行政院國家委員會專題研究計畫成果報告

毫米波電路與天線(II)子計畫三：注入鎖定主動天線陣列(1/3)
Injection-Locked Active Antenna Array (1/3)

計畫編號：NSC87-2213-E-002-058
執行期限：86**年**8**月**1**日至**87**年**7**月**31**日**
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一、 中文摘要

本計畫旨在建立注入鎖定主動天線陣列之理論分析、模擬與實驗量測，以及N-埠網路S-參數之量測原理、校準、裝置與應用。

本報告將敘述第一年之研究成果，包括：1、使用負載擾動法，建立分析耦合效應對注入鎖定主動天線陣列特性影響之理論，以及模擬與實驗量測，2、建立線性分析耦合效應對注入鎖定主動天線陣列特性之理論，3、建立N-埠網路S-參數之降埠量測方法，4、應用三-埠網路分析儀量測，並萃取雙閘極MESFET之線性等效電路元件參數。

關鍵詞：注入鎖定主動天線陣列、N-埠網路量測技術、等效電路元件參數萃取。

英文摘要

The purpose of this three-year research project is to develop the basic theory, numerical simulation and experimental measurement of an injection locked active antenna array and the basic principle, calibration, arrangement and measurement of the S-parameter of an N-port network.

In this first-year report, the study results include: (1) using load perturbation method to study the mutual coupling effect on injection locked active antenna array, (2) linear analysis the mutual coupling effect on injection locked active antenna array, (3) port reduction method for S-parameter measurement of an N-port network (4) using three-port vector network analyzer to measure and extract the linear parameters of a dual-gate MESFET.

Key words: injection locked active antenna array, N-port network measurement technique, parameter extraction.

二、 計畫緣由與目的

Using active array structure with each element consisting of an antenna and a solid state oscillator is a practical approach to construct a microwave or millimeter wave spatial power combiner (or source). In order to coherently combine these solid state sources to generate high output power, the oscillators are usually injection locked to a reference signal. This then leads to the structure of an injection locked active antenna array (ILAA).

Two-port vector network analyzer (for example, HP8510C) is a well-known two-port S-parameter measurement instrument. For an N-port network (for example, ILAA) its S-parameter is then usually acquired by using HP8510C for each selected two-port pair and all other ports are terminated with perfectly matched loads. However, this measurement technique is not valid and may degrade the S-parameter measurement performance for an N-port device as the operating frequency increases.

The objective of this three-year research project has two. One is to develop the basic theory, numerical simulation and experimental measurement of an injection locked active antenna array. Two is to develop the basic principle, calibration, arrangement and application for the S-parameter measurement of an N-port network.

In the following section, we will briefly describe the approaches and results of this first-year study.

三、研究方法及成果

As shown in Fig.1, the schematic diagram of an ILAA consists of an injection source, a power distribution network and an array of ILO (injection locked oscillator) with associated antenna. Since the antennas are closely distributed, the locking performance of ILAA will then be affected by the array mutual coupling. In the previous year, we developed a circuit model of ILAA, in which the antenna array is equivalent to an admittance matrix loaded with nonlinear equivalent circuits of ILOs. However, the nonlinear circuit equations become difficult to solve as the number of ILAA increases. Instead of completely solving ILAA circuit equation, we develop a load perturbation method [4] by which only single ILA is required to be considered. External sources due to mutual coupling are treated as a perturbation of the load admittance as shown in Fig.2. This then gives an efficient approach to study the locking performance of ILAA due to mutual coupling effect. From both the simulation and experimental results, we observe that the perturbation admittance with its phase in a certain range can enhance the locking capability of ILAA, i.e., the critical power for locking is reduced. While the phase is not within this range, the ILAA will be unlocked due to the improper mutual coupling effect. This load perturbation method is not only useful to quantitatively describe the effect of mutual coupling, but also gives the physical inside to interpret the array locking capability caused by mutual coupling.

