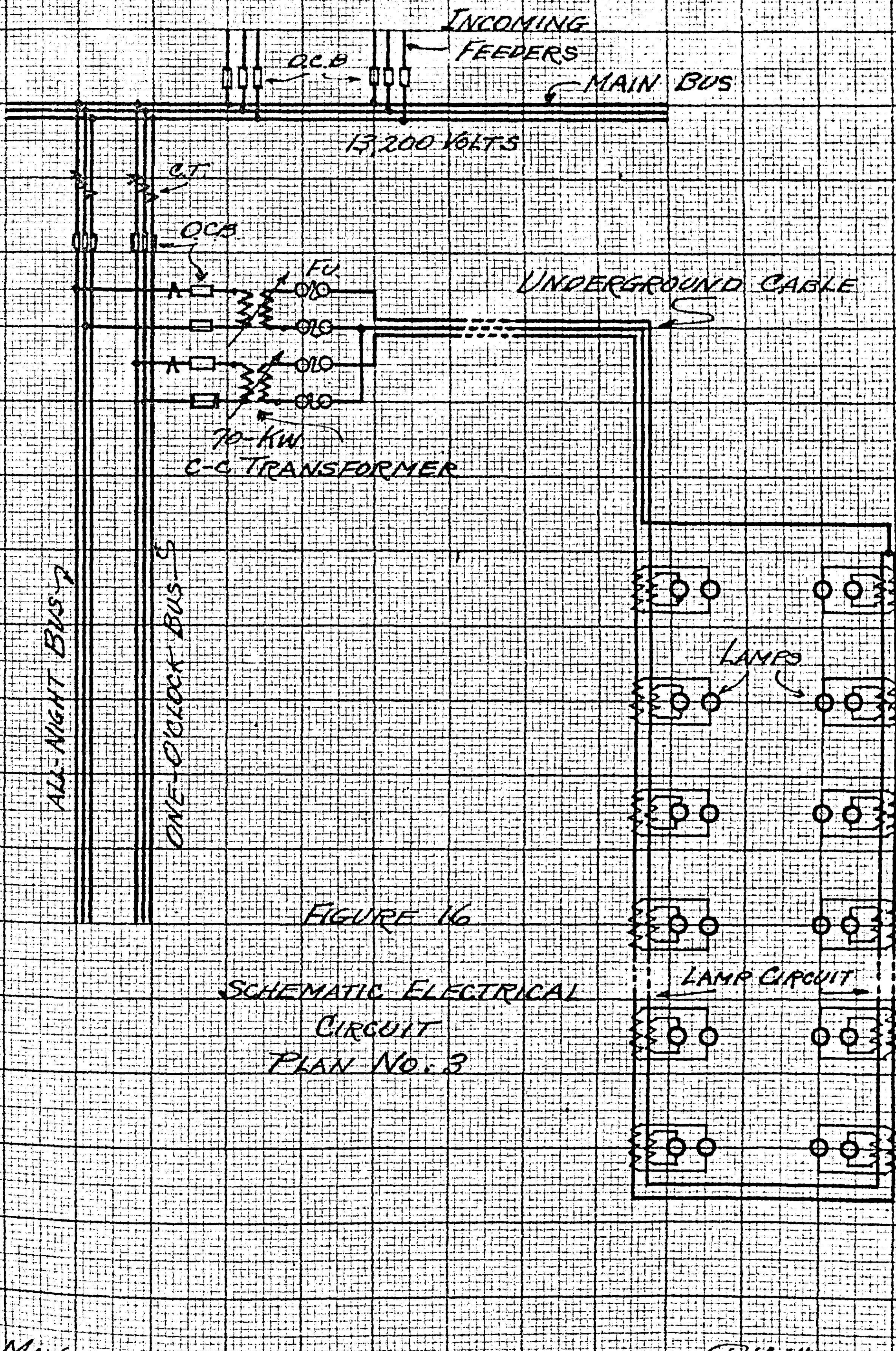


FIGURE 16

SCHEMATIC ELECTRICAL CIRCUIT
PLAN NO. 3

MAY 3, 1928

R.M. Warner

transformer which automatically regulates for constant secondary current. It requires no attention after it is once installed, aside from occasional inspecting and adjusting. It is rated at 70 kilowatts, 13,200 volts primary, normal-load secondary voltage 10,600 and an open-circuit secondary voltage of 14,500 volts. The primary input is 96.6 kilovolt-amperes at all loads. Although the full-load voltage of the secondary series circuit is 10,600 volts, the lamp circuit, the cables, the cut-outs and the Type-IL transformers must be able to withstand the open-circuit potential of 14,500 volts. The line insulators will be rated at 15,000 volts. The cable will have the same rating. The cut-outs and the Type-IL transformers are tested for 22,000 volts.

The efficiency and power-factor of the Type-RF transformer are shown in Table IV.

TABLE IV. TYPE-RF TRANSFORMER CHARACTERISTICS.

Capacity Kw.	Per Cent Load	Per Cent Efficiency	Per Cent Primary Power-Factor
70	100	98.0	81.0
70	75	96.5	61.0
70	50	93.5	40.0

A 70-kilowatt, Type-RF transformer has a recommended capacity for 42, 25,000-lumen lamps, 67, 15,000-lumen-lamps or 168, 6,000-lumen lamps, with the corresponding Type-IL transformers. Any combination of these lamps of different sizes may be placed in the circuit as long as the total equivalent load is not exceeded.

The constant-current transformers will all be located in one substation which will be supplied by 13,200-volt feeders direct from the generating station. A total of 33 constant-current transformers will be required,-- 32 are needed for the circuits and one as an emergency spare. Oil circuit breakers will connect each transformer to the station bus. There will be an all-night, and a one-o'clock, 13,200-volt bus.

The individual breakers will have over-load protection and will be "automatic-reclosing" with a duty cycle of 3 reclosures at intervals of 15, 30 and 75 seconds.

Main oil circuit breakers will connect the busses to the incoming feeder bus. These breakers will be operated by automatic time-clocks in accordance with the street light burning schedule.

There will be no attendants in this station since it will be fully automatic. It is proposed to locate this station in the block between Wyandotte and Central, and between Thirteenth and Fourteenth Streets.

LOAD INVOLVED.

There will be required 16 all-night and 16 one-o'clock circuits each supplied by a 70-kilowatt, Type-RF transformer. The input of each transformer is 96.6 kilovolt-amperes. Therefore, the all-night load on the 13,200-volt feeders will be 1,546 kilovolt-amperes. The load to be turned off at one o'clock will be the same, making a total of 3,092 kilovolt-amperes.

The load of the lamps including the insulating transformers is 1,635 kilowatts as shown previously. The line losses will be 6 kilowatts and the transformer losses will be 43 kilowatts, making a total input to the constant-current transformers of 1,684 kilowatts. Therefore, the power-factor on the 13,200-volt lines will be 50.3 per cent.

COMPARATIVE CHARACTERISTICS.

The chief advantages of this plan are as follows--

1. The line losses will be low on account of the high voltage.
2. It is readily adapted to being made an all-underground system.
3. Lower voltage branch circuits may be carried on series transformers.
4. All testing of the circuits and of the transformers can be done at the substation. This will reduce the maintenance expense.
5. The transformer losses will be lower than if smaller transformers were used.

6. There will be no overhead wires between the transformers and the lamp circuits.

7. The load will be placed on the 13,200-volt system, which is in line with the present practice for loads of this size.

8. The system can be expanded to meet the needs of many years to come.

The chief disadvantages are--

1. Any trouble on a circuit will affect the lamps over a great area.

2. There will be 13,200 volts potential on the series lamp circuits on the trolley poles.

3. The primary power-factor will be low.

4. The transformer substation will be very expensive.

PLAN NO. 4 -- SERIES MULTIPLE

This plan is similar to Plan No. 1 except that the constant-current transformers will be omitted. The lamps with Type-IL insulating transformers will be operated in series and connected directly to the 2,300-volt, primary feeders. A typical layout, Fig. 17, shows the schematic, electrical circuit from the lamps to the substation.

