United States Patent [19]

Nagai

[11] **3,731,313**

[45] **May 1, 1973**

[54] **VAN-ATTA ARRAY ANTENNA DEVICE**

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[21] Appl. No.: **179,053**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 868,415, Oct. 22, 1969, abandoned.

[52] **U.S. Cl.** **343/854**, 343/893

[51] **Int. Cl.** **H01q 3/26**

[58] **Field of Search** 343/779, 786, 853, 343/854, 893

[56] **References Cited**

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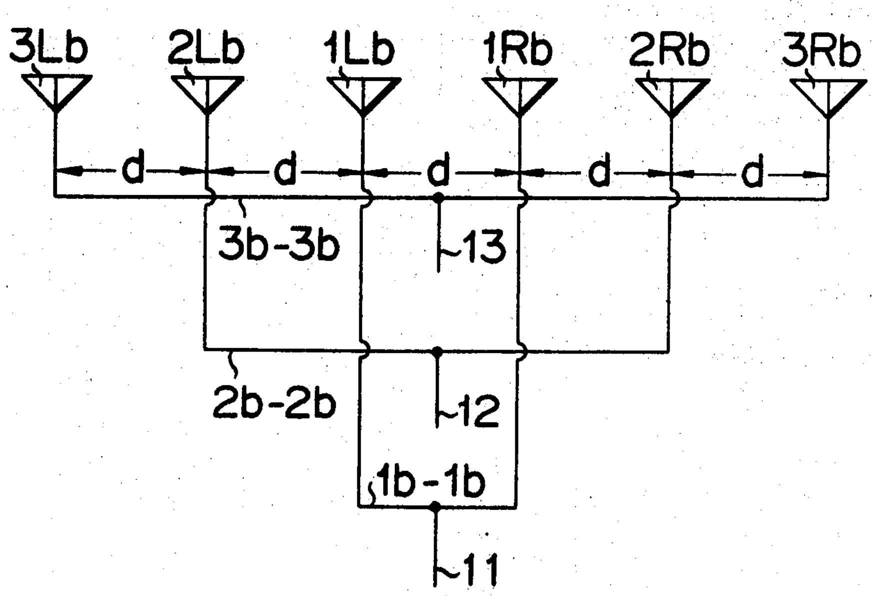
[57] **ABSTRACT**

In a Van-Atta array antenna device of the type wherein a plurality of equally spaced antenna elements are disposed in parallel and respective pairs of antenna elements disposed symmetrically with respect to the center of the antenna array are interconnected by feeders of substantially the same length, impedance matching stubs having an adjustable length are connected to substantially the center of respective feeders in order to enable incoming electromagnetic waves to be reradiated either straight backward or in an opposite direction to that in which they are receiving, with respect to the antenna boresight, without changing the characteristic impedance of feeders.

