Jan. 13, 1970 S. PICKLES 3,490,025

HIGH-ISOLATION ANTENNAS

Filed Oct. 6, 1967 3 Sheets-Sheet 1

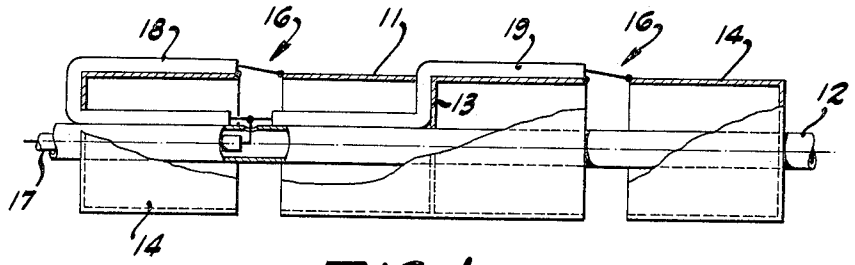


FIG-1

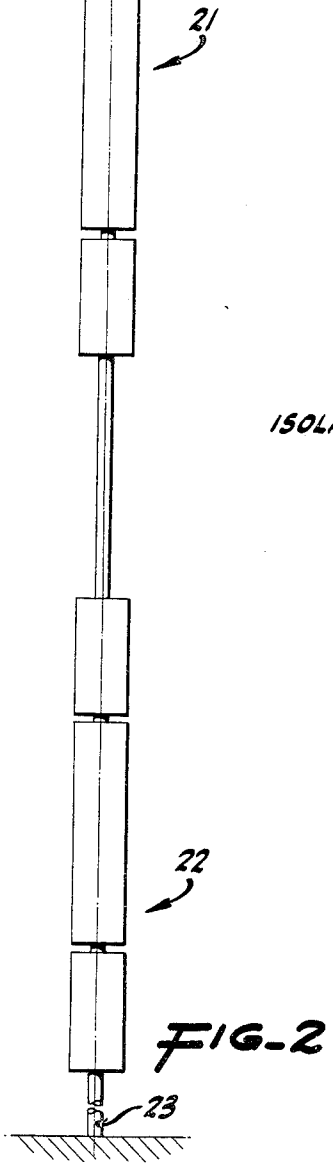


FIG-2

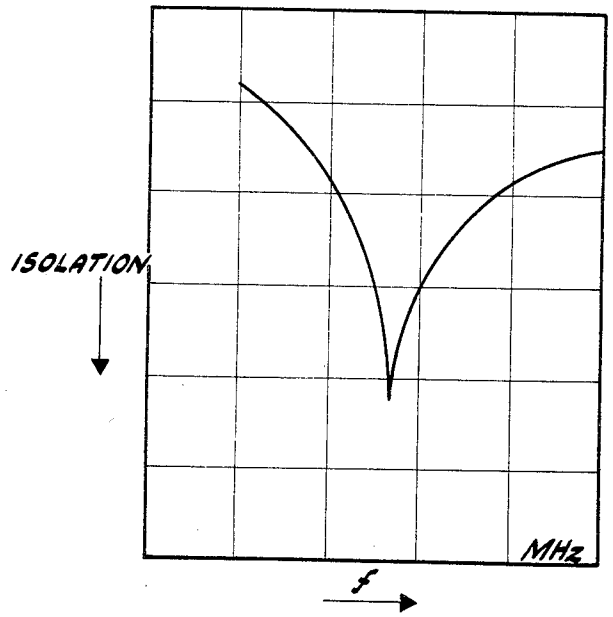


FIG-3

INVENTOR.
SIDNEY PICKLES
BY
Lippincott, Ralls & Hendrickson
ATTORNEYS