A primary, series circuit is run overhead from the series, lamp circuit to a convenient location for connection to the primary feeder. This feeder is a three-phase, four-wire, 2,300/4,000-volt, wye line with the neutral wire grounded at the substation. The street lighting circuits

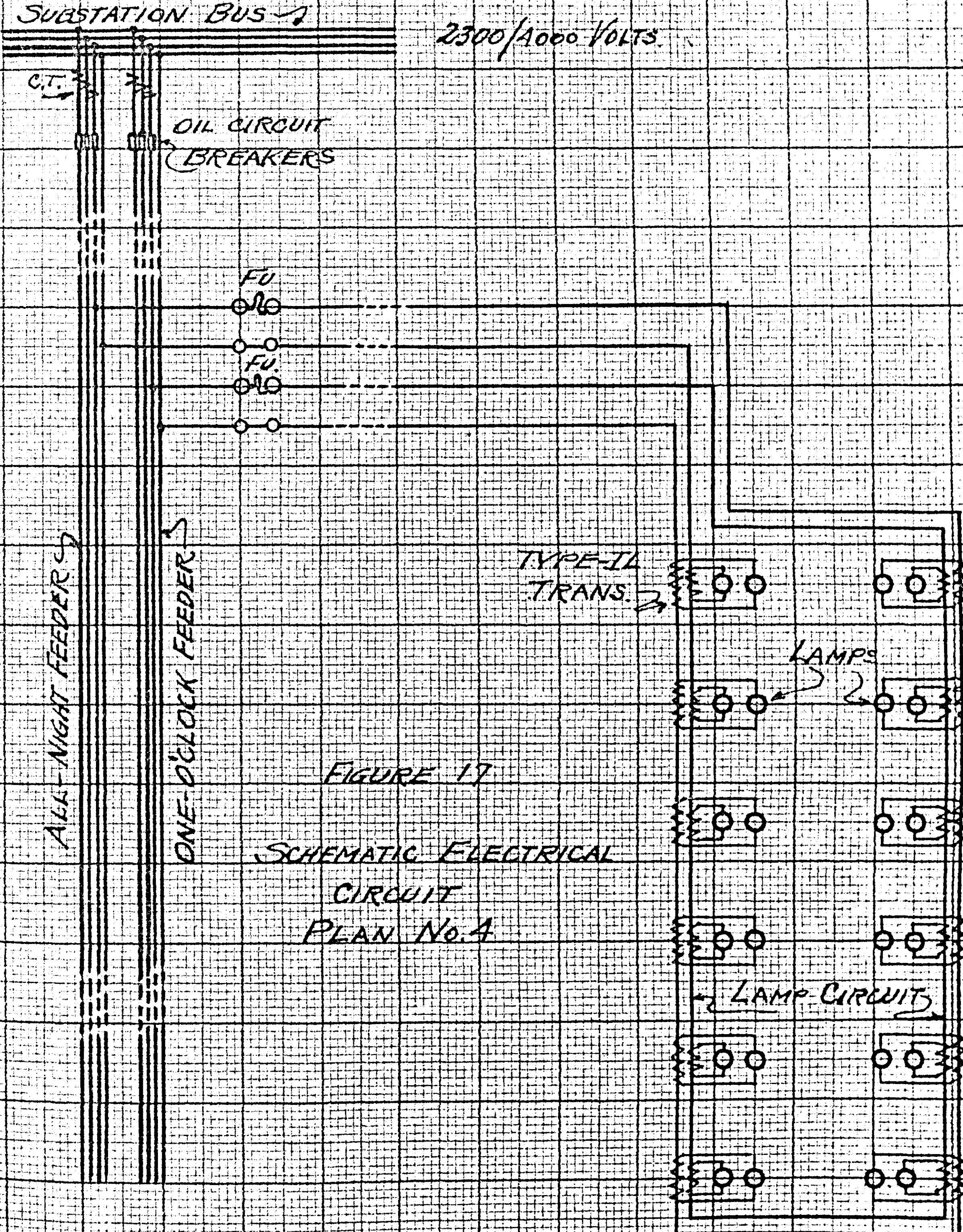


FIGURE 17

SCHEMATIC ELECTRICAL CIRCUIT PLAN No. 4

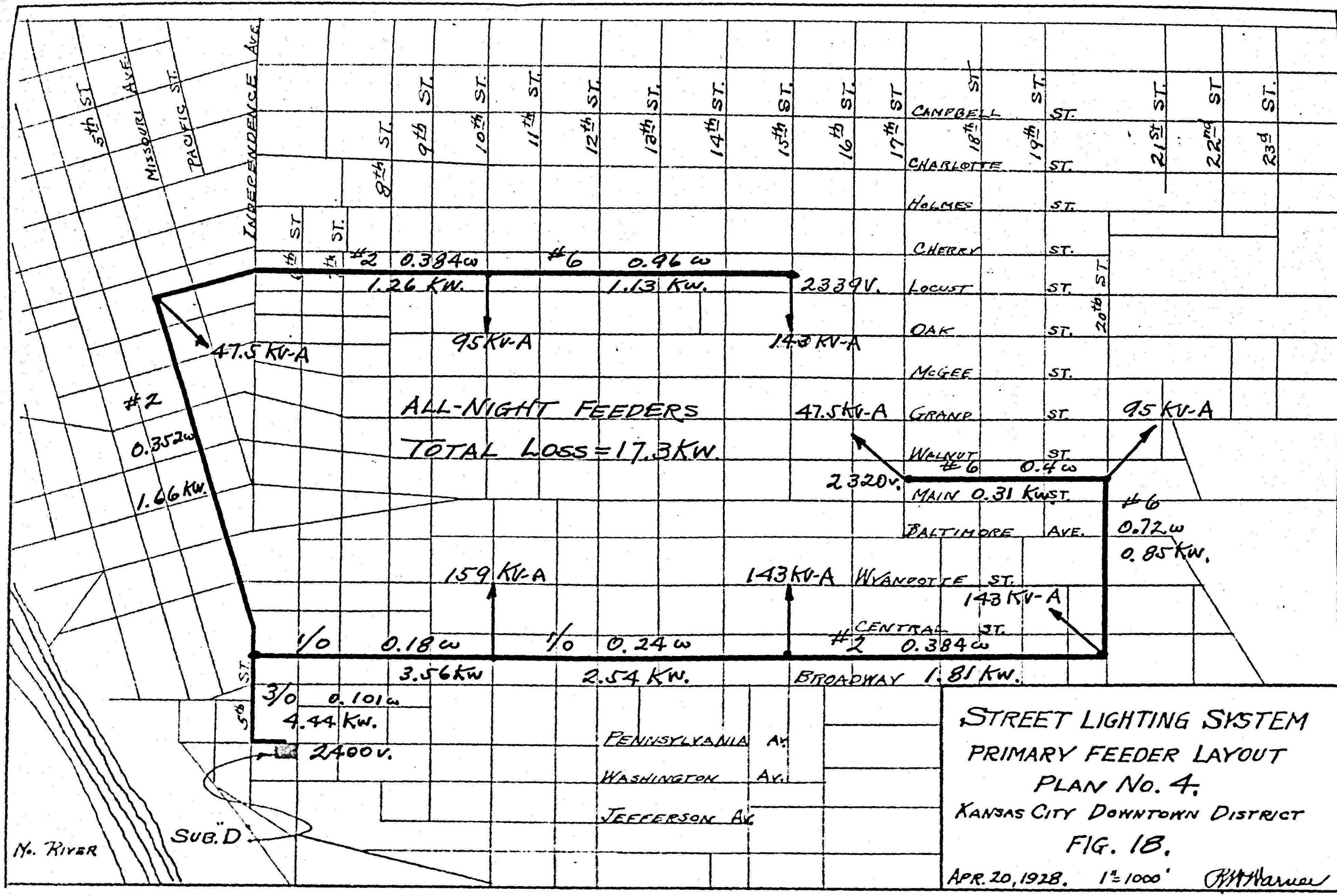
MAY 2, 1928

R.W. Warner

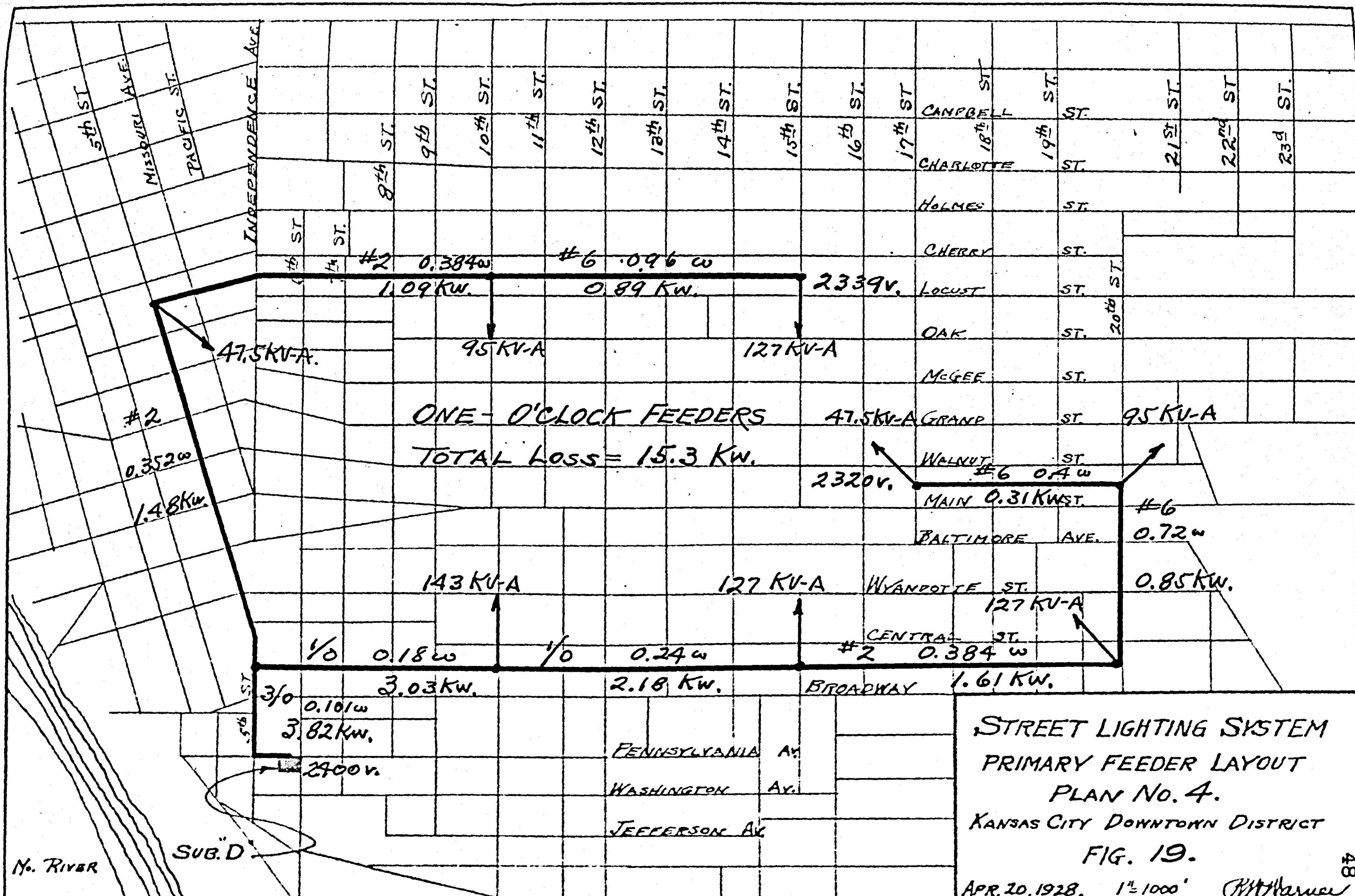
will be connected to a phase-wire and the neutral. A 10-ampere, pyrene fuse will be placed in the connection to the phase wire for short-circuit protection. A disconnecting cut-out will be placed in the connection to the neutral wire. By means of the fuse and the cut-out the circuit can be cleared from the primary feeder for testing purposes.