2 Claims, 8 Drawing Figures



Patented May 1, 1973 3,731,313

2 Sheets-Sheet 1

PRIOR ART

FIG. 1

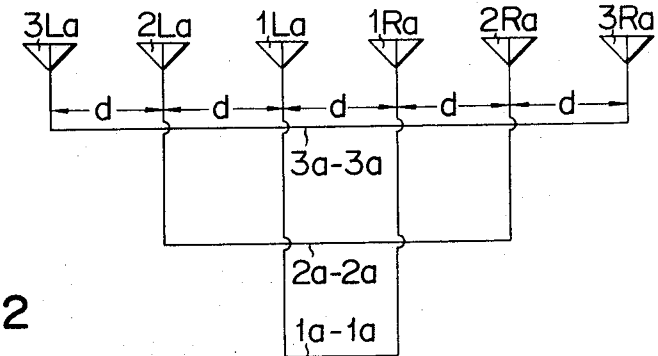


FIG. 2

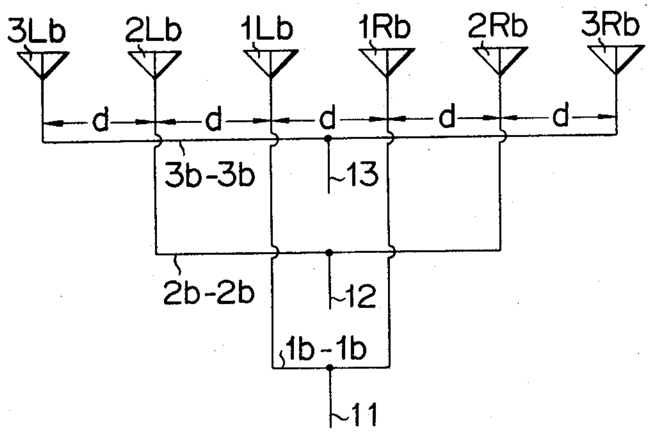


FIG. 3

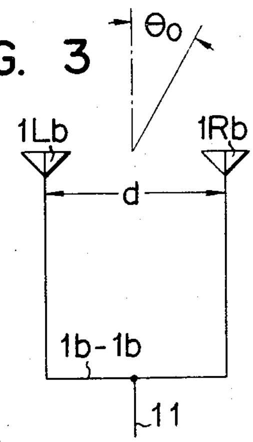


FIG. 4A

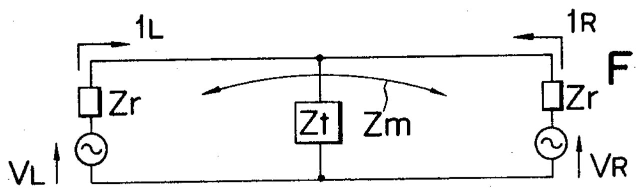


FIG. 4B

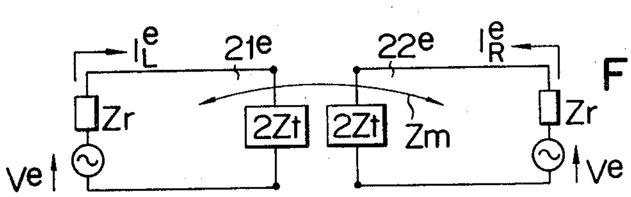
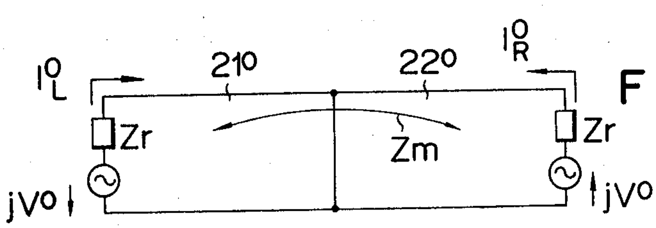


FIG. 4C



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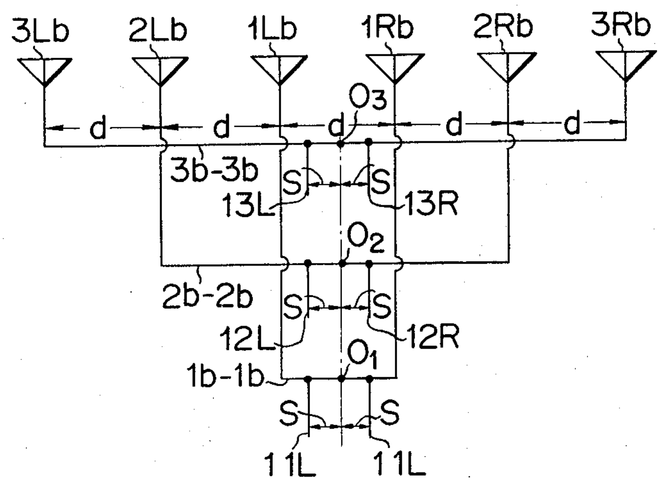
3Lb
2Lb
1Lb
1Rb
2Rb
3Rb
O3
d
d
d
d
d
3b-3b
S
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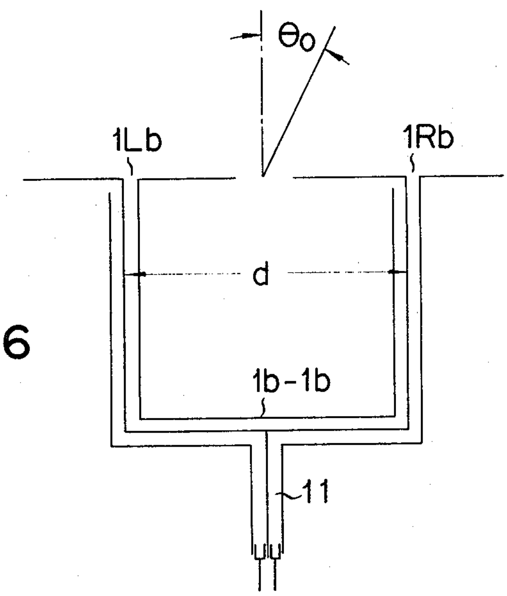
S
S
11L
11L


θ0
1Lb
1Rb
d
1b-1b
11

F I G. 6

VAN-ATTA ARRAY ANTENNA DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

This is a continuation-in-part of U.S. Pat. application Ser. No. 868,415, filed Oct. 22, 1969, now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to a Van-Atta array antenna device and more particularly to a Van-Atta array antenna device which can be mounted on artificial space satellites for communication with other artificial satellites or ground stations or can be utilized as dummy objects in radar systems.

