AN ABSTRACT OF THE THESIS OF

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Title The Attenuation of Radio Frequency Disturbances of High Voltage Transmission Lines.

Abstract Approved:
(Major Professor)

[redacted]


This thesis is a report of the results of an investigation of a new method of attenuating the radio interference originating on, and being transmitted by, high-voltage transmission lines. In order to show the need for such an attenuating system the problem of radio interference and contributions to its solution are briefly reviewed.

Radio frequency interference is transmitted long distances on high-voltage transmission lines with remarkably little attenuation. The object of the discussion in this thesis is to explain the theory, design, laboratory characteristics, and expected field characteristics of radio frequency filter sections to be used on high-voltage transmission lines. These filter sections are to be installed at particular points where it is desired to isolate sections of lines free from radio interference from sections of the same lines that are not free from interference.

The filter section is to be constructed by making filter circuits, whose band pass characteristics lie in the radio broadcast band of 500 to 1500 kilocycles, between the line and ground. The filter circuits are created by using conventional high-voltage insulators as capacitors and installing suitably designed inductance coils between the ungrounded insulator pins and ground to produce series resonance at the desired frequencies.

The experimental filter section was designed for using pin type insulators, and the laboratory tests were made with conventional 66 kv. units. However, the fundamental principle is applicable to other types of insulators as well.

The resonant frequencies of the individual filter circuits must be so distributed that the bands of frequencies passed by the separate circuits over-lap in such a manner as to make the line to ground impedance quite uniformly low throughout the total band of frequencies to be passed by the filter.

Three experimental circuits, of the ten necessary for each conductor to filter all frequencies from 500 to 1500 kilocycles were constructed, and the individual and composite impedance characteristics of this partial filter section were obtained.

The laboratory results show that a satisfactory filter circuit can be constructed and an actual installation on a transmission line is planned.

Radio frequency series choke coils have been used in high voltage transmission lines to attenuate radio interference transmission, but they have not been entirely satisfactory because they do not attenuate the whole band of radio breadcast frequencies satisfactorily and their cost is high.

A filter section such as described in this thesis utilizes the insulators of the line as capacitors and the inductance coils are at ground potential and carry only the radio frequency currents therefore allowing the use of coils that are relatively small and simple in construction. Consequently, such an attenuating system should be economical.

# THE ATTENUATION OF RADIO-FREQUENCY DISTURBANCE ON HIGH-VOLTAGE TRANSMISSION LINES

by

MELVIN JULIUS KOFOID

A THESIS

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## ACKNOWLEDGEMENT

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The encouragement and continued assistance and suggestions given by Professors F. O. McMillan, A. L. Albert, and E. C. Starr of the Electrical Engineering Department of Oregon State College is very gratefully acknowledged.

The laboratory investigation was made possible by the financial support and laboratory facilities furnished by the Oregon State College Engineering Experiment Station and Electrical Engineering Department.

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## INTRODUCTION

### The Problem of Radio Frequency Interference from High Voltage Transmission Lines:

A high-voltage transmission line causes interference in radio receivers because of the electromagnetic radiation resulting from disturbances on the conductors or associated equipment. The magnetic and dielectric fields of this radiation are between conductors and between conductors and ground, the major portion of the interference caused in radio receivers being due to the fields between conductors and ground.

A common source of electrical disturbances of radio frequencies from high-voltage transmission lines is the ionization and break-down of over-stressed air in the pin hole of the insulator, and between the conductor, tie wire, and insulator head. In some cases interference is caused by leakage currents flowing through conducting deposits of various kinds on the insulator surface. Other sources of interference are poor connections, loose tie wires, loose hardware, and defective equipment.

The most evident problem that presents itself is that of the elimination of the source of the disturbances as completely as possible. High class line construction and maintenance is necessarily rather expensive, and while essential for the complete elimination of sources of interference in urban areas, its use throughout, on long power lines traversing sparcely inhabited districts between the plant and the load center in many cases is not economically justified. The additional expense of constructing a new line so that it would be free from radio frequency interference causing disturbances may not be great since insulators quite free from radio interference are now available, but the riddance of disturbance from a complete line already installed generally would involve an expense that would be prohibitive.

While high frequency disturbances on a line in lightly populated areas is not of serious consequence in such areas, such disturbances will travel along the transmission line for long distances with remarkably small attenuation, into what may be otherwise disturbance-free sections. Satisfactory means of isolating interference-producing and interference-free sections of transmission lines at radio frequencies are therefore necessary.

## Some Previous Contributions to the Elimination of Radio Frequency Interference:

Radio interference due to corona on the head and in the pin holes of insulators can be satisfactorily eliminated by applying an asphalt emulsion treatment to replace the regions of otherwise over-stressed air with solid insulating material.[3] Insulator manufacturers have, and are, doing much work in designing radio interference-free insulators. The other sources of interference can obviously be quite completely eliminated by proper maintenance.

Choke coils have been designed and manufactured for isolating interference-free and interference-producing sections of lines. These devices are air-core coils of such inductance as to offer exceedingly high impedance to currents of radio frequencies and practically zero impedance to currents of power frequencies. A choke coil is inserted in series with each of the conductors at the point of the desired isolation.

## Limitations of Present Methods of Radio Frequency Interference Attenuation:

Series choke coils must conduct the total line current and must be mechanically and electrically capable of withstanding line surges. Choke coils capable of conducting comparitively small currents, such as might be required to prevent interference from being conducted into the vicinity of a radio transmitter over the power line supplying the transmitter present a lesser problem and have been used satisfactorily. But choke coils designed for major distribution lines carrying large amounts of power at high voltages must be rugged, are massive, and are very expensive.

# RADIO-FREQUENCY FILTER SECTIONS FOR HIGH-VOLTAGE TRANSMISSION LINES

## Field of Application:

This paper is a report on an investigation of the possibility of constructing a radio-frequency filter section to afford a low impedance path for radio frequencies between conductors and between conductors and ground, utilizing the high-voltage pin type insulators as capacitors. Such a filter section, if found highly efficient, should be a convenient and relatively inexpensive means of preventing disturbances from being conducted on into a disturbance-free section from the section of its origin. This study is limited to power lines using pin type insulators. A filter of the same type could be constructed for use on a line employing suspension type insulators; pin type insulators have higher capacitances than suspension type insulators and therefore much larger inductances would be required in the filter circuits when suspension type units are used. Steel tower construction with the suspension insulators does not constitute nearly as serious a radio frequency interference problem as does wood pole construction using pin type insulators.

## Frequency Range of Attenuation:

The experimental filter section was designed for effective operation between the frequencies of 500 and 1500 kilocycles. In a commercial installation the range should perhaps be extended to the slightly higher frequencies now being used for broadcast programs. The attenuation, due to the normal characteristics of the line, of disturbances being transmitted on a power line is much greater at very high frequencies than at the regular broadcast frequencies. A single high-voltage insulator of 20 micro-micro-farads capacitance would have approximately a head to pin impedance of 8000 ohms at 1000 kilocycles, or 300 meters, and an impedance of only 800 ohms at 10,000 kilocycles, or 30 meters. Therefore, it is expected that the interference conducted into a high class section of a line of such frequencies as to interfere with short wave braodcast reception should be comparitively small.

Plan of Filter Section Construction:

The filter section is to be composed of a number of filter circuits in parallel, each composed of an insulator, acting as the capacitor, and a coil of such inductance as to cause series resonance with the capacitor at some desired frequency in the radio braodcasting band. At the resonant frequency the inductive reactance, $2\pi fL$, of this circuit is numerically equal to the capacitive reactance, $1/2\pi fC$, and the impedance is the resistance only. At frequencies other than the resonant frequency the total impedance of the particular circuit is equal to the square root of the sum of the square of the resistance plus the square of the difference of the capacitive and inductive reactances. Therefore, a series filter circuit makes the greatest reduction in the impedance through it at its resonant frequency and reduces the impedance to various lesser degrees in the band of frequencies on either side. The impedance characteristics of several individual experimental filter circuits are shown in Figs. 6 and 7. By utilizing a number of filter circuits in parallel between a conductor and ground, and having their resonant frequencies differ by a suitable amount, an over-lapping of their band-pass characteristics can be obtained that will reduce the line to ground impedance to a relatively small value for an entire band of frequencies. See Figs. 2, 8, and 9. Thus, a filter section was designed to lower the conductor to ground impedance, and the impedance between conductors for the entire radio broadcast band of 500 to 1500 kilocycles.

