

Nov. 2, 1965

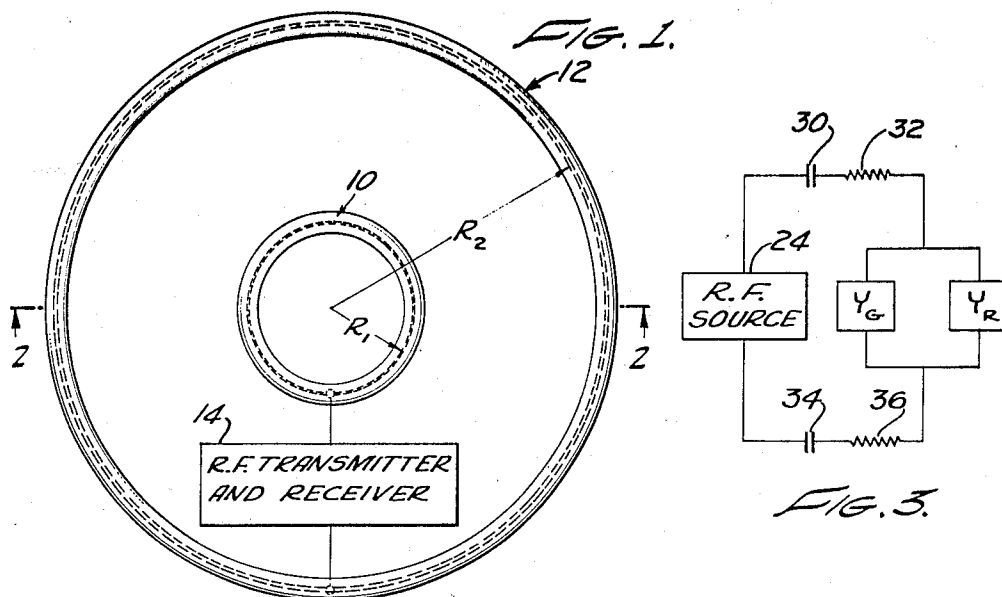
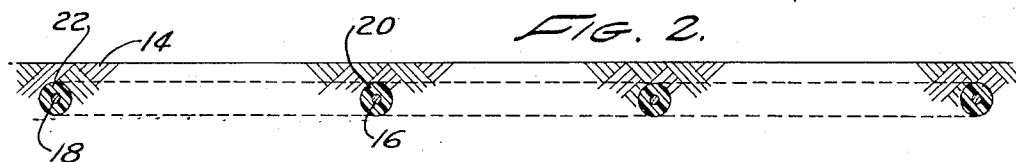
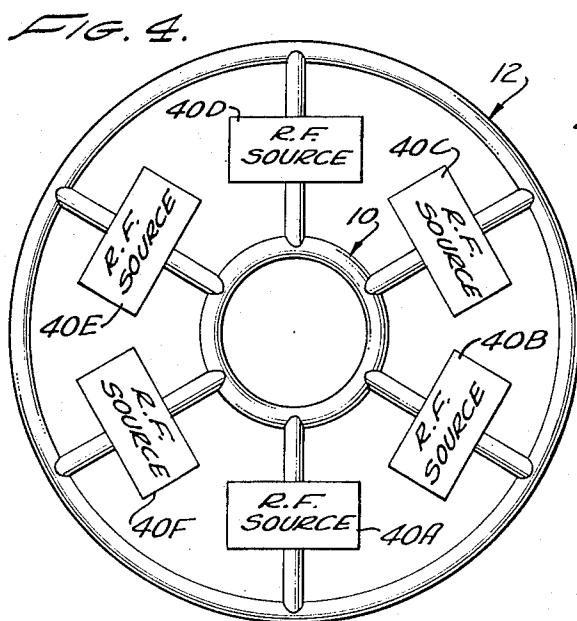
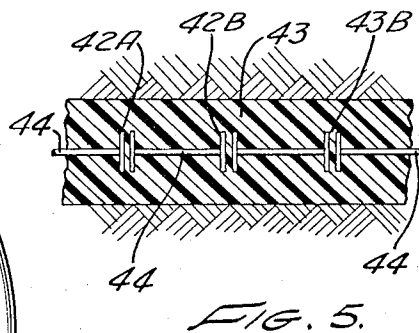
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3,216,016

