THE CORRECTION OF RADIO INTERFERENCE
WITH SPECIAL REFERENCE TO COTTRELL
PRECIPITATION INSTALLATIONS

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

For

THE DEGREE OF MECHANICAL ENGINEER

By

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1926
PREFACE

In the operation of Cottrell electrical precipitator installations and similar apparatus where high potentials are used, electro-magnetic radiation sometimes occurs which causes local interference with radio reception. With a view of eliminating the interference considerable research work has been done during the past few years by various precipitator plants and organizations, and wherever serious radio interference has been caused, means have usually been devised for entirely eliminating or greatly minimizing the interference to radio reception. The problem has been solved by different methods at the various plants, and in some cases the solution has been quite expensive. Moreover, no simple universally applicable solution to the problem had been found so it was decided to make a more fundamental study of the general problem of radio interference and methods for its prevention for Cottrell precipitator installations, and other types of high and low voltage equipment. This investigation was undertaken jointly by the two companies who have developed the art of electrical precipitation in America; the Western Precipitation Company and the Research Corporation.

The investigation was divided into three
main divisions. First, a theoretical study was made of the entire problem and its various field ramifications. A series of experiments was next conducted and data obtained regarding the electrical characteristics of precipitator circuits. These experiments were conducted in the laboratory and at various operating electrical precipitator installations. For obvious reasons the names and locations of the plants are not given in this report, but designated as Plant No. 1, No. 2 and No. 3. Plant No. 1 is a large cement plant, while Plants No. 2 and No. 3 are acid precipitators at oil refineries. At the conclusion of these tests the data so obtained were used in designing a set of radio interference correction equipment which was then installed and studied in the laboratory and at numerous commercial installations. As the result of this work a standard set of interference correction equipment has been developed which may be installed in any precipitator and similar high-tension installation for the complete stopping of all radio interference, without changing the electrical characteristics of the circuit or interfering with the proper operation of the apparatus.

In this paper, the main theoretical considerations of the interference problem will be discussed
and a brief account given of the experimental work, together with description and specification of the radio interference correction equipment.

The detailed drawings and specifications of the radio interference correctors shown in this report are the property of the Western Precipitation Company, 1016 West Ninth Street, Los Angeles, California. The written consent of this company should be obtained before publication of this material in any medium intended for public distribution.
ACKNOWLEDGMENTS

The writer desires to express his appreciation for the many suggestions received from his associates during the course of the investigations, especially W. A. Schmidt, E. Anderson, F. H. Viets, K. I. Marshall, A. W. Knight, and others of the Western Precipitation Company and the Research Corporation; Prof. E. R. Rath, Department of Electrical Engineering, University of Pittsburgh; and Robert S. Kruse, of the American Radio Relay League.
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INTRODUCTION

The electrical precipitation process (Reference No. 1) of removing suspended particles from gases is being applied on a large scale to a great number of industrial processes, at plants located in practically all countries of the world. Electrical precipitation is accomplished by passing the gas (containing the material to be removed) through a high potential electrostatic field. This field is usually obtained by connecting one terminal of a source of high potential direct current to small electrodes, called the discharge electrode; and connecting the other terminal to large electrodes called the collecting electrodes. In usual commercial practice the potential is maintained as close to the breakdown voltage as possible. Changing characteristics of the gas causes "snapovers" or slight arcing within the treaters.

The high potential direct current is usually obtained by mechanically rectifying the high potential output of an alternating current step-up transformer, by means of synchronized double-wave rectifiers. In Fig. 1 is shown the control room of a modern Cottrell precipitator installation. The control panels may be
seen on the left, while the motor-generators and synchronous disc rectifiers are on the right. In this installation the high tension transformers are located under the floor of the operating room. By means of hand-wheel switches (shown directly in front of each rectifier unit) the units may be connected to the precipitators or switched to an auxiliary line.

The precipitators used in connection with the Cottrell system may be divided into two general classes, pipe and plate types. In the pipe treaters a small central discharge wire is charged negative while the pipes are connected to the positive terminal and grounded. In the plate treaters small discharge wires are centrally suspended between parallel plates; the wires, as before, being negative charged.

Fig. 2 is an installation at a cement plant. The plate precipitators and electrical equipment are housed in the sheet-iron superstructure shown in the rear. In front of the superstructure and on the ground may be seen an auxiliary precipitator, which is of the pipe type. The bank of vertical pipes may be seen in the photograph.
FACTORS AFFECTING RADIO INTERFERENCE

GENERAL SOURCES OF HIGH FREQUENCY CURRENTS.

In practically any type of electrical circuit where the current flows in a pulsating or non-continuous manner with a steep wave front, high frequency line transients may be generated. The most prolific source of high frequency currents, as regards radio interference, is the result of any sparking in a circuit having proper values of inherent capacity, inductance and resistance. The generation of such high frequency currents may be explained by simple oscillatory condenser discharge phenomena.

Such high frequency currents flowing in the circuit may be radiated as electro-magnetic waves. Such waves will cause interference in radio reception - the extent of which depends upon the magnitude of the high frequency currents and the facility with which these currents may be radiated into space or carried as line-radio by power, lighting, telephone and telegraph lines to radio receivers.

RADIO INTERFERENCE DEFINED.

In this thesis, radio interference has been
more or less arbitrarily defined as the transmission of any energy, which causes interference with radio receiving apparatus, by means of electromagnetic waves originating in a circuit, without connecting linear conductors guiding the waves. The degree or magnitude of interference is a relative quantity which varies with the field strength of the received station, frequency of modulation or period of the interfering high frequency energy, design of the receiving apparatus and type of program.

LINE - RADIO INTERFERENCE.

Line-radio may be compared to ordinary wire telephony in so far as transmission of energy over conductors is concerned, and similar to radio in every phase except in the use of a connecting metallic circuit between stations instead of the other. The interference caused by line-radio is confined largely to receiving apparatus located in close proximity to such circuits— which may extend many miles from the seat of the interference.

FREQUENCIES AFFECTING INTERFERENCE.

The magnitude or degree of interference is dependent largely upon two frequencies; (1) the
frequency of the radiated interfering wave or carrier, and (2) the frequency of modulation of either the interfering wave or the frequency of the "beats" produced between this wave and the desired received signal.

The radiated interfering wave, or its harmonics, must have a frequency within the wavelength or frequency spectrum of the receiving sets within range of the interference. This condition is necessary even for strong interferences causing shock excitation. If the interfering energy is of a pure continuous wave it may produce interference by either of the following methods; (1) production of audio frequency "beat" notes with the desired wave being received, or (2) production of infra- or super-audio beat notes, or the overloading of the receiving set tubes at frequencies lying outside the audibility range. Continuous wave interference, while theoretically possible in commercial circuits is never encountered practically. (Continuous wave telephone and telegraph unmodulated waves are not included.)

Practically all interference encountered in practice consists of a high frequency wave, modulated or
interrupted at frequencies within the audibility range.

HIGH FREQUENCY CURRENTS AND CIRCUIT CHARACTERISTICS.

In many power circuits the voltage wave consists not only of a definite fundamental combined with its higher harmonics, but also contains currents of irregular pulses of varied frequencies. The combination of a fundamental with a series of higher frequency currents of irregular values may produce a very complex wave form. The relative values of resistance, inductance, and capacity in the circuit determine to a large extent the shape and magnitude of the resultant current wave.

In a circuit containing resistance only, the higher frequencies receive the same relative attenuation as the fundamental. In circuits where both resistance and inductance predominate, the higher harmonics suffer greater attenuation since the inductive reactance increases with the frequency. The current wave, is, therefore, less peaked. This effect will be considered in more detail in the discussion of the use of inductive chokes in the latter part of this paper. In circuits where resistance and condensance predominate, the effect is just the reverse, since an increase in the frequency
results in a reduction of the capacitive reactance and resultant impedance with a proportionate increase in current flow. As a result, the original current wave suffers greater attenuation than the higher frequency currents and the resultant current wave is highly distorted and peaked.

HIGH FREQUENCY CURRENTS IN PRECIPITATION CIRCUITS.

Due to the sparking and interrupted current flow in the gaps of the mechanical rectifier and in the precipitators themselves, many frequencies are present other than the initial 60 cycle rectified wave. These frequencies probably range from the lower harmonics of the 60 cycle current to the very high frequencies caused by the oscillatory nature of the spark discharge across the rectifier terminals and "snapping" within the precipitators.

The current flow or pulse in the precipitator circuit is not of the "square" or simple type wherein the voltage rises suddenly, holds this value for a given period of time, and then suddenly drops. The effects of such a pulse can often be calculated, knowing the constants of the circuit. The actual precipitator current consists of a series of regular impulses, superim-
posed on which are high frequency irregularly timed impulses caused by the sparking at the rectifier contacts and the leakage ("snapping") in the precipitator tubes. The effects of transient currents superimposed on a current of regular period may be seen from Fig. 3. In curve "A" is a hypothetical double-wave rectified current, with the lower portion of the wave cut-off by the mechanical rectifier. In curve "B" is shown a higher frequency surge as assumed to be present in an oscillatory path of the precipitator circuit. The resultant e.m.f. of these two waves is shown in curve "C". It will be noted that the resultant wave has lost its original form and is highly distorted and peaked. The wave also has lost its unidirectional properties and fluctuates on each side of the zero line. Currents of this type, having characteristic beats, produce "frying", "buzzing" or "hissing" when received by radio sets. Under proper circuit conditions the oscillatory current will exist in a series of trains or groups of the same frequency as the primary pulse, i.e., a radio-frequency current which is modulated at the frequency of the rectifier interruptions. The radiated wave of such current, when picked up by a radio set, gives a sound with the frequency of that of the pulse. A 120 cycle pulse would, therefore, produce a 120 cycle hissing or buzzing sound in the radio set. For this reason it
Theoretical e.m.f.
from mechanical
rectifiers.
CURVE A

Assumed high
voltage surges
in treaters
and lines.
CURVE B.