Jan. 13, 1970 S. PICKLES 3,490,025

HIGH-ISOLATION ANTENNAS

Filed Oct. 6, 1967 3 Sheets-Sheet 2

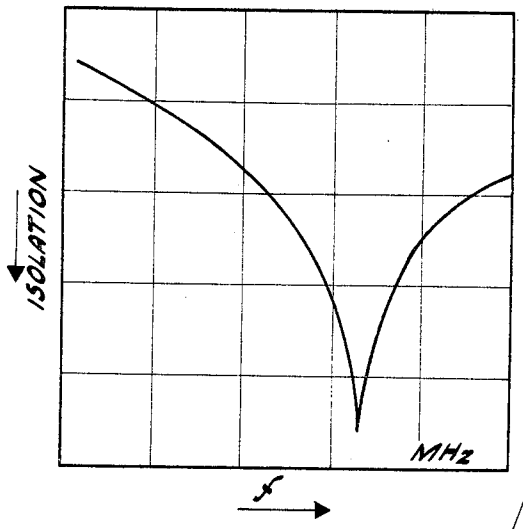


FIG-5

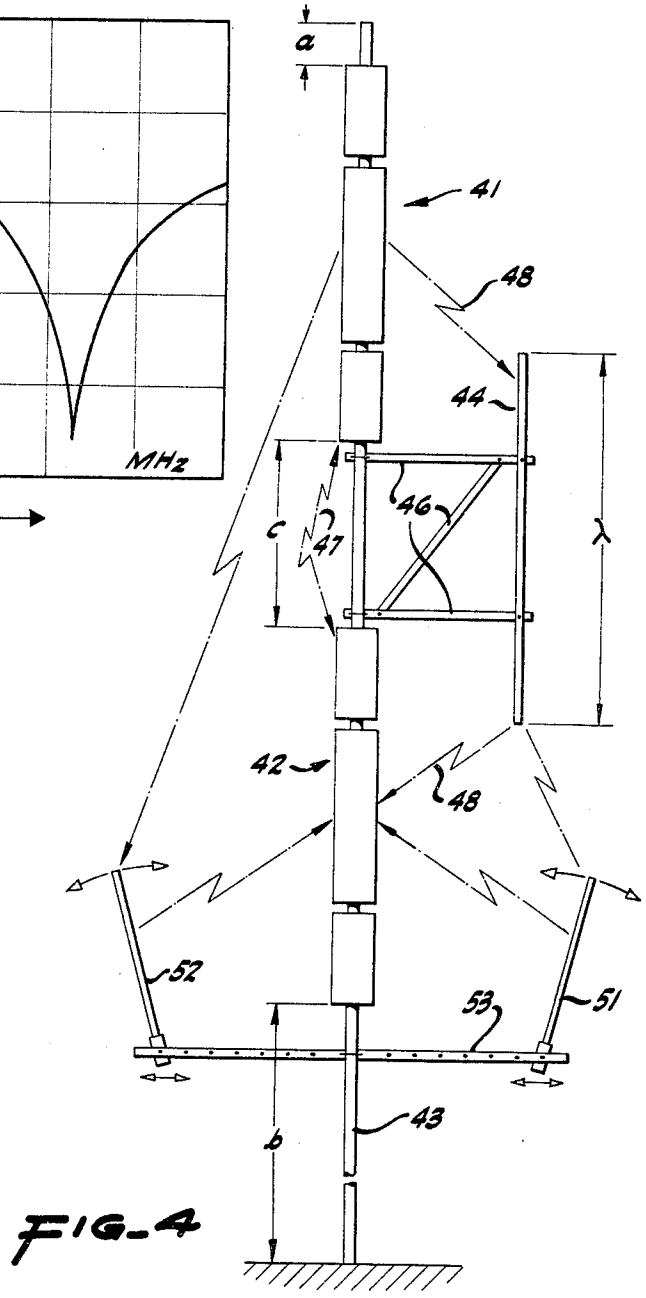


FIG-4

INVENTOR.
SIDNEY PICKLES

BY

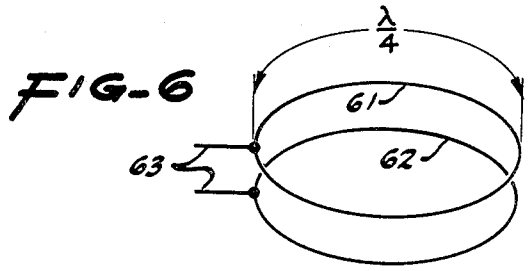
Lippincott, Ralls & Hendrickson
ATTORNEYS