# FILTER SECTION DESIGN AND THEORETICAL CHARACTERISTICS

## Desired Impedance Characteristics:

A well designed filter section should offer as nearly as possible the same admittance to all frequencies within the band, with the admittance in no case deviating very greatly from the average admittance.

The average admittance should be made as high as is economically feasible.

## Theoretical Impedance Characteristics:

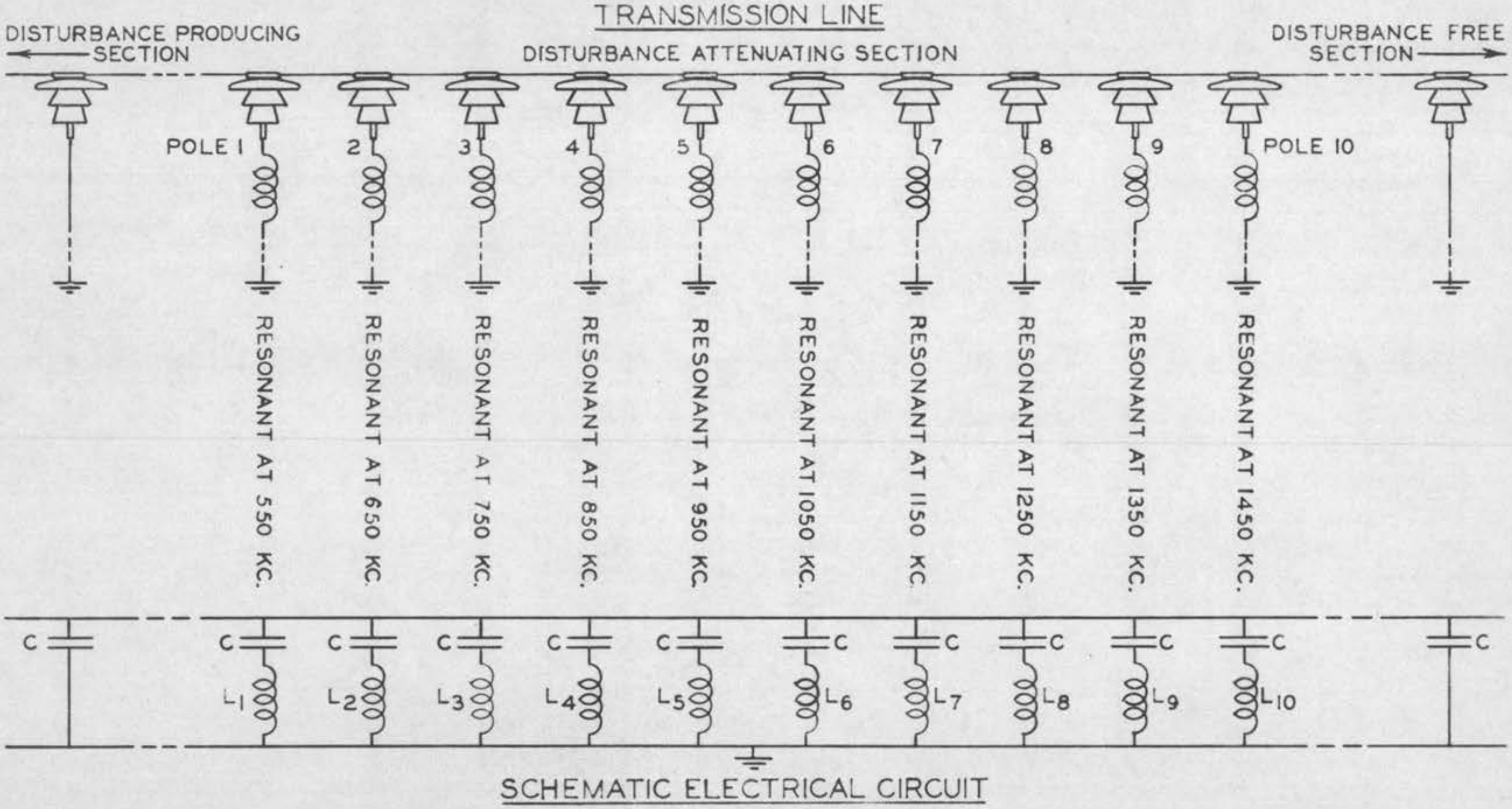
The diagram of Fig. 2 indicates roughly the desirable admittance characteristics of ten individual filter circuits, a filter section composed of ten individual filter circuits in parallel, and the ten insulators of the filter circuits in parallel without the inductances. The diagram represents no particular data but is presented merely to indicate desirable theoretical characteristics.

At 1,000 kilocycles the reactance of a 66 kv. insulator may be 8,000 or 10,000 ohms. At this same frequency, the impedance through this same insulator and an inductance to complete the filter circuit, may be as low as 150 or 200 ohms.

It appears that with an infinite number of filter circuits the impedance at no frequency in the band considered should be greater than the impedance at resonance of

## INSTALLATION OF INDUCTANCES ON A HIGH-VOLTAGE TRANSMISSION LINE FOR ATTENUATING RADIO-FREQUENCY DISTURBANCE

FIG. I




NOTE: THE 3-PHASE LINE IS REPRESENTED AS A SINGLE CONDUCTOR. AT EACH POLE IDENTICAL COILS ARE PLACED BETWEEN EACH INSULATOR PIN AND GROUND

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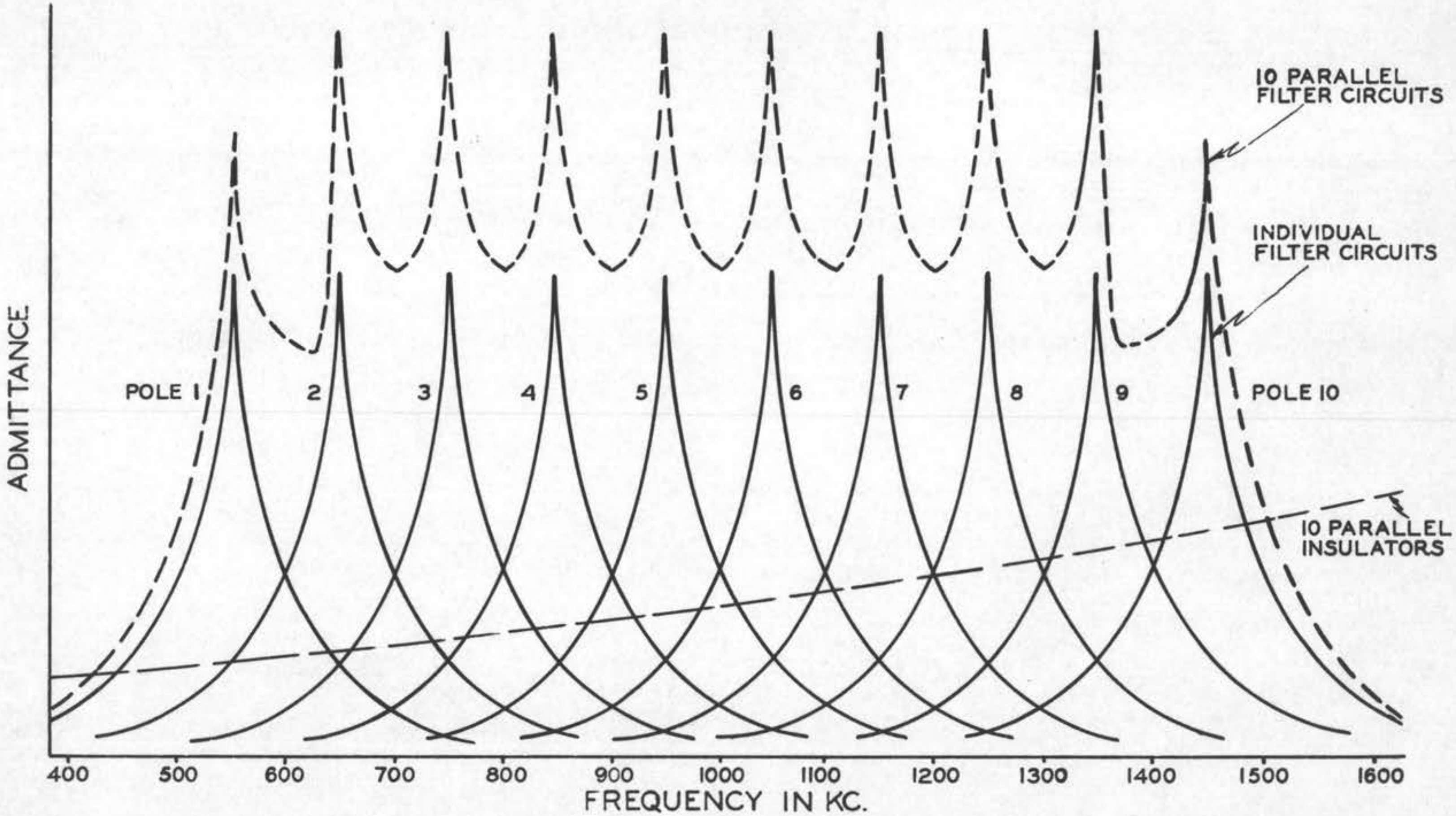
A THEORETICAL ADMITTANCE DIAGRAM OF AN R.F. FILTER SECTION ON A HIGH-VOLTAGE TRANSMISSION LINE

