Circuit Based Optimization of Radiation Characteristics of Single and Multi-Port Antennas

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Abstract. *A method for analyzing and optimizing multi-port antennas is presented and exemplified. The method was first presented in [1]-[3] and uses data from full wave electromagnetic field (EM) solvers in combination with circuit simulations for efficient calculations of radiation properties of multi-port antennas. The main advantage of the proposed method is that only a few full-wave simulations, which usually are time consuming, are needed when e.g. optimizing the matching circuits for a multi-port antenna. Since embedded element patterns are used, all relevant antenna parameters such as radiation efficiency, diversity gain, available MIMO capacity etc. can efficiently be computed for any port excitation and loading configuration. The methodology has been implemented in software called MPA (Multi-Port Antenna evaluator) which imports port response matrices and embedded element patterns from commercial full-wave codes and post processes the data making it possible to e.g. optimize capacity for a MIMO system. The optimization is done by changing the feeding and matching networks in a circuit simulator that is invoked by the MPA. Finally the software is used on two examples which are analyzed and optimized to illustrate the potential of the method.*

Keywords

Embedded element pattern, optimization, multi-port antenna, antenna efficiency, antenna diversity, impedance matching.

1. Introduction

Present trends in mobile communications create new challenges in the design and integration of antennas in mobile terminals. This basically originates from the fact that several antennas are needed in order to implement all functionalities that are required by the end users, at the same time as the terminal should be sufficiently small. The antenna designer has to fit several antennas, some of which need to be multi-port antennas, in a limited space which also put restrictions on the possible shapes for the antennas. In addition to the functional requirements, the time to market limits possible development work for each antenna. This all together gives a background for why an efficient methodology for multi-port antenna design and integration is needed. Of course, to this date much research has been done on the design of terminal antennas. Physical limitations of antennas in terms of size have been studied [4]-[5] as well as the design of small single band [6]-[9] and multi-band antennas [10]-[12]. Work has also been done on multi-port antennas such as diversity antennas and antennas for MIMO terminals [13]-[15].

In this paper a method for analyzing and optimizing multi-port antennas and a few application examples are presented. The method is based on using a standard circuit simulator in combination with a full-wave electromagnetic field (EM) simulator. The method has already been presented in conference papers [1]-[3], but here a more complete description of the theory and its applications is given. The main advantage of this method is that only a few full-wave EM simulations, which usually are time consuming, are needed when e.g. optimizing matching circuits for a multi-port antenna. Since embedded element patterns are used all relevant antenna parameters and in addition some wireless system parameters, e.g. MIMO system capacity [16]-[17], can be efficiently computed for any network connected to the antenna ports and used as design goal in the optimization.

The basic idea behind the analysis method is to first compute a port response matrix and a set of embedded element patterns in a full-wave EM simulator program. In this context the port response matrix could e.g. be the commonly used scattering matrix (S-matrix) or just as well any other type of matrix relating the voltages and currents at the antenna ports. The embedded element patterns represent the radiation from the multi-port antenna when one of the ports is excited and all others are terminated. Thus, for an N-port antenna we need to compute N embedded element patterns in the EM simulator program. This is done in the same way as for phased array antennas [18] and is preferably done at the same time as the port response matrix is computed in order to save time. In the second step, the port response matrix is used in a circuit simulator program, such as e.g. the well known Spice program [19]. Here we use the circuit simulator program for computing the currents at antenna ports for any feeding network connected to the ports. There are, in principle, no restrictions on the network and the component values as well as the circuit topology might be subject to optimization in later steps. Finally, by weighting the previously computed embedded element patterns with the new port currents we are able to compute the total radiation from the multi-port antenna with the connected network. It should be pointed out that this can be done very efficiently since there is no need for additional lengthy full-wave EM simulations; it is only a matter of matrix and vector multiplications. Since we only need to perform N full-wave EM simulations in order to fully characterize the N-port antenna this methodology is especially useful for optimizing circuits connected to the antenna ports. In such a case the goal function can be any antenna or circuit parameter or a combination of both.

