April 21, 1970 A. F. SNYDER 3,508,269

ACTIVE RETRODIRECTIVE ANTENNA ARRAY EMPLOYING SPIRAL ELEMENTS AND TUNNEL DIODE AMPLIFIERS

Filed May 2, 1968

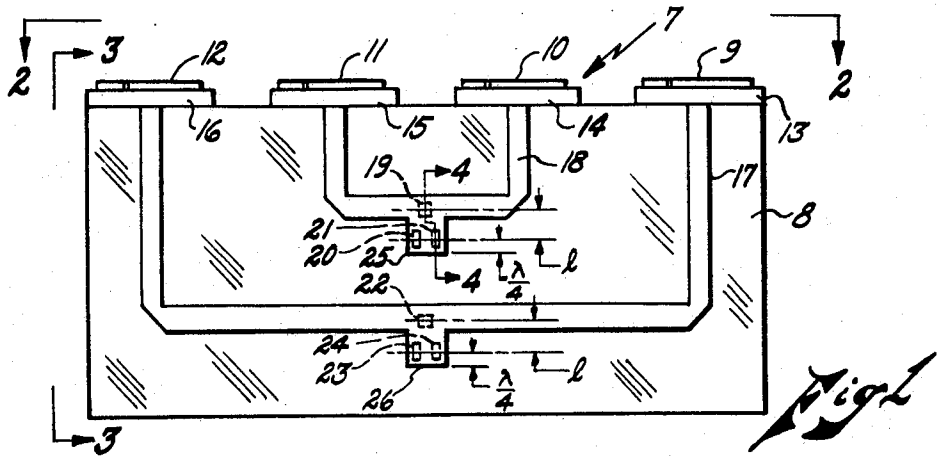

Fig. 1

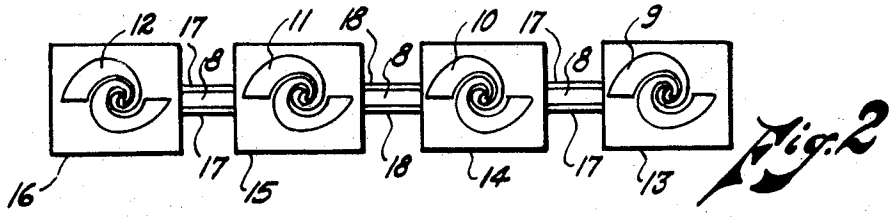

Fig. 2

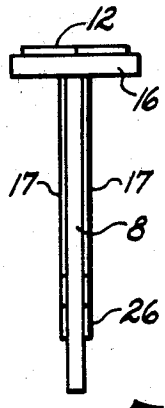

Fig. 3

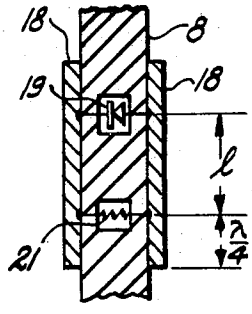

Fig. 4

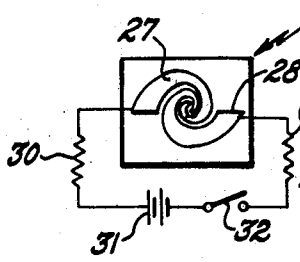

Fig. 5

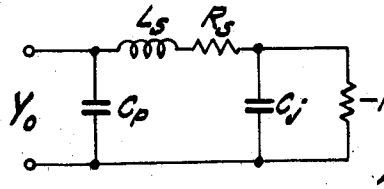

Fig. 6

INVENTOR.
ANTHONY F. SNYDER

BY Harry A. Herbert Jr. and Willard R. Matthews Jr.
ATTORNEYS

United States Patent Office 3,508,269
Patented Apr. 21, 1970

3,508,269

ACTIVE RETRODIRECTIVE ANTENNA ARRAY EMPLOYING SPIRAL ELEMENTS AND TUNNEL DIODE AMPLIFIERS

Anthony F. Snyder, Boonville, N.Y., assignor to the United States of America as represented by the Secretary of the Air Force

Filed May 2, 1968, Ser. No. 726,190
Int. Cl. H01q 1/36
U.S. Cl. 343—701 5 Claims

ABSTRACT OF THE DISCLOSURE

There is disclosed herein an active retrodirective antenna array. The array consists of a plurality of antenna element pairs having conjugate antenna elements connected equidistant from the array center by microwave transmission lines. A negative resistance bilateral amplifier is integrated into each transmission line. Amplifier susceptance cancelling means are also integrated into each transmission line. A particular illustrative embodiment of the invention includes equiangular spiral antenna elements, balanced strip transmission lines, tunnel diode amplifiers, and susceptance cancelling means comprising resistance loaded open circuited transmission line stubs.