Jan. 13, 1970 S. PICKLES 3,490,025

HIGH-ISOLATION ANTENNAS

Filed Oct. 6, 1967 3 Sheets-Sheet 3

FIG-6



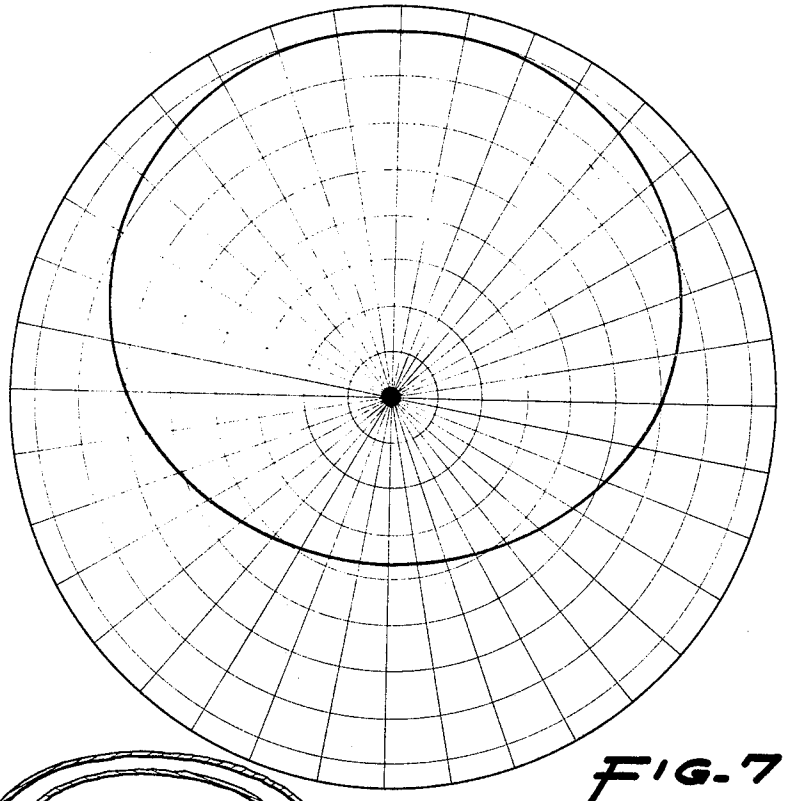


FIG-7

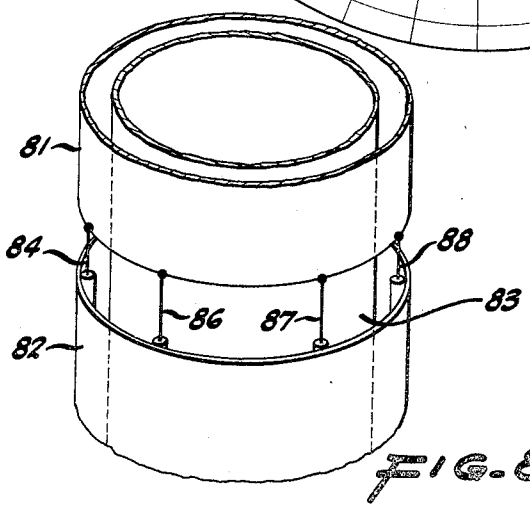


FIG-8

INVENTOR.
SIDNEY PICKLES

BY

Lippincott, Ralls & Hendrickson
ATTORNEYS

United States Patent Office 3,490,025
Patented Jan. 13, 1970

3,490,025

HIGH-ISOLATION ANTENNAS

Sidney Pickles, Colusa, Calif., assignor to Edith Rental Services, Carmel, Calif., a sole proprietorship

Filed Oct. 6, 1967, Ser. No. 673,334
Int. Cl. H01q 9/16
U.S. Cl. 343—792 10 Claims

ABSTRACT OF THE DISCLOSURE

The present invention provides a system with very high isolation between antennas mounted in close proximity. The invention employs slot-type antennas mounted upon a single mast and achieving an unexpectedly high isolation between the antennas at a predetermined frequency by virtue of particular spacing and further by the provision of feedback radiation elements.

BACKGROUND OF INVENTION

Many antenna applications require a high degree of isolation between separate antennas preferably located in close physical proximity. Such a situation occurs in circumstances wherein a signal is to be received by an antenna at a specific location, amplified and reradiated from another antenna at or near the same location. The foregoing operation is commonly termed "repeater service," and it has become a standard practice therein to provide physical isolation between the transmitting and receiving antennas operating at substantially the same frequency. Such isolation may be accomplished by physically displacing the antennas sufficiently, or by providing some type of shielding barrier between the receiving and transmitting antennas. Sufficient physical separation of the antennas requires a substantial amount of available area, and in many instances this poses quite a problem. Provision of some type of shielding barrier necessarily limits the performance of one of the antennas so as to reduce the area that can be covered by the repeating equipment.

Although it may be postulated that the provision of both receiving and transmitting antennas of a repeater station, for example, on a single mast would be highly desirable, the problems of antenna coupling have previously precluded this type of solution. Mounting of both antennas on a single mast would reduce the available space required and could conceivably provide essentially the same coverage area for both antennas. Quite naturally, this would be highly advantageous, but achievement thereof necessitates solution of the problem of cross-coupling between two antennas located in close physical proximity.

Before proceeding with a description of the present invention, it is of interest to note further the nature and magnitude of the coupling problem involved in the problem overcome by the present invention. Standard antennas which are not specifically designed for repeater service, or the like, do normally perform as claimed with regard to receiving and transmitting signals; however, some energy is radiated in undesired directions. As an example consider that ten percent of the energy is radiated in undesired directions and it is noted that this will only reduce the gain in the desired direction by some one-half decibel. Normal communication systems incorporate at least a one-half-decibel margin in their designs; thus it will be apparent that antennas of conventional types when placed on a single mast in close proximity will only have relatively small isolation between the separate antennas, or units. Experience shows that an isolation of 20 to 30 decibels is about all that can be expected. When it is considered that in a conventional repeater station a repeated signal may be as little as 0.6 mHz. away from a received signal in the 160 mHz. region, it is realized that the isolation problem is indeed significant. Thus, with a received signal producing 1 microvolt in a 50-ohm antenna wherein the transmitter is expected to raise this signal to 2 watts, or say 10 volts into a 50-ohm antenna, the difference in signal levels will be seen to be 20 log. $10/10^{-6}$ which equals 140 decibels. Assuming the best circumstances with standard antennas, it would be expected that if they were placed on the same mast they might have about 30 decibels of isolation, so that the receiver would then be required to work on a signal when a 110-decibel-greater signal only 0.6 mHz. away is also present. It would be expected that this much greater signal would quiet the receiver so that the desired input would not be heard, and this is indeed the case. In the foregoing example it would seem appropriate for the antenna system itself to provide about one-half of the necessary isolation, i.e., of the order of 60 to 70 decibels. This is about twice what might be expected from standard antennas, and thus it will be seen that the problem herein is of serious magnitude. The present invention is directed to the solution of this problem.