Prior art Van-Atta array antenna devices are ordinarily constructed as shown in FIG. 1. Thus a plurality of equally spaced (d) antenna elements 1La and 1R*a*; 2L*a* and 2R*a*; 3L*a* and 3R*a* are disposed in parallel. Each pair of antenna elements symmetrical with respect to the center of the array, i.e., antenna elements 1L*a* and 1R*a*; 2La and 2R*a*; 3L*a* and 3R*a* are interconnected by antenna feeders *1a—1a; 2a—2a;* and *3a—3a* having substantially the same length. With such a type of Van-Atta array antenna device, it is necessary, as is well known, to adjust respective antenna elements such that incoming electromagnetic waves are reradiated either straight backward or in an opposite direction to that in which they are received, with respect to the antenna boresight. However, with the prior art Van-Atta array antenna device constructed as above described, in order to cause part of the incoming waves to be reradiated either straight backward or in an opposite direction to that in which they are received, with respect to the antenna boresight, it has been necessary to adjust the length of respective antenna feeders and the characteristic impedances thereof. However, such adjustment is very troublesome.

SUMMARY OF THE INVENTION

It is, therefore, an object of this invention to provide a Van-Atta array antenna device wherein the waves radiated from the respective antenna elements are caused to be carried either straight backward or in an opposite direction to that in which they are received, with respect to the antenna boresight, without the necessity of adjusting characteristic impedances of antenna feeders.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. 1 is a diagrammatic representation of a prior art Van-Atta array antenna device;

FIG. 2 is a diagrammatic representation of one embodiment of a Van-Atta array antenna device constructed in accordance with the principle of this invention;

FIG. 3 shows one set of antenna elements shown in FIG. 2;

FIG. 4A is an equivalent circuit of the antenna element shown in FIG. 3;

FIG. 4B shows an equivalent circuit of the even-mode system when the circuit shown in FIG. 4A is subdivided into even-mode and odd-mode systems;

FIG. 4C shows an equivalent circuit of the odd-mode system;

FIG. 5 is a diagrammatic representation of another embodiment of a Van-Atta array antenna device constructed in accordance with the principle of this invention; and

FIG. 6 shows a set of antenna elements, illustrating the stub of a coaxial line.

DETAILED DESCRIPTION OF THE DRAWINGS

As shown in FIG. 2, the Van-Atta array antenna device comprises a plurality of equally spaced antenna elements 1L*b*, 1R*b*; 2L*b*, 2R*b*; and 3L*b*, 3R*b*. Pairs of antenna elements symmetrically disposed with respect to the center of the array, i.e., antenna elements 1L*b* and 1R*b*; 2L*b* and 2R*b*; and 3L*b* and 3R*b* are interconnected by antenna feeders *1b—1b*, *2b—2b* and *3b—3b* of substantially equal length, each consisting of two parallel lines, a coaxial line or a wave-guide. To substantially the middle points along the length of antenna feeders are connected parallel impedance matching stubs or traps **11**, **12** and **13** whose lengths are adjustable. Each of these stubs is comprised by two parallel lines, a coaxial line or a wave-guide.

To have a better understanding of the operation of the Van-Atta array antenna device of this invention, a set of antenna elements as shown in FIG. 3 will now be considered. This set may be represented by an equivalent circuit as shown in FIG. 4A, wherein $\dot{V}_L$ and $\dot{V}_R$ represent received open terminal voltages appearing at terminals of the left and right antenna elements 1L*b* and 1R*b* in the absence of antenna feeders *1b—1b*, Zr the impedance of antenna elements, Zt the impedance of stub **11** connected to the middle point of antenna feeder *1b—1b* and $L_L$and I_R represent antenna currents flowing in opposite directions through the feeder *1b—1b* from antenna elements 1L*b* and 1R*b*.