2. Theory

As mentioned in the introduction the methodology is based on using embedded element patterns and a port response matrix. Normally these are computed in a full-wave EM simulator but of course they could just as well represent measured values.

The port response matrix is simply the standard multiport matrix relating port voltages and currents that is used in ordinary network analysis, see e.g. [20]. The methodology is most simply explained by considering a simple two port example although it should be remembered that it is valid for any number of ports. Referring to Fig. 1, the procedure is as follows.

1. Excite antenna element 1 and terminate element 2. In the full-wave simulator compute; I_{11} (current feeding port 1), I_{21} (current induced in port 2) and E_1 (embedded element pattern).
2. Excite antenna element 2 and terminate 1. Compute I_{22}, I_{12} and E_2.
3. From steps 1 and 2 form the matrix:

$$\mathbf{A} = \begin{bmatrix} I_{11} & I_{12} \\ I_{21} & I_{22} \end{bmatrix}^{-1} \quad (1)$$

When steps 1 through 3 have been done we can compute the total radiation for the general case, shown at the bottom of Fig. 1, by using only a circuit simulator as described in the following steps.

4. Import the port response matrix in the circuit simulator, connect arbitrary networks to the ports (shown as Thévenin equivalents in Fig. 1) and compute the port currents I_x and I_y.
5. Compute the radiation pattern from the multi-port antenna as:

$$E = \alpha E_1 + \beta E_2 \quad (2)$$

where

$$\begin{bmatrix} \alpha \\ \beta \end{bmatrix} = \mathbf{A} \begin{bmatrix} I_x \\ I_y \end{bmatrix}. \quad (3)$$

As steps 4 and 5 are done solely in the circuit simulator they can be done very fast. This means that we are able to try different loading and excitation conditions and see how they will affect the radiation properties in a short time. This is of course a big advantage if we would like to do some optimization, especially if a global optimization scheme which requires a large number of evaluations of the goal function should be used. It shall be emphasized that the radiation pattern obtained in step 5 can be further processed in order to get e.g. the radiation efficiency, correlation, diversity gain or whatever is of interest. It should also be noted that the embedded element patterns from steps 1 and 2, and consequently from step 5, do not have to be far-field patterns, they could just as well represent field values in the near-field region. Thus we could e.g. define points in a region for SAR (specific absorption rate) calculations and use this methodology for minimizing SAR values by adjusting port loadings and excitations.

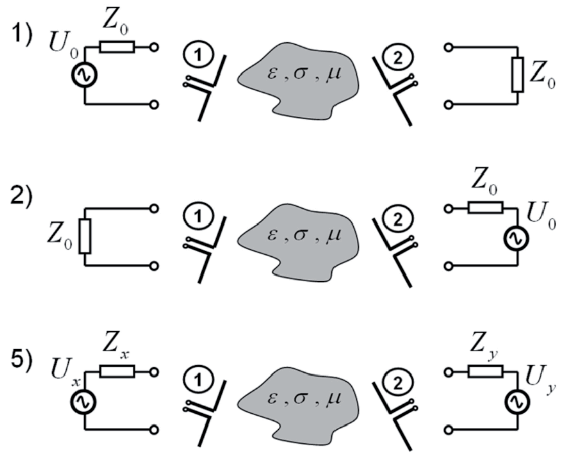

Fig. 1. Two-port antenna for illustration of the methodology.

3. The MPA Software

The theory of the previous section has been implemented in a computer code called MPA (Multi-Port Antenna evaluator). The MPA takes data from a commercial full-wave EM simulator and uses an in-house developed circuit simulator for computing the port currents for arbitrary loading and excitation conditions. The circuit simulator is as many similar simulators based on the modified nodal analysis (MNA) method [21]. The main reason for using this code instead of a commercial is that it uses a simple file format so that we easily can change component values as well as the circuit topology in the MPA when doing optimizations. Of course, it is also an advantage to have the source code so that the program can be tailored to specific needs if necessary. How the MPA software communicates with the full-wave EM simulator and the circuit simulator is shown in Fig. 2.