FIG. 2



an individual circuit. In fact, it appears that it may be much less than this value.

The total admittance between the line and ground at a particular frequency is the vector sum of the admittances at this frequency of all of the filter circuits in parallel between the line and ground. In Fig. 2, it is indicated (by the broken curve) that when all of the circuits are in parallel, the admittance at 1050 kilocycles is greater than the admittance of circuit 6, which is resonant at 1050 kilocycles, by the admittances of circuits 5 and 7, 4 and 3, and all of the remaining circuits by respectively lesser amounts. At 1000 kilocycles circuits 5, 6, 4, 7, and all other circuits contribute jointly to the admittance.

The composite curve of Fig. 2 is actually erroneous in that it is simply a representation of the numerical sum of the admittances. The actual characteristic is much different, and very much more complex, as the admittances actually add vectorially. Later in this paper, in the discussion on the experimental characteristics of three filter circuits in parallel, the results of the vector addition of the several admittances is clearly shown and discussed.

The admittances of the ten insulators, alone, in parallel add directly.

But, it is evident that the average, and even the minimum, admittance of the filter section to the band of frequencies for which it is designed may be greater than the total admittance of the insulators in the section alone.

Number of Filter Circuits in Section:

The admittance characteristics of the filter section over a band of frequencies is determined by the combined admittances of the component circuits. The number of circuits used will be determined by the resultant over-all characteristics and the economics of the problem.

The use of ten filter circuits, necessitating the construction of thirty inductances for an installation on a three-phase line, seemed reasonable from the point of the expense involved. Therefore, the experimental section was designed with ten different filter circuits arranged as shown in Figs. 1 and 2; the success of an arrangement of this degree of complexity to be used as a criterion of the practical value of such a filter section.

Distribution of Resonant Frequencies of Filter Circuits In a Filter Section:

Best results should be obtained with uniform spacing of the resonant frequencies, as then the maximum admittance will be the least and the minimum admittance will be the greatest, each being nearer the average admittance.

It is not desirable to have a circuit resonant at a boundary frequency as then half of its filtering value is unused.

# FILTER CIRCUIT CAPACITORS

## Dielectrics of High-Voltage Insulators:

Insulators are made of high quality porcelain having a dielectric constant of about six and of pyrex glass having a dielectric constant of about five. The leakage resistances are so high that the impedance may be treated as entirely capacitive reactance for practical purposes. The dielectric constant at very high frequencies may be considerably lower than the value at low frequencies. Severe temperature and humidity conditions should not be detrimental to the operation of a filter section utilizing insulators as capacitors because only very damp conditions could change the capacitance and the leakage resistance appreciably, and under such conditions the dielectric flux distribution of the insulator would be improved so that the interference caused by corona on the insulator would be eliminated. Any changes in the capacitances or inductances would merely shift the band of frequencies passed by the section.

## Capacitance of High-Voltage Insulators:

The capacitance of standard 60 to 70 kv. pin type insulators is small. Measurements were previously made at the Oregon State College Electrical Engineering Laboratories of the capacitance of pin and pedestal type insulators.[4] The average capacitance of fourteen representative standard 60 to 70 kv. insulators was 19.5 micro-micro-farads. Special types of insulators may have a quite different value of capacitance; three 66 kv. insulators with pressed metal thimbles instead of porcelain insulator thread in the pin hole had an average capacitance of 29.2 micro-micro-farads. Treating insulators with some form of conductive coating for the elimination of radio interference also increases their capacitance. The values of capacitance quoted above were measured with a Western Electric 4-A Capacity Unbalance Bridge at a frequency of 1200 cycles.

In the laboratory filter circuit test Jeffrey-Dewitt No. 94 porcelain insulators of a nominal rating of 66 kv. were used. The heads of these insulators were made of metal and were secured to the porcelain body of the insulators by means of projections secured in recesses in the porcelain by a special alloy designed to match the thermal expansion characteristics of the porcelain. Their capacitance when measured on the above mentioned capacity unbalance bridge at a frequency of 1000 cycles was found to be uniformly 20.0 micro-micro-farads. From the reactance data of later experimental tests their capacitance varied but slightly for frequencies from 530 to 1500 kilocycles; this is clearly shown by the curves of Fig. 5. Their capacitance was calculated to be 17.5 micro-micro-farads at 530 kilocycles.

When using insulators as capacitors in a filter section, it is very desirable to have the insulator capacitances fairly uniform. It is obvious that the use of insulators with higher capacitances allow the use of smaller inductances in the filter circuit.

# FILTER CIRCUIT INDUCTANCES

## Inductance Requirements:

For the experimental filter section ten sets of three identical inductances were required; each coil of a set in series with an insulator of very closely 17.5 micro-micro-farads capacitance to resonate at some particular frequency in the breadcast band. The ten selected frequencies were 550, 650, 750, 850, 950, 1050, 1150, 1250, 1350, and 1450 kilocycles.

## Practical and Economical Considerations:

For uniformity and ease of production it is desirable that the coil forms be of the same diameter, and as compact as possible consistent with meeting the electrical requirements. They should be of a design that is simple and economical to construct. The form must have sufficient strength to prevent its collapse if a large current surge should pass through the winding.

## Electrical Considerations:

In case of a flash-over of one of the insulators in the filter section, the filter circuit inductance would have to carry the short circuit current until the protective gap across the coil broke down or the oil switch supplying the line opened. The winding was designed for use on a 66 kv. system with a 20,000 kva. load, assuming the short-circuit current to be ten times the normal current and that the oil switch would open in one-tenth of a second, or less. Under these conditions the short-circuit current at the maximum load of 20,000 kva. would be 1750 amperes. The wire size selected for winding the inductance coils was No. 14 A. W. G. with double cotton insulation. With 1750 amperes flowing through the wire the temperature will increase from 20 to 475 degrees centigrade in 0.07 second and will increase to 1083 degrees centigrade, or the melting point of copper, in 0.12 second.[5] The charring temperature for the cotton insulation is approximately 475 degrees centigrade, for very short time transient heating and cooling of the conductor. Therefore, this size of conductor was considered adequate for the conditions assumed.

The distributed capacitance of the radio-frequency filter coils should be low, so as to eliminate the necessity of additional turns to gain the necessary inductance because the increased resistance of additional turns causes the resonance characteristic to be less sharp and the impedance at all times to be greater. Of the several types of coils, the single layer solenoid has the least distributed capacitance and was the type used for the filter circuit inductances. A two layer bank winding does not have a high distributed capacitance and since it would allow a considerable saving in form material and space requirements, the characteristics of this type of coils should be investigated in conjunction with this problem.

