Jan. 31, 1967 H. S. HENDRICKSON 3,302,208

DIPOLE ANTENNA INCLUDING FERRITE SLEEVES ABOUT THE MEDIAL PORTIONS OF ITS RADIATING ELEMENTS

Filed March 20, 1964 3 Sheets-Sheet 1

FIG. 1

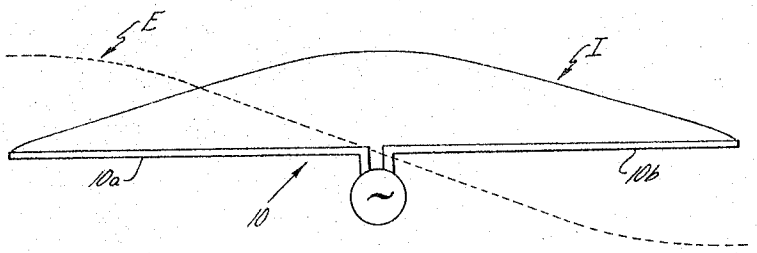


FIG. 2

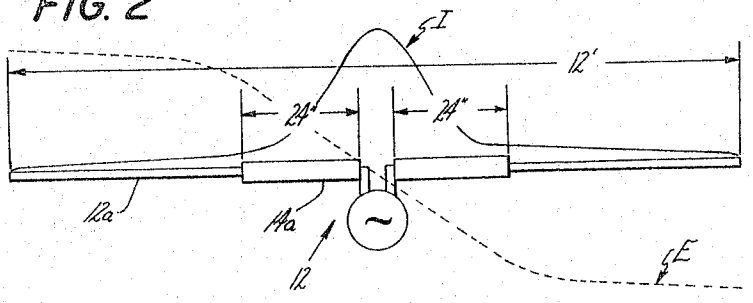
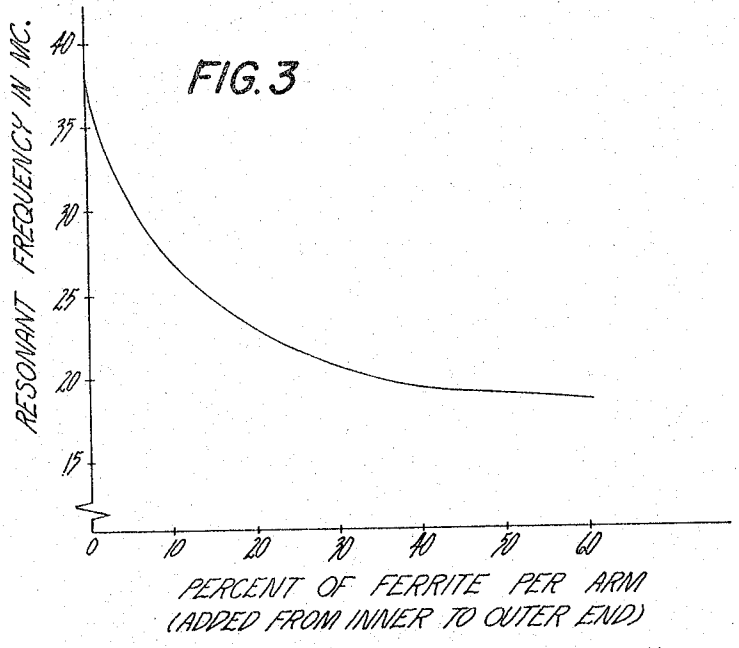


