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Titre : Utilisation d'une MAM et d'un algorithme génétique pour optimiser une antenne monopôle à microbande UWB avec FEM et HFSS

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Résumé : Le but de ce travail est la conception et l'optimisation d'une nouvelle forme d'antenne monopôle à patch cardioïde à microbande avec un comportement de coupure de fréquence, dans le but de rejeter la bande de fréquences 5-6 GHz pour assurer la compatibilité avec les réseaux WLAN/WiMAX. Par rapport aux structures monopôles précédentes utilisant des méthodes similaires, les dimensions réduites de l'antenne ne sont que d'environ $25 \times 25 \times 1 \text{ mm}^3$, ce qui est 15 fois plus petit que la conception précédente proposée. Ce travail utilise une méthode d'analyse (la méthode d'analyse polyvalente) pour la conception de microbandes, qui utilise des ports artificiels dans une analyse par la méthode des éléments finis afin d'évaluer rapidement plusieurs configurations, pour la conception d'une antenne monopôle à microbande à bande ultra-large avec une coupure de fréquence. La bande passante mesurée de l'antenne réalisée avec des paramètres optimisés s'étend de 2,5 à 11 GHz (4,4:1, 126 %) pour un VSWR inférieur à 2.

Mots-clés : algorithme génétique, antenne monopôle à microbande UWB, FEM, HFSS, optimisation, antenne monopôle à patch cardioïde à microbande, méthode des éléments finis, antenne monopôle à bande ultra-large, fréquence de 2,5 GHz à 11 GHz.

Using a MAM and Genetic Algorithm to Optimize UWB Microstrip Monopole Antenna with FEM and HFSS

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Abstract— The purposes of this work is the design and optimization of a new form of microstrip cardioid patch monopole antenna with frequency-notched behavior intended to reject the 5–6 GHz frequency band for WLAN/WiMAX compatibility purposes. In comparison to the previous monopole structures with similar methods, the miniaturized antenna dimension is only about $25 \times 25 \times 1 \text{ mm}^3$, which is 15 times smaller than the previous proposed design. This work makes use of a analysis method (the Multipurpose Analysis Method) for microstrip design which features the use of artificial ports in a Finite Element Method analysis in order to fast evaluate several configurations, for the design of a frequency notched microstrip Ultra Wide Band monopole antenna. The measured bandwidth of the realized antenna with optimized parameters is from 2.5 to 11 GHz (4.4:1, 126%) for $VSWR < 2$.

Keywords-component: Finite element methods (FEMs), piecewise linear approximation, Multi Admittance matrix, UWB antennas, Cardioid.

I. INTRODUCTION

THE fast development of wireless communication systems urges the need of Ultra Wide Band (UWB), multi-band or dual-band antennas [1],[2]. Wireless personal network (WPAN) is one of the most popular applications of modern wireless technology, also Ultra Wide Band technology is developed to provide the requirements of the WPAN network using 3.1-10.6GHz frequency band, approved by FCC. For Ultra Wide Band systems, released by the FCC in 2002, printed monopole antennas specifications are good candidates. These antenna features controllable bandwidth, good radiation properties and low profile, simple structure have been widely

used for a long time. On the other hand, a lot of work is being carried out to reject some frequencies to prevent from interfere with other systems. Particularly, coexistence between these different WLAN (HIPERLAN, IEEE 802.11a) and Ultra Wide Band systems are a important concern. Since all of these systems works in a common frequency band which can be isolated between sub-bands 5150–5350 and 5725–5825 MHz (specified by IEEE 802.11a) [1], [2], research efforts have been done towards the rejection of these bands.

II. ANTENNA DESIGN

The design procedure which is proposed has nothing to do with HFSS and FEM analyses within the optimization processes. It is based on a GA and the use of a MAM method [3]-[4]. Particularly, genetic algorithms (GA) are a familiar optimization technique, which have been used before in electromagnetic design with exciting results, even with frequency notched antennas as in this case. In according with Genetic Algorithm, an efficient and adaptable analysis tool is demanded, which is required to compute each solution. In order to get the desired results from these methods, the cost function defined for rejection bands in the optimization algorithm for earn best results and higher the rejection in the selected band. Meanwhile, the use of this global optimization process allows the creation of arbitrarily shaped antennas optimized to present desire rejection bands, while maintaining low return loss(S_{11}) in the rest of the Ultra Wide Band frequency band. The MAM method allows the description of the electromagnetic problem in circuit analysis terms by the creation of artificial ports in the full wave FEM analysis which, in order can be short or open circuited in a post processing step [3]. The GA optimization method directly related to the ability of the Multipurpose Admittance matrix

