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Fong

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(45) **Date of Patent: Mar. 28, 2017**

(54) **RADIAL-FREE COLLINEAR OMNI-DIRECTIONAL TRIBAND HALF WAVELENGTH ANTENNA WITH VIRTUAL GROUND, SINGLE COAXIAL CABLE FEEDPOINT, AND WITH MINIMAL INTERACTION OF ADJUSTMENT BETWEEN BANDS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 47 days.

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(22) Filed: **Aug. 25, 2015**

(51) **Int. Cl.**

H01Q 9/04	(2006.01)
H01Q 21/30	(2006.01)
H01Q 9/18	(2006.01)
H01Q 1/36	(2006.01)

(52) **U.S. Cl.**
CPC ***H01Q 21/30*** (2013.01); ***H01Q 1/362*** (2013.01); ***H01Q 9/18*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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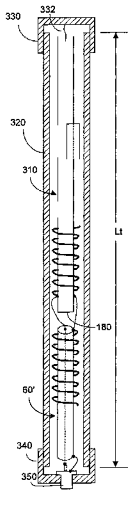
(57) **ABSTRACT**

An omni-directional triband antenna operates without ground radials with gain commensurate with a half wavelength vertical on each band. The triband antenna includes a dual-band twinlead J-pole providing half wavelength radiators for UHF and VHF, and an impedance transformer defining feedpoints to which a length Lc of coaxial cable is attached. The Lc lower end is the triband antenna connector port. Intermediate band radiators are first and second wire elements that collectively are a half-wavelength at the intermediate band. The first element is wound helically about the impedance transformer, with upper end floating and lower end connected to a first feedpoint. The second element is wound helically about the Lc upper portion of coaxial cable, with upper end connected to the remaining feedpoint, and lower end of the element floating. The helical windings radiate vertically and there is no cross-interference between antenna radiation in any of the three bands.

20 Claims, 12 Drawing Sheets



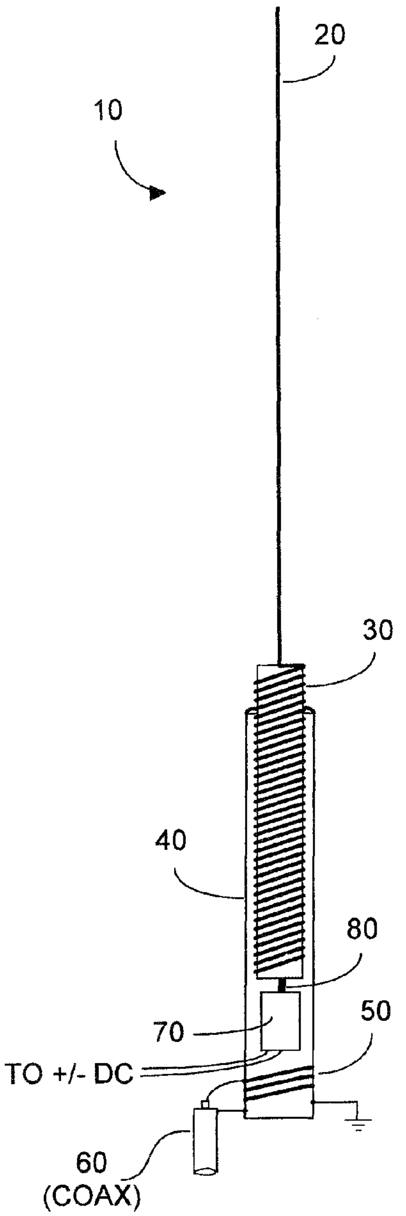


FIG. 1A
(PRIOR ART)

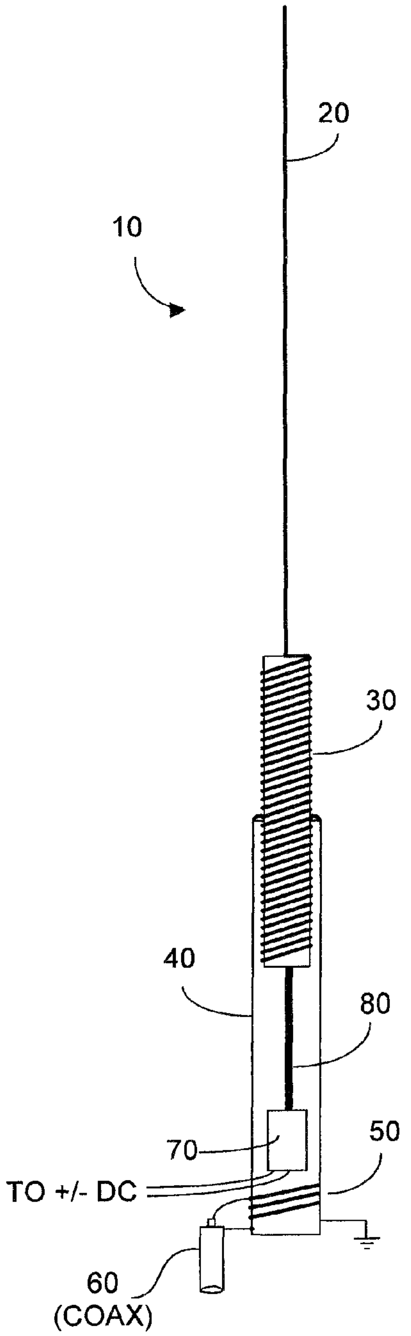


FIG. 1B
(PRIOR ART)

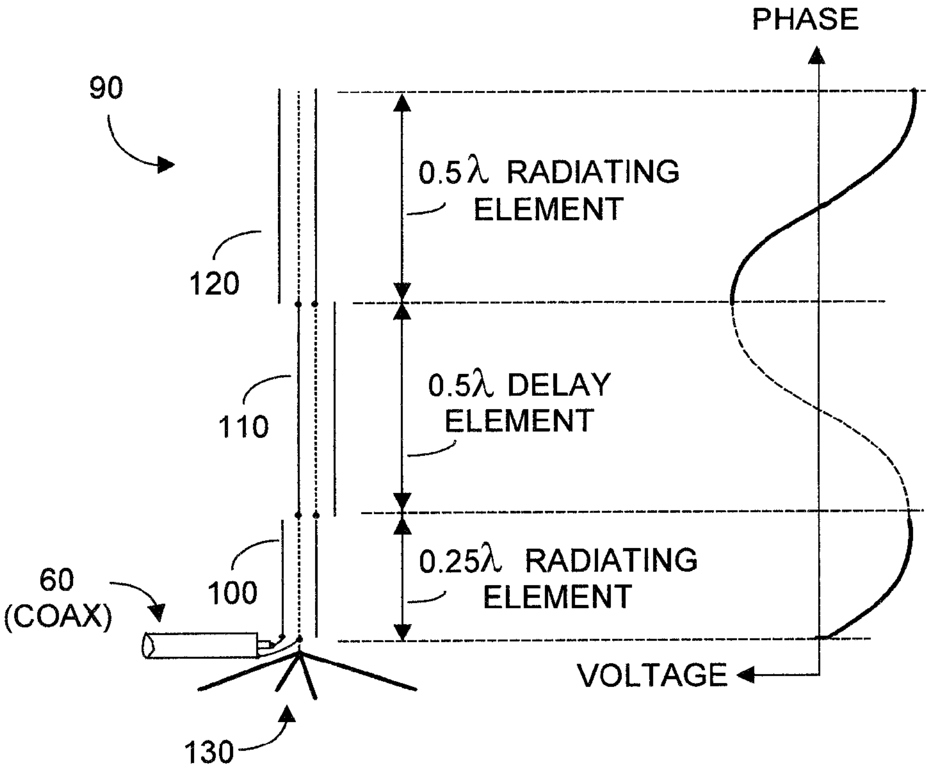


FIG. 2A
(PRIOR ART)

FIG. 2B
(PRIOR ART)

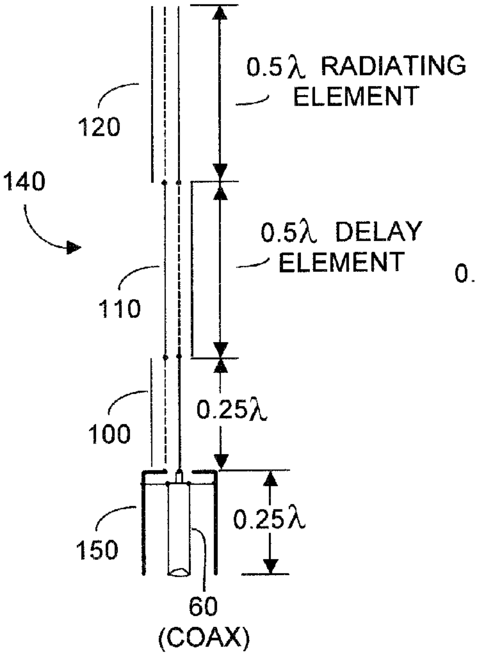


FIG. 3
(PRIOR ART)

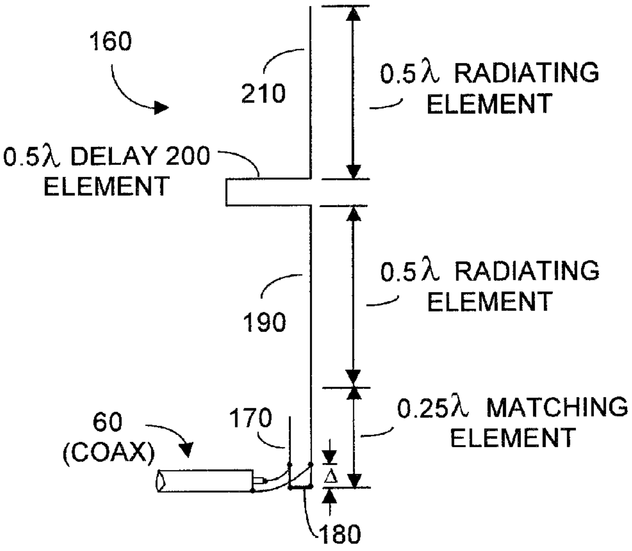


FIG. 4
(PRIOR ART)

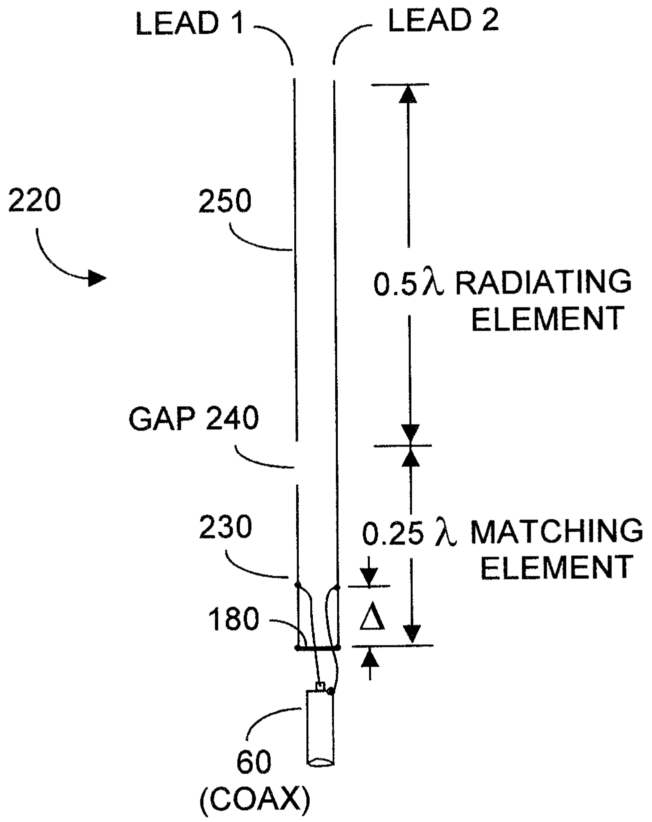


FIG. 5
(PRIOR ART)

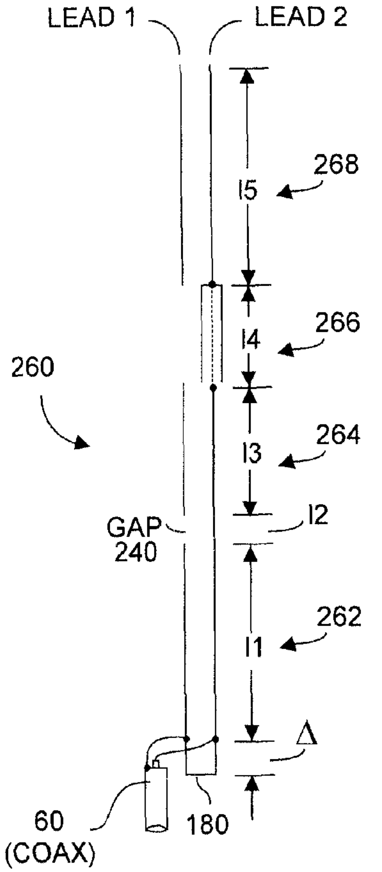


FIG. 6A
(PRIOR ART)