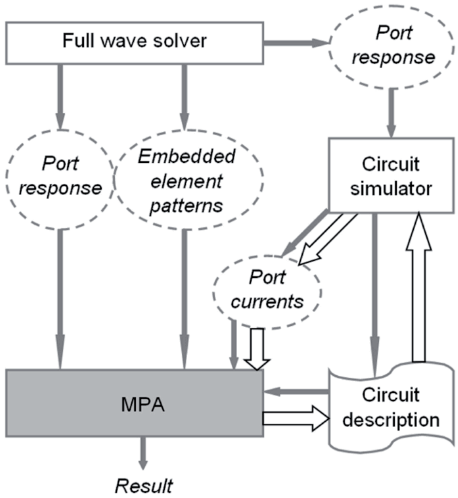

Fig. 2. Block diagram of the MPA software. Grey arrows describe the data flow during a single computation and white arrows the flow during optimization.

The output from the MPA is basically the radiation pattern for an arbitrary excitation of the multi-port antenna. By integrating the radiation pattern we can compute the radiated power (see e.g. [22]) and thereby the radiation efficiency as well as the total radiation efficiency where the matching efficiency is taken into account. Since we are dealing with multi-port antennas it is convenient to use the embedded element efficiency. This is defined on an element basis as the radiation efficiency when a particular port is excited and all other ports are terminated, usually in 50 ohm.

Another parameter of importance for diversity and MIMO antennas is the correlation coefficient. In order to obtain as high diversity gain or MIMO capacity as possible the correlation coefficient should be as low as possible. The correlation coefficient between antenna elements i and j can be computed from the embedded far field patterns as, [17]:

$$\rho_{ij} = \frac{\left| \iint_{4\pi} E_i^H E_j d\Omega \right|}{\sqrt{\iint_{4\pi} E_i^H E_i d\Omega \iint_{4\pi} E_j^H E_j d\Omega}} \qquad (4)$$

where H denotes the Hermitian (complex conjugate) transpose.

An alternative to (4) where the electric field is integrated is to compute the correlation from scattering parameters [23], as described in equation (5):

$$\rho_{ij} = \frac{\left| S_{ii}^* S_{ij} + S_{ji}^* S_{jj} \right|^2}{\left(1 - \left|S_{ii}\right|^2 - \left|S_{ji}\right|^2\right)\left(1 - \left|S_{jj}\right|^2 - \left|S_{ij}\right|^2\right)} . \qquad (5)$$

This expression has the advantage that it is faster to compute than (4) but it also suffers from two drawbacks: it is limited to passive and lossless antenna elements. Another advantage of computing the correlation from far fields is the possibility to modify the expression in (4) to take a non-isotropic environment into account.

When the correlation coefficients are known we can compute the diversity gain, either apparent or effective diversity gain as defined in [24]-[25]. In the latter the radiation efficiency is also taken into account, i.e. $G_{eff} = e_{tot.rad} G_{app}$, where $e_{tot.rad}$ is the total radiation efficiency of the strongest antenna branch. The apparent diversity gain for an N-port antenna, when selection combining is used, can be approximated by, [26]:

$$G_{app} = D_{N\,branches} \sqrt{1 - \left| \max\left(\rho_{ij}\right) \right|^2} \qquad (6)$$

where $D_{Nbranches}$ is the maximum diversity gain that can be obtained with N branches of Rayleigh fading signals and $\max(\rho_{ij})$ is the correlation coefficient for the most correlated antenna element pairs in the multi-port antenna. As an example $D_{Nbranches}$ is approximately 10 dB for two branches and 15 dB for four branches at a cumulative probability level of 1%.

For optimization of the feeding network connected to the multi-port antenna, i.e. to find component values as well as network topology in order to reach some goal, a global Particle Swarm Optimization (PSO) scheme [27]-[28] has been implemented in the MPA. In the software different fitness functions can be selected and these can be either single or multi-objective. The objectives in the fitness functions can be circuit parameters, such as e.g. return loss, or radiation parameters, such as e.g. diversity gain, or a combination of both types. It is also possible to weight the objectives in the fitness function by their importance. To set the weights we normally use a Pareto front approach [29].

4. Application Examples

In order to illustrate some of the capabilities of the methodology and the MPA software, two simple application examples are presented in the following.

