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E. F. W. ALEXANDERSON.
ANTENNA.
APPLICATION FILED SEPT. 13, 1917.

Patented Nov. 23, 1920.
2 SHEETS—SHEET 1.

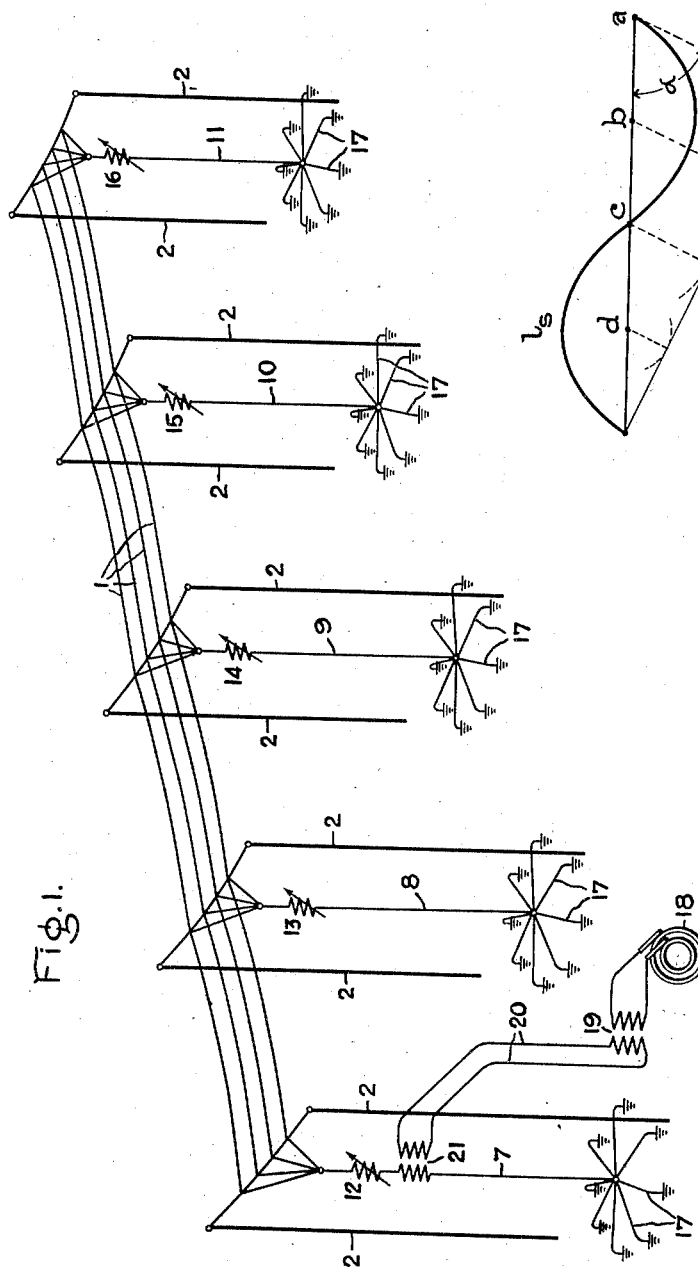


Fig. 1.

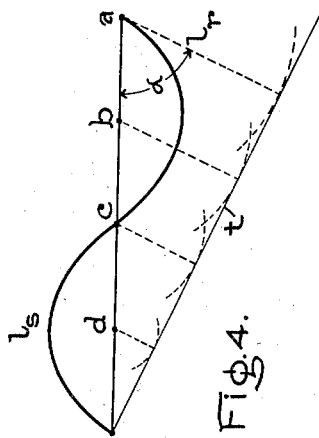


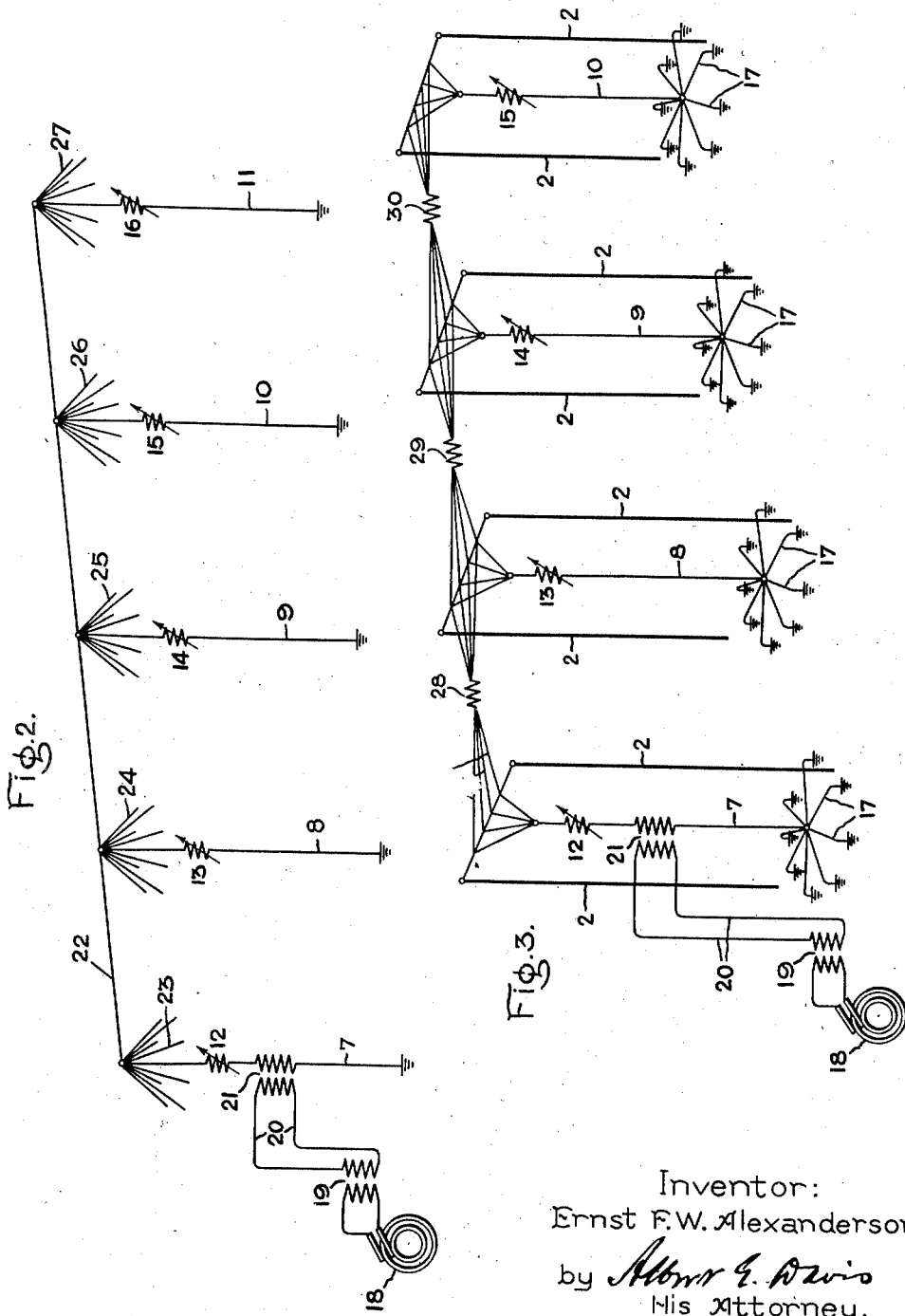
Fig. 4.

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UNITED STATES PATENT OFFICE.

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ANTENNA.

1,360,167.

Specification of Letters Patent. Patented Nov. 23, 1920.

Application filed September 13, 1917. Serial No. 191,110.

To all whom it may concern:

Be it known that I, ERNST F. W. ALEXANDERSON, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Antennæ, of which the following is a specification.

My present invention relates to antennæ for radio signaling systems and more particularly to the manner in which the radiation of the transmitting system is effected. My present application is a continuation in part of my prior application Serial No. 123,276 filed Oct. 2, 1916.

The antenna of a radio signaling system as previously constructed has consisted of an elevated electrical conductor or a network of conductors which is charged by a source of high frequency energy in such a way that it becomes a source of energy radiation of the type known as the Hertzian oscillator. The theory for the radiation of an antenna has therefore been universally treated by the mathematical theory of the Hertzian oscillator.

The usual radiating antenna system may be considered as a single Hertzian oscillator. It has been proposed heretofore to employ a plurality of such oscillators in order to increase the amount of radiation or to secure directive effects but no practical use has been made of this idea because of the difficulties of controlling the phase of the oscillations in the different radiators in such a way that they would produce a combined radiation of a predetermined desired character.

One of the objects of my invention is to provide means whereby it will be possible to operate a plurality of practically separate radiators in such a way that a combined radiation of the desired character may be readily obtained.

There are several advantages which may be obtained by operating a radiating system as a plurality of separate radiators instead of as a single radiator. One of these advantages is that less energy consumption is required in order to produce a given strength of signals. This advantage may be explained briefly as follows:

In any single radiator, the strength of the electrostatic and the electromagnetic field of the radiated wave is proportional to the

current and voltage supplied to the radiator. The energy consumed by the radiator is proportional to the product of current and voltage and is consequently proportional to the square of the field intensity of the radiated wave. The general theory of wave motion, however, teaches that if several systems of waves are superimposed, they combine in such a way that the field intensity in any one place is the algebraic sum of the momentary intensities of all the separate waves. If a system consisting of a plurality of separate radiators is controlled in such a way that the relative phase of the oscillations from the individual radiators is made to combine in a predetermined desired way, it will be possible to operate the system in such a manner that the field intensity in the receiving station is the arithmetic sum of the field intensities produced by all of the individual radiators. A radiation of unity intensity from a station with a single radiator may be said to produce a field intensity of unity in the receiving station. If a system comprising a plurality of radiators is operated in such a way that each of the radiators emits a wave of unity intensity, the effect on the receiving station will be the same as that of a wave with a field strength of as many times unity as there are individual radiators.

The energy consumption of the single radiator may also be called unity and the energy consumption of each of the individual radiators of the multiple system will also be unity when operated as described. If then we assume that there are six individual radiators we will obtain with an energy consumption of six times that of the single radiator a field intensity at the receiving station which is six times as great as that obtained with a single radiator. If it were, on the other hand, desired to produce by a single radiator, a wave at the receiving station having a field strength equal to six times unity it would be necessary to increase the current as well as the voltage in the single radiator to six times unity and consequently the energy consumption of the single radiator would be 36 times unity. Thus it will be seen that the energy consumption of the single radiator will be six times as great as that of the six individual radiators in order to produce the same intensity of signals.

A second advantage of my multiple radiation system is that it renders possible the production of signals of greater intensity than it has been possible to produce heretofore regardless of the amount of energy consumed. With any antenna there is a practical limit to the amount of radiation which may be obtained, this limit being partially fixed by the maximum voltage for which it is practical to insulate the aerial. In other words, it is not possible to increase the strength of the signal above a certain value by increasing the amount of energy supplied to a single radiator, whereas with a plurality of individual radiators any increase in the signal strength desired may be obtained merely by increasing the number of radiators.

A third advantage of my system of multiple radiation is that it renders possible the production of a radiation of energy with a decided directive effect comparable with the focusing of a beam of light by a lens or a mirror. While the desirability of such an effect has frequently been mentioned and various means have been proposed for securing it none of the means heretofore proposed have been found to be applicable to practical operation.

A second object of my invention is to provide a convenient and practical means for adjusting the phase relations of the individual radiations so that the advantages of directive radiation may be realized.

In the usual type of antenna corresponding to a single Hertzian oscillator which has heretofore been used the energy is introduced through a ground lead in series with a loading coil. In an antenna of this type designed for long distance transmission assume that the current introduced through the loading coil is 100 amperes and the potential of the aerial is 50,000 volts. The energy required to maintain oscillations in such an antenna may be 50 kilowatts. This means that the energy component of the oscillating voltage is 500 volts, or as it is commonly expressed, the antenna has a resistance of 5 ohms. Thus the energy required for maintaining oscillations is delivered in the form of 100 amperes at 500 volts. While it might be possible to supply energy to each one of a plurality of radiators in this way such a method would, if the individual radiators were located at a considerable distance from each other, involve unnecessary losses due to inductive or resistance drop in the feeding wires.

A further object of my invention is to provide a system for supplying energy to the individual radiators which will overcome this disadvantage.

In attaining this object of my invention I transform the energy to the form of high potential and low current and instead of

supplying it at the ground point of the loading coil supply it at a high tension point. For example, in the case above mentioned, the energy may be supplied to the radiators at 50,000 volts and one ampere. Thus while in each case 50 kilowatts of energy is required the old form of antenna consumes this energy in the same form as if it were a resistance of five ohms whereas the radiator supplied in accordance with my invention consumes the energy in the form of a resistance of 50,000 ohms. This may be explained by reason of the fact that in the old form of antenna the energy is introduced in series with the inductance and capacity of the antenna whereas in the form of a radiator which I employ the energy is introduced to a circuit which is the equivalent of the antenna capacity in parallel with the inductance. By introducing the energy to the individual radiators in this way it is possible to feed a large number of such radiators located at a considerable distance from each other without incurring any great losses in the transmission conductors. In order to transform the energy into the desired form it might be possible to use a transformer of the ordinary type with the required ratio of transformation. I have found, however, that it is more convenient to use one of the radiating circuits as an oscillation transformer, and to supply the energy to all of the other radiators from the high tension end of the first radiator. In its preferred form then, my multiple radiating system may be considered as being made up of a primary radiator which at the same time serves as an oscillation transformer for supplying high tension energy to one or more secondary radiators. In order to have a completely balanced system of radiation, it might appear desirable to locate the primary radiator in such a way relative to the secondary radiators that the energy connections to each of the secondary radiators can be made directly to the primary radiator through wires of equal length. While this might be a practical method of construction, I have found in actual practice that it is not necessary to connect each of the secondary radiators directly to the primary radiator and that it is of practical convenience in the construction of the antenna to connect the secondary radiators successively to each other, that is so that energy current flowing from the primary radiator reaches the secondary radiators in succession. In one case in which my invention has been applied in practice the antenna has the character of a horizontal transmission line supported on towers. This antenna is divided into a plurality of individual radiators by means of ground connections with loading coils therein at suitable intervals along its length. The aerial

wires which serve as radiators also serve for transmitting energy to all of the successive radiators. Since the energy is transmitted to the secondary radiators in the form of high potential and low current it is apparent that a large number of radiators may be connected to such a transmission line without causing any appreciable changes in voltage and phase.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself however, both as to its organization and method of operation together with further objects and advantages thereof will best be understood by reference to the following description taken in connection with the accompanying drawing in which Figures 1, 2 and 3 show diagrammatically as many different modifications and Fig. 4 is a diagram explanatory of the directive radiation feature of my invention. In the form of my invention indicated in Fig. 1 the radiating system is composed of a plurality of horizontal conductors 1 of considerable length elevated above ground by means of the supports 2 from which they are insulated. This system is divided into five individual radiators by means of the ground connections 7, 8, 9, 10, and 11, individual tuning or loading coils 12, 13, 14, 15, and 16 being included in each ground connection. The ground connections indicated consist of a plurality of wires 17 stretched over the surface of the ground, the end of each conductor being permanently earthed. The energy for signaling purposes is supplied to the first radiator of the series by a high frequency alternator 18, connected through the transformer 19 to a transmission line 20 which conveys the current to the transformer 21 by means of which it is introduced into ground connection 7.