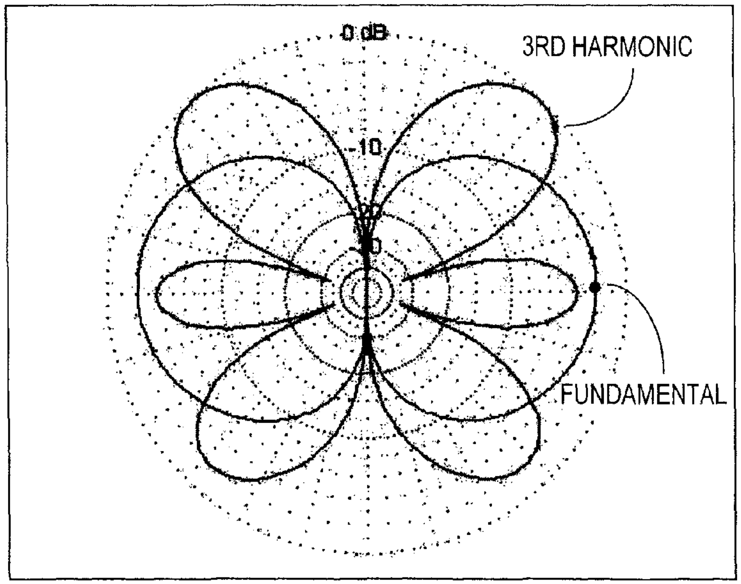


FIG. 6B
(PRIOR ART)

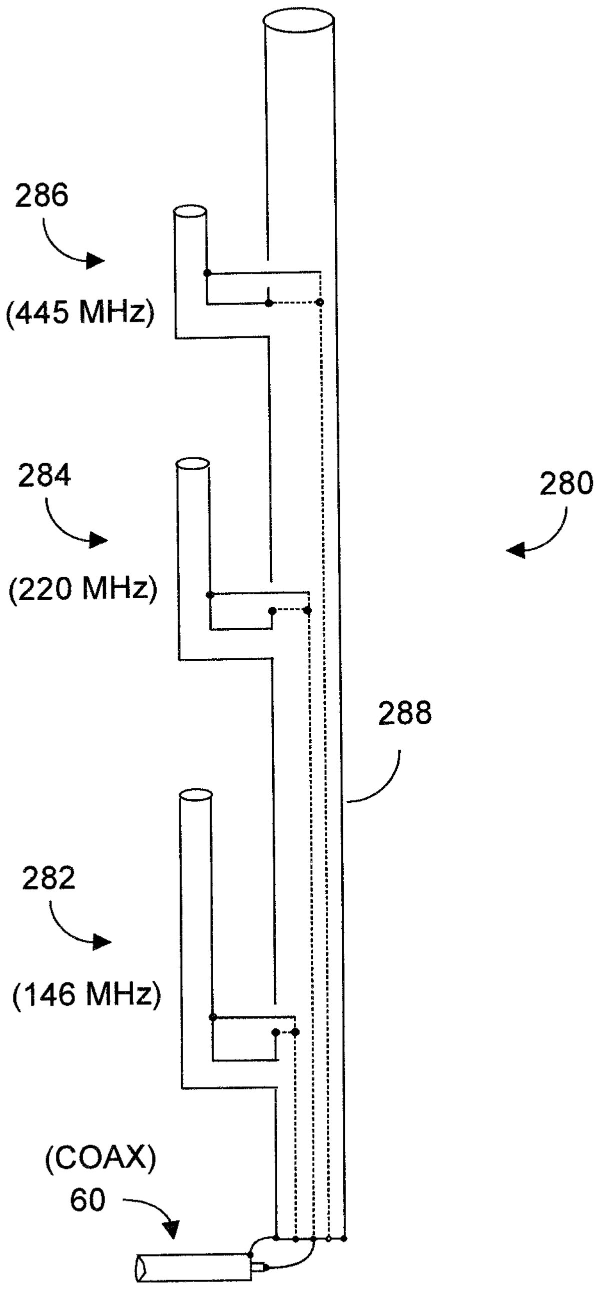


FIG. 7
(PRIOR ART)

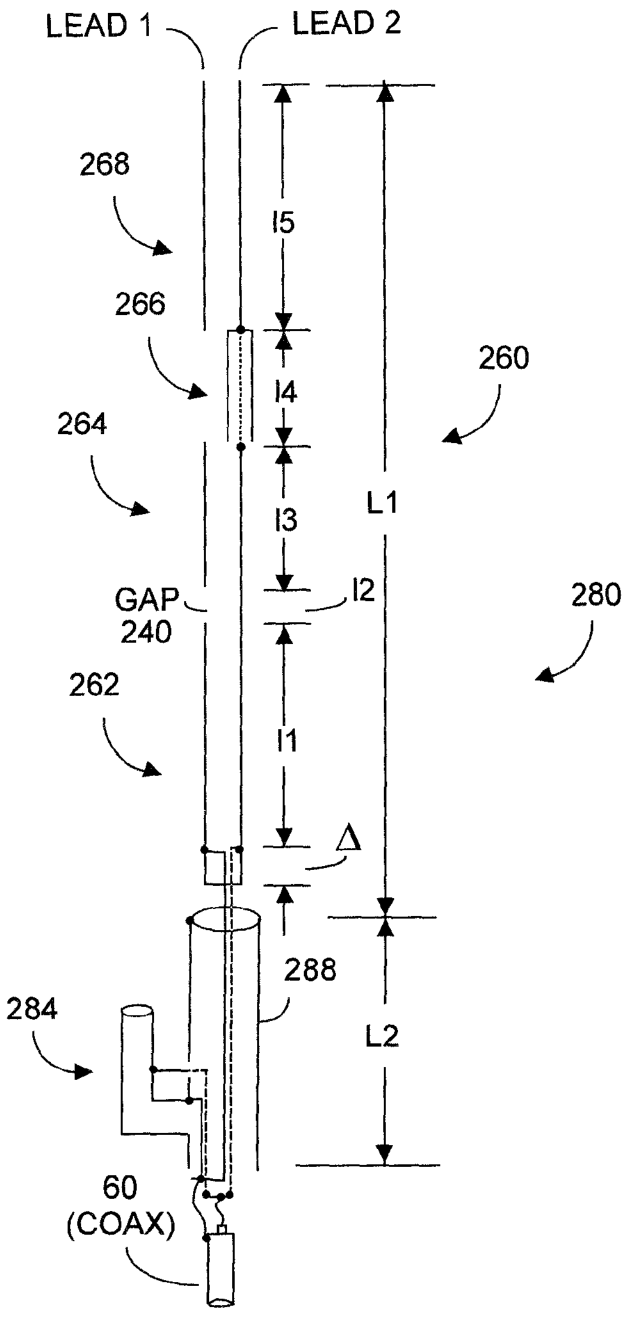

LEAD 1
LEAD 2
268
l5
266
l4
260
264
l3
L1
GAP
240
l2
280
262
l1
Δ
288
284
L2
60
(COAX)

FIG. 8

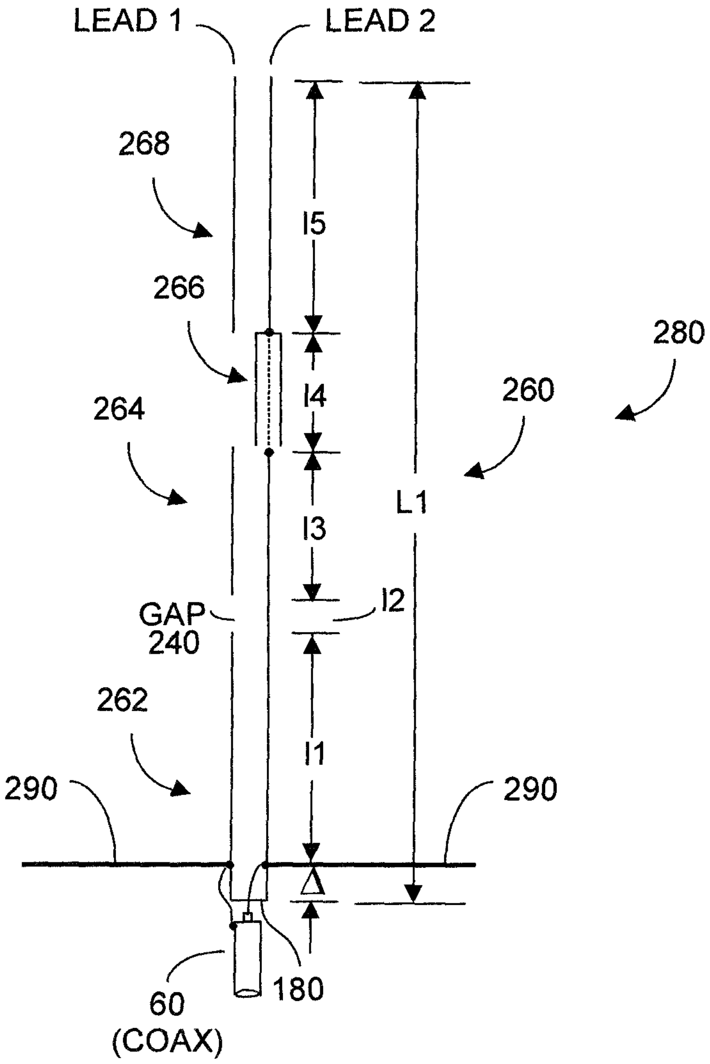

LEAD 1
LEAD 2
268
l5
266
280
l4
264
260
L1
l3
GAP
240
l2
262
l1
290
290
Δ
60
(COAX)
180

FIG. 9

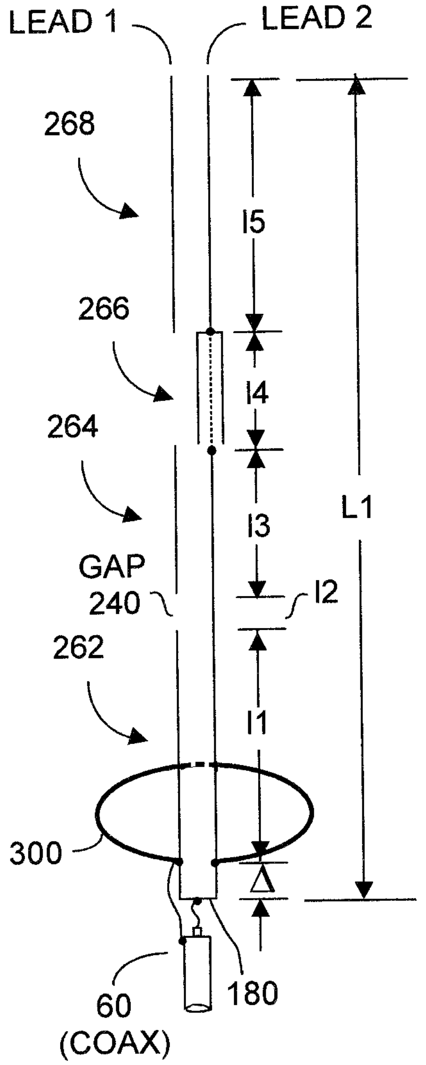

LEAD 1
LEAD 2
268
266
264
GAP
240
262
300
60
(COAX)
180
l5
l4
l3
l2
l1
Δ
L1
260
290