SUMMARY OF INVENTION

The present invention provides a pair of slot-type antennas, such as disclosed in U.S. Patent No. 3,000,008, mounted one above the other on a single metal mast, or support tube, extending axially through the cylindrical antenna structures. The receiving and transmitting antennas, as they are hereinafter termed, are identical in structure, but are each carefully dimensioned for a particular frequency. An individual antenna consists primarily of a half-wavelength cylinder disposed coaxially about the support mast and supported by a metal diaphragm at the center. End shields, mounted on the mast, are disposed adjacent each end of the radiator. These end shields may take the form of shorted quarter-wavelength cylinders. Feed lines extend through the hollow mast, or support tube, with half-wavelength connecting lines impressing voltages across the gaps at the ends of the half-wave radiator. There is accomplished in this manner a minimum energization of the mast itself, as described in more detail below and in the above-referenced patent.

Although it is to be expected that the antennas described above would have a substantial degree of isolation therebetween, the present invention provides a very material increase in such isolation by particular spacing of the antenna separation and support mast lengths above and below the antennas. This unexpected increase in isolation is obtained at a particular frequency determined by the above-noted spacings which are defined in terms of wavelength λ. Thus, with the proper dimensions in terms of wavelength extremely high isolation is attained at any predetermined frequency. Additionally, the invention provides "outriggers," or feedback radiation elements for selective feedback coupling between the antennas to thereby further improve the isolation between separate antennas. These additional elements, or outriggers, receive a very small signal from one of the radiators and return it to the other in phase opposition to the small coupling normally existing therebetween. The magnitude and phase adjustment of the feedback signal is controlled by a variety of different feedback elements, or reradiators, described herein, and it is possible to therewith achieve decoupling between the two antennas of the order of 60 to 80 decibels. It is noted that with this high degree of isolation it is necessary to consider contributions made by objects of the same level as the antenna and having appropriate lengths to feed back signals between the two antennas which increase or decrease de-

coupling. Cross-coupling at other than operating frequencies is also considered herein and provision made for cancellation thereof by the same units as briefly identified above.

DESCRIPTION OF FIGURES

FIGURE 1 is a plan view of a single antenna as may be employed in the present invention and having portions broken away, as shown, to illustrate internal connections;

FIGURE 2 is a side elevational view of a high-isolation antenna system in accordance with the present invention and employing antenna units as illustrated in FIGURE 1;

FIGURE 3 is a plot of isolation vs. frequency for the antenna combination of FIGURE 2;

FIGURE 4 is an elevational view of an antenna unit incorporating both "outriggers" and "vernier cancellation units" in accordance with the present invention;

FIGURE 5 is a plot of isolation vs. frequency for the antenna combination of FIGURE 4;

FIGURE 6 is a schematic representation of an antenna gap across which feed voltages may be applied;

FIGURE 7 is a plot of a horizontal radiation pattern for a particular gap size of FIGURE 6; and

FIGURE 8 is a partial illustration of an enlarged antenna structure showing multi-feed connections.

DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention employs a pair of slot-type antennas mounted upon a single support mast in relatively close proximity to each other; each of the antennas may be similarly constructed as slot-type antennas of the type shown in FIGURE 1. Referring briefly to FIGURE 1, there will be seen to be provided a cylindrical half-wave radiator **11** coaxially disposed about a support tube, or mast, **12** and mounted thereon by a central diaphragm **13**. The radiator, mast and diaphragm are formed of a metal, and the diaphragm is located at the center of the radiator **11** internally thereof. The ends of the half-wave cylindrical radiator **11** are open; thus this radiator, with the central diaphragm **13** therein, forms a pair of back-to-back quarter-wave cavities having the open ends extending away from each other. At each end of the radiator **11** there are provided end shields **14**, with each being formed as a metallic cylinder with an open end facing the open-ended dipole adjacent same and having a closed opposite end secured to the mast **12**. These end shields **14** are each substantially one-quarter wavelength long and define, with the radiator **11**, a gap **16** which is preferably made quite short longitudinally of the mast and radiator. It will thus be seen that the above-described structure forms a symmetrical unit of three hollow elements concentrically disposed upon the support mast and axially aligned therealong, with the dipole radiator **11** shorted to the mast of the center thereof and the quarter-wavelength end shields shorted to the mast at the outer ends thereof.

The above-described single antenna radiator is preferably energized by a coaxial cable **17** extending through the hollow support mast **12**, with the outer conductor of such cable shorted to the support mast, as at the gap **16** between the lower shield **14** and radiator **11**. A pair of feed cables **18** and **19** of equal electrical length feed energy from the cable **17** across the gaps **16** of antenna. The center conductors of each of these feed cables **18** and **19** are connected together and to the central conductor of the input cable **17**. The cable **18** is shown to extend downwardly along the mast **12** from the lower gap **16** and thence through the bottom end of the lower shield **14** and back up the outside thereof to the gap **16**, whereat the outer sheath of this cable **18** is electrically connected to the end shield and the central conductor is extended across the gap into electrical connection with the half-wave radiator **11**, as shown. The other feed cable **19** is illustrated to extend from the lower gap **16** upwardly along the support mast **12** to the central mounting diaphragm **13** and thence radially outward through the dipole **11** and upwardly along the exterior thereof to the upper gap **16**. At this point the cable **19** has the outer sheath thereof electrically connected to the dipole **11** and the inner connector extended across the gap **16** into electrical connection with the lower end of the upper shield **14**.