It is desirable that the form material have a low dielectric constant and high body resistance combined with high mechanical strength. "Micarta", a bakelite varnish impregnated paper material was therefore selected.

Before installation, the windings are to be treated with Glyptal lacquer or a similar protecting coating to render them impervious to moisture. A test was made and the lacquer was found to not increase the distributed capacitance appreciably.

Inductance Calculations and Coil Design:

From the measured value of insulator capacitance and the relation $2\pi fL = 1/2\pi fC$ in a series resonant circuit, the inductance required to produce resonance at the selected frequency in each of the filter circuits of the filter section was calculated. The number of turns and the coil dimensions were calculated using Lorenz's formula, $L = an^2Q$, where Q is a function of 2a/b; a being the radius to the center of the winding, b the total length of the winding, and n the number of turns. For a table of values of Q and for the formula derivation the reader is referred to U. S. Bureau of Standards Scientific Paper No. 169.[6] The calculated values and the values of inductance of the constructed coils, measured with a Western Electric Impedance Bridge at a frequency of 1000 cycles, were comparable with an error of only a fraction of a per cent. However, due to the distributed capacitance of the inductance coil, to other stray capacitances, or some other phenomena that was not accounted for, the filter circuits were resonant at frequencies less than their designed values. The filter circuit that experimentally resonated at 1350 kilocycles, should have resonated at 1720 kilocycles according to calculations using the values of capacitance and inductance measured at 1000 cycles.

The coil diamter of eight inches was chosen after preliminary calculations, as being the most desirable for the average coil if all coils are to be of the same diameter.

# LABORATORY DETERMINATION OF FILTER CIRCUIT AND FILTER SECTION CHARACTERISTICS

## Test Inductances and Insulators:

A filter section consisting of three filter circuits was tested in the laboratory to obtain their frequency-impedance characteristics. Three 66 kv. Jeffrey-Dewitt No. 94 pin type insulators were used. Inductances of 50, 46, and 42 turns of No. 14 double cotton covered copper wire were close wound on eight inch Micarta tubes one-eighth inch in thickness. When placed in a closed circuit consisting of an inductance, an insulator, and a vacuum thermocouple, their resonant frequencies, as determined with a General Radio Precision Wavemeter, were 1150, 1250, and 1350 kilocycles, respectively.

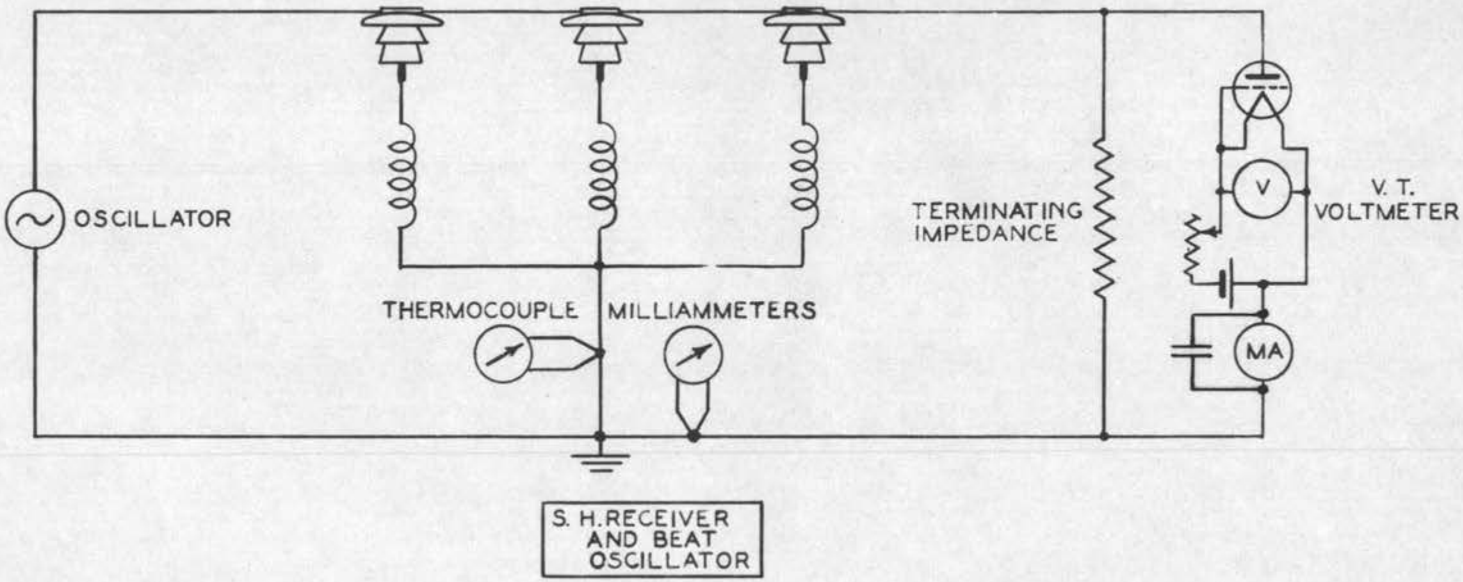
## Test Circuits, Apparatus, and Arrangements:

Photographs of the laboratory arrangements are shown in Figs. 3A and 3B. The electrical circuit is shown diagramatically in Fig. 4.

Radio frequency energy was supplied by a 100 watt General Electric oscillator which is the center lower unit of the high-voltage cathode ray oscillograph shown. This energy was fed to a short transmission line attached to the filter circuit, or filter circuits, and terminated in an impedance of approximately 430 ohms at 1000 kilocycles;

Fig. 3A. Laboratory Arrangements for Obtaining the Impedance of Radio-Frequency Series Filter Circuits

Fig. 3B. Laboratory Arrangements for Obtaining the Impedance of Three Radio-Frequency Series Filter Circuits in Parallel




CIRCUIT DIAGRAM FOR OBTAINING IMPEDANCE CHARACTERISTICS
OF R.F. FILTER CIRCUITS

FIG. 4

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471 ohms was the pure resistance value of the terminating impedance. The return circuit was grounded at one point, as shown in the diagram.

The radio-frequency potential between the line and the return conductor was of the order of 100 volts maximum, and was measured with a vacuum tube voltmeter at the terminal impedance. The voltmeter utilized a type 31 triode vacuum tube operating as a half wave rectifier with the grid connected to the filament at the tube socket. The rectified plate current was read with a 0-10 direct current milliammeter shunted with a two micro-farad paper condenser to by-pass the radio-frequency current. The vacuum tube voltmeter was calibrated on 60 cycles alternating current and was also checked on direct current potentials.

The value of the terminal impedance was determined by measuring the current through the voltmeter and impedance with a Robert Paul 0-50 vacuum thermocouple milliammeter, making corrections for the rectified current and the current through the voltmeter due to inter-electrode capacitances.

The current through the filter circuits was measured with Western Electric vacuum thermocouples and a 0-150 Weston micro-ammeter. Three thermocouples were used to cover a range of currents from 0.2 to 215 milliamperes.

The frequency was determined with a Western Electric field strength measuring set by adjusting the superhetrodyne receiver to the power oscillator frequency and zero beating with this, a signal from the calibrated local oscillator of the field strength measuring set. The power oscillator calibration was not used because its calibration is exact when supplying a sweep wave to the oscillograph but changes a small amount with change in load.

In general, the circuit and apparatus were arranged to minimize the losses that would introduce error in the measured quantities.

Testing Procedure:

Tests were first made on each individual filter circuit consisting of a single coil and insulator. Fig. 3A shows the arrangement for these investigations.

Finally, a test of a partial filter section with the three filter circuits resonant 100 kilocycles apart was made. The arrangement for this test is shown in Fig. 3B and differs from the above arrangement only in the coil and insulator configuration. It was necessary to make slight adjustments in the inductances in this test due to slightly different stray capacitances, different locations of the circuits with respect to the field of the oscillator, and a slight difference in insulator capacitances at radio frequencies.