FIG. 10

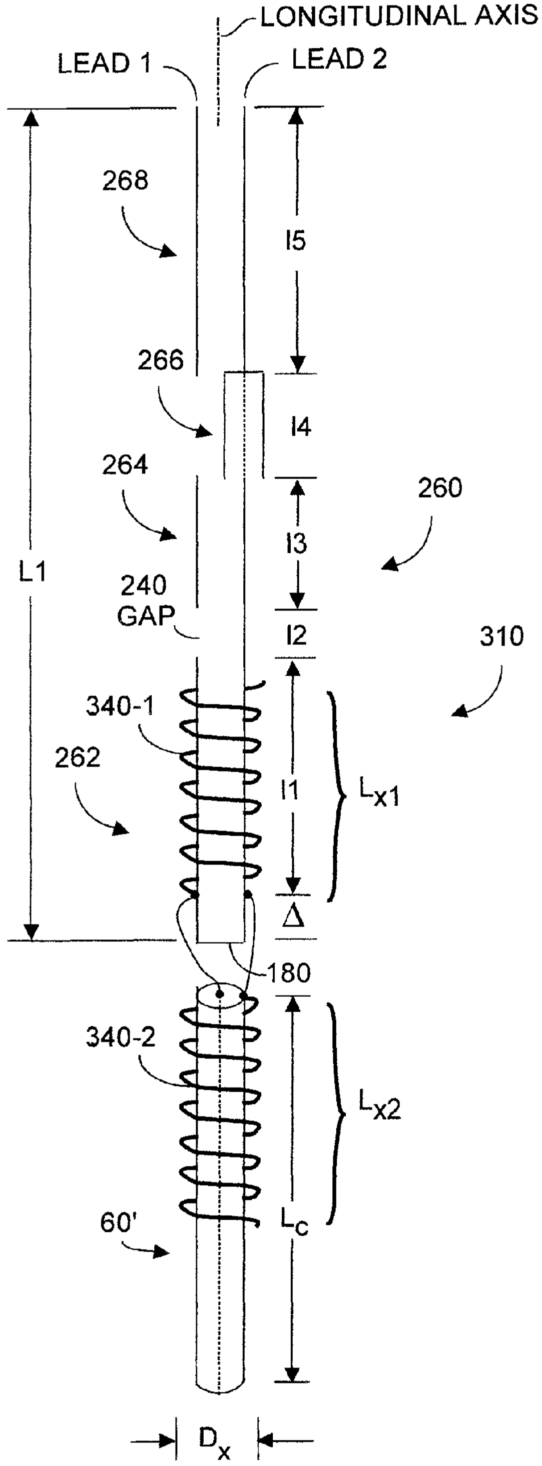


FIG. 11A

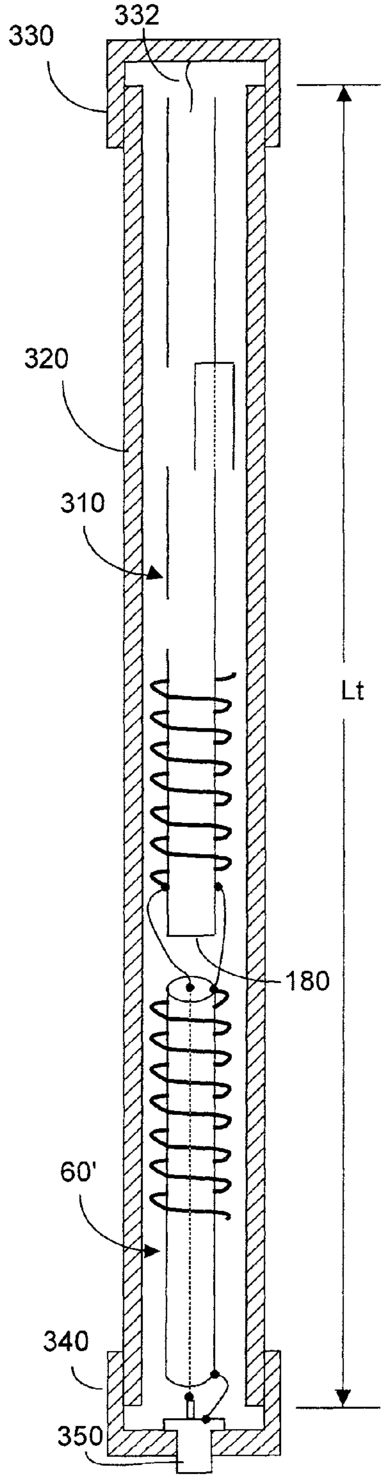


FIG. 11B

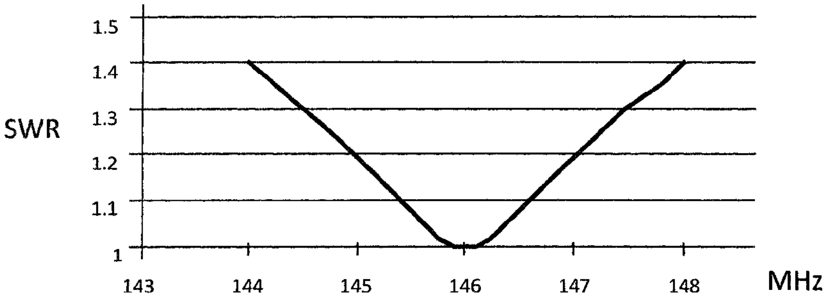


FIG. 12A

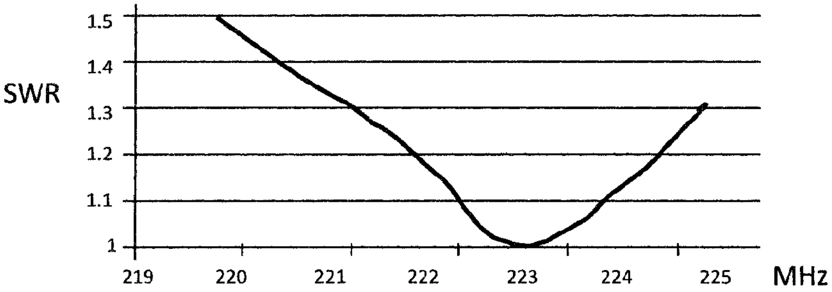


FIG. 12B

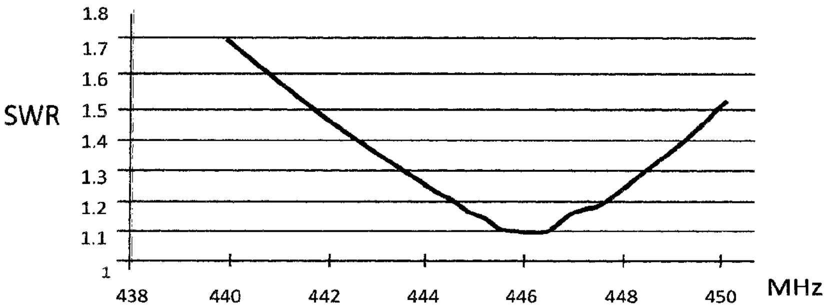


FIG. 12C

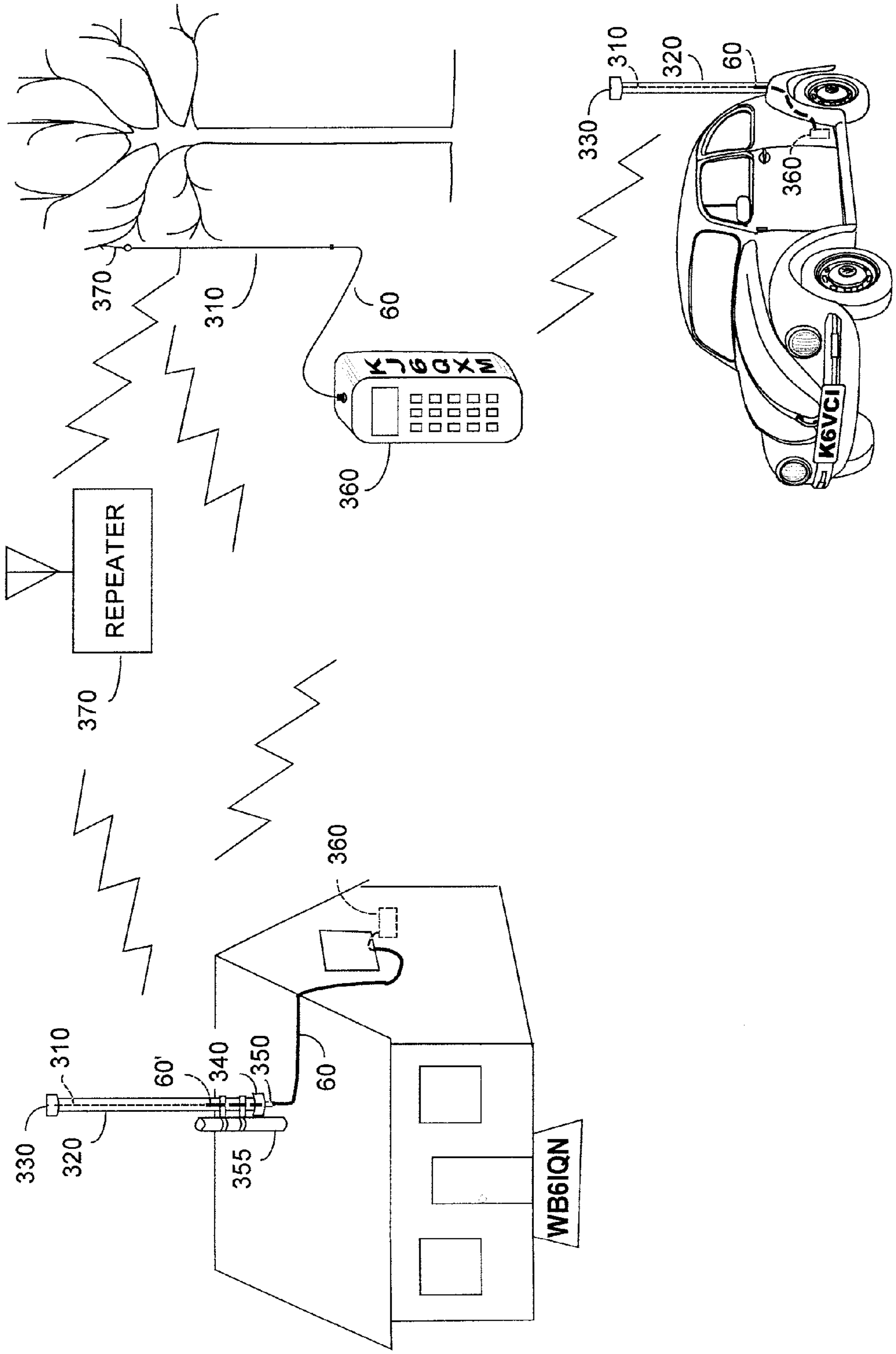

330
320
310
60'
340
350
355
60
360
WB6IQN
370
REPEATER
370
310
60
360
KJ6QXM
330
310
320
60
360
K6VCI

FIG. 13

RADIAL-FREE COLLINEAR OMNI-DIRECTIONAL TRIBAND HALF WAVELENGTH ANTENNA WITH VIRTUAL GROUND, SINGLE COAXIAL CABLE FEEDPOINT, AND WITH MINIMAL INTERACTION OF ADJUSTMENT BETWEEN BANDS

FIELD OF THE INVENTION

The invention relates generally to antennas that radiate and receive radio frequencies (RF) preferably for use in the very high frequency (VHF) range (about 140 MHz-170 MHz), an intermediate range (about 220 MHz-225 MHz), and ultra-high frequency (UHF) range (about 420 MHz-470 MHz), which antennas do not require radials or connection to absolute ground. Preferably such antennas should be mechanically robust over extremes of temperature and wind, and should be relatively inexpensive to mass produce and transport, with a length under about 2 m. Further, such antennas should exhibit gain commensurate with a half wavelength dipole over at least three bands ranging from VHF to UHF, including operation intermediate VHF and UHF frequencies. The antenna should exhibit minimal inter-band interaction if antenna adjustments are made, should have a single coaxial cable feed point, and should be relatively maintenance free.

BACKGROUND OF THE INVENTION

Radio frequency (RF) antennas are used to receive and/or radiate RF signals.

An effective antenna for use in transmission will exhibit an acceptably low standing wave ratio (SWR) at the frequencies of interest, and will present a reasonably good impedance match to the output of the transmitter, typically 50Ω to 75Ω. While some antenna designs such as beams exhibit directionality, i.e., more antenna gain in one direction compared to another, in many applications it is desired that the pattern of radiation from the antenna be omnidirectional. Further it is often desired that the antenna not require ground radials. Ground radials undesirably increase antenna wind load thus lessening robustness and portability, and increase manufacturing cost.

Many innovations in antenna design have come from the amateur radio community. Pioneer work in the area of so-called fractal antenna has been accomplished by Nathan Cohen (W1IR, W1YW) of Belmont, Mass., e.g., U.S. Pat. Nos. 6,104,349, 6,127,977, 6,140,975, 6,445,352, 7,019,695, and 7,701,396, among others.

Another innovation in multi-band antenna design is depicted in FIGS. **1**A and **1**B, namely the so-called Don Johnson screwdriver antenna, invented in March 1991 and named after its late inventor Don Johnson (W6AAQ) of Esparta, Calif. Overall antenna **10** includes a whip portion **20**, typically 3' to perhaps 8' in length, mounted to make electrical connection with the upper end of an inductor **30**. Inductor **30** typically is formed about a non-conductive cylinder of perhaps 2" diameter and perhaps 12" length. The upper portion of housing **40** includes conductive finger stock that presses against inductor **30**, effectively grounding to housing **40** all portions of inductor **40** that are within the housing. Inductor **30** and the cylinder it is formed upon can be urged vertically upward and downward within a metal cylinder housing **40** to alter magnitude of the effective inductance protruding from housing **40**. A threaded rotatable shaft **80** is connected between the lower end of the inductor **30** cylinder and the rotatable shaft of a small DC motor **70**. Motor **70** is typically a motor from an electric screwdriver, hence the "screwdriver" name for the antenna. Two wires from motor **70** can be applied to a plus or a minus polarity DC voltage, to cause motor **70** to rotate clockwise or counterclockwise, causing more or less of inductor **30** to lie within housing **40**, which is to say to decrease or increase magnitude of the effective inductance protruding from the housing. A matching inductor **50** is formed at the base of the antenna and a length of typically 50Ω coaxial cable **60** is connected as shown. The other end of coaxial cable **60** will typically go to a transceiver, or transmitter, or receiver. Tuning antenna **10** simply involves applying plus or minus DC voltage to motor **70** to mechanically resonate the antenna to a desired frequency range. Antenna **10** can be tuned by first setting the transceiver (or receiver) to a desired frequency and then adjusting the effective length of inductor **30** by rotating motor **70** in the proper direction (by applying plus or minus voltage to motor **70**) to resonate the antenna, as evidenced by a peak in amplitude of received signals.