Resultant
treater voltage.
CURVE C.
is often difficult to distinguish between Cottrell and some types of power line interferences.

ELECTRICAL CHARACTERISTICS OF PRECIPITATOR CIRCUITS.

A schematic wiring diagram of a simple precipitator circuit is shown in Fig. 4-A. The apparatus consists essentially of a high voltage step-up closed-core power transformer; a synchronous double wave spark-gap rectifier; the necessary connecting line, insulators and bushings between the high voltage apparatus and the precipitators; and the precipitator equipment—consisting of fine wire-electrodes suspended between plates or axially within pipes or tubes, through which the gas to be treated is passed.

For continuous or low frequency currents the schematic diagram represents the circuit sufficiently well. However, due to the electrical characteristics of a Cottrell installation, a more detailed circuit diagram is necessary for a complete understanding and explanation of the high frequency phenomena. The effects of small circuit capacities and inductances are negligible in dealing with continuous current or low frequency alternating current, but must be considered when high frequencies are involved. As previously stated, the current delivered by
Precipitator and Equivalent High Frequency Circuits

General Diagram of connections for precipitator circuits

Fig 4-A

Equivalent High Frequency Circuits

Fig 4-B
by the synchronous rectifier is not a simple rectified alternating current, but contains, in addition to the 60 cycle component, typical surging and transient currents.

Under such conditions an equivalent precipitator circuit with its various distributed, as well as lumped capacities and inductances, would be represented somewhat as in Fig. 4-B. Various capacities, due to bushings, windings, etc., exist at the transformer. The synchronous rectifier may be represented as a double spark-gap between which exists various capacities due to transformer bushings, case, coils, core et cetera. The high tension line connecting the rectifier and the precipitators contains small values of inductance and various capacities to ground. The precipitators may each be represented as a capacity shunted by a resistance, due to the current leakage caused by ionized gas.

An equivalent precipitator circuit will, therefore, be recognized as a plurality of parallel oscillatory circuits the constants of which may vary in each part of the installation. It should be noted that very little of the transformer inductance is actually in the oscillatory circuit, due to the many parallel capacities which readily by-pass the higher frequencies.
The circuit, therefore, is not a simple series circuit containing lumped inductance, capacity and resistance, but these effects are distributed at various points. Such a circuit will not obey the relationship expressed by formulae which govern simple series circuits containing lumped values of inductance, capacity and resistance.

Various investigators (Reference No. 2) have calculated the values of resistance, capacity or inductance required to give certain effects in a precipitator circuit. Such calculations were made using simple circuit formulae where lumped values are considered. The extent to which such calculations hold true is determined largely by the magnitude with which the actual circuit, with its parallel capacity effects, deviates from the simple series circuit implied by the usual formulae expressing resonance and oscillatory conditions.

As an illustration, the theoretical resistance may be calculated which will stop all high frequency oscillations in a given series circuit. The insertion of such a resistance in a series circuit will stop oscillations. On the other hand, the insertion of such a resistance in a complex circuit may have very little effect. It will often stop oscillations in that portion of the circuit in
which it is located, but other parallel paths or circuits may have considerable high frequency currents present, so that the resultant effect may not be noticeable as regards radio interference. In other words, it is important not only to have the required values of resistance in a circuit, but to have it placed at the correct points in such a circuit. Large lumped values of resistance, inductance or capacity may be used for series circuits, but they can not be as efficiently used for parallel or multi-pathed circuits such as encountered in usual precipitator installations.

A circuit containing lumped inductance, capacity and resistance, has a reactance equal to zero at a single frequency, called the resonance frequency and the maximum current will flow if the e.m.f. is of that frequency. This, however, is strictly true only when the capacity and inductance are concentrated at definite points in the circuit. In the precipitator high voltage circuit, the inductance and capacity are distributed at various points and maximum currents or peaks are obtained for a number of different frequencies. Waves of various frequencies are radiated and may not bear a harmonic relationship to each other - depending largely upon the various parallel paths comprising the equivalent precipitator circuit.
THEORETICAL METHODS FOR PREVENTING RADIO INTERFERENCE.

The radio interference from an oscillatory circuit may be stopped by one of four general ways: (1) Shifting of the frequency to a higher or lower value where no local commercial, amateur or broadcast interference will be encountered; (2) lowering the frequency to a value where the radiated current will be negligible - the radiated current varying directly with the second or higher power of the frequency; (3) complete shielding of all conductors and coupled circuits carrying high frequency currents; and (4) completely stopping all radiation by preventing high frequency currents in the circuit, or by absorbing a major portion of the energy in properly designed coupled circuits.

Shifting of the Frequency.

Shifting of the frequency in order not to interfere with local reception is only a partial solution to the problem, and one which cannot be applied generally to all radio interference problems, since various frequencies are of importance in different locations due to proximity of radio stations of various uses. The broadcast range (approximately 500,000 to 1,500,000 cycles) is used in practically
all parts of the United States. Higher frequencies are used for experimental, relay, amateur, ship and governmental (Coast Guard, Signal Corps, Navy, et cetera) stations. The lower radio frequencies are used, especially in coast localities, by transoceanic, government, ship, et cetera stations.

Lowering Frequency.

Shifting of the frequency to a very low value where negligible radiation takes place offers possibilities in preventing radio interference, but is difficult to accomplish and control in practical applications.

Shielding High Frequency Circuits.

Complete shielding of all high voltage lines is not considered a practical solution to the problem for two major reasons: (a) High installation cost and voltage insulation difficulties, and (b) line-radio interference caused by feed-back into power circuits, through transformer or equipment capacities or by induction. It is practically impossible to prevent the high frequency currents from traveling along metallic conductors which are connected or coupled electrostatically or electromagnetically with lines carrying high frequency currents. A number of cases are on record where the radiated interference is negligible, but the wired-wireless interference
extended many miles from the plants.

Various methods of shielding have been used in commercial practice. All high tension lines and apparatus may be surrounded with a grounded metallic network or screen. This is illustrated in Figures 5 and 6. The German practice is of a similar nature but utilizes a high voltage metallic covered cable, the outer metallic covering being grounded. This cable is shown in Fig. 7, and consists of the conventional copper conductors surrounded with impregnated paper tape, over which is wound a copper or steel covering. The metallic covering is usually wrapped with impregnated cord or fabric. The use of such cable is costly. Due to the capacity added to the system, it causes an increase in the high frequency surges or currents, and often with a decrease in treater efficiency.

Suppression and Absorption of High Frequency Currents.

The complete suppression of all radiation by stopping high frequency oscillations is an absolute solution to the problem as regards radio interference.

EFFECTS OF RESISTANCE IN PRECIPITATOR CIRCUITS.

One of the easiest ways of stopping oscillations in a circuit is by adding resistance. For a simple series
series circuit, the resistance required to prevent oscillations may be calculated knowing the constants of the circuit. The natural frequency of any simple series circuit may be expressed by the general formula:

\[ f = \frac{1}{2\pi} \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}} \]

in which

- \( L \) is inductance
- \( C \) is capacity
- \( R \) is resistance
- \( f \) is frequency

In cases where \( \frac{R^2}{4L^2} \) is equal to or greater than \( \frac{1}{LC} \), free oscillations in the circuit are impossible. Such a circuit is said to be "aperiodic" - it will not allow free oscillations and has no free period of its own. Mathematically this condition may be expressed as follows:

\[ \frac{R^2}{4L^2} \geq \frac{1}{LC} \]

\[ R^2 \geq \frac{4L^2}{LC} \geq \frac{4L}{C} \]

\[ R \geq 2 \sqrt{\frac{L}{C}} = \text{condition for non-oscillatory circuit.} \]

Therefore, when the resistance of a simple series...
circuit is equal to, or greater than, twice the square root of \( L/C \), the circuit will not oscillate. This elementary formula, given by many writers, can not be applied directly to practical interference problems of a complex nature, because a majority of commercial installations are not simple series circuits.

The effective resistance of a conductor varies with the frequency. In an oscillatory circuit the following factors determine the effective resistance, (1) ohmic resistance of the conductor itself, (2) skin effect and diameter of conductor, (3) resistance of neighboring closed circuits and their proximity, (4) permeability of magnetic material near conductors carrying high frequencies, (5) dielectric and hysteresis losses, (6) corona losses, (7) radiated energy - which causes the radio interference.

The combined magnitude and effects of the above govern largely the oscillatory currents flowing in a circuit of given values of inductance and capacity.

The ohmic or direct current resistance of the precipitator circuit is usually relatively low. The skin effect on such conductors may greatly increase the high frequency resistance - depending upon the general distribution of current in the conductor (dependent upon
nearby conductors and diameter). The resistance of neighboring closed circuits is of considerable importance. If the high tension lines supplying the precipitators are closely coupled to closed circuits (such as closed railings, wire nettings, etc.) the effective resistance will be increased. Dielectric losses may be quite high, mainly occurring in the precipitators where considerable insulation is used to support the high tension discharge member assembly.