In addition, we develop the formulation to linearly analyze the locking performance of two injection locked active antennas [5]. Each active antenna consists of a FET oscillator. Based on the connection-scattering method, a matrix equation to relate the input signals and output signals of each injection-locked active antenna is formulated. In this matrix equation, the antenna mutual coupling effect is represented by a mutual coupling coefficient. The FET is represented by its small signal S-parameter. After proper matrix manipulation, one can express the each active antenna output signal in terms of the injection signal, mutual coupling coefficient, FET S-parameter and the antenna input impedance. From which, one can derive an explicit formulation of locking bandwidth of the active antenna and effective Q of the oscillator. By using the resulting equations, one can study the effects of each active antenna parameter, for example, antenna mutual coupling, FET S-parameter, feedback network or antenna input impedance to the locking performance. This linear analysis approach may be useful to find the explicit formulation for an injection-locked active antenna array.

As described previously, the port reduction method is a method to measure the S-parameter of an N-port network by terminating certain ports to reduce the order of measured ports. As the order is reduced to two, an N-port network can be measured by using conventional two-port network analyzer directly. In this year we develop a generalized port reduction method and its calibration procedure [6]. This port reduction method can reduce the order of measured ports to three for a non-reciprocal N-port network, and two for an N-port reciprocal network. In addition, the terminators connected can be partially known. The developed port reduction method then relaxes the requirement of an N-port network analyzer and associated special calibrators. Based on the developed port reduction method, the port description is given in Table 1. It shows that to reconstruct the S-parameter of a four-port network. a total of six two-port S-parameter measurements for a reciprocal network or a total of four three-port S-parameter measurements for a non-reciprocal network is required. Experimental results of a four-port circuit show the good accuracy using the developed port reduction method.

Application of three-port S-parameter measurement technique is developed to directly measure the 3x3 S-parameter of a three-port device. The instruments, measurement procedure and calibration are controlled by a SUN SPARC-10 workstation. The measurement can be conducted for MMIC devices using probe station or components with microstrip lines or SMA connectors. The operation frequency range is from 45MHz to 50GHz. We have measured an 1*um* dual-gate GaAs MESFET MMIC fabricated by Hexawave Corporation in Hsinchu Science Park. The parameter extraction technique is developed using cold- and hot-measurements to analytically calculate its element values in the equivalent circuit. The resulting extracted parameters of its small signal equivalent circuit from the measured 3x3 S-parameters are given in Table 2 [1,3]. This MMIC will be used in the design of ILAA. In addition, we have developed a six-port technique for a microwave diversity imaging system given in [2].

四、結論與討論

In this report, study results of (1) analysis of antenna mutual coupling effects in an ILAA using load perturbation method, (2) linear analysis of two injection locked active antennas including mutual coupling effect, (3) a generalized port reduction method for the S-parameter measurement of an N-port network, and (4) an automated three-port vector network analyzer measurement system and parameter extraction of a dual-gate MESFET small-signal equivalent circuit, are presented. This work not only is a basic research study, but also finds applications in the areas of microwave and millimeter industry, for example, stable source, nonlinear or active array, multiport MMIC or device measurement techniques and microwave imaging radar.

五、 發表論文

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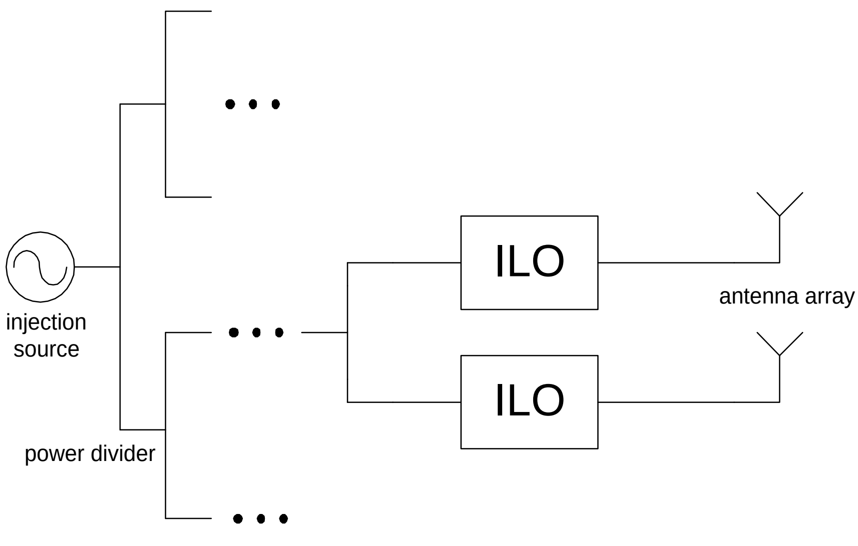