BURIED INNER AND OUTER LOOP CONDUCTORS FORMING ANNULUS
PRODUCING RADIATION IN PLANE OF ANNULUS

Filed Aug. 9, 1962

2 Sheets-Sheet 1

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2 Sheets-Sheet 2

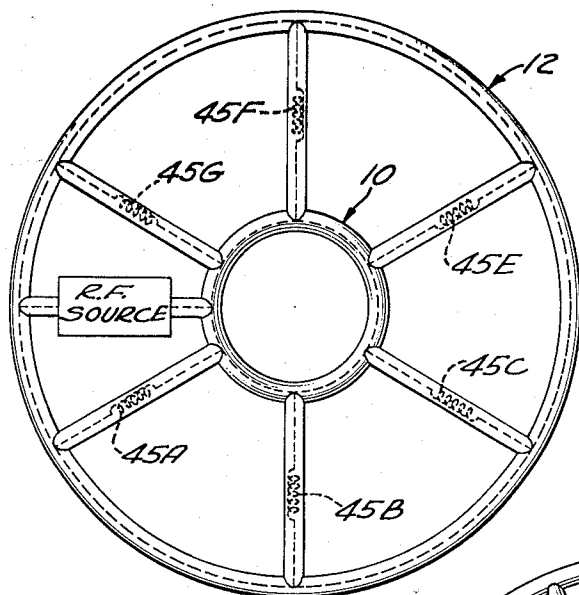


FIG. 6.

FIG. 7.

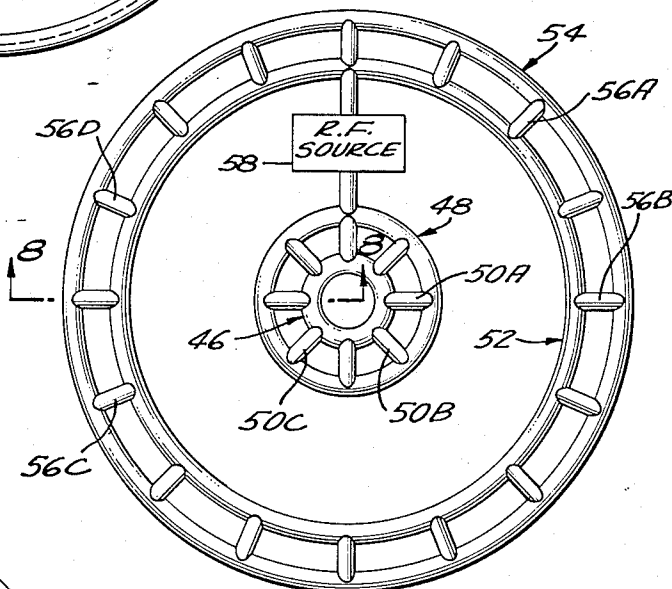
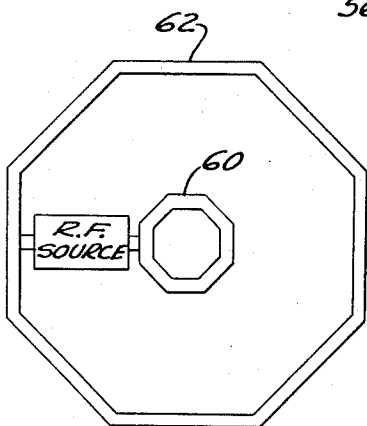


FIG. 9.

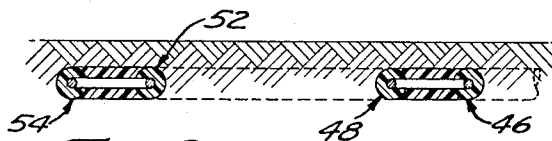


FIG. 8.