The first radiator comprises the ground connection 7 and the portions of the conductors 1 adjacent thereto and this radiator serves as an oscillation transformer to step up the voltage applied through transformer 21. Energy is thereby supplied directly at a high potential from the first radiator to the second radiator, which comprises the ground connection 8 and the portions of the conductors 1 adjacent thereto. The second radiator also acts as an oscillation transformer changing the high potential low current energy into the form of lower potential larger current producing an oscillating charging current in ground connection 8 which may be of the same magnitude as the charging current in ground connection 7. The conductors 1 also serve as a transmission line for conveying the high potential energy to the third, fourth and fifth radiators in succession. These radiators function in the same manner as the second ra-

diator so that charging currents of the same order of magnitude are set up in all of the ground connections. As an indication of the advantage which may be obtained by the use of my invention tests have been made with an antenna of the type shown in Fig. 1 which was divided up into 6 individual radiators. When 50 kilowatts of high frequency energy were supplied to the antenna and a single ground connection used a charging current of about 100 amperes was obtained. When six ground connections were used the charging current in each ground connection was about 45 amperes making a total charging current of 270 amperes. In other words the effective radiation with the same amount of energy was about 2.7 times that which was obtained when the antenna was operated as a single radiator.

In accordance with the Hertzian theory of radiation the ability of a certain aerial to radiate is determined by the so-called radiation resistance. This radiation resistance is proportional to the square of the ratio between height and wave length. It is also well known that an antenna to be used efficiently should be operated at a somewhat lower frequency than its natural periodicity. This method of operation calls for a certain amount of inductance which is ordinarily used for tuning. If it is attempted to operate the antenna at a higher frequency than the natural periodicity it is necessary to introduce a capacity instead of an inductance for loading and it is known that the operation in this way is inefficient. For long distance working antennæ of large horizontal dimensions are employed. The large horizontal dimensions give high electrostatic capacity and consequently the natural periodicity of the antenna which is determined by the physical dimensions of the aerial is low. Thus if such an antenna is operated at its natural periodicity, or at a lower frequency the wave length is much greater than the height and consequently the ratio between height and wave length results in a low radiation resistance and a high ratio between the radiation resistance and the ground resistance; in other words, in low efficiency. The value to which the ground resistance may be reduced is also limited to a certain extent in practice by the physical dimensions of the antenna. Hence it may be said that such an antenna when used as a simple Hertzian oscillator has a definite maximum possible efficiency or natural ratio between radiation resistance and ground resistance. When, however, the antenna is provided with a plurality of ground connections in accordance with my invention, its natural periodicity is increased beyond the value determined by its physical dimensions when used as a simple Hertzian oscillator,

that is, the natural periodicity of the entire antenna is equal to the natural periodicity of each individual section which is supplied with a ground connection, assuming that the natural periodicity of all of the sections is the same. In other words, the natural periodicity of the antenna is increased to a value much greater than the value which is determined by its physical dimensions. As a result the antenna can be operated efficiently at much shorter wave lengths thereby increasing the radiation resistance inversely with the square of the wave length. The result of this is a more favorable ratio between radiation resistance and ground resistance, since the effect of providing a plurality of ground connections is to decrease the ground resistance; that is, the ratio between radiation resistance and ground resistance or efficiency of the antenna may be greatly increased.

The form of my invention illustrated in Fig. 2 differs from that shown in Fig. 1 merely in its constructional details. In this case each individual radiator takes the form of an umbrella type of antenna and the individual radiators are all connected by a transmission line 22 which supplies high potential energy from the first radiator 23 to the secondary radiators 24, 25, 26 and 27 in succession. A radiating system constructed in this way operates in the same manner as the one illustrated in Fig. 1.

In Fig. 3 I have indicated a modification of my invention which may be employed when it is desired to obtain a directive effect. In this case the individual radiators are separated by inductances 28, 29 and 30 which may be made of such a value as to give the phase displacement in the waves radiated by successive radiators, required to secure the desired directive effect. If desired, condensers may be employed between the individual radiators instead of inductances.

In determining a method whereby a system comprising a plurality of individual radiators may be adapted for directive radiation an antenna such as illustrated in Figs. 1 or 2 may be considered as a uniformly distributed capacity between a linear conductor and ground. The electrostatic field surrounding the conductor extends in three directions but for the purpose of this discussion it will be sufficient to consider the potential gradient only in two directions, that is in the vertical direction between conductor and ground and in the horizontal direction along the conductor. When an aerial conductor is set into oscillation by a source of continuous waves of definite frequency standing waves are formed in the electrostatic field. These waves must be analyzed in accordance with the horizontal as well as the vertical distribution of poten-

tial. If the conductor is not connected to ground in any way it has a natural period of horizontal oscillations. In this case no oscillations will occur in the vertical plane. If one end of the conductor is connected to ground it will have another natural period. The oscillations in this case will be horizontal and also to some extent vertical inasmuch as a charging current will pass between the conductor and ground. An aerial conductor thus arranged with the ground connection at one end has previously been used to considerable extent. If such a conductor is connected to ground through a large number of uniformly distributed coils it becomes a multiple radiating antenna as described previously. Furthermore, if the inductance of these coils is so adjusted that the oscillations in all of the different coils are substantially in phase the antenna may be said to have vertical oscillations but no horizontal oscillations. It is, however, possible to tune the antenna in such a way that it has both vertical and horizontal oscillations simultaneously. The vertical and horizontal oscillations may be of different frequency if a source of energy supply of more than one frequency is available. This might be the case if the antenna was excited by an arc generator or a pliotron oscillator. In the present case, however, it will be most convenient to consider the radiation as of a single frequency such as may occur if the antenna is excited by a high frequency alternator, in which case the horizontal and vertical oscillations that take place simultaneously are necessarily of the same frequency. In the case where the conductor is connected to ground at one end only the horizontal oscillations occur in such a way that the grounded end is a node and the open end has maximum amplitude. It was at one time considered that an antenna of this type would produce a directive radiation. It has now, however, been proved that this is not the case, the reason being that the length of the antenna has been less than one-fourth of the wave length of radiation at which it has been operated, whereas to secure an effective directive radiation it would be necessary that the length of the antenna should be at least equal to one-half of the wave length of radiation. In a simple horizontal antenna such as has been described the distribution of capacity and inductance has always been found to be such that the wave length of the standing wave along the antenna is shorter than the wave length of radiation. This condition, as will be explained more fully hereafter, prevents the securing of the most effective radiation. The fundamental rule which should be followed and which will be explained in the following discussion is that the wave length of the standing wave should be equal to or

greater than the wave length of radiation. If radiation is desired in the longitudinal direction of the antenna the standing wave should have a length equal to the wave length of radiation, whereas if a directive radiation is desired at right angles to the direction of the antenna the length of the standing wave should be infinity. For any intermediate angle the relative length of the standing wave and the radiation wave should be equal to the secant of the angle between the direction of radiation and the direction of the antenna. In order to prove this relation geometrically, assume that a wave begins to travel with the velocity of light from one end of the antenna. It is desirable in order to secure maximum efficiency of radiation that the wave as it travels along the antenna should always receive impulses which are in phase with the wave itself. For this reason the standing wave should have a wave length equal to the wave length of the traveling wave. If an antenna oscillates with a standing wave which has a greater wave length than the wave length of radiation, that is, if the wave travels along the antenna at a velocity greater than that of light, the different points of the antenna may be assumed to emit radiation of different phases and the locus for points at which individual waves are of a certain phase may be represented by circles drawn around the different centers of radiation.

Referring now to Fig. 4, assume that the standing wave is represented by l_s . Around point a of the standing wave which is represented as a node a circle may be drawn having a radius equal to the wave length of radiation l_r . Around point b a circle may be drawn of a radius one-quarter of a wave length shorter. Around point c the circle has a radius of one-half a wave length and around point d a radius of one-quarter of a wave length. The line t which is tangent to all of these circles indicates the direction of radiation, the radiation being greatest in a direction perpendicular to this tangent, and it will be apparent from an inspection of this figure that $l_r = l_s \cos \alpha$ where α is the angle between the direction of the antenna and the direction of radiation. Applying the above formula to a case where the standing horizontal wave is shorter than the wave length of radiation the direction of such radiation would be expressed by a cosine greater than unity. This condition being impossible means that no directive radiation can take place and that the radiation will be inefficient.

The type of horizontal antenna connected to ground at one end which has previously been used as such distribution of inductance and capacity that the standing wave is theoretically equal to but in practice has been shorter than the wave length of radiation. In other words, the wave travels along the antenna at a velocity less than the velocity of light. If it is desired to increase the velocity at which the wave travels along the antenna and thereby lengthen the standing wave either the inductance or capacity must be decreased. Anything however which is done in this direction by changing the combination of the wires will defeat the object sought. An additional parallel wire will decrease the inductance but increase the capacity and fewer parallel wires will decrease the capacity but increase the inductance. By the use of a plurality of radiators such as I have described the desired object may be attained. The capacity between the aerial and ground may be neutralized by distributed inductance between the aerial and ground. If the distributed capacity is entirely neutralized by distributed inductance for the frequency at which the antenna is excited the standing wave will have a length equal to infinity, which means that all parts of the aerial conductor will oscillate in phase. This condition produces non-directive radiation if the antenna is shorter than half of the wave length of radiation and directive radiation at right angles to the antenna if the antenna is sufficiently long in relation to the wave length of radiation. If a long antenna is used and directive radiation is desired at any angle except a right angle, the necessary length for the standing wave may be determined from the wave length of the radiation and the desired angle. The inductance of the aerial being known it will then be possible to calculate the amount of distributed capacity which will create a standing wave of the desired length. This required capacity will be found to be lower than the capacity between the aerial and ground. The method to be followed then will be to neutralize the portion of the capacity to ground which is not desired, leaving a balance of distributed capacity which will give a standing wave of the desired length. Instead of neutralizing the capacity to ground it will be possible to neutralize the longitudinal inductance of the aerial conductor by series condensers. Both of these methods may be used in combination if desired.

If the method of adjusting the tuning of the antenna is considered from the above point of view it will be found that the method of radiation which consists in using a number of independent radiators excited from a common source of high frequency energy in such a way as to operate in phase is only a specific case of a composite horizontal antenna with a horizontal standing wave. This specific case is one where the length of the standing wave is infinity and this method of radiation whether directive or nondirective may be differentiated from

the methods of radiation that have been proposed heretofore by the characteristic that the standing wave has a length equal to or greater than the wave length of radiation, whereas such antennæ as have been used previously have had standing waves of a wave length shorter than the wave length of radiation. The term "standing wave" as used in the above description and in the claims which follow is not employed in the restricted sense in which it is commonly understood, namely, as the resultant of two waves traveling with equal velocity in opposite directions so as to produce points of large amplitude and intermediate nodes of zero amplitude. The phenomenon described by this term is also of a different nature than that known as a "traveling wave" since the latter term as ordinarily used implies a complete transfer of energy from one point to another at the same rate that the wave travels. While in the present case energy is transferred from one point to another this transfer is merely incidental as a large portion of the energy remains fixed in position. Moreover, such transfer as does occur may take place in the opposite direction to the traveling wave effect. At any point along the length of the antenna the amplitude of oscillations is the same as at any other point, but when the standing wave, as the term is here used, is of finite length the oscillations of different portions of the antenna are displaced in phase. The maxima of successive portions occur in succession, however, so that the effect, so far as the wave in the ether is concerned, is that of a traveling wave.

While I have illustrated and described the preferred form of my invention, it will be apparent that many modifications therein may be made without departing from the scope of the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. A radiating antenna system comprising a primary radiating unit supplied by a source of radio-frequency current and a plurality of secondary radiating units an individual ground connection for each of said radiating units, the secondary radiating units being connected successively to a transmission line which supplies energy from the primary radiating unit to the secondary radiating units.

2. A radiating antenna system comprising a primary radiating unit and a plurality of secondary radiating units connected successively together and to the primary unit, an individual ground connection for each of said radiating units, a source of high frequency current connected to the primary unit, the primary radiating unit being directly connected to the first of said secondary units and serving as an oscillation

transformer for supplying energy successively to all of the secondary radiating units at a high potential.

3. A radiating antenna system comprising a set of horizontal aerial wires, a plurality of inductance coils connected between said aerial wires and ground at substantially uniformly distributed points along the length of said wires and a source of radio frequency current for supplying energy to the aerial wires at one point, the energy thus supplied being distributed through the aerial wires to maintain synchronous oscillations in each of the oscillating circuits formed by one of said inductances, and the capacity to ground of the portions of the aerial wires adjacent thereto.

4. A radiating antenna system comprising a plurality of sections, all of the different sections being joined together successively by aerial wires, each section consisting of aerial wires connected to ground through an inductance and forming a separate oscillating circuit, and a source of radio frequency current for supplying energy to the aerial wires which join the several sections, each oscillating circuit being tuned to the frequency of the energy thus supplied.

5. The method of supplying energy to a radiating system comprising a plurality of radiating units which consists in supplying energy to one of said units at a comparatively low potential, utilizing said unit as an oscillation transformer for producing a comparatively high potential and distributing energy at the high potential thus produced from the first unit successively to all of the other units.

6. The method of maintaining synchronous oscillations in a plurality of radiating units which consists in supplying radio frequency energy directly to one of said units and supplying energy from said first unit successively to all of the other radiating units.

7. The method of radiating electromagnetic energy from a system of horizontal conductors which consists in producing an electrostatic field in said conductors which has a horizontal standing wave formed therein having a wave length which is at least as great as the wave length which is to be radiated.

8. The method of radiating electromagnetic energy from a radiating antenna system which consists in producing by a single source of radio frequency energy an electrostatic field in said radiating system which has a horizontal standing wave formed therein having a wave length which is at least as great as the wave length which is to be radiated.

9. A radiating antenna system comprising a set of aerial conductors, means for exciting said conductors by a single source of radio

frequency energy, and means for neutralizing, by resonance, the distributed capacity between the aerial conductors and ground, the conductors being so arranged and said means being so adjusted as to produce a standing wave of potential along the aerial conductor having a wave length at least as great as the wave length to be radiated.

10. A radiating antenna system comprising aerial conductors arranged in a horizontal line, a single source of radio frequency current for exciting said antenna system, a plurality of inductances distributed along said aerial conductors and connected between said conductors and ground, said conductors being so arranged and said inductances being adjusted so as to partly neutralize the distributed capacity between the aerial conductor and ground in such a way that the distribution of potential along the aerial conductors will form a standing wave of a wave length at least as great as the wave length to be radiated.

11. The method of radiating electromagnetic energy which consists in charging an insulated continuous system of aerial conductors through a plurality of vertical grounded conductors connected thereto in multiple, the oscillating charging currents in the different ground conductors being regulated so as to have a progressive phase displacement.

12. The method of radiating electromagnetic energy which consists in charging an insulated continuous system of aerial conductors through a plurality of vertical grounded conductors connected thereto in multiple, the oscillating charging currents in the different ground conductors being regulated so that they are progressively shifted in phase to such a degree as to give a directive radiation in a desired direction.

13. The method of radiating electromagnetic energy from a radiating antenna system which consists in neutralizing distributed capacity between said system and ground at a plurality of points in the system, exciting said system by a single source of radio frequency energy, and producing a standing wave of potential along the system having a wave length at least as great as the wave length to be radiated.

14. The method of creating an electromagnetic wave with a directive radiation in a system of aerial wires having a plurality of inductance coils connected between said aerial wires and ground at substantially uniformly distributed points along said wires which consists in producing synchronous oscillating currents in all of the ground conductors by means of energy introduced into the system through one ground conductor and regulating the currents in the different conductors so that they will have a progressive phase displacement.

15. The method of directive signaling which consists in supplying energy from a source of radio frequency current to a radiating unit, supplying energy from said radiating unit to a plurality of other radiating units and adjusting the relative phases of the currents in the different radiating units so that the waves emitted by all of the units add accumulatively at points in a certain predetermined direction.