Denoting the spacing between the antenna elements 1L*b* and 1R*b* by *d*, the angle of the incoming electromagnetic wave as viewed from the boresight of antenna elements 1L*b* and 1R*b* by θ_o and the effective length of respective antenna elements 1L*b* and 1R*b* by h_{eff}, then the receiving open terminal voltages $\dot{V}_L$ and $\dot{V}_R$of the antenna elements 1L*b* and 1R*b* can be expressed as follows:

$$\left.\begin{aligned}\dot{V}_R &= h_{eff}\cdot\epsilon\cdot e^{-j\psi}\\ \dot{V}_L &= h_{eff}\cdot\epsilon\cdot e^{+j\psi}\end{aligned}\right\}\ldots\ldots \quad (1)$$

where $\psi = k(d/2)\sin\theta_o$, $k = 2\pi/\lambda$ and λ represents the wavelength of the antenna current.

When these voltages $\dot{V}_L$ and $\dot{V}_R$ are decomposed into an even-mode voltage and an odd-mode voltage expressed by

$$\left.\begin{aligned}\text{even-mode voltage } V^e &\equiv \epsilon\cdot h_{eff}\cos(k(d/2)\sin\theta_o)\\ \text{odd-mode voltage } V^o &\equiv \epsilon\cdot h_{eff}\sin(k(d/2)\sin\theta_o)\end{aligned}\right\}\ldots \quad (2)$$

then the receiving open terminal voltages $\dot{V}_L$ and $\dot{V}_R$ can be expressed, respectively, by

$$\left.\begin{aligned}\dot{V}_L &= V^e - jV^o\\ \dot{V}_R &= V^3 + jV^o\end{aligned}\right\}\ldots\ldots \quad (3)$$

FIG. 4B shows an equivalent circuit of the even-mode system under these conditions and since source voltages V^e at opposite ends have the same magnitude and direction, the impedance Zt of stub **11** is divided into two parts respectively contributing as 2Zt for the source voltages V^e.

Whereas FIG. **4C** shows an equivalent circuit for the odd-mode system under the same condition and since the source voltages V^o at the opposite ends are equal in magnitude but opposite in phase, the middle portion is short circuited regardless of the presence or absence of impedance Zt provided by stub **11**. In both FIGS. **4B** and **4C**, Zm represents the mutual impedance between antenna elements **1L***b* and **1R***b*.

Further, in FIGS. **3** and **6**, let Zo denote the characteristic impedance of antenna feeder **1***b*—**1***b*, l the length thereof, neglecting the transmission loss of the feeder, β represent the phase constant, and let Zo/2 represent the characteristic impedance of stub **11**, l' the length thereof and assuming open terminal in the even-mode system shown in FIG. **4B**, regarding two closed loops **21**^{e} and **22**^{e} including the source voltages V^e the following equations hold.

For closed loop **21**^{e}

$$V^e - I_R^e\,Zm\,Z - I_L^e\,[Zr - jZo\cot\beta((l/2)+l')] = 0$$

For closed loop **22**^{e}

$$V^e - I_L^e\,Zm - I_R^e\,[Zr - jZ_o\cot\beta((l/2)+l')] = 0 \qquad (4)$$

Accordingly, from equation (4)

$$I_L^e = I_R^e = V^e/[Zr + Zm - jZo\cot\beta((l/2)+l')] \qquad (5)$$

Similarly, in the odd-mode system shown in FIG. **4C**, with respect to two closed loops **21**^{o} and **22**^{o} including terminal sources jV^o the following equations hold.

For closed loop **21**^{o}

$$jV^o + I_R^o\,Zm - I_L^o\,(Zr + jZo\tan\beta(l/2)) = 0$$

For closed loop **22**^{o}

$$jV^o + I_L^o\,Zm - I_R^o\,(Zr + jZo\tan\beta(l/2)) = 0 \qquad (6)$$

From equation (6)

$$I_L^o = I_R^o = j\,V^o/[Zr - Zm + jZo\tan\beta(l/2)] \qquad (7)$$

Therefore, from FIGS. **4B**, **4C** and equations (5) and (7)

$$\left.\begin{aligned} I_R = I_R^e + I_R^o &= \frac{V^e}{Zr + Zm - jZo\cot\beta\left(\frac{l}{2}+l'\right)} + j\frac{V^o}{Zr - Zm + jZo\tan\beta\frac{l}{2}} \\ I_L = I_L^o - I_R^o &= \frac{V^e}{Zr + Zm - jZo\cot\beta\left(\frac{l}{2}+l'\right)} - j\frac{V^o}{Zr - Zm + jZo\tan\beta\frac{l}{2}} \end{aligned}\right\} \quad (8)$$

