Experimental Investigation on High Efficiency Decoupling Using Tunable Metamaterials

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***Abstract*—More than 110 dB isolation is experimentally realized in a narrow band in this work. Multiple varactors based tunable metamaterials were placed between two co-polarized monopole antennas. The metamaterials are controlled using an genetic algorithm (GA) based optimization program. The optimization goal is to minimize the transmission coefficient of a . After 3000 generations of evolution, more than 110 dB isolation ratio is achieved. This method is verified by two experiments with different metamaterial structures.**

***Index Terms*—Metamaterial, tunable metamaterial, isolation, decoupling.**

I. Introduction

Isolation closely placed co-polarized antennas with high ratio is challenging but practical significant. Many multiple antenna systems have isolation requirements on mutual coupling [1]–[5]. A natural method to isolate antennas is to place metal plate between the antennas [6], [7]. This method can be understood as setting up obstacles in the signal propagation path. Recently, it is improved by many different methods [8]–[10]. Although good isolations are achieved by these methods, when dealing with very strong narrow band mutual coupling, higher isolation is still needed by many cases. For example, a fire control radar usually has thousands of watts of output. If a GPS receiver is close to the radar, it is very easy get saturated and loss of function.

In this work, we focus on the phenomena that varactors based metamaterials have the ability of changing amplitude and phase response of the transmission signal continuously. This behavior can be used to control the near field distribution. Thus, the transmission coefficient of these two antennas can be manipulated. By carefully tuning the amplitudes and phases high level isolation can be achieved. To verify this idea, we built a dual antenna system with varactors based tunable metamaterials between them. This system is controlled by a genetic algorithm based optimization program. Two different kinds of metamaterial are employed. More than 100 dB isolation ratio is achieved for both of them.

II. The method of near field manipulation using tunable metamaterials

The simplified theoretical signal model of this method is shown in Fig. 1. The system is assumed to be symmetrical. Antenna A is considered as the source. The signal emits from antenna A and reach the metamaterials. After that, the signals with different amplitudes and phases re-emit from the metamaterials and finally reach antenna B. The amplitudes and phases are determined by the status of the metamaterials which is controlled by the bias voltages added on the varactors. In this model, the signals passing through the gaps of the metamaterials are all included in the diffraction signal since this signal is not directed controlled by the bias voltages.

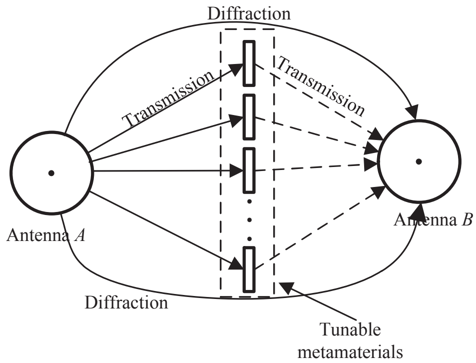

Fig. 1. Signal model of near field transmission.

The signal received at the port of antenna B can be expressed as

$$E_B = \sum_{i=1}^{n} ae^{-j\theta_0} T_i^2 e^{-j2\theta_i} + ae^{-j\theta_0} De^{-jd} \qquad (1)$$

where a and θ_0 are the amplitude and phase of the emitted signal; T_i and θ_i are the amplitude and phase of the i resonator; D and d are the amplitude and phase coefficient of diffraction signal. Since this model is symmetrical, T_i and θ_i are also the the amplitude and phase response of antenna B to the re-emitted signal. By tuning the bias voltages, the statuses of resonators are controlled. Thus, T_i and θ_i are manipulated. If the parameters are properly, it is possible to cancel the signal received on antenna B. However, this signal model can not be calculated directed with analytical method. That is because the relationships between the bias voltage and the amplitude and phase response are complicated and the strong mutual coupling between the metamaterial unit cells is unknown. Nowadays, problems without analytical solutions are quite normal. Artificial intelligence has developed for years to deal with the problems without analytical solutions. In this work we use GA based optimization because it is a global method and easy to realize.