16. The method of directive signaling by means of electromagnetic waves which consists in supplying energy from a source of radio frequency current to a radiating unit and supplying energy from said radiating unit to a plurality of other radiating units which are so adjusted that the interference effect of the waves emitted therefrom creates a maximum amplitude of signal in a desired direction and a minimum amplitude in another direction.

17. The combination in a radio signaling system of an insulated system of aerial conductors, a plurality of vertical conductors each of which has one end connected to said aerial system and the other end grounded, means for supplying energy to the entire system through one of said vertical conductors to produce synchronous oscillating currents in all of the vertical conductors, and means for adjusting the phase relation of the currents in the different vertical conductors in such a way as to produce a directive radiation.

18. The combination in a radio signaling system of an insulated system of aerial conductors, a plurality of vertical conductors each of which has one end connected to said aerial system and the other end grounded, means for supplying energy to the entire system through one of said vertical conductors to produce synchronous oscillating currents in all of the vertical conductors and means for adjusting the relative phases of the different oscillating currents so that the waves produced by these currents add accumulatively at points in a certain predetermined direction.

19. The combination in a radio signaling system of an insulated system of aerial conductors, a plurality of vertical conductors each of which has one end connected to said aerial system and the other end grounded, means for supplying energy to the entire system through one of said vertical conductors to produce synchronous oscillating currents in all of the vertical conductors and means for adjusting the relative phases of the different oscillating currents so that the interference effect of the waves produced creates a maximum amplitude of signal in a desired direction and a minimum amplitude in another direction.

20. A radiating antenna system comprising a continuous system of aerial conductors

arranged in a horizontal line, a plurality of ground connections for said system containing tuning means located at substantially uniformly distributed points along the length of said system whereby said system is divided into a plurality of radiating units capable of oscillating substantially independent of one another, and means for supplying energy to said system through a single one of said ground connections.

21. A radiating antenna system comprising a system of continuous elevated horizontal conductors, a plurality of ground connections for said system containing tuning means located at substantially uniformly distributed points along the length of said system whereby said system is divided into a plurality of radiating units capable of oscillating substantially independent of one another, and means for supplying energy to said system through the ground connection nearest one end whereby said elevated conductors serve both as a plurality of substantially independent radiating units, and to transmit energy at a high potential from the first radiator to the other radiators in succession.

22. An antenna for a wireless signaling system comprising a long horizontal continuous conducting network supported above the earth and connections between said network and earth at a plurality of successive points along its length whereby the natural periodicity of the antenna is increased beyond the value determined by its physical dimensions when used as a simple Hertzian oscillator, all of said earth connections including inductances adjusted in such a way that the multiple impedance of the inductances is equal to that of a single inductance necessary for tuning the whole antenna at the operating frequency.

23. The combination in a wireless signaling system of an antenna comprising a long horizontal conducting network supported above the earth and connections between the said network and earth at a plurality of successive points whereby the natural periodicity of the antenna is increased beyond the value determined by its physical dimensions when used as a simple Hertzian oscillator, all of said earth connections including inductances, and means for supplying the energy necessary for maintaining oscillations of a single definite frequency in the entire system through one of the multiple paths to ground.

24. The combination in a wireless signaling system of an insulated system of long horizontal continuous aerial conductors, a plurality of successive vertical conductors each of which has one end connected to said aerial system and the other end grounded, and a source of sustained high frequency oscillations for producing synchronous oscillating currents of a single definite frequency

in a plurality of multiple paths, each of which comprises a vertical conductor and the space capacity of a portion of the aerial.

25. The combination in a wireless signaling system of an insulated system of long horizontal continuous aerial conductors, a plurality of vertical conductors each of which has one end connected to said aerial system and the other end grounded, and a source of sustained high frequency oscillations for producing substantially in phase oscillating currents of a single definite frequency in all of the vertical conductors.

26. The combination in a wireless signaling system of an insulated system of long horizontal continuous aerial conductors, a plurality of vertical conductors each of which has one end connected to said aerial system and the other end grounded, and a source of sustained high frequency oscillations for producing oscillating currents of a single definite frequency in all of the vertical conductors which differ in phase from one another by less than 90° .

27. An antenna for a wireless signaling system comprising a long horizontal continuous conducting network supported above the earth and having of itself a low natural periodicity and connections between said network and earth at a plurality of successive points along its length, whereby its natural periodicity is increased to a much greater value, all of said earth connections including inductances for tuning said antenna.

28. The combination in a wireless signaling system of an insulated system of continuous aerial conductors, a plurality of vertical conductors each of which has one end connected to said continuous aerial system and the other end grounded, means for producing synchronous oscillating currents in all of the vertical conductors, and means for adjusting the phase relation of the currents in the different vertical conductors in such a way as to produce a directive radiation.

29. The combination in a wireless signaling system of an insulated system of continuous aerial conductors, a plurality of vertical conductors each of which has one end connected to said continuous aerial system and the other end grounded, means for producing synchronous oscillating currents in all of the vertical conductors, and means for adjusting the relative phases of the different oscillating currents so that the waves produced by these currents add accumulatively at points in a certain predetermined direction.

30. The combination in a wireless signaling system of an insulated system of continuous aerial conductors, a plurality of vertical conductors each of which has one end

connected to said continuous aerial system and the other end grounded, means for producing synchronous oscillating currents in all of the vertical conductors, and means for adjusting the relative phases of the different oscillating currents so that the interference effect of the waves produced creates a maximum amplitude in a desired direction and a minimum amplitude in another direction.

31. An antenna for a wireless signaling system comprising a long horizontal conductor insulated from the earth and having such natural constants that an electrical wave will travel along its length at a velocity less than the velocity of light, and means uniformly distributed along the length of said conductor for increasing the velocity at which an electrical wave will travel along the conductor.

32. An antenna for a wireless signaling system comprising a long horizontal conductor insulated from the earth and having such natural constants that an electrical wave will travel along its length at a velocity less than the velocity of light, and means uniformly distributed along the length of said conductor for increasing the velocity at which an electrical wave will travel along the conductor to a velocity at least equal to the velocity of light.

33. An antenna for a wireless signaling system comprising a long horizontal conductor insulated from earth and having such natural constants that an electrical wave will travel along its length at a velocity less than the velocity of light, and a plurality of inductances uniformly distributed along the length of the conductor and connected between the conductor and

earth for neutralizing a portion at least of the shunt capacity thereof and thereby increasing the velocity at which an electrical wave will travel along the conductor.

34. An antenna for a wireless signaling system comprising a long horizontal conductor insulated from earth and having such natural constants that an electrical wave will travel along its length at a velocity less than the velocity of light, and a plurality of inductances uniformly distributed along the length of the conductor and connected between the conductor and earth for neutralizing a portion at least of the shunt capacity thereof and thereby increasing the velocity at which an electrical wave will travel along the conductor to a velocity at least equal to the velocity of light.

35. An antenna for a wireless signaling system comprising a long horizontal conductor insulated from earth and having such natural constants that an electrical wave will travel along its length at a velocity less than the velocity of light, a plurality of inductances uniformly distributed along the length of the conductor and connected between the conductor and earth for neutralizing a portion at least of the shunt capacity thereof, and thereby increasing the velocity of the electrical wave in the conductor, and a plurality of inductances connected in series with said conductor between the different earth points for decreasing the velocity of the electrical waves in the conductor to a desired value.

In witness whereof, I have hereunto set my hand this 11th day of September, 1917.

ERNST F. W. ALEXANDERSON.

l)

A) The electrostatic capacity of the Bolinas array can be divided into two distinct categories:

- 1) That part of the electrostatic field confined between the elevated capacity and the ground plane:

$$C_c = 1.5 \times 10^{-8} \quad \text{farad} \quad 0.015 \text{ uFd}$$

- 2) That part of the electrostatic field which extends from the elevated capacity to space:

$$C_s = 3.5 \times 10^{-9} \quad \text{farad} \quad 3500 \text{ pFd.}$$

And therefore a total electrostatic capacity of:

$$C_o = 1.9 \times 10^{-8} \quad \text{farad}$$

With a ratio of:

$$C_s : C_c = 0.35.$$

And a transmission efficiency of:

$$C_s : C_o = 19 \text{ percent.}$$

B) The electrostatic potential is given as:

$$E_o = 100 \quad \text{kilovolts.}$$

With an angular velocity of:

$$1.2 \times 10^5 \quad \text{radians per second.}$$

Energy is supplied to this potential at a rate of:

$$P = 200 \quad \text{kilowatts.}$$

C) For a peak potential of 100 kilovolts, the two electrostatic fields are:

1) The confined field:

$$\Psi = 1.8 \times 10^{10} \quad \text{lines of force}$$

$$W = 32 \quad \text{watt-second}$$

2) And the transmitted field:

$$\Psi = 4.2 \times 10^9 \quad \text{lines of force}$$

$$W = 7 \quad \text{watt-second}$$

D) For potential variation of 1.2×10^5 radians per second, the power flow of the two electrostatic fields are:

1) Confined power flow:

$$P_c = 17 \times 10^6 \quad \text{volt-amperes}$$

$$X_c = 6 \times 10^2 \quad \text{sec. per farad (ohm)}$$

2) And the transmitted power flow:

$$P_s = 4.8 \times 10^6 \quad \text{volt-amperes}$$

$$X_s = 2 \times 10^3 \quad \text{sec. per farad (ohm)}$$

E) The total electric current transmitted into the earth is hence given:

$$I_o = 48 \quad \text{amperes}$$

With a transmission loss of 200 kilowatts and a corresponding electromotive force of:

$$E_o = 4200 \quad \text{volts}$$

F) For the entire array the total power flow is:

$$P = 21 \times 10^6 \quad \text{volt-amperes}$$

And for a dissipation rate of 200 kilowatts, the power multiplication factor is thus given:

$$\mathcal{P} = 100 \times \quad \text{dimensionless}$$

II) The entire array is divided into three distinct section elements: element 1 and element 2, and a third terminal element

A) The mid-section elements are of the following electrical dimensions:

1) Electrostatic capacity to space:

$$\begin{array}{lll} C_s = 1.4 \times 10^{-9} & \text{farad} & 1400 \text{ pFd} \\ P_s = 1.7 \times 10^6 & \text{volt-amperes} & \\ I_s = 17 & \text{amperes} & \\ X_s = 6 \times 10^3 & \text{sec. per farad} & 6K_{\Omega} \end{array}$$

2) Electrostatic capacity to ground:

$$\begin{array}{lll} C_c = 4.9 \times 10^{-9} & \text{farad} & 4900 \text{ pFd} \\ P_c = 5.6 \times 10^6 & \text{volt-amperes} & \\ I_c = 56 & \text{amperes} & \\ X_c = 1.8 \times 10^3 & \text{sec. per farad} & 1.8K_{\Omega} \end{array}$$

3) Electromagnetic inductance:

$$\begin{array}{ll} L = 1.3 \times 10^{-4} & \text{Henry} \\ X_L = 16 & \text{Henry/sec. (OHM)} \end{array}$$

4) The electro-motive force developed by the electromagnetic induction of the element half-section $L/2$ is given by the relation:

$$E_L / I_T = X \quad E = 550 \quad \text{volts}$$

And therefore, the power flow of this induction:

$$E_L \times I_T = \quad P = 40 \times 10^3 \quad \text{volt-amperes}$$

And thus the ratio of magnetic to electrostatic power flow is:

$$P_L : P_O = 40:7300 = 1.5 \text{ percent}$$

B) Having derived the electromagnetic and the electrostatic coefficients of the elemental sections, the electromagnetic propagation coefficients are thus:

Z_c = transmission impedance of confined electromagnetic wave

$$Z_c = 173 \text{ ohm}$$

Z_s = transmission impedance of un-confined electromagnetic wave

$$Z_s = 316 \text{ ohm}$$

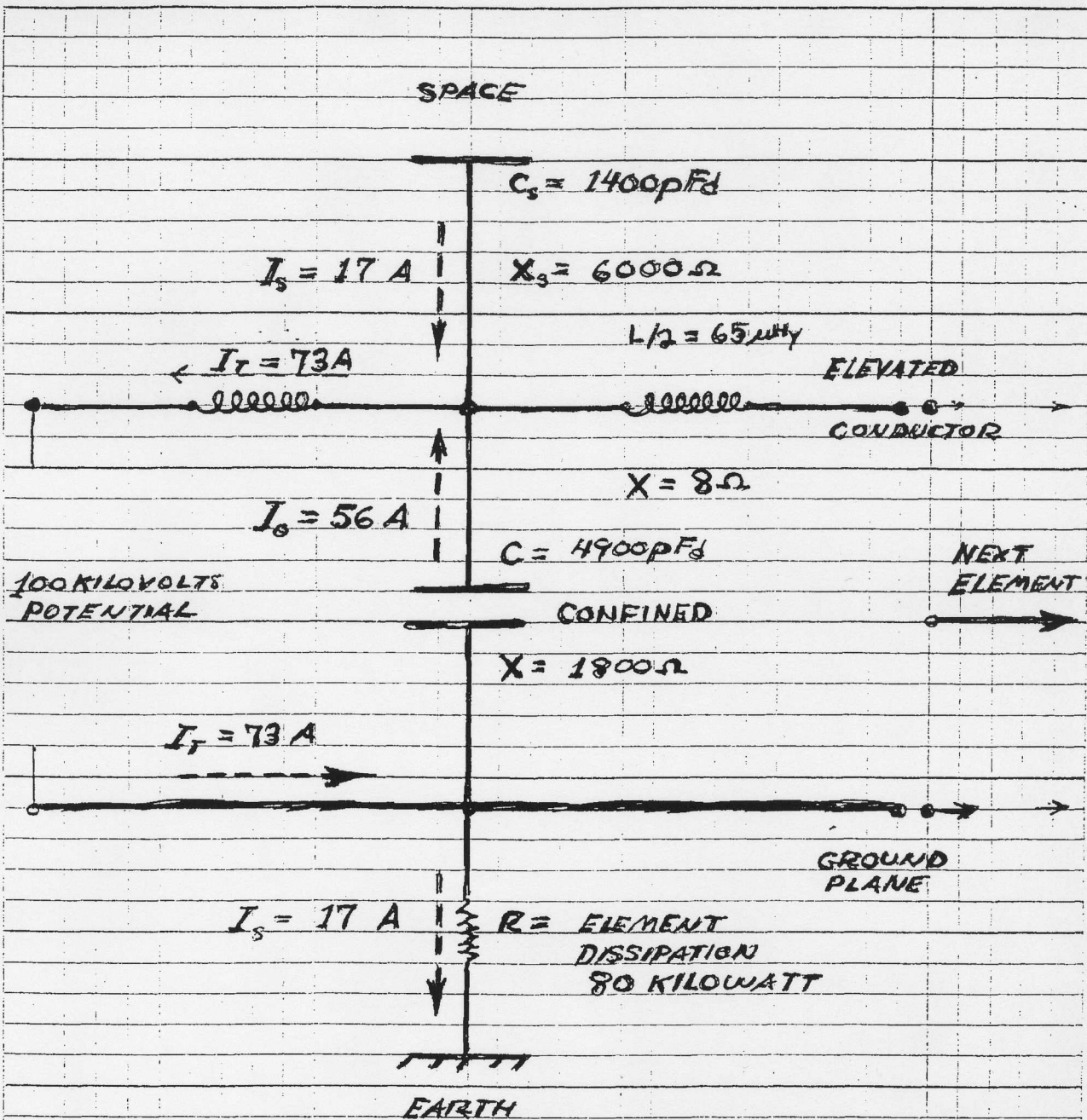
And likewise:

V_o = transmission velocity of confined propagation

$$V_o = 3 \times 10^{10} \text{ cm./sec.}$$

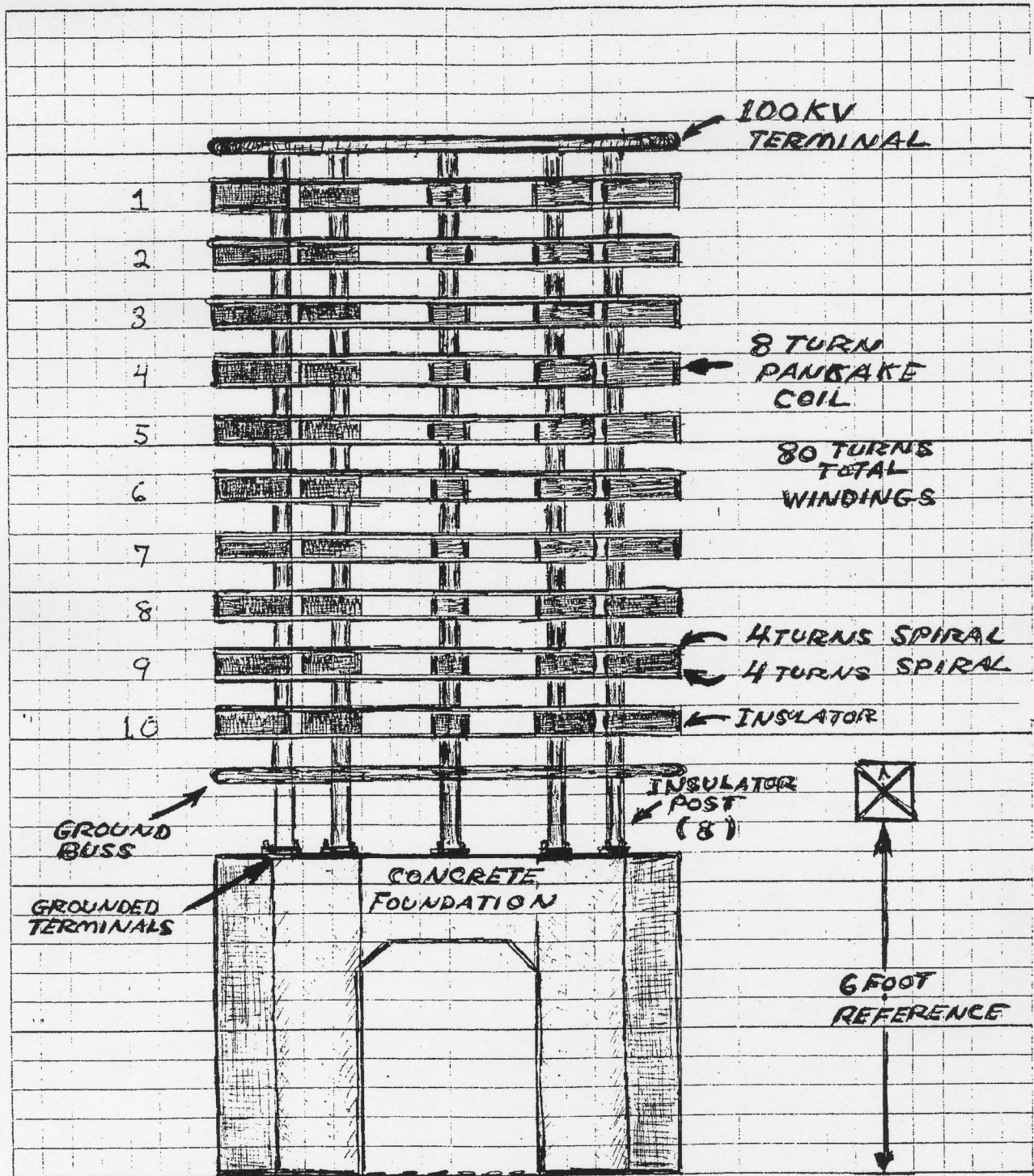
V_s = transmission velocity of un-confined propagation

$$V_s = 5.6 \times 10^{10} \text{ cm./sec.}$$



EQUIVALENT CIRCUIT
OF ELEMENTAL
SECTION OF BOLINAS
ALEXANDERSON ARRAY

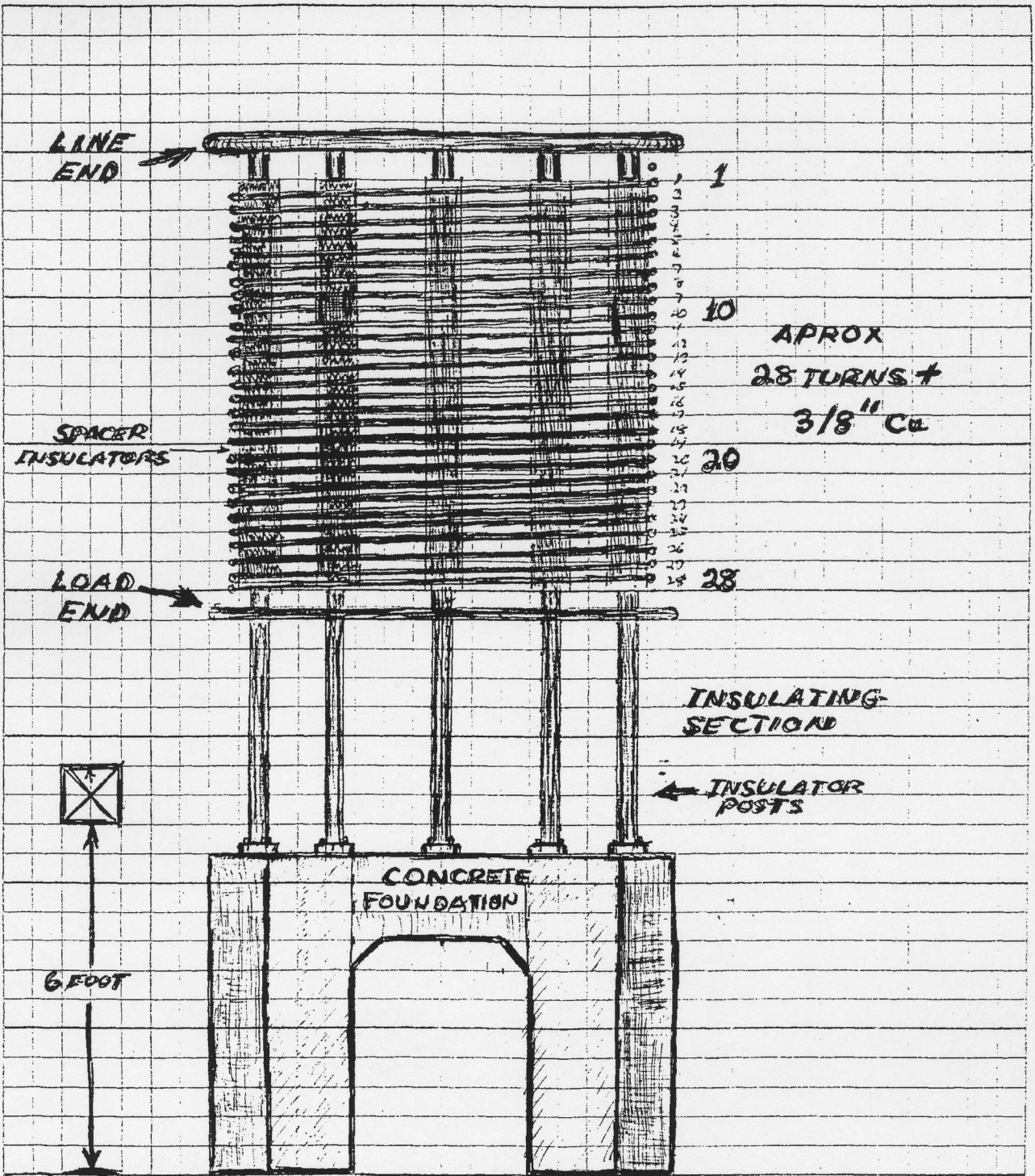
9-3 Equivalent Circuit of Elemental Section of Bolinas Alexanderson Array



**ALEXANDERSON
POTENTIAL (SHUNT)
COIL ARRANGEMENT**

SCALE APPROXIMATE

9-5 Alexanderson Potential (Shunt) Coil Arrangement

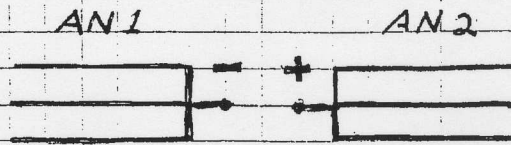


**ALEXANDERSON
CURRENT (SERIES)
COIL ARRANGEMENT**

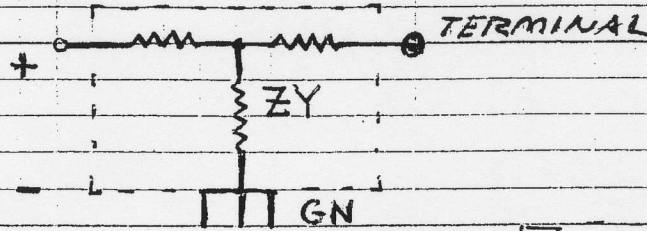
SCALE APPROXIMATE

9-6 Alexanderson Current (Series) Coil Arrangement

ARCH TYPICAL WIRELESS SYSTEMS



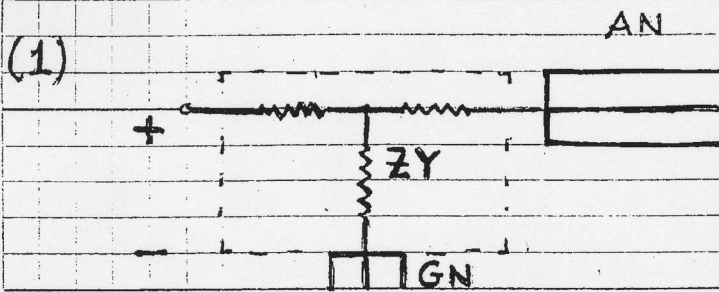
HERTZ



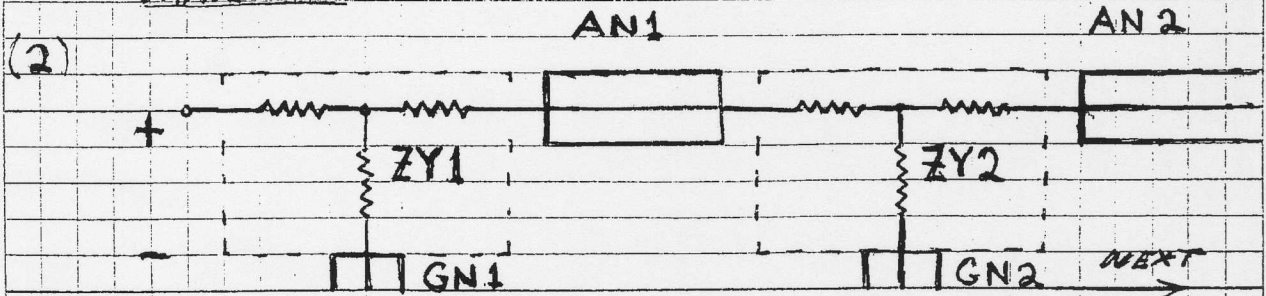
TESLA

GN, GROUND WIRES
AN, ANTENNA WIRES
ZY, TRANSFORMER
+-, INPUT

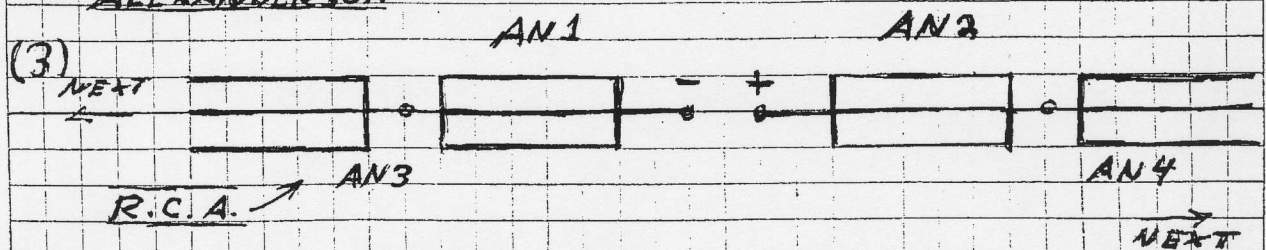
DERIVATIVE SYSTEMS



MARCONI



ALEXANDERSON

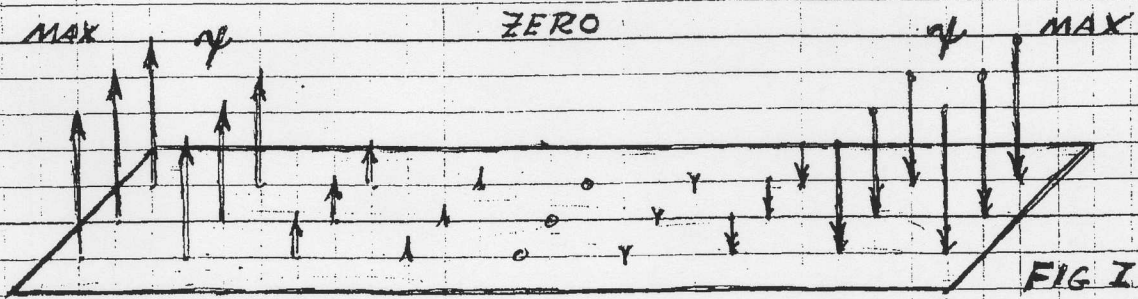


R.C.A.