Thus, by adjusting the length l of antenna feeder **1***b*—**1***b* and the length l' of stub **11** such that the denominators of the first and second terms of equation (8) are equal to $R_1(1\pm j)$ and $R_2(1\pm j)$ respectively and that $R_1 = R_2$, it is possible to obtain a Van-Atta array antenna device in which incoming electromagnetic waves are reradiated either straight backward or in an opposite direction, with respect to the boresight of both antenna elements 1Lb and 1Rb from which they are received.

In equation (8), when putting $Zr = R_{11} + jX_{11}$ and $Zm = R_{12} + jX_{12}$, then the real part of the denominator of the first term of equation (8) will become $R_{11} + R_{12}$ while that of the denominator of the second term will become $R_{11} - R_{12}$.

It will thus be clear that it is necessary to adjust the length l of the feeder **1***b*—**1***b* and the length l' of the stub **11** to satisfy the following relations.

$$\left.\begin{aligned} &\text{The denominator of the first term of equation (8):} \\ &Zr + Zm - jZo\cot\beta((l/2)) + l') = (R_{11} + R_{12}) + j(R_{11} + R_{12}) \\ &\text{The denominator of the second term of equation (8):} \\ &Zr - Zm + jZo\tan\beta(l/2) = (R_{11} - (R_{11} - R_{12}) - j(R_{11} - R_{12}) \end{aligned}\right\} \quad (9)$$

Then, the antenna currents I_R and I_L in equation (8) can be given by the following equations.

$$\left.\begin{aligned} I_R &= \frac{V^e}{R_{11} + R_{12} + j(R_{11} + R_{12})} + j\frac{V^o}{R_{11} - R_{12} - j(R_{11} - R_{12})} \\ &= \frac{1}{2(R_{11}^2 - R_{12}^2)}\{(R_{11} - jR_{11} - R_{12} + jR_{12})V^e + j(R_{11} + jR_{11} + R_{12} + jR_{12})V^o\} \\ &= \frac{R_{11}\cdot E\cdot h_{\text{eff}}}{2(R_{11}^2 - R_{12}^2)}\left(\cot\psi - j\cos\psi - \frac{R_{12}}{R_{11}}\cos\psi + j\frac{R_{12}}{R_{11}}\cos\psi + j\sin\psi - \sin\psi + j\frac{R_{12}}{R_{11}}\sin\psi - \frac{R_{12}}{R_{11}}\sin\psi\right) \\ &= \frac{R_{11}\cdot E\cdot h_{\text{eff}}}{2(R_{11}^2 - R_{12}^2)}\left\{\left(1 + j\frac{R_{12}}{R_{11}}\right)(\cos\psi + j\sin\psi) - j\left(1 - j\frac{R_{12}}{R_{11}}\right)(\cos\psi - j\sin\psi)\right\} \\ &= \frac{R_{11}\cdot E\cdot h_{\text{eff}}}{2(R_{11}^2 - R_{12}^2)}\left\{\left(1 + j\frac{R_{12}}{R_{11}}\right)\cdot e^{j\psi} - j\left(1 - j\frac{R_{12}}{R_{11}}\right)\cdot e^{-j\psi}\right\} \\ &\text{Similarly,} \\ I_L &= \frac{R_{11}\cdot E\cdot h_{\text{eff}}}{2(R_{11}^2 - R_{12}^2)}\left\{\left(1 + j\frac{R_{12}}{R_{11}}\right)\cdot e^{-j\psi} - j\left(1 - j\frac{R_{12}}{R_{11}}\right)\cdot e^{j\psi}\right\} \end{aligned}\right\} \quad (10)$$

The second term in each bracket of equation (10) is the term that represents the retrodirective characteristic while the first term in each bracket represents the wave reradiated in an opposite direction to that in which the incoming wave is received, relative to the boresight of respective antenna elements. The first term and the second term in respective brackets in equation (10) have the same amplitude, which means that one half of the incident power is reradiated either straight backward or in an opposite direction to that in which the incoming wave is received.

