PSO-based Combined Antenna and Matching Network Optimization for Mobile Terminals

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***Abstract*—In this paper, the challenge of antenna design for a full-screen smartphone will be analyzed and an optimization methodology is introduced. The Particle Swarm Optimization algorithm is used in combination with HFSS and Optenni commercial software in order to simultaneously optimize the antenna geometry and the matching network. Optimizing antenna and matching network separately, as conventionally done, does not guarantee the optimal performance. The proposed method is tested on a very space constraint model with a $5mm \times 5mm \times 73mm$ volume for the antenna and a $140mm \times 73mm$ ground plane. Within this space, an antenna solution covering the 700-960 MHz and 1690-2700 MHz bands with a minimal total efficiency higher than 50% has been obtained. This methodology has the potentials to enable an automatically and systematically design process for antenna-matching network systems.**

***Index Terms*—mobile antenna, optimization, PSO.**

I. Introduction

Nowadays, there is a strong technology competition among mobile manufacturers, including tech-giants like Apple, Samsung, Xiaomi, etc. One of the most ambitious goals is to enlarge as much as possible the coverage ratio of screen over the device surface. Apple tried to make full screen, Samsung has pushed their phones screens over the borders, and ViVo claimed their success on integrating fingerprint reader on screen, so they can maximize available screen area. However, making full screen is not just the challenge of producing bigger screen, but also how to maintain and improve the performance of every other vital component. Concerning antenna integration, the loss of groundplane clearance zone results in a higher Q factor and lower radiation efficiency. To make things even more complicated, more than one antenna will have to be integrated for Multiple-Input Multiple-Output (MIMO) purpose, even for sub-GHz bands [1].

Two different approaches to solve the problems of full screen mobile antenna design can be found in literature. One is finding a specific way to design an effective antenna structure. The other one is to use an additional lumped Matching Network (MN) to improve antenna performance. The first approach dominates antenna researches when having a ground clearance at the top and/or at the bottom side of the printed circuit board (PCB) is considered as an acceptable solution for mobile phones. Huang *et al.* designed a monopole antenna covering 675-1050 MHz and 1600-2800 MHz inside a volume of $70mm \times 7mm \times 6mm$ [2]. Similarly, Liu *et al.* succeeded in building an antenna covering the same bands inside an even smaller area $5mm \times 56mm$ [3]. While these designs still require ground-free space, Xu *et al.* proposed the use of a conductive rim around the mobile terminal to work as the antenna at low-band, which can be applicable for full screen case [4]. However, such solution is expected to be sensitively affected by the user hand and the area for the metal rim is not assured when the screen goes over the phone border. A restrain from the first approach is that the radiation power of the antenna cannot be good if the antenna must cover low frequency bands while being compacted inside a restricted area [5]. Moreover, the antenna structures might have to change completely when components are placed between the antenna and the ground plane.

In the second approach, only the lumped element based circuits are taken into account to truly tackle the limited volume for the antenna system. As a matter of fact, impedance matching using stubs might result in occupying roughly the same area as the antenna itself. As the antenna impedance matching problem is handled by a circuit, the antenna geometry can be simpler and easier to integrate, with the radiation efficiency depending on the available space. If the MN is properly design, the total efficiency might be ideally improved [6]. In real life, however, the additional losses from lumped components, together with their limitation in terms of range of values, must be carefully taken into account.

The antenna geometry and the MN designs are often addressed as separated tasks. This can lead to suboptimal results and consequently the need for integrated strategies emerges. In this works, an effective methodology for antenna-MN combined design for mobile terminals is proposed and verified. The Particle Swam Optimization (PSO) algorithm is applied for automatically identifying the optimal design.

The paper is organized as following. The second section will give more details on the optimization methodology. In third section, two antennas on full screen mobile are modeled and optimized with MN using the proposed method, then their performances are presented on forth section. The fifth section presents post optimizing steps in case simplification is required from manufacturers. The final section will conclude and mention future developments and applications.

II. Optimization Methodology

In literature, PSO has been used for numerous applications, including antenna design [7]. In [8], the algorithm is applied to optimized spline-based structure for Ultra Wide Band antenna.