In FIG. **1**A, DC voltage has been applied to motor **70** to rotate nearly all of inductor **30** into housing **40**. The effect at RF frequencies is that only the portion of inductor **30** protruding from housing **40** functions as an inductor. The antenna operates as a center loaded device whose resonance is determined primarily by the effective inductance **30** and the whip **20**. In FIG. **1**B, DC voltage was applied to motor **70** to rotate threaded shaft **80** such that more of inductor **30** can now resonant with whip **20** such that the additional effective inductance lowers the resonant frequency of the overall antenna. Advantageously the antenna can operate continuously within a very wide range of frequencies, merely by applying DC voltage to motor **70** to cause more or less inductance to be used. In practice, many thousands of Don Johnson (W6AAQ) screwdriver antennas have been used worldwide with great success over frequencies ranging from as low as about 3.5 MHz to as high as perhaps 144 MHz.

In other applications, especially higher frequency applications, a less mechanical antenna may be desired, especially for considerations of cost and ease of construction. In the radio amateur community, high frequency bands of interest include VHF (2 m range wavelengths, typically about 144 MHz to about 148 MHz), UHF (70 cm range wavelengths, typically about 420 MHz to about 450 MHz), and intermediate to VHF and UHF, the 1.25 m range wavelengths (typically about 222 MHz to about 225 MHz). One common type of antenna, especially for VHF (2 m range wavelengths) and/or UHF (70 cm range wavelengths), is the so-called collinear antenna. A collinear antenna is an array of at least two dipole antennas, configured such that every element of each dipole is an extension, relative to a longitudinal antenna axis, of the other dipoles in the array. Collinear antennas can exhibit gain over an isotropic radiator.

FIG. **2**A depicts an antenna **90** comprising collinear elements **100**, **110**, **120**, used with at least four antenna base-mounted quarter-wavelength radials **130** that function as a ground plane. Preferably coaxial cable **60** is coupled to antenna **90**, with the other end of coaxial cable **60** coupled to a transceiver, a transmitter, or a receiver (not shown). Lowermost element **100** in FIG. **2**A is a quarter-wavelength at the nominal frequency of interest. Intermediate element **110** is coupled to act as a half-wave delay element, and uppermost radiating element **120** preferably has a length equal to a half-wave. The various elements **100**, **110**, **120** can be fabricated from lengths of coaxial cable, whose center conductor is indicated by phantom lines, and whose outer shield conductor is indicated by solid lines on either side of the center conductor. Note that the collinear arrangement alternates electrical connection between the center conductor of an element and the outer conductor.

In FIG. **2**A, if one tried to use quarter-wavelength element **100** with an extension half-wavelength (i.e., center-conductor to center-conductor, shield-to-shield), no additional gain would result due to phase cancellation of radiation in the quarter-wave and half-wave elements. FIG. **2**B depicts voltage amplitude versus phase for the various elements of antenna **90**. As confirmed by FIG. **2**B, non-radiating half-wave delay element **110** provides the desired ground reference function. This results from coupling the shielded outer conductor of element **100** to the inner conductor of element **110**, which inner conductor acts as a ground reference. Note at the base of antenna **90** that radials **130** are also coupled to this ground reference via the center conductor of element **100**. As shown in FIG. **2**A, after a quarter-wavelength at the junction of elements **100** and **110**, the shield and inner conductor are swapped. At its upper end, element **110** is coupled to the lower end of half-wave coaxial element **120**, again by swapping of center conductor and shield outer conductor. As the radiated radio frequency energy exits the upper end of element **120** it is back in phase with quarter-wavelength radiating element **100**. If desired additional elements, i.e., another triplet of elements **100**, **120**, **120** could be added atop present uppermost element **120** in collinear fashion. However a point of diminishing returns effectively occurs at about four elements in that marginal further increase in gain does not warrant the cost of the additional elements.

Disadvantageously, antenna **90** requires several, typically at least four, quarter-wavelength radials **130**, preferably bent downward at an angle of perhaps 45° to establish an RF ground. As noted, an RF ground reference node exists at the junction of radials **130** and the outer shield of coaxial cable **60**. Radials often require machining to properly make good electrical connection at the base of antenna **90**. In practice stainless steel radials are preferred for reasons of strength and electrical contact over less expensive aluminum radials. The presence of radials impacts the robustness of the antenna design. Radials can easily break off in the presence of strong winds, or by birds perching on the radials. If the radials are on the ground, they may be damaged from being walked upon. Further, the electrical conductivity between the radials and the shield of coaxial cable **60** will inevitably deteriorate over time.

FIG. **3** depicts an attempt in the prior art to eliminate radials by using a quarter-wave sleeve. Referring to FIG. **3**, antenna **140** has at its base a quarter-wave element **100**, then a half-wave delay element **110**, above which is disposed an upper half-wave radiating element **120**. These collinear elements **100**, **110**, **120** in antenna **140** are configured similarly to the same elements in antenna **90** in FIG. **2**A, and are made from segments of coaxial cable. Rather than employ radials (as in FIG. **2**A), antenna **90** employs a conductive quarter-wavelength sleeve **150** to implement an effective quarter-wavelength foldback and RF ground reference. The term "foldback" is used in that sleeve **150** covers a portion of the connecting coaxial cable **60**. Sleeve **150** is commonly made of conductive brass or copper pipe, and the connection to coaxial cable **60** is typically made within the sleeve. This configuration advantageously gains robustness by eliminating radials, and exhibits a slightly lower angle of radiation that can add to transmitting and receiving range of the antenna. However the sleeve configuration can make it difficult to achieve desired low SWR due to inherent coupling between the outer shield conductor of coaxial cable **60** and the wall of sleeve **150**.

FIG. **4** depicts yet another attempt in the prior art to implement an omnidirectional antenna without radials. As shown in FIG. **4**, a portion of this antenna looks like the letter "J", and this configuration is sometimes referred to as a "Super-J" antenna. A full description of antenna **160** may be found in the ARRL Antenna Handbook, 19*th* ed., chapter 16, pp. 24-27, "The Supper J Maritime Antenna." Referring to FIG. **4**, the lower end of antenna **160** is a quarter wavelength matching element **170**, typically 300 twinlead, whose two leads or wires are shorted together at the bottom **180**. The RF impedance at the shorted bottom **180** is of course 0Ω, but at a distance Δ above bottom **180**, the RF impedance will be close to the impedance of coaxial cable **60** to be a good match, e.g., 50Ω or so. The upper end of quarter-wavelength matching element **170** is coupled to a half-wave radiating element **190**, as the upper end of quarter-wavelength matching element **170**, and either end of half-wave radiating element **190** are both RF high impedances.

Referring still to FIG. **4**, note that elements **190** and **210** are disposed vertically and are RF radiating elements. By contrast, the upper end of half-wave radiating element **190** is coupled to a horizontally disposed delay element **200**. Delay element **200** comprises two parallel quarter-wavelength element coupled in a horizontally-disposed "U"-shaped configuration. The horizontally polarized RF energy associated with the lower and with the upper elements of delay element **200** are 90° out-of-phase with respect to each other and thus cancel one another. Ideally the phase delay and radiation patterns associated with element **200** would be perfectly out-of-phase, but in practice some phase error and associated antenna inefficiency will exist. "U"-shaped delay element **200** may be thought of as contributing an outgoing lower quarter-wavelength delay and an incoming quarter-wavelength delay. The net result is that these horizontally disposed elements represent an effective half-wave delay element **200**. The upper portion of "U"-shaped delay element **200** is connected to the lower end of a vertically disposed (and vertically radiating) half-wave radiating element **210**. In this fashion the antenna of FIG. **4** implements the functional equivalent of the ready access to ground that was present in the antenna of FIG. **2**A. The desired overall half-wavelength delay with desired non-radiating characteristics for 180° of the phase waveform is achieved by "U"-shaped element **200**.

Regrettably, antenna **160** is not robust in that delay element **200** projects out horizontally from the vertical antenna into the environment, and is difficult to reliably fasten between radiating elements **190** and **210**. Alternatively some designs also seek to achieve phase delay with inductor-capacitor (LC) components rather than with an element **200**. However such solutions are not optimum because losses and tolerance changes in the L and C components vary over time, which can reduce effectiveness of the desired delay function.

FIG. **5** depicts a so-called conventional mono-band "J-pole" antenna that can be fabricated from a single length of 300Ω twin lead cable, comprising LEAD 1 and LEAD 2, that has a gap or notch cut in one lead (LEAD 1). The lowermost end of antenna **220** has a short **180** between LEAD 1 and LEAD 2 to establish a 0Ω region, adjacent to which is a quarter-wavelength impedance matching element **230**, sometimes referred to as a shorting stub element. Impedance matching element **230** is passive in that it does not radiate RF energy. A perhaps 0.25" gap or notch **240** is formed in LEAD 1 to separate element **230** from the remainder of antenna **220**. A half-wave RF radiating element **250** is formed above gap **240** in LEAD 1 and above matching element **230** in LEAD 2. The uppermost end of antenna **220** is open ended, or high impedance, and the lowermost end by virtue of the short is 0Ω. Experimentally a pair of low impedance, e.g., 50Ω, feedpoints are found a distance Δ (typically about 1.25") above the 0Ω short **180**. Coaxial cable **60** (typically RG174A) center conductor is connected to one feedpoint and the coaxial cable braid shield is connected to the other feedpoint.

Antenna **220** in FIG. **5** may be cut or sized for the 144 MHz VHF band for use within protective 0.75" O.D. 200 PSI PVC pipe, with the detuning effect of the PVC pipe being accounted for in the following dimensions. As such for VHF half wavelength RF radiating element **250** will measure about 37.25", gap **240** will be 0.25", distance Δ will be about 1.25", and quarter wavelength matching element **230** will be about 16". If antenna **220** were cut or sized for the 440 MHz UHF band within the same protective PVC pipe, half wavelength RF radiator **250** would measure about 12", gap **240** will be 0.25", distance Δ will be about 0.5", and quarter wavelength matching element **230** will be about 5", with RG174A coaxial as a preferred cable **60**. Of course antenna **220** in FIG. **5** could be scaled to operate in the 220 MHz band, in which case half-wavelength radiating element **250** would be about 26" in length, quarter-wavelength impedance matching element **230** would be about 9.75", the latter 0.75" being the dimension of Δ. These exemplary dimensions assume the finished antenna will be mounted with 0.75" diam. 200 PSI PVC pipe. The term "J-pole" arises from the "J-shape" defined by the LEAD 1 portion of region **230** including the 0Ω short, including Lead 2 extending to the top of the antenna.

Monoband J-pole **220** in FIG. **5** operates as a half wavelength vertical end-fed dipole antenna. In a conventional half-wave antenna, the antenna ends are high impedance and the antenna center including the feedpoints is low impedance. However in the half wavelength J-pole configuration of FIG. **5** the inclusion of the passive quarter wavelength impedance matching section **230** enables end matching to the antenna with an approximately 50Ω feedpoint pair. If antenna **220** is mass produced, it suffices to measure distance Δ on a prototype antenna using an antenna analyzer, and to fine tune location of gap **240**, and then to replicate the prototype antenna in quantity. Vertical end-fed monoband J-pole dipole antenna **220** in FIG. **5** has a radiation pattern close to an ideal dipole, thanks to end-fed coaxial cable **60** being in-line with the antenna axis or length. By contrast, in a conventional center-fed vertical dipole, the coaxial cable connects to the center of the antenna at 90° to the axis or length of the antenna, and thus distorts the dipole radiation pattern. A well-designed J-pole antenna **220** is a good half-wave radiator that provides about 2.1 dB gain over an isotropic radiator, but no gain relative to an ideal half-wave antenna.

It will be appreciated that monoband J-pole antenna **220** is omni-directional, inexpensive to fabricate, and requires no radials. In practice the antenna can be inserted within a length of UV-resistant PVC pipe that is sealed at the top and bottom, to provide a robust configuration with relatively low wind resistance. Understandably the dimensions of the J-pole antenna will be adjusted somewhat to compensate for the velocity factor effect of the surrounding PVC pipe upon the antenna characteristics in open air, to avoid detuning. In practice J-pole antenna **220** can achieve about a 1.5 dB gain improvement over a quarter wavelength ground plane antenna because it is a true half wavelength antenna. In a conventional ground plane antenna such as was described in FIG. **2**A, ground radials **130** were necessary to act a counter element (e.g., ground or earth). With radials bent downward from say 0° (i.e., horizontal) to about 45°, and disadvantageously a relatively high angle of radiation will result. By contrast, monoband J-pole antenna **220** has no radials and advantageously exhibits a lower angle of radiation, which results in a gain of about 1.5 dB in the horizontal plane relative to a conventional ground plane antenna.