BACKGROUND OF THE INVENTION

Retrodirective antenna arrays are commonly used to improve communication signals passing between transmitting and receiving points which are otherwise blocked from each other. Also, with appropriate signal modulation means, retrodirective antenna arrays find utility in radar beacon systems. Such applications often call for installation of the antenna array in aircraft. Simplification of circuits, reduction of weight, improved reliability and maximum range capability are, therefore, important design objectives. The retrodirective antenna array, with proper amplification, meets these design objectives. However, approaches used in prior art systems to achieve adequate amplification have been something less than satisfactory. The use of unilateral amplifiers requires that one set of antennas be used for receiving and a second set be used for transmitting. This method subtracts from the available array aperture due to the additional antenna elements required. Amplification has also been achieved with only two antenna elements per retrodirective pair by separating the incident energy and the energy to be reradiated through the use of separate transmission lines, ferrite isolation, frequency blocking networks, mixers and unidirectional amplifiers. The added number of components and greatly increased weight and expense of such amplification means make it undesirable for airborne amplification. The present invention is directed toward overcoming these and other deficiencies prevalent in prior art systems.

SUMMARY OF THE INVENTION

The present invention comprehends the integration of bilateral tunnel diode amplifiers into the interconnecting transmission lines of a retrodirective antenna array. The purpose of a retrodirective antenna array is to return the incident electromagnetic energy in the direction of the transmitting source. The subelements in the array consist of 2 equiangular spiral antennas connected by a balanced strip transmission line. At the midpoint between antenna elements a bilatral tunnel diode amplifier is integrated into the strip transmission line.

In operation, the electromagnetic energy, of frequency within the design constraints of the array, incident upon

the dual antenna aperture gives rise to current and voltage flow in the interconnecting transmission line. The tunnel diode, when placed across the line, represents a discontinuity in the line that results in a reflected and a forward travelling wave at the diode boundary. The discontinuity, having a negative resistance value when properly biased, imparts energy to both the reflected and forward travelling wave. There are two antennas connected to each diode. The resulting terminal current at each antenna is due to a component that originated at its self and was amplified by the diode during reflection, plus a component that was launched down the line from the other member of the antenna pair and was amplified by the diode during its forward flow across the diode boundary.

The resulting terminal current for each antenna has proper phase to construct two equiphase fronts (principal maxima) travelling away from the total array aperture. One maxima represents a "mirror" reflection term while the other gives the desired retrodirective characteristics. The two maxima appear as a result of the unique characteristics of the tunnel diode amplifier used. The wave that experiences transmission amplification gives rise to the retrodirective scattering while the wave that is reflected and amplified forms the mirror scattering (characteristic of arrays of independent antennas terminated in an effective negative resistance).

It is a principal object of the invention to provide an improved active retrodirective antenna array that is capable of reradiating energy of an amplitude greater than that received.

It is another object of the invention to provide an active retrodirective antenna array that is lightweight and inexpensive.

It is another object of the invention to provide an active retrodirective antenna array having a minimum number of components and improved efficiency of operation.

It is another object of the invention to provide an active retrodirective antenna array having signal amplification provided by a single tunned diode per antenna element pair.

These, together with other objects, advantages and features of the invention will become more apparent from the following detailed description when taken in conjunction with the illustrative embodiments in the accompanying drawings.

DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a view, in elevation, of an active retrodirective antenna array incorporating the principles of the present invention;

FIGURE 2 is a view of the antenna array of FIGURE 1 taken at 2—2;

FIGURE 3 is a view of the antenna array of FIGURE 1 taken at 3—3;

FIGURE 4 is an enlarged sectional view of the antenna array of FIGURE 1 taken at 4—4 and illustrates in detail the bilateral amplifier and associated susceptance cancelling means of the invention;

FIGURE 5 is a schematic representation of one means for biasing the tunnel diode amplifiers of the invention; and

FIGURE 6 is an equivalent circuit of a typical bilateral tunnel diode amplifier of the type comprehended by the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A presently preferred embodiment of the invention is illustrated in the accompanying drawing by FIGURES 1, 2 and 3. The retrodirective antenna array 7 therein disclosed comprises antenna elements 9, 10, 11 and 12,

balanced strip transmission lines **17** and **18** and tunnel diodes **19** and **22**. Antenna elements **9** and **12**, together with interconnecting transmission line **17**, comprises a subelement as do antenna elements **10** and **11** and transmission line **18**. Although only two pairs of antenna elements are described, it is to be understood that arrays having any number of such subelements are comprehended by the invention.

Antenna arrays of the type herein described can be conveniently fabricated by etching antenna elements and transmission lines from copper clad insulating sheet material. Thus, in FIGURES 1, 2 and 3, transmission lines **17** and **18** are etched copper strips residing on both sides of sheet insulating material **8** and constitute balanced strip transmission lines. Insulating sheet material **8** may be any suitable low dielectric factor plastic such as that commercially available under the trade name Rexolite 1422. Antenna elements **9**, **10**, **11** and **12** are likewise etched from copper plated insulating sheets **13**, **14**, **15** and **16**. Electrical connections between transmission lines and antenna elements are made in a conventional manner.

It is requisite that conjugate antenna elements be positioned equidistant from the array center and that the transmission lines be some integral number of wavelengths long. It is also necessary that the tunnel diodes **19** and **22** be integrated into transmission lines **18** and **17** at the midpoint between antenna elements. These tunnel diodes in combination with open circuit stubs **25** and **26** and their associated resistors **20**, **21** and **23**, **24** provide amplification for the subelements. FIGURE 5 discloses a convenient means for biasing tunnel diodes. Such a means comprises a D.C. bias source **31**, current limiting resistors **29** and **30** and switch **32**. The bias is applied as illustrated to the outer edges of equiangular spiral antenna elements **27** and **28**.

The tunnel diodes and their associated resistors can be integrated into the balanced strip transmission lines in the manner illustrated in FIGURE 4. Resistors **21** and **22** are inserted into insulating sheet **8** a distance of a quarter wavelength from the open end of stub **25** and a distance l from tunnel diode **19**. Electrical connections are made to strip transmission line **18** as shown.

The equiangular spiral antenna is an optimum antenna type for tunnel diode stabilization. The unconditional stability criteria, for preventing diode oscillations,

$$R_D > R_T$$

where

R_D=the negative resistance of the diode when biased in the minus resistance region

R_T=total circuit resistance,

demands that the proper resistive load be presented to the tunnel diode below its resistive cutoff. The low frequency stabilizing resistors (such as resistor **20**, **21** and **23**, **24** of FIGURE 1) are an effective load up to design frequency of the amplifier. The antenna impedances must act as the stabilizing elements from the design frequencies of the amplifier to the resistor cutoff of the tunnel diode. The equiangular spiral antenna is considered a frequency independent structure because its effective arm lengths are entirely specified by angles. A frequency change, therefore, is an effective rotation in the plane of the antenna. Thus, the impedance of the antenna is considered constant for bandwidths of greater than 20:1. The upper frequency limits of such antennas are determined by the feed point construction.

In accordance with the principles of the invention, the impedance of each transmission line is matched to its antenna. Also, the line lengths between each diode and its associated antenna elements are made an integral number of wavelengths long. This eliminates any large antenna impedance transformation over the line length to the

diode. For a balanced strip transmission line the characteristic impedance Z_0 can be calcuated using the formulas:

$$Z_0 = \frac{377}{\sqrt{e}} \frac{S}{W};\ S \ll W$$

$$Z_0 = \frac{276}{\sqrt{e}} \log_{10} \frac{4S}{W};\ S \gg W$$

where W is the width of the strip transmission line, and S is the thickness of the insulating material separating them.