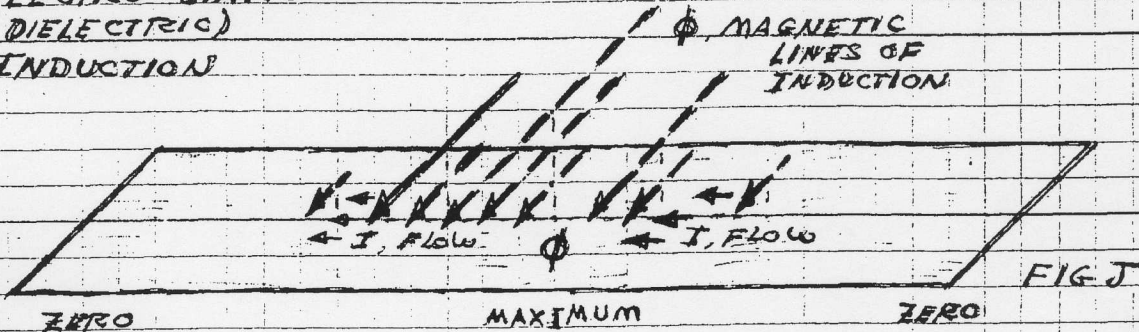
9-7 Archtypical Wireless Systems (2 diagrams) and Derivative Systems (3 diagrams)

ELECTRO-MAGNETIC RADIO ANTENNAE

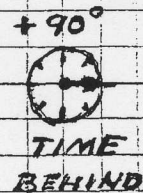
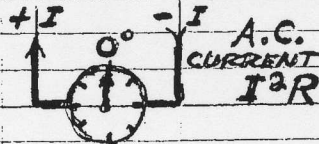
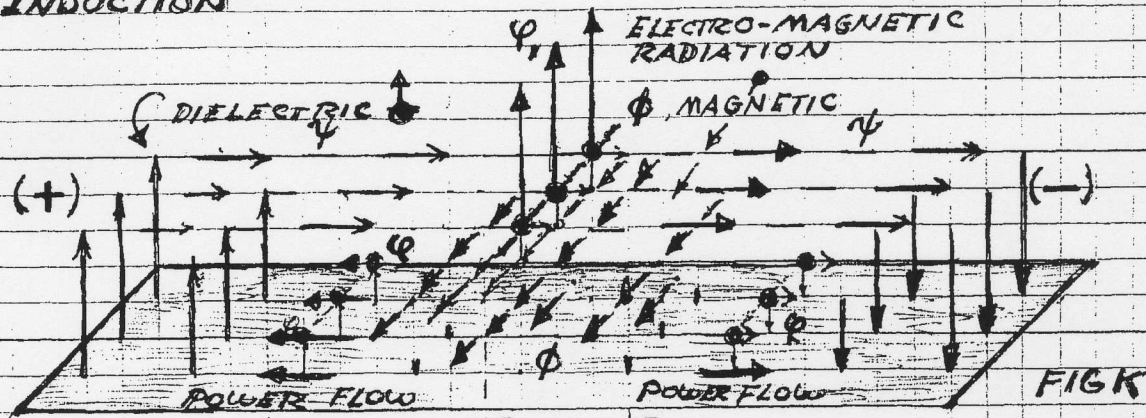
← ONE HALF WAVELENGTH →



ELECTRO-STATIC
(DIELECTRIC)
INDUCTION



MAGNETIC
INDUCTION

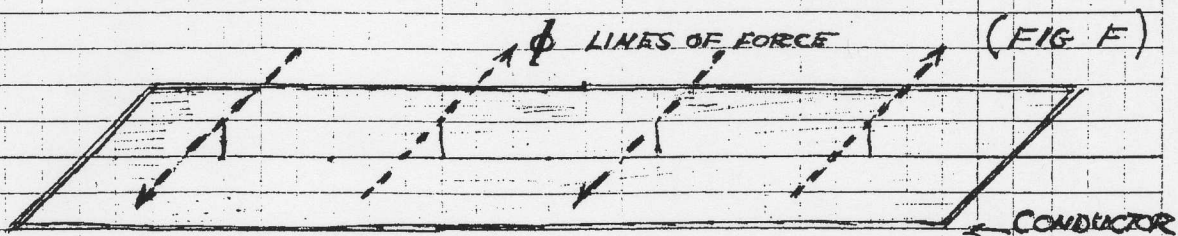


← 180° →

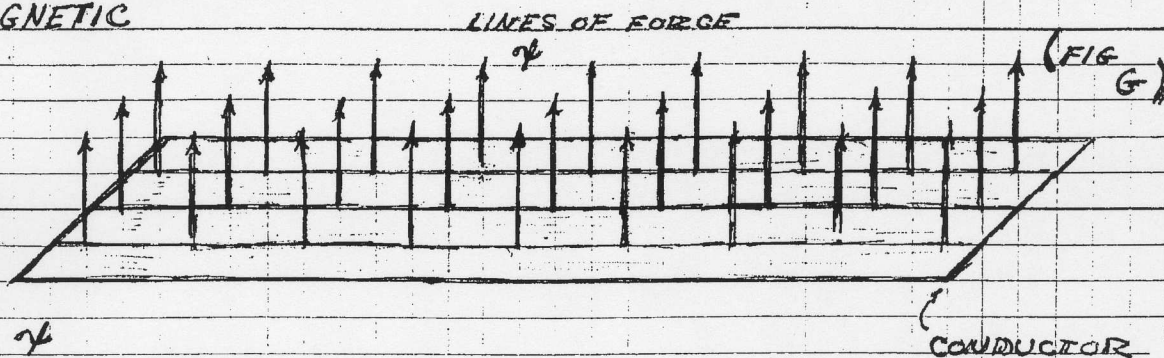
ELECTRO-MAGNETIC RESULTANT
RADIATION & POWER FLOW

ψ DIELECTRIC
 ϕ MAGNETIC
 ψ ELECTRO-MAGNETIC

ELECTRO-STATIC ANTENNAE (NO WAVELENGTH)

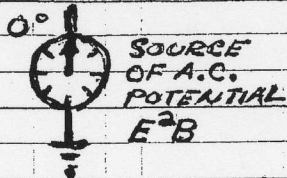
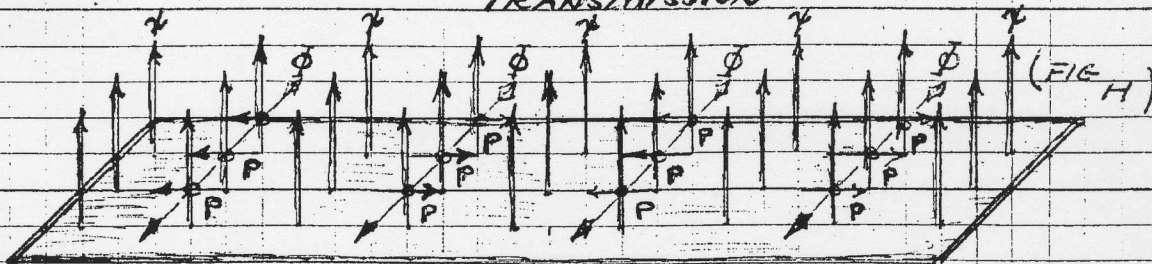


ϕ
MAGNETIC



ψ
DIELECTRIC

ELECTRO-STATIC TRANSMISSION



COMPOSITE
ELECTRIC FIELD
& POWER FLOW

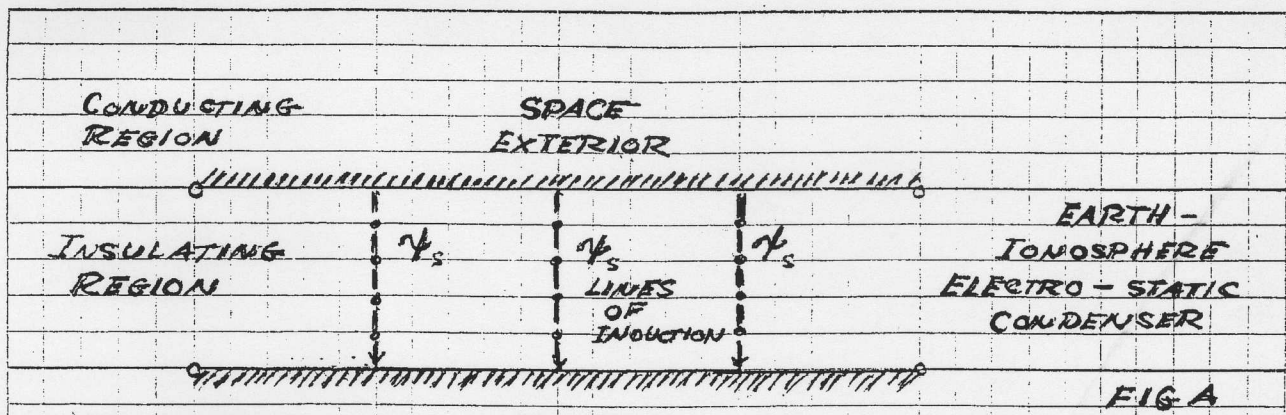


FIG A

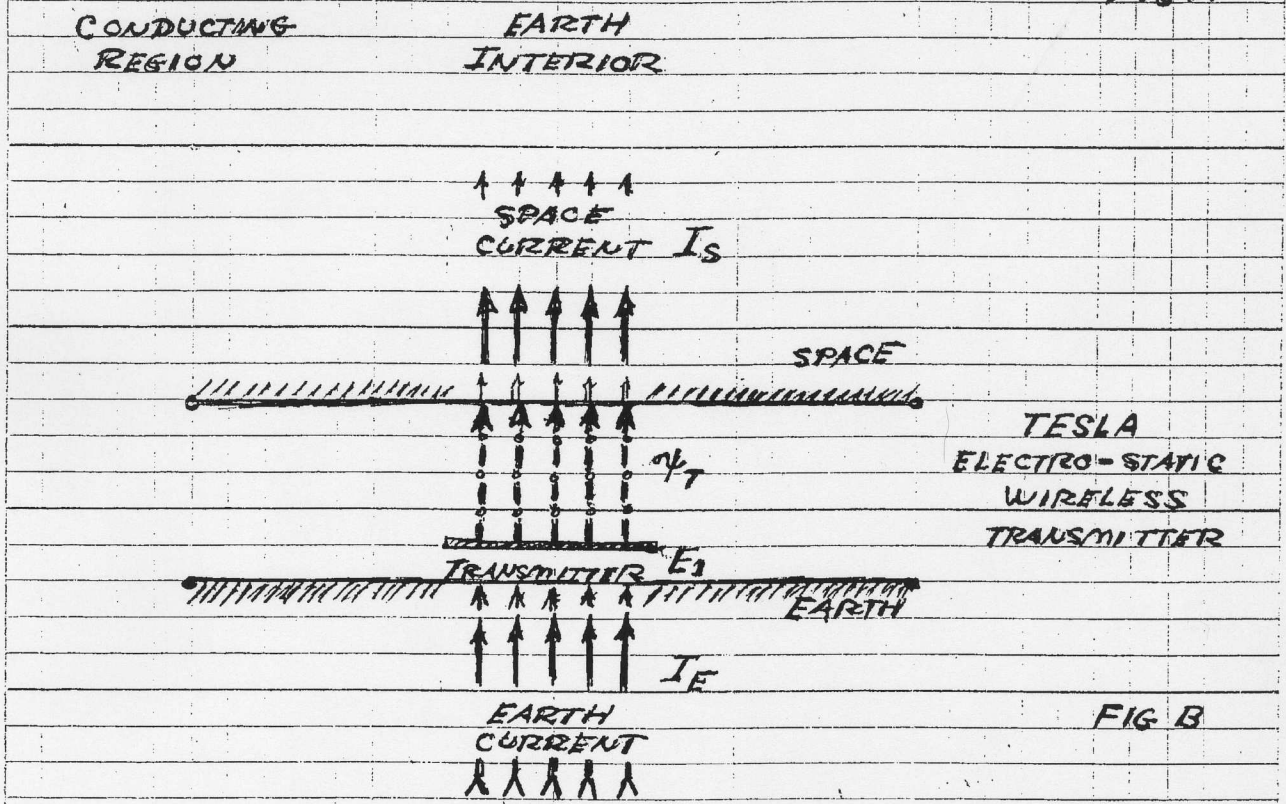


FIG B

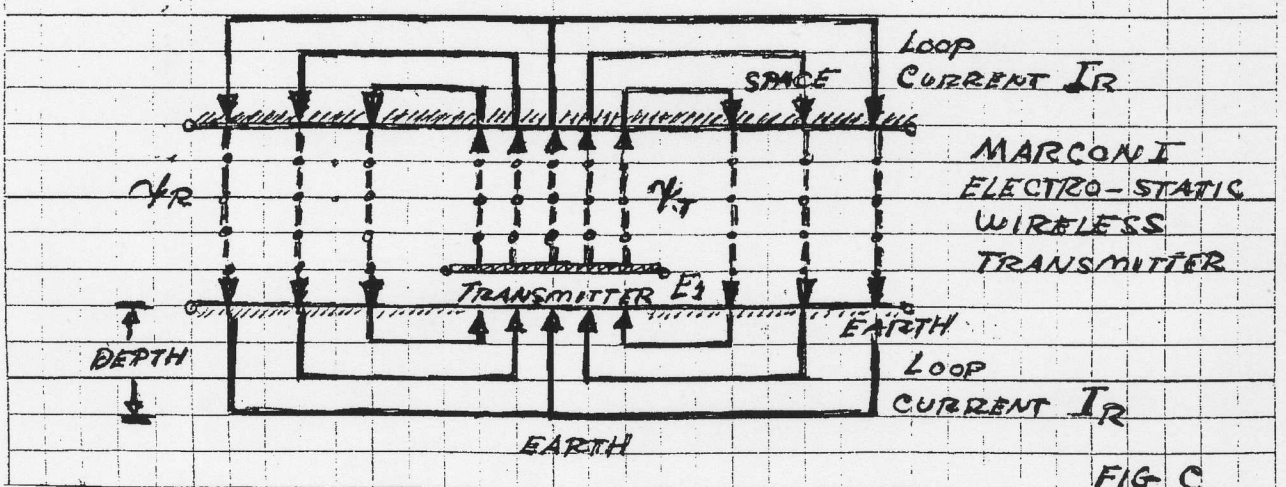
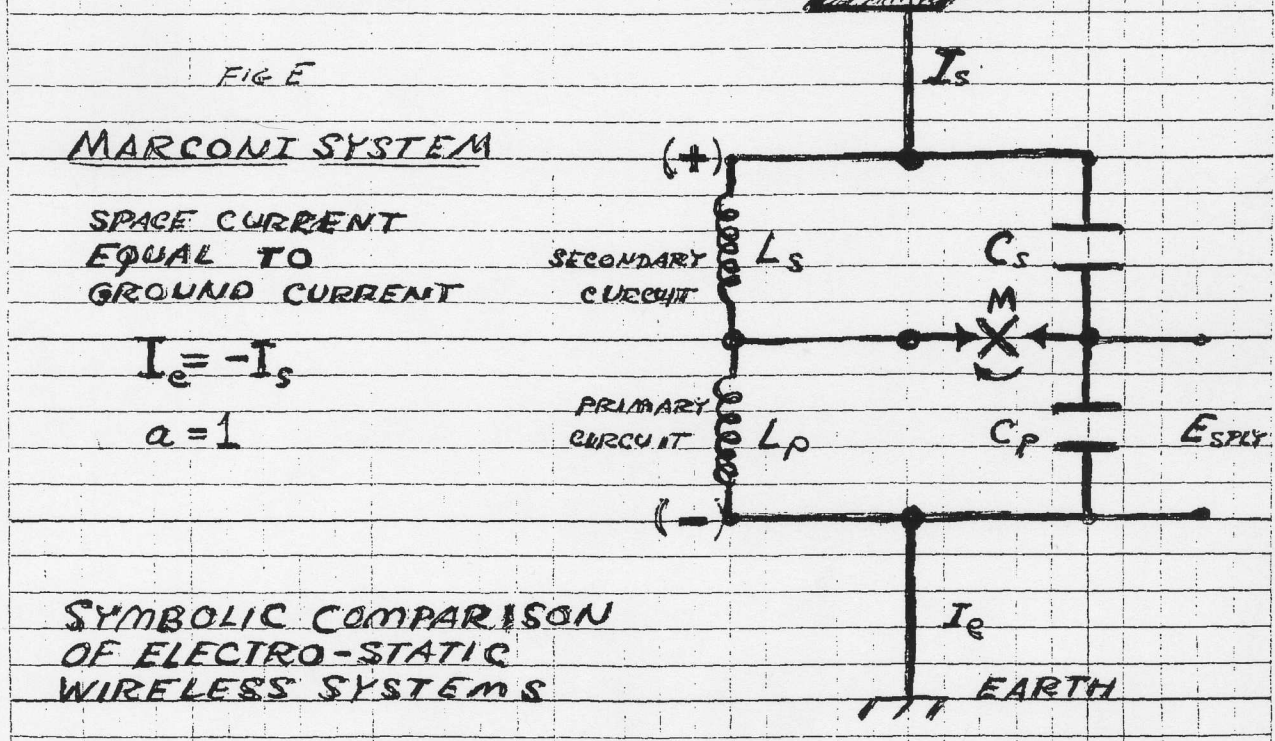
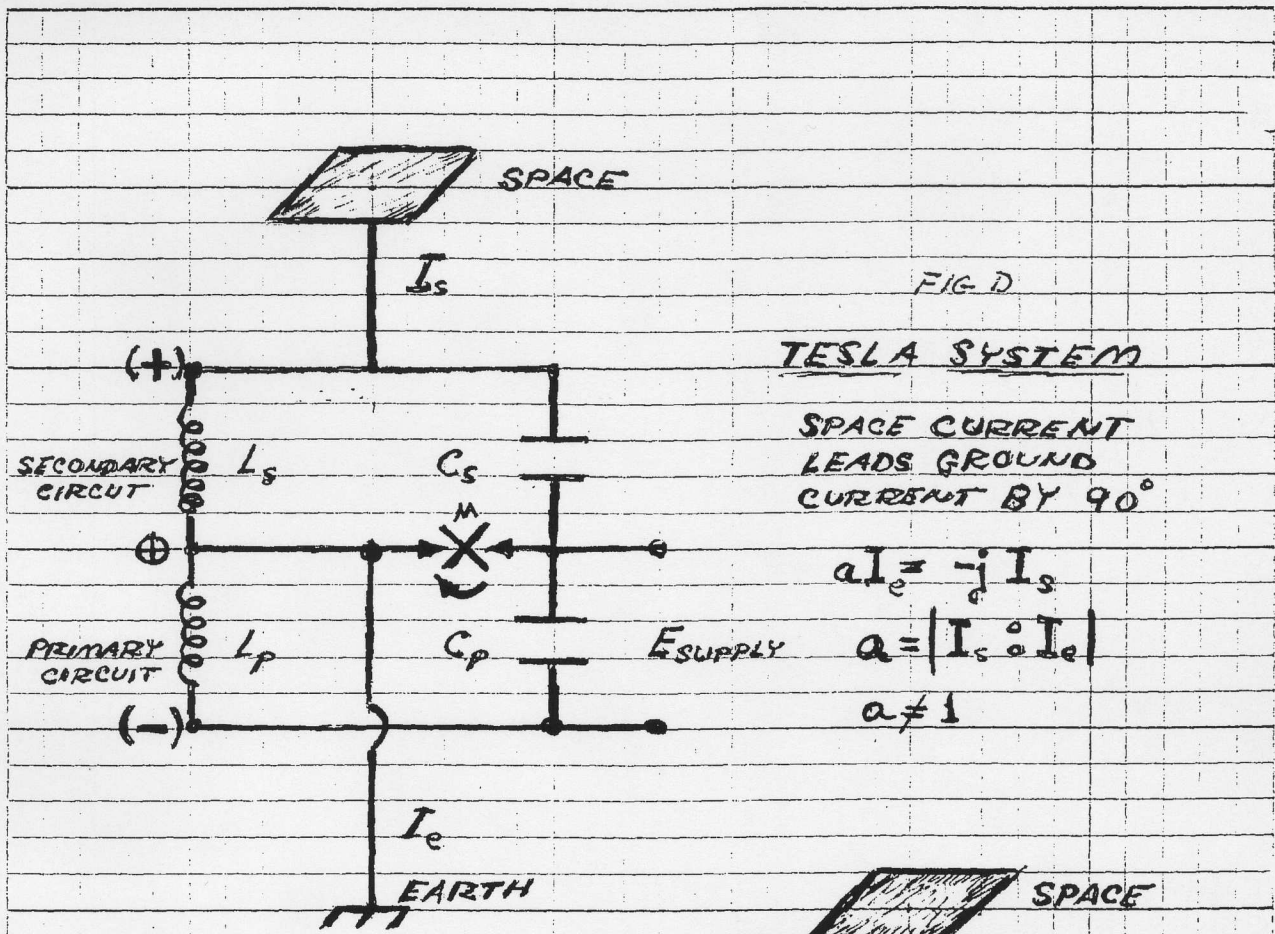