FIG. 3



INVENTOR.
HAROLD S. HENDRICKSON

BY

McCormick, Paulding & Huber

ATTORNEYS

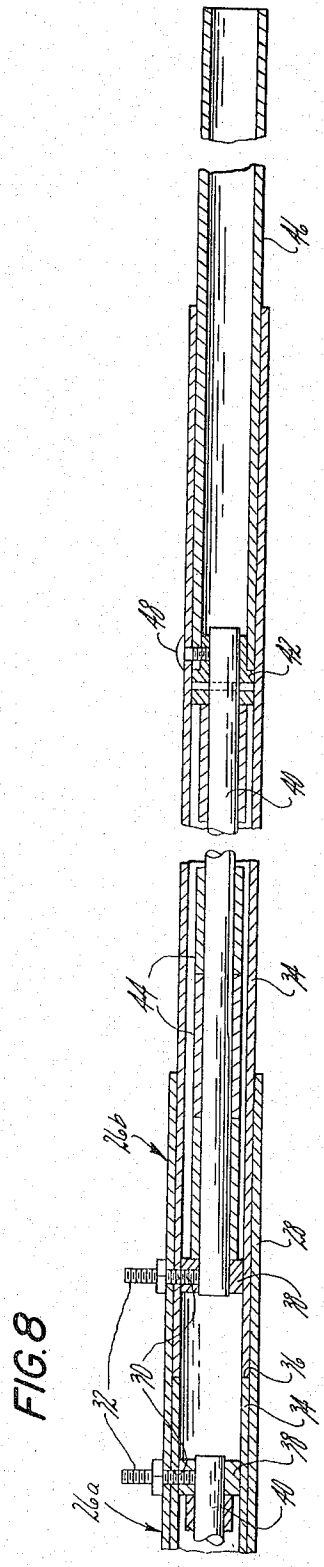

46
48
42
40
44
34
26b
28
30
32
36
38
26a

FIG. 8

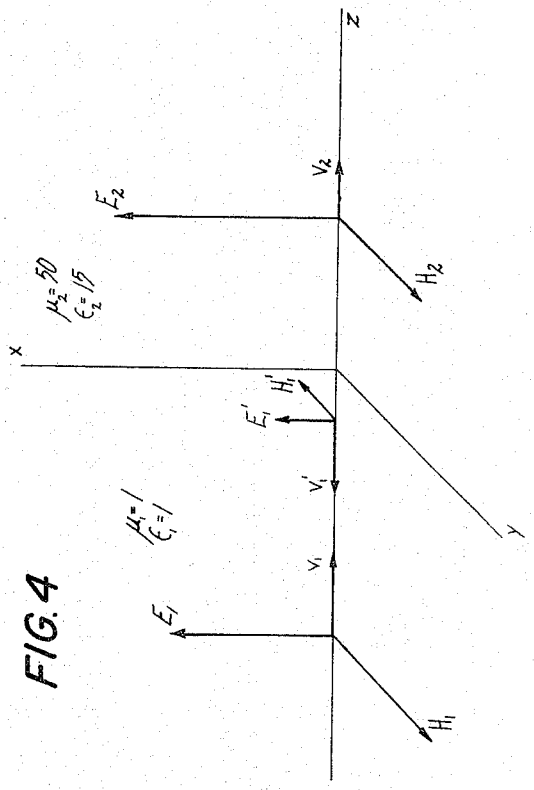

z
V_2
E_2
H_2
$\mu_2=50$
$\epsilon_2=15$
x
H_1'
E_1'
V_1'
$\mu_1=1$
$\epsilon_1=1$
V_1
E_1
H_1
y