It will be seen that by the foregoing connections the opposite ends of the dipole **11** are excited by voltages of equal amplitudes and opposite phase; furthermore, that the end shields **14** are energized with voltages equal and opposite to the adjacent ends of the radiator **11**. The voltage that each feed line **18** and **19** impresses across the feed points, or gaps, will be seen to see substantially symmetrical impedances in each direction; therefore, wavelets traveling in each direction are nearly identical. At one-half cycle later than any particular point of energization these wavelets will be seen to meet their opposite mates traveling in the same direction toward the support mast at each end of the system. If the opposite kinds, or polarities, of wavelets traveling in the same direction are of identical size, the effect is complete cancellation. It will be appreciated that inasmuch as some energy is lost in radiation, and that the impedances in opposite directions are not exactly identical, complete cancellation of support excitation is not quite accomplished. It is noted, however, that the remnant is extremely small and measurements indicate that the mast, or support structure, appears to be substantially free of excitation.

The above-described antenna structure of FIGURE 1 is illustrated and described in greater detail in the above-noted U.S. Patent No. 3,000,008. The present invention provides for the utilization of two such antennas, or radiation systems, supported by a single mast in the manner illustrated in FIGURE 2. No attempt is made in FIGURE 2 to illustrate electrical connections of the antennas inasmuch as same are preferably energized in the same manner as described above in connection with FIGURE 1. There is shown in FIGURE 2 a pair of antennas **21** and **22** coaxially mounted about a support mast **23** in the same manner as the antenna of FIGURE 1 is mounted to the mast thereof. For illustrative purposes, it may be assumed that one of the antennas on the mast **23** is intended to receive signals at 168 mHz. Consequently this antenna, as for example the upper antenna **21**, is dimensioned so that the central radiator thereof has a length equal to one-half wavelength at the indicated received-signal frequency; likewise, the end shields of same are dimensioned to have a length equal to one-quarter wavelength at that frequency. In an application of the present invention for a repeater station the received signal would then be fed through a coaxial cable extending downwardly interiorly of the mast **23** of an amplifier system that may include a transmitter modulated by the receiver, and thence fed back to the lower antenna **22** at a slightly changed frequency of 167.4 mHz., for example. Of course it would be highly advantageous to reradiate at the same frequency to simplify the amplifier system and with sufficient isolation between antennas this becomes more practical. In the example above, both antennas are dimensioned according to the frequency at which each is designed to operate and this may be the same frequency.

In accordance with this invention the two antennas are spaced apart approximately one and one-half wavelengths between centers of the radiators. Thus the adjacent ends of the radiators are spaced apart about one wavelength, but this is herein increased slightly, as to 1.095λ. The invention provides for separation of adjacent ends of the antenna radiators by slightly more than one wavelength, say 1.1λ (when both antennas are operating at the same frequency). In this respect it is noted that such high isolation is achieved herein that minor adjustments are often required to compensate for small external influences;

however, the foregoing spacing is sufficiently close for establishing the "cusp" of FIGURE 3. It is also important in isolation of the two antennas to employ a sufficiently elongated base section of the mast which may, for example, be somewhat less than two wavelengths from ground to the bottom of the lower antenna, preferably about one and two-thirds wavelengths. At very high isolation figures backscatter from the ground becomes quite important; consequently even a minor tilt of the mast from vertical may materially reduce the isolation between antennas. It is thus important that the mast be positioned vertically, although it is noted to be possible to intentionally tilt the mast slightly in adjusting for maximum isolation. With this arrangement, as illustrated in FIGURE 2, there is achieved a very substantial isolation between the two antennas, or radiation systems, as indicated in the graph of FIGURE 3, wherein a very high degree of isolation is seen to be achieved at and adjacent the operating frequencies of the radiation systems.

In addition to isolation, it is also necessary to consider the type of radiation pattern about the radiation systems. It is generally desirable to produce a circular radiation pattern, and in this respect it is important to match the input impedance of the transmission line to the impedance of the radiation system. It may be considered that a coaxial transmission line is formed by the half-wavelength radiator and axially-disposed metal support mast shorted at the center of the radiator. The input impedance of the shorted transmission line is given by the relationship $Z=jz_0 \tan \theta$. For a quarter wavelength, θ is 90° and the tangent thereof is infinity, so that the shunting impedance of the shorted quarter-wavelength line is very high, or almost an open circuit. Consequently, essentially only the radiation resistance of the half-wavelength radiator is placed across the feed line. It is further noted that the end-fed impedance of a half wavelength of wire is quite high; in fact, is is considerably more than an appropriate match for a transmission line. Thus, it would be considered that if the radiator is approximated by a half wavelength of wire, impedance matching becomes difficult. This problem may be overcome by considering the radiator as a plurality of parallel wires, and thus choosing an appropriate diameter of the wire cage formed thereby as the skin of the radiator itself, so that the parallel impedance of all these individual radiators matches the transmission-line impedance. In general, the radiation system is limited to the dimension wherein the half circumference of the elements is less than a quarter wavelength of the frequency handled by the system. Modifications of this limitation are discussed below; however, the limitation is important in obtaining a circular radiation pattern from the antenna system illustrated in FIGURE 2 and in the absence of modifications, as discussed below.

