A LINEAR ACTIVE DIPOLE ARRAY LOADED WITH NEGATIVE RESISTANCE DEVICES

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Abstract–Analyses of a linear active dipole array loaded with negative resistance devices under injection-locked arrangement are presented. In the arrangement, each dipole loaded with an active diode is treated as a microwave source, and an external injection plane wave illuminates the active dipoles to sychronize the linear active array. Analysis is based on the method of moments of dipoles and the stability analysis of injection-locked oscillators. Simulation results yield the array radiation field intensity and locking range for various incident field strength. Variation of loaded diode characteristics on the array performance are also considered.

I. Introduction

Solid-state microwave sources have several advantages over tubes due to their size, life time and small power consumption. The limited output power level, however, makes them not practical for many applications. Combining solid-state devices to generate high output power then becomes attractive. Since the loss of guide-wave type power combiner reduces its efficiency in the microwave and millimeter wave regions, the quasi-optical power combining techniques have been proposed experimentally [1]–[3] by combining the radiation field of each microwave source through antennas in the spatial domain. However, their simulation models did not include the nonlinear effect of active devices.

The purpose of this study is to present quantitative analysis of an active dipole array under injection locking. In the modelling, linear dipole antennas and two terminal negative resistance active devices (for example, Gunn diode) are considered. First, each dipole antenna is treated as an equivalent circuit using the method of moments. A nonlinear circuit equation is then construced to include the injection-locked oscillator (ILO). Due to the nonlinearity, multi-values of its output power are obtained, and stability criteria are derived to study the stability properties of the injection-locked dipole antenna. Numerical examples show the array radiation field intensity and locking range under different injection wave strength. The radiation patterns of uniform or different characteristics of actve devices in the array are also given.

II. Analysis

Consider a linear dipole array loaded with negative resistance devices as in Fig.1(a). If the incident wave field strength is large enough, the mutual coupling effect of dipole array can be neglected [4]. The equavalent circuit of each element is expressed using the method of moments as in Fig.1(b), where Y_{in} is the dipole input admittance and I_{eq} is the short-circuit current induced by the incident field E_{in}. The active two-terminal device is modeled to include

0-7803-1246-5/93/$3.00

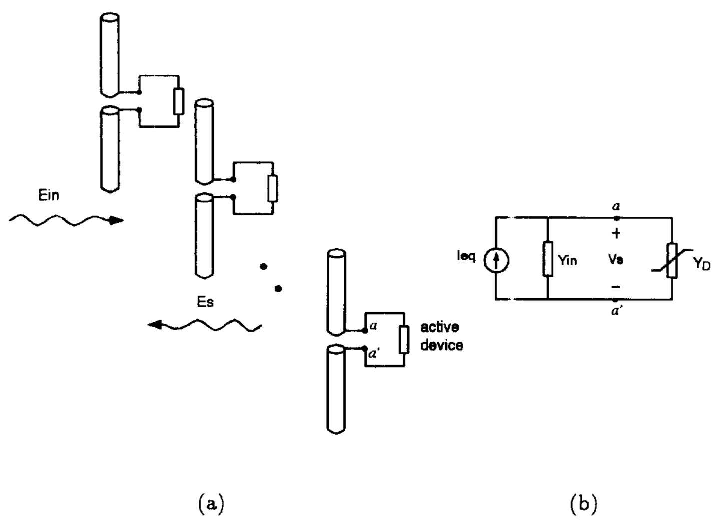

Figure 1: (a) A linear active dipole array loaded with negative resistance devices and (b) its equivalent circuit of each element.

the third order nonlinearity as [5]

$$Y_D = G_{n0} + G_{n2}V^2 \tag{1}$$

As $Y_{in}+Y_D = 0$ and $I_{eq} = 0$, the dipole may radiate without incident wave, i.e., in the free-running oscillation state. The operating frequency ω_o and terminal voltage V_{so} of each dipole can then be solved. As an external incident wave E_{in} with frequency ω_{in} illuminats the dipole array to sychronize each dipole elements, the injection-locked oscillator (ILO) can then be constructed. The circuit equation becomes

$$(Y_{in} + Y_D)V_s e^{j\phi} = I_{eq} \tag{2}$$

Solving V_s in eq.(2), it is found that there may be multi-values including false solutions. To evaluate the stability properties of each solution, one can use the first-order approximation of the total admittance expansion with respect to ω_{in}, and perturb the variables V_s. The stable condition for the injection-locked oscillator becomes [5]