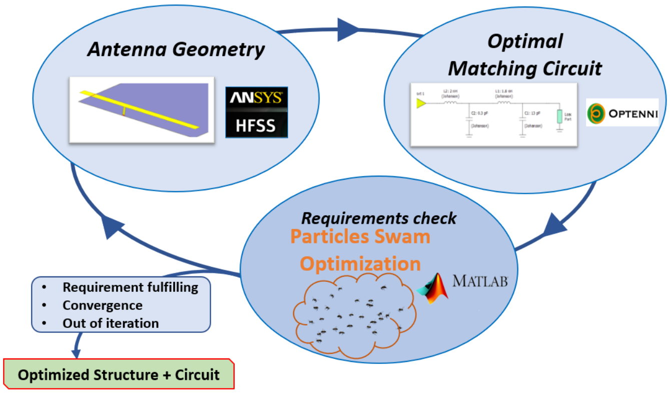

Fig. 1. The combined antenna and MN optimization procedure.

The potential of this algorithm is given from its nature: its convergence process mimics the behaviors of a swam of small animals, like bees, looking for resource in a closed space [9].

As shown in Fig. 1, the proposed optimization is a finite loop of consecutive antenna simulations, circuit calculations and requirements verification. In the setup stage, a raw design need to be realized based on constrains of space and performances to achieve. Its geometrical parameters are studied to identify the ones having more influence on the antenna electrical behavior. At first, multiple antenna geometries are generated by randomly fixing the values of those parameters, which are considered as variables, while keeping the others as fixed. The more variables the designer select, the bigger will be the PSO solution space, and hence a longer time will be need for the optimization. Each design (trail solution) is simulated using HFSS electromagnetic software, and the scattering parameters and radiation efficiency are calculated. These results are directly sent in the second stage to Optenni Lab, an MN optimizing software, which computes the optimal MN circuit to adapt the antenna. In third stage, the performance of the overall antenna-MN system are evaluated and used as cost function of the optimization. Such an optimization process iterates until the performance requirements are met or a maximum number of iterations has been reached.

III. Antenna Design with Matching Network on Full Screen Mobile

In this work, the mobile terminal structure is simplified for the sack of reducing optimization time. Full screen is made as a large copper plate the size of $140mm \times 73mm$, a typical size of large screen mobile phone (Fig. 2). It plays the role of a large conductive ground. Two antennas are placed at the top of the terminal $5mm$ mm above the groundplane and cover an area of $5mm \times 73mm$. The gap between the two antennas is $1mm$. Antennas are modeled as simple horizontal patches excited from 2 points connected to ground. It is expected that this simplification on antennas structures will improve the radiation efficiency. The three parameters that are mainly responsible for the system performance are the two

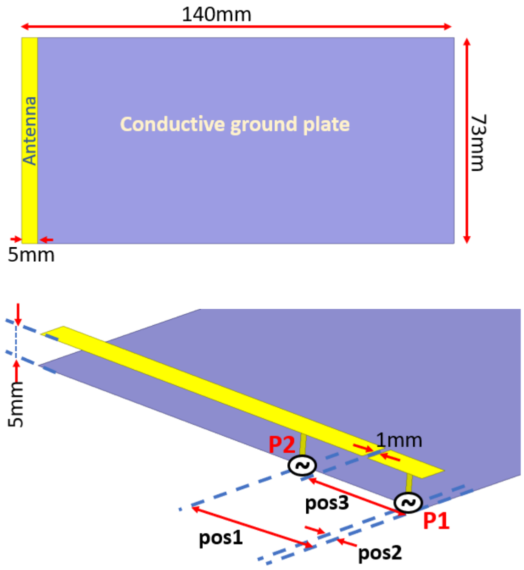

Fig. 2. The mobile terminal structure and the antenna geometry.

excitation positions *(pos1, pos2)* and the gap position *(pos3)*. Therefore, these parameters will be the input variables of the optimization, as mentioned in the second section.