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BURIED INNER AND OUTER LOOP CONDUCTORS FORMING ANNULUS PRODUCING RADIATION IN PLANE OF ANNULUS

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Radiofrequency transmitting and receiving antennas, as is commonly known, are placed on towers. The realization has arisen, however, that in the presence of an explosion, both towers and antennas can be destroyed. In order to insure that urgent communications are maintained, it has been proposed that the antennas be buried in the earth, which can serve as a blast shield. This has been done, but, as was to be expected, the efficiency of the antenna system is tremendously reduced. Another problem that arises with buried antennas is that, when it is desired to operate using frequencies on the order of hundreds of kilocycles, the size of the antenna is substantial. Thus, in order to bury an antenna which is to transmit in this frequency range, a considerable amount of digging in the ground is required, and, further, a considerable amount of real estate must be acquired in which the antenna has to be buried.

An object of this invention is the provision of a buried antenna which has a higher efficiency than theretofore achievable.

Another object of this invention is the provision of a buried antenna which is cheaper to install than previous types of buried antennas.

Yet another object of the present invention is the provision of a novel buried antenna.

Still another object of the present invention is the provision of an efficient buried antenna which is substantially inexpensive.

These and other objects of the invention may be achieved by buying two closed-loop conductors which are substantially concentric with one another. By the term "loop" is meant that the geometrical shape of the conductors may be circular or polygonal, but, in all cases, is substantially regular in form. The concentric loops are buried in the earth at a predetermined depth. This depth should be the minimum required for obtaining the desired blast protection, since the deeper in the earth the antenna is buried the more the antenna signal is attenuated. Furthermore, this depth should be small when compared to the depth of skin penetration in the earth of the radiofrequency which is to be employed to excite the antenna.

Each one of the antenna loops will comprise a central conductor, surrounded by dielectric material having a thickness which is large relative to the diameter of the central conductor. The difference between the radius of the outer loop and the radius of the inner loop should be very much larger than the indicated skin depth. The loop structures are made so that when excited substantially no phase difference occurs around the loop. This antenna structure, when excited, provides an annular current sheath in the earth, which radiates signals into free space in the manner that a slot antenna radiates signals into free space.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention itself, both as to its organization and method of operation, as well as additional objects and advantages thereof, will best be understood from the following description when read in connection with the accompanying drawings, in which:

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FIGURE 1 is a plan view of an embodiment of this invention;

FIGURE 2 is a view in section along the lines 2-2 of FIGURE 1;

FIGURE 3 is a circuit diagram which is an analogue of the embodiment of the invention;

FIGURES 4, 5, and 6 are diagrams of arrangements in accordance with this invention for securing substantially no phase variations around the antenna loops;

FIGURE 7 is a diagram in accordance with this invention for securing a reduction in antenna loss resistance;

FIGURE 8 is a cross section of FIGURE 7; and

FIGURE 9 is a view of another antenna configuration in accordance with this invention.

Reference is now made to FIGURE 1, which is a plan view of an embodiment of the invention, and to FIGURE 2, which is a section along the lines 2-2. By way of illustration, two concentric loops, which comprise the buried antenna, are shown as being circular in form. This should not be construed as a limitation upon the invention, since, although it functions best with a circular arrangement, other geometric forms for the two loops may be employed to provide satisfactory operation as a buried antenna, which will still be within the scope of the present invention. There is a smaller loop 10, having a radius R1, and a larger loop 12, having a radius R2. These loops are buried below the surface of the earth 14 to a depth which is determined at the outset as the minimum depth, which will afford the desired blast protection. However, this depth preferably should be small, when compared to the skin depth, or depth to which a radiofrequency wave passing over the surface of the earth will penetrate into the earth.

The loops are substantially circular, as well as substantially concentric. The inner and outer loops respectively include a central conductor 16, 18, which is surrounded by dielectric material, respectively 20, 22. The radius of this dielectric material should be as large as practicable, but in practice will be much smaller than the skin-depth distance. The difference R2 minus R1 should be very much greater than the skin-depth distance. A transmitter and/or receiver 24 may be connected to the antenna by being connected between the inner and outer loops, as shown in FIGURE 1. Connection must be by one or a multiplicity of conductors, also surrounded by dielectric material having a thickness which is large compared with the diameter of the conductor. In addition, phase delay on this conductor should be minimized by techniques to be described hereinafter.