FIG. 4

FIG. 5

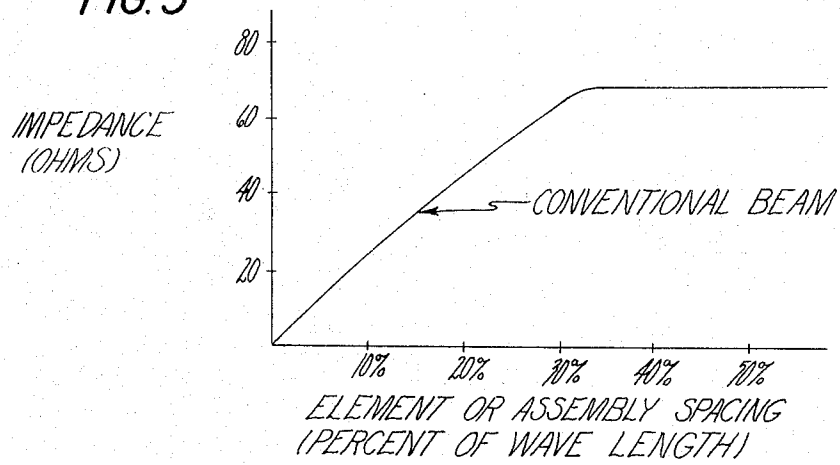


FIG. 6

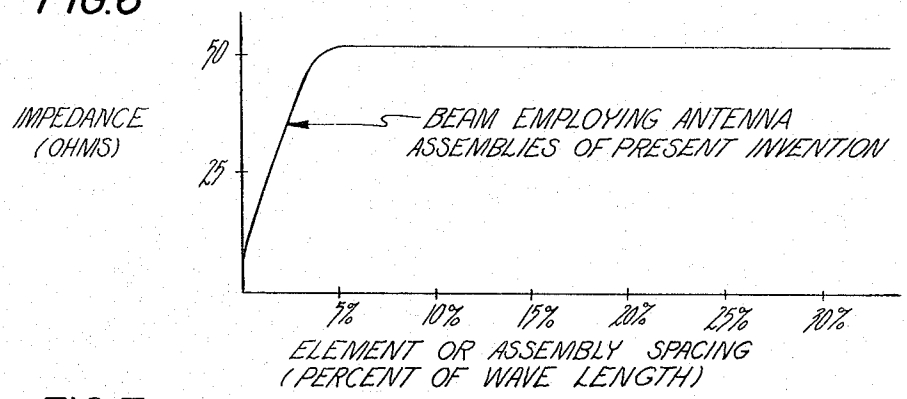
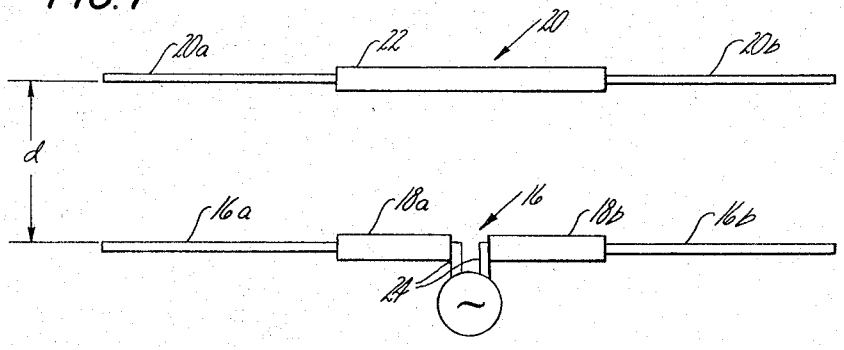


FIG. 7



United States Patent Office 3,302,208
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3,302,208

DIPOLE ANTENNA INCLUDING FERRITE SLEEVES ABOUT THE MEDIAL PORTIONS OF ITS RADIATING ELEMENTS

Harold S. Hendrickson, 9 Sunset Lane, Bloomfield, Conn. 06002; Alice Hendrickson, administratrix of said Harold S. Hendrickson, deceased

Filed Mar. 20, 1964, Ser. No. 353,371
6 Claims. (Cl. 343—787)

This application is a continuation-in-part of my copending application, Serial No. 209,052, now abandoned, filed July 11, 1962 on "Antenna."

This invention relates to antennas such as may be employed in radio systems and is equally adaptable to transmitting and receiving antennas although described hereinbelow particularly for transmitting antennas.

One object of the invention is to provide an antenna of the type mentioned which is much smaller in size than more conventional antennas resonant at the same frequency but which nevertheless exhibits characteristics equal to and in some respects superior to those of conventional antennas.

Another and a more specific object of the invention resides in the provision of an antenna of the type mentioned which includes at least one conventional element and at least one associated ferrite element, the ferrite element being arranged relative to the conventional element in such manner that a major portion of the antenna's magnetic induction field is confined within the ferrite while the antenna's far field radiation is unaffected by the presence of the ferrite.

Still another specific object of the invention is to provide an antenna assembly permitting unusually close spacing of a plurality of antenna elements arrayed as in a Yagi or broad band antenna system.

Another specific object of this invention is to provide an antenna employing ferrite and having an input impedance which will match a standard coaxial line.

A still further object of this invention is to provide an antenna employing ferrite wherein the ferrite is arranged so as to provide for an efficient use thereof achieving a maximum or near maximum shortening effect on the antenna, economy of material and a reduction of power loss.

The drawings show a preferred embodiment of the invention and such embodiment will be described, but it will be understood that various changes may be made from the construction disclosed, and that the drawing and description are not to be construed as defining or limiting the scope of the invention, the claims forming a part of this specification being relied upon for that purpose.

Of the drawings:

FIG. 1 is a diagrammatic illustration of a conventional one-half wave dipole antenna.

FIG. 2 is a diagrammatic illustration of a one-half wave dipole antenna constructed in accordance with the present invention.

FIG. 3 is a curve illustrating the effect of adding ferrite to a conventional dipole antenna.

FIG. 4 is a diagram illustrating the reflection of a portion of an electromagnetic wave at a boundary of the ferrite material used in the antenna of FIG. 2.

FIG. 5 is a curve of impedance versus element spacing in a conventional beam antenna assembly.

