July 23, 1963 A. F. WICKERSHAM, JR., ETAL 3,098,973

ANTENNA INCORPORATING ACTIVE ELEMENTS

Filed May 27, 1960 2 Sheets-Sheet 1

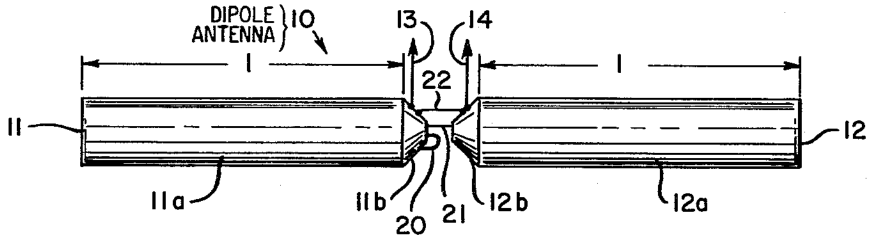

FIG-1

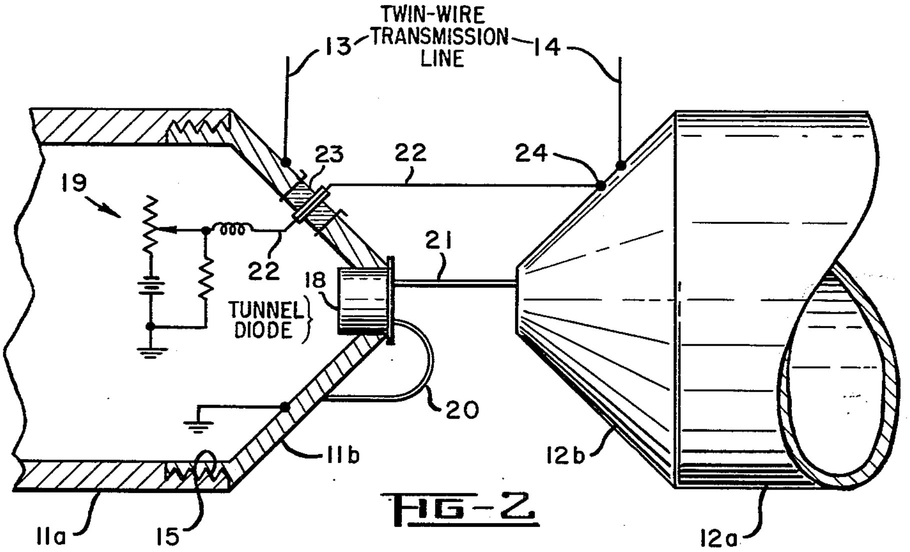

FIG-2

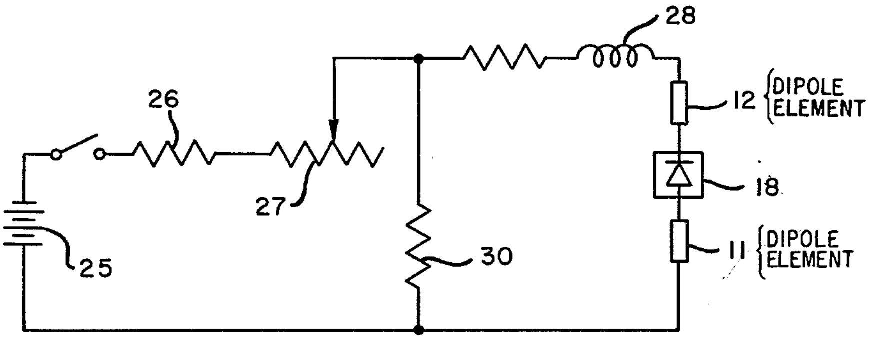

FIG-3

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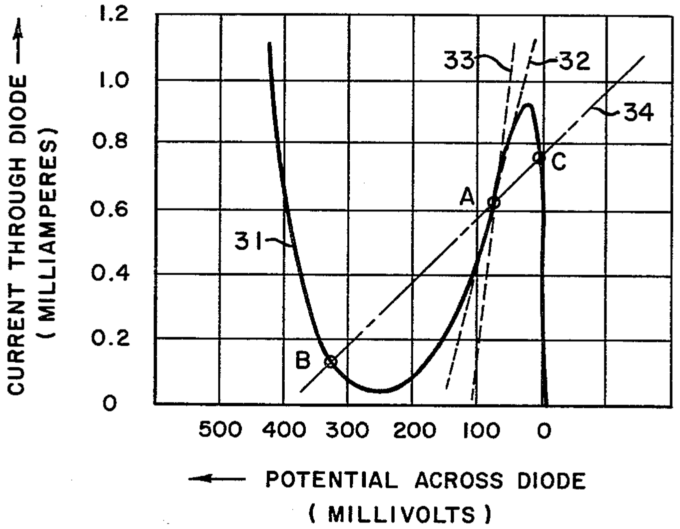