method to get a fast analysis method attached with a global optimization method [4]. Finally, the purpose of this work is to design a miniaturized band-notched UWB printed cardioid patch monopole antenna with band rejection characteristics in the 5-6 GHz band, and we want mentioned that the design starting point will be the Ultra Wide Band planar monopole designed in [1], [2], [4]. According to published results on that work, the good adjustment results are obtained by changing the profile of the antenna, so that it acts as a good transition between the free space and the SMA connector. For more details about the formulation method can be refer to here [3]-[7]. The purpose of the Multipurpose Admittance Matrix formulation is obtaining an admittance matrix although the boundary conditions are not known before [4]. The MAM formulation was initially considered in [3], [4], and in this section, a brief description is given as it is the theoretical tool used in this study. This MAM formulation will be tested on the slotted printed monopole, which we are trying to optimize that. The purpose of this MAM formulation is to help a Finite Element Method simulation with purpose to leave the unnecessary slots in the printed monopole.

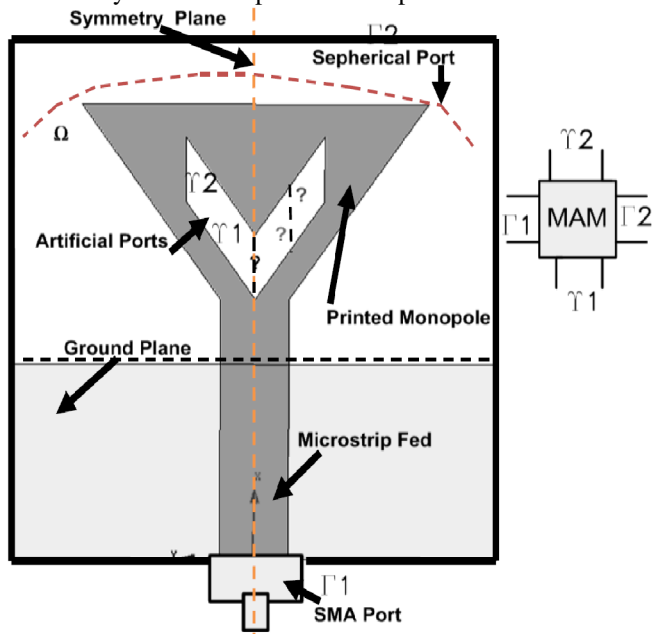


Fig. 1. General slotted printed monopole antenna. Analysis domain and Four port network considered in the MAM method.

At first, for clarifying two modal ports will be defined in the analysis domain Ω : 1) a SMA port Γ_1 show the input and 2) a spherical port Γ_2 which is the radiating port and then we inserted four slots in the printed monopole symmetrically. Taking the symmetrical condition into account for the analysis, Y_1 and Y_2 are defined in order to take into account the possible slots as two additional artificial ports. Undefined electromagnetic boundary conditions shown in Fig. 1 by questions marks. These conditions make it possible to perform the full wave response of multiple slot configurations easily. It is observed from the formulation result, a MAM is obtained, which describes the electromagnetic behavior within the analysis domain Ω . Once the MAM has been determined, full

wave responses for many different device configurations can be obtained easily.

Fig.1 shows the model problem, which contain four-port network results, where two ports are artificial. Therefore, different circuit manipulations can be effect on related artificial ports, and different slot modifications in the printed microstrip monopole easily [4]. Particularly, the tangential electric field can be canceled by setting up perfect electric conductor (PEC) conditions on both artificial ports Y_1 and Y_2 , when these ports are being short-circuited [4]. This condition will be done by imposing $v^{Y_1} = 0$ and $v^{Y_2} = 0$. Therefore, the admittance matrix that defines the electromagnetic manners of the printed monopole without slots is a generalized Admittance matrix.[4] On the other hand, if these ports are being open-circuited. Perfect magnetic conductor conditions (PMC) can be considered by canceling the tangential magnetic field on both artificial ports Y_1 and Y_2 [4]. This time, a matrix inversion is required in order to impose $i^{Y_1} = 0$ and $i^{Y_2} = 0$. In this manner, a generalized impedance matrix (GIM), Z , will be produced and also direct inversion formula will be provided the generalized admittance matrix (GAM)[4]. This work will be adds a slot on both of the artificial ports, because perfect electric conductor is the Electromagnetic boundary condition (EBC) have need the symmetry plane. Although we need the size of GIM matrix for produce a matrix inversion, but we needed lower computational try in comparison with a full Finite Element Method analysis.