FIG. 6 is a curve of impedance versus element spacing in a beam antenna assembly constructed in accordance with the present invention.

FIG. 7 is a diagrammatic illustration of a two-element beam antenna constructed in accordance with the invention.

FIG. 8 is a longitudinal section through an antenna element constructed in accordance with the invention.

It is known that ferrite and other high permeability material can be employed in an antenna assembly to effectively shorten the length of electromagnetic waves and to thereby reduce the size of an antenna element resonant at a given frequency. The present invention involves the use of ferrite in a particular arrangement and combination with other electrically conductive elements whereby the advantage of antenna size reduction and other advantages are obtained without also obtaining certain disadvantages present in other known ferrite antennas. It also involves the use of a ferrite material having permeability and dielectric constant valves so related as to cause desirable results stemming from the reflection of a portion of the electromagnet waves at the ferrite interface or from other unknown phenomena. More specifically, one or more ferrite elements having a given combination or permeability and dielectric constant values are arranged on a conventional electrically conductive antenna element, such as for example an electrically conductive wire, rod or tube, so as to be in close proximity to the antenna's zone of greatest current flow and so as to be as far removed as possible from the antenna's zone of greatest voltage or charge accumulation. Ferrite antenna assemblies heretofore known have employed ferrite more or less indiscriminately with respect to the location of the ferrite along the length of the antenna and with respect to the current and charge distribution and, in consequence, advantages have been obtained in the reduction of antenna size but disadvantages have been encountered in the introduction of detrimental effects on the radiation field.

FIG. 1 shows a conventional center-fed dipole antenna assembly **10** including two electrically conducting arms or elements **10***a* and **10***b*. The curve labeled I indicates the current distribution along the length of the antenna and the curve labeled E indicates the corresponding charge distribution. As is well known, the zone of heaviest current flow occurs at the central portion of the dipole while the zone of heaviest charge accumulation or electric potential is found adjacent the end portions thereof. As is well understood, the current flow and charge accumulation set up magnetic and electric fields, respectively, which fields within the vicinity of the antenna have their greatest strengths near the zones of greatest current flow and charge accumulation, respectively. That is, in the vicinity of the antenna the electric field is highest in strength at the ends of the antenna and the magnetic field is highest in strength at the middle of the antenna. Now, if ferrite or other high permeability material is employed throughout the length of each of the left- and right-hand arms or antenna elements **10***a* and **10***b*, for example, as small sleeves mounted on the arms, there will be a substantial reduction in the resonant frequency of the antenna, or, conversely the antenna will exhibit characteristics corresponding to a much longer conventional antenna.

In accordance with the present invention, however, ferrite or other high permeability material is employed only over a limited portion of an arm or element of an antenna assembly and is of selected values of permeability and dielectric constant for the purpose of reducing the resonant frequency or, conversely, to permit the use of a substantially shorter antenna element for a given resonant frequency. For example, in FIG. 2 there is shown schematically a dipole antenna **12** made in accordance with this invention and having left- and right-hand arms or elements **12***a* and **12***b* with left- and right-hand ferrite elements **14***a* and **14***b*, respectively, which extend only over the inner portions of the arms. The ferrite ele-

ments **14***a* and **14***b* are sleeves mounted on and surrounding the arms **12***a*, **12***b* which may be conventional aluminum rod or tubing. The ferrite elements **14***a* and **14***b* may conveniently each comprise a plurality of small identical sleeves arranged in end-to-end relationship on the associated arm.

In experimenting with various different ferrite materials for the elements **14***a* and **14***b*, it has been discovered that some ferrite materials will produce very good results and others will not. Further investigation of this phenomenon shows that to obtain the desired good results the ferrite material must have a dielectric constant which is smaller (preferably several times smaller) than its permeability. The reason for this is not yet entirely clear, but it is believed that it can be explained on the basis of the influence the ferrite has on the reflection and transmission of waves, as presented in more detail hereinafter, passing from one of the arms to the associated ferrite element.

Still referring to FIG. 2, it will be understood that if the antenna illustrated by this figure is to be used for the same figuring as the antenna of FIG. 1 it will be substantially shorter than the FIG. 1 antenna. Also, it will be observed that the ferrite elements **14***a* and **14***b* extend respectively over approximately 30% of the length of the arms **12***a* and **12***b*. More specifically, FIG. 2 represents an experimental antenna in which the arms **12***a* and **12***b* were each approximately six feet long and in which the ferrite elements **14***a* and **14***b* each included a series of six (6) ferrite sleeves each four (4) inches in length. The arms or elements were aluminum rods of approximately 7/32 inch diameter and the ferrite sleeves were .233 inch in inside diameter and .39 inch in outside diameter. The ferrite employed had a permeability (μ) of 50 and a dielectric constant (ϵ) of 15.

