# Dual-Band Compact Array of Printed Dipole Antennas

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***Abstract*** **─** Compact array of printed dipole antennas loaded with reactive elements is proposed. A novel and practical applications of the metamaterial (MTM) inclusion in dipole antenna designs is presented. The simulation results show a reasonable reduction in mutual coupling between antenna elements and provide a possible way to reduce the element separation. A prototype of the proposed array antenna is fabricated and tested. Measurement shows that the isolation with inter-antenna spacing of less than 0.075$\lambda$ (at $f$=0.9 GHz) through the first frequency band (811 MHz–955 MHz) is above 12.5 dB, while the proposed design provides more than 15 dB isolation with inter-antenna spacing of less than 0.133$\lambda$ at $f$=1.6 GHz (1325 MHz–1880 MHz).

***Index Terms*** **─** Compact array, printed dipole antenna.

## I. INTRODUCTION

The increasing demands on compact multifunctional devices have necessitated the development of miniaturized/multi-frequency printed dipoles which can be integrated into familiar devices such as laptop computers and mobile phones [1]. Due to unique electromagnetic properties [2-6], MTMs have been widely considered in monopole and dipole antennas to improve their performance [7-12].

The applications of composite right/left handed (CRLH) structures to load the printed dipole have been investigated both numerically [13] analytically [14], and experimentally [15 and 16]. However, main drawbacks of this method are low gain and low efficiency.

In the field of array antenna, there is a great interest to reduce the array size while it may be worked properly. Due to increasing mutual coupling effects in such compact array antennas, one of the researcher interests is to reduce mutual coupling between densely packed array elements, so that array elements can be designed separately, without consideration of mutual coupling arising from neighboring elements. The strong mutual coupling between array elements imposes a tremendous limitation on the practical packing density of arrays.

There are various methods that can be utilized to improve array isolation, using EBG structures [17-19], defected ground structure (DGS) [20], coupling element [21], using meta-surface [22], modified ground plane [23], artificial substrate [24], slotted-complementary split-ring resonators (SRR) [25], soft-surface [26], and MTM isolator [27 and 28].

However, in all mentioned methods, the designer has to make changes in antenna ground plane or using additional structures. These changes increase the complexity as well as time and cost factors of design and manufacturing processes.

In [9], a compact printed dipole antenna is proposed using reactive loading, which is inspired by ENG-MTM inclusions. The antenna has a broad bandwidth which is significantly wider than the bandwidth of other miniaturized MTM loaded dipole antennas. Due to enhancement of both antenna gain and bandwidth in [9], one may chose

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it as a good candidate for compact, broadband array antennas.

Using the compact printed dipole antenna of [9] as an element of a simple linear array antennas, in contrast to all mentioned methods, the proposed miniaturized array provides isolation enhancement, without need to make any change in ground plane or using any additional structure. This fact consequently leads to simple low profile, low cost and low weight array antennas. A prototype of the proposed antenna is fabricated and tested. It is found that the proposed method may result more than 12.5 dB isolation with inter-antenna spacing of less than 0.075$\lambda$ at $f$=0.9 GHz and 0.133$\lambda$ at $f$=1.6 GHz (25 mm) demonstrating that significant improvement in isolation between antenna elements can be obtained. The commercial software Ansoft HFSS is adopted for the simulations. The numerical simulation results show good agreement with the measurements.

## II. ANTENNA DESIGN, SIMULATION AND FABRICATION

An array of closely spaced loaded dipole antenna which is also worked with reduced mutual coupling is presented here. It is well-known that the dipole antennas exhibit significant mutual effects when they implemented in side-by-side arrangement. These effects are much higher than collinear configuration, since in side-by-side arrangement, the antennas are placed in the direction of maximum radiation [1]. Hence, in this paper, the side-by-side arrangement is used to show the effects of proposed method on the correlation coefficients.