FIG C

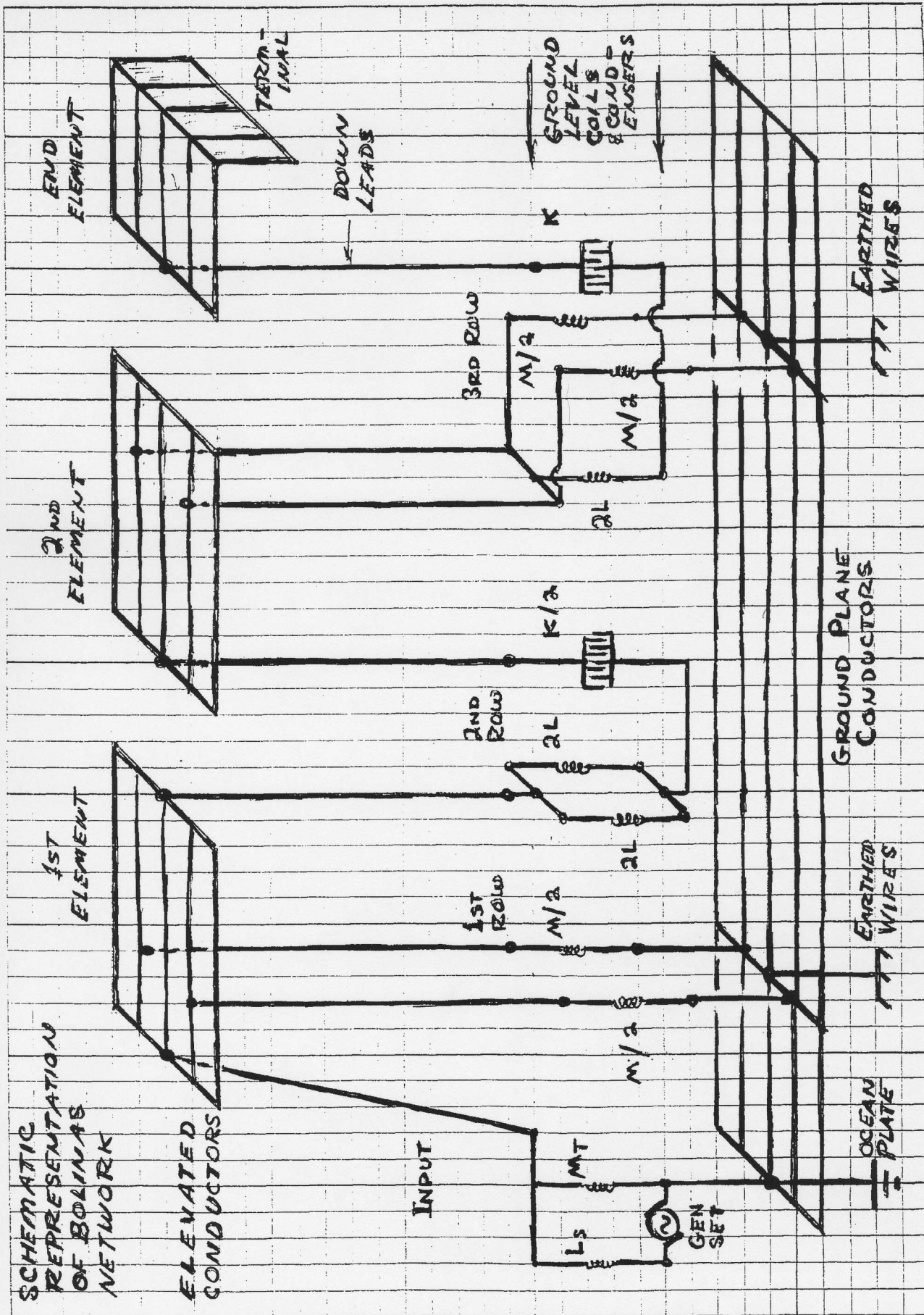
9-8 Three diagrams: "Earth-Ionosphere Electro-Static Condenser." (Fig. A); "Tesla Electro-Static Wireless Transmitter." (Fig. B); & "Marconi Electro-Static Wireless Transmitter" (Fig. C).



SYMBOLIC COMPARISON
OF ELECTRO-STATIC
WIRELESS SYSTEMS

TESLA VS MARCONI

L, COIL
C, CONDENSER
M, CHOPPER (BREAK)



9-12 Schematic Representation of Bolinas Network

**ALEXANDERSON -
ELEMENTARY DIAGRAM**

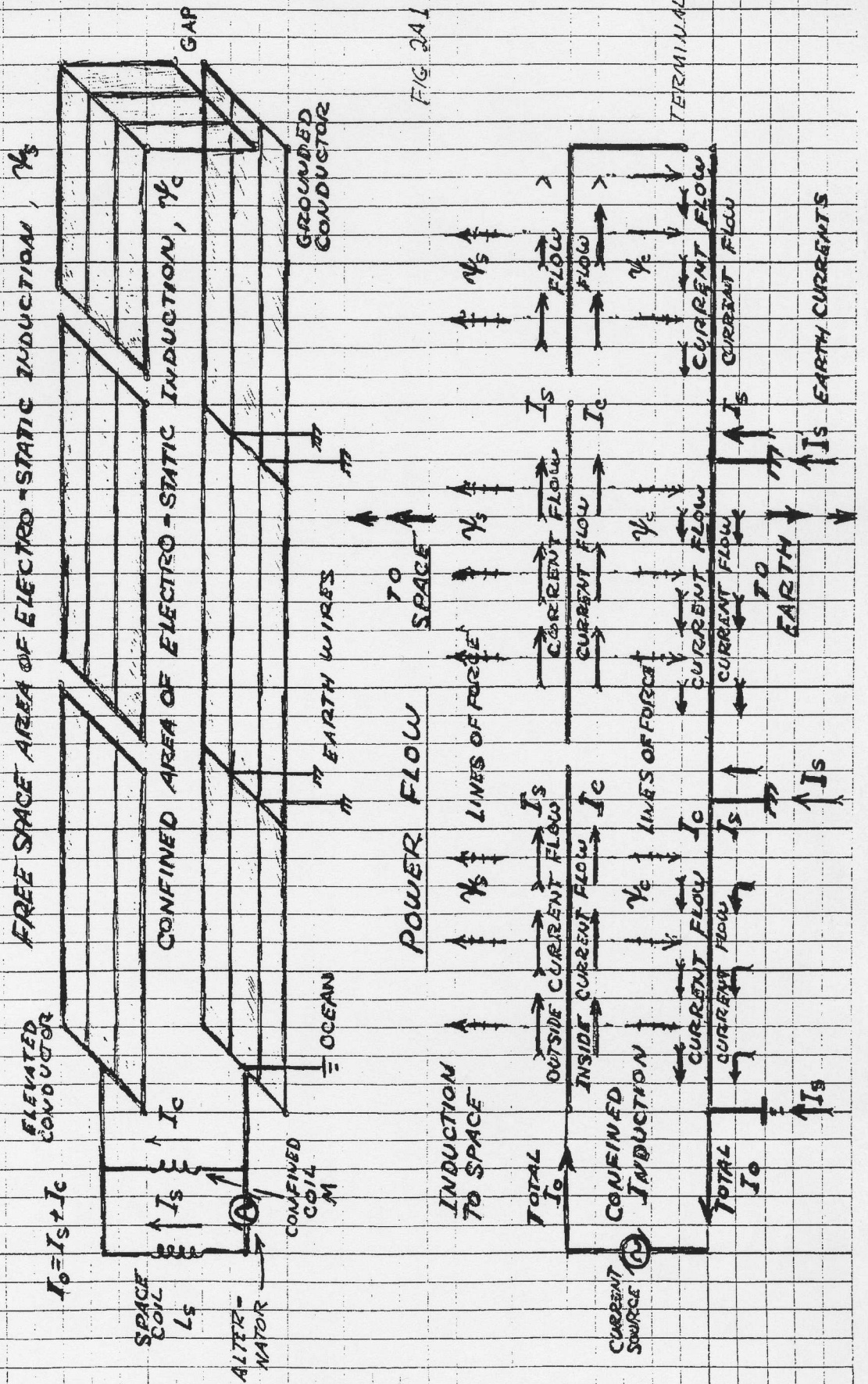


FIG 2A1

XIII FIRST EXPERIMENTAL SCALE MODEL OF
ALEXANDERSON ANTENNA NETWORK

a) SCALE $\alpha = 0.01$, POWER

$\alpha^{1/2} = 0.10$, E.M.F. & CURRENT

LENGTH 2700 FT $\alpha = 27$ FT

EACH ELEMENT 720 FT $\alpha = 7.2$ FT $l_1 = 86$ INCH

WIDTH 240 FT $\alpha = 2.4$ FT $w = 28$ INCH

HEIGHT 300 FT $\alpha = 3.0$ FT $h = 36$ INCH

FREQ 19 KC/SEC $\alpha = 1900$ KC

COIL HEIGHT 8 FT $\alpha^{1/2} = 10$ INCH $l_0 = 10$ INCH

COIL DIAM. 6 FT $\alpha^{1/2} = 7$ INCH $d = 7$ INCH

$M = 15$ mHy, $1800 \Omega = 150$ μ Hy, 1800Ω

$\frac{1}{2}M = 30$ mHy, $3600 \Omega = 300$ μ Hy, 3600Ω

$L_s = 20$ mHy, $2400 \Omega = 200$ μ Hy, 2400Ω

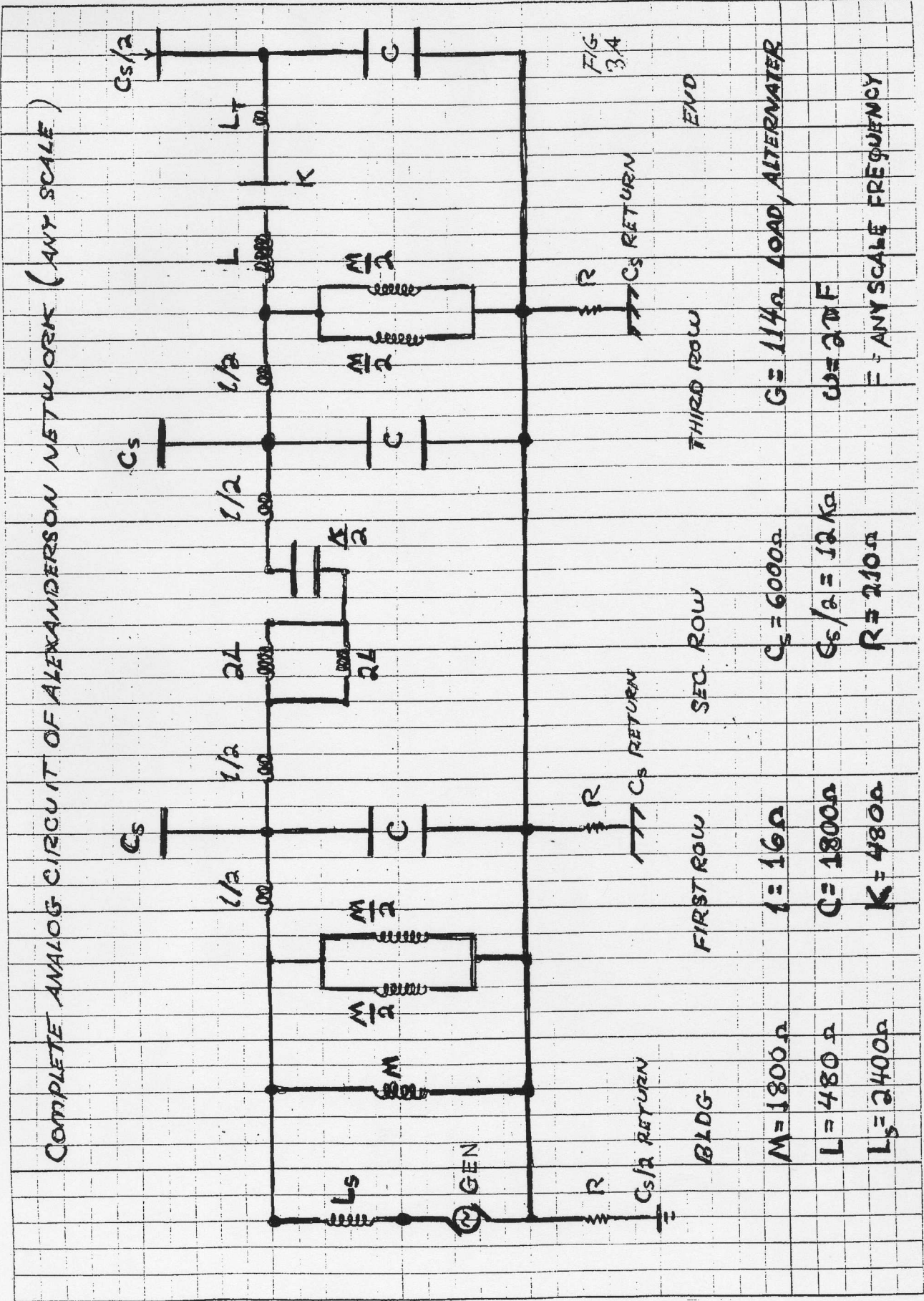
$L = 4$ mHy, $480 \Omega = 40$ μ Hy, 480Ω