For good conductors, the continuous current resistance is usually lower than the high frequency resistance due to re-distribution of current at high frequencies due to skin effect. The writer has, however, observed cases where the high frequency resistance of certain types of resistors was considerably lower than the continuous current resistance. Especially is this true of those resistors depending upon "point contact." The capacity and "point" effects of the particles in the resistor, often lower the effective resistance. As previously shown, however, the failure of resistances to completely stop radio interference is probably due as much to the complex nature of the precipitator circuit as to the low effective resistance of some types of resistor rods.

While it therefore should be possible to entirely stop oscillations in a precipitator circuit by the use
of high frequency resistors in various parts of the circuit, the design of a simple and practical type of resistor suitable for field and plant operation offers difficulties. The power losses incidental to the use of such resistances are not conducive to the most efficient operation, as regards electrical efficiency.

EFFECTS OF CAPACITY IN PRECIPITATOR CIRCUITS.

In any given installation, the addition of capacity will be favorable for an increase in magnitude of the transients. Capacity need not be added in the well known form of high voltage condensers, but may be added unintentionally by connecting additional treaters to the circuit, or by additional line or insulation capacities.

Increasing the capacity of a treater installation may often decrease the frequency (increase wave length) due to the higher oscillation constant. The increase, however, will not be as great as would be predicted by simple series circuit formulae, due to the complex nature of the equivalent treater circuit.

The addition of treater units to an installation with a given electrical equipment is a special case whereby additional capacity is added to the system, at the same time decreasing the circuit resistance.
For any given installation the addition of precipitators will be favorable for an increase in magnitude of the radio-frequency currents. This may be predicted mathematically by the previously given general oscillatory series circuit formula.

The amplitude of the oscillations increases with a decrease of \( R \) and with an increase in \( C \). If each precipitator is considered as equivalent to a capacity shunted by a resistance, then the greater the number of treaters in parallel in the circuit, the greater the total circuit capacity, \( C \), and the lower the resistance, \( R \).

**EFFECT OF INDUCTANCE IN PRECIPITATOR CIRCUITS.**

The addition of inductances to a simple series circuit, produces results similar to the addition of capacity previously mentioned. The equivalent circuit resistance is increased, however, due to the high frequency resistance of any inductance coil. The effects of added capacity or inductances must be considered not only as regards radio interference but also in connection with the operation of the precipitators. The promiscuous insertion of inductance in a precipitator circuit is liable to interfere with the proper operation of the treaters and also cause excessive arcing or burning at the rectifier.
Effects of Internal Coil Capacity.

A "choke" coil, for use in suppressing radio frequency currents, must have, in addition to the desired inductance, a low distributed capacity in order to offer a high reactance to radio frequency currents.

The internal capacity of the coil varies with the type of construction. The relative values of distributed capacity for various types of coils is illustrated in Fig. 8. In this figure the capacity between adjacent turns is represented by the imaginary condenser C_a. This capacity is the same, or course, for any type of winding where each turn is wound adjacent to the next.

In the case of a multi-layer coil, as shown at A and B, the capacity between layers varies with the type of winding. The "honeycomb", "bank" wound or similar type of windings have a lower capacity, C_1, the terminal capacity C_T is greater for the multi-layer coil than for the honeycomb type of windings. Multi-layer coils usually have a fairly high internal capacity which may be of sufficient value to offer relatively low capacitive impedance to the high frequencies. Especially is this true of many of the so-called "low distributed capacity" coils. Such coils are quite compact, often with high capacity.
Internal Capacity of Coils

A

“Low-distributed capacity” windings, multi-layer bank-wound coils.

B

Multi-layer and scramble-wound coils.

C

Single layer Solenoid

D

Continuous Iron-core

Laminated iron-core

E

Sectional Iron-core

Sectional Laminated iron-core
between ends of the winding. The single layer solenoid type of winding actually has the lowest distributed capacity and is, therefore, the best suited for use as a radio frequency choke.

**Design of Iron-Core Chokes**

The iron-core choke coil offers advantages, if properly designed, for use in precipitator circuits. The use of iron increases the effective resistance of the coil which is advantageous in absorbing the high frequencies. Iron core chokes have been tried for suppressing transients in treater circuits, but numerous investigators have reported negative results.

What information is available, however, of previous investigations indicates that insufficient attention was paid to the design of the choke for the higher frequencies. In Fig. 8 is shown an equivalent choke and continuous iron-core circuit. It will be noted that considerable capacity exists between the winding and the core. Especially is this true when the core is merely wrapped with a heavy layer of insulating material, over which is wound the wire. The capacity $C_c$ between core and winding, allow the high frequency currents to travel from the first few turns of winding to the core, thence through the iron core to the other end of the coil. The iron and the core-to-winding-capacity, therefore,
serve as a by-pass for the high frequencies. In order to overcome this and at the same time allow the use of iron, a special type of sectional core may be used. The core is built in short sections - each section insulated from the other. As a result, the high frequency currents leaking to the first section of the core are prevented from by-passing the coil, due to the low capacities existing between core sections. This is illustrated in E. The German precipitator company, the Metallbank und Metallurgische Gesellschaft, affiliated with the Western Precipitation Company, has adopted a continuous iron core coil, with the core connected to ground. Such a design is satisfactory as regards stopping of high frequency transients but requires insulation between core and winding of a value sufficient to withstand full precipitator voltage, which in various installations ranges from 20,000 to 100,000 volts.

REFLECTION PHENOMENA AND RADIO-FREQUENCY POTENTIALS.

The use of chokes to prevent the passing of transients and high frequency currents often causes high voltages to build up ahead of the choke, due to reflection phenomena and the high reactance of the choke. This potential may be of considerable magnitude, depending upon the frequency and the electrical characteristics of
the circuits. Such potentials superimposed on the low frequency voltages of the precipitator circuit may cause disruptive peak voltages. This is of particular importance in connection with proper operation of the mechanical rectifier. For certain parts of the circuit, the choke must, therefore, not only prevent such high frequencies from proceeding further in the circuit, but should also absorb or dissipate the high frequency energy. In addition, the choke should contain a minimum of effective inductance and a maximum of effective resistance. Such a choke, called an absorber coil, was developed in the course of the experimental investigation.

The e.m.f. developed due to the impedance of the chokes, when inserted in the circuit, varies with the inductance, wave length, or frequency of the transients, and the characteristics of the precipitator circuit. The highest potential is usually obtained across the terminals of the chokes placed in series with the transformer. Potentials higher than 100,000 volts have been measured. The potential across the ground line choke is usually of a lower value and about 10,000 volts. The potential across the chokes in the precipitator high tension circuit varies from 5,000 to 15,000 volts, depending upon conditions, number of chokes, etc.
The potential developed across the choke coils placed in series with the transformer secondary leads, vary with the capacity in the circuit. As previously mentioned, the capacity across the secondary winding of the transformer is composed of the coil-to-core capacity, insulator capacities to case and across terminals, etc. Where ordinary porcelain or bakelite lead-in bushings are employed for the high tension terminals the total capacity in the secondary circuit is seldom of a value to cause high potentials than 20,000 volts to be developed across the chokes. When transformers employing the "condenser-type" bushing are used, the additional capacity added to the circuit causes high potentials to be developed across the coils. With this type of lead-in bushing, potentials of over 100,000 volts are often developed. In order to take care of these higher potentials and prevent break-down or leakage, it is necessary to insert an additional choke in series with the secondary chokes, as indicated in Fig.

ABSORBER CIRCUITS.

The theory governing the design of the absorber type coil depends upon the change in effective resistance of two inductively coupled transformer circuits.
Designating the primary resistance and inductance as $R_1$ and $L_1$ respectively; and the resistance and inductance of the single turn ring or secondary as $R_2$ and $L_2$. (The use of more than one ring in parallel in the secondary circuit results in closer coupling, lower effective secondary resistance, higher flux density, and greater radiating surfaces for dissipating the secondary power.)

The theoretical voltage induced in the secondary circuit is

$$E_2 = 2\pi f \times Ml, \quad \text{or} \quad 2\pi f M$$

The current in the secondary is therefore

$$I_2 = \frac{E_2}{Z_2} = \frac{2\pi f M}{Z_2}$$

Due to phase relations between primary and secondary currents and the coupling, it can be shown that the effective resistance of the primary is,

$$R^\prime_{\text{Effective}} = R_1 + \left(\frac{2\pi f M}{Z_2}\right)^2 \times R_2$$

The mutual induction between the two circuits may be expressed as:

$$M = K \sqrt{L_1 \times L_2} \quad \text{in which}$$
$K =$ coefficient of coupling - near unity for well designed closed core transformers at low frequencies, but considerably less for high frequencies and air core transformers.

$L_1 =$ Total self induction of the primary circuit,

$L_2 =$ Total self induction of the secondary circuit,

$Z =$ Impedance,

The effective resistance therefore may be expressed as

$$R' = R_1 + \left(\frac{2\pi K L_1 L_2}{Z_2}\right)^2 \times R_2 = R_1 + \left[\frac{2}{\left(\frac{2\pi K L_1 L_2}{Z_2}\right)}\right] R_2$$

From these relationships, it may be seen that the high frequency effective resistance of the absorber coil may be many thousands of ohms, while the low frequency resistance for the rectified pulsating current is only a few ohms greater than the resistance of the primary winding itself.