Under this method of operation it is planned to carry the entire street lighting load of the downtown district from Substation "D". In order to do this it will be necessary to rebuild the present street lighting feeder from this station and also to build a new three-phase 2,300/4,000-volt feeder for the circuits which will be turned off at one o'clock. The layouts, Fig.18, for the feeders of the all-night lamps and, Fig.19, for the feeders of the one-o'clock lamps show the route and loads in all of the sections.

In selecting the wire sizes it was attempted to arrive at the most economical system. The cost of the copper wire as shown on Figure No.18 and No.19 will be $7,180.00. The annual fixed investment charges will be 15 per cent or $1,078.00. The annual energy losses are 305,200 kilowatt-hours for the one-o'clock circuits and 691,600 kilowatt-hours for the all-night circuits making a total of 996,800 kilowatt-hours. These losses, if capitalized at $0.01 per kilowatt-hour, will represent an annual cost of $996.80 as compared with the annual



STREET LIGHTING SYSTEM
PRIMARY FEEDER LAYOUT
PLAN No. 4.
KANSAS CITY DOWNTOWN DISTRICT
FIG. 18.
APR. 20, 1928. 1" = 1000' [signature]



STREET LIGHTING SYSTEM
PRIMARY FEEDER LAYOUT
PLAN NO. 4.
KANSAS CITY DOWNTOWN DISTRICT
FIG. 19.
APR. 20, 1928. 1" = 1000'

investment charge of $1,078.00. The total annual cost will be $2,074.80. It is seen that slightly smaller conductors would be more economical, but in the interest of good voltage regulation, the sizes shown are to be preferred.

At the substation it will be necessary to provide the oil circuit breakers and the equipment necessary to control the new feeder. Three single-phase breakers will be needed. They will have over-load and short-circuit protection. If opened on account of over-load or short-circuit they will be reclosed automatically three times at intervals of 15, 30 and 75 seconds. If the cause of the overload still persists after the third reclosure, the breaker will be locked open automatically and must be inspected before it can close again.

The breakers for the all-night and for the one-o'clock feeders will be operated by separate time-clocks in conformity to the street light burning schedule.

LOAD INVOLVED.

A total of 55 all-night circuits and 51 one-o'clock circuits will be required for this method of operation. Each of these circuits will be designed with the necessary number of lamps in series so that the current flowing through the circuit will be 6.6 amperes.

The total current of the all-night circuits will be

363 amperes or a load of 880 kilovolt-amperes. This will be added to the present load of the street lighting feeder from Substation "D" making a total load of 1,170 kilovolt-amperes.

The total load of the one-o'clock circuits will be 808 kilovolt-amperes. This added to the all-night load makes a total of 1,688 kilovolt-amperes. The lamp load alone is 1635 kilowatts and the line losses 4 kilowatts making a total of 1639 kilowatts. The power-factor will be 97.9 per cent.

REGULATION.

Under this plan the voltage and current in the lamp circuit will depend directly on the voltage of the substation bus and on the voltage drop of the feeder and of the circuit to the lamps. The total drop of the feeder from the substation to the most distant lamp circuit is 80.0 volts or 3.3 per cent from phase to neutral. Each circuit is designed with a combination of lamps so as to compensate as nearly as possible for this drop.

The voltage regulation of the substation bus is 1.7 per cent during the hours when the street lights are burning. This means that the current in the lamps will vary approximately 1.7 per cent and the illumination, as shown by Fig.6, will vary 10 per cent. This will not be objectionable, because the variation will take place slowly and will not be noticeable to the eye.

COMPARATIVE CHARACTERISTICS.

The chief advantages of this plan of operation are as follows--

1. The power factor of the system will be high.
2. There will be no constant-current transformer troubles.
3. There will be no transformer losses.
4. The primary feeder losses will be low.
5. The expense for constant-current transformers will be eliminated.
6. No testing of transformers will be required.

The chief disadvantages of the plan are--

1. A ground on the series lamp circuit will probably cause all of the lamps between that point and the connection to the phase wire of the feeder to be burned out.
2. There is no way to regulate or change the current in the lamp circuit except by adding or subtracting lamps or their equivalent.
3. The current in the lamp circuit depends on the voltage regulation of the substation bus.
4. The circuits must have exactly the correct number of lamps in them.

PLAN NO. 5 - SERIES.MULTIPLE

This plan calls for the use of 13,200/4,000 volt constant-potential, power transformers for supplying the street lighting load in the downtown district. The lamps with Type-IL insulating transformers will be connected directly to the 4,000-volt secondaries of these transformers. The schematic, electrical circuit is as shown, Fig. 20.

A primary series circuit will extend overhead from the series, lamp circuit to a convenient location for the constant-potential transformers. This series circuit will be entirely ungrounded.

The constant-potential transformers will all be located in one substation situated in the block between Wyandotte and Central Streets and between Thirteenth and Fourteenth Streets. This substation will be supplied by 13,200-volt cables direct from the generating station of the power system, which supplies the entire city.

A total of 32 power transformers rated at 55 kilovolt-amperes will be required. Each transformer will handle two circuits. One spare transformer will be provided for emergency use.

The power transformers will have 10-ampere pyrene fuses on the low-tension secondary side and oil circuit breakers on the primary side to connect them to the station bus. There will be an all-night bus and a one-o'clock bus. These busses will be operated and controlled in the same manner as