FIG-4

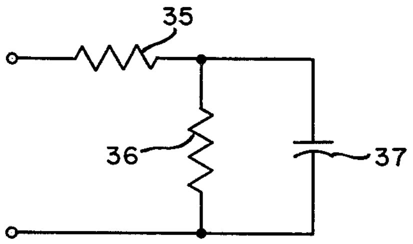

FIG-5

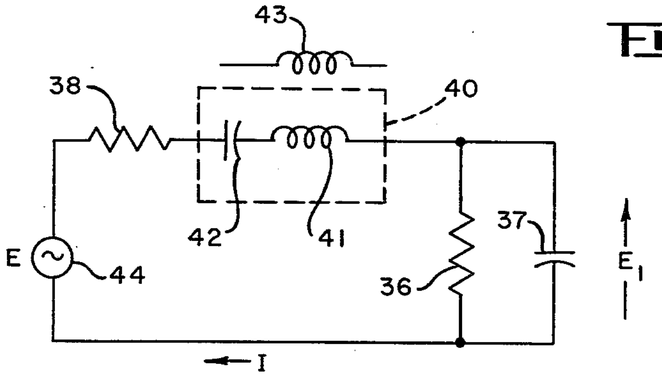

FIG-6

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ANTENNA INCORPORATING ACTIVE ELEMENTS

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2 Claims. (Cl. 325—375)

This invention relates to antennas, and more particularly to an active antenna in which antenna and electronic amplification functions are fully integrated within one structure.

In present-day radio practice, it is common to regard an antenna as a separate unit connected by means of a transmisison line to another separate unit which may be a receiver or transmitter. In the case of a receiving station comprising an antenna and receiver combination, it is the purpose of the antenna to intercept radio energy in space and to deliver such energy to a receiver. It is the purpose of the receiver to amplify and modify the signal and so achieve a desired signal utilization. While the discussion in the specification which follows relates to the antenna-receiver combination, it will be understood that the underlying principle of the invention applies, with appropriate modification, to an antenna-transmitter combination.

Briefly, the present invention, in its preferred form, comprises a combination of a tunnel diode and a simple dipole antenna. The tunnel diode is connected across the center of a series-fed type dipole, the circuit constants of which are utilized as constants for a tunnel diode amplifier, the latter being suitably biased into its negative resistance operating region. This antenna is operated with a matched transmission line conventionally connected to the dipole, the received signal being transferred in phase to the transmission line with gain provided by the tunnel diode amplifier. Alternatively, if no transmission line is utilized, the received signal is amplified and re-radiated by the structure.

An object of the present invention therefore is to combine the function of the antenna with at least one of the functions, the amplifying function, of the receiver and to provide a single physical embodiment capable of performing both functions simultaneously.

A further object is the provision of an antenna assembly which eliminates the need for a receiver structure spatially separated from and independent of the antenna. By eliminating the separate receiver, the invention also eliminates the need for radio frequency transmission line between the antenna and receiver. This not only removes power losses associated with the transmission line, but also achieves further economy and simplicity in the overall system by doing away with RF rotary joints, bends, twists, etc.

Another object is the provision of an antenna-receiver combination that avoids problems associated with impedance matching of the antenna to the transmission line and matching of the transmission line to receiver.

A further object of the invention is to reduce electrical noise, eliminate components, and improve efficiency of operation, reduce the overall size of the antenna-receiver package, and to greatly reduce the cost of fabrication of such systems.

Another object is to provide a simple unit which may be used either as a receiving station (antenna-receiver combination embodied in a single-physical unit) or as an active scatterer or repeater, i.e., a simple unit capable of reradiating energy of amplitude greater than that received. Such a unit, combining functions usually ascribed to antenna and receiver and transmitter, and used either as a receiving station or an amplifying repeater station, is not

a passive component. Therefore, it is called an "active antenna" in this specification.