In any coupled circuit the apparent reactance of the primary is always changed by presence of the secondary. The reactance may be expressed by a relationship similar to that given for resistance, and is

$$L' = L_1 - \left(\frac{w M}{Z_2}\right)^2 \times L_2$$
From which it may be seen that the effective inductance of the primary is decreased by the current flowing in the secondary circuit. Considering the relationships existing between effective resistance and inductance in coupled circuits of this type, it is seen that the effect of the current flowing in the secondary is to increase the resistance of the primary circuit by the amount

$$\int_{x}^{2} \left( \frac{2\pi K L_1 L_2}{Z_2} \right)^2 \times R_2$$

and to decrease its self-induction by the amount,

$$\int_{x}^{2} \left( \frac{2\pi K L_1 L_2}{Z_2} \right)^2 \times L_2$$

It should also be noted that these effects vary directly theoretically with the square of the frequency. This, of course, is not strictly true in practice, due to current redistribution and skin effect, capacity effects, magnetic losses, decreased permeability of \( \mu \), etc., at high frequencies. The combined effects may be summarized by stating that the low frequencies suffer only slightly from the small change in effective resistance, while for
the higher frequencies the effective resistance is greatly increased and the self inductance is greatly decreased. The increase in resistance and decrease in inductance thereby tend to inhibit oscillation. The design of the absorber coils is such that when used in conjunction with the choke coils, the electrical characteristics of the treater circuit will not be changed sufficiently to cause a decrease in operating efficiency of the treaters.

In the early forms of iron-core coils, the iron was placed within the winding in accordance with usual practice. This necessitated rather bulky construction in order to take care of the heat generated by eddy and hysteresis losses in the iron. In the later design the iron is placed outside of the winding, and while not quite as efficient from all theoretical viewpoints, is better in commercial practice as the heat may be readily radiated and construction simplified. The iron is also allotted to prevent the decrease in apparent permeability at the higher frequencies.

LABORATORY STUDIES

EQUIPMENT FOR LABORATORY INVESTIGATIONS.

Test "Block."
In the experimental investigations, studies were made of the high frequency transient currents in various parts of the precipitator circuit and the resultant radiations due to such currents. These studies were made in the laboratory and at several commercial precipitator installations. The actual currents in the circuit were obtained by opening the line and inserting a "test block." The test block, Fig. 9, contained a 1 to 1-2-3- high frequency current transformer, a current limiting resistance, a 0 - 1.0 ampere R. F. thermogalvanometer, a 0 - 150 milliamperes direct current meter, and a two microfarad high voltage condenser. The primary of the current transformer and the direct current meter are connected in series, and connected to the two terminal posts on the test block. The direct current meter is shunted by the condenser to by-pass radio frequency currents. The radio-frequency meter and resistance are connected in series with the transformer secondary. Due to the direct current component of a majority of the radio frequency meters on the market, a transformer is necessary in order to prevent errors due to the direct current supplied the treaters.

Radio Receiving Apparatus.

Radio interference was studied by using a small
Fig. 9.

Diagram showing components including:
- **LINE**
- **RESISTANCE**
- **R.F. METER**
- **TRANSFORMER**
- **D.C. METER**
- **BY-PASS CONDENSER**
- **LINE**
two circuit portable loop receiver which is so arranged that regeneration may be employed if desired, and equipped with calibrated inductances, for measuring any frequency from 37 to 5000 kilocycles.

The receiver was calibrated to read wavelength and frequency over the broadcast range. Higher and lower frequencies were measured by means of the tapped loop and special inductances connected in place of the loop. The receiver was calibrated from the known assigned frequencies of local long and short-wave broadcast stations, and the harmonics of a laboratory oscillator.

For studying interference, at some distances from the source, within the broadcast wavelengths, a Radiola six-tube semi-portable superhetrodyne receiver, rotatably mounted in an automobile, was used. This receiver is of the second harmonic oscillating detector type, employing one stage of radio frequency, detector, one reflex and one stage of long wave radio frequency, second detector and two stages of audio frequency amplification. A small internally built loop of approximately 9 inches by 18 inches is employed. The outfit being fairly sensitive, there was no difficulty in receiving 500 watt and greater
broadcast stations within a radius of 500 miles.

Considerable difference of opinion has been voiced regarding the correct set and the desired sensitivity for a receiver used in radio interference investigations. Various types of receivers have been used by the writer and the two-tube set shown in Fig. 10 adopted. A more sensitive type of receiver was found to be undesirable for two major reasons; (1) the two-tube receiver is sensitive enough to "get-down" to the noise level prevailing in commercial plants and near power circuits, and (2) a sharply tuned set (especially of the tuned radio-frequency and superheterodyne type) makes rapid observation impossible and merely complicates the taking of data. An observer may also rest assured that when no interference is noticeable on a simple set located a few feet from various parts of the treater circuit, no interference will be heard on more sensitive receivers located more remotely from the source of the interference.

The method of using the test set is shown in Fig. 11. The set is entirely self contained, and when carried has the loop in a vertical position. The set may readily be turned in any direction by the observer and rapid observations made. The use of head-phones, in
Fig. 10.
preference to loud speaker on more powerful sets, shuts out a majority of external plant sounds.

Various types of choke coils, absorbers, condensers, etc., were used during the investigations. In order to save space, description of all of this equipment will not be given. Complete description and specifications are included, however, of the final equipment which was adopted and is being used for the correction of radio interference in commercial installations.

Resistors.

The resistance units used during the tests were of two types; General Electric Company's noninductive carborundum rods, having approximately 16,000 ohms each, and Ward-Leonard Company's inductive wound resistance-wire tubes having approximately 2000 ohms each. Suitable mountings were provided to allow connection to the circuit.

Inductances.

Various types of inductances were experimented with, but the single layer, small wire type was found to be most satisfactory. The following units were constructed:

Air core adjustable, a single layer winding of No. 26 D.C.C. wire wound on a 2-3/4 inch diameter bakelite
tube, inductance of approximately 3400 microhenries variable in five equal steps.

**Strain Reactors.**

Special reactances were constructed for insertion in the high tension lines of field installations. The reactors were constructed of 1-1/2 inch by 1-1/2 inch by 18 inch long square bakelite rods and provided with heavy strap and terminals to allow for direct insertion in the lines, similar to strain insulators. These coils had an inductance of approximately 1700 microhenries each.

**Iron Core Reactors.**

The iron-core reactors were of the same construction as the air core type, having 2-1/2 inch diameter short iron core sections. The cores were built into 2 inch sections of bakelite tubing and consisted of lengths of No. 26 gauge parallel iron wires held in place by sealing wax. Various members of core sections could be used by insertion in the coils. The reactance, at radio-frequencies was approximately 5000 microhenries.

**Iron Absorber Coils.**

The coil consists essentially of a 2-5/8" bakelite tube with 12-1/2 inches of No. 26 D.C.C. single
layer winding. Iron rings, 3 inches in diameter and 1 inch long, were placed outside of the winding and spaced therefrom with bakelite strips.

**Interference Measurements.**

Due to the many variables encountered in field observations and the fact that quantitative data were not required, no field strength measurements were made of the interference. Relative audibility measurements were made in the early stages of the investigations, but later this procedure was abandoned in order to facilitate making observations and the taking of data.

**Electrical Laboratory Equipment.**

Preliminary studies were made on a small size laboratory treater. The electrical equipment consisted essentially of (1) control panel containing necessary meters and transformer primary control switches, circuit breaker, auto transformer, rheostat and protective switches; (2) 15 Kva, 60 cycle, 110 to 10,000-250,000 volt rectangular type closed core step-up transformer; (3) rotating disc synchronous rectifier; (4) needle-plate gap to determine polarity of secondary or high voltage circuit; (5) electrostatic and sphere-gap voltmeters for measuring peak and r.m.s. voltages.
Experimental Treaters.

The treater consisted of three six inch by six foot vertical tubes with a No. 26 iron discharge wire, operating in the air. Connections were provided for operating one, two or three tubes in parallel. The treater was located at various distances from the rectifier set, depending upon factors desired for the various tests conducted. The high tension line connecting treater and rectifier was a No. 14 gauge copper wire. Insulated supports and terminals were provided for inserting chokes or resistances as desired in the circuit. The connections were essentially as shown in Fig. 4-A.

RESULTS OF LABORATORY TESTS.

The laboratory precipitator was used for the initial work and served as a basis for the design of the experimental interference correction equipment. Detailed accounts of the laboratory work are omitted in this report mainly because many of the tests, etc. were found to be "on the wrong track." As soon as the fundamental principles were obtained, the work was continued at a nearby commercial installation (Plant A) where large scale tests could be conducted. The following laboratory data is included, however.
Wave Length Measurements.

Measurements of the wave length of the different interference bands indicated that no definite relationship exists between size of installation, distance between rectifier and treater, etc. The interference peaks for each installation apparently do not bear any definite relation to each other. Various parts of the circuit oscillated more or less independently and harmonic relationships were not apparent in the data secured.

The insertion of sufficient resistance or inductance in one part of a circuit often removed one of the interference bands, while the others were only slightly diminished, or in some cases, increased. By the insertion of chokes in various parts of the circuit, it was possible to draw tentative conclusions as to the various oscillating circuits of the precipitator system. Two main oscillating circuits exist in the laboratory treater. The first circuit comprised the transformer leads to the rectifier, and the second the connecting line between treaters and rectifier terminal.

The insertion of chokes at various points in the laboratory precipitator circuit gave the following results:
### TABLE 5.

