Comparison between matching circuits and parasitic patches to enlarge the bandwidth of a mobile phone

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1. Introduction

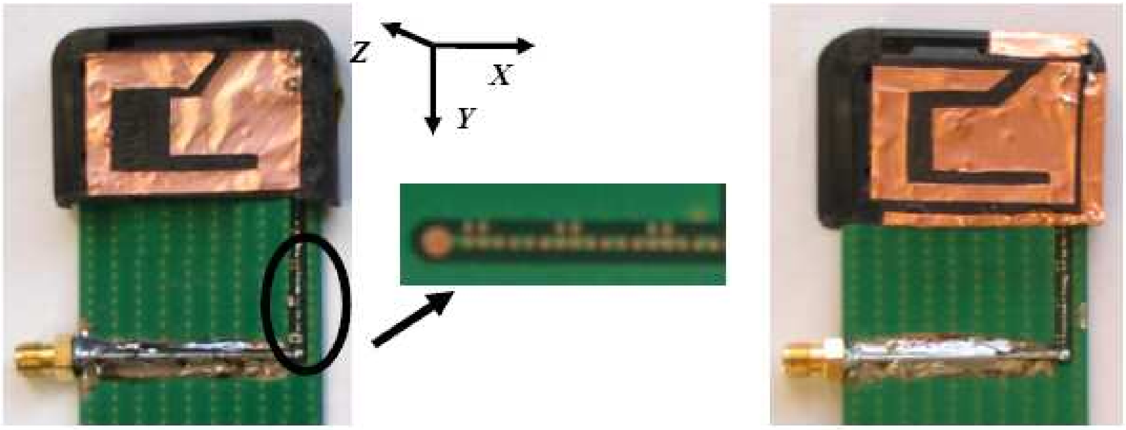
While designing a mobile phone antenna, the obtained bandwidth results from a trade-off between several objectives subject to various constraints. For example, the antenna designer tries to maximize the total free-space efficiency (e_t) and simultaneously reduce the Specific Absorption Rate (SAR), while a smaller and smaller volume is generally required. Comparing with adding parasitic elements, adding reactive matching circuit between an antenna and its feed line is becoming more and more used recently, since such a circuit is small-volume, easy to implement, and low-cost. The aim of this article is to compare between the two mentioned methods of bandwidth enlargement, not only in terms of occupied volume and design complexity, but also of reflection coefficient (S_{11}) and radiation performance. The two methods are here implemented experimentally on a PIFA antenna-chassis combination, with goal to transform a not well covered tri-band terminal into a penta-band one.

2. Antenna configurations

The initial antenna is a PIFA - chassis combination as shown in Figure 1 (a). It occupies a volume of 35*22*8 mm^3. The PCB card is 40*100 mm^2 with reserved place for lumped elements (Figure 1 (b)). The antenna is made with copper tape and placed on a plastic support. Then bandwidths are broadened in two different ways: the first one is to add a matching circuit (up to seven lumped elements are implemented in the reserved place inside the black circle of Figure 1 (a)); the second is to add parasitic patches (Figure 1 (c), the reserved place for lumped elements is not used here, it is simply strapped by tin solder). The goal is to transform the initial antenna (a not well covered tri-band GSM 850 / DCS / PCS antenna) to a penta-band antenna (GSM 850 / GSM 900 / DCS / PCS / UMTS) by introducing additional resonances. The input impedance of the initial antenna is shown in Figure 2 (a).