With the foregoing values in mind it will be noted that the resonant frequency of the FIG. 2 antenna without ferrite (that is of an ordinary twelve foot long dipole antenna) is approximately 38 megacycles. This may be found from the usual expression of:

$$f=458/L$$

where:

f=frequency in megacycles
L=antenna length in feet

Starting with only the aluminum rods or arms of the FIG. 2 antenna, four inch sleeves of the ferrite material mentioned were added, one sleeve to each arm at a time, and the resonant frequency determined after each sleeve addition. The results obtained were sa follows:

Number of Sleeves per Arm	Length of Arm Covered with Ferrite, Percent	Resonant Frequency, mc.	Corresponding Length of Conventional Antenna, ft.
0	0.0	38.0	12.0
1	5.5	30.7	14.9
2	11.1	26.7	17.2
3	16.6	24.4	18.8
4	22.2	22.5	20.4
5	27.7	21.2	21.6
6	33.3	20.5	22.4
7	38.8	19.9	23.0
8	44.4	19.5	23.5
9	49.9	19.0	24.1
10	55.5	18.7	24.5
11	61.0	18.3	25.0

FIG. 3 is a plot of these results, and from FIG. 3 and the above table it will be observed that throughout the inner 30% of the length of the antenna arms, addition of the ferrite sleeves produces a sharp drop in resonant frequency but thereafter throughout the outer 70% of the length of the arms little or no additional benefit is secured in the use of ferrite on the arms. With the aforementioned experimental antenna of FIG. 2, the ferrite elements shown actually covered 33⅓% of the total length of each arm and the resonant frequency was reduced from approximately 38 megacycles to about 21 megacycles, approximately a 45% frequency reduction. In terms of antenna length this of course indicates a similar reduction and opens the way to antennas of practical size in the lower frequency ranges. As shown by the above table, for example, the illustrated 12 foot antenna of FIG. 2 is equivalent to a conventional dipole antenna approximately 22.4 feet in length, a reduction in length of almost 50%.

As mentioned previously the reasons for the results obtained are not known with certainty; however, they are believed to be due to the reflection and transmission of portions of the electromagnetic field passing from the antenna arms or conductors into the ferrite. For a better understanding of this theory reference is made to FIG. 4 which represents an electromagnetic wave passing outwardly from the aluminum arm or conductor to the ferrite. In this figure the x–y plane represents the interface between the aluminum and ferrite and the z axis represents the axis along which the wave is waving. The material to the left of the x–y plane is aluminum having a permeability μ_1 and a dielectric constant ϵ_1, both of which may be taken to be 1. The material to the right of the x–y plane is ferrite having a permeability μ_2 and a dielectric constant ϵ_2. If desired an air gap may be considered to exist between the ferrite and the aluminum conductor without changing anything in the discussion which follows since air has a permeability and a dielectric constant substantially equal to 1 similar to the case with alumnium. E_1, H_1, and v_1 are vectors representing the electric field component, the magnetic field component and the velocity, respectively, of an electromagnetic wave incident on the ferrite; E_2, H_2 and v_2 are the corresponding quantities of the electromagnetic wave transmitted through the ferrite, and E_1', H_1' and v_1' are the corresponding quantities of the reflected wave.

Considering normal incidence of the wave, as shown in FIG. 4, the incident and reflected waves are related by the following expression (as given, for example, at page 275 of Constant, Theoretical Physics, Addison-Wesley Publishing Company, Inc., 1958, to which reference is made for a derivation of the expression and further information regarding the same):

$$\frac{E_1'}{E_1}=\frac{\sqrt{\epsilon_1/\mu_1}-\sqrt{\epsilon_2/\mu_2}}{\sqrt{\epsilon_1/\mu_1}+\sqrt{\epsilon_2/\mu_2}}=-\frac{H_1'}{H_1}$$

For the materials given:

$\epsilon_1=1$ $\quad\mu_1=1$
$\epsilon_2=15$ $\quad\mu_2=50$

Substituting these values into the equation given, we have:

$$-\frac{H_1'}{H_1}=\frac{E_1'}{E_1}=\frac{\sqrt{1/1}-\sqrt{15/50}}{\sqrt{1/1}+\sqrt{15/50}}=\frac{1-.55}{1+.55}=\frac{.45}{1.55}=0.29$$