A further object of the invention is to provide an active antenna of simple and rudimentary form which may be regarded as a sub-component of more elaborate antenna arrays and configurations. The use of the elementary sub-unit to form elaborate arrays may be either for the purpose of obtaining results now achievable only with a complex of antennas and receivers, or for obtaining results not realizable with present combinations of separate antennas and receivers.

These and other objects of our invention will become apparent from the following description of a preferred embodiment thereof, reference being had to the accompanying drawings in which:

FIGURE 1 is a side elevational view of dipole antenna embodying our invention;

FIGURE 2 is a greatly enlarged view of the center part of FIGURE 1, a portion of the antenna being shown in section to illustrate details of construction;

FIGURE 3 is a diagram of an equivalent circuit of our active antenna;

FIGURE 4 is a curve showing the current-voltage characteristics of a tunnel diode used in our active antenna;

FIGURE 5 is an equivalent circuit of a tunnel diode; and

FIGURE 6 is an equivalent circuit of a tunnel diode and the dipole antenna.

Referring now to the drawings, a preferred embodiment of the invention is shown in FIGURE 1 as a cylindrical dipole **10** having elements **11** and **12** center-fed by connection to a twin-wire transmission line **13**, **14** or alternatively by a coaxial line through a balun (not shown). The main body portions **11***a* and **12***a* of the dipole elements comprise hollow cylindrical conductors which have tapped inner ends, the inner end of element **11** being indicated at **15** in FIGURE 2, by means of which frusto-conically shaped inner caps **11***b* and **12***b* are removably secured to the main bodies of the elements.

Mounted within one of the caps, for example, cap **11***b*, is an electric cell and biasing network which biases a tunnel diode indicated at **18** preferably mounted in and supported by cap **11***b*. The associated electrical network is indicated schematically at **19** and is provided for the purpose of biasing tunnel diode **18** for operation in its region of negative resistance as will be explained below. Leads **20** and **21** connect the tunnel diode electrically to dipole element **11** (through cap **11***b*) and to element **12** (through cap **12***b*), respectively. Biasing network **19** has a lead **22** which extends through an insulator **23** in cap **11***b* for connection at **24** to cap **12***b* of the opposite dipole element. The purpose of leads **20** and **22** is to make electrical connection of the diode and the bias network represented by diode **18** and circuitry **19**, respectively, to the amplifier network represented by and contained in the physical dipole elements. The arms of the dipole are not only important antenna elements, but are also physically and electrically important tank circuit elements of the tuned amplifier circuit which is described more fully below.

A schematic diagram of the biasing network for tunnel diode **18** is shown in FIGURE 3. The source of bias potential may be and preferably is a small cell or battery **25**, such as a common flashlight cell or a mercury cell. Resistor **26** drops the bias potential to a value near its desired level and potentiometer **27** provides a means of fine adjustment of the bias potential. A suitable radio frequency choke **28** prevents high frequency energy from being coupled through the direct current supply circuit and shunt resistor **30** across the diode and choke provides a low impedance bias supply necessary for stability of operation. Dipole elements **11** and **12** and tunnel diode **18** are electrically connected in series in this circuit so that when the proper bias potential is applied to diode **18**, these elements may be utilized as an amplifier.

The bias supply elements, being few in number and small in size, occupy a minimum of space so that they may readily be mounted within the cap of a hollow dipole element having a diameter of one inch. Access to the bias supply for adjustment of potentiometer **27**, replacement of battery **25**, or removal and inspection of diode **18** is readily accomplished by removal of cap **11*b*** from the main body **11*a*** of the dipole.

Dipole elements **11** and **12** are shown in FIGURE 3 to indicate their approximate location in the circuit. The function of the dipole elements, as far as circuit operation is concerned, is not only to intercept or receive an electromagnetic wave, thereby producing a signal voltage, but also to supply inductive reactance with some distributed shunt capacitance so that these elements together with the tunnel diode **18** may properly amplify radio frequency signals.