<table>
<thead>
<tr>
<th>Location of 3000 micro-henry choke air core</th>
<th>Interference wave lengths, meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>No choke in circuit</td>
<td>130 170 230 290 410 640 720</td>
</tr>
<tr>
<td>Transformer terminal</td>
<td>170 220 290 410</td>
</tr>
<tr>
<td>Transformer terminal</td>
<td>170 230 290 410</td>
</tr>
<tr>
<td>Negative terminal of rectifier</td>
<td>130 170 230</td>
</tr>
<tr>
<td>Middle of high tension line connecting treater and rectifier</td>
<td>130 230 290 410</td>
</tr>
<tr>
<td>At treaters</td>
<td>130 170 230 290</td>
</tr>
<tr>
<td>Ground wire of treaters</td>
<td>130 170 230 410</td>
</tr>
</tbody>
</table>

Chokes in either of the leads connecting transformer and rectifier terminals removed the interference bands at 130, 640, and 720 meters. Placing the choke at the negative terminal of the rectifier removed all bands above 230 meters. When a choke was placed in the center of the high tension line connecting treater and rectifier, the bands at 170, 640, and 730 meters were re-
moved. Placing the choke at the treater end of the high tension line removed the 410, 640 and 730 meter bands. The bands at 290, 640, and 730 were removed by insertion of a choke in the ground wire from the treaters. Similar tests on different laboratory treaters and plant installations, while not conclusive enough to warrant theories as to the various high frequency paths in the treater circuit, do indicate that the various paths are oscillating more or less independently of each other and that insertion of inductance in any one branch may have little or no effect on the other oscillating circuits.

**Length of High Tension Lines.**

In order to ascertain if the length of the high tension line affected the wave length of the radiated energy, the treater unit was moved to various distances from the rectifier. No difference, except well within experimental error, was noted in any of the interference wave lengths. It seems probably that the slight capacity and inductance of the high tension line is so small in comparison to the constants of the balance of the treater circuit as to have little effect.

**Effect of Number of Treaters on Wave Length.**

Changing the number of treaters in the labor-
Oscillations in High Tension Lines.

The high tension line connecting the rectifier and the treaters, is one of the main radiating parts of the precipitator installation. In the tests on the laboratory installation, it was found that when chokes were inserted at each of the four rectifier terminals and at the treaters, some radiation was still taking place at 130 and 170 meters. Inserting a choke in the center of the line eliminated the 170 meter band. In the tests at Plant No. 1, it was found that an interference band was being radiated at 180 meters. The insertion of chokes at the auxiliary treaters and rectifier terminals, did not help matters, so the high tension line connecting treaters and rectifier was lowered and a strain type choke inserted in the center of the line. This entirely removed the interference.

Other Oscillating Paths.

It must not be thought that the high tension lines themselves are the only radiating members. In some installations it was found that long ground lines, es-
especially in arid regions, are sources of radiations. It is also interesting to note that some portions of the high tension circuit oscillate and radiate, while other portions do not. This is due to the many parallel capacitive paths which exist between high tension line and ground. Every supporting insulator, switch, mountings, etc., act as a condenser. The capacity to ground of the large pole-operated knife switches, such as used for connecting to auxiliary line, etc., is quite high, depending upon type of insulation, mountings, etc.

**PLANT EXPERIMENTS**

**TESTS AT PLANT NUMBER ONE.**

Three series of tests were conducted at Plant No. 1.

**Tests on Auxiliary Treater.**

The first tests were on an auxiliary treater unit which is located in a separate building from the high tension generating equipment. Two lines are used for connecting rectifier and treaters. One line is surrounded or "caged" in a grounded network, while the other wire is not shielded. The kilns for the auxiliary treater were not operating, so exact plant conditions could not be duplicat-
ed or studied. The treaters were, therefore, operated cold and on air. The behavior of the unit as regards interference, etc., was found to be almost identical to the laboratory treaters.

The main radio interference band was between 150 to 280 meters, and was practically the same for either the shielded or the unshielded line. The interference intensity for the shielded line was approximately twenty-five per cent that of the bare line. Aside from intensity, both lines behaved alike during the observations. The additional tests and insertion of chokes were carried out on the unshielded line to facilitate work.

Insertion of a 3000 microhenry choke at the rectifier decreased the received radio interference about 50 per cent. A similar effect was noted when the choke was removed and placed at the treater end of the line. Two chokes were then inserted in the circuit, one at each end of the line. The interference was reduced to approximately twenty-five per cent of its original strength. A strain-type choke was next inserted in the center of the line and eliminated one of the main interfering bands. The slight amount of interference remaining was below 200 meters and could not be heard when the receiver was moved to a dis-
tance greater than approximately two hundred feet from the treaters or high tension line.

**Line - Radio Interference**

When the receiver antenna or loop was placed close and parallel to the high tension line, considerable interference resulted. This same line-radio effect was noted when near any metallic circuit, such as power and lighting circuits, which extended into the plant or treat-er building. When the three chokes were inserted in the line, the radio interference was reduced to a value low enough to allow the sparking and arcing within the other operating treaters to be heard. Numerous chokes (both air and iron core) were placed at various places in the treater circuit, but complete elimination of arcing (as when measuring voltage with sphere gap) or treater sparking could not be obtained. Apparently the inductance of the radio chokes was not great enough to prevent steep wave front current flow, which caused shock excitation of the receiver. Interference of this type is similar to any irregular current flow, such as opening or closing of switches, etc.

Further tests on the elimination of radio inter-
ference from the auxiliary treaters could not be made, due to the radiated radio interference from the other operating
treaters. The use of the three chokes brought the interference of the unshielded line auxiliary treater down-to or lower than the level produced by the remaining treaters. As regards radiation, differentiating from line radio effects, the auxiliary treater unshielded line before insertion of chokes produced much greater interference than the remainder of the plant.

**Tests on experimental Treaters**

A set of experimental plate treaters were used for additional experiments to determine the effects of adding additional treater units to the auxiliary treaters, and the effect of a longer high tension line.

The addition of the experimental unit to the auxiliary treaters caused a slight increase in the interference. Insertion of chokes at the experimental treaters and at the point where the experimental treater line connected to auxiliary treaters, lowered the interference level to that produced by the remainder of the plant.

The high tension line connecting the experimental treater units to auxiliary treater, gave considerable interference, due to direct induction when the receiver antenna was parallel to the line. This interference was reduced by merely placing the antenna at right angles to the
line or moving it further away.

Tests with Main Treaters

The main treaters and high voltage generating and rectifying equipment are housed in a sheet iron super-structure. No outside connecting wires are used to carry the high voltage precipitator current, and even within the building the high tension lines are shielded (for safety of workmen) with heavy wire screen grounded to the steel framework of the building.

A number of tests were made with the regenerative receiver to determine the extent of the interference. The directional properties of the loop could not be utilized as various directions were noted for maximum interference strengths. In only a very few cases did the received signal come in a direction toward the treater building. Numerous readings were made in various parts of the plant grounds. The results of these tests indicated that a major portion of the interference was not being radiated but was traveling as line-radio over power, lighting and telephone circuits. Very loud interference was noted whenever the pick-up system (loop or antenna) of the receiver was in close proximity to the electric circuits.

Radio and Line-Radio Field Tests

A series of observations were made to determine
the extent of the line-radio interference in the vicinity of the plant. The super-heterodyne receiver was mounted in the rear seat of an automobile and observations made at a radius of about two miles. At distances greater than about one-quarter to one-half mile from the plant only very slight direct radio interference could be picked up, using the full possible amplification of the set. Observations were made both during the day and night time. At night no difficulty was had in receiving the broadcast stations at Los Angeles (distance of 50 miles air line) and San Francisco (450 miles air line). No fading was noted in the reception from the Los Angeles stations, but the usual fading was noticed in reception from San Francisco. When minimum signal volume was caused by fading, the precipitator interference was quite noticeable, and often drowned out the signals.

The line-radio interference varied considerably at various distances from the plant and with the characteristics of the metallic carrier. The interference was greatest when in proximity to the Pacific Electric Company's trolley lines and least from the telephone circuits. Power circuits conducted the interference with varying degrees of attenuation. Difficulty was had in tuning-in the interference on some power circuits, due to the power line inter-
ference caused by the load characteristics of the power circuit.

In only one instance was it noted that more than the usual precipitator interference existed when not in close proximity to power circuits. This point was about one mile southeast of the plant, in the middle of a field, the nearest electric power circuits being about one-half mile distant.

The results of these observations indicated that the interference was proceeding from the plant largely as line-radio, with only a small amount of energy being directly radiated.

The results of these tests agree fairly with reports by various radio amateurs in the vicinity. Numerous radio dealers and broadcast set operators were interviewed regarding the particular localities of the interference. The following is typical of the information received and is quoted from a letter received from the manager of a radio supply store located in a town near Plant No. 1.

"At your request I am, in the following lines, giving you information regarding the "Interference Situation" in and about -- -- --.

In the past year we have made numerous
tests with the management of the Cement Company to determine positively that the noise was coming from the dust treaters.

This constant buzz seems to cover the entire broadcast range but is more severe on the waves of 175 to 300 meters.

It is during the winter months that this interference is most annoying as everyone is trying to bring in the distant stations and in certain sections it creates a virtual blanket over the signals. We have tuned in distant stations with the treaters off and as soon as they started again the station would fade away. This was noticed at a distance of six miles from the plant.

Regarding the location of this disturbance, we find it almost impossible to sell a radio west of --- on account of noise. The interference is the beginning of the residential section west of town and gradually decreases as we go east and south until three miles out of the city we get practically no noise. In other words it covers the thickly settled part of --- , and dies out when we get to the outskirts."

Attention may be called to the fact that electric power and lighting circuits do not extend beyond --- at the localities where interference is not encountered.