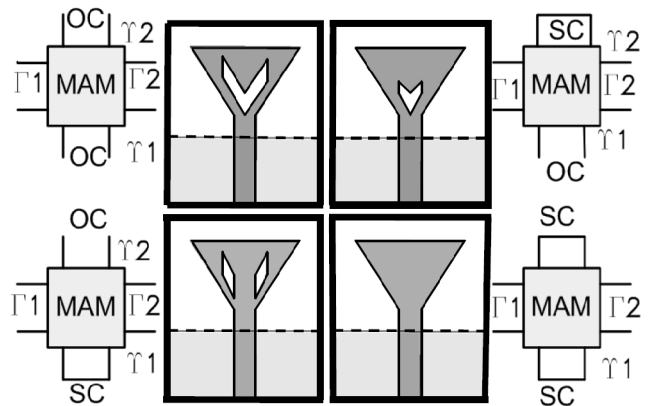


Fig. 2. GAM transformations. Different radiating structures of circuit manipulations within the MAM method for proposed antenna design shown in Fig.1. (OC means open circuit and SC denotes short circuit.)

Fig. 2, shows more combinations of circuit performances for different radiating structures that we can use into our accounts. These transformations are called GAM, which reduces computational works for multiple structure modifications with using the Multi Admittance matrix method. More details about this method of the formulation can be seen there [3], [4]. As shown in Fig. 3 for using the maximum advantages of the Multi Admittance matrix analysis method that was presented on previous design [3], [4], the cardioid shape of the proposed designed antenna's patch was divided into 100 square blocks, With these definitions, a FEM problem with 102 ports (100 artificial ports and the 2 "natural" ones) is defined which leads to a MAM with 102 ports. In order to increase evaluate

process the above described circuit manipulations in Fig.2 with workable configuration, can be used in the obtained Multi Admittance matrix. Meanwhile, under analysis final admittance matrix of the configuration is efficiently obtained with less computational work in comparison that needed for a Full Finite Element Method analysis. Also, efficiency of this method in comparison with previous method dramatically will be increase. The selected cost function directly related to the maximum return losses in the notched band and the pass band for earn the required criteria:

$$-(\Delta^{\text{pass}} - \Delta^{\text{reject}}) + 15 \quad (1)$$

Δ^{pass} and Δ^{reject} are functions that directly related on the S_{11} values on the rejected and pass band, respectively, and the 15 value is used to increase the result so that the result is greater than zero with a high probability and this value can be variable for different design, in comparison with pervious proposed antenna. Therefore, for maximize adaptability, Δ^{pass} is taken $\Delta^{\text{pass}} = \max|S_{11}^{\text{pass}}|_{\text{dB}}$ and in order to maximize rejection in the filtered band, Δ^{reject} is taken as $\Delta^{\text{reject}} = \langle |S_{11}^{\text{reject}}|_{\text{dB}} \rangle$ [4]. For the above reasons, solutions will be present higher mean rejection values across the the filtered band. This method exactly references from [3]-[6], therefore for more details about formulation refer to [3]-[6].

III. NUMERICAL AND EXPERIMENTAL RESULTS

Fig.3 shows the proposed antenna profile obtained with the Genetic Algorithm optimization (GA) and [5] using the MAM method. Meanwhile, the proposed antenna structures were simulated parallel using a High Frequency Structure Simulator (HFSS, ver. 11). The effects of great SMA connector and bad soldering to the measured results are considered during simulation process by adding different blocks and metal strips to the antenna structure and layout.[6] As shown in Fig.3, the geometry of the proposed small cardioid patch antenna, consists of 1mm^2 multiple slots, a semi-ellipse shaped ground plane and heart shaped conductor patch. The proposed monopole antenna is printed on an FR4 substrate with permittivity of 4.4, a loss tangent of 0.024 and Compact dimension of $25 \times 25 \times 1 \text{mm}^3 (= h)$. The cardioid patch has a length of R_1 , width of R_2 , printed on the front surface of the substrate. The name cardioid comes from the heart shape of the curve.[1] The cardioid is given by the following parametric equations Eq. 2.[1] Here r_1, r_2 without units are the radius of the circles which generate the curve. Cusp will be turned 180deg when r_1, r_2 are negative [1]. A little adjustment κ in the Fig.3 was necessary because the actual mapping ($1 \times 1 \text{mm}^2$ squares) may not give the better results possible. Finally, Fig. 4 shows the rejection band characteristics in VSWR graph. Fig.5 shows variation of the Maximum gain of the proposed antenna across the UWB. It is clear from Fig. 5 across the rejected 5-6GHzband, the antenna gain is -6 dBi. The measured result of the radiation patterns of the proposed antenna were presented in Fig.6. The results include co-polarization and cross polarization in the E(xz)-plane and the H(yz)-plane (Fig. 3).