In each test the procedure in obtaining the data was the same. The power oscillator was set at a desired frequency, the frequency was accurately checked with the field strength measuring set, and readings of the vacuum tube voltmeter and the filter circuit micro-ammeter were recorded. From the actual values of voltage and current, the filter circuit, or filter section impedance at that frequency was calculated.

It was necessary to observe several precautions such as keeping all apparatus in the same exact relation to each other throughout the tests, to minimize stray pick-up by the measuring instruments to a negligible amount, and to not interfere with the field of the circuit while taking the readings.

# EXPERIMENTAL FILTER CIRCUIT AND FILTER SECTION CHARACTERISTICS

## Impedance Characteristics of Insulators Alone:

At 530 kilocycles the impedance of a single insulator was found to be 17,000 ohms and that of three insulators in parallel to be 5,700 ohms, indicating capacitances of 17.6 and 52.4 micro-micro-farads in the respective cases. The average capacitance of the three insulators in parallel was 17.5 micro-micro-farads.

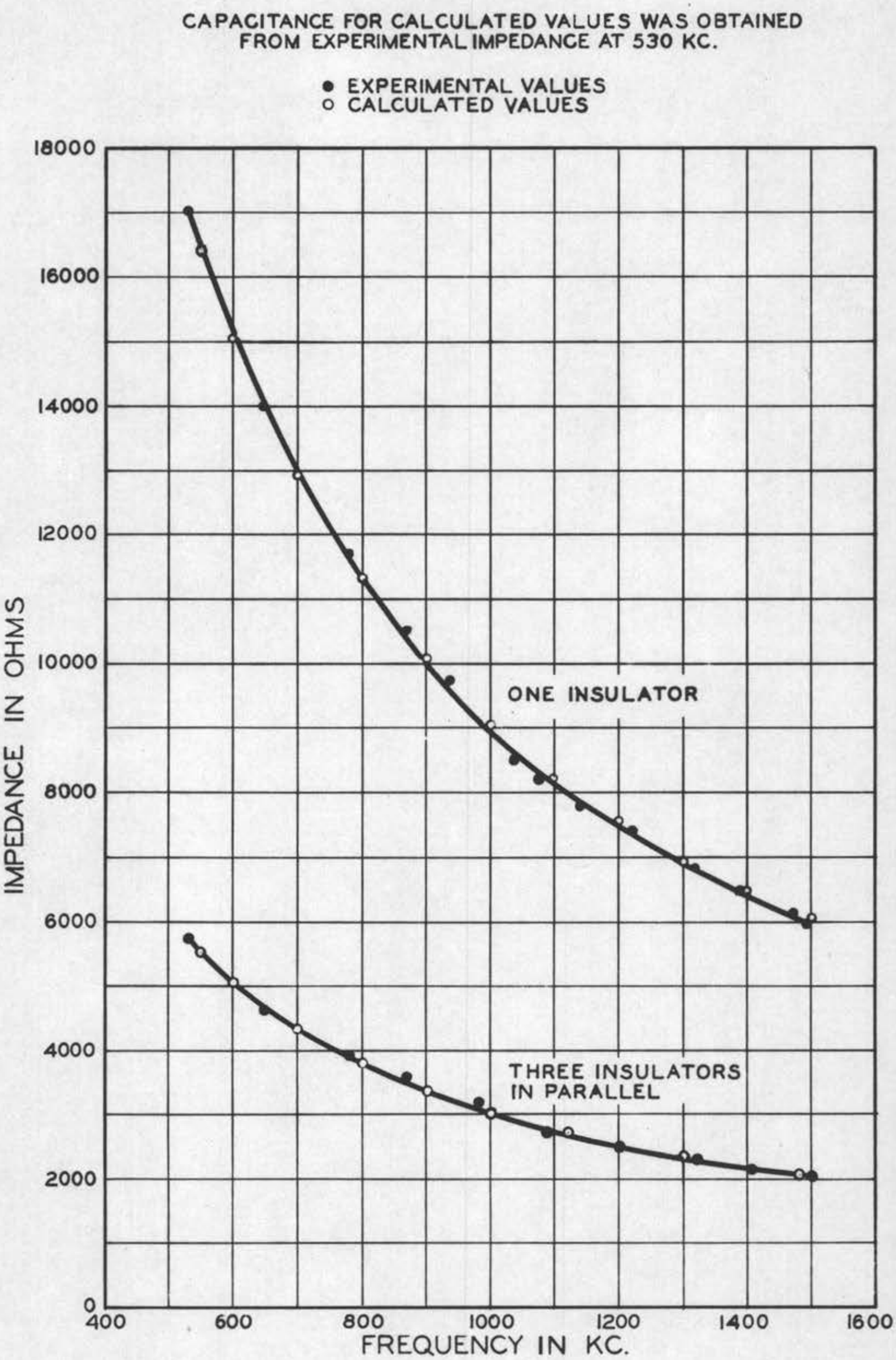
The impedances for one insulator and for three insulators in parallel were calculated over the range of frequencies from 530 to 1500 kilocycles, using the values of experimental capacitances determined at 530 kilocycles. The agreement between these calculated values and the measured values of impedance over the range of frequencies investigated, as shown in Fig. 5, indicates that there is no appreciable change in capacitance with frequency.

## Impedance Characteristics of Individual Filter Circuits:

The impedance characteristics of the individual filter circuits are shown by the curves in Fig. 6. The lower portions of these curves are shown to a larger scale in Fig. 7. The ratio of the impedance of the insulators alone to the minimum impedance of the filter circuits was 70 for circuit 7 at 1150 kilocycles, 40 for circuit 8 at 1250