Since the result is a positive number, this indicates that E_1' is in phase with E_1 and that H_1' is 180° out of phase with H_1. Accordingly, in the aluminum conductor the reflected magnetic component H_1' subtracts from the incident magnetic component H_1 and as a result decreases the intensity of the magnetic field component. Similarly, the reflected electric component E_1' adds to the incident magnetic component E_1 and as a result increases the intensity of the electric field component. This changing of the electric and magnetic field components in turn changes the current and charge distribution on the antenna to produce distributions such as shown by the curves E and I in FIG. 2, the curve E representing the charge distribution and the curve I representing the current distribution. Because of the concentrated magnetic field produced in the center of the antenna by the ferrite, the current flow

is concentrated at the center of the antenna and drops off sharply in moving away from the center point, whereas the charge is concentrated along the outer ends of the antenna arms.

It will therefore be seen that as ferrite is added to the arms of the antenna the current will tend to be more and more concentrated at the center of the antenna so that as additional ferrite is added it will be placed adjacent a zone of lesser current and therefore have less beneficial effect. FIG. 2, for instance, shows that after adding ferrite to the inner one-third of each arm the current in the arms beyond the ferrite is relatively small and therefore the use of ferrite beyond the one-third point would have little effect, as is confirmed by experiment. Furthermore, it will be evident that due to the concentration of the charge at outer portions of the antenna arms the electric field will be strongest in this region and along this region the antenna arms are not surrounded by ferrite. This is of great importance insofar as it eliminates power losses which would otherwise result if the electric field had to pass through ferrite in leaving the antenna. That is, an alternating electric field passing through a dielectric such as ferrite produces heat losses which are avoided by the antenna construction of the present invention while nevertheless retaining the length shortening effect of ferrite.

Referring back to the equation presented above for determining the relative values of incident and reflected waves, it will be noted that should the solution of the expression result in a negative number the reflected magnetic component H_1' would be in phase with the incident magnetic component H_1, and the reflected electric component E_1' would be 180° out of place with the incident electric component E_1, and as a result the desired results would not be obtained. From inspection of the equation it will be evident that, since most materials (air or an electrical conductor) which would provide the interface with the ferrite would have a permeability (μ) and a dielectric constant (ϵ) both equal to approximately 1, an unwanted negative result would be obtained whenever the ferrite was such as to have a dielectric constant greater than its permeability and a desired positive result would be obtained whenever the ferrite was such as to have a dielectric constant smaller than its permeability. The greater the difference between the dielectric constant and permeability the better, and preferably the dielectric constant should be several times smaller than the permeability. This critical relationship between the dielectric constant and permeability of the ferrite used in the antenna has been borne out by experiments.

From the foregoing it will be apparent that the present invention involves a selective use of ferrite wherein substantially the maximum benefit in frequency and/or length reduction is obtained without attendant disadvantages. That is, the available benefit of frequency and/or length reduction is derived substantially to its fullest extent and only an insignificant portion or degree thereof is lost due to the absence of ferrite over the remaining or outer portions of the antenna arms or elements. Balanced against this very slight loss is the substantial gain of eliminating or at least drastically reducing the power losses. It is found that the antenna of FIG. 2 exhibits far field radiation characteristics equal in all respects to those of the conventional dipole of FIG. 1.

Now in designing antennas for different frequencies in accordance with the present invention, ferrite elements with different permeabilities may be employed and the portion of the antenna arm or element covered with ferrite may vary. Ferrite is frequency sensitive and various different ferrite materials have different practical frequency ranges. Generally speaking, it is desirable to use a ferrite with as high a permeability as possible, but unfortunately the permeability usually varies inversely with the upper limit of the practical frequency range. By way of example, one manufacturer among a wide variety of ferrite types lists the following types which have the necessary characteristic of a permeability higher than the dielectric constant:

Ferrite Type Designation	Permeability	Dielectric Constant	Practical Frequency Range (mc.)to—
4A	600	15	2.0
4A2	850	15	2.0
4B	250	15	8.0
104	200	15	14.0
4C	125	15	17.5
106	30	15	30
4D	50	15	38
4E	15	15	120
1Z2	15	15	200

In the above list of characteristics the dielectric constant (ϵ) is in all cases the value measured at an applied frequency of 10 megacycles. As the frequency is increased the dielectric constant decreases, and therefore, although the last two materials listed would appear unsuitable for the antenna of the present invention, they would at the higher frequencies at which they would be used, have lower dielectric constants than set forth so as to satisfy the requirement of a permeability greater than the dielectric constant.