FIG. **6**A depicts the DBJ-1 (WB6IQN) dual-band J-pole antenna **260**, invented by applicant herein, which resonates and radiates efficiently as a half-wavelength vertical antenna on each of the VHF and UHF bands, using a single feedline, without need for a ground. Referring to FIG. **6**A, at the very bottom region **180** of antenna **260** the twinlead (comprising LEAD 1, LEAD 2 with the plastic insulating material not shown) is shorted together to form a 0Ω region. However above this short at a distance Δ (typically about 1.25") a low impedance (preferably about 50Ω) feedpoint pair can be located. Coaxial cable **60**, e.g., RG174A, is attached to the antenna at this feedpoint pair and preferably exits antenna **260** collinearly rather than perpendicular to the antenna longitudinal axis or length, to reduce interference with the antenna RF radiation pattern.

Referring still to FIG. **6**A, immediately above the low impedance feedpoints antenna is twinlead extending upward a distance l**1** (typically about 16"), which together with the small distance Δ (about 1.25") functions as a passive, non-radiating impedance transformer **262**. At VHF impedance transformer **262** functions as a quarter wavelength stub matching transformer but at UHF functions as a three-quarter wavelength stub matching transformer, electrically the series sum of a quarter-wavelength and a half-wavelength. As it is non-radiating and passive, impedance transformer **262** does not interfere with UHF RF radiating section **264** or with VHF RF radiating section **268** of antenna **260**. A notch or gap **240** of length l**2** (about 0.25") is formed in LEAD 1 to separate impedance matching stub region **262** from the remaining regions **264**, **266**, **268** of the antenna above.

Continuing upward in FIG. **6**A, element **264** is the UHF half wavelength radiating portion of antenna **260** and comprises length l**3** (about 11.25") of twinlead. As will now be described region **266** functions as a mechanism to decouple the upper end of UHF half wavelength radiator **260** from region **266** and region **268**. In theory such UHF decoupling mechanism might be a self-powered SPST relay that sensed when to open (during UHF triband antenna use) and when to close (during non-UHF triband use). In theory such UHF decoupling mechanism might be an ideal inductor in parallel with an ideal capacitor, the inductor-capacitor resonating in the UHF band, i.e., exhibiting infinitely high impedance. But in practice such relays do not exist, and perfect inductors and capacitor (which components have no loss, and do not drift in value) do not exist.

Applicant found a suitable, lightweight and inexpensive UHF decoupling mechanism to be the quarter wavelength stub **266**, shown in FIG. **6**A. UHF decoupling stub **266** comprises a length l**4**, a quarter wavelength at UHF (about 4.25"), of preferably RG174A coaxial cable disposed in LEAD 2 to terminate or isolate UHF radiating region **264** from VHF radiating region **268** above at UHF frequencies. At the upper end UHF decoupling stub **266** has its shield and center conductor soldered together to form a zero impedance, which at a UHF quarter wavelength transforms to an open or high impedance at the lower end or bottom of the stub. At the open lower end of stub **266**, the center conductor of the coaxial length comprising the stub is soldered to the region of LEAD 2 opposing gap **240**, and the braid shield is left floating. At UHF frequencies, UHF decoupling stub **266** presents an open circuit (high impedance) but at VHF frequencies acts as a closed circuit, albeit with small inductance. Above UHF decoupling stub **266** is a length l**5** (about 17") of twinlead that coupled with length l**4** and length l**3** of element **264** comprises the VHF radiating region **268** of antenna **260**. It will be appreciated that UHF decoupling stub **266** acts somewhat as a switch that ideally is closed at VHF frequencies to allow lengths l**2**+l**3**+l**4**+l**5** combine to function as a half-wave RF VHF radiator **268**, but at UHF frequencies acts ideally as an open switch that decouples regions **266** and **268** from region **264**. Region **264**+l**2** then act as a half-wavelength RF UHF radiator. On the other hand, at VHF frequencies decoupling stub **266** acts like a closed switch, and antenna regions **268** and **264** (and the length of decoupling stub **266**) and the slight contribution from l**2** combine to form a half wavelength at VHF. Consequently antenna **260** resonates well and radiates RF well at both VHF and UHF frequencies.

DBJ-1 antenna **260** as shown in FIG. **6**A has enjoyed great acceptance with the radio amateur community, as well as with numerous emergency services agencies, federal, state, and local, that rely upon VHF/UHF communications devices. More than 10,000 DBJ-1 antennas have been constructed and deployed in the U.S. and abroad. The antenna of FIG. **6**A may be fabricated from 300Ω twinlead, and fed with RG174A coaxial cable, cable **60**, preferably coupling to the antenna along the antenna longitudinal axis, to minimize interference with the antenna RF radiation pattern. Twinlead fabrication of antenna **260** contributed to low manufacturing cost and portability. The twinlead portion of the antenna is small and lightweight, and can be mailed to a user. If the antenna will be used mounted within a specified type of PVC tubing, the antenna twinlead (LEAD 1, LEAD 2) is pre-cut during fabrication, taking into account the PVC tubing characteristics. The pre-cut twinlead is mailed to the user with instructions to buy the specified PVC tubing locally, and mount the antenna within. A complete description of this antenna is set forth in the article "A Dual Band VHF-UHF Single Feedline J-Pole", *QST*, February 2003, vol. 87, no. 2, pages 38-40, by E. Fong, applicant herein. Further details regarding the design of antenna **220** may be found at QST magazine, February 2003, pp 38-401, E. Fong (WB6IQN), "The DBJ-1: A VHF-UHF Dual-Band J-Pole", and QST magazine, March 2007, E. Fong (WB6IQN), "The DBJ-2: A Portable VHF-UHF Roll-up J-pole Antenna for ARES".

Thus as used herein, the term DBJ-1 dual-band J-pole antenna is understood to refer to VHF-UHF twinlead antenna **260** as depicted and described above with reference to FIG. **6**A. It will be appreciated that at UHF the radiating element is the lead 2 portion l**5**+l**2**, and that the the lead 1 portion above gap **240** is simply floating, does not radiate, and in fact could be removed. Similarly it will be appreciated that at VHF the radiating element is the lead 1 portion of l**5**+stub **366**+the lead 1 portion of l**3**+l**2**, and that the lead 1 portion above gap **240** is simply floating, does not radiating, and could be removed. Thus above the level of l**1**, the twinlead comprising lead 1 and lead 2 could be replaced by a single wire denoted lead 2, with lead 1 being completely removed.

FIG. **6**B depicts a fundamental and a third harmonic radiation pattern for a dual band J-pole such as shown in FIG. **6**A, depicting radiation performance with and without UHF decoupling stub **266**. In FIG. **6**B, if the UHF decoupling stub were absent, radiation is the third harmonic pattern, a somewhat distorted butterfly pattern. This distortion results because the third harmonic of VHF is UHF, and has the undesired characteristic that perhaps 75% of the radiation emanates up into the sky. The fundamental radiation pattern, by contrast, results when UHF decoupling stub is used, as in antenna **260**, and is a clean half wavelength dipole radiation pattern.

FIG. **7** depicts a prior art attempt to implement a triband antenna operable in the in the 2 m (144 MHz) VHF band, the 1.25 m (220 MHz) intermediate VHF-UHF band, and the 70 cm (440 MHz) UHF band. Antenna **280** in FIG. **7** is a stacked triband antenna described by J. L. Harris "A VHF/UHF) 3 Band Mobile Antenna", QST Magazine, February 1980. Antenna **280** is essentially three parallel J-pole antennas, one antenna for each of the three bands, comprising a quarter-wave wavelength stub **282** for 146 MHz, a quarter-wavelength stub **284** for 220 MHz, and a quarter-wavelength stub **286** for 445 MHz, all fabricated using soldered-together 0.5" O.D. copper plumbing pipe and copper plumbing elbow joints. These copper quarter-wavelength stubs are soldered to a vertical copper member **288**, that comprises the main body of triband antenna **280**.

Within hollow member **288** three lengths of coaxial cable such as **60** run vertically. One length has its center lead (shown in phantom) soldered to the shell of stub **286**, and has its shield soldered to the shell of member **280** adjacent the entry hole. A second length of coaxial cable has its center lead soldered to the shell of stub **284** and its shield soldered to member **280** adjacent the entry hole. A third length of coaxial cable has its center lead soldered to the shell of stub **282**, and has its shield soldered to member **280** adjacent the entry hole. At the bottom of antenna **280**, all three center leads from the three coaxial cables are soldered together and to the center lead of feed coaxial cable **60**, RG174A or the like. The shield of feed coaxial cable **60** is soldered to the shell of member **288** at the bottom of antenna **280**. At the relevant resonant frequency band, each quarter-wave copper stub presents an approximately 50Ω impedance. Unfortunately antenna **280** in FIG. **7** lacks a mechanism to decouple the UHF radiator portion of the antenna from the VHF radiator portion, e.g., a mechanism serving the role of UHF decoupling stub **266** in DBJ-1 antenna **260** in FIG. **6**A. Consequently because it is harmonically related, the VHF portion of antenna **280** will resonant at UHF frequencies, which disturbs the antenna radiation pattern at UHF. Another shortcoming is that triband antenna **280** in FIG. **7** is not especially robust, especially with the three small entry holes into the main vertical member, through which water can enter to the detriment of the center lead connections to coaxial cable **60** at the antenna bottom. Robustness is compromised by the inherent weakness of solder joints, especially in inclement weather. The overall antenna is about 1.6 m from top-to-bottom, is rigid but fragile, and is not readily shippable. However one advantage of the copper tubing fabrication is that the effective cross-section of the antenna is far greater than if twinlead were used. Consequently a copper tubing J-pole can exhibit greater bandwidth than a J-pole made of very narrow wire twinlead. However on balance, the cost, weight, lack of robustness, and difficulty in transporting a copper J-pole mitigate against using such material.

What is needed is an inexpensive, readily fabricated triband antenna that provides performance commensurate with a half wavelength vertical antenna on each band, has a virtual ground requiring no radials, provides independent adjustment, if needed, on each band without substantially affecting performance on the remaining bands. Such antenna should be collinear in form factor, robust, radiate omnidirectionally, should be lightweight and inexpensive to fabricate. Further the antenna should be readily shippable and readily deployable in portable applications, and should be less than about 1.7 m in length. Finally, there should be a single antenna connection port common to all three bands such that a single external coaxial cable can be connected to the triband antenna for operation at any or all of the three bands.

The present invention provides such an antenna.

SUMMARY OF THE PRESENT INVENTION

The present invention provides a triband antenna operable with acceptable standing wave ratio (SWR) performance in the VHF (about 140 MHz-170 MHz), UHF (about 420 MHz-470 MHz), and intermediate VHF-UHF (about 220 MHz-225 MHz), bands. The antenna performs on each band with the gain of a half wavelength vertical antenna, which is to say 0 dB relative to a dipole, or 2.1 dB gain relative to an isotropic antenna. This performance is 6 dB-8 dB more gain than is provided by commonly used “rubber-duck” antennas used on many portable VHF-UHF transceivers. At VHF band and at UHF band the triband antenna is a half-wavelength end-fed vertical dipole, and at intermediate band the triband antenna is a half-wavelength center-fed vertical dipole. The triband antenna exhibits good omni-directional RF radiation performance, notwithstanding that the intermediate band is not harmonically related to the VHF or the UHF band. The triband antenna operates without radials or an absolute ground and at its bottommost region provides a low impedance antenna port to which an external coaxial cable can be coupled for antenna operation over any or all of the three bands. The other end of the external coaxial cable would be coupled to a transceiver or the like operable on any or all of the three bands. The antenna preferably is fabricated from inexpensive twinlead and may be mounted within PVC tubing, which provides protection against inclement weather, UV radiation, and enables a robust manner of antenna mounting. Triband antennas according to embodiments of the present invention can be fine-tuned on one band without affecting the other two bands, in part due to the unique topology employed.