In order to better understand the operation of tunnel diode **18** as a component in a radio frequency amplifier circuit, a plot of the current-voltage characteristic of a commercially available tunnel diode is shown in FIGURE 4. The vertical scale indicates current through the diode and the horizontal scale shows a potential impressed across the diode. It is seen that the characteristic curve **31** displays a negative resistance between 30 and 250 millivolts. It is the purpose of the electrical network shown in FIGURE 3 to bias the diode so that it is operating in this region of negative resistance. The dotted line **32** passing through point A of the curve is the slope of the characteristic curve in the neighborhood of point A and represents a negative conductance or load line. For stable operation, this diode must have a dynamic load line slope equal to or greater than that of the static load line. Stable devices characterized by slopes of magnitude greater than the slope of the static load line are termed "short-circuit stable." A dynamic load line for stable operation is shown at **33** in FIGURE 4. Also shown in this figure is a load line **34** with less slope than the static load line; and, since this load line of less slope crosses the current-voltage curve at several points (points A, B and C), it depicts a condition of unstable or oscillatory operation. It is noted that the load line is the threshold or dividing line between stable and oscillatory conditions.

A radio frequency circuit which is the equivalent of a tunnel diode is shown in FIGURE 5 wherein the resistance **35** is a series resistance, resistor **36** is a negative resistance and capacitance **37** is the shunt capacitance of the diode. The resistance **36** will be negative as long as the diode is biased to operate on the negative slope of the current-voltage characteristic as shown in FIGURE 4. Resistance **35** is the dissipative resistance of the diode including losses inherent in the connections to outside circuits, and, in general, is small in value compared to resistance **36**. While capacitance **37** is relatively large, i.e., for an abrupt junction with 4×10^{10} carriers/cm.^{2} in the bulk material, the capacitance will be approximately 5 μf./cm.^{2} of the junction area.

FIGURE 6 illustrates the equivalent radio frequency circuit of the diode as shown in FIGURE 5 combined with the equivalent of the dipole antenna represented by the broken line rectangle **40**. The latter includes an inductance **41** corresponding to the distributed inductance of the two arms of the dipole, and a capacitance **42** representing the distributed shunt capacitance of the dipole arms. By making the length *l*, see FIGURE 1, of each dipole element slightly longer than the resonant length, i.e., slightly greater than a quarter wavelength at the midpoint of the operating frequency range, the result is that the equivalent reactance of the dipole is inductive as represented by the equivalent inductance **43** in FIGURE 6. Resistance **38** represents the sum of resistance **35** in FIGURE 5 and the radiation resistance of the dipole. Voltage generator **44** represents the signal input to the antenna from intercepted electromagnetic waves when the antenna is used for receiving purposes, and corresponds to a transmitter when the antenna is used for transmission purposes or both if the antenna is used as a repeater station. The voltage E developed by source **44** is amplified by the circuit and appears as a larger voltage E_1 as indicated at the right side of FIGURE 6. The signal E_1 is carried by transmission lines **13**, **14** to associated utilization circuits or may be re-radiated by the antenna itself if such action is desired.

It should be noted that in an active antenna constructed in accordance with our invention certain individual components provide both antenna and amplifier functions. For example, the arms **11** and **12** of the dipole are not only important antenna elements, but are also physically and electrically important tank circuit elements in the amplifier circuit. These dual purpose elements perform the antenna and receiver functions simultaneously, resulting in a compact, efficient and economical device.

The equivalent circuit illustrated in FIGURE 6 may be used to show that a dipole length which is slightly greater than the normal resonant length provides conditions under which the combined circuit acts as a stable amplifier. To find the required increase in length, the necessary inductance, L, must be determined from the circuit equations:

$$(-G+j\omega_0C)E_1=I \qquad (1)$$

$$(R+j\omega_0L)I=E-E_1 \qquad (2)$$

where G is negative conductance, ω_0 is angular frequency, C is capacitance, E_1 is radio frequency voltage, I is radio frequency current, R is resistance, L is inductance, and E is impressed radio frequency voltage.

Elimination of E_1 from Equations 1 and 2 leads to:

$$\frac{I}{E}=\frac{(RG^2+\omega_0^2RC^2-G)-j\omega_0(\omega_0^2LC^2+LG^2-C)}{(RG+\omega_0^2LC-1)^2+\omega_0^2(RC-LG)^2} \qquad (3)$$

The frequency ω_0 now is further restricted by choice of the new length of the dipole to correspond to a frequency at which the above circuit admittance is real, but that frequency is still represented by the symbol ω_0. Under this condition the imaginary part of the admittance equation can be solved for ω_0:

$$\omega_0=\sqrt{\frac{C-LG^2}{LC^2}} \qquad (4)$$

For given values of ω_0, C, and G, L can be determined; and from recorded values of L, a corresponding dipole length can be found. Thus a resonant frequency, ω_0, of the circuit can be associated with a given length of dipole, where the dipole is operating slightly above its own natural resonant frequency.