As described in [9], to miniaturize a printed dipole antenna, someone may use a reactive loading method based on ENG-MTM inclusions. The behavior of a dipole antenna loaded with MTM inclusions has been examined in [9]. It has been revealed that embedding epsilon negative (ENG)-inclusions in a simple dipole antenna can provide an opportunity to design miniaturized/multi-band antenna. Results show that placing proposed MTM cells in close proximity of a printed dipole antenna makes it miniaturized. The dimensions of the proposed MTM cell is optimized to meet the specifications of the mobile bands (890.2 MHz–914.8 MHz, and 1710 MHz–1784 MHz) while maintaining its compact size.

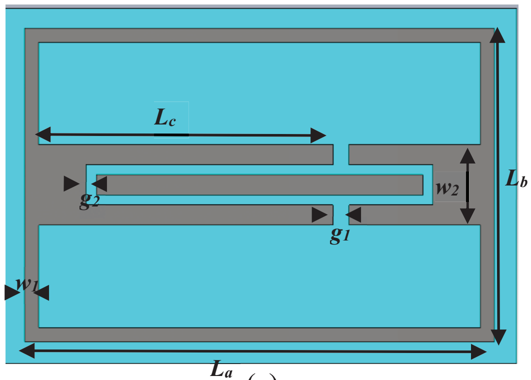
The antenna radiation efficiency at the first resonance frequency is significantly higher than those reported for other miniaturized printed dipoles in the literature [13]. It is worthwhile to point out here that the subject of single-cell MTM loading is not new and has been studied by other authors [15].

In [9, Fig. 2], the return loss of symmetrically loaded and unloaded dipole antennas is shown. The proposed antenna has a broad bandwidth of 15.96% at 940 MHz (which is significantly wider than the bandwidth of other miniaturized MTM loaded dipoles [14]) and 32.35% at 1.7 GHz.

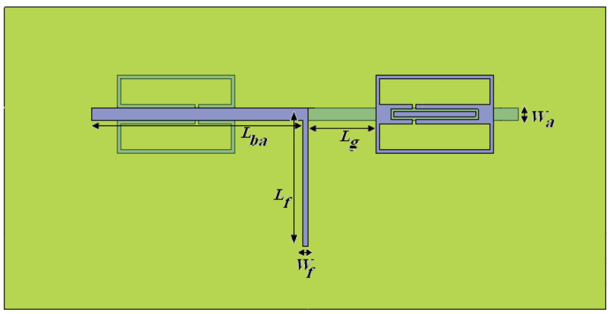
According to [9], again the array is considered to print on a FR4 substrate with a thickness of 0.8 mm and a dielectric constant of 4.4. All the dimensions are the same as the antenna described in [9]. Figure 1 (a) and Fig. 1 (b) show a single cell MTMs and array element respectively. The printed dipole array is fabricated to validate the simulation results, (see Fig. 2). Figure 1 (c) shows a photograph of the fabricated array antenna.

According to Fig. 2, the dipole array antenna along with the loading elements provides good matching at both expected frequency bands. In Fig. 2 (a), although the simulated and measured results are in reasonable agreement, slight frequency shift in some frequencies is observed. Frequency shift in microstrip antenna may be attributed to the fabrication process and dielectric constant tolerance in a frequency regime. This phenomenon is more critical in multiband microstrip antenna which was observed in copious previous works. From the measurement result, the isolation and the 10 dB return-loss bandwidth at first resonance frequency (0.9 GHz) are above 12.5 dB and 144 MHz (16.3%) respectively. It is found that the design may provide more than 15 dB isolation with inter-antenna spacing of less than 0.133$\lambda$ at $f$=1.6 GHz (25 mm), demonstrating that significant improvement in isolation between antenna elements can be obtained.