Antenna structure at VHF and UHF frequencies is similar to a DBJ-1 dual-band J-pole preferably fabricated at least in part from twinlead comprising first and second leads. At the very bottom of the J-pole the first and second leads of the twinlead are shorted together to define a 0Ω impedance, above which at a distance Δ a nominal low impedance, e.g., about 50Ω, feedpoint pair exists. The upper end of a length Lc of coaxial cable is coupled to these feedpoints, and the lower end of this length of coaxial cable is the connection port to the triband antenna. This connection port enables one end of a length of typically 50Ω external coaxial cable to be coupled to the triband antenna, with the other end of the external coaxial cable coupled to a transceiver or the like operable on VHF and/or intermediate band and/or UHF frequencies. At the upper end of the length Lc, the coaxial cable center conductor is preferably connected to the first lead of the twinlead at the low impedance feedpoint, and the braid shield of the coaxial cable is connected to the second lead of the twinlead at the low impedance feedpoint, although these two connections of the upper end of the Lc length of coaxial cable could be reversed. A notch is cut in the first lead a distance above the low impedance feedpoint, to define in the twinlead below the notch a passive, non-radiating, impedance matching transformer antenna region. This impedance matching transformer region is a quarter wavelength at VHF frequencies and a three-quarter wavelength at UHF frequencies. Above the notch cut in the first lead is a length of twinlead that is a half wavelength radiator at UHF frequencies. A UHF decoupling stub is disposed in the second lead above the UHF radiator. This UHF decoupling stub exhibits high impedance at UHF frequencies and serves to decouple the UHF half-wavelength radiator below this stub from the remainder of the antenna above the stub. The first lead in the twinlead is cutaway opposite the UHF decoupling stub in the second lead of the twinlead. Above the UHF decoupling stub is a length of twinlead representing a portion of the radiator at VHF frequencies. At VHF frequencies the UHF decoupling stub essentially couples the upper end of the UHF half-wavelength radiator and the length of the UHF decoupling stub itself to the VHF radiator to collectively form a half-wave radiator at VHF frequencies. The UHF decoupling stub may be implemented as a quarter wavelength of coaxial cable whose center conductor is shorted to the coaxial cable shield at the top of the quarter wavelength, but is not shorted at the bottom. At a quarter wavelength the zero impedance at the top of the UHF decoupling stub transforms to an open or high impedance at the bottom of the stub.

The radiating element for the intermediate band is formed as first and second helical windings of electrical wire, whose combined stretched-out length is a half wavelength at the intermediate band. The first helical winding is wound around the passive, non-radiating quarter wavelength/three-quarter wavelength impedance matching transformer at the bottom of the DBJ-1 J-pole antenna. The length of the first helix may extend from the antenna feedpoint region upwards to the notch cut in the first lead. The upper end of the first helix is not connected to anything, whereas the lower end of the first helix is connected to one of the two low impedance feedpoints, perhaps the feedpoint in the first lead of the twinlead. The second helix is wound around the upper region of the Lc length of coaxial, with the upper end of the second helix connected to the remaining low impedance feedpoint, perhaps the feedpoint in the second lead of the twinlead. The lower end of the second helix is not connected to anything. The unwound stretched-out length of the each helix is about 12", a quarter wavelength at the intermediate band, and the top-to-bottom length of each helix is Lx**1** or Lx**2**, about 7" each. The diameter of each helix preferably is such that the finished antenna can fit within the diameter of commonly available PVC pipe, perhaps 0.75" O.D. PVC pipe.

As noted, the region of the antenna about which the first helical radiator for the intermediate band is wound is passive and non-radiating. Similarly the region of the coaxial cable about which the second helical radiator for the intermediate band is wound is passive and non-radiating. Consequently antenna RF radiation at the intermediate band does not interfere with antenna RF radiation at VHF or UHF frequencies. Similarly the VHF and UHF radiating portions of the antenna do not interfere with antenna RF radiation in the intermediate band. The radiators for the intermediate band are helically and concentrically disposed relative to the length or longitudinal axis of the antenna, and the radii of the helix windings are much less than an intermediate band wavelength. Consequently and advantageously, adverse magnetic coupling between the helical windings and the rest of the antenna is substantially reduced and a good RF radiation pattern exists on each of the three bands.

Adjustments made to antenna lengths in one or more of the three bands do not affect antenna performance in the remaining bands, which advantageously simplifies final adjustment. The total length of the overall antenna, from top to bottom of the Lc length of coaxial cable, is about 64", which is a practical length to protectively house the antenna within 0.75" diameter PVC pipe for protection against weather, UV radiation that could damage the twinlead, and to facilitate outdoor robust mounting of the triband antenna. The cost of the antenna materials is minimal, and an assembled antenna may be mailed in a lightweight package, with instructions to the end user to purchase the PVC pipe and mount the assembled antenna within. As the velocity factor associated with the PVC pipe affects the antenna performance, the detuning effects of the PVC pipe are taken into account when fabricating the antenna, individually and in mass production quantities.

Other features and advantages of the invention will appear from the following description in which the preferred embodiments have been set forth in detail, in conjunction with their accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A and **1**B depict a wide-frequency range, omnidirectional Don Johnson type screwdriver antenna, according to the prior art;

FIG. **2**A depicts an omni-directional collinear antenna that requires radials, according to the prior art;

FIG. **2**B depicts voltage amplitude versus phase for various elements of the collinear antenna of FIG. **2**A, according to the prior art;

FIG. **3** depicts an omni-directional collinear antenna that uses a quarter-wave sleeve rather than radials, according to the prior art;

FIG. **4** depicts a so-called "Super-J" omni-directional antenna with a half-wave delay element that operates without radials, according to the prior art;

FIG. **5** depicts a mono-band omni-directional "J-pole" antenna with slight gain that operates without radials, according to the prior art;

FIG. **6**A depicts a DBJ-1 (WB6IQN) dual-band J-pole antenna that operates without radials, according to the prior art;

FIG. **6**B depicts the irregular radiation pattern that would result if the DBJ-1 antenna of FIG. **6**A omitted a UHF decoupling stub, according to the prior art;

FIG. **7** depicts a triband J-pole comprising three parallel coupled J-poles fabricated from copper tubing, according to the prior art;

FIG. **8** depicts a triband antenna comprising a DBJ-1 dual-band (VHF-UHF) J-pole antenna coupled at the low impedance feedpoint region to a 220 MHz copper pipe J-pole antenna, according to a first experimental prototype of the present invention;

FIG. **9** depicts a triband antenna comprising a DBJ-1 dual-band (VHF-UHF) J-pole antenna coupled at the low impedance feedpoint to a 220 MHz horizontal dipole, according to a second experimental prototype of the present invention;

FIG. **10** depicts a triband antenna comprising a DBJ-1 dual-band (VHF-UHF) twinlead J-pole antenna coupled at the low impedance feedpoints to a 220 MHz horizontally disposed segmented hoop element concentric about the antenna length, according to a third experimental prototype of the present invention;

FIG. **11**A depicts a triband antenna comprising a DBJ-1 dual-band (VHF-UHF) twinlead J-pole antenna coupled at the low impedance feedpoints to a first 220 MHz quarter wavelength length of wire coaxially disposed around the passive non-radiating impedance matching region of the J-pole antenna, and a second 220 MHz quarter wavelength length of wire coaxially disposed around the upper region of the coaxial cable connected to the triband antenna, according to preferred embodiments of the present invention;

FIG. **11**B depicts the triband antenna of FIG. **11**A mounted within a protective length of end-capped PVC pipe, according to preferred embodiments of the present inventions;

FIG. **12**A, FIG. **12**B, FIG. **12**C depict respective acceptably good SWR vs. frequency characteristics for the 2 m, 1.25 m, and 70 cm frequency ranges of the triband antenna of FIG. **11**A, according to preferred embodiments of the present invention; and

FIG. **13** depicts exemplary deployment of embodiments of the triband antenna of FIG. **11**A, according to preferred embodiments of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. **8** depicts applicant's initial attempt to design a triband antenna. Antenna **280** comprises a DBJ-1 (WB6IQN) dual-band VHF-UHF stacked J-pole twinlead antenna portion **260** (similar to antenna **260** in FIG. **6**A), comprising sections **262**, **264**, **266**, and **268**. However at the bottom of the passive non-radiating impedance transform section **262** of VHF-UHF J-pole **260** there is coupled a 220 MHz 0.5" diam. copper J-pole antenna portion **288** with copper quarter-wavelength stub **284** (similar to the 220 MHz portion **284** of antenna **280** in prior art FIG. **7**). Two lengths of coaxial cable, e.g., RG174A or the like, are disposed within copper antenna portion **288**. The center conductor of one coaxial cable is coupled to lead 2 of the above-lying stacked J-pole assembly, and the center conductor of the other coaxial cable exits via an entry hole from member **288** and is soldered to the shell of copper stub member **286**. The ground shield of this second coaxial cable is soldered the copper housing **288** near the exit hole. At the bottom of the overall antenna, the two center conductors are joined together to the feed coaxial cable **60** center conductor. The shield of cable **60** is soldered to copper member **288** as shown.

Referring still to FIG. **8**, the resultant antenna **280** did perform well as a triband antenna in the 2 m, the 1.25 m, and the 70 cm frequency ranges. The dual-band J-pole portion **260** of antenna **280** may be sized similarly to antenna **260** shown in FIG. **6**A: l5 was about 17", UHF decoupling stub **266** was a length l4 of about 4.25" length l2 of RG174A coaxial cable, the l3 portion of **264** was about 11.25", gap **240** was length l2 of about 0.25", length l1 of portion **262** was about 16", and distance Δ was about 1.25". (These dimensions assume that the dual-band J-pole antenna portion **260** will be encased in PVC tubing.) However the overall vertical size of antenna **280** was too large: L1 was about 49", and L2 was about 36" for a total vertical size of about 85" or about 2.2 m. The antenna vertical size and the presence of the soldered copper pipe region **286**, **288** caused applicant to reject this initial design.

The configuration of FIG. **9** was next investigated by applicant, wherein a DBJ-1 (WB6IQN) dual-band VHF-UHF twinlead antenna portion **260** (similar to antenna **260** in FIG. **6**A) includes a horizontally disposed 220 MHz dipole comprising elements **290**, each element **290** being a quarter wavelength at 220 MHz (about 12" in length). The 220 MHz dipole elements **290** are coupled preferably at the dual-band J-pole antenna low impedance feedpoints, whereat coaxial cable **60** is connected. Dimensions l**1**, l**2** (gap), l**3**, l**4** and l**5** are similar to what has been given with respect to the dual-band J-pole antenna configuration portions shown in FIG. **6**A and FIG. **8**. Triband antenna **280** had overall height L**1** about 49". While antenna **280** exhibited triband functionality in the 2 m, 1.25 cm, and 70 cm bands, unfortunately the horizontally disposed radial-like 220 MHz dipole **290** radiated RF horizontally, whereas the vertically disposed 2 m and 70 cm portions of the antenna radiated RF vertically, as is generally preferred. Further horizontally extending 220 MHz dipole elements **290** reduced robustness of overall antenna triband antenna **280**.

Applicant next experimented with the triband antenna configuration shown in FIG. **10**. The upper portion of triband antenna **290** comprises a DBJ-1 (WB6IQN) dual-band stacked J-pole VHF-UHF twinlead antenna portion **260** (similar to antenna **260** in FIG. **6**A, and antenna portions **260** in FIG. **8**, FIG. **9**, and FIG. **10**), coupled preferably at the low impedance coaxial cable **60** feedpoints to a horizontally disposed 220 MHz segmented circular hoop element **300** made of wire and having a circumference of about 24", e.g., a half wavelength at 220 MHz. Element **300** is two semi-circles. One end of each semi-circle terminates at one of the two low impedance feedpoints, and the other end of each semi-circle is separated from the other end of the other semicircle by a small insulation piece, shown in phantom in FIG. **10**. The vertical axis of antenna **290** lies through the center of the twinlead and passes through the center of the plane of circular hoop element **300**, which extends outward from the vertical axis with a radius of about 3.8". To minimize interaction with the main J-pole configuration, circular hoop element **300** wants to stand off and away from the J-pole at the feedpoints by at least 1".

Understandably having to secure segmented circular half wavelength element **300** to J-pole **260** decreases robustness of the overall antenna. In FIG. **10**, dimensions l**1**, l**2**, l**3**, l**4**, l**5** are similar to that given with respect to antennas shown in FIG. **6**A and FIG. **8**, with overall height L**1** being about 49". While antenna **290** functioned as a working triband antenna, horizontally disposed hoop element **300** radiated RF at 220 MHz substantially horizontally rather than the more preferred vertical radiation. However in the embodiment of FIG. **10** it was realized that disposing the 220 MHz element **300** coaxially about the length of J-pole antenna **260** advantageously kept 220 MHz RF radiation from substantially interfering with RF radiation in the 140 MHz band or the 440 MHz band, and vice versa. All in all the configurations of FIG. **9** and FIG. **10** encouraged applicant that his experiments were leading in a proper direction, and that a practical triband antenna design might be attainable notwithstanding that the desired third (intermediate) band was not harmonically related to either the VHF or UHF bands.

FIG. **11**A depicts a triband antenna **310**, according to embodiments of the present invention that satisfies the initially stated design criteria. The upper portion of triband antenna **310** includes a DBJ-1 dual band J-pole **260** as has been described with respect to FIG. **6**A, and the upper portions of the antenna structures shown in FIGS. **8**, **9**, and **10**. Thus looking at antenna **310** from the top down, uppermost is a portion of the VHF RF radiator **268** of length l**5** (about 17"), below which in LEAD 2 appears UHF decoupling stub **266**, preferably a length l**4** (about 4.25") of RG74A coaxial cable With the outer shield connected at the top to the coaxial cable center conductor, but open at the bottom end of the decoupling stub. As noted the short at the top of decoupling stub **266** translates at a quarter wavelength of UHF to an open circuit at the bottom of the stub. Continuing downward with antenna **310**, beneath UHF decoupling stub **266** occurs UHF radiator **264** of length l**3** (about 11.25"), a half wavelength at UHF. At UHF frequencies, decoupling stub **266** appears somewhat like an open circuit and decouples the portions of the antenna higher than element **264**, which allows element **264**+l**2** to operate as a half wave UHF RF radiator. However at VHF frequencies, decoupling stub **266** acts somewhat like a short circuit, allowing a half wave VHF RF radiator to be formed from the series-connected combination of antenna portions l**2**+**264**, **266**, and **268**.