Insofar as dimensioning and relative positioning of the individual antennas upon the single mast are concerned, it is noted that certain dimensions are quite important. Thus, aside from the proper dimensioning of the individual antennas, isolation may be varied by varying the distances indicated by the letters *a*, *b* and *c* in FIGURE 4. Despite the fact that the present invention operates to substantially eliminate energization of the mast, it has been determined that maximum isolation at a particular frequency is, at least in part, dependent upon the length of these sections of mast. It is also to be noted that variation in the length of any of these sections tends to displace the frequency at which maximum isolation is achieved between the antennas. Unfortunately, the relationships are exceedingly complex; thus it is only possible to identify the important variables and to set forth basic criteria experimentally determined to produce the results desired in the present invention. Thus, the foregoing relationships concerning the lengths of antenna elements and mast lengths are only general limitations, subject to minor variations for maximizing isolation. As described in connection with FIGURE 3, the two antennas are to be separated along the mast about one and one-half wavelength between the centers of the radiators of the antennas. In actuality, it is found that an increase in the separation *c* between adjacent ends of the antennas from that obtained with this relationship does increase the isolation. Thus it might be expected that for an antenna having a 32"-long central element, or radiator, for example, would result in a separation of 32" between adjacent ends of the two antennas. In actual practice, it has been found that a separation of about 42" is preferable. Although this particular variation from theoretical is relatively understandable in view of the fact that increased separation should decrease coupling, the dependency of isolation upon the extent of the top and bottom of the mast is not so readily explainable. In the foregoing example the top of the mast preferably extends up about one-eighth of a wavelength, while the bottom of the lower antenna is separated from ground by a distance of about 1.7 wavelengths. Rather naturally, the frequency at which maximum isolation is obtained varies with the relative lengths of the antennas themselves.

Although the isolation between radiation systems of the arrangement of FIGURE 2 can be made very high, as illustrated in FIGURE 3, there are various factors aside from the antennas themselves which affect such high isolation. As previously noted, a careful choice of mast lengths is necessary, and also the problem of reflections from ground and other objects becomes critical. Thus reflection from adjacent buildings may substantially change the isolation between radiation systems. As an example, with isolation in excess of 60 decibels, a large metal building 100 feet distant from the mast may change the isolation as much as plus or minus 5 decibels, or more, in moving the antenna toward or away from the building one-quarter wavelength of the frequency in use. In many circumstances the stringent requirements for clear area about the antenna cannot be met, and appropriate dimensioning of the base section of the mast is not possible. Under these circumstances, the desired high degree of isolation may be attained by feedback, and in this respect reference is made to FIGURE 4.

Referring now to the embodiment of the present invention illustrated in FIGURE 4, it will be seen that there is provided a pair of antennas **41** and **42** coaxially mounted one above the other upon a metal support mast **43** in the same manner as the embodiment of FIGURE 2. Each of the antennas **41** and **42** is dimensioned in accordance with the present invention to form the central radiator of each as a half wavelength at the particular frequency for which that antenna is designed to operate. Likewise, the end shields, or cavities, of each of the antennas are formed as quarter-wavelength sections. The two antennas **41** and **42** have the centers thereof separated substantially one and one-half wavelengths apart which, thus, will be seen to provide for a separation of approximately one-half wavelength between the lower end of the upper antenna and the upper end of the lower antenna. In this embodiment of the present invention there is provided at least one feedback radiator **44** also mounted on the mast **43**, as by appropriate support members **46**. This feedback radiator **44** has an overall length of approximately one-half wavelength, or an integral multiple thereof, at the frequencies with which the antennas operate and is disposed parallel to the mast about one-half wavelength, or a multiple thereof, away from same. The length and spacing of the feedback radiator are chosen so that signals received from one antenna are in fact radiated to the other out of phase for maximizing isolation. Insofar as the actual structure of feedback mechanism is concerned, the supports **46** are preferably nonmetallic in order that they do not contribute to reception or radiation of signals, although it is possible to employ a metallic mounting such as a single arm. In this latter circumstance, wherein a metallic mounting arm is employed for the feedback radiator, it is necessary to

take into account the reception and radiation properties of the arm. The radiator **44** itself is located further away from the mast as the radiator diameter is increased and is preferably formed as a metal wire, or rod, having a plastic coating or other type of insulating coating thereon.

Some small amount of interaction between the two antennas **41** and **42** does occur, as schematically illustrated by the dashed line **47**; and this may, in good part, be cancelled by the feedback radiator **44**, in asmuch as some small portion of the energy radiated from the antennas **41** and **42** will be picked up by the feedback radiator and reradiated back to these antennas: this is generally indicated by the dashed lines **48**. It is to be appreciated that the degree of isolation desired between the antennas of the present invention is extremely high, and, as noted above, various factors or objects exteriorly of these antennas may affect the coupling therebetween. Thus the feedback radiator **44** serves to return a cancelling signal to compensate for unintentional low-degree coupling between the antennas. Adjustment of the feedback radiator for particular circumstances is desirable; normally this radiator may be adjusted while reading radiation and reception from the two antennas to achieve a null or maximum isolation between the antennas at and about the operating frequencies thereof. Many antenna installations of the repeater type herein taken as an example are so located as to make access to the individual antennas and, also, to the feedback radiator rather inaccessible. For this and other reasons, it is provided hereby that additional feedback radiators may be employed, as also indicated in FIGURE 4.