$K = 0.018$ μ Fd, $480 \Omega = 180$ pFd, 480Ω

$\omega = 1.2 \times 10^5$ RAD/SEC 1.2×10^7 RAD/SEC

9-13 First Experimental Scale Model of Alexanderson Antenna Network

COMPLETE ANALOG CIRCUIT OF ALEXANDERSON NETWORK (ANY SCALE)

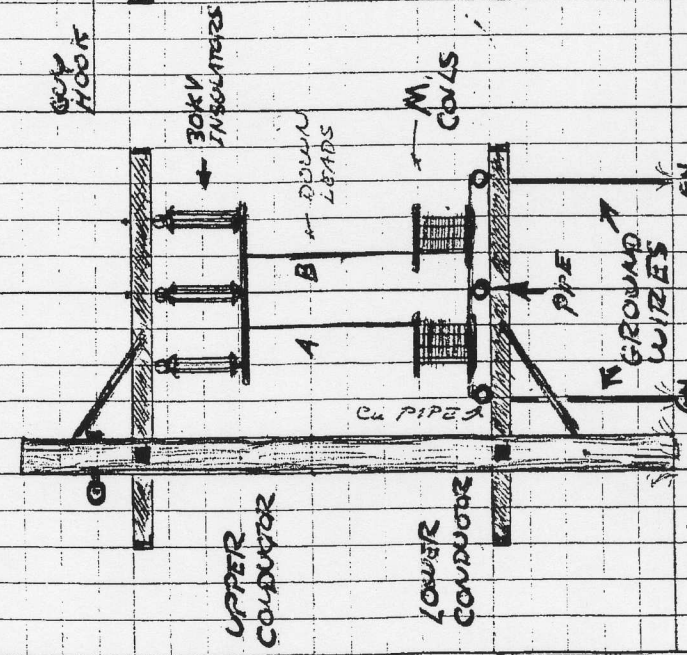


9-4 Complete Analog Circuit of Alexanderson Network (any scale)

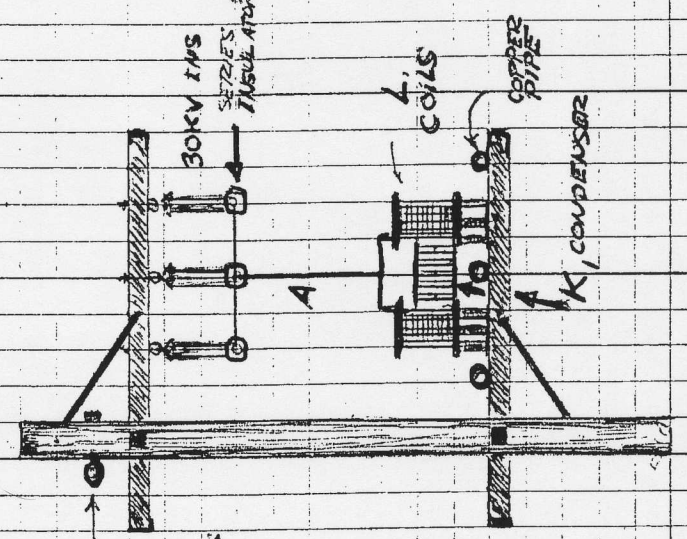
1900 Kc/sec (1:100 SCALE MODEL)
 MODEL NETWORK, COIL SCALE
 (12 FOOT POLES, 6 FOOT CROSS ARMS)

$Q = 0.01$ RATIO
 $NAL = 0.10$ RATIO

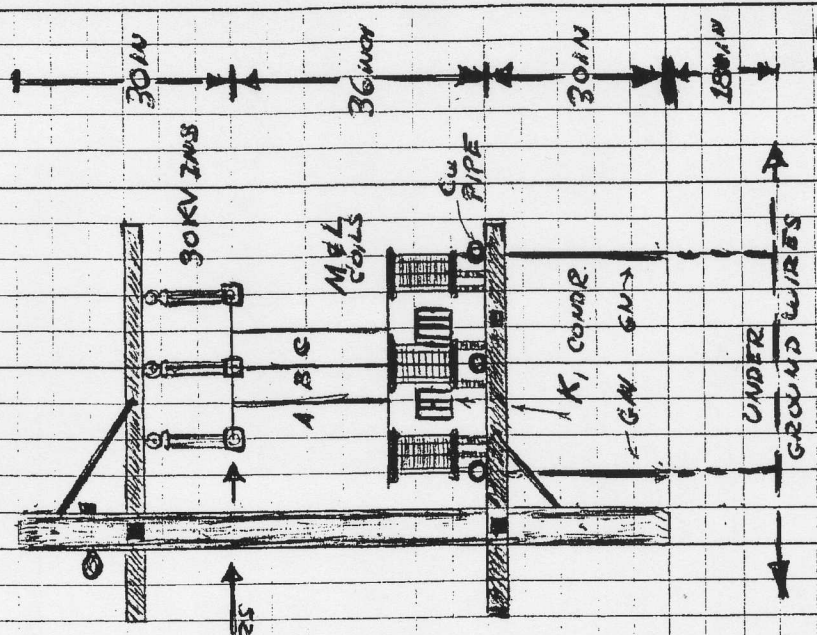
FIRST ROW
 POLE STRUCTURE



SECOND ROW
 POLE STRUCTURE



THIRD ROW
 POLE STRUCTURE



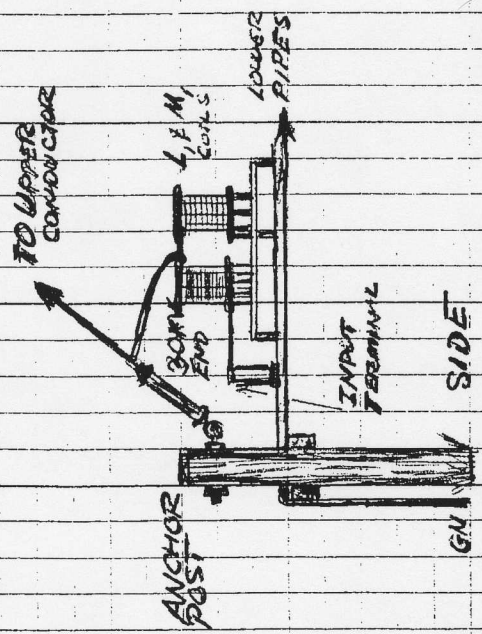
ALL COILS 6" X 10" HEIGHT

FIG 3B

1900 Kc/SEC
MODEL NETWORK

1:100 = a
COILS = \sqrt{a}

6 INCH
SQUARE



INPUT
END

ANCHOR POST

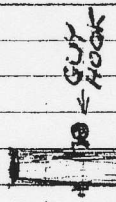
INPUT TERMINAL

30K END

TO UPPER CONDUCTOR

4 X 1/4 COILS

LOWER PIPES

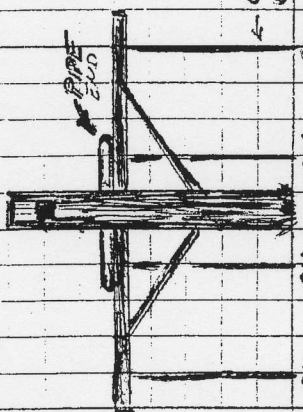


SIDE

DEAD END
30K INSULATORS

DOUBLE ARM

TERMINAL
END

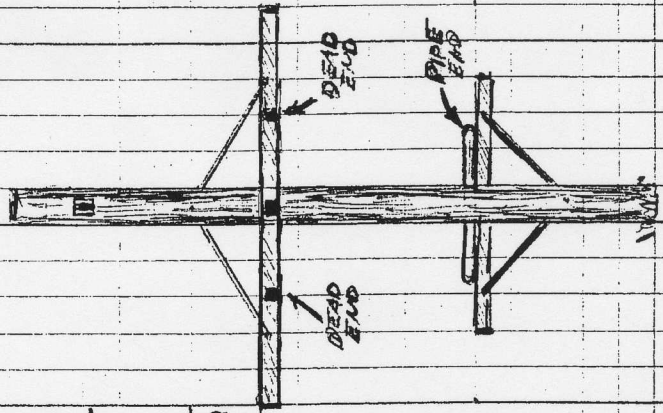


BACK

GROUND WIRES

PIPE END

PIPES



BACK

DEAD END

PIPE END

UNDER GROUND
WIRES NO. 8, 60K

GN GN GN GN

9-15 1900 Kc/sec Model Network, Input End and Terminal Ends

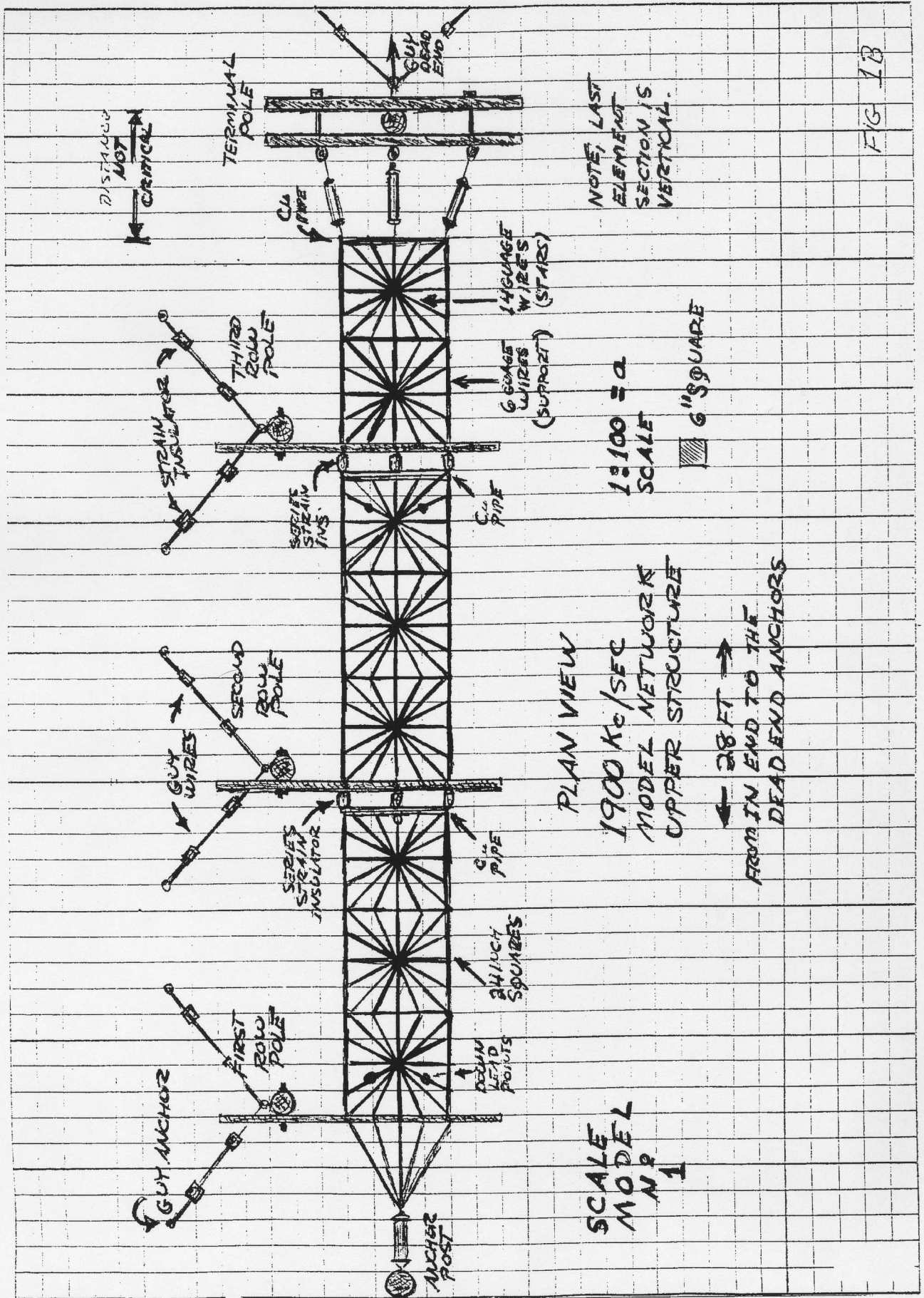


FIG 1B

9-16 1900 Kc/Sec Model Network, Upper Structure (plan view)