4.1 Miniaturization of an Inverted F-antenna while Maintaining the Radiation Characteristics

In this example an inverted F-Antenna (IFA) mounted on a ground plane with a size comparable with the size of a normal mobile terminal is considered. We assume that the IFA originally was constructed using the normal design guidelines and that the resonance frequency is 1800 MHz. The CST [30] model of the IFA is shown in the left part of Fig. 3. The details for the IFA are; length 40 mm, height 7 mm, distance between feed and short 5.25 mm and wire radius 0.75 mm. The size of the ground plane is 50 by 100 mm. Now, we assume that the antenna designer get new requirements with the implication that the antenna is too large, it has to be made shorter. The maximum allowable length is 25 mm, i.e. only 62.5% of the original length. The question is if we can use the MPA software in order to determine a feeding network so that we can use the same antenna but with a shorter length and still maintain the radiation characteristics.

When using the optimization in MPA the goal is to maximize the total radiation efficiency in the frequency interval 1750-1850 MHz for the short IFA. To allow the optimizer to find circuit components not only connected to the feed, but also to the short the full wave simulations generating the embedded element patterns must be done both for a source at the feed and at the short. This generates two embedded element patterns and a two port response matrix, see Fig. 4. Of course, during optimization only radiation characteristics from the feed is taken into account since this is how the antenna will be excited when used. It should also be pointed out that during optimization the only thing modified is the circuit components, not the geometry of the antenna.

The optimization is started with a network consisting of general complex impedances, i.e. $Z = R + jX$. When the optimization has been performed, the general impedances are replaced by realizable lumped RLC circuit elements. In this case the realized optimum solution was the feeding network shown in Fig. 4 with the component Z1 equal to an inductor of 15 nH and Z2 equal to an inductor of 9.5 nH. The total radiation efficiency for all three cases (original full length, reduced length without network and reduced length with optimized network) are shown in Fig. 5. Simulations were done with CST and the measurements were done in a reverberation chamber. As can be seen in Fig. 5 the efficiency drops about 8 dB for the reduced length IFA compared to the original, but when the two inductors are used the efficiency is recovered and at some frequencies even improved.

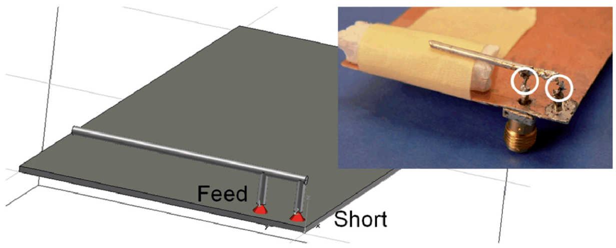

Fig.3. IFA on finite sized ground plane. Left – computer model. Right – hardware used for measurements (reduced length) including optimized circuit components (in white circles).

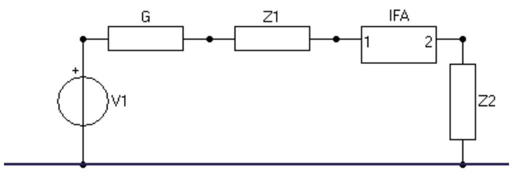

Fig. 4. Feeding network for the IFA. Port 1 on the IFA is the normal feed port and port 2 is the short. V1 is voltage source, G generator impedance (50 ohm) and Z1, Z2 are components subject to the optimization.

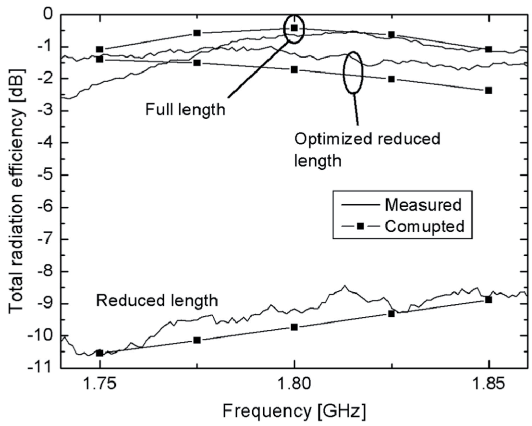

Fig. 5. Total radiation efficiency for the IFA. Full length = length 40 mm, Reduced length = length 25 mm without network, Optimized reduced length = length 25 mm with optimized network.