There is shown in FIGURE 4 a pair of vernier half-wave radiators **51** and **52** adjustably located on a crossbar **53** secured to the mast below the bottom radiator **42**. This crossbar **53** may be provided with a plurality of apertures along the length thereof on both sides of the mast and may be secured to the mast by a clamp, or the like. The individual vernier radiators **51** and **52** are mounted on the crossbar **53** in movable and adjustable fashion. Thus, for example, the radiators **51** and **52** may have lower mounting ends with a bolt extending therefrom for insertion in any one of the crossbar apertures, so that a locking nut, or the like, may be threaded thereon to secure the radiator to the crossbar in desired location and inclination with respect to vertical. These lower radiators **51** and **52** also serve the purpose of feeding back cancelling signals, and are so located as to be much more accessible to one installing the antenna system. The movable and adjustable nature of the vernier-feedback radiators **51** and **52** provides the installer with a capability of adjusting the position of each of these radiators to maximize isolation between the two antennas **41** and **42**. It is to be appreciated that there is a substantial number of coupling paths existing between the various radiators of the overall antenna system illustrated in FIGURE 4. At least certain of these paths are identified by lightly dashed lines extending between separate radiators. In actual practice, following initial mounting of the antennas **41** and **42** upon a mast and with proper dimensioning of these antennas, the primary feedback radiator **44** is mounted substantially as indicated with about one-half wavelength separation from the mast, and then the position and angle of the vernier-feedback radiators **51** and **52** are adjusted to achieve maximum isolation between the antennas.

The foregoing adjustment may be accomplished by energizing one of the antennas while monitoring the signal received by the other therefrom. The relatively convenient location of the vernier radiators makes it possible for adjustments, both in lateral disposition and angular orientation, to be readily made by one installing the system. It is possible, by appropriate adjustment, to achieve very remarkable isolation between the two antennas closely spaced from each other and mounted on a single mast. This is illustrated in FIGURE 5 wherein there will be seen to be shown a plot of isolation vs. frequency, and, in practice, an isolation in excess of 80 decibels is achieved.

A further feature of considerable importance in connection with the present invention is the capability of this invention to be employed for extremely large structures. For certain applications, it may be desirable to form a pair of antennas in accordance with the present invention as a tower wherein the mast itself has a sufficient diameter to serve as physical access, and possibly also to contain receiving and transmitting equipment. There is, however, to be considered a further matter of antenna feed for any radiator having a half circumference in excess of one-quarter wavelength. In this respect, reference is made to FIGURE 6 illustrating only the adjacent ends of two elements defining one gap of an antenna in accordance herewith. As shown, these ends comprise parallel loops **61** and **62** with voltage being impressed between them, as across the terminals **63**. With the half circumference of each of these loops **61** and **62** being equal to a quarter wavelength, there will be seen to be provided the equivalent of two transmission lines leaving a common feed point and rejoining each other on the opposite sides of the loops. The voltage rises in an open-circuited transmission line, i.e., a quarter waveline, with the maximum being at the open end. This, then, results in an unequal voltage appearing across various portions of the gap between the loops **61** and **62**, and the result is a variation in the horizontal radiation pattern. It has been found that the H-plane radiation pattern of such a system approaches a cardioid shape, such as shown in FIGURE 7. The particular pattern shown in FIGURE 7 was plotted for an antenna having a diameter equal to 0.2λ which will be noted to provide a half circumference greater than one-quarter of a wavelength. This property may be employed for particular applications wherein it is desired to vary the horizontal radiation pattern; and, in fact, with increasing diameter, loops will be formed in the horizontal radiation pattern which may be quite desirable for certain applications. On the other hand, a large number of applications require a substantially circular pattern. This is achieved in accordance with the present invention by providing a multi-feed system, such as illustrated in FIGURE 8.

Referring to FIGURE 8, there will be seen to be shown portions of adjacent elements **81** and **82** mounted about a mast **83** wherein the diameter of the elements **81** and **82** is substantially in excess of the maximum amount for a circular radiation pattern in accordance with the prior description. In this structure the half circumferences of the elements **81** and **82** are well in excess of half wavelengths. A multi-feed system is herein employed, as illustrated at **84**, **86**, **87** and **88** of FIGURE 8. Energization at these feed points spaced less than a quarter wavelength apart about the circumference of the gap between elements **81** and **82** is schematically illustrated by the connection of the sheaths of coaxial cables to the lower element **82** and connection of the central conductors of these coaxial lines to the upper element **81**. The number of separate feed points required to maintain a circular pattern of horizontal radiation can be determined by lengthy trigonometric calculations or, more quickly, from a perusal of a table of Bessel functions. It is also possible to obtain single and multi-directional horizontal radiation patterns by unsymmetrical feed arrangements.