When excitation is applied between the inner and outer loops, there is a current flow which is established therebetween. The result is an annular current sheath having an inner radius R1 and an outer radius R2. Such current sheath will have concomitant electric and magnetic fields, and thus will radiate. Since the current between the two loops is established in the form of an annular sheath with a concomitant annular area of radially directed tangential electric field, this can be analogized to an annular slot antenna, in which an annular area of radially directed electric field is established. Indeed, the mathematics of the radiation into free space of the antenna shown in FIGURE 1 is substantially identical with the mathematics of the radiation into free space of an annular slot antenna.

Analogous to an annular slot antenna, an optimum radiation along the plane of the ground is achieved when the mean radius of the annular current sheath is substantially equal to $2.405/2\pi$ times the wavelength of the frequency of excitation. The number 2.405 will be recognized as the first zero of the zero-order Bessel

function $J_0(x)$ or as the maximum of $J_1(x)$. The mean radius of the annular current sheath is equal to $\sqrt{R_2 \times R_1}$.

FIGURE 3 is a circuit diagram which is circuit analogue of the antenna shown in FIGURE 1. This includes the RF source 24, which is connected between the inner and outer loops. The inner loop will comprise a capacitance 30, which is established by the inner conductor, the dielectric surrounding that inner conductor, and the earth, which acts as the outer conductor here. The capacitor is shown as being connected in series with a resistor 32. This resistor is the resistance which the current flowing in the earth encounters near the surface of the dielectric surrounding the inner conductor in charging the capacitor 30. Similarly, the other loop will include the capacitor 34 and resistor 36, connected in series with the other side of RF source 24 and which are formed by reason of the inner conductor and the dielectric and earth surrounding the dielectric, which operates as the outer conductor as well as the resistance seen in charging this capacitor.

Between the inner and outer conductors there exists a parallel admittance, which may be identified as Y_R , representing the radiation admittance which the antenna sees as it radiates into the atmosphere from the earth, and Y_G , which is the admittance which the antenna sees looking into the earth. As indicated previously, since with the arrangement shown for the antenna an annular current sheath is established, the design which optimizes the radiation admittance is achieved by using dimensions for the radius of the inner and outer loops, such that the geometric mean radius when measured in radian-lengths (a radian-length is a wavelength divided by 2π) equals 2.405, which is the first root of the Bessel function J.

To minimize the values of the resistances 32, 36, which are existent in the antenna, one may resort to increasing the radius of the dielectrics 20, 22, which respectively surround the inner conductors of the loops, whereby the concentration of charge on the surface of the dielectric is reduced. The capacitors 30, 34 may be reduced in size by reducing the radius of the inner conductors 16, 18. Reducing the size of conductors, and consequently of capacitors, also serves the purpose of diminishing the attenuation and phase delay of a wave traveling around the loop. This is of assistance in helping to establish a voltage of uniform magnitude and phase on the loop. A point of diminishing returns is reached here, since, as the radius is reduced, the resistance to current flow within the conductors is increased. The limitation on the size of the dielectric is an economic one, since with such size increase the costs of the loops increase. Another way of reducing the values of the resistors 32, 36 is, as shown in FIGURES 7 and 8, to use more than one inner and outer loop whereby the surface area of the dielectric is considerably increased. When a multiplicity of inner and outer loops are used, all of the inner loops are connected together and all of the outer loops are connected together.

Where forms other than circular are used for the loops, the Y_R is made large when the current annulus is made large. This is also the case for circular loops, with the further proviso that the real component of Y_R is as indicated above when the geometric means radius of the annulus in radian-lengths substantially equals the first root of the Bessel function J.

The antenna system described does differ from the annular slot antenna in that there is a component of radiation into the ground which is represented in the circuit of FIGURE 3 by Y_G . However, if the conductivity of the ground and the skin depth are known, this component can be calculated and taken into consideration. It should be remembered that the indicated relative dimensions optimize the amount of power radiated relative to the amount of power which is absorbed into the ground.

In order to insure a uniform radiation pattern in free

space, it is desirable to eliminate any phase variations which may occur around the inner and outer loops when they are excited or, reciprocally, when they are receiving signal currents. Minimization of phase variations and minimization of losses due to current flow may be achieved in any of the ways well known in the antenna art, such as by applying excitation currents to a plurality of locations around the inner and outer loops. An alternative method for achieving uniform phase on the loops is to insert capacitors in series with the loop conductors at intervals relatively short, compared with the wavelength of a wave traveling around the loops. Such capacitors should have values selected to produce series resonance with the inductance of the length center conductor between points at which the capacitors are installed.