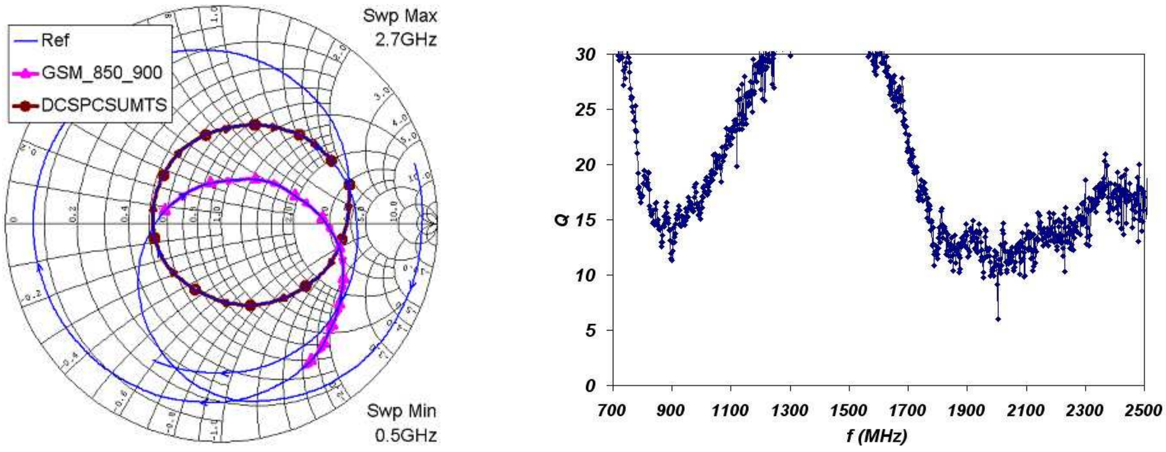
Adding a matching circuit -- The feasibility of adding a matching circuit in order to cover all the five bands with a maximum allowed reflection coefficient amplitude is studied first. The minimum achievable amplitudes of S_{11} ($|S_{11}|_{min}$) in certain bands are estimated. It can be considered that there are two non-contiguous bands: GSM 850 + GSM 900 bands and DCS + PCS + UMTS bands. Each of the two bands has only one resonance. The quality factor (Q) of the initial antenna is calculated by using the expression of Q developed by Yaghjian & Best for a single – resonant system [1]. Next, by using the relationship between Q and $|S_{11}|_{min}$ according to the results in [2], it is possible to obtain $|S_{11}|_{min}$ about -20dB in both GSM 850 + GSM 900 bands and DCS + PCS + UMTS bands by adding an infinite number of lossless elements. Then the measured S_{11} of the initial antenna is imported in AWR MicroWave Office (MWO) and different numbers of lumped elements are added as matching circuit. $|S_{11}|$ smaller than given values, over two separate bandwidths, has been set as the optimization goal. A gradient-based algorithm is launched and the values of the various lumped elements have been obtained according to the different goals. The ideal elements are then replaced by the realistic model of elements taken from the library of the manufacturer. Finally the elements are implemented on the initial antenna. The simulation results and the measured results agree well (as shown in Figure 3 (b)).

Adding parasitic patches -- Two additional resonances have been created by adding two parasitic patches. The long patch aims to create an additional resonance at GSM 900 and the short patch aims to create a resonance at the high frequency. The shape of the initial antenna has to be changed a little because adding parasitic patches modifies the current distribution. The long parasitic patch occupies a volume of $22*4*5\text{mm}^3 + 33*2*4\text{mm}^3$ and the short parasitic patch occupies a volume of $15*5*4\text{mm}^3$.



(a) (b) (c)

Figure 1: (a) A PIFA - chassis combination with lumped elements. Inside the black circle: matching circuit. (b) Reserved place for lumped elements. (c) A PIFA - chassis combination with parasitic patches.