$$\begin{aligned} x(t) &= 2r_1(\cos(t) - 0.5 \cos(2t)) \\ y(t) &= 2r_2(\sin(t) - 0.5 \sin(2t)) \end{aligned} \quad (2)$$

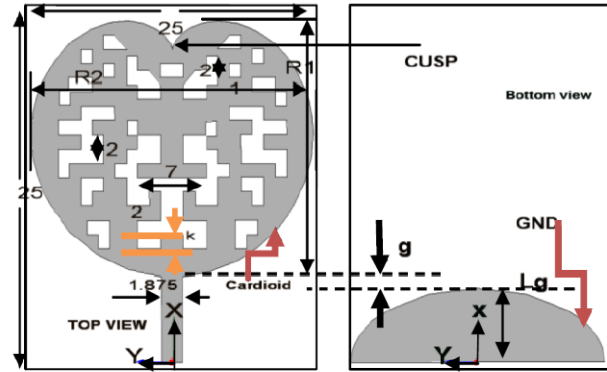


Fig. 3. Geometry of proposed printed monopole antenna with rejected Band. ($W_{\text{sub}}=25, L_{\text{sub}}=25, W_f=1.8, L_f=6.5$)

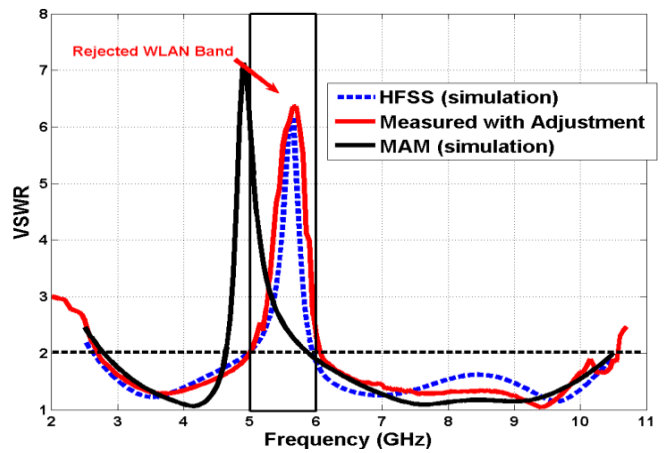


Fig. 4. Simulation and Measured VSWR of realized antenna.

The patterns resemble a donut shape with an approximately omni-directional H-plane pattern and a figure of eight pattern in the E-plane up to 10.6 GHz.

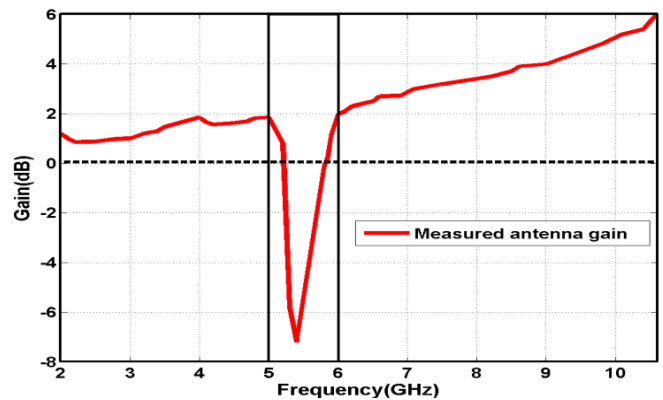


Fig. 5. Measured proposed antenna Maximum gain.

The photograph of the realized compact monopole antenna is shown in Fig.7 and also Fig. 8 shows a photograph of the built antenna with similar method including 10 cm radius ground plane [4], [5], [6].

It is also very interesting to mention that the proposed modified antenna in Fig.7 has an area of 625 mm^2 ($25\text{mm} \times 25\text{mm}$), which is 15 times smaller than the area of the similar structure presented antenna (300cm^2) in [4], [5], [6] with dimension of $(\pi \times 10 \times 10\text{cm}^2)$. [9] It is also interesting to notice with only using similar method exactly explained in section.II from [3], [4], [5], [6] these results measured. Also, the half ellipse ground plane of the proposed structure has no limitation in size and shape in comparison with the proposed disk ground plane of the antenna in [3], [4], [5], [6].