With this configuration, almost every set *(pos1, pos2, pos3)* yields very high the radiation efficiency, usually above 90%. So, the optimization of the total efficiency is moved to circuitry part, which can be calculated by Optenni Lab. In this example, two circuits including eight lumped components are needed to match two ports (4 components per port). These two antennas are designed to cover the 700-960 MHz low band and the 1690-2700 MHz high band, which include the sub-GHz band GSM900 and band LTE2500. The challenge of designing two antennas covering dual wide bands puts the proposed approach into the test.

IV. Optimization Results

After the optimization process, the antenna system results to be characterized by *(pos1, pos2, pos3) = (1.95mm, 38.20mm, 5.09mm)* and by the MN shown in Fig. 3.

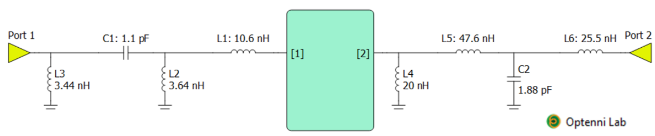

Fig. 3. The optimized MN.

Fig. 4 shows the impedance matching of the two antennas including the MN (solid lines). For the sake of comparison, the matching for the same antenna geometries without MN is reported in dashed lines. As it can be noticed, the matching is mainly due to the MN, which allows $S_{11} < -3$ dB in the bands 700-960 MHz and $S_{11} < -4$ dB in 1690-2700 MHz.

As for the isolation between the two antennas, $|S_{21}|$ is lower than -39 dB all over the requested bands (Fig. 5).

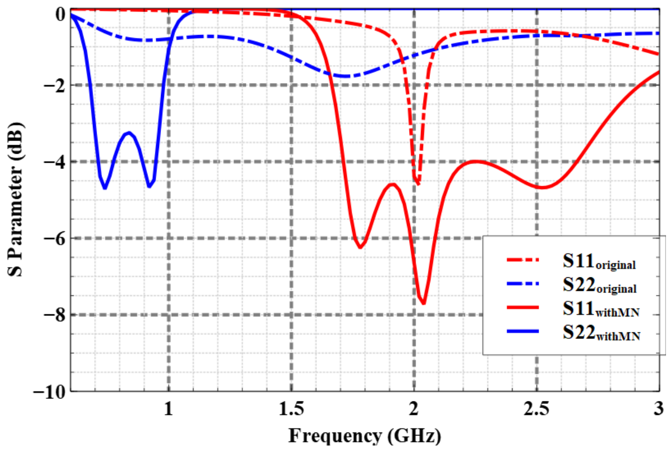

Fig. 4. Impedance matching of the two antennas (with and without the MN).

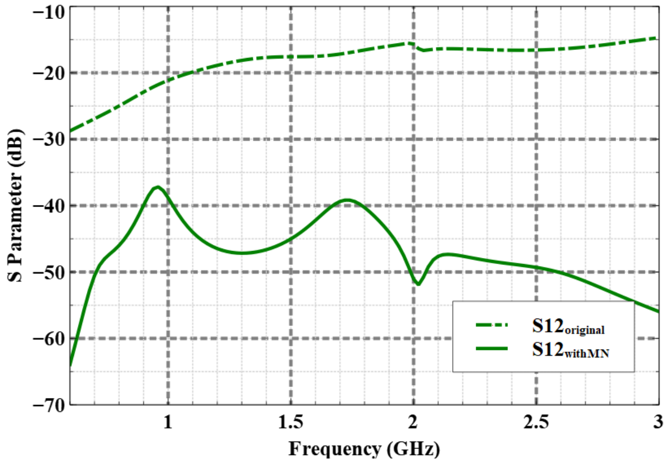

Fig. 5. Isolation between the two feeding ports.

TABLE I
TOTAL EFFICIENCY VALUES

Port	Band (GHz)	Minimum Total Efficiency (%)	Average Total Efficiency (%)
1	1.7 - 2.7	53.7	66.1
2	0.7 - 0.96	52.5	58.9

The total efficiency of the two antenna systems are shown in Fig. 6. As it can be noticed, a minimum efficiency of -2.8 dB (corresponding to 52.5%) and -2.7 dB (corresponding to 53.7%) are obtained in the lower and higher bands, respectively. The efficiency values are summarized in Tab. I.