In a concrete case where, in the Van-Atta array antenna device of FIGS. **3** and **6** the antenna elements **1L***b* and **1R***b* are comprised by the dipole antenna, each having a length equal to half the wave length of the antenna current, and the antenna feeder **1***b*—**1***b* consisting of a coaxial line has a characteristic impedance of $Z_o = 50(\Omega)$, determination is made in the following manner of the concrete value of the length l of the feeder and that of the length l' of the adjustable stub **11** having a characteristic impedance of $Z_o/2 = 25(\Omega)$.

Assuming

$Zr = R_{11} + jX_{11} = 73.3 + j42.2(\Omega)$

$Zm = R_{12} + jX_{12} = -12.5 - j29.5(\Omega)$

then there result from the equation (9) above

$Z_o \cot \beta((l/2) + l') = 48.1(\Omega)$

$Z_o \tan \beta(l/2) = 14.1(\Omega)$

Since Z_o amounts to $50(\Omega)$, there result

$\cot \beta((l/2) + l') = 0.962$

$\tan \beta(l/2) = 0.282$

Therefore, the concrete value of the length l of the feeder and that of the length l' of the stub **11** may be determined as follows:

$l = \nu\lambda + 0.0875\lambda$

$l' = 0.0843\lambda$

where:

ν = integer

λ = wave length of antenna current

The above relation is also true for sets of antennas other than that shown in FIG. **3**.

FIG. **5** represents a Van-Atta array antenna device according to another embodiment of the invention. The same parts of FIG. **5** as those of FIG. **2** are denoted by the same numerals and description thereof is omitted.

In the foregoing embodiments, there were connected in parallel single stubs **11**, **12** and **13**, each consisting of two parallel lines, a coaxial line or a wave-guide near the substantially middle point of the respective antenna feeders **1***b*—**1***b*, **2***b*—**2***b* and **3***b*—**3***b*. However, it is also possible to connect, as shown in FIG. **5**, in parallel groups of two stubs **11L**—**11R**, **12L**—**12R** and **13L**—**13R**, each displaying the same radiation characteristics as in the preceding embodiment to points equally spaced right and left from the centers O_1, O_2 and O_3 of the respective antenna feeders in the lengthwise direction thereof.

Thus, this invention provides a Van-Atta array antenna device capable of causing incoming electromagnetic waves to be reradiated either straight backward or in an opposite direction to that in which they are received relative to the boresight of respective antenna elements without varying the characteristic impedance of feeders interconnecting antenna elements symmetrically disposed on the opposite ends thereof as was necessary in the prior art arrangement, whereby it was heretofore necessary to adjust the length of each stub.

What is claimed is:

1. A Van-Atta array antenna device comprising:

a plurality of antenna elements juxtaposed at substantially equal distances from each other;

every two of said elements being disposed in a symmetrical relationship with respect to the center of said antenna array; respective antenna feeders connecting said every two elements together being designed to have substantially the same length; and

a number of pairs of impedance matching stubs, the stubs of each pair being parallely connected at substantially equally spaced points on either side of the center of respective antenna feeders in the lengthwise direction thereof, said stubs being so arranged and having a length such that incoming waves are reradiated either straight backward or in an opposite direction to that in which they are received.

2. A Van-Atta array antenna device comprising:

a plurality of equally spaced antenna elements;

feeders of substantially equal length interconnecting respective pairs of said antenna elements which are symmetrically located with respect to the center of the antenna array; and

a number of impedance matching stubs, each being connected to the corresponding feeder and having such a length that the incoming waves are reradiated either straight backward or in an opposite direction to that in which they are received, without changing the characteristic impedance of said feeders, the length l' *of said stubs, when the characteristic impedance thereof is assumed to be* $Z_o/2$ and the transmission loss of the feeders is neglected, being set to satisfy the equation:

$Zr + Zm - jZ_o \cot \beta((l/2) + l') = (R_{11} + R_{12}) + J(R_{11} + R_{12})$

$Zr - Zm + jZ_o \tan \beta\cdot(l/2) = (R_{11} - R_{12}) - J(R_{11} - R_{12})$

where:

Zr = the impedance of said antenna elements,

Zm = the mutual impedance between said antenna elements,

Z_o = the characteristic impedance of said feeders,

R_{11} = the real part of said Zr,

R_{12} = the real part of said Zm,

β = the phase constant, and

l = the length of said feeders.

* * * * *