There has been described above an antenna system wherein a pair of antennas are located in close proximity to each other with very high isolation therebetween, even when operating at substantially the same frequencies. It is noted to be possible to obtain substantial isolation between closely adjacent antennas when they are operating at very different frequencies, as, for example, by the reactance method shown in U.S. Patent No. 2,924,823 to Carter. Unfortunately, this approach to the problem is not satisfactory for the circumstances contemplated by the present invention. It is to be further noted that the present

invention is particularly adapted for utilization with several receivers and several transmitters connected to the same antenna system and all operating at only incrementally different frequencies. Commonly, diplexers are employed as filter elements under these circumstances; however, it is normally necessary for there to be a separation frequency of about one percent, or more, for such units to operate satisfactorily. The present invention overcomes this limitation as it is not based upon frequency difference. Thus the high isolation obtained by the present invention finds wide applicability.

In accordance with the present invention, particular slot-type antennas may be mounted upon a single electrically-conducting mast, one above the other, and appropriately located with respect to each other and to the mast itself for attaining very high isolation between the antennas. Additionally, the present invention provides for the utilization of feedback radiators, or outriggers, to additionally decouple the antennas of the system for achieving extremely high isolation, even in the presence of exterior elements such as metal buildings, or the like, in the vicinity of the installation. The present invention is particularly directed to the problem of operating two closely adjacent antennas at substantially the same frequencies without interaction between the two antennas. While many prior art devices comment upon high isolation, it is desired to emphasize herein that the magnitude of isolation, or decoupling, provided hereby is very substantially greater than that obtainable with such prior art teaching. Commercially available antennas, even when particularly designed for isolation, common claim a maximum isolation of the order of 40 decibels, while the present invention provides an isolation in the range of 60 to 80 decibels. This, then, clearly provides a very marked advance in the art.

Although the present invention has been described with respect to particularly preferred embodiments thereof, it is not intended to limit the invention to the details of illustration or description; instead, reference is made to the following claims for a precise delineation of the true scope of this invention.

That which is claimed is:

1. A high-isolation antenna system comprising an electrically conducting mast, first and second antennas coaxially mounted on said mast and spaced apart therealong, each of said antennas including a hollow cylindrical half-wave radiator and an end shield closely spaced from each open end thereof, said radiator having a metal-mounting diaphragm at the center thereof engaging said mast, each of said antennas having means electrically connecting the gaps between each end of the radiator and end shields in phase opposition, each of said antennas being dimensioned for the frequency of operation thereof, and said antennas being spaced apart along said mast substantially one and one-half wavelengths of one of the antennas between centers of the antenna radiators.

2. The system of claim 1 further defined by the half circumference of the antenna radiators being less than one-quarter wavelength of the operating frequency of the antenna.

3. The system of claim 2 further defined by each of the end shields of each antenna comprising a hollow cylinder of substantially one-quarter wavelength with a closed end engaging said mast at the end thereof away from the radiator of the antenna, and the spacing between antennas being substantially 1.1 wavelength between adjacent ends of the radiators of the two antennas.

4. The system of claim 3 further defined by the antennas of said system having substantially the same operating frequencies, said antennas being separated between adjacent end shields along said mast a distance of approximately two-thirds of the wavelength of said frequency, the bottom-end shield of said mast being spaced from an electrical ground at the mast base approximately one and seven-tenths wavelengths of said frequency, and said mast extending upwardly from the top-end shield of upper-end shield approximately one-eighth of a wavelength of said frequency.

5. The system of claim 1 further defined by a feedback radiator parallel to said mast and spaced therefrom a distance of substantially an integral multiple of one-half wavelength of a frequency intermediate the frequencies of said first and second antennas and having a length of one-half or one wavelength.

6. The system of claim 5 further defined by at least two half-wave radiators at a frequency intermediate the operating frequency of said first and second antennas, and means mounting said radiators on said mast on the opposite side of said second antenna from said first antenna in movable relation to said mast for adjustable positioning to maximize isolation between said antennas by feedback between antennas.

7. The antenna system of claim 3 further defined by said mast being vertical, said antennas having substantially the same operating frequency, a feedback radiator having a length of one-half or one wavelength at said frequency and spaced from said mast substantially an integral multiple of one-half wavelength, and electrically nonconducting means mounting said feedback radiator parallel to said mast substantially equally spaced from the centers of the antenna radiators.

8. The antenna system of claim 7 further defined by a pair of half-wave radiators at said frequency, and means extending from said mast beneath said antennas mounting said half-wave radiators in adjustable position relative to said mast for controlled feedback between antennas and said full-wave radiator to maximize isolation between said antennas.

9. The antenna system of claim 1 further defined by the radiators of said antennas each having a half circumference greater than one-quarter wavelength of the antenna-operating frequency, and said electrical connections across the gaps between radiators and end shields being spaced apart about the gap circumference a distance less than said one-quarter wavelength for establishing circular antenna-radiation patterns in planes normal to the antenna radiators.

10. The antenna system of claim 1 further defined by the electrical connections across the gaps between antenna radiators and end shields having a separation about the gap that is an odd multiple of one-quarter wavelength of operating antenna frequency for establishing particular antenna-radiation patterns in a plane normal to the antennas.

References Cited

UNITED STATES PATENTS

2,234,234	3/1941	Cork et al.	343—790 X
3,000,008	9/1961	Pickles	343—792
3,031,668	4/1962	Bryson	343—790
3,159,838	12/1964	Facchine	343—792

HERMAN KARL SAALBACH, Primary Examiner

T. VEZEAU, Assistant Examiner

U.S. Cl. X.R.

343—841, 857, 885