HEAD TO PIN IMPEDANCE OF
66 KV. JEFFREY DEWITT NO. 94 INSULATORS

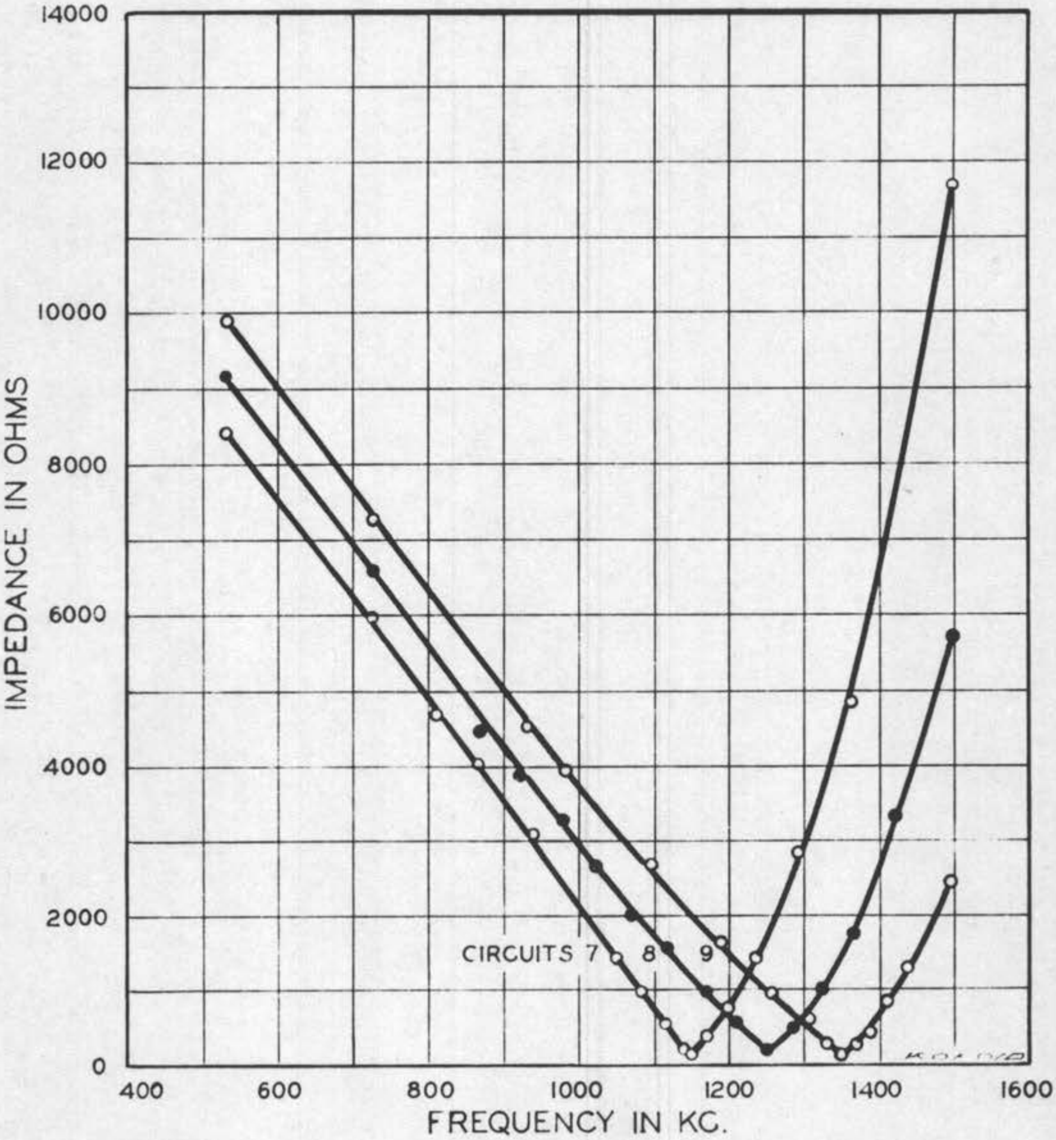
FIG. 5



## LINE TO GROUND IMPEDANCE OF R. F. SERIES FILTER CIRCUITS

## FIG. 6

CAPACITANCES– 66 KV. JEFFREY DEWITT NO. 94 INSULATORS
INDUCTANCES– NO. 14 D. C. C. COPPER WIRE ON 8 IN. MICARTA FORMS
CIRCUIT 7– 50 TURNS
CIRCUIT 8– 46 TURNS
CIRCUIT 9– 42 TURNS