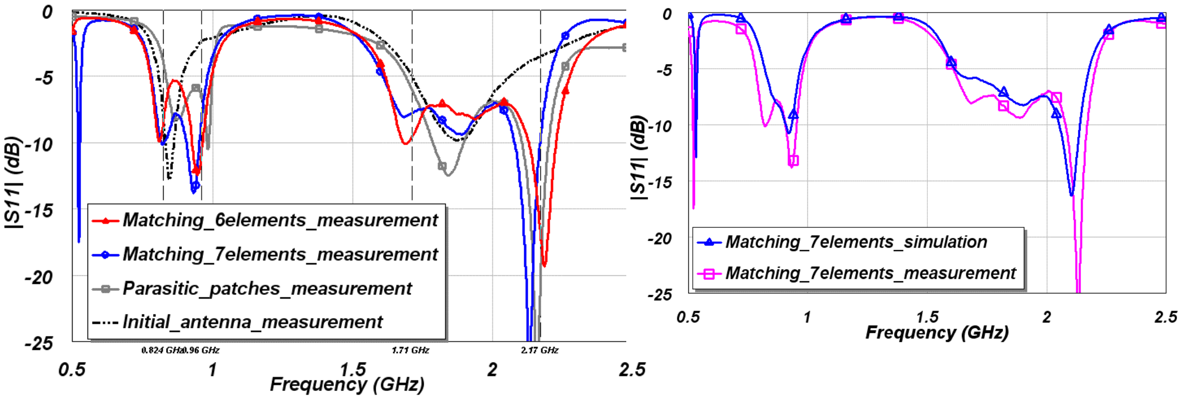


(a) (b)

Figure 2: (a) Input impedance of the initial PIFA – chassis combination of Figure 1 (a). (b) Q of the initial PIFA – chassis combination of Figure 1 (a) according to the expression of Q developed by Yaghjian & Best [1].

3. Experimental results and comparisons

Figure 3 (a) shows $|S_{11}|$ (dB) as a function of frequency for the initial antenna of Figure 1 (a) and after adding the parasitic patches as well as matching circuit (six and seven elements respectively). The four dashed vertical lines indicate the GSM 850 + GSM 900 bands (824MHz – 960MHz), and DCS + PCS + UMTS (1710MHz – 2170MHz) bands. $|S_{11}|$ of the initial antenna is indicated with black dashed curve. With the two parasitic patches, two additional resonances have been created (grey curve with squares). The bandwidths are not well covered at the beginning of GSM 850 band and DCS band. For the other frequencies, GSM 850 + GSM 900 bands are covered with $|S_{11}|$ inferior to –5.5dB, DCS + PCS + UMTS bands are covered with $|S_{11}|$ inferior to –7dB. With six lumped elements, GSM 850 + GSM 900 bands are covered under -5dB and DCS + PCS + UMTS bands are covered under -7dB (red curve with triangles). With seven lumped elements, all of the five bandwidths are covered under -7dB but an unnecessary resonance appears around 0.5GHz (blue curve with circles). Note that it is then not necessarily interesting to have a larger number of elements because the improvement in bandwidth or VSWR rapidly reaches saturation. Comparing with adding the parasitic patches, it is more convenient to create new resonances by adding a matching circuit. There are two reasons: 1) a parasitic patch requires a large volume at low frequency. 2) when adding a new parasitic element, it is needed to readjust the shape of the other patches because current distributions are modified.



(a) (b)

Figure 3: (a) $|S_{11}|$ (dB) of the initial antenna in Figure. 1 (a), with parasitic patches and with matching circuit (6 and 7 lumped elements respectively). (b) Simulated and measured results of $|S_{11}|$ (dB) of the initial antenna in Fig. 1 (a) with 7 lumped elements.