**Insertion of Chokes at Negative Rectifier Terminals.**

Sufficient equipment was not available for placing chokes in each portion of the rectifier circuit
where previous tests had indicated it necessary to completely stop radiation. Enough equipment was available, however, to place one choke in the high tension line at the negative rectifier terminal of each treater. The following chokes were inserted in each of the rectifiers which were operating at the time of the tests:

**TABLE 1.**

<table>
<thead>
<tr>
<th>Treater</th>
<th>Choke Type</th>
<th>Core Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>#2</td>
<td>3400 microhenry choke</td>
<td>air core</td>
</tr>
<tr>
<td>#3</td>
<td>3400 microhenry choke</td>
<td>air core</td>
</tr>
<tr>
<td>#4</td>
<td>5000 microhenry choke</td>
<td>iron core</td>
</tr>
<tr>
<td>#5</td>
<td>5000 microhenry choke</td>
<td>iron core</td>
</tr>
<tr>
<td>#6</td>
<td>5000 microhenry choke</td>
<td>iron core</td>
</tr>
<tr>
<td>#7</td>
<td>5000 microhenry choke</td>
<td>iron core</td>
</tr>
<tr>
<td>#8</td>
<td>5000 microhenry choke</td>
<td>iron core</td>
</tr>
<tr>
<td>#9</td>
<td>3400 microhenry choke</td>
<td>iron core</td>
</tr>
</tbody>
</table>

Additional observations were now made, using the super-heterodyne receiver mounted in the automobile, as before. Because of limited time, observations were made at points where maximum interference had been encountered in the previous tests.
RECEPTION TESTS

WEDNESDAY, SEPTEMBER 2, 1925.

Radiola Super-heterodyne mounted in rear of car.

ON ROAD DIRECTLY OPPOSITE TREATERS: 7:40 P.M.

Interference heard at 294 and 361 meters. Louder at 361 meters. Near pole line carrying power circuits.

IN FRONT OF PLANT OFFICE: 7:45 P.M.

Interference very dim at 361, but fairly loud at 294 meters. Buried lighting circuits.

ON HIGH ROAD ABOVE PLANT GARAGES:

Slight interference at 294 meters. Inaudible at 361 meters. Set loop pointed directly to treaters, which are about 200 feet distant. KFI at Los Angeles heard very well. Considerable static.

ONE-HALF MILE NORTH OF PLANT:

No interference heard. Loop pointing direct at treaters. Loop almost at right angles to Los Angeles but KFI can be heard plainly.
ONE MILE NORTH OF PLANT - AT CROSSING
OF PACIFIC ELECTRIC CAR LINE.

8:10 P.M.

Interference can be heard. Slight noise heard which resembles motor commutator sparking.

KFI heard very well.

KPO at San Francisco fairly loud.

Interference at this same place quite bad before installing chokes.

TWO MILES EAST OF CITY.

9:30 P.M.

No treater interference heard.

some power line interference noticeable from Southern California Edison Company high tension lines which run overhead.

TESTS AT HOTEL. (Three miles from plant) 10:30 P.M. to 1:30 A.M.

Absolutely no treater interference detected within tuning range of Radiola super-heterodyne. Considerable static and motor (elevator) noises.

Loud speaker reception on KFI Los Angeles, KPO San Francisco, KHJ Los Angeles, KNX Los Angeles.

Variations in Interference Produced by Individual Treaters:

In order to determine the relative interference
produced by each treater, the entire plant was shut down and each treater alternately started and stopped. The chokes inserted at each rectifier as listed in Table 1, were short circuited with a piece of heavy wire.

**Table 2.**

<table>
<thead>
<tr>
<th>Treater</th>
<th>Observations with two tube regenerative receiver located 100' from treaters. 50 feet antenna, 6 feet high; Observer: K. I. Marshall</th>
<th>Observations with a six tube Radiola Super-Heterodyne receiver mounted in auto about 500' from treaters. Observer: J. J. J.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 2</td>
<td>Noisy - not loud</td>
<td>Dim, but audible</td>
</tr>
<tr>
<td>3</td>
<td>Very noisy</td>
<td>Very loud</td>
</tr>
<tr>
<td>4</td>
<td>Very noisy</td>
<td>Very loud, greater than #3</td>
</tr>
<tr>
<td>5</td>
<td>Noisy - less than #3</td>
<td>Dim, but audible</td>
</tr>
<tr>
<td>6</td>
<td>Faint</td>
<td>Inaudible</td>
</tr>
<tr>
<td>8</td>
<td>No noise</td>
<td>Inaudible</td>
</tr>
<tr>
<td>9</td>
<td>No noise</td>
<td>Inaudible</td>
</tr>
</tbody>
</table>

Note - When all treaters were shut down, there was no interference or noise.

Treater No. 4 was found to give the greatest interference, while with No. 3 had only slightly less volume.
The chokes were next included in the circuit by removing the short circuiting wires and additional observations made, the results of these tests being as follows:

**TABLE 3.**

<table>
<thead>
<tr>
<th>Treater</th>
<th>Observations with two tube regenerative receiver located 100' from treater. 30 foot serial 6' high.</th>
<th>Observations with a six-tube Radiola Super-Heterodyne receiver mounted in auto about 500' from treaters.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 2</td>
<td>Very faint</td>
<td>Inaudible</td>
</tr>
<tr>
<td>3</td>
<td>Noisy</td>
<td>Loud</td>
</tr>
<tr>
<td>4</td>
<td>Noisy</td>
<td>Very loud</td>
</tr>
<tr>
<td>5</td>
<td>Dim, half as noisy as #3</td>
<td>Faint (Intermittent)</td>
</tr>
<tr>
<td>6</td>
<td>Less noisy than #5</td>
<td>Inaudible</td>
</tr>
<tr>
<td>8</td>
<td>No noise</td>
<td>Inaudible</td>
</tr>
<tr>
<td>9</td>
<td>No noise</td>
<td>Inaudible</td>
</tr>
<tr>
<td>10</td>
<td>Noisy (slight)</td>
<td>Inaudible</td>
</tr>
</tbody>
</table>

From these tests, Tables 2 and 3, it will be noted that although the single chokes at the rectifier terminal did not completely stop radiation, they reduced it considerably for those treaters which gave the greatest inter-
Additional Observations at Plant No. 1.

Inasmuch as each of the treaters and auxiliary equipment at the plant are identical in construction, it was thought possible that the variation in interference from the different units may be due to different operating conditions, such as stack or treater gas temperature, deposition of cement on treater plates and electrodes, sagging or shifting of discharge wires, etc., in operation. Additional observations were therefore made two weeks after the first observations.

The regenerative receiving equipment used in the previous test was set up at the same point as in the previous tests, using the same antenna and having conditions as near the same as possible.

The following table lists the treaters which were operating, and the relative interference therefrom (no chokes in circuits):
### TABLE 4.

<table>
<thead>
<tr>
<th>Rectifier No.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Faint interference, maximum peak at 205 meters</td>
</tr>
<tr>
<td>3</td>
<td>Loud interference, maximum peak at 220 meters</td>
</tr>
<tr>
<td>4</td>
<td>Loud interference, maximum peak at 225 meters</td>
</tr>
<tr>
<td>6</td>
<td>Less than #3 but greater than #2 maximum peak at 200 meters</td>
</tr>
<tr>
<td>7</td>
<td>Less than #2, maximum peak at 200 meters</td>
</tr>
<tr>
<td>8</td>
<td>Inaudible between 150 meters to 1050 meters</td>
</tr>
<tr>
<td>9</td>
<td>Inaudible between 150 meters to 1050 meters</td>
</tr>
<tr>
<td>10</td>
<td>Inaudible between 150 meters to 1050 meters</td>
</tr>
</tbody>
</table>

The entire Cottrell equipment was shut down and then each treater alternately started and stopped while observations were being made. During these tests programs from KGO at San Francisco and KFI at Los Angeles, about 450 and 60 miles distant, respectively, were heard. Practically all of the treater interference exists below 220 meters, although a slight interference exists on higher wave lengths. The higher wave interference offers practically no difficulty when receiving strong broadcast
signals, but oftentimes drowns out the weaker signals when fading occurs.

Effects of Reactance in Treater Circuits.

Treater No. 3, producing the maximum interference, was selected for these tests. In the first test a 4000 ohm inductively wound resistance wire was placed in the line at each treater. The interference was reduced about 50 per cent of that of the original treater circuit. Inasmuch as this value of resistance is considerably greater than the theoretical value required for complete suppression of oscillations, in a series circuit, the tests indicated that, either (1) the high frequency resistance of the resistors was lower than the direct current resistance (due to skin effect, surface leakage and corona phenomena), or, (2) the place of insertion of the resistance was not the only path for the high frequency currents; i.e., due to the various distributed capacities to ground and inductances in the complete circuit various portions of the circuit were in shunt.

In order to check the first supposition, a 3400 microhenry choke was inserted in series with each of the resistance units. The interference, practically 10 per cent less loud than before, indicated that even if
the resistance units allowed a little of the high frequencies to pass, other multiple paths existed.

The resistances and chokes at the treaters were allowed to remain, and in addition a series of iron core chokes (800 milhenries total) was next placed in the circuit at the rectifier end of the line. This reduced the interference audibility to a value of probably 10 per cent its original volume. Because of the high impedance in the line connecting the treater and rectifiers, it seemed quite probable that the oscillations remaining were in the circuit composed of the rectifier gaps and capacities existing within the transformer itself. A 1700 microhenry choke was inserted in each lead from the high voltage transformer. This completely stopped all interference and it was impossible to obtain even a beat note when searching for any of the treater waves with the receiver oscillating. The receiver antenna was then placed parallel (and as close to the power circuit as possible to obtain oscillations and regeneration of the detector), to the power circuit and additional observations made. The interference had been entirely suppressed.