Continuing further downward, a gap **240** is cut in LEAD 1 with gap height l**2** of about 0.25" to isolate UHF radiating element **264** from lower sections of the antenna. Below gap **240** is found the passive non-RF radiating impedance transforming section **262**, having length l**1** of about 16". As noted, section **262** acts as a quarter wavelength impedance stub at VHF and acts as a three-quarter wavelength stub at UHF, as the UHF band is an odd harmonic (third harmonic) of the VHF band. The bottommost region of DBJ-1 dual-band J-pole **260** is shorted together at **180**, and at a distance Δ (about 1.25") above the short there is found a low impedance region (about 50Ω) whereat first and second feedpoints are present. A length Lc, typically about 14", of coaxial cable **60'**, e.g., RG174A, has its upper end connected to the two feedpoints. For example the center conductor of cable **60'** may be connected to the first feedpoint on LEAD 1 and the braid shield of cable **60'** may be connected to the second feedpoint on LEAD 2, or vice versa. As shown in FIG. **11**A, the center conductor of coaxial cable **60** (typically RG174A) connects to one feedpoint, while the braid shield of the coaxial cable **60** connects to the other feedpoint. The bottommost portion of length Lc of coaxial cable **60'** is the antenna port for triband antenna **260**, the region whereat an external length of coaxial cable (who other end is connectable to a transceiver or the like) may be connected to the triband antenna.

Thus far antenna **310** as described implements performance on the VHF band and the UHF band. Triband antenna performance at intermediate band (about 220 MHz-225 MHz) as provided in preferred embodiments of the present invention will now be described. Intermediate band functionality is created by providing near the bottom portion of antenna **310** a half wave RF radiator at intermediate band frequencies, comprising a first quarter wavelength of wire **340-1** and a second quarter wavelength of wire **340-2**. Each wire **340-1**, **340-2** if stretched out would be a quarter wavelength at the intermediate band, about 12" length. Adequate stiffness is provided by single 16 gauge wire for **340-1**, **340-2**. As noted from applicant's earlier experiments with the triband antenna configurations of FIG. **9** and FIG. **10**, the intermediate band elements should have minimal adverse magnetic coupling effects that could distort good patterns of RF radiation on each of the three bands. It is further desired to maintain a compact and robust form factor for antenna **310**. Thus the first quarter wavelength of wire **340-1** is wrapped helically about at least a portion of the passive non-RF radiating impedance transforming section **262** of the antenna, namely a helix top-to-bottom length Lx**1** of the length l**1** of section **262**. The bottom end of wire **340-1** is attached to one of the two low impedance feedpoints, and the upper end of wire **340-1** is left floating. Length **11** of impedance transforming section **262** is about 16", and the wound top-to-bottom helix length for wire **340-1** Lx**1**, about 7". The second quarter wavelength of wire **340-2** is wrapped around a length Lc, preferably about 14") of the upper approximately half of coaxial cable **60'** and will have a wound top-to-bottom helix length Lx**2**, which occupies about half of length Lc. Length Lx**1** and length Lx**2** may but need not be equal and will be in the range of 6" to about 8". Length Lc could be much longer than 14", e.g., many feet, but an approximate 14" length is convenient for mounting the antenna, which includes length Lc, within PVC tubing of reasonable height.

In FIG. **11**A, wire **340-1** and wire **340-2** should each be wound in the same direction, e.g., both wound clockwise or both wound counter-clockwise, to avoid distortions in the generated RF pattern. In the embodiment shown in FIG. **11**A, the upper end of wire **340-2** is connected to the remaining low impedance feedpoint, while the lower end of this wire is left floating, e.g., is not connected to anything. If desired the helix winding connections to the two feedpoints could be reversed. Better intermediate band RF radiation occurs if helical windings **340-1**, **340-2** are stretched out with a smaller turns/inch pitch (without overlying an active portion of the antenna), rather than wound very closely together. In practice a winding pitch of about one turn/inch works out well. If diameter Dx of the two helical windings were too large, magnetic effects could distort RF radiation at intermediate band frequencies, which is not desired. Note that winding **340-2** preferably is not allowed to simply fall vertically, as it would then be parallel to coaxial cable **60'**, and its magnetic field would distort the RF radiation pattern, and adversely affect the impedance matching, or SWR. In practice Dx preferably is small such that triband antenna **310** can fit within a length of 0.75" O.D. 200 PSI PVC pipe, e.g., Dx< 0.75". Such PVC pipe or tubing provides protection for the antenna within against inclement weather, UV radiation that can weaken the twinlead, and facilitates robust outdoor mounting. FIG. **11**B depicts such installation.

It is noted in FIG. **11**A, that both quarter-wavelength windings **340-1**, **340-2** are wound helically advantageously about passive, non-RF radiating regions of triband antenna **310**. As noted region **262**, about a portion of which is wound first helix **340-1**, is simply an impedance transformer and radiates no RF at any band. Further, coaxial cable **60** has, by definition, a surrounding braid shield and is also passive, and radiates no RF at any band. Thus, second helix **340-2** is thus also wound about a passive, non-RF radiating element. This coaxial helical disposition of the vertically disposed intermediate band RF radiating elements **340-1**, **340-2** relative to the longitudinal axis of triband antenna **310**, and the relatively small helix diameter Dx, e.g., < **0.75**", relative to 220 MHz quarter wavelengths (about 6") minimizes adverse magnetic coupling effects. Advantageously this results in maintaining a low SWR in each of the three bands, and also promotes a substantially undistorted intermediate band RF propagation pattern. The radiating elements for VHF, UHF are each half wavelength end-fed vertical dipoles, and the radiating element for intermediate band operation is a half wavelength center-fed vertical dipole. Consequently there is substantial elimination of cross-band radiation interference between VHF, intermediate band, and UHF operation, and no substantial degradation of triband antenna performance.

As noted, dimensions given for antenna **310** are approximate within a few percent, and assume the finished antenna will be mounted within PVC tubing, as in FIG. **11**B. Were such not the case, the various dimensions would be increased by about 4%-5%. Dimensions may also vary, for example, if twinlead having a different velocity factor is used to make antenna **310**. In general, overall length Lx of triband antenna **310** will be about 64" or about 1.6 m. (If antenna **310** is deployed within protective PVC tubing, the tubing length with endcaps may be about 1.7 m.) Note too in FIG. **11**A that coaxial cable **60'** is connected to and drops down vertically and substantially parallel to the longitudinal axis of the remainder of triband antenna **310**. This disposition advantageously reduces the potential for this length Lc of coaxial cable **60'** to physically interfere with radiated RF at any of the three bands.

In practice an antenna **310** is cut and assembled and is then inserted into a length of appropriate PVC tubing such as **320** in FIG. **11**B. Antenna characteristics are then measured at UHF, at intermediate band, and at VHF frequencies, using a network analyzer (e.g., an Agilent 8753D) or an antenna analyzer (e.g., an MFJ-269 Pro). Instruments such as these can measure the complex impedance of triband antenna **310** at frequencies in each band, and can measure the standing wave ratio (SWR) at different frequencies in each band. Ideally impedance should be about 50Ω with no substantial complex component, and ideally SWR is 1:1. Adjustments to the characteristics of antenna **310** can generally be made at UHF by changing slightly the magnitude of l2, usually by cutting away slightly more material from the bottom of the gap. Next antenna **310** is characterized at VHF, with adjustments made to the upper end of l**5**. Finally the antenna is characterized at the intermediate band by slightly compressing or extending both helixes **340-1**, **340-2**, preferably equally. Advantageously the topology of the preferred embodiments allow these adjustments to be made without disrupting adjustments already made on the other bands. Once an individual triband antenna **310** has been fine-tuned per the above procedure or equivalent, the antenna can be permanently inserted into PVC tubing as shown in FIG. **11**B, and described below.

As shown in FIG. **11**A and FIG. **11**B, triband antenna **310** comprises 300Ω twinlead with a small, typically 4.24" section of coaxial cable (UHF decoupling stub **266** two lengths of preferably 16 gauge wire (**340-1**, **340-2**), and an approximately 14" length of coaxial cable **60'**. These components are relatively lightweight and inexpensive, and can be rolled up and mailed as a lightweight package to an end user. If the antenna was cut and dimensioned for use within PVC tubing, preferably the antenna, but not PVC tube **320** (see FIG. **11**B), is mailed to the end user with instructions to obtain the specific type of PVC tubing **320** locally, e.g., 0.75" OD 200 PSI PVC, for which the antenna was designed, and to insert the antenna within and then cement on PVC end caps. If desired, PVC upper end cap **330** with nylon string or the like **332** glued to the inner cap surface to secure the upper end of antenna **310** through a hole in the uppermost portion of the plastic twinlead material (not shown to avoid cluttering the drawings), and lower end cap **344** with coaxial antenna connector **350** attached, may be mailed to the end user along with the rolled-up antenna and instructions.

In some embodiments it may be desired to always deploy the antenna without protective PVC tubing. In such cases the antenna dimensions will typically be 4%-5% greater than those given for in-PVC tubing embodiments due to the change in velocity factor of PVC vs air, and characterization of the antenna will take place in open air, using the exemplary procedure noted above. As such, the rolled up antenna, without end caps, and with a coaxial or other connector attached to the bottom end of coaxial cable **60'**, or indeed with length Lc increased to several feet is lightweight and compact. The antenna can be kept in a vehicle glove compartment, in a desk drawer, or even in a shirt pocket, for deployment when needed, often with a handheld handi-talkie transceiver. In such applications the typically 6 dB-8 dB gain realized by a triband antenna according to embodiments of the present invention over the performance of a typical so-called rubber duck antenna used on such devices is very substantial. If Lc is several feet in length, antenna **310** may be suspended from a tree branch or a house door, to provide a bit of elevation.

As noted earlier, portions of lead 1 in regions **268** and **264** are simply floating and do not radiate RF and these portions of lead 1 could be omitted. If desired, lead 2 in regions **268**, **264**, and **240** could simply be a single wire. As such, a triband antenna according to the present invention may be said to be fabricated at least in part from twinlead. In some embodiments, the twinlead runs the full length L**1** of the dual-band J-pole antenna portion of the triband antenna, and in other embodiments twinlead may only be the length of Δ+l1 or Δ+l1+l2 (with gap **240** formed in lead 1). In such latter embodiments, there would be no lead 1 higher than gap **240**, and lead 2 may be a single wire, but not necessarily wire in a portion of twinlead.

FIG. **11**B depicts triband antenna **310** as shown in FIG. **11**A, mounted within a length Lt, typically about 65"-66" (about 1.7 m), of preferably 0.75" O.D. 200 PSI PVC tubing **320**. The top of antenna **310** can be suspended with a nylon string **332** or the like from the inner surface of PVC end cap **330**, perhaps with glue. Antenna **310** then extends downward within tubing **320** and at the bottommost end, a coaxial or other bulkhead type receptacle **350** is attached to a bottom PVC end cap **340**. This receptacle attaches to the lower end coaxial center conductor and braid shield of coaxial cable **60'** is becomes the connection port triband antenna **310**. Exemplary such receptacles include an SO-239 connector, N-type, or chassis mount screw type Amphenol® 554-77 connector. The upper and lower PVC end caps may be permanently attached to PVC tube **320**, i.e., with adhesive. In use, an external length of coaxial cable **60** (see FIG. **13**) with a suitable mating plug simply attaches to the bottom of antenna **310** at connector **350**. The bottom 7"-8" of PVC **320** surrounds only the passive, non-radiating bottom portion of coaxial cable **60'**. This readily enables clamping the bottom portion of the tubing, and thus the antenna, to a metal vent pipe (see **355** in FIG. **13**) or the like.