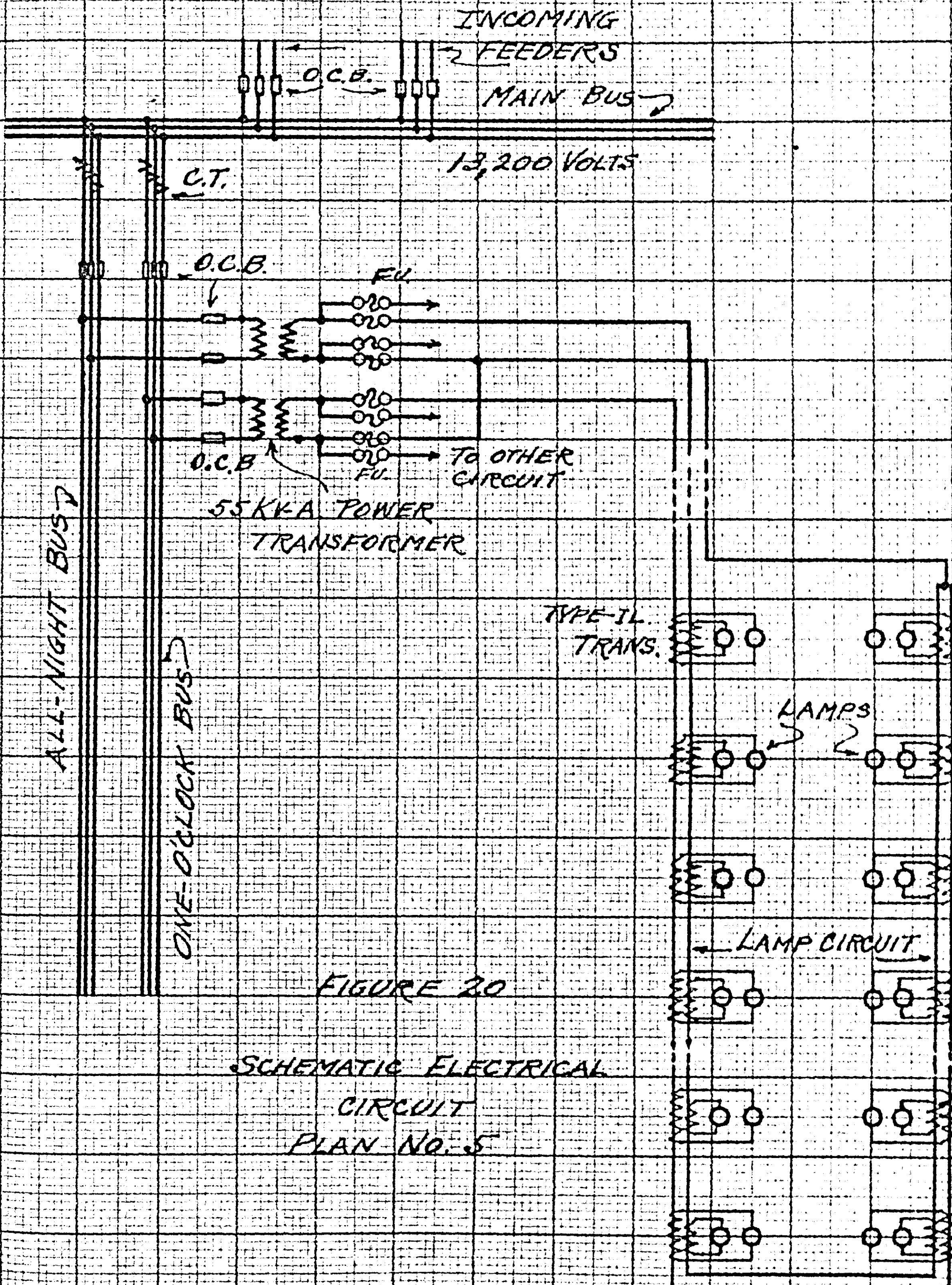


FIGURE 20

SCHEMATIC ELECTRICAL
CIRCUIT
PLAN No. 5

MAY 2, 1928

R.W. Warner

those under Plan No. 3.

LOAD INVOLVED.

A total of 32 all-night circuits and 31 one-o'clock circuits will be necessary. Each of these circuits will be designed so that the current in the series lamp circuit is 6.6 amperes. The total all-night load will be 211 amperes or 844 kilovolt-amperes. The total one-o'clock load will be 198 amperes or 792 kilovolt-amperes, making a total load of 1,646 kilovolt-amperes. The load on the primary 13,200-volt feeders will be 1,685 kilovolt-amperes. The primary power-factor will be 96 per cent.

COMPARATIVE CHARACTERISTICS.

The chief advantages of this plan are as follows--

1. The power-factor will be high.

2. No constant-current transformer tests or adjustments will be required.

3. The taps on the transformer can be used to adjust the secondary current to the correct value.

4. All testing of the circuits can be done at the substation.

5. The load will be placed on the 13,200-volt system.

6. A single ground on the series lamp circuit will not cause any damage.

7. The efficiency of the constant-potential transformer is better than that of the constant-current transformer.

8. The potential on the series lamp circuit will be less than under Plan No.3.

9. The open-circuit voltage of the constant-potential transformer is only slightly higher than the full-load voltage.

The chief disadvantages are--

1. The cost of the transformer substation will be high.

2. The circuits must have a fixed number of lamps in order that the current in the series circuit may be correct.

3. The constant-potential transformer is of a special rating. It will cost approximately 10 per cent higher on this account than a transformer of a standard rating.

IV. TESTS

A number of tests were made in order to verify some of the data received from the manufacturers of the equipment and also to secure other information about the apparatus which would be of value in designing and in operating the system.

INSULATING TRANSFORMERS.

A laboratory test was made on a Type-IL series transformer with a 15,000-lumen lamp. The current in the primary circuit was varied over a considerable range. Simultaneous readings were taken of the primary and secondary current, and of the primary and secondary voltage. From the results of these tests the curves, Fig. 21, were drawn.

It should be noted that the secondary current does not increase as rapidly as the primary current. The primary current can rise to 75 per cent above the normal value before the secondary current will increase more than 45 per cent above the normal.

This characteristic would be very important in Plan No. 4. An accidental ground on the series circuit in this plan would cut out the lamps between the grounded point and the connection to the neutral wire. This would leave full

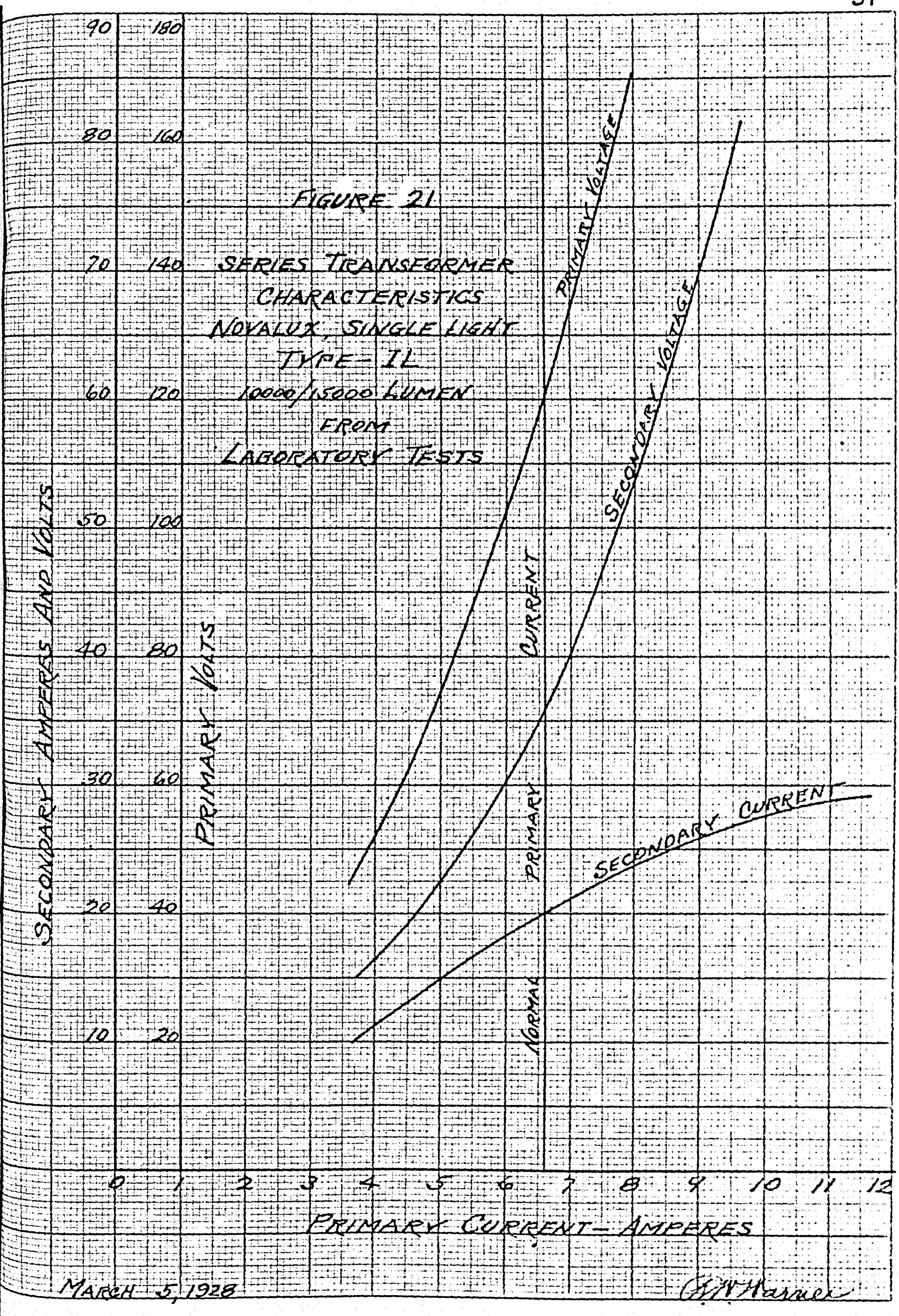


FIGURE 21
SERIES TRANSFORMER
CHARACTERISTICS
NOVALUX, SINGLE LIGHT
TYPE-IL
10000/15000 LUMEN
FROM
LABORATORY TESTS
PRIMARY VOLTAGE
SECONDARY VOLTAGE
SECONDARY CURRENT
NORMAL PRIMARY CURRENT
SECONDARY AMPERES AND VOLTS
PRIMARY VOLTS
90 180
80 160
70 140
60 120
50 100
40 80
30 60
20 40
10 20
0 1 2 3 4 5 6 7 8 9 10 11 12
PRIMARY CURRENT-AMPERES
MARCH 5, 1928

line voltage on the remaining lamps and the series current would be increased accordingly. The lamps will stand approximately 50 per cent above the normal current for a few hours without any appreciable damage. As a result of this current regulating characteristic of the Type-IL transformer, as many as 40 per cent of the lamps in the circuit may be grounded out before the current in the lamps themselves will exceed 50 per cent above the normal value.

ILLUMINATION TESTS.

There are at the present time two circuits of only 15,000-lumen lamps in service on Twelfth Street. A series of illumination tests was made on the lamps in them.

These circuits are connected directly to the 2,300-volt primary feeder without a constant-current transformer. One is an all-night circuit and the other is a one-o'clock circuit. Both are on the same trolley poles.