Amplification in each subelement is achieved by placing a tunnel diode between the balanced transmission line at the midpoint between the two antennas (such as tunnel diodes **19** and **22** of FIGURE 1). The equivalent circuit for such a tunnel diode is shown in FIGURE 6. Having reference now to FIGURE 6, C_P represents the diode package capacity, L_s the diode series inductance, R_s the diode series resistance, C_j the diode junction capacity, and $-R$ the diode negative resistance. The diode admittance Y_D is

$$Y_D = \frac{R_s - R(1 - W^2 R R_s C_j^2)}{(R_s - R + W^2 R L_s C_j)^2 + W^2 (L_s - R R_s C_j)^2} + j \left[\frac{W(R^2 C_j [1 - W^2 L_s C_j] - L_s)}{(R_s - R W^2 R L_s C_j)^2 + W^2 (L_s - R R_s C_j)^2 + W C_P} \right]$$

The imaginary term in this equation is the effective susceptance jY_C of the diode.

It is necessary to tune this susceptance out for proper amplifier operation. To do this, an open circuit line is connected at right angles to the balanced lines containing the diode. This is illustrated in FIGURE 1 by stubs **25** and **26**. One quarter of a wavelength from the open circuit, resistors **20**, **21** and **23**, **24** are put in parallel across the lines to stabilize tunnel diodes **19** and **22** at lower frequencies. Because the resistors are located one-quarter of a wavelength from the open circuit, they are effectively short circuited at the operating frequency of the amplifier. The necessary line length required to cancel the susceptance of each diode is determined and this is the line length between the diode and its associated stabilizing resistors. The admittance of a short circuited transmission line Y_s can be written

$$Y_s = -Y_0 \cot (Bl)$$

Therefore, the required tuning length l can be calculated from

$$jY_D = j\omega C_D = jY_0 \cot (Bl)$$

where:

C_D is the effective diode capacitance
Y_0=the stripline characteristic admittance
$W/2\pi$=the frequency of operation
$B=2\pi/\lambda$

This is the only tuning required as the antenna impedances are real and have no reactive component.

Referring now to FIGURE 5, there is illustrated thereby means for providing appropriate bias for the tunnel diode amplifiers. The diode biasing circuit must be isolated from the amplifier circuitry to eliminate any amplifier detuning and R-F conduction in the bias leads. Such isolation is accomplished by feeding the bias voltage through the end points of the spiral antennas. Isolation is produced because of the rapid attenuation of the R-F fields near the end points of this antenna type. The expression for the individual antenna terminal current is

$$I_T = \frac{I_0 Y_D/2}{Y_a - Y_D/2}$$

where:

Y_D=diode admittance
Y_a=Antenna admittance
I_0=Effective Norton current source
I_T=Total terminal current for the antenna.

This shows that as $Y_D/2$ approaches the value of Y_a, large values of terminal current flow into the antenna terminals

thereby enhancing the energy scattered from the antenna.

Although the invention disclosed herein has been described with reference to specific embodiments, it is not intended that it be so limited. Various modifications such as the use of coaxial cable or unbalanced strip transmission lines and variations to the amplifier tuning technique can be made without departing from the true scope of the invention. Accordingly, it is to be understood that the scope of the invention shall be limited by the claims only.

What is claimed is:

1. An active retrodirective antenna array comprising at least one pair of antenna elements, transmission line means engaged between conjugate elements of each antenna element pair, a bilateral amplifier integrated into each said transmission line means at the midpoint thereof, and susceptance cancelling means integrated into each said transmission line means, said susceptance cancelling means being adapted to cancel the effective susceptance of each said amplifier.

2. An active retrodirective antenna array as defined in claim 1 wherein each said antenna element comprises an equiangular spiral antenna.

3. An active retrodirective antenna array as defined in claim 2 wherein each said transmission line means comprises a microwave strip transmission line.

4. An active retrodirective antenna array as defined in claim 3 wherein said bilateral amplifier comprises a tunnel diode.

5. An active retrodirective antenna array as defined in claim 4 wherein each said susceptance cancelling means comprises an open circuited stub located at midpoint on said transmission line means and at right angle thereto and resistance means incorporated within said open circuited stub, said resistance means being adapted to stabilize said tunnel diode at low frequencies.

References Cited

UNITED STATES PATENTS

3,296,536 1/1967 Copeland et al. ------ 343—701

ELI LIEBERMAN, Primary Examiner

U.S. Cl. X.R.

343—864, 895