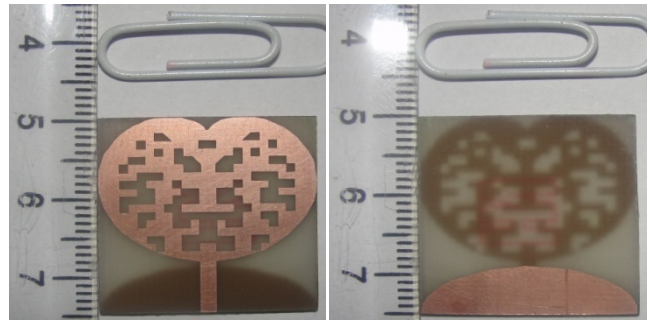


Fig. 7. Photograph of the realized compact monopole antenna with this method.

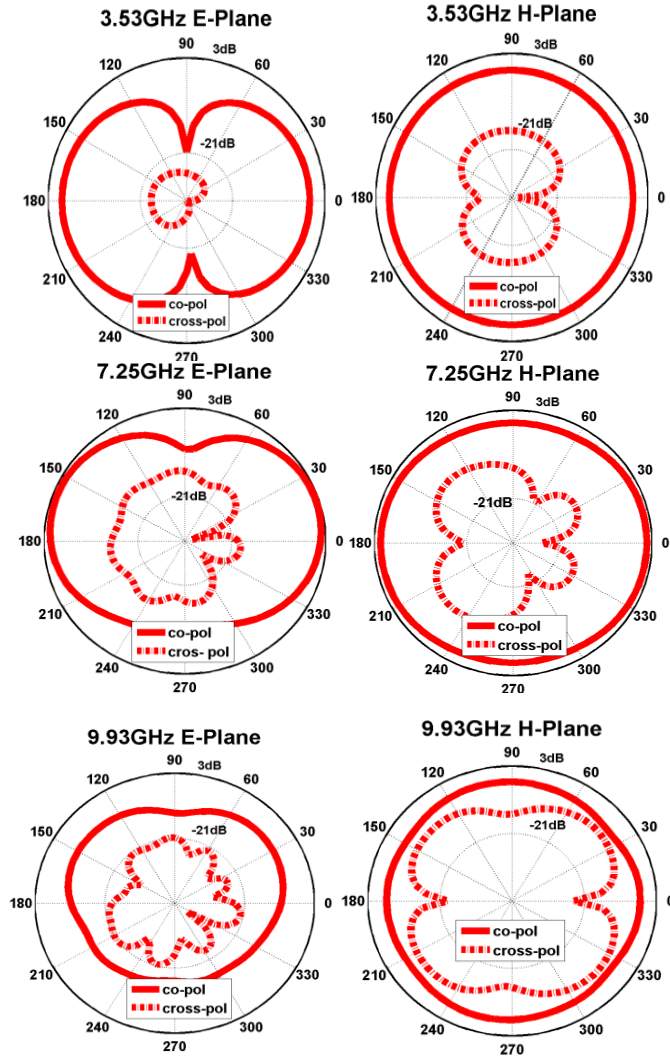


Fig. 6. Measured (Left) *E*-plane and (Right) *H*-plane radiation patterns of the Realized antenna at 3.53GHz, 7.25GHz and 9.93GHz.



Fig. 8. Photograph of the built antenna with similar method including 10 cm radius ground plane. Ref.[4],[5],[6]

IV. CONCLUSIONS

This work presents the design and optimization of a frequency notched printed Ultra Wide Band monopole antenna designed for minimal S_{11} in the 3.1-10.6 GHz band with maximum rejection in the 5-6 GHz band. For this purpose, a Finite Element Method-based analysis method which dramatically reduces the computational effort of the Finite Element Method and optimizes time with HFSS has been introduced: the Multi Admittance matrix approach. The good band rejection, the printed profile and the excellent return loss make the designed antenna, an excellent design in comparison with previous similar design for Ultra Wide Band (3to10.6GHz, 111%) applications and handheld devices which need WLAN rejection. These results show that an optimization process based on the MAM method was valuable tool to carry out profile optimizations. As a result, the proposed simple compact microstrip monopole antenna that optimized with GA (Programs with C++) and MAM method can be very suitable for various applications of the future developed Ultra Wide Band(UWB) technologies and also for future handheld devices. [1]-[6]

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