The current in the series lamp circuit was varied above and below the normal in several steps with a constant primary feeder voltage.

A number of specially made jumpers were used for taking lamps out of one circuit and adding them to the other. The series current was reduced below the normal in this way.

The current was raised above the normal by removing the series cut-out plugs on a number of the lamps.

The series current and the voltage across the primary side of the Type-IL transformer were recorded at each step. These results are shown on Fig.22, and agree very closely with the laboratory tests.

A series of photometer measurements of the illumination in the center of the street was made at the same time. These results are shown on Fig. 23.

The results of the current-voltage tests check very closely with the data furnished by the manufacturer and can be used in designing the lamp circuits for Plans No.4 and 5.

The illumination intensities measured on the street are somewhat lower than the theoretical values for a street of this width. This can be accounted for largely by the fact that the lamps had been in service for several weeks or about 75 per cent of their normal life and the bulbs were slightly blackened as a result.

FUSED CIRCUITS.

The type of circuit operation called for by Plan No. 4 is relatively new. In order to determine how satisfactory this method would be with 15,000-lumen lamps, two important circuits in the downtown street-lighting district were chosen for testing. The constant-current transformers were removed and the

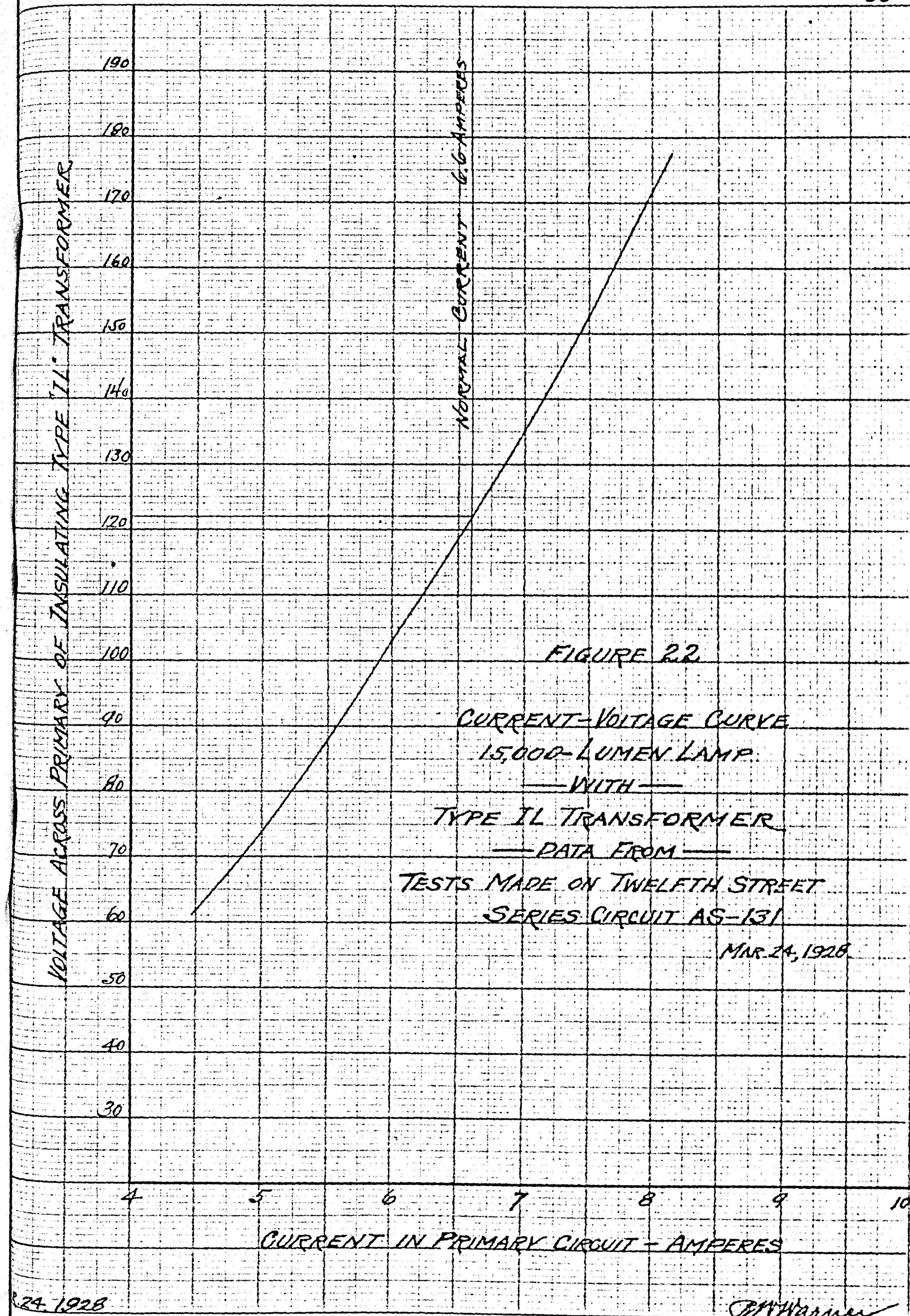


FIGURE 22

CURRENT-VOLTAGE CURVE
15,000-LUMEN LAMP
—WITH—
TYPE IL TRANSFORMER
—DATA FROM—
TESTS MADE ON TWELFTH STREET
SERIES CIRCUIT AS-131

MAR. 24, 1928

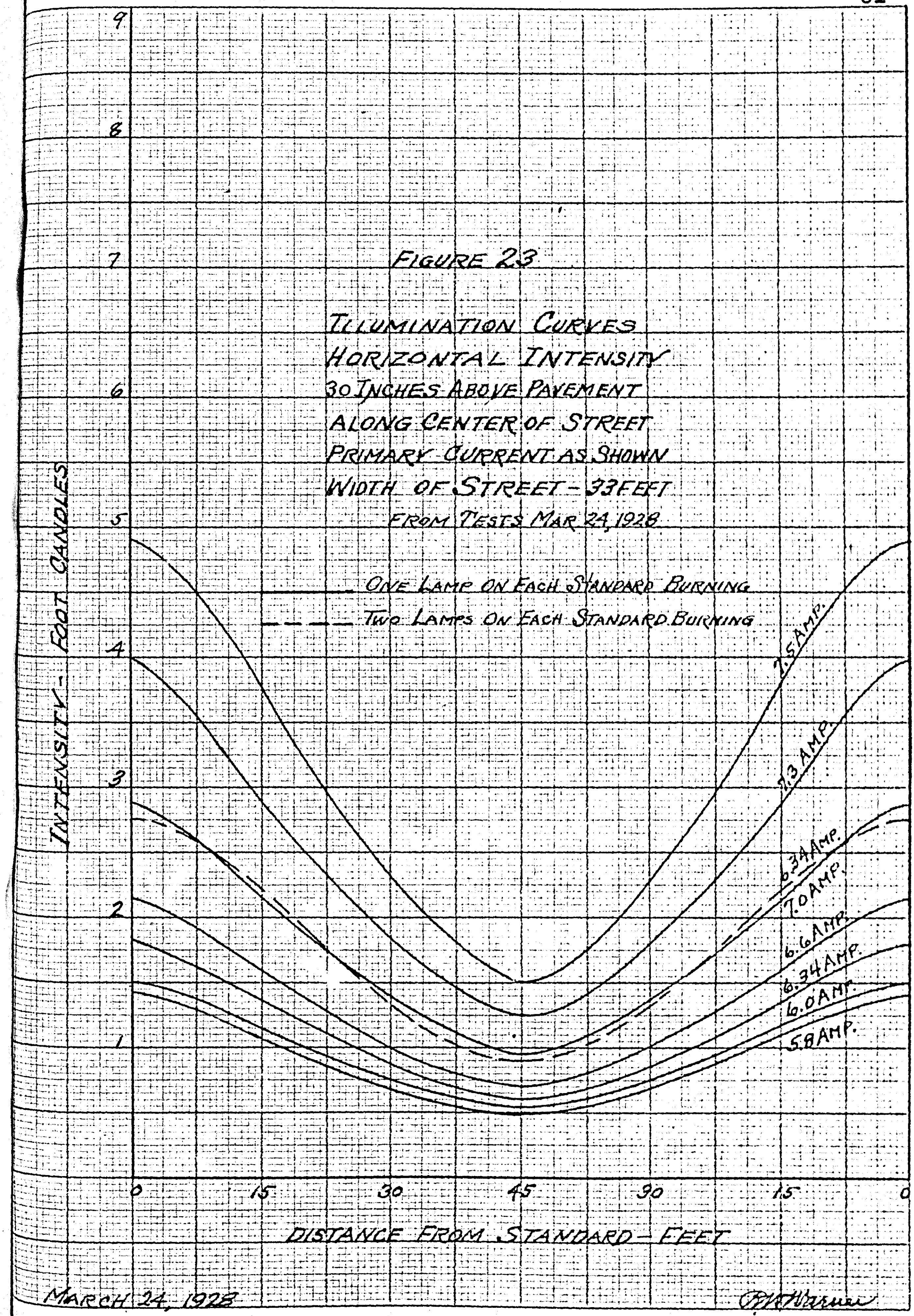


FIGURE 23
ILLUMINATION CURVES
HORIZONTAL INTENSITY
30 INCHES ABOVE PAVEMENT
ALONG CENTER OF STREET
PRIMARY CURRENT AS SHOWN
WIDTH OF STREET - 33 FEET
FROM TESTS MAR 24, 1928
ONE LAMP ON EACH STANDARD BURNING
TWO LAMPS ON EACH STANDARD BURNING
INTENSITY - FOOT CANDLES
9
8
7
6
5
4
3
2
1
7.5 AMP.
7.3 AMP.
6.34 AMP.
7.0 AMP.
6.6 AMP.
6.34 AMP.
6.0 AMP.
5.8 AMP.
0
15
30
45
30
15
0
DISTANCE FROM STANDARD - FEET
MARCH 24, 1928

series circuit was connected directly to the 2,300-volt street lighting feeder with only pyrene fuse protection.