Thus, in the low frequency ranges ferrite elements with a comparatively high permeability are available for use and very desirable results may be obtained in the five (5) to twenty (20) megacycle range and below where conventional antennas are excessive in size. However, ferrite utilizing antennas constructed in accordance with the invention may be employed for higher frequencies particularly in complex systems to secure the benefits of induction field confinement as will be explained hereinafter.

Now with reference to the foregoing it will be apparent that the present invention is not limited to an antenna construction comprising a specific type of ferrite element disposed over a particular percentage of the length of an electrically conducting antenna element. The presently preferred construction comprises ferrite elements having a permeability greater than the dielectric constant disposed in the region of maximum current distribution along the antenna element and over a portion of the total length of the antenna element ranging up to 50% of the total length.

Prior mention has been made of the induction field confinement or storage effect of the ferrite elements in the antenna construction of the present invention. It is found that the magnetic induction field associated with the present antenna is effectively held close to the antenna element so as not to excite or couple with nearby metal objects. This results in an obvious advantage in shipboard use and in other installations on vehicles containing metal and also provides a substantial advantage in the design of various complex antenna systems employing two or more antenna assemblies. Illustrating the foregoing, it can be noted that a conventional dipole antenna operating on a frequency of two (2) megacycles will have an associated magnetic induction field which may "couple out" as far as 115 feet. In a similarly excited antenna, constructed in accordance with the present invention, induction field coupling will be reduced to 10 to 12 feet.

As is well known the induction field coupling characteristics of conventional antennas impose severe limits on the spacing of antenna assemblies in systems employing two or more such assemblies. The input impedance characteristics vary substantially with the spacing of assemblies and, in consequence, impedance matching devices are usually required. Thus, it is a conventional practice to space dipoles, for example, in a conventional two-dipole assembly beam antenna system, at approximately 10% of a wave length. With this spacing a substantial drop in input impedance is encountered and impedance matching devices are required. Referring to the curve of FIG. 5 it will be noted that input impedance

is reduced starting approximately at a spacing of 30% of a wave length and that a substantial drop in impedance occurs as antenna assemblies are brought closer together.

Referring now to FIG. 6, the corresponding characteristics of a ferrite antenna constructed in accordance with the invention will be noted. Initially, it will be observed that the input impedance of the driven dipole is substantially lower than that of the driven dipole in a conventional beam system, i.e., approximately 50 ohms as compared with about 70 ohms. The 50 ohm value is found advantageous in that standard 52 ohm cable can be conveniently employed without the necessity of matching devices. Secondly, and of greater importance, it is to be observed that the input impedance of the driven dipole remains constant down to an antenna assembly spacing of approximately 3 or 4% of a wave length. Thus, an antenna system of the two-element beam type may be arranged as illustrated diagrammatically in FIG. 7 wherein a driven dipole assembly is shown at **16** with electrically conductive arms or elements **16***a* and **16***b* and ferrite elements **18***a* and **18***b*, and wherin a parasitic assembly is shown at **20** with electrically conductive arms or elements **20***a* and **20***b* and with a ferrite element **22** surrounding the inner ends of the arms. The spacing *d* between the elements or assemblies **16** and **20** may be as low as 5% of a wave length and yet a standard cable, such as indicated at **24**, of 52 ohms impedance may be employed without the need for impedance matching devices. Obviously, a very substantial reduction in the size of various complex antenna systems can be thus accomplished.

Still referring to the diagrammatic illustration of FIG. 7, it should also be observed that the ferrite antenna of the present invention, such as **16** in FIG. 7, is found to resonate only at its fundamental and not at harmonic frequencies. This characteristic of the antenna provides substantial advantage in the construction of broad band antenna systems wherein several antenna assemblies can be arranged with their resonant frequencies perhaps 10 to 16% apart. Obviously, two antennas in such a system would be capable of independent operation even though the resonant frequency of one might be a multiple of the resonant frequency of the other.