V. POST OPTIMIZATION: SINGLE PORT DESIGN

Mobile antenna designs have to follow the specifications from manufacturer. Usually, the number of RF ports has to be

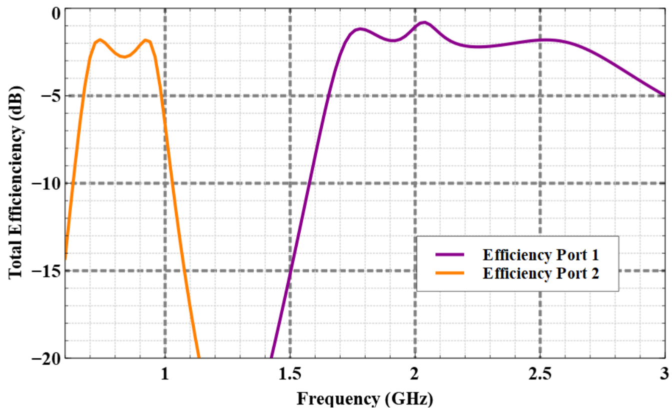

Fig. 6. Total Efficiency of the two antenna systems.

reduced as much as possible in order to simplify the mobile phone assembly. The two ports at the input of the two matching networks are consequently merged in the same point. In Fig. 7, the green curve shows the impedance matching obtained in this configuration. Thanks to high isolation level between the original ports, the $|S_{11}|$ behavior is basically a combination of the matching of the separated antenna systems. The 5 resonances as in the 2-ports model are still visible, however, the higher $|S_{11}|$ values between the resonances does not allow operation all over the requested bands.

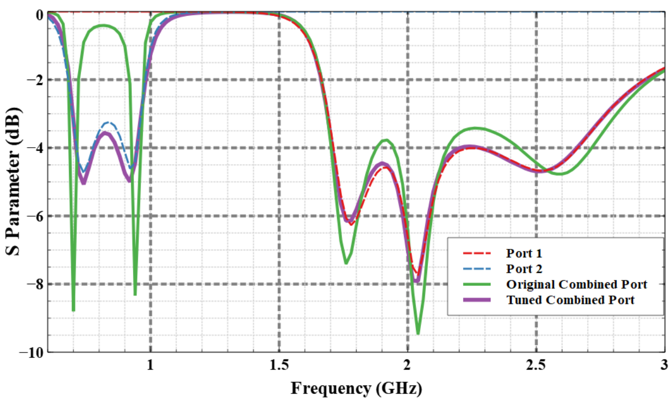

Fig. 7. Impedance matching of the single port antenna system.

TABLE II
COMPONENTS' CHANGES
(PF FOR CAPACITORS AND NH FOR INDUCTORS)

Config.	C1	C2	L1	L2	L3	L4	L5	L6
2 Ports	1.1	1.88	10.6	3.64	3.44	20	47.6	25.5
1 Port	1.1	3.16	10.5	3.66	7	21	36.4	8.8

To solve such a problem, a slight tuning of the MN components' values is therefore performed. Table II indicates the variations. As expected, the components near ports outputs (e.g., C1, L3, and L6) are the ones requiring the largest modifications. The final purple curve (Fig. 7) totally matches the original $|S_{11}|$ in lower band and $|S_{22}|$ in higher band.

VI. CONCLUSION

In this paper, a methodology for the combined design of the antenna and the MN using the PSO has been presented. The approach has been tested solving the problem of designing a miniaturized dual band antenna system for mobile terminals. The constraint here is the screen fully covering one face of device, leaving small no groundplane-free space for antennas. A dual antenna system with high total efficiency in the two bands of interest and with good isolation has been obtained. The possibility of realizing a single port antenna system exhibiting the same impedance matching of the original 2-ports configuration is also demonstrated.

The obtained results suggest the effectiveness of combined antenna-MN design, especially in dealing with miniaturized terminals, such as for IoT applications. Future work will be aimed at testing more complicated antenna and MN configurations.

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