These circuits have been in operation for 10 circuit-months. There have been no operating troubles of any kind during that time. A total of 4 lamps or 10 per cent have burned out up to the present time after being in service 1520 hours, which is 12.6 per cent above their normal life.

The indications are that a system composed of circuits of this type would be entirely successful.

V. COST OF INSTALLATION

The street lighting system for the downtown business district has been divided into a number of natural divisions for the purpose of determining the cost of installation. The cost of each part is determined separately. This provides a convenient and ready basis for the comparison of the five plans of operation which are under consideration. Some of the sections of the system are identical under two or more of the plans. The divisions are as follows:

1. The Lamp Units including the standards.
2. The circuit at the lamps -- both overhead and underground.
3. The lines from the lamp circuits to the transformer or network.
4. The control of the system.
5. The transformer or fuse station.
6. The circuit from the transformer to the substation.
7. New substation equipment required.
8. The proportional part of the original substation.

A constant multiplier has been used in all of these cost figures in order to avoid the disclosing of confidential information. This will affect in no way the comparison of the different parts of the system under the plans being considered. Neither will it affect the choice of the most economical system.

In each case the cost of the material, of the labor, of the engineering expense, and of the freight will be shown.

SECTION No.1 - THE LAMP UNITS

The lamp fixtures such as the globes, the brackets and the boulevard standards will be the same for all of the plans. A multiple-type lamp will be used in Plan No.2. A series-type lamp will be used for the other plans. The cost is the same.

The transformers for insulating the lamps from the high voltage series circuit will not be required for the lamps in the multiple plan. The cost of each lamp standard or pole will be given as a unit. The cost of all of the lamps and fixtures for the entire system is then readily determined.

The costs for the series lamp units are as follows--

a. Overhead trolley-pole unit having 2, 15,000-lumen lamps-

Material	$199.26	
Freight	5.20	$204.46
Labor	54.16	
Engineering	2.31	56.47
Total		$260.93

b. Overhead trolley-pole unit having 2, 25,000-lumen lamps-

Material	$213.04	
Freight	5.65	$218.69
Labor	63.10	
Engineering	2.47	65.57
Total		$284.26

c. Boulevard - standard unit having 2, 15,000-lumen lamps-

Material	$340.03	
Freight	5.20	$345.23
Labor	94.13	
Engineering	4.97	99.10
Total		$444.33

d. Boulevard - standard unit having 2, 25,000-lumen lamps-

Material	$356.24	
Freight	5.65	$361.89
Labor	96.80	
Engineering	4.97	101.77
Total		$463.66

The costs for the multiple lamp units are as follows-

a. Overhead trolley-pole unit having 2 750-watt lamps-

Material	$141.83	
Freight	5.20	$147.03
Labor	53.16	
Engineering	2.31	55.47
Total		$202.50

b. Overhead trolley-pole unit having 2, 1000-watt lamps-

Material	$141.76	
Freight	5.65	$147.41
Labor	63.10	
Engineering	2.47	65.57
Total		$212.98

c. Boulevard - standard unit having 2, 750-watt lamps-

Material	$282.48	
Freight	5.20	$287.68
Labor	94.20	
Engineering	4.97	99.17
Total		$386.85

d. Boulevard - standard unit having 2, 1000-watt lamps-

Material	$285.14	
Freight	5.65	$290.79
Labor	96.20	
Engineering	4.97	101.17
Total		$391.96

The total number of each type of unit for Plans No. 1, 3, 4 and 5 with the cost of each is as shown below-

Trolley-pole units-			
536	15,000-lumen	@ $260.93	$138,858.48
190	25,000-lumen	@ $284.26	54,009.40
Boulevard-standard units-			
72	15,000-lumen	@ $444.33	31,991.76
17	25,000-lumen	@ $463.66	7,882.22
		Total	$232,741.86

For Plan No. 2 the total number of each type of unit with the cost of each is as follows--

Trolley-pole units			
536	750-watt	@ $202.50	$108,540.00
190	1000-watt	@ $212.98	40,466.20
Boulevard-standard units			
72	750-watt	@ $386.85	27,853.20
17	1000-watt	@ $391.96	6,663.32
	Total for Section No.1, Plan No.2		$183,522.72

SECTION No.2 - THE LAMP CIRCUIT-

The circuit at the lamps will be similar for Plans No.1, 3, 4 and 5. In each case it consists of two parts- a double, overhead, wire circuit and a double, underground, cable circuit. The overhead wire circuit is the same for all of the plans. It consists of two, No.6, weatherproof, wires carried on cross-arms mounted on wooden trolley-pole extensions and insulated for 15,000 volts. For Plans No.1, 4 and 5, the underground cable section will consist of two No.6, 5000-volt parkway cables. These will not be run in conduit, but simply buried approximately two feet under the surface. These cables for Plan No.3 will be rated at 15,000 volts.

The overhead lamp circuit for Plan No.2 will consist of three No.0 weatherproof stranded cables carried on secondary racks attached to the trolley poles. The underground circuit for the boulevard standards will consist of three No. 0, 750-volt, underground cables. These will be single-conductor cables rather than three-conductor, because of the greater ease in handling and installing. No bulky pothead at the standard will be required. The cost of the three-conductor cable is equal to the cost of three single-conductor cables of the same rating.

The cost of the circuit for Plans No. 1, 3, 4 and 5 is as follows--

Overhead Section, Plans No. 1, 3, 4 and 5 -

Material		$10,369.40
Labor	$8,658.90	
Engineering	725.00	9,383.90
Total		$19,753.30

Underground Section, Plans No. 1, 4 and 5 -

Material		$ 5,440.05
Labor	$8,470.00	
Engineering	974.60	9,444.60
Total		$14,884.65

Underground Section, Plan No. 3 -

Material		$ 9,451.20
Labor	$9,905.50	
Engineering	1,083.50	10,989.00
Total		$20,440.20

The cost of the circuit for Plan No. 2 is as follows--

Overhead Section

Material	$37,242.10	
Freight	110.00	$37,352.10
Labor	19,157.60	
Engineering	1,567.00	20,724.60
Total		$58,076.70

Underground Section

Material	$24,298.20	
Freight	55.00	$24,353.20
Labor	15,560.05	
Engineering	1,584.00	17,144.05
Total		$41,497.25

SECTION No.3 - THE CIRCUIT TO THE SECONDARY SUPPLY.

The secondary source of supply for Plans No.1 and 3 is the secondary or series side of the constant-current transformer. For Plan No.2 it is the 115/230-volt Edison system network in the direct-current district and the secondary side of the constant-potential transformer in the alternating-current district. In Plan No.4 the corresponding point is the fuse station where the series circuit is connected to the 2300/4000-volt primary feeder. The secondary side of the power transformer is considered the secondary source of supply in Plan No.5.

The secondary supply circuits in Plans No.1 and 4 are identical and consist of No.6 weatherproof wire carried overhead on cross-arms attached to wooden extensions on the trolley poles. These circuits are insulated for 15,000 volts. They extend from the series lamp circuits to convenient locations for the constant-current transformers in Plan No.1 or to convenient places for connecting to the primary feeders in Plan No.4.

The cost of these circuits for Plans No.1 and 4 is as follows-

Material		$ 3,458.40
Labor	$2,232.50	
Engineering	176.00	2,408.50
Total		$5,866.90

The circuit to the direct-current network in Plan No.2 will be run underground with cables ranging in size from No.000 to 500,000 circular mils, insulated for 5,000 volts. These cables will extend from the manhole connections at the direct-current network to the nearest point of reaching the lamp circuits. The connections here will be made through fused junction boxes.

The cost of this part of the direct-current circuit is as follows--

Material		$27,595.70
Labor	$21,492.90	
Engineering	1,732.50	23,225.40
Total		$50,821.10

For the alternating-current part of Plan No.2, this circuit consists of the overhead lines from the distribution transformers to the lamp circuits.

The cost is as follows--

Material		$12,239.80
Labor	$6,846.40	
Engineering	810.00	7,656.40
Total		$19,896.20
Total for Plan No. 2		$70,717.30

This part of the circuit in Plan No.3 consists of 3-conductor, 15,000-volt cables run underground through existing ducts from the lamp circuits to the constant-current transformer substation. The cost is as follows-

Material		$85,312.70
Labor	$26,951.00	
Engineering	2,656.50	29,607.50
Total		$114,920.20

Under Plan No.5 this section of the circuit will consist of No. 6 weatherproof wire carried overhead on cross-arms attached to wooden extensions on the trolley poles.