$$2(G_T\frac{\partial B_T}{\partial \omega} - B_T\frac{\partial G_T}{\partial \omega}) + (\frac{\partial G_T}{\partial V_s}\frac{B_T}{\partial \omega} - \frac{\partial B_T}{\partial V_s}\frac{\partial G_T}{\partial \omega})V_s > 0 \tag{3}$$

$$G_T(G_T + \frac{\partial G_T}{\partial \omega}V_s) + B_T(B_T + \frac{\partial B_T}{\partial V_s}) > 0 \tag{4}$$

where G_T and B_T are the total conductance and susceptance respectively. Based on eqs.(3), (4) the locked state can be determined by checking the stability properties of each possible value V_s^2 under the injection condition.

III. Numerical Examples

In the simulation example, each dipole is with 10cm long and 0.135cm diameter, and the diode parameters G_{n0}, G_{n2} are −0.04 and 0.24. For single active dipole element calculation, the free-running frequency is 1.40523GHz and $V_{so}^2 = 0.10948V^2$. At the injection condition, Fig.2(a) shows the stability diagram with normally incident plane wave E_{in}=10.0mV/m. Note the solution is shown unstable under the stability boundary curve. The locking range corresponds to the frequency interval covered by the oval-shaped line.

Fig.2(b) shows the incident and radiated field strength. For small injection field strength, the radiated field strength is almost unchanged because of the free-running power dominant. The ILO acts as an amplifier as a larger injection field applied, and causes the radiated field strength increases drastically.

A 7-element linear active dipole array is considered with uniform or different diode characteristics for the array simulation. Fig.3(a) shows the array locking range for various incident field strength. The locking range decreases a little as the device parameters are simulated with normal distribution. The resulting array radiation patterns are shown in Fig.3(b). It can be observed that they differ slightly at the sidelobe levels.

IV. Conclusion

In this study, an approach based on the moment method and stability analysis is presented to simulate a linear active array under injection locking. The array locking range and output radiation field strength are calculated numerically. Simulation results indicate that variation of active device parameters may reduce the locking range slightly, but the radiation pattern is almost unchanged.

References

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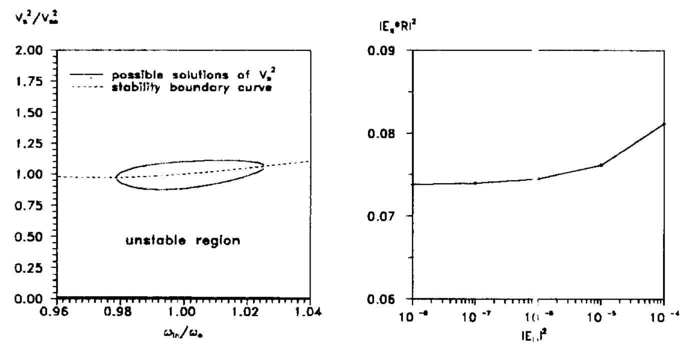
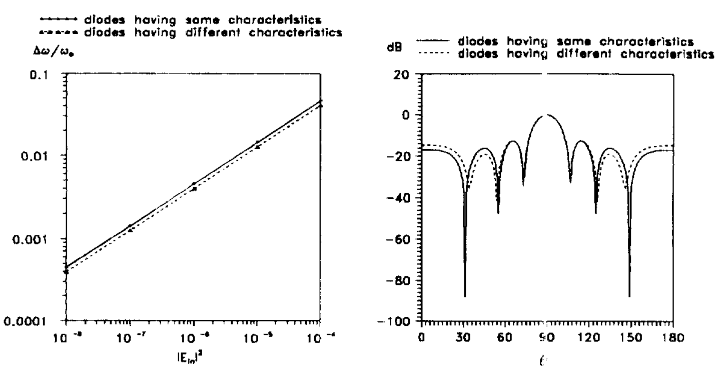


(a) (b)

Figure 2: (a) Stability diagram of a single active dipole antenna where E_{in}=10mV/m and (b) the scattered field for various incident wave strength.



(a) (b)

Figure 3: (a) The locking range of the linear active dipole array for various incident wave strength and (b) the radiation pattern of the array at E_{in}=1.0mV/m, where uniform and different loaded diode characteristics are shown.