Some typical dimensions of an antenna which is built in accordance with this invention may be, for example, at a frequency equal to 300 kilocycles, which provides a wavelength of 1000 meters; the skin depth of normal ground is approximately ten meters. It is preferable to bury an antenna at a depth on the order of one-tenth of skin depth, which, accordingly, in this illustration would be at a depth of one meter. Calculating the geometric mean radius in radian-lengths (in this case a radian-length will be 159 meters), such that it is equal to the first root of the Bessel function J, and assuming that it is desired that the radius of the inner loop equals one-half of the radius of the outer loop, the radius of the inner loop will equal approximately 250 meters and the radius of the outer loop will equal approximately 500 meters for optimal radiation. The diameter of the dielectric employed in the inner and outer loops is preferably on the order of four inches, with the diameter of the inner conductor on the order of one-eighth to three-eighths inch. The ratio of radii of the dielectric to the inner conductor is preferably on the order of ten times or greater. An antenna built in accordance with these specifications will provide a radiation efficiency on the order of nine to ten percent. This is significantly greater than the radiation efficiency achieved by other arrangements.

FIGURES 4, 5, and 6 show arrangements for insuring that there is no difference in phase existing around the antenna loop and also insure that there is substantially no voltage drop around the loop. In FIGURE 4, the antenna loops 10 and 12 are excited by a plurality of sources of RF excitation, respectively 40A through 40F, which are connected between the inner and outer loops. The number of sources which are employed are sufficient to insure the absence of phase variation around the loop, as well as to minimize the voltage drops around the inner and outer loops.

FIGURE 5 shows a construction for a section of line, which construction may be employed for the line in the inner and outer loops to solve the problem of phase difference and voltage drop. The phase difference on each of the loops is principally a result of the finite velocity of propagation of a wave propagating on the coaxial transmission line formed by the center conductor, the dielectric sheath, and the earth as the outer conductor. To those skilled in the art, it is well known that by inserting capacitances, respectively 42A, 42B, 42C, periodically in series with the inner conductor, the value of which is selected to provide substantial series resonance with the inductance of the section of line at the frequency of transmission or reception, the phase velocity of a wave propagating on the line becomes extremely large, approaching infinity, thereby substantially eliminating phase variations around the loops.

Another method for achieving uniform phase on the loops would be to have loop 10 joined to loop 12 by shunt inductors 45A, 45B, 45C, 45D, 45E, 45F, 45G, said inductors being spaced from one another a distance which is small when compared to a wavelength of a wave traveling on the lines. These inductors should have a value required to produce substantial parallel resonance with

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the capacitive reactance formed by the series combination of capacitors 30 and 34. To those skilled in the art, it will be evident that by this means also the phase velocity of waves on the lines is made very high, so that the phase on the lines is substantially constant. In practice, the shunt inductors can be lengths of wire connecting loops 10 and 12, encased in dielectric sheaths, which are much larger in diameter than the wires.

FIGURE 7 and FIGURE 8, which is a cross section taken along the lines 8—8 of FIGURE 7, show an arrangement which may be employed when it is desired to use a multiplicity of loops. By way of illustration, and not by way of limitation, there are two loops, respectively 46, 48, adjacent one another, which are connected together at a number of points along their lengths by conductors, such as 50A, 50B, 50C, said conductors also to be covered by a dielectric sheath. The outer loop is formed of at least two loops 52, 54, which are connected together by a plurality of conductors, respectively 56A, 56B, 56C, 56D, which are spaced along the lengths of the two outer loops in order to make two outer loops act electrically as one. The connections 50A through 50C between the two inner loops 46, 48 are provided to make the two inner loops act electrically effectively as one. In practice, and for the embodiment in which series capacitors are used to maintain uniform phase loop 46 could be joined to 48, and loop 52 could be joined to 54 at the points in which the series capacitors are inserted. An RF source 58 is shown connected between the inner and outer loops for the purpose of providing the required RF excitation. The multiplicity of loops are employed for the purpose of reducing the resistance, as 32, 36 shown in FIGURE 3, which represent the resistance seen by the current as it seeks to charge up the capacitors presented by the dielectric material around the inner conductors of the loops.