III. Experimental investigation

A. Genetic algorithm based system

To optimize the isolation ration between two closely placed antennas, a GA based system is built and installed in a microwave anechoic chamber as illustrated in Fig. 2. A tunable metamaterial screen is placed between two co-polarized antennas. A voltage controller is connected with the screen to provide the multiple channel bias voltages to the different unit cells. A vector network analyzer (VNA) is connected with antennas to continuously measure the transmission coefficient (S_{21}) and send it to the computer. The computer running a GA based optimization program adjusts the multiple channel voltages according to the S_{21}.

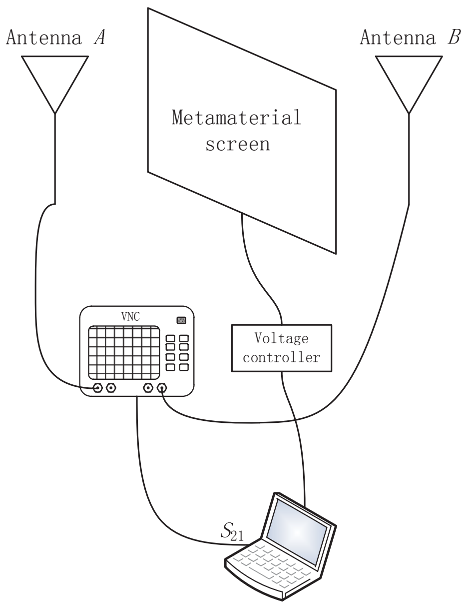

Fig. 2. Signal model of near field transmission.

B. Experiments with vertical extending metamaterials

The fabricated prototype of this work is shown in Fig. 3. Two vertical positioned same monopoles are installed symmetrically with respect to a resonator screen. The elevations of these monopoles are all at the center of the screen. The length of the monopoles is 30.6 mm, and they resonate at 2.4 GHz. The distance between these monopoles is 10 cm, that is 0.8 λ at 2.4 GHz. A circular ground plate with a diameter of 40 mm is added for getting a more stable matching. This resonator screen is constructed with seven same columns. Each column has six same unit cells. Bias voltages are added at the bottom of each column through a jacket connector. Thus the six resonators within one column have the same bias voltage.

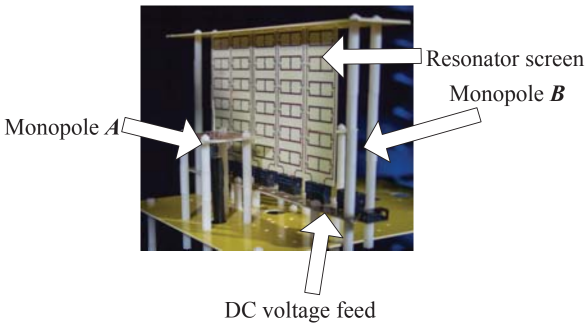

Fig. 3. Configuration of the prototyped system

But the voltages of different columns are individual.The other parts of this prototype are made of FR4 board and nylon sticks which support the structures in position.

The structure and dimensions of the resonators are shown in Fig. 4. It is realized using a single layer FR4 board. An additional bias grid is added beside the patches to supply controlling voltage for the varactors. 10 K-Ohm resistors are added on the bias grid for the purpose of choking the high frequency signals on the bias grid. The varactors used in this work are BB857, provided by Infineon, and they are tunable from 0.54 pF to 6.6 pF.