Finally, reference may be had to FIG. 8 for an illustration of a presently preferred embodiment of the invention in a conventional dipole assembly. A portion of a left-hand arm or element of the assembly is shown at **26***a* and a right-hand arm or element is shown at **26***b*. The portion of the left-hand arm or element **26***a*, not shown, may be identical with that shown for the right-hand arm or element. A center portion of the assembly may comprise a Fiberglas tube **28** provided with suitable openings **30**, **30** for antenna input connections in the form of bolts **32**, **32** Right- and left-hand Fiberglas sleeves **34**, **34** are disposed within the sleeve **28** and meet centrally at a junction **36**. Disposed within the sleeves **34**, **34** are right- and left-hand aluminum bushings **38**, **38** connected with the terminal bolts **32**, **32** respectively. Left- and right-hand aluminum rods **40**, **40**, respectively, have ther inner end portions entered in the bushings **38**, **38** and the outer end portions of said rods are entered in outboard bushings **42**, **42** (right-hand only shown).

Now the ferrite elements may be employed in various manners as mentioned. However, it is the presently preferred practice to employ a series of small ferrite sleeves in end-to-end relationship on and about the aluminum rods **40**, **40**. Sleeves **44**, **44** shown extend between the inboard and outboard bushings **38** and **42** on each of the arms **26***a* and **26***b*. As mentioned, the ferrite sleeves are of a type of ferrite material having a permeability greater than the dielectric constant and are preferably employed over 30% of the length of each arm or element in the antenna assembly. The ferrite is so arranged in the construction shown.

The remaining portion of each arm of the antenna assembly preferably comprises an aluminum tube such as the tube **46** shown on the arm **26***b*. The Fiberglas sleeve **34** receives an inner end portion of the tube and the outboard bushing **42** may serve for connection of the tube as by means of a suitable screw **48** passing through the sleeve **34**, the tube **46**, and into the bushing **42**.

From the foregoing it will be apparent that a substantially improved antenna construction has been provided. Efficient and economical use is made of the ferrite material and power losses are minimized. Substantial advantages in frequency and/or in size reduction are achieved without attendant losses in radiation effectiveness. Additional advantages are obtained in the use of the antenna assembly in various antenna systems requiring two or more such assemblies. As mentioned, the invention has application to receiving as well as transmitting antennas. An antenna constructed as described and employed as a receiver is found to exhibit the substantial advantage of size reduction with little or no detrimental effect on gain or other characteristics.

Finally it is to be observed that the term element used herein and in the claims which follow is to be given its broad meaning. Thus, while "element" is employed in referring to one "arm" of a dipole, the term is meant to include any one of several parts found in a wide variety of antenna types. For example, the term may refer to the single element in an upright "one-element" antenna assembly.

The invention claimed is:

1. A one-half wave dipole antenna assembly comprising two opposite but identical arms arranged generally end-to-end, each of said arms comprising a straight elongated electrically conductive antenna element adapted when excited to have a high charge concentration at its outer end portion and a high current concentration at its inner end portion, and each of said arms further including a quantity of ferrite material in the form of at least one tubular sleeve having a magnetic permeability greater than its dielectric constant over the range of frequencies with which the antenna assembly is used located on and surrounding said antenna element thereof adjacent its inner end.

2. An antenna assembly as set forth in claim **1** including driving means connected centrally with said two arms, and also including a second one-half wave dipole antenna assembly spaced substantially less than ten percent (10%) of a wave length from said first mentioned assembly.

3. An antenna assembly as set forth in claim **2** wherein said second antenna assembly includes opposing first and second arms and at least one ferrite sleeve disposed adjacent the inner end portions of said arms.

4. An antenna assembly as set forth in claim **3** wherein said first and second dipole assemblies are respectively resonant at first and second frequencies one of which is a harmonic of the other.

5. The combination in a one-half wave dipole antenna assembly of an elongated antenna arm comprising inner and outer portions respectively in the form of an aluminum rod and an aluminum tube, said inner portion comprising approximately thirty percent (30%) of the total length of the arm, and ferrite material received on and surrounding said aluminum rod and extending along substantially the entire length thereof.

6. An antenna arm comprising an electrically conductive first part extending from the first end of said arm toward the second end thereof for a distance equal to less than one-half the length of said arm, an electrically conductive and tubular second part fixed relative to said first part with the adjacent end portion of said first part received in the bore thereof and extending from said first part to said second end of said arm, and ferrite material received on and surrounding said first part and extending along substantially the entire length thereof.

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HERMAN KARL SAALBACH, *Primary Examiner.*

M. NUSSBAUM, *Assistant Examiner.*