The stability of the current when it is operating in the condition described above is now examined. Recalling that the tunnel diode is a short-circuit stable device, stable operation is obtained when the magnitude of the admittance in shunt with the diode is larger than the absolute value of the negative conductance:

$$\left|\frac{1}{R+j\omega_0L}+j\omega_0C\right|\geq|G| \qquad (5)$$

or

$$\left|\frac{\{R^2+\omega_0^2[-R^2C+L(1-\omega_0^2LC)]^2\}^{1/2}}{R^2+\omega_0^2L^2}\right|\geq|G| \qquad (6)$$

For a first approximation, assume that the frequency ω_0 is not far removed from the natural undamped resonant frequency of the circuit and so ω_0^2 can be replaced by $1/LC$ in the last term of the numerator (but replaced by Equation 4 elsewhere). This results in

$$\left|\frac{\left[1+\frac{CR^2}{L}\left(1\frac{L}{C}G^2\right)\right]^{1/2}}{1+\frac{L}{CR^2}\left(1-\frac{L}{C}G^2\right)}\right|\geq|RG| \qquad (7)$$

as the condition for stability.

Representative values of the parameters are $R=50$ ohms, $G=0.01$ ohms, and $\sqrt{L/C}=50$ ohms. For these values the above inequality is clearly satisfied, the expression reducing to

$$\frac{2}{\sqrt{7}}\geq 1/2$$

It is thus seen that stability is achieved and it remains to show that amplification can be obtained under the same operating conditions.

Examination of the conditions for amplification dictates that an expression for the power delivered to the load, represented by radiation resistance R, must be found. Eliminating ω_0 by using Equation 4 and the expression for admittance, Equation 3, an expression for the current in R is obtained:

$$I=\frac{CE}{RC-LG} \qquad (8)$$

consequently, the power dissipated in the load will be

$$P=E^2R\left(\frac{C}{RC-LG}\right)^2 \qquad (9)$$

When the denominator of the power expression vanishes, i.e., when

$$\frac{L}{C} \text{ is equal to } \frac{R}{G}$$

the power becomes indefinitely large and this condition approximately corresponds to the condition for maximum gain.

If again,

$$\sqrt{\frac{L}{C}}=50 \text{ ohms and } R=50 \text{ ohms}$$

the condition for maximum gain is now satisfied by now taking $G=0.02$ ohms. For these values of the parameters the stability condition reduces to $1\geqslant RG$, which is satisfied with the equality sign. Thus, it is seen that maximum gain is achieved at the edge of stability; if less than maximum gain is acceptable, fully stable operation is achieved.

From the foregoing description it will be seen we have provided a self-contained antenna-amplifier which is capable of functioning as a transmitting element or a receiving element or as a repeater element. The dipole elements 11 and 12, in the preferred embodiment herein described, in essence simultaneously provide inductive reactance as well as radiation resistance, the radiation resistance being essential to the antenna function and the reactance being essential to the amplifying function. Therefore, both of these functions are provided by a single simple structural element.

While the above described preferred embodiment consists of a simple dipole as a radiating element, it will be apparent to those skilled in the art that the invention may be incorporated in a folded dipole, a unipole, a loaded unipole, or in various other types of elementary radiators. Accordingly, the invention is not to be limited to the preferred embodiment described above but the scope thereof is defined in the appended claims.

We claim:

1. A dipole antenna comprising a pair of axially aligned hollow conducting elements having their inner adjacent ends axially spaced apart, a tunnel diode mounted within one of said elements and having two leads, bias voltage supply means mounted within one of said elements, means for electrically connecting the leads of said diode to the inner ends respectively of said elements, means for electrically connecting the output of said supply means across said elements whereby the supply means and the elements and the diode are connected together in electrical series, the output of said supply means being of such magnitude that said diode operates in the negative resistance region of its voltage-current characteristic, each of said dipole elements having a length slightly greater than its resonant length at the midpoint of the operating frequency range of the antenna whereby said elements and said tunnel diode jointly function as a microwave amplifier of signals impressed on said elements.

2. The antenna according to claim 1 in which the inner end of at least one of said elements is removably secured to the remainder of the element.

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