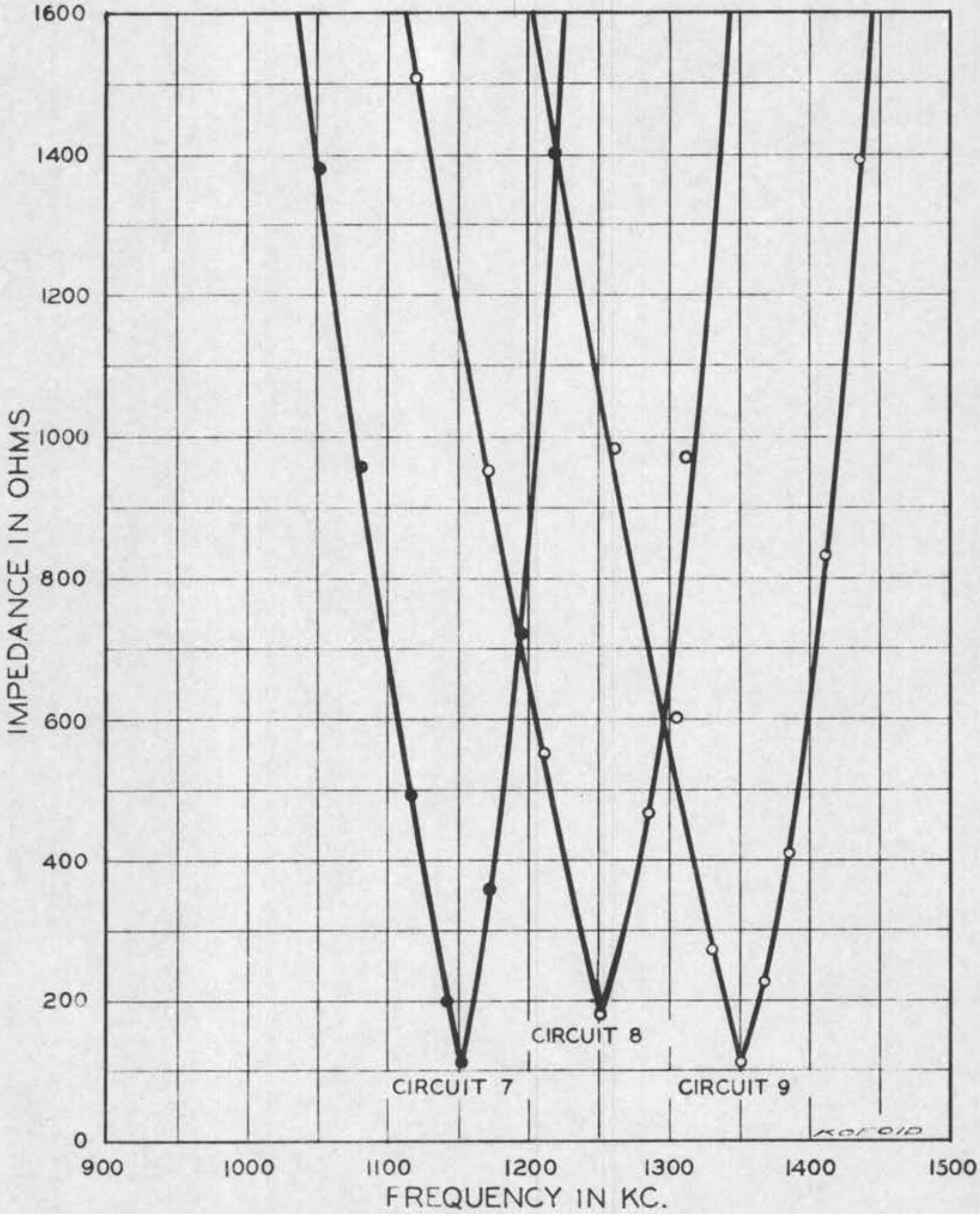
# LINE TO GROUND IMPEDANCE OF R. F. SERIES FILTER CIRCUITS

FIG. 7

CAPACITANCES – 66 KV. JEFFREY DEWITT INSULATORS NO. 94

INDUCTANCES – NO. 14 D.C.C. COPPER WIRE ON 8 IN. MICARTA FORMS

CIRCUIT 7 – 50 TURNS
CIRCUIT 8 – 46 TURNS
CIRCUIT 9 – 42 TURNS

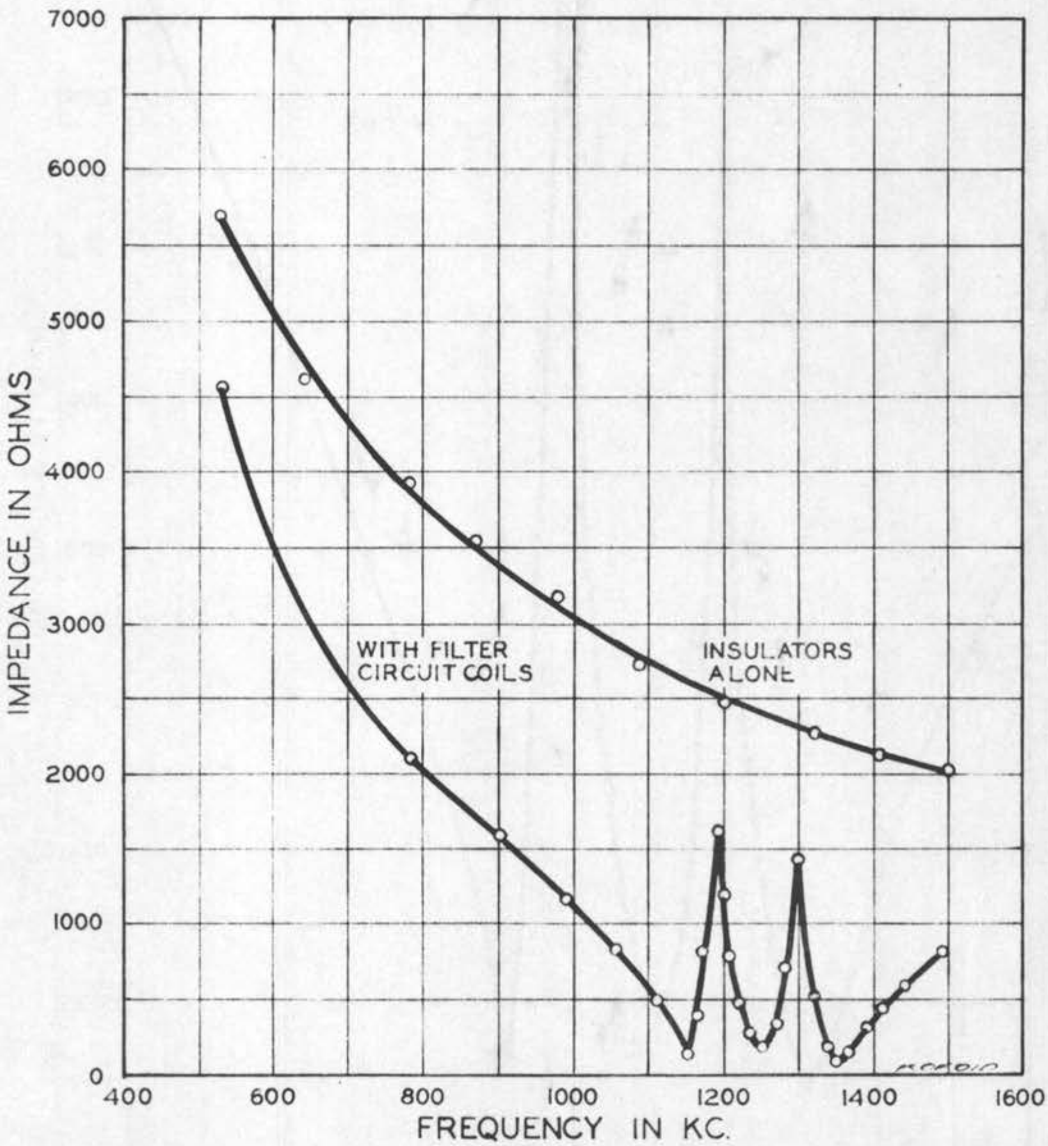


## LINE TO GROUND IMPEDANCE OF THREE R. F. SERIES FILTER CIRCUITS IN PARALLEL

## FIG. 8

CAPACITANCES – 66 KV. JEFFREY DEWITT NO. 94 INSULATORS

INDUCTANCES – NO. 14 D.C.C. COPPER WIRE ON 8 IN. MICARTA FORMS
CIRCUIT 7 – 50 TURNS
CIRCUIT 8 – 46 TURNS
CIRCUIT 9 – 42 TURNS



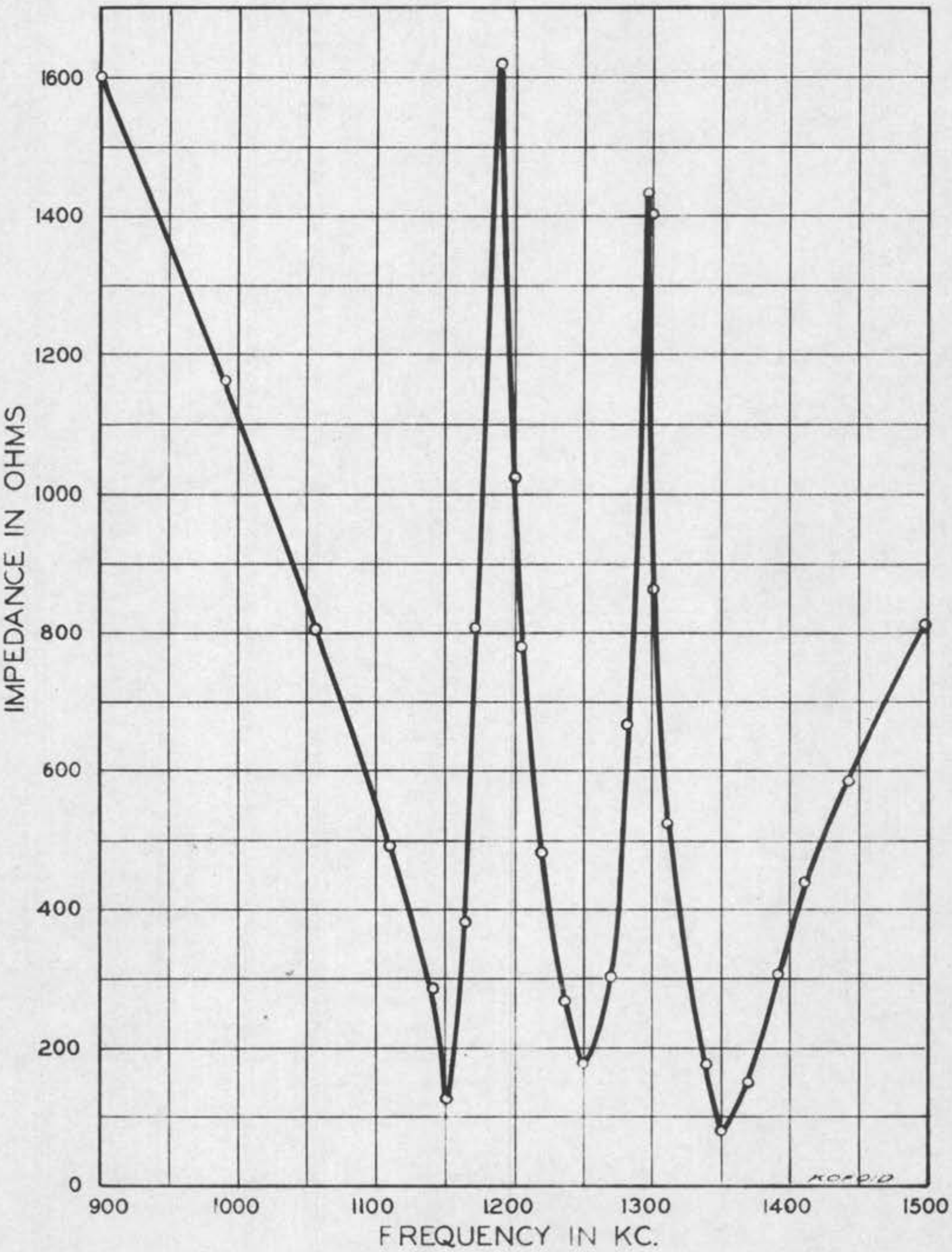
# LINE TO GROUND IMPEDANCE OF THREE R. F. SERIES FILTER CIRCUITS IN PARALLEL

FIG. 9

CAPACITANCES – 66 KV. JEFFREY DEWITT NO. 94 INSULATORS

INDUCTANCES – NO. 14 D. C. C. COPPER WIRE ON 8 IN. MICARTA FORMS

CIRCUIT 7 – 50 TURNS
CIRCUIT 8 – 46 TURNS
CIRCUIT 9 – 42 TURNS



kilocycles, and 60 for circuit 9 at 1350 kilocycles. The degree of sharpness of resonance and the low minimum impedance indicates satisfactory coil design.

Impedance Characteristics of a Part of a Complete Filter Section:

The characteristic of three filter sections in parallel over the range of frequencies between 530 and 1500 kilocycles is shown in Fig. 8. The impedance characteristic of these sections is shown to a larger scale in Fig. 9.

In this case the ratio of the impedance of three parallel insulators alone to the combined impedance of the three parallel filter circuits was 22 at 1150 kilocycles, 14 at 1250 kilocycles, and 27 at 1350 kilocycles. However, the maximum impedances in this range were of such values as to limit the reduction in impedance to only 1.5 at 1195 kilocycles and 1.6 at 1300 kilocycles.

It should be noted that the impedance rises to a maximum of 1600 ohms at 1195 kilocycles. The impedance at this frequency with filter circuits 7, 8, and 9 in parallel is greater than the impedance of either circuit 7 or 8. The impedances of circuits 7 and 8 were each 700 ohms, but the reactance of circuit 7 was predominatingly inductive while that of circuit 8 was capacitive. The vector sum of the lagging current of circuit 7, the leading current of circuit 8, and the smaller leading current of circuit 9, was small indicating a high impedance for the circuits in parallel. This action is characteristic of inductance and capacitance in parallel. The maximum impedance at 1300 kilocycles is explainable in the same manner.