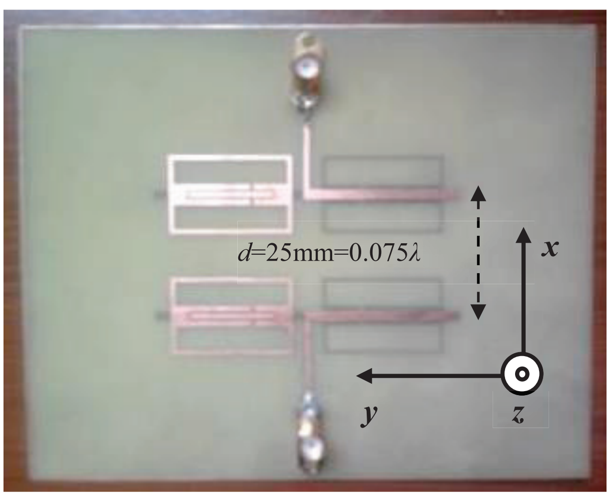
The simulation results for the antenna gain and radiation efficiency are also illustrated in Fig. 2 (b). It seems clear that the antenna radiation efficiency is high through the entire frequency band (>75%). Moreover, the gain of the proposed antenna is about -5 to -2 dBi. As revealed in this figure, the antenna radiation is good while it matched through the broad band frequency.




(a)

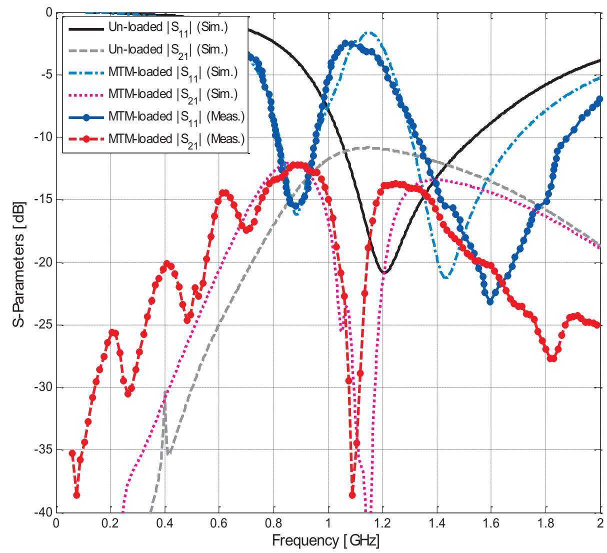



(b)

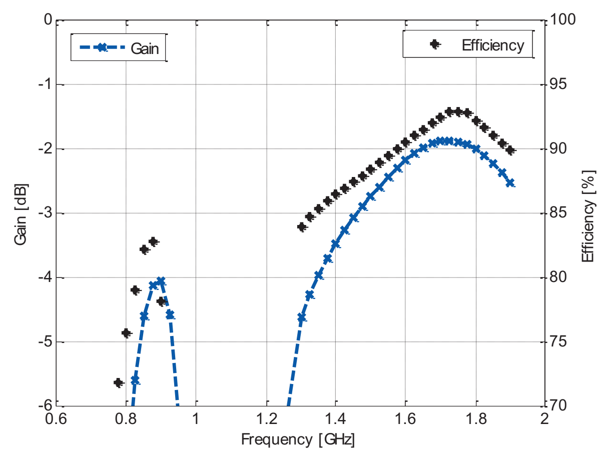



(c)

Fig. 1. Array of printed dipoles symmetrically loaded with single cell MTM: (a) single cell parameters: $L_a$=23.54 mm, $L_b$=15.55 mm, $L_c$=14.78 mm, $w_1$=0.7 mm, $g_1$=0.8 mm, $w_2$=4 mm, $g_2$=0.5 mm, $L_s$=26.75 mm, and $w_s$=2.5 mm as the width of the antenna arms; (b) antenna element, [9]: $L_{ba}$=42.05 mm, $L_f$=27.5 mm, $L_g$=12.52 mm, $W_a$=2.5 mm, $W_f$=0.8 mm; (c) prototype: $d$=25 mm≈0.075$\lambda$ at $f$=0.9 GHz and ≈0.133$\lambda$ at $f$=1.6 GHz.