The cost is as follows--

Material		$4,643.10
Labor	$3,180.10	
Engineering	239.80	3,419.90
Total		$8,063.00

SECTION No. 4 - THE CONTROL OF THE SYSTEM.

The control of the entire system is centered in the automatic substations in Plans No.1, 3, 4 and 5. Automatic time-clocks will turn the circuits on and off. The cost of the clocks and the necessary relays is included with the switching equipment in the substation. In Plan No. 2 there will be a system of magnetic-type contactors operated in multiple over two pilot wires by means of master time-clocks.

The cost is as follows-

Material		$9,229.00
Labor	$2,728.00	
Engineering	467.50	3,195.50
Total		$12,424.50

SECTION No.5 - THE TRANSFORMER OR FUSE STATION.

The transformer station for Plan No.1 consists of a constant-current transformer mounted on a pole with two, 30-ampere, fused cut-outs on the secondary or series side and two, 50-ampere, cut-out boxes on the primary side.

The cost is as follows-

Material	$67,346.40	
Freight	1,017.50	$68,363.90
Labor	$16,058.00	
Engineering	1,743.50	17,801.50
Total		$86,165.40

The cost of the distribution transformers for the alternating-current district of Plan No.2 is as follows--

Material	$12,051.60	
Freight	275.00	$12,326.60
Labor	$ 2,612.50	
Engineering	110.00	2,722.50
Total		$15,049.10

The cost of the transformers in Plans No.3 and 5 are included with the substation.

The cost of the fuse station for Plan No. 4 is as follows--

Material		$ 5,725.00
Labor	$ 5,160.00	
Engineering	337.00	5,497.00
Total		$11,222.00

SECTION No.6 - THE CIRCUIT FROM THE TRANSFORMER TO THE SUBSTATION.

The circuit from the constant-current transformer in Plan No.1 to the substation consists of two, three-phase, four-wire, 2300/4000-volt feeders. The route and wire sizes have been shown on Figures No.13 and 14. One of these feeders supplies the all-night circuits and the other carries the one-o'clock circuits.

The cost of both circuits is as follows--

Material		$19,850.00
Labor	$8,698.80	
Engineering	753.50	9,452.30
Total		$29,302.30

The distribution transformers which supply the alternating-current district in Plan No.2 will be connected to the present 2300-volt street lighting feeders. Hence, there will be no additional expense for primary line extensions.

In Plan No.3 the transformers are located in the primary, supplying substation, so that there will be no expense to be listed under this cost section.

The circuit from the fuse stations in Plan No.4 to the substation is similar to that of Plan No.1, except with smaller wire sizes. The route and wire sizes have been shown on Figures No.18 and 19. One of these three-phase feeders will supply the all-night circuits and the other will take care of the one-o'clock circuits.

The cost is as follows--

Material		$12,139.00
Labor	$7,198.80	
Engineering	753.50	7,952.30
Total		$20,091.30

In Plan No.5 the constant-potential power transformers are located in the substation so that there will be no expense for primary feeders.

SECTION NO.7 - NEW SUBSTATION EQUIPMENT.

In order to take care of the new 2300/4000-volt feeder for the one-o'clock circuits of Plans No.1 and 4, it will be necessary to provide three circuit breakers with the control equipment at the substation. The cost of this will be as follows--

Material	$6,573.60	
Freight	220.00	$6,793.60
Labor	$3,004.10	
Engineering	440.00	3,444.10
Total		$10,237.70

No additional substation equipment will be required for Plan No.2.

A complete 13200-volt, automatic substation will be necessary for the primary transformers in Plans No.3 and 5. The cost will be $130,020.00 for the station.

SECTION No.8 - THE PROPORTIONAL PART OF THE PRESENT SUBSTATION.

A comparison of this nature would not be complete without including a proportional part of the existing substation equipment. This proportion should be based on the rating of the new feeders and the corresponding rating of the rest of the station. The total feeder rating of the present substation, including one new feeder for the one-o'clock circuits, is 19,500 kilovolt-amperes. The new load will be 3125 kilovolt-amperes or 16 per cent. The cost of the present substation is $279,620.00. The substation equipment required for the new circuit will cost $10,237.00 as is shown in Section No.7. This makes a total station cost of $289,857.00. The proportional part of this for the new load, 16 per cent, is $46,377.00.

The new load under Plan No.4 will be 1688 kilovolt-amperes or 8.6 per cent of the total station rating. This proportion of the total station cost is $24,928.00.

The amount of load to be placed on the direct-current system under Plan No.2 is 5.2 per cent of the total load of the system. This proportion of the original station cost is $57,200.00. The amount of load to be placed on the alternating-current system is 3.5 per cent of the total substation feeder rating.

It will not be necessary to provide any additional substation equipment. This proportion of the original substation cost of $279,630.00 is $9,787.00. The total prorated substation cost for this plan is, therefore,$66,987.00.

Since the substations for Plans No.3 and 5 will be entirely new, there will be no cost allocated to this section under those plans.

SUMMARY - COST OF INSTALLATION.

The following Table V. indicates the total cost of the new lighting system as proposed under each plan.

TABLE V. COST OF INSTALLATION

SECTION NO.	PLAN No.1 2300v.S-M	PLAN No.2 Multiple	PLAN No.3 13200v.S-M	PLAN No.4 2300v.S-M	PLAN No.5 4000v.S-M
1. Lamp Units	$232,742.00	$183,523.00	$232,742.00	$232,742.00	$232,742.00
2. Lamp Circuit					
Overhead	19,753.00	58,077.00	19,753.00	19,753.00	19,753.00
Underground	14,885.00	41,497.00	20,440.00	14,885.00	14,885.00
3. Circuit to Transformer	5,867.00	70,717.00	114,920.00	5,867.00	8,063.00
4. Control System	Included in (7)	12,424.00	Included in (7)	Included in (7)	Included in (7)
5. Transformer Station	86,165.00	15,049.00	Included in (7)	Included in (7)	11,222.00
6. Circuit to Substation	29,302.00	----	----	20,091.00	----
7. New Station Equipment	10,238.00	----	130,020.00	10,238.00	130,020.00
8. Proportion of Present Station	46,377.00	66,987.00	----	24,928.00	----
TOTAL	$445,329.00	$448,274.00	$517,875.00	$328,504.00	$416,685.00

VI. LOSSES

In order to investigate the economy of the operation of the lighting system it is necessary to determine the power losses in each section of the system. This will be done in a manner similar to the way in which the cost of installation was determined. After the power losses have been found, it will be a simple process to calculate the energy losses for the entire year.

SECTION No. 1 - THE LAMP UNITS.

The actual lamp load for all of the all-night, series lamps is 814 kilowatts. The efficiency of the insulating current-transformers is 96 per cent. The loss here is therefore 33.9 kilowatts. The loss at the one-o'clock lamps is 31.5 kilowatts. This loss is the same for Plans No.1, 3, 4 and 5. There is no corresponding loss for the multiple Plan No.2.

SECTION No. 2 - THE LAMP CIRCUIT.

The copper loss in the No. 6 series wire from lamp to lamp in Plans No.1, 3, 4 and 5 amounts to 1.6 kilowatts for the all-night circuits and the same amount for the one-o'clock circuits.

SECTION No. 3 - THE CIRCUIT TO THE SECONDARY SUPPLY.

The loss in the wire from the lamp circuits to the constant-current transformers in Plan No. 1 is 0.2 kilowatts each for the all-night and for the one-o'clock circuits. The corresponding loss for Plan No. 4 is the same. The copper loss of this section in the Multiple Plan No. 2 is 4.2 kilowatts for the all-night circuits and 2.8 kilowatts for the one-o'clock circuits.

In Plan No. 3 the cable loss between the lamp circuits and constant-current transformers is 0.9 kilowatts and 1.9 kilowatts for the all-night and one-o'clock circuits respectively.

The line loss in Plan No. 5 between the lamp circuits and the power transformers is 1.6 kilowatts for the all-night circuits and 3.2 kilowatts for the one-o'clock circuits.

SECTION No. 4 - THE CONTROL FOR THE SYSTEM.

The only loss in this section is for Plan No. 2. There is a small loss in the coils of the magnetic control contactors and pilot wires used in this plan. This is 1.6 kilowatts for the all-night circuits and 2.2 kilowatts for the one-o'clock circuits. There are 22 contactors required for the all-night circuits and 31 contactors needed for the one-o'clock circuits. The loss in each coil is 70 watts. The pilot-wire losses are negligible.

SECTION No. 5 - THE TRANSFORMERS.

The efficiency of the 20-kilowatt constant-current transformers used in Plan No. 1 is 95 per cent. The transformer output for the all-night circuits is 850.0 kilowatts. The transformer losses are therefore 45 kilowatts. The transformer output to the one-o'clock circuits is 789.0 kilowatts including the line loss beyond the transformers. Therefore, the one-o'clock transformer losses are 42 kilowatts.

In Plan No. 2 the only transformer losses are those of the distribution transformers in the alternating-current district. The efficiency of those transformers is 97.5 per cent. The output is 265.9 kilowatts for the all-night circuits and 257.5 kilowatts for the one-o'clock circuits. Therefore, the transformer losses are 7.1 kilowatts and 6.5 kilowatts.