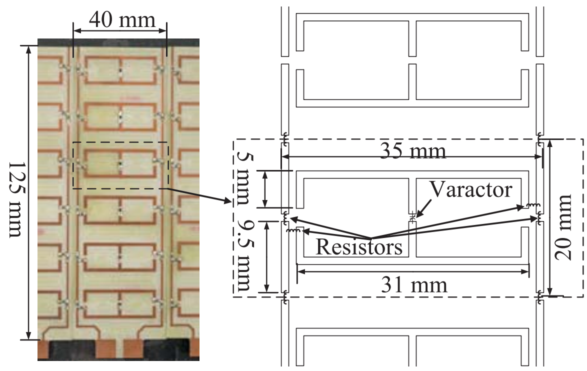

Fig. 4. AFSS structure and dimensions.

The stop band frequency is tunable when varying the bias voltage to change the capacitance of the varactors. Simulated and measured results are shown in Fig. 5. The resonant frequency can be tuned from 2.0 GHz to 2.75 GHz which covers the working band of the monopoles.

After optimization procedure, S_{21} reach -113.0 dB. This result is close to the sensitivity limit of the VNA. The direct transmission (nothing is between the monopoles) is -26.9 dB. We replace the resonator screen with a metal board having the same dimension (280 mm by 125 mm), the transmission coefficient is about -53.0 dB. The results are shown in Fig. 6. Compared with the metal screen, the resonator screen has significant advantage from 2.434 GHz to 2.446 GHz.

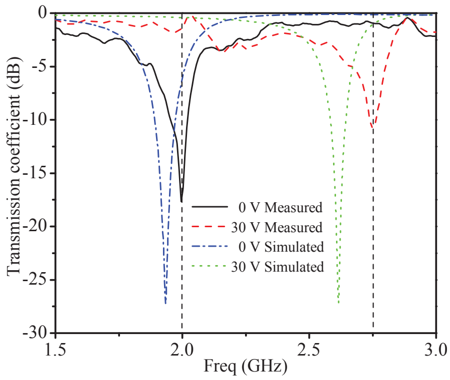

Fig. 5. Simulation and measurement transmission coefficients of the AFSS.

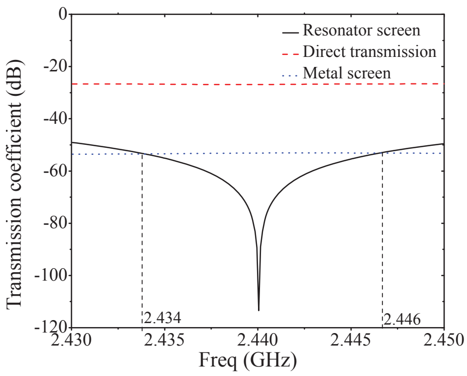

Fig. 6. Transmission coefficients comparison.

C. Experiments with horizontal extending metamaterials

We also use horizontal extending metamaterials to verify this theory. As shown in Fig. 7, This resonator screen is constructed with eight rows of resonators. There are three uniform resonators within each row. Bias voltage is added individually at the end of each row. Thus the resonators in the same row has the same bias voltage. But the voltages of different rows are individual.

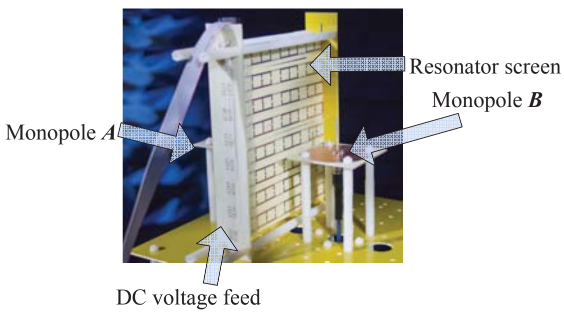

Fig. 7. Configuration of the prototyped system

The fabricated resonator screen and the structure is shown in Fig. 8. The dimensions are as follows: d = 44 mm, a = 30 mm, l_1 = 4 mm, l_2 = 4.25 mm,l_3 = 6 mm, $W_1 = W_2 = W_3$ = 1.5 mm, s = 0.75 mm and g_1 = 1 mm. The varactors are also BB857 as the previous experiment.