(a)




(b)

Fig. 2. (a) Return loss and isolation of array of printed dipoles unloaded and symmetrically loaded with single cell MTM, simulation and measurements comparison, and (b) gain and radiation efficiency of the printed dipoles symmetrically loaded with single cell MTM.

In Fig. 3, the simulation results of reflection and correlation coefficients of an array of printed dipoles symmetrically loaded with single cell MTM, versus frequency with regards to array element distance, $d$, has been depicted. Comparing simulation results with un-loaded dipole array antennas, Fig. 2 (a), it is clear that, MTM loaded array shows a dual band behavior while the antenna isolation is enhanced at least 5 dB. The isolation may enhance about 10 dB while the array distance increases as it is shown at 32 mm (0.096$\lambda$).

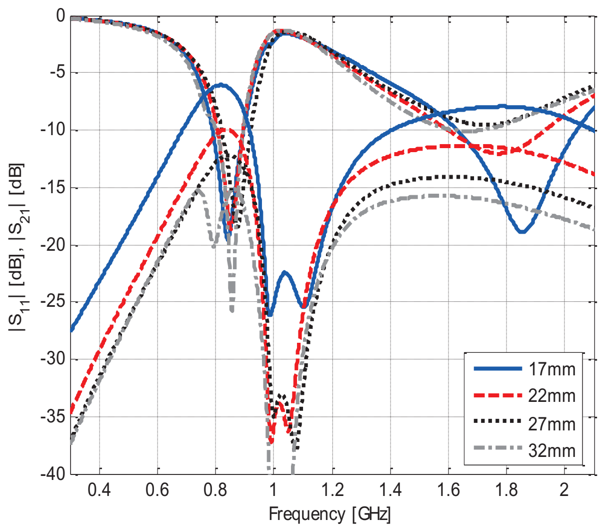
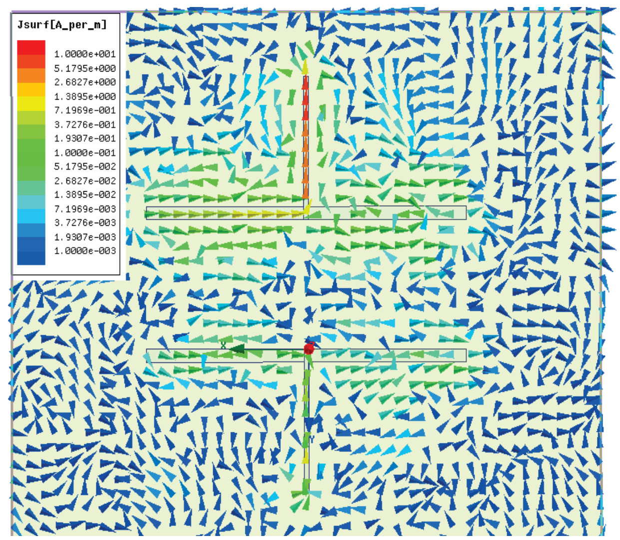


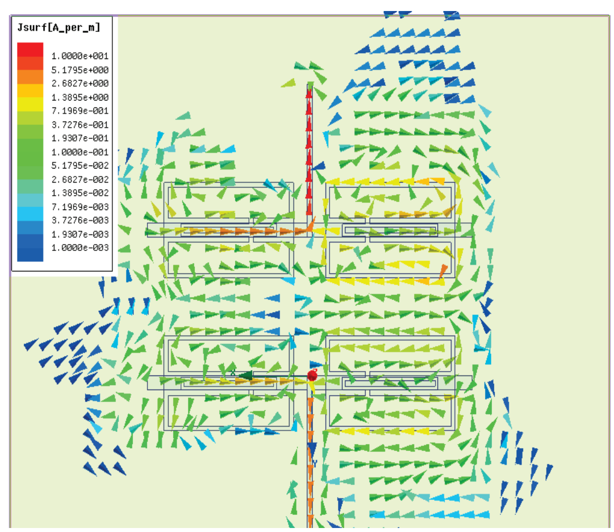

Fig. 3. Simulation results of reflection and correlation coefficients of an array of printed dipoles symmetrically loaded with single cell MTM, versus frequency with regards to array element distance, *d*.