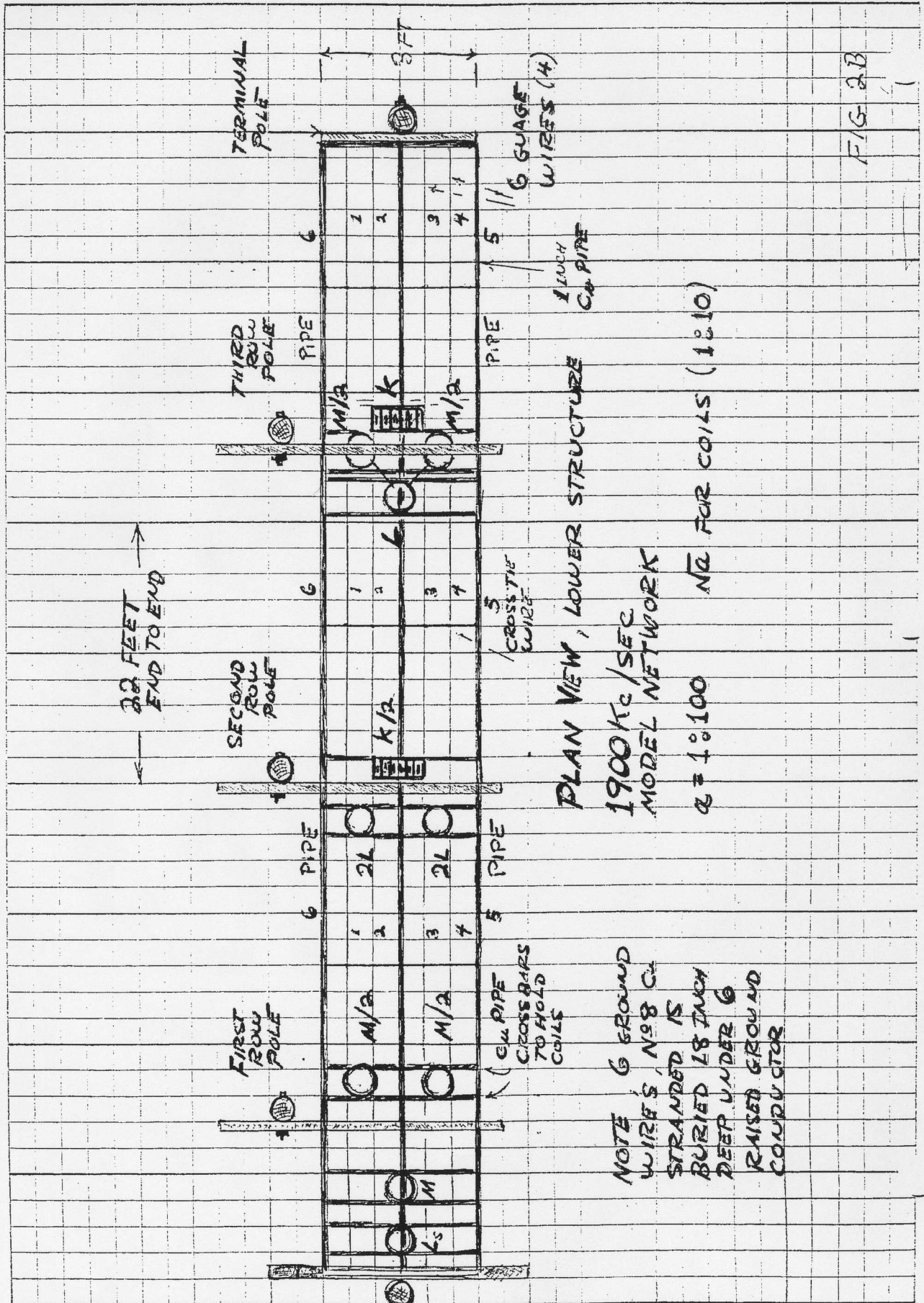
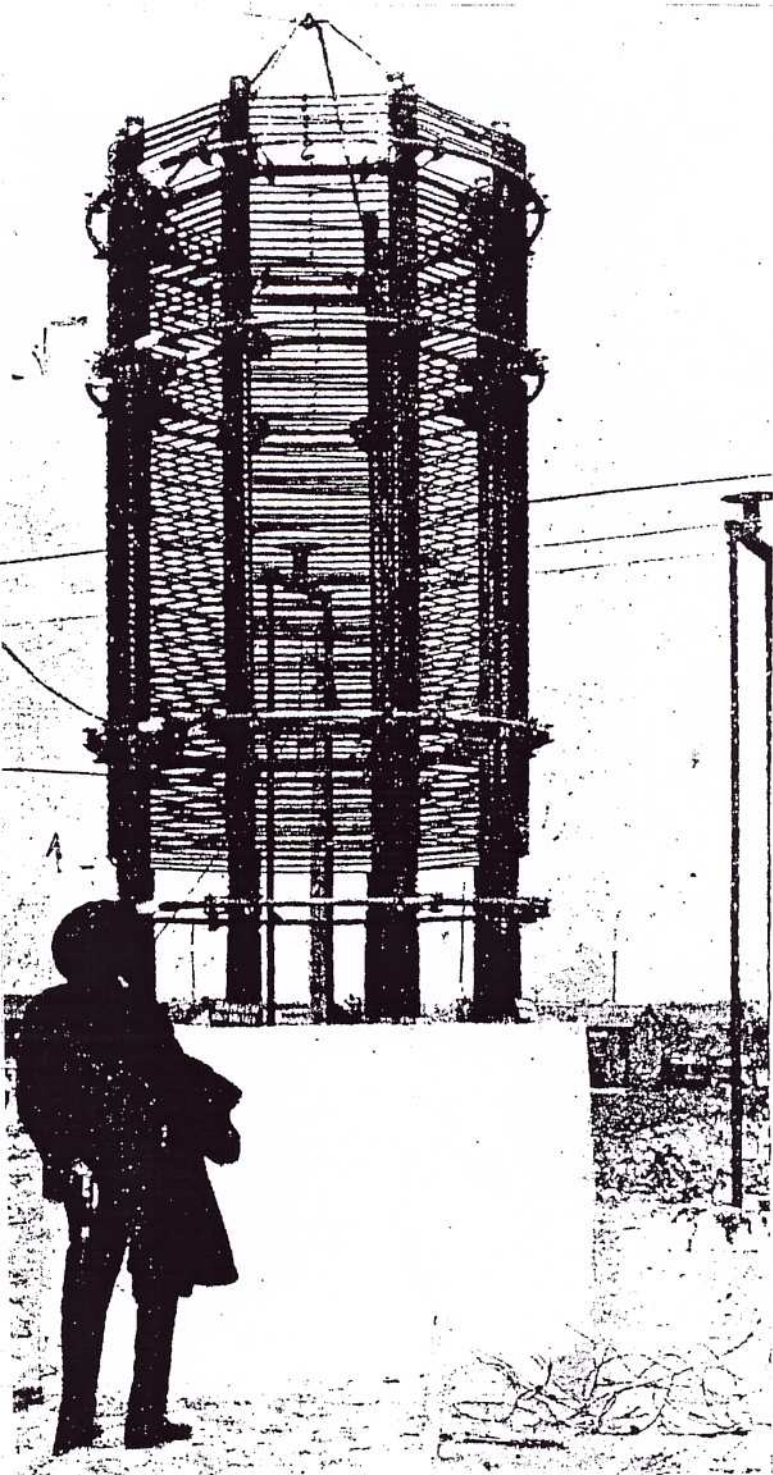
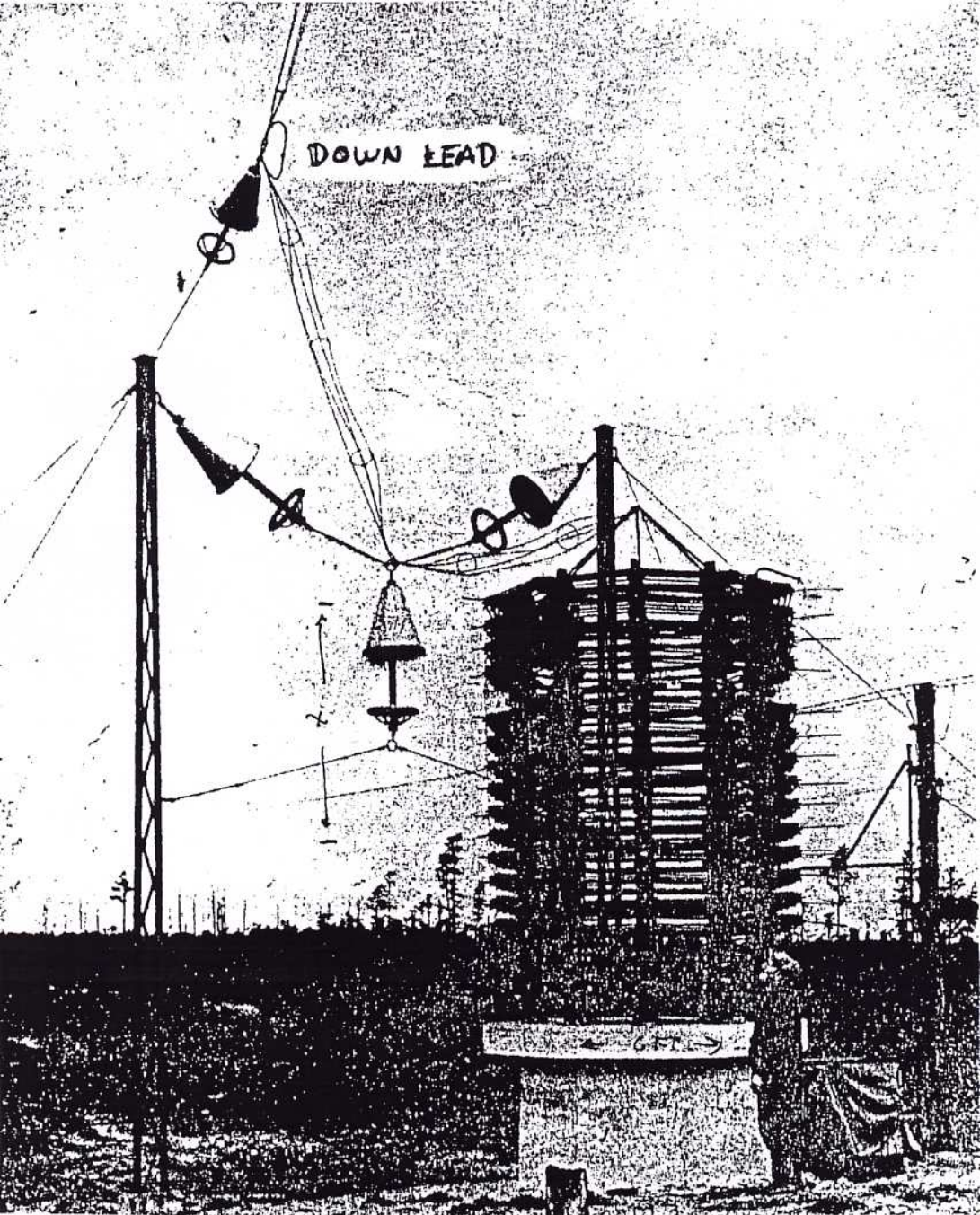


FIG. 2B

9-17 1900 Kc/sec Model Network, Lower Structure (plan view)



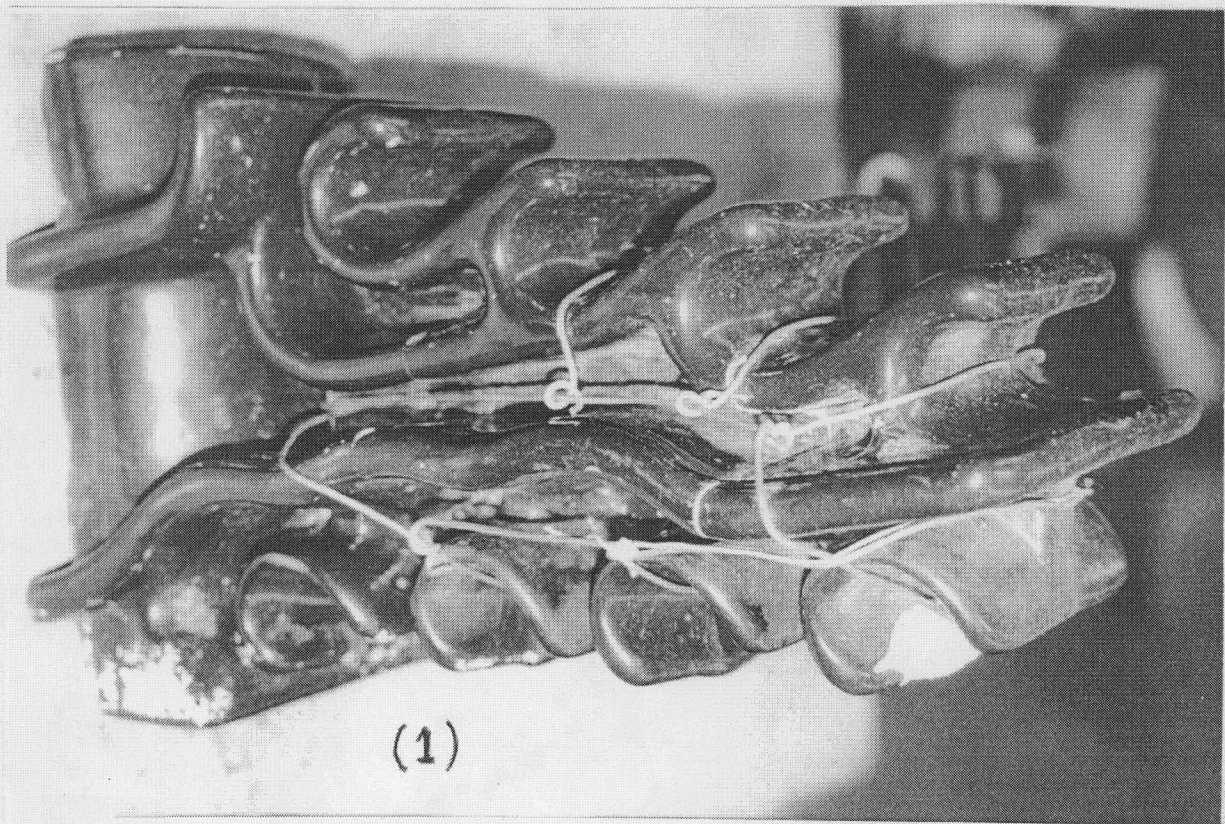
8-29 Series Coil (photo no. 2)



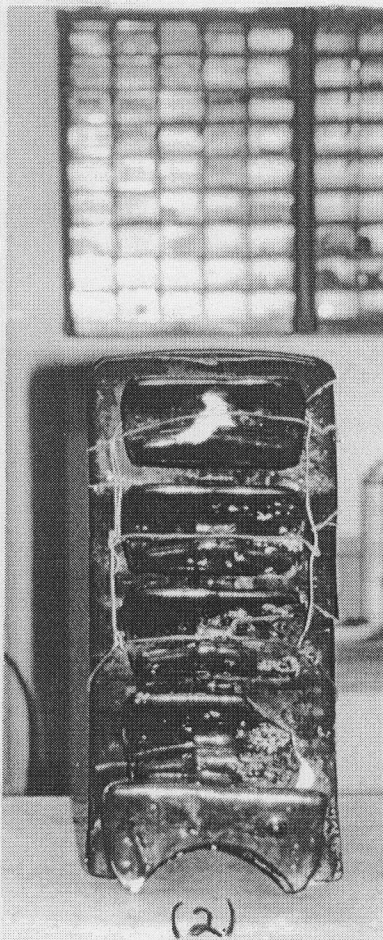
DOWN LEAD

← 647.5 →

8-30 Shunt Coil

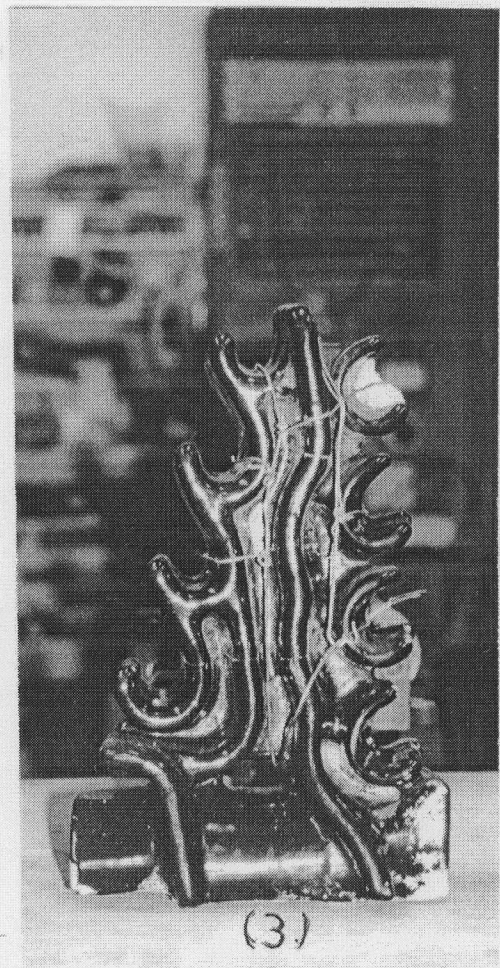


8-48 Shunt Coil Insulator, as mounted (EPD fig. 22-1)



SHUNT
COIL
INSULATOR
1) AS MOUNTED
2) TOP VIEW
3) SIDE VIEW

FIG 22



8-49 Shunt Coil Insulator, top view (EPD fig. 22-2)

8-50 Shunt Coil Insulator, side view (EPD fig. 22-3)