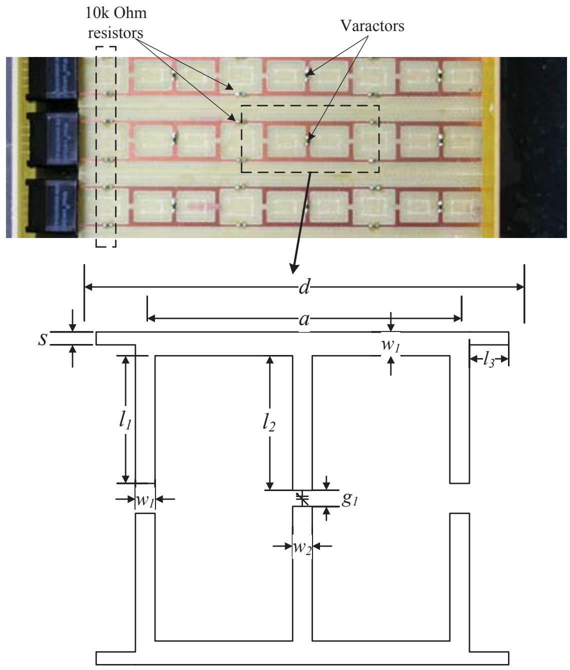

Fig. 8. Resonators' structure and dimensions.

Simulation results of the resonator structure under unit cell boundary condition are shown in Fig. 9. When biased from 0 to 30 V, the stop-band of this resonator is tuned from 1.89 GHz to 2.61 GHz. The transmission rate of the peak is from -12.1 dB to -17.4 dB. Same to a notch, the phase response shifts dramatically. Furthermore, the amplitude and phase response is not individually tunable. They are all determined by the bias voltage at the same time. The relationship of amplitude and phase is decided by the patch structure and varactors' parameters.

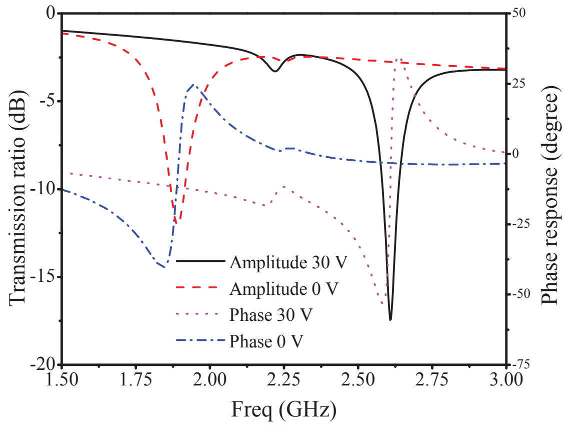

Fig. 9. Simulation results of transmission rate.

We perform the optimizations at 2.4 GHz. The results compared with direct transmission (nothing between the monopoles) and metal plate isolation (a metal plate with the same dimensions with the resonator screen) are shown in Fig. 10. Similar to previous experiment, at the targeting frequencies, the transmission coefficient is -107.1 dB.

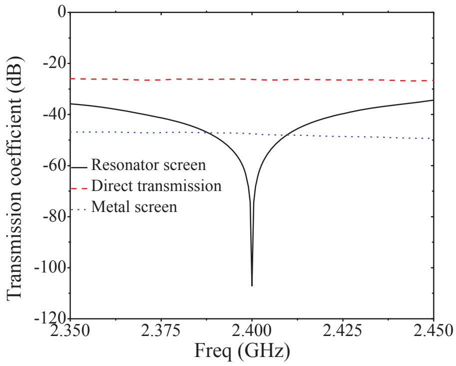

Fig. 10. Measured results at 2.4 GHz.

IV. Conclusion

In this paper, novel method about using tunable metamaterials based on varactor to get high level isolation is experimentally proved. However, the method is narrow band. In the future work we will focus on improving the band width to make this method more practical.

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