FIG. **12**A, FIG. **12**B, and FIG. **12**C respectively depict standing wave ratio (SWR) vs. operating frequency for operation in the radio amateur VHF band, the intermediate VHF-UHF band, and the UHF band for triband antenna **310** as shown in FIG. **11**A. In an ideal world with a perfect antenna the SWR would be 1:1 at all frequencies. However in practice an SWR≤1.5:1 or so is acceptable. As such, the data in FIG. **12**A, FIG. **12**B, and FIG. **12**C demonstrate that a very acceptable SWR is present when using the triband antenna of FIG. **11**A on any or all of the three bands for which it is designed. As noted, fine tuning antenna **310** to optimize performance on one of the three bands advantageously does not substantially affect performance on the remaining bands

Turning now to FIG. **13** various deployments of triband antenna **310** as described in FIG. **11**A are shown. For example at the upper left portion of FIG. **13** antenna **310** is depicted in phantom mounted to a vent pipe **355** on a house roof within a length of PVC pipe **320** having a top end cap **330** and a bottom end cap **340**, with receptacle connector **350** at the bottom, similarly to what was described in FIG. **11**B. After exiting the bottom of antenna **310**, coaxial cable **60** enters the house adjacent a window and is shown coupled to the RF connector of an electronic device **360**, e.g., a transceiver, receiver, or transmitter suitable for use at the wavelengths for which triband antenna **310** was designed. Typically electronic device **360** is a transceiver, which means it can transmit and can receive at the frequencies of interest. Often device **360** will communicate via a repeater **370**, which can receive a relatively weak incoming signal, perhaps from device **360**, and rebroadcast it, typically on a different frequency or band, often using an antenna disposed in a favorable location, perhaps atop a tall tower. Of course device **360** can also communicate directly with other equipment **360**, without recourse to a repeater, e.g., in so-called simplex mode.

At the upper right portion of FIG. **13**, device **360** is a low power, typically 3 W to 5 W, handheld transceiver, show coupled to triband antenna **310** via coaxial cable **60**. The upper end of antenna **310** is shown connected by a string or the like **360** to an overhead branch of a tree. In an emergency situation where the user of the handheld transceiver (or handi-talkie) must make radio communication to summon help, the 6 dB to 8 dB gain provided by antenna **310** over a rubber duck antenna can make the difference between successful communications and no communications. Advantageously, as noted if triband antenna **310** is designed for use, and used, without protective PVC tubing, the antenna can literally be rolled up and stuffed in a backpack or even a pocket. In practice triband antenna **310** can safely handle RF transmitted power in the range of about 75 W over the three bands for which the antenna was designed.

At the lower right corner of FIG. **13**, antenna **310** is again protected by PVC tubing **320** and is mounted at the rear of a vehicle in a mobile configuration. Coaxial cable **60** is brought into the vehicle and coupled to device **360**, which is often hidden in the trunk or other out-of-sight location to minimize theft. In such installations a remote head connects electrically to device **360** and may be mounted by the driver's seat, with connection for a microphone, and with full control over the remotely located device.

To summarize, the present invention provides a triband omni-directional collinear antenna that operates without radials or an absolute ground on any or all of the VHF, intermediate band, and UHF band frequencies. The resultant antenna is inexpensive to fabricate, e.g., using 300Ω twinlead or the like, some wire, some coaxial cable, and is light weight and thus readily and inexpensively shipped. The antenna can be designed and deployed within protective PVC pipe, or can be designed and use without pipe. In the latter case, the antenna can be rolled-up and kept in a backpack, or a glove compartment for use when needed, perhaps with a VHF, UHF, or intermediate band mobile transceiver. The antenna has the gain performance of a half wavelength dipole on each band, namely 2.1 dB gain over an isotropic radiation, and provides about 6 dB to about 8 dB gain over the rubber duck type antenna found on handheld VHF-UHF-intermediate band handheld transceivers. At UHF and at VHF operation the triband antenna provides an end-fed half-wavelength vertical dipole, and at intermediate band operation the triband antenna provides a center-fed half-wavelength vertical dipole. The antenna can be adjusted or fine-tuned to affect operation on one band without interfering with the performance of the antenna on the other two bands. Depending upon presence or absence of a protective PVC tubing sheath, antenna height is about 1.6 m-1.7 m. In short, all of the design goals set out by applicant have been met by embodiments of the present invention.

While embodiments of the preferred invention have been described with respect to designing a triband antenna operable over VHF, UHF, and intermediate band frequencies, it will be appreciated that a triband antenna operating over a different selection of three bands could also be made. Further it will be appreciated that applicant's use of a helically wound half wave antenna formed over passive components of a J-pole antenna could be used even if that J-pole were a monoband antenna rather than a dual band antenna.

Modifications and variations may be made to the disclosed embodiments without departing from the subject and spirit of the invention as defined by the following claims.

What is claimed is:

1. An omni-directional triband antenna operable absent ground radials in at least one band selected from VHF band, UHF band, and intermediate VHF-UHF band, with performance of a half wavelength vertical dipole on each band, comprising:

- a dual-band (VHF-UHF) J-pole antenna of length L**1** formed from a first lead of wire spaced-apart and parallel to a second lead of wire, and includes:
  - a half wavelength vertically disposed VHF radiator;
  - a half wavelength vertically disposed UHF radiator; and
  - a passive impedance transformer having length l**1** of said total length L**1**, disposed between a bottommost region of said UHF radiator and a bottommost region of said J-pole antenna whereat said first lead and said second lead are connected together to form a 0Ω bottom end of said J-pole antenna such that a distance Δ above said 0Ω bottom end there exists a first feedpoint in said first lead and a second feedpoint in said second lead;
  - a length Lc of coaxial cable having a center conductor with a first end coupled to one of said first feedpoint and said second feedpoint, and having a second end defining a center conductor connection port for said triband antenna, and having a braid shield with a first end coupled to whichever of said first feedpoint and said feedpoint is unconnected to said first end of said length Lc of coaxial cable, and having a second end defining a braid shield connection port for said triband antenna;
  - wherein said center conductor connection port and said braid shield connection port at said second end of said length Lc of coaxial cable define an antenna connection port for said triband antenna, to which antenna connection port a device operable in at least one said band can be coupled via an external length of coaxial cable
- a vertically disposed half wavelength intermediate band antenna that includes:
  - a first helix comprising a first length of wire, having an upper end and a lower end and a quarter wavelength at said intermediate band therebetween, wrapped helically concentrically in a first direction about said passive impedance transformer section of said J-pole antenna with a helix length of Lx**1**<l**1**, said upper end of said first length of wire allowed to float, and said lower end of said first length of wire connected to one of said first feedpoint and said second feedpoint; and
  - a second helix comprising a second length of wire, having an upper end and a lower end and a quarter wavelength at said intermediate band therebetween, wrapped helically concentrically in said first direction about an upper portion of length Lx**2**<Lc of said length Lc of coaxial cable, said upper end of said second wire connected to whichever one of said first feedpoint and said second feedpoint is unconnected to said first helix, and said lower end of said second wire allowed to float;
- whereby a diameter of each said helix is substantially less than a wavelength at said intermediate band such that said half wave intermediate band antenna is substantially vertically disposed; and
- whereby cross-band interference with said J-pole antenna from said half wavelength intermediate band antenna is substantially eliminated as said first helix and said second helix are each formed about a passive region of said triband antenna.

2. The triband antenna of claim **1**, wherein said triband antenna has at least one characteristic selected from a group consisting of (i) an impedance between said first feedpoint and said second feedpoint of about 50Ω, and (ii) an impedance at said antenna connection port of about 50Ω.

3. The triband antenna of claim **1**, wherein at least a portion of said length L**1** is twinlead comprising said lead 1 and said lead 2, said twinlead having an impedance of about 300Ω.

4. The triband antenna of claim **1**, wherein said passive impedance transformer acts as a quarter wavelength at VHF and is three-quarter wavelength at UHF.

5. The triband antenna of claim **1**, further including means for decoupling said UHF radiator from at least a portion of said VHF radiator.

6. The triband antenna of claim **5**, wherein said means for decoupling includes a length l**4** of coaxial cable having an upper end with center conductor and braid shield coupled together and to a lower end of at least a portion of said VHF radiator, and having a lower end whereat said braid shield floats and said center conductor of length l**4** is connected to an upper end of said UHF radiator; wherein l**4** is a quarter wavelength at said UHF band.

7. The triband antenna of claim **1**, wherein with respect to each said helix, said first direction is selected from a group consisting of (i) clockwise relative to a longitudinal axis of said triband antenna, and (ii) counterclockwise clockwise relative to a longitudinal axis of said triband antenna.

8. The triband antenna of claim **1**, wherein overall length of said antenna is about 64".

9. The triband antenna of claim **1**, where said VHF band includes a frequency range from about 140 MHz to about 170 MHz.

10. The triband antenna of claim **1**, wherein in said VHF band, SWR≤1.5 over a frequency range of about 144 MHz to about 148 MHz.

11. The triband antenna of claim **1**, wherein said UHF band includes a frequency range from about 420 MHz to about 470 MHz.

12. The triband antenna of claim **1**, wherein in said UHF band, SWR≤1.7 over a frequency range of about 440 MHz to about 450 MHz.

13. The triband antenna of claim **1**, wherein said intermediate band includes a frequency range from about 220 MHz to about 225 MHz.

14. The triband antenna of claim **1**, wherein in said intermediate band, SWR≤1.5 over a frequency range of about 220 MHz to about 225 MHz.

15. The triband antenna of claim **1**, further including a protective sheath of PVC tubing sized to encase said triband antenna.

16. A triband antenna having an upper, high impedance, end and a lower end defining a low impedance antenna connection port, and operable as a half wave vertical antenna absent ground radials in at least one band selected from VHF, UHF, and intermediate VHF-UHF, comprising:

an uppermost length l5 of twinlead, whose uppermost end is said upper high impedance end of said triband antenna and whose lower end is also high impedance, said twinlead comprising a first lead spaced apart from a parallel second lead; said length l5 forming a portion of a half wave VHF radiator for said triband antenna;

means for decoupling UHF, having an upper end coupled to said second lead of said lower end of said length l5 of twinlead, and having a lower end, with a length l4 therebetween;

wherein a length of said lead 1 opposite said means for decoupling UHF defines a cut extending said length l4;

a length equal to (L1-l5-l4) of twinlead extending downward from said lower end of said means for decoupling and at a lower end defining a 0Ω region of said triband antenna;

an uppermost region of length l3 of said length equal to (L1-l5-l4) forming a quarter wavelength vertically disposed UHF radiator for said triband antenna, said second lead of said length l3 coupled to said lower end of said means for decoupling, and said first lead of said length l3 floating at each end;

wherein at VHF band operation, said length l3 operates with said length l5 and said length l4 to form a half wave vertically disposed VHF radiator of said triband;

a short length l2 of twinlead coupled to a lower end of said length l3, said second lead of said length l2 coupled to a lower end of said second lead of a bottommost region of said length l3, and said first lead of said length l2 defining a cut extending said length l2:

a passive impedance transformer having length (l1+Δ) of twinlead having an upper end coupled to a lower end of said length l2, and having a lower end defining a 0Ω region of said triband antenna, and defining a first low impedance feedpoint on said lead 1 and defining a second low impedance feedpoint in said lead 2 at a distance Δ above said 0Ω region;

a length Lc of coaxial cable having a center conductor and a braid shield, said center conductor at an upper end of said length Lc coupled to one of said first low impedance feedpoint and said second low impedance feedpoint, and said braid shield at said upper end of said length Lc coupled to which low impedance feedpoint is unconnected to said upper end of said center conductor;

wherein said center conductor connection port and said braid shield connection port at said second end of said length Lc of coaxial cable define a connection port for said triband antenna, to which antenna connection port a device operable in at least one said band can be coupled via an external length of coaxial cable,

a first helix comprising a first length of wire, having an upper end and a lower end and a quarter wavelength at said intermediate band therebetween, wrapped helically concentrically in a first direction about said passive impedance transformer a helix length of Lx1<l1, said upper end of said first length of wire allowed to float, and said lower end of said first length of wire connected to one of said first low impedance feedpoint and said second low impedance feedpoint; and

a second helix comprising a second length of wire, having an upper end and a lower end and a quarter wavelength at said intermediate band therebetween, wrapped helically concentrically in said first direction about an upper portion of length Lx2<Lc of said length Lc of coaxial cable, said upper end of said second wire connected to whichever one of said first low impedance feedpoint and said second low impedance feedpoint is unconnected to said first helix, and said lower end of said second wire allowed to float;

whereby a diameter of each said helix is substantially less than a wavelength at said intermediate band such that said first helix and said second helix together form a vertically disposed half wave intermediate band antenna; and

whereby cross-band interference from said half wavelength intermediate band antenna is substantially eliminated as said first helix and said second helix are each formed about a passive region of said triband antenna.

17. The triband antenna of claim **16**, wherein said means for decoupling is a quarter wavelength UHF stub.

18. The triband antenna of claim **16**, wherein said means for decoupling includes a length l4 of coaxial cable having an upper end with center conductor and braid shield coupled together and to a lower end of at least a portion of said VHF radiator, and having a lower end whereat said braid shield floats and said center conductor of length l4 is connected to an upper end of said UHF radiator; wherein l4 is a quarter wavelength at said intermediate band.

19. The triband antenna of claim **16**, wherein:

said antenna exhibits an SWR≤1.5 over a frequency range of about 144 MHz to about 148 MHz;

said antenna exhibits an SWR≤1.7 over a frequency range of about 440 MHz to about 450 MHz; and

said antenna exhibits an SWR≤1.5 over a frequency range of about 220 MHz to about 225 MHz.

20. The triband antenna of claim **16**, wherein said twinlead is approximately 300Ω impedance, and said antenna connection port has an impedance of about 50Ω.

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