It should be noted that, although in side-by-side arrangement, the distance between the antennas are usually considered as arms separation (25 mm≈0.075$\lambda$); here, due to significant coupling between MTM cells, someone may consider the inter-antenna spacing of 10.5 mm (0.0315$\lambda$). This fact is depicted in Fig. 4.

However, using MTM cells, the correlation between the ports is decreased. This phenomenon is clearly seen in Fig. 4, while it seems that the surface current confined around the arms of dipoles and MTM cell regions. This causes to reduce coupling factor between loaded printed dipoles. This fact is confirmed when comparing the radiation pattern of loaded and un-loaded dipole array antennas, Figs. 5 and 6. The radiation patterns for each port of un-loaded array antennas have been shown in Fig. 5. The maximum gain of the antennas are about -8 and -7 dBi at *f*=0.9 GHz and *f*=1.6 GHz respectively, while its cross-polarizations are about 14 and 22 dB lower than its main lobes. The radiation patterns of each port of array of MTM loaded printed dipole antennas are also shown in Fig. 6. The maximum gain of the antennas are about -4 and -2 dBi at *f*=0.9 GHz and *f*=1.6 GHz respectively. The cross-polarization levels at these frequencies are about 20 and 25 dB lower than their main lobes which are better than un-loaded printed antennas. Moreover, reducing surface current causes to increase radiation gain in the case of MTM loaded printed dipole antennas.

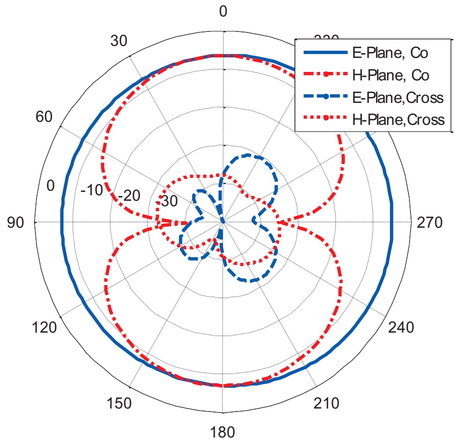



(a)

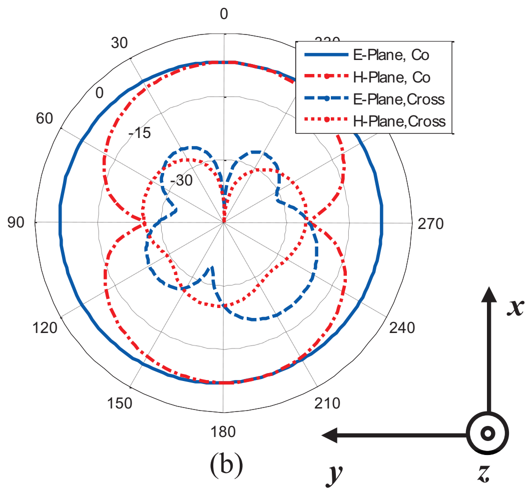



(b)

Fig. 4. Simulation results for the vector surface current of the array of printed: (a) un-loaded, and (b) symmetrically loaded with single cell MTM dipoles at *f*=0.9 GHz.