By the method of finding the total area under the curve and dividing this by the length of the base to find the average ordinate, the average impedance with three filter circuits, between 1100 and 1400 kilocycles was calculated to be 460 ohms. The average impedance of three insulators in parallel for this band of frequencies was 2500 ohms. The average reduction of impedance between 1100 and 1400 kilocycles was thereby approximately 5.5.

A very noticeable reduction in impedance is shown for the entire broadcast band while employing filter circuits peaked at only 1150, 1250, and 1350 kilocycles.

When the average reduction in impedance is not as large as is desired when a uniform resonant frequency separation is employed, in a practical field installation the resonance points for the individual circuits constituting the filter section may be selected to resonate at the frequencies of the important broadcasting stations serving that particular area. By this method of installation the number of resonant circuits in a filter section may be reduced to the number of broadcast frequencies on which reception is particularly desired. Such an arrangement makes it possible to effect a maximum improvement in broadcast reception at a minimum expense.

# FILTER SECTION INSTALLATION OF A THREE-PHASE LINE

## Arrangement of Coils Throughout Section:

The design of a complete filter section for the broadcast band of frequencies utilizes thirty inductance coils resonating with the capacitances of the insulators at ten particular frequencies, as indicated in Fig. 1. Three coils are mounted on each of ten consecutive poles; all coils on a particular pole are to be identical.

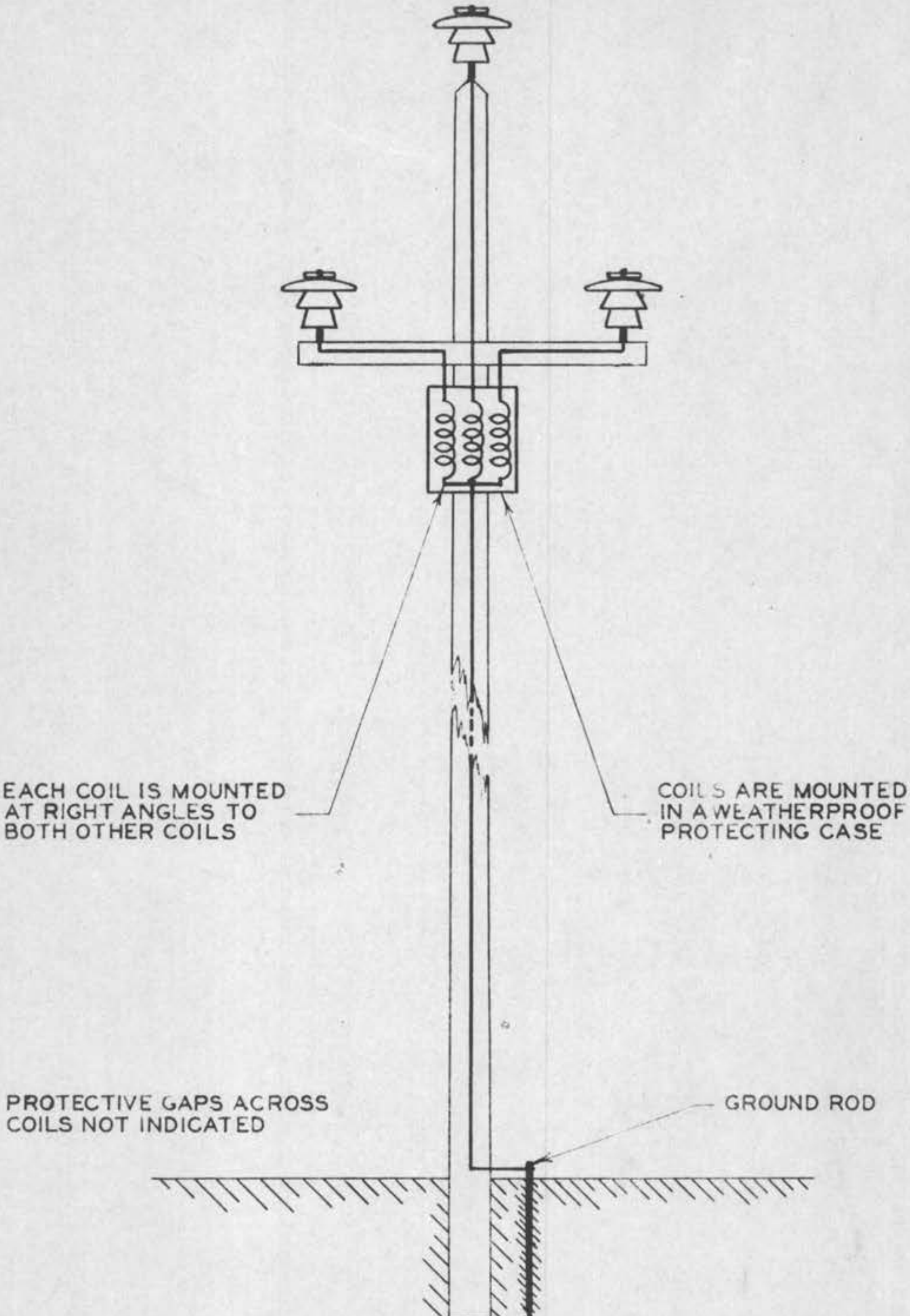
Other coil arrangements were considered but none was discovered that afforded greater economy of coils or a more simplified arrangement.

## Installation of Coils:

The sketch in Fig. 10 shows an installation on the simplest type of transmission line construction, but all except the exact physical arrangement could be identical for an H-frameor other type of construction.

Common practice finds insulator pins both ungrounded and bonded and grounded. In the former case ground rods must be installed, and in the latter the bonds and ground wire need but be broken and the filter coils inserted between the pins and the ground conductor.

The coils are to be installed in a suitable weather-proof housing fastened on the pole near the cross-arm. Each coil is placed so that the axis of its magnetic field is at




TYPICAL INSTALLATION OF ATTENUATION COILS
ON A WOOD POLE OF A 3-PHASE LINE

FIG. 10

right angles to those of both other coils in order to reduce the mutual coupling to a minimum.

An inexpensive protective gap is to be installed across each coil.

A good ground is necessary, or else the ground resistance may become an appreciable part of the radio-frequency conductor-to-earth impedance.

Adjustment of Inductance of Coils:

Small capacity discrepancies in insulators and perhaps capacitance differences due to coil positions are to be expected; small shifts from the designed resonant frequencies will result. It is practical, then, to use tapped coils capable of adjustment of several turns more or less than their design calls for.

Final adjustments are to be made after the coils are in place, by means of a small pick-up coil antenna mutually coupled with the filter circuit inductance and connected to a sensitive compact radio receiver. This receiver must have an accurate frequency calibration, so that it may be adjusted to any frequency at which resonance may be desired. The tapped inductance in a filter circuit would then be adjusted to resonance by setting the receiver at the desired resonant frequency and adjusting the inductance to give maximum receiver output.

## CONCLUSIONS

1. Laboratory tests on three filter circuits, utilizing standard 66 kv. pin type insulators and resonant at 1150, 1250, and 1350 kilocycles, showed an average reduction in conductor to ground impedance of approximately 5.5 between 1100 and 1400 kilocycles. The minimum reduction was 1.6 and the maximum reduction was 26.

2. Upon completion of the remaining filter circuits of the section, as designed, the impedance in the frequency range already investigated in laboratory tests may be further materially reduced by the action of the additional circuits.

3. Impedance characteristics obtainable with filter circuits peaked at frequency differences of 75 and even 50 kilocycles may be worthy of serious investigation.

4. A radio frequency filter section of this type, if proven successful in field tests, should be an economical means of isolating sections of transmission lines from radio-frequency interference foreign to these sections.

5. The maximum improvement in broadcast reception on a limited number of frequencies can be made at a minimum expense by adjusting the circuits of a filter section to resonate at the frequencies of the important broadcasting stations serving a particular area.

6. In an installation, where the ability of the inductances to carry the short-circuit current in case of

an insulator flash-over, is not necessary or is not considered economically justified, much more compact inductances may be constructed by using smaller wire.

7. The direct grounding of ungrounded insulator pins will increase the attenuation of radio-frequency interference being conducted by a line.

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