TESTS AT PLANT NUMBER TWO.

Field Tests.

The treater and auxiliary equipment of the acid
plant of an oil refinery at San Pedro Harbor are housed in a steel building. The equipment consists essentially of a 10 KVA step-up transformer, control panel with necessary meters and switches, double unit synchronous rectifiers, connecting line between high voltage equipment and treaters, and the acid mist precipitators or treaters. The high tension line is entirely surrounded by a grounded screen.

Practically no radiated interference was found to exist, but considerable interference was found when the receiver antenna was placed in proximity to power or lighting circuits. Insertion of a 3400 microhenry choke at the rectifier terminal reduced the interference about 50 per cent. 3400 microhenry chokes were next inserted in each lead of the transformer. This completely eliminated the interference. Before insertion of the chokes, the main interference band existed at about 200 meters.

TESTS AT PLANT NUMBER THREE.

Field Tests.

The electrical equipment at Plant No. 3 is very similar to that at Plant No. 2. The equipment, however, is housed in a separate building from the treaters,
and located on the ground adjacent to the acid plant building. A vertical wire is used to connect the high tension terminal of the rectifier to the treaters. This line is about 60 feet long and unshielded. Considerable radiated interference was found to exist and was practically as great as the line-radio interference. Insertion of chokes gave the same results as in the previous tests. No treater interference, or even a carrier wave could be detected with the regenerative receiver oscillating and the antenna located about fifty feet from the high tension line.

DESIGN OF RADIO INTERFERENCE CORRECTION EQUIPMENT

After completion of the field and laboratory tests, the various types of interference correction equipment (comprising the strain, choke or plain, and absorber type coils) was designed. These coils are shown in Fig. 12.

CHOKE TYPE CORRECTOR.

The choke-type correctors, shown at "A" in Fig. 12 consist of a single layer spaced wound inductance. As is well known, the reactance offered by an inductance
Fig. 12.
to the flow of alternating current varies directly as the frequency. This may be expressed as follows:

\[ x = 2\pi fL \]

in which \( x \) is the reactance, \( f \) the frequency, and \( L \) the inductance. From this equation it will be seen that the reactance offered by a coil to low frequency, say the 60 cycle pulsating precipitator current, is only a minute fraction of the reactance offered to the high frequency radio currents, having frequencies in the neighborhood of 500,000 to 1,500,000 cycles per second. The blue-print of Fig. 13 gives detailed construction and specifications for this corrector.

**STRAIN TYPE CORRECTOR.**

These correctors are fundamentally of the same design as the choke type, but so designed as to be weatherproof and inserted directly in the high tension line connecting rectifier and precipitator buildings. This type of corrector is shown at "C" in Fig. 12, and the construction is shown in Fig. 14.

**ABSORBER TYPE CORRECTOR.**

After completion of the field and laboratory
Last \( \frac{1}{2} \)" of winding on each end, 10 turns \( \frac{1}{2}" \)

\[ 2.48" \]

\[ 2.4" \]

\[ 2.2" \text{ Winding} \]

No. 26 D.C.C. Wire wound 32 turns per inch.

\[ \text{2}\frac{5}{8}\text{" dia. wood core wound with one layer of 26 D.C.C. wire and paraffine impregnated.} \]

\[ \text{Solder wire to casting.} \]

Brass casting weight 13\( \frac{1}{2} \) oz.

Stagger 2\( \frac{5}{8} \)" brass pins 3" lg. to hold cap on.

Wrap winding spirally with \( \frac{1}{2} " \) Empire Tape 0.12" thick.

Flow finished corrector with varnish.

Counter Bore to suit cover \( \frac{3}{8} " \).

Disc of paper over ends of wood core.

\[ \text{SECTION "A-A"} \]

\[ \text{Total weight of Corrector 2 lbs. 13 oz.} \]

For location of Corrector in Treater Circuit see dwg. #3975.
ASSEMBLY OF STRAIN TYPE CORRECTOR

Core, wound with one layer of 26 D.C.C. Wire and again paraffine impregnated.

Core paraffine impregnated.

Slip bakelite covering over winding and inside cap.

Last 1/2 of winding on each end, 10 turns 1/2, 1 1/3.

Stagger 3 holes each end for 1/4 brass pins.

Drill holes in cap for 3/4 dia. 1/8 brass pins staggered.

CAP MARK 4060-C 
2 REQ'D. 
BRASS

Scale: 6"-1/0"

CORE MARK 4060-A 
1 REQ'D. 
HARD WOOD (Maple)

Scale: 6"-1/0"

Bakelite Covering MARK 4060-B 
1 REQ'D. 
Bakelite Tubing

Scale: 6"-1/0"

Solder wire to casting

Solder wire to casting

Flow finished corrector with varnish. Be sure this joint is water tight.

We groove in end for 26 C. Wire

Drill with cap. in place.

45 drilled hole for D.C.C. Wire

13/54 rounded hole

4060

Western Precipitation Co. 
Los Angeles, Calif.

Radio Interference Corrector 
Strain Type
tests the most effective design for an absorber coil was adopted. The primary winding consists of a single layer coil, wound on a Bakelite tube, over which are placed one-turn iron secondary coils. The design of the secondary coils (taking into account permeability and resistance of the iron) is such as to give low capacity effects, increased flux density, and high losses to the transient currents, consistent with fairly close coupling.

The effective resistance of the absorber coil varies with some power (approximately the square) of the frequency. The higher transients therefore suffer much greater attenuation than the low frequency pulsating rectified current. As a result, the losses for the rectified current are reduced to minimum, while the losses for the undesirable high frequency transients are great. Only one of the absorber coils is required in the average precipitator installation. The completed coil is shown at "B" in Fig. 12, and the construction shown in Fig. 15.

LOCATION OF CORRECTING EQUIPMENT.

As previously mentioned, a plurality of parallel circuits exists in the precipitator installation. The interference correcting equipment should be so placed
ASSEMBLY OF CORRECTOR - ABSORBER TYPE

1. pieces of W1. Pipe
2. No. 26 DCC Wire
3. Bakelite Spacer
4. Wood core
5. Bakelite rings between iron pipe
6. Bakelite strips
7. 3 grooves in each piece as shown

SECTION "A-A"

Core wound with No. 26 DCC wire wound 32 turns/inch and again paraffine impregnated.

Solder wire to casting.

Stagger 2-3 pins 3/4" each end to hold cap on.

Casted in paper over ends of wood core.

Cored core mark 4059-A

Wood (Clear Sugar Pine)

Core paraffine impregnated.

1.8" winding

Drilled hole end for C. Wire

Steel rings mark 4059-E

Scale 6:1-0

Selby tubes 3.5" tubing mark 4059-E

6" notches spaced as shown to hold bakelite strips in place.

Rings mark 4059-C

Scale 6:1-0

4059-C BAKELITE

8 reqd.

Spacers mark 4059-G

2 reqd.

Scale 6:1-0

BAKELITE STRIPS mark 4059-D

6 reqd.

Bakelite rings between iron pipe

3 grooves in each piece as shown

MARK 4059-D BAKELITE

Scale 6:1-0

Bevel at ends

RINGS mark 4059-C

8 reqd.

Scale 6:1-0

MARK 4059-C BAKELITE

Weight 13.2 lbs.

CAP mark 4059-B

2 reqd.

Scale 6:1-0

MARK 4059-B BRASS

MARK 4059-A WOOD (Clear Sugar Pine)

Scale 6:1-0

Total weight of Corrector

For location of Corrector in Treater Circuit see dag 43972 for Recifier see dag 4052
as to be included in each of the main oscillating circuits. The recommended locations of the various correctors are shown in Fig. 16. Correctors should be placed close to the feeder bus of each treater section. The correctors should be located as close to the treaters as possible without undue exposure to hot treater gases or high temperatures, which are detrimental to the insulation. For those installations where the correctors can not be installed sufficiently close to the treaters without exposure to high temperatures, a special type of corrector has been developed which may be exposed to temperatures up to 600°F. without injury. The corrector should be installed between the precipitator and the high tension switching equipment.

Details for mounting the correctors on the rectifier are given in Fig. 17.

Method of Insertion in Treater Circuit.

The choke and absorber type correctors are provided with one-half inch female standard pipe threads for direct insertion in the one-half inch pipe high tension lines. No further connections to windings are necessary, as the ends of the windings are soldered during coil
Note: When using transformers with condenser type bushings use additional choke corrector.

2 Std. pipe

Surge Coils

Transformer

Rectifier

Absorber Type corrector

Floor flange

Choke type corrector

Good ground connection

Hand operated switch

Wall Bushing

Sub-Station

Choke type corrector

Hand operated switches

Treater House

Strain type correctors equally spaced in high tension line and at distances not greater than 50 to 75 feet.

To sections of treaters

Note: End of absorber and choke type correctors are tapped 2 Std. pipe tap. The electrical circuit is completed by screwing the 2 pipe high tension lines into end caps on absorber and choke type correctors.

Western Precipitation Co.
Los Angeles, Cal.

Recommended Location of Radio Interference Correctors in Treater Circuit

Drawn By: Date: 12-17-23
Traced By: Date: 12-18-23
Checked By: Date: 
Approved By: 

Scale: None

Revised
2 3
assembly to the bronze ends of each corrector, and screwing the pipe into the bronze ends completes the circuit.