The total efficiency represents how well a mobile phone converts the input power at the antenna feed into radiated power (with mismatch included). The total efficiency measurements at different frequencies (Figure 4) have been performed in SAGEM's measurement facility, inside a fully anechoic chamber (2-D pattern measurement in xy-plane and yz-plane, the orientation is indicated in Figure 1 (a)). e_t at GSM band are globally better than at DCS + PCS + UMTS bands, even though a worse S_{11} is obtained in GSM band. It is generally the case for the mobile phones whose PCB length is near half wave length at GSM center frequency. With parasitic patches, good e_t are obtained at almost all the frequencies except at the beginning of GSM and DCS bands. Not enough power is transferred to the antenna at 824MHz and 1710MHz according to the S_{11} in Figure 3 (a). For most of the frequencies, the smaller is the $|S_{11}|$, the better the total efficiency. However, at the end of UMTS band, especially at the last three frequencies, e_t of the antenna with 7 matching elements is low even though a very good $|S_{11}|$ is obtained. Transmission coefficient (S_{21}) from the beginning of the matching circuit to the feed of the antenna has been calculated at the considered frequencies in simulation with realistic circuit element models. The second port is not terminated with 50Ω but with the impedance corresponding to that of the initial antenna at the considered frequency. It has been found that for the matching circuit with seven lumped elements at 2170MHz, the $|S_{21}|$ is only 0.69 in linear and $|S_{11}|$ is 0.32, the sum of $|S_{21}|^2$ and $|S_{11}|^2$ is 0.58, which is far away from the ideal lossless case 1, which means that the transferred power is largely reduced by the imperfection of the real elements. At 2100MHz and 2130MHz, smaller losses due to the matching circuit are found.

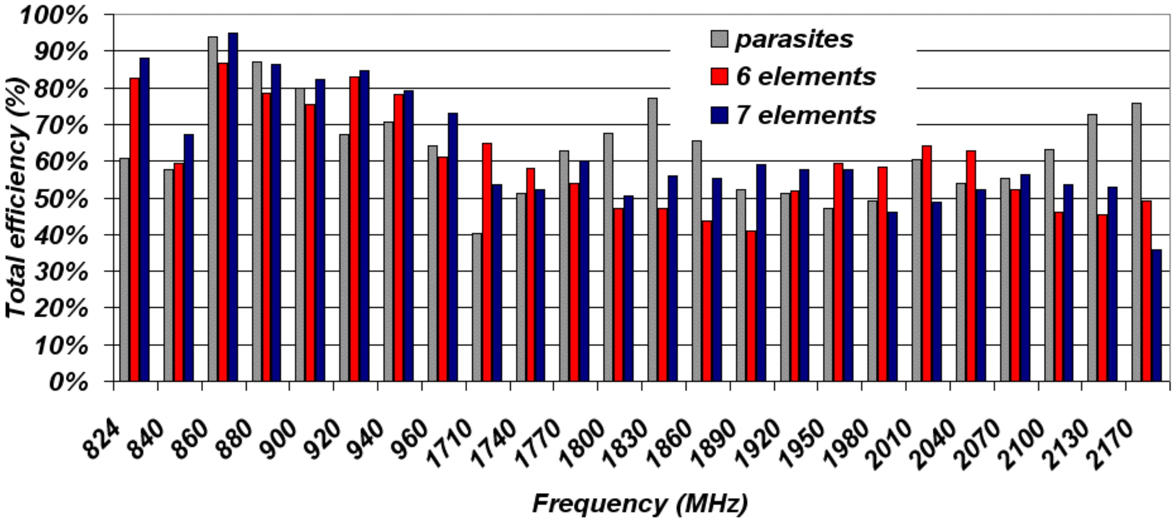


Figure 4: Total efficiency of the initial antenna with parasitic patches and with matching circuit (6 and 7 lumped elements respectively).

4. Conclusion

This article presents a comparison of two different methods of bandwidth enlargement, in terms of potential impact on antenna total free-space efficiency. Adding parasitic patches results in a good total efficiency provided that the conventional maximum $|S_{11}|$ of -6dB is obtained. Patches indeed radiate. On the other hand, adding a matching circuit enables a significant increase of the bandwidth even when the antenna size is fixed: this solution is globally more wide-band, compact and convenient to implement than parasitic elements. Nevertheless, though the larger decrease of $|S_{11}|$ can sometimes help in gaining total efficiency, limitations due to elements losses may appear at particular frequencies.

References

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