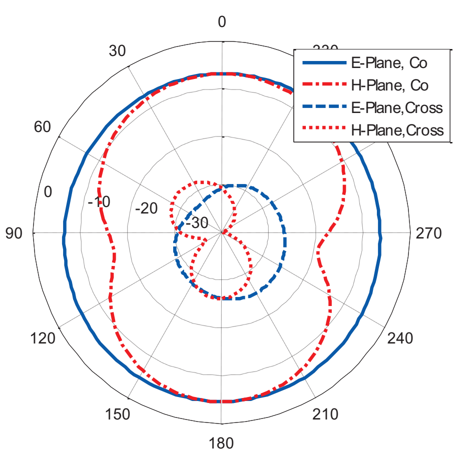



(a)

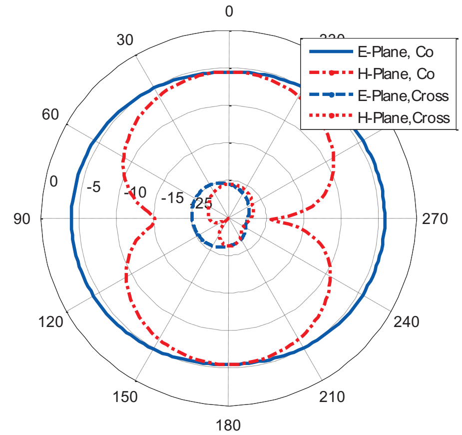



(b)

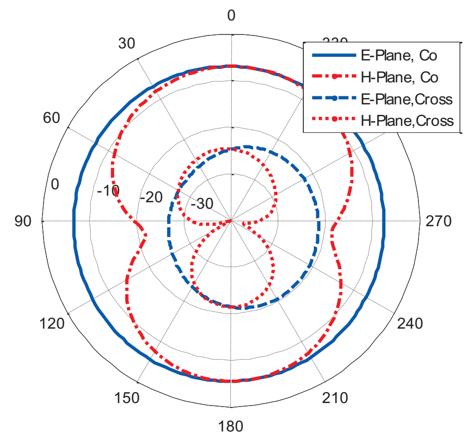
Fig. 5. Simulation results for the radiation pattern of the array of printed dipoles for both Co- and Cross- polarizations, *f*=0.9 GHz at: (a) port 1, and (b) port 2.



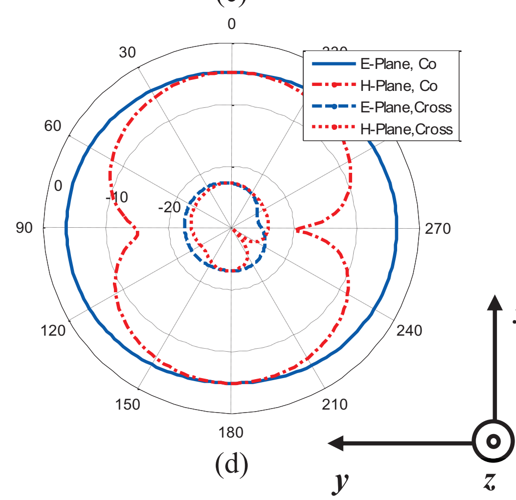

(a)




(b)




(c)




(d)

Fig. 6. Simulation results for the radiation pattern of the array of printed dipoles symmetrically loaded with single cell MTM for both Co- and Cross- polarizations at port 1: (a) *f*=0.9 GHz, and (b) *f*=1.6 GHz; and at port 2: (c) *f*=0.9 GHz, and (d) *f*=1.6 GHz.

## III. CONCLUSION

A compact printed array of dipole antenna has been proposed. The proposed antenna provides isolation enhancement, without need to make any change in ground plane or using any additional structure. This fact consequently leads to simple low profile, low cost and low weight array antennas. Simulations show that the proposed array antenna provides isolation above 15 dB with inter-antenna spacing of less than 0.075$\lambda$. A prototype of the proposed array antenna is fabricated and tested. The simulation results have been confirmed by measurements.

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