Fig.1 Schematic diagram of an injection locked antenna array (ILAAA).

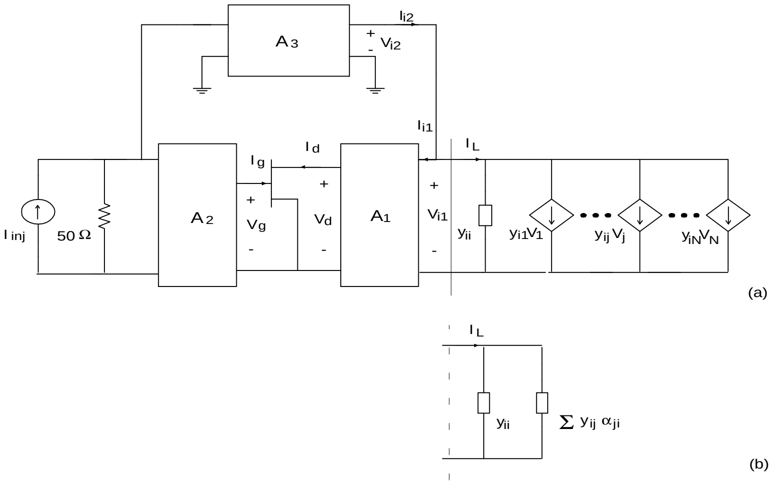

Fig.2 Equivalent circuit used in the load perturbation method for analysis of mutual coupling effect in an ILAA.

Ports of resulting four-port S-matrix	Ports of intermediate three-port S-matrix	Ports of measured two-port S-matrix	Ports of actually measured two-port S-matrix
1234	123_1	12_11	12_11
		13_11	13_11
		23_11	23_11
	124_1	12_11	---
		14_11	14_11
		24_11	24_11
	134_1	13_11	---
		14_11	---
		34_11	34_11
	234_1	23_11	---
		24_11	---
		34_11	---

Table 1 Port description of the scattering matrix for using the developed port reduction method.

Elements	Initial values	Final values
Cgs1, Cgs2	*0.2pF, 0.295pF*	*0.22pF, 0.24pF*
Ri1, Ri2	*7 t , 10 t*	*6.44 t , 9 t*
gm1, gm2	*0.058A/V, 0.03A/V*	*0.0618A/V, 0.025A/V*
²1,²2	*7.6ps, 8.04ps*	*7.2ps, 7.7ps*
Cdg1,Cdg2	*63fF, 68fF*	*64.3fF, 60fF*
gd1, gd2	*100S, 170S*	*104S, 150S*
Cds1, Cds2	*0.15pF, 0.034pF*	*0.051pF, 0.03pF*
Rg1, Rg2	*NKQO t I=NKMQ t*	*NKPO t I=MKVS t*
Rs, Rd	*QKUS t I=QKUN t*	*QKUO t I=QKMQ t*
R12	*PKMS t*	*PKMQ t*
Cpg1,Cpg2, Cpd	*87fF, 120fF, 58fF*	*72fF, 105fF, 57fF*
Ls, Ld, Lg1, Lg2	*0.001nH,0.089nH,0.0186nH,0.0173nH*	*0.001nH,0.095nH,0.019nH,0.0168nH*

Table 2 Extracted initial and final values of the small-signal equivalent circuit of a dual-gate MESFET.