The efficiency of the 70-kilowatt constant-current transformers of Plan No. 3 is 97.5 per cent. The losses are 22.5 kilowatts and 20.5 kilowatts for an output of 850.6 kilowatts and 789.5 kilowatts to the all-night and to the one-o'clock circuits respectively.

Plan No. 4 does not call for any constant-current or distribution transformers and, hence, has an advantage of there being no losses in this section of the circuit.

The constant-potential transformers of Plan No. 5 have an efficiency of 97.5 per cent. Their output is 851 kilowatts and 792 kilowatts for the all-night and for the one-o'clock circuits. The corresponding losses are 21.7 kilowatts and 20.1 kilowatts.

SECTION No. 6 - THE CIRCUIT FROM THE TRANSFORMER TO THE SUBSTATION.

The 2300-volt, primary, line losses between the constant-current transformer of Plan No. 1 and the substation are indicated on the feeder diagrams, Figures 13 and 14. The total loss for the all-night feeder is 34.8 kilowatts and 30.2 kilowatts for the one-o'clock feeder.

The primary line loss for the alternating-current district under Plan No. 2 is 1.7 kilowatts for the all-night circuits and 2.2 kilowatts for the one-o'clock circuits.

In Plan No. 3 the transformers are located in the substation so that there will be no primary distribution losses.

The primary line loss in Plan No. 4 between the point where the connection is made to the lamp circuit and the substation is indicated on the feeder diagrams, Figures 18 and 19. The total loss for the all-night feeder is 17.3 kilowatts and 15.3 kilowatts for the one-o'clock feeder.

SECTION No. 7 - THE PRIMARY SUBSTATION.

The efficiency of the 13,200 to 2,300/4,000-volt, station transformers is 98.5 per cent. The substation output to the all-night feeders in Plan No. 1, including the feeder loss, is 920 kilowatts and 861 kilowatts to the one-o'clock feeders. The corresponding transformer losses are, therefore, 14.0 and 13.5 kilowatts.

The primary substation losses in Plan No. 2 consist of two parts -- first, the losses in the rotary-converters and transformers of the Edison system substations and, second, the losses in the station power transformers that supply the alternating-current part of the street lighting system.

The efficiency of the rotary-converter substations is 88 per cent. The output from the direct-current network to the street lighting system is 484 kilowatts to the all-night lamps and 437 kilowatts to the one-o'clock lamps. Therefore, the substation losses are 60.8 and 58.6 kilowatts for the all-night and for the one-o'clock circuits respectively.

The alternating-current district is supplied from a 13,200 to 2300/4000-volt substation. The output to the all-night feeders is 274.7 kilowatts and 266.1 kilowatts to the one-o'clock feeders. The transformer efficiency is 98.5 per cent. Hence, the losses are 4.0 and 3.9 kilowatts for the all-night and for the one-o'clock feeders respectively.

The substation losses for Plans No. 3 and 5 have been given under Section No. 5 of the system losses.

The load for the lighting system in Plan No. 4 is supplied by a 13,200 to 2,300/4,000-volt substation. The transformer efficiency is 98.5 per cent. The output from the station, including the line loss, is 867.2 kilowatts to the all-night feeder and 804.2 kilowatts to the one-o'clock feeder. The losses, therefore, are 13.0 and 12.0 kilowatts for the all-night and for the one-o'clock feeders respectively.

SUMMARY --- LOSSES.

A summary of the losses by sections is shown in TABLE VI. The all-night lamps burn 4000 hours per year and the lamps which are turned off at one o'clock burn 2000 hours per year. Hence, the annual energy losses are determined by multiplying the total all-night power loss by 4000 and the total one-o'clock power loss by 2000. The totals are shown for each plan in TABLE VI.

TABLE VI. LOSSES. -- KILOWATTS

SECTION NO.	PLAN No.1 2300v. S-M		PLAN No.2 Multiple		PLAN No.3 13200v. S-M		PLAN No.4 2300v. S-M		PLAN No.5 4000v. S-M	
	A-N	1-A.M.	A-N	1-A.M.	A-N	1-A.M.	A-N	1-A.M.	A-N	1-A.M.
1. Lamp Units	33.9	31.5	---	---	33.9	31.5	33.9	31.5	33.9	31.5
2. Lamp Circuit	1.6	1.6	3.9	7.8	1.6	1.6	1.6	1.6	1.6	1.6
3. Circuit to Transformer	0.2	0.2	4.2	2.8	0.9	1.9	0.2	0.2	1.6	3.2
4. Control System	---	---	1.6	2.2	---	---	---	---	---	---
5. The Transformers	45.0	42.0	7.1	6.5	22.5	20.5	---	---	21.7	20.1
6. Circuit to Substation	34.8	30.2	1.7	2.2	---	---	17.3	15.3	---	---
7. Substation a - c	14.0	13.5	4.0	3.9	---	---	13.0	12.0	---	---
d - c	---	---	60.8	58.6	---	---	---	---	---	---
TOTAL	129.5	119.0	83.3	84.0	58.9	55.5	66.0	60.6	58.8	56.4

The annual kilowatt-hour losses are as follows--

Plan	All-Night	One-o'clock	Total
No.1	518,000	238,000	756,000
No.2	333,200	168,000	501,200
No.3	235,600	111,000	346,600
No.4	264,000	121,200	385,200
No.5	235,200	112,800	348,000

VII. ANNUAL CHARGES

The total annual cost of the street lighting system consists of the sum of the annual fixed investment charge and the cost of the annual energy loss. The most economical system will be the one which has the lowest annual cost.

INVESTMENT CHARGES.

The investment required to install the entire street lighting system, including the means of supplying the lamps proper, has been determined previously. A figure of 15 per cent will be used as a fair value for the annual fixed investment charges. This includes the taxes, depreciation, maintenance and the interest on the original investment.

The cost of installing the street lighting system and the annual investment charge is as shown below.

Plan	Total Cost	Annual Charge
No.1	$445,329.00	$66,799.35
No.2	448,274.00	67,241.10
No.3	517,875.00	77,681.25
No.4	328,504.00	49,275.60
No.5	416,685.00	62,502.75

ENERGY CHARGES.

The charge for energy losses is based on the annual kilowatt-hours lost and the cost of producing the energy. A figure of $0.01 per kilowatt-hour will be used in this discussion. On this basis the cost of the yearly energy lost under each plan is as shown below-

Plan	Annual Energy Loss	Cost of Energy Loss
No.1	756,000 Kw.-Hrs.	$7,560.00
No.2	501,200	5,012.00
No.3	346,600	3,466.00
No.4	385,200	3,852.00
No.5	348,000	3,480.00

The total annual cost for the system under each plan is as shown below-

Plan	Investment Charges	Energy Cost	Total Cost.
No.1	$66,799.35	7,560.00	$74,359.35
No.2	67,241.10	5,012.00	72,253.10
No.3	77,681.25	3,466.00	81,147.25
No.4	49,275.60	3,852.00	53,127.60
No.5	62,502.75	3,480.00	65,982.75

These results show that Plan No. 4 will be the most economical system to install and operate.

VIII. CONCLUSIONS

ECONOMICAL.

It has been shown that the system as outlined under Plan No. 4 will be the most economical from the standpoint of the annual cost. However, Plan No. 4 will not have the lowest cost for the yearly energy loss. Plan No. 3 and Plan No. 5 both have lower losses. The one single item of greatest expense in Plan No. 3 is the constant-current transformer substation. Plan No. 5 carries the same handicap, but does not have the expensive underground cable circuits that are involved in Plan No. 3.

PRACTICAL.

Aside from the economical considerations there are a number of other things which enter into the selection of the type of system which is to be installed.

It must be physically possible to install the system. This has been taken care of in the design. No physical impossibilities were allowed to creep into any of the proposed plans.

The distribution part of the system must be of an attractive appearance, or at least not be objectionable or unsightly in any respect. A congestion of overhead wires would be objectionable and the time would probably come when the power company would be asked to remove them.

There is a strong sentiment in favor of having all of the lighting and power lines placed underground in the downtown business district. This undoubtedly improves the appearance of the streets.

The trend of the present day engineering practice is toward higher voltages in order to cut down the energy losses. Plan No. 3 is in this direction. This plan calls for an underground series distribution system which again is in its favor.

When a system of this sort is proposed, the time element plays a considerable part in the final choice of the type of system to be installed. It might be necessary to select a type which would not be the most economical, in view of some of the practical considerations mentioned above. If the installation were not to be made all at one time but rather to be extended over a number of years, it might be possible to have the immediate installation conform to the most economical plan. At the same time, the installation should be made so that it could be changed over with a minimum loss to a more favorable type in the future.

This is the final decision as the result of the foregoing discussion and study. Plan No. 4 is the most economical but it has some unfavorable future aspects. Plan No. 3 is the most attractive from a future standpoint. The first two sections of the system -- the lamps and the overhead lamp-circuits -- are the same under both plans. As parts of this new lighting system are installed they will conform to Plan No. 4. If it ever becomes necessary in the future to change the system so as to conform to Plan No. 3, the lamps and overhead lamp circuits will not be affected in any way. The loss due to the change in the distribution part of the system will be slight. In this manner it will be possible to build up an economical system which will be, to a considerable extent, in accordance with probable future developments.

BIBLIOGRAPHY

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