The strain-type correctors are so designed as to be inserted directly in the high tension lines. The correctors are inserted in the line in a manner similar to the insertion of the familiar strain-type insulators. The correctors are equipped with suitable terminals by means of which direct connection is made to the line. It is deemed necessary to insert correctors in these lines at distances of approximately fifty to seventy-five feet, if all broadcast interference is to be eliminated. Method of installation is shown in Fig. 16.

INDUCED CURRENTS.

During tests, it was noticed that sparking oftentimes occurred between pipe framework and entrance gates on the guard rails surrounding the high tension equipment. Although the entire system is grounded, considerable current flows in various portions of the circuit. The induced currents are of high frequencies and could be taken through the body. Small flashlight bulbs were lit with great brilliancy. The potential between one of the gates and the pipe guard rail was estimated (by sparking distance) to be approximately 1000 volts. Such induced
currents are quite common in high frequency work. Attention should be called to the fact that although the entire pipe guard railings were grounded, locally induced currents can be generated and will flow through closed loops of the system.

These induced currents generally do cause radio interference more than a few feet from the guard railings. A quite serious form of line-radio interference may be caused, however, if exposed or open (not in grounded conduit) power or lighting wires are close enough to a part of the treater circuit carrying high frequency currents. Even a small amount of radio frequency energy may travel considerable distances over conductors. In the initial layout of an electrical precipitator or similar installation, care should be taken to see that exposed power, lighting, telephone or signal wires are not run parallel to any of the high tension treater circuits. Should it be necessary to bring such wires in the proximity (10 feet) of treater circuits, the wires should be enclosed in grounded (flexible or pipe) metallic conduit.

Radio currents traveling as wired-wireless or carrier-current, will produce considerable interference if allowed to get on a main distribution line extending
outside the plant property. Precipitator interference which may be received only over short distances as radio will often extend for many miles if traveling as line-radio over suitable conductors. Especially is this true for conditions existing in high tension distribution lines where transformers, etc., which tend to block the radio-frequency currents, are placed considerable distances apart. It is well known that signals traveling over suitable conductors suffer less attenuation than when radiated as in pure radio. For the same power output and over good conductors, transmitted radio frequency currents can often be heard from fifteen to thirty times as far by line radio as by pure radio.

RESULTS OBTAINED BY INSTALLATION OF CORRECTORS.

Various types of laboratory and field installations have been studied and the radio interference problem was not considered solved until all precipitator interference was eliminated on the test set when operated a few feet from the Cottrell installation. In addition, the cooperation of nearby amateur and broadcast listeners was obtained, if possible, and night reception tests conducted. It was possible to tune-in distant broadcast and code
stations without any radio interference from the precipitators. The laboratory set-ups studied during the investigation were of such a nature as to give more severe conditions than expected in practice, or encountered in any of the plants where field studies have been made. Temporary test installations have been made at the precipitators in the vicinity of Los Angeles. These installations included a large cement plant where twelve rectifier sets are used, and two oil refinery acid plants using single rectifier sets. Careful studies were made at each of these installations. A number of permanent installations are being carried out at present and the interference at the following plants has been corrected:

The Magnolia Refining Company, at Beaumont, Texas, has recently (Dec. 1925) placed in operation a single unit precipitator in an acid recovery plant. This precipitator was installed and upon initial operation the radio interference was found to be quite bad. Complaint was immediately made by the operators of the Magnolia Refining Company broadcast station, KFDM, located about five hundred feet from the precipitator. Installation of the correction equipment completely eliminated the interference.

The interference at the Alpha Portland Cement
Company's plant at Cementon, New York, was of such magnitude as to seriously interfere with operation of nearby receivers. This plant has three large rectifier sets, and six plate-type treaters. Interference correction equipment was installed in January 1926, and eliminated the interference.

Equipment similar to that described in this report has been installed by the United Verde Copper Company, at Clarkdale, Arizona. This installation has ten rectifier sets and we are advised (Jan. 1926) by Mr. F. X. Mooney of that company, that the interference there has been practically eliminated.

Similar installations have been made by Lodge-Cottrell, Limited, of England, who report complete elimination of all interference.

At the present time (April 1926) installations are being made at Universal Portland Cement Company at Duluth, Minnesota; Knickerbocker Portland Cement Company at Hudson, New York; The Alpha Portland Cement Company at Ironton, Ohio; and the Huron Portland Cement Company at Alpena, Michigan.
ECONOMIC ASPECTS OF RADIO INTERERENCE

Good radio reception has recently become an important factor in the home life of plant employees. In plants where the men work at hard physical labor, they welcome the evening's entertainment supplied by a radio receiving set. Especially is this true when the plant and its community are located at places away from the larger cities with their diversified amusements. Plant officials now recognize the importance of the radio and practically all "club", boarding and community houses at the larger plants are equipped with good loud-speaker operating radio receivers. Any interest or amusement which will provide entertainment for employees and their families is of direct economic value to any industrial center. The labor turnover at the plant is less, and a better class of workers and families are secured. The elimination of radio interference is, therefore, of direct interest to the officials of a plant. Many forms of radio interference exist in a large industrial center, and the Cottrell precipitation equipment is only one source of such interference. This source of interference can be eliminated by the equipment described in this report. In order to insure good distant radio reception, attention should be given to the minimizing of other radio interference if existent. Especially is this true when the plant community is located
close to the plant or mill, and where the community houses are supplied with lighting current taken directly from the plant power circuits. In plants where heavy power requirements prevail, as in cement plants, steel mills and "heavy" manufacturing a terrific amount of line-radio interference usually exists. In some plant communities the high local noise level or interference prevents even local reception. In such localities a radio receiver can be operated only with difficulty.

GENERAL NOTES
REGARDING RADIO INTERFERENCE.

Interfering noises in a radio receiver may be grouped under three general heads; pure radio, line radio, and set noises. Before any attempt can be made toward the elimination of interference, it is necessary to determine the type of interference.

Interference of the pure radio type is picked up by the antenna in the same way as the desired radio signals. Because of the minute energy generated in the receiving antenna by a passing radio wave, it is necessary that the radio receiver be a very delicate amplifying device. It amplifies any and all electric waves for which
it may be adjusted or "tuned." Unfortunately, a majority of the interfering waves have no definite wavelength, but usually cover a more or less broad band. Any electric spark produced by any electric equipment may, under proper conditions, radiate waves which will be picked up by a sensitive receiver and amplified along with the desired radio signals.

In order to determine if the interfering noise is coming in via the antenna (or receivers using outside antenna instead of a loop), the aerial and ground wires should be disconnected. If there is a reduction in the intensity of the noise, attention should be given the location of the antenna and ground wires. If the trouble is believed to be due to improper location of the antenna, such as near trolley, power, or lighting circuits, etc., a temporary antenna held a few feet above the ground can be used, and the set operated as the direction of the antenna changed. Oftentimes it will be found that the interference can be minimized by changing the direction or the location of the antenna, etc.

The ground wire is often a collector of interference. Especially is this true when the ground wire is placed alongside of telephone, power, or lighting circuits for appreciable distances before reaching the ground
connection. Interference is often encountered when the radio ground connection is fastened to an existing telephone, signal or other ground pipe. It is always advisable to use a separate ground connection for the receiver.

If when the antenna and ground wires are disconnected from the set there is no reduction in the intensity of the noise, while the radio reception is stopped by the disconnection, the probability is that the source of the noise is either in the set itself, or is being picked up by the set from close lighting or telephone circuits. If the noise is believed to be due to some imperfect part of the set, such as run down batteries, leaky condensers, etc., it is usually advisable to compare the set with another set by substitution and operating on the same batteries, tubes and antenna. If the set is found to be in proper condition, line radio interference sources should be investigated.

Many line radio interferences are of a purely local nature, originating in such sources as a lamp loose in its socket, or a loose plug of a heater, or other faulty connections in a household appliance. Local interference can often be ascertained by two tests. First, while the interference is continuous, slowly open and close
the main house service switch, while the receiver is operating. If the noise stops in exact synchronism with the opening and closing of the switch, the interference is due either to local sources or is coming in via the lighting circuit. The next step in locating the interference is to turn off each light and other current-consuming devices in the house. This can be checked by noting the meter and if the disc is absolutely stationery, the house load is probably removed. If the interference is due to a loose connection on some particular device in the home, it can usually be located if the radio set is operating and an observer stationed at the set. Should the interference still be present, or increase in volume, it is quite probable that it is coming in from the outside via the lighting circuit. Conclusive decision regarding this can not be reached until a similar procedure has been followed in regard to telephone and other lines entering the home. Eliminating radio interference requires patience.

As previously mentioned, considerable interference will be found to be present on the lighting and power lines supplying any large industrial center. Fortunately, however, a major portion of line radio interference is confined to the line itself. The radiated energy usually
extends only a short distance from the line. Line radio interference is easily picked up by the more sensitive types of receivers, and especially those utilizing the lighting circuit for plate, or filament battery supply by use of "B" battery eliminations, etc. Line radio interference entering a home over the outside service lines may often be eliminated or greatly minimized by the use of proper radio frequency chokes inserted in the house supply wires. The construction of such chokes is shown in Fig. 18; the design being such as to safely carry the average domestic home lighting load. The larger size wire is recommended for homes of more than three rooms, especially if electrical heating equipment, such as irons, toasters, etc., is used.
DIAGRAM OF CONNECTIONS

LINE RADIO INTERFERENCE CORRECTOR

Cover with two layers of Empire Cloth before winding.

Impregnated Wood or Bakelite Cylinder

Wind with #14 Ga. D.C.C. copper wire for 3 ampere load, and give one coat of clear varnish.
BIBLIOGRAPHY


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