FIGURE 9 shows a polygonal arrangement of an inner and outer conductor, respectively 60, 62, which exemplifies another arrangement in accordance with this invention whereby a buried antenna may radiate and receive signals with a higher degree of efficiency than thought achievable heretofore.

In the foregoing description a novel, useful, and simple antenna configuration has been described for providing radiation when buried in the ground. The simple geometric form of the antenna minimizes the cost of the installation as well as the required amount of ground which must be reserved for the antenna itself. While instructions have been given for securing optimal results, with this invention, deviations therefrom can be made where necessary, because of factors such as expense of the acquiring of ground, or because of other factors which are introduced by reason of the desired radiation frequency. In this event, there can be a departure from these optimal-design considerations, such as reducing the size of the loops to reduce the size of the annular current sheath, or reducing the size of the dielectric around the inner conductor because of cost considerations. However, such deviations do not depart from the spirit of this invention, nor from the scope of the claims herein.

I claim:

1. An antenna for burial in the ground comprising an inner-loop conductor an outer-loop conductor said outer-loop conductor having a radius larger than said inner-loop conductor and being positioned relative thereto to define therewith an annulus, the radii of said inner and outer loop having dimensions such that the square root of their product when measured in radian-lengths substantially equals 2.405.

2. An antenna as recited in claim 1 wherein both said

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inner and outer loops comprise a central conductor surrounded by a dielectric material, said central-conductor radius being small when compared to the radius of the dielectric material surrounding it.

3. An antenna for burial in the earth comprising conductive means for defining an annulus therebetween, said conductive means being buried in the earth to establish said annulus parallel to the surface of the earth, said conductive means being buried to a depth which is small when compared to the skin depth of penetration into said earth at the desired operating frequency for said antenna, said conductive means including a plurality of inner loops each of which comprises a central conductor surrounded by a dielectric material, the central conductors of all said inner loops being connected together, each of said outer loops comprising a central conductor surrounded by dielectric material, the central conductors of each of said outer loops being connected together, all said inner loops being concentrically disposed adjacent one another, all said outer loops being concentrically disposed relative to one another, relative to said inner loops, and being adjacent to one another.

4. An antenna as recited in claim 3 wherein said conductive means includes a first and a second closed loop respectively placed relative to one another to define the inner and outer boundaries of said annulus, said first and second closed loops each comprising a plurality of series-connected sections each section comprising a length of conductor and a capacitor connected thereto, said capacitor having its value selected to provide series resonance at the frequency of operation of said antenna with the inductance of the length of conductor to which it is connected, whereby the phase velocity of a wave propagating around said first and second conductive loops becomes sufficiently high to substantially minimize phase variations around said loops.

5. An antenna for burial in the earth comprising conductive means for defining an annulus therebetween, said conductive means being buried in the earth to establish said annulus parallel to the surface of the earth, said conductive means being buried to a depth which is small when compared to the skin depth of penetration into said earth at the desired operating frequency for said antenna, said conductive means including a first and a second closed loop respectively placed relative to one another to define the inner and outer boundaries of said annulus, a plurality of inductors connected between said inner and outer loops, the spacing between adjacent inductors being small when compared to the wavelength of the frequency of operation of said antenna, said inductors having their values selected to substantially provide parallel resonance with the capacitive reactance of said first and second closed loops whereby the phase velocity of a wave propagating around said first and second conductive loops becomes sufficiently high to substantially minimize phase variations around said loops.

References Cited by the Examiner

UNITED STATES PATENTS

1,362,383	12/20	Beakes	343—719
1,837,778	12/31	Klein	343—719
2,989,621	6/61	Barton	343—719

FOREIGN PATENTS

654,142	6/51	Great Britain.
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OTHER REFERENCES

Jasik: Antenna Engineering Handbook, McGraw-Hill, 1961, pages 8—8 and 8—9 (two pages) cited.

HERMAN KARL SAALBACH, *Primary Examiner*.