4.2 Miniaturization of a Two-port IFA

The second example is similar to the first, but here a diversity antenna with two orthogonal IFA antenna elements is considered, see Fig. 6. For this structure the challenge once again is to reduce the lengths of the antenna elements and still maintain the radiation characteristics in terms of total radiation efficiency and here also diversity gain.

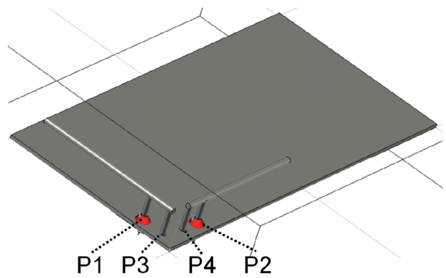

Fig. 6. Original diversity antenna consisting of two IFA antenna elements. P1-P4 numerates embedded element patterns and ports in the Z-matrix (of which P1 and P2 are the feeds).

The size of the antenna elements as well as the ground plane is inherited from the first example. The antenna elements are placed orthogonally to each other and the distance between them is 5 mm. Again the reduced length case is realized by cutting the wires, same lengths as in the first example is used, i.e. 25 mm.

As this is a diversity antenna a multi objective optimization focusing on high efficiency and low correlation will be performed. This means that the optimal solution will be a combination of low correlation and high efficiency where low correlation results in high diversity gain. The network feeding the antenna elements (see Fig. 7) can be described as follows: Port 1 and port 2 of the Z-matrix represents the first and second port of the antenna. These ports are connected to complex impedances (Z1, Z2) in series with 50 ohm generators (V1, G1, V2, G2). Port 3 and port 4 of the Z-matrix are the shorts of the IFA elements and are connected to three complex impedances (Z3-Z5). To achieve realistic solutions from the simulations, the circuit components cannot be purely imaginary, and therefore small resistive impedances are added in series with the complex impedances (Z1-Z5), which are subject to optimization. The size of those resistive impedances can be determined from components data sheet and were in this example in the order of 2 ohm. The optimization was performed in the frequency interval 1750 – 1850 MHz and the optimal components were found to be inductors for all components except Z3 which should be open, see Fig. 8.

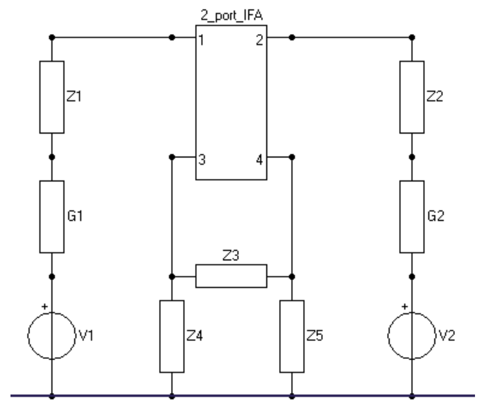

Fig. 7. Feeding network for two antenna elements constituting a diversity IFA antenna. V1, V2 are voltage sources, G1, G2 generator impedances (50 ohm) and Z1-Z5 are complex impedances subject for optimization.

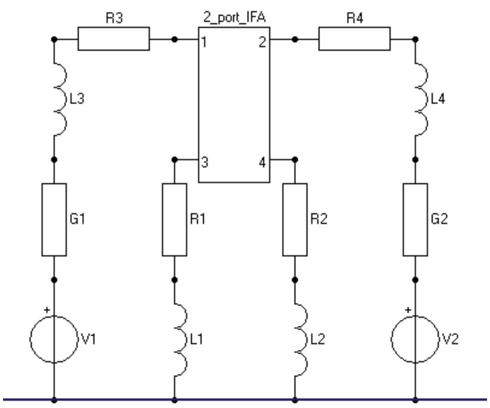

Fig. 8. Optimized feeding network. R1-R4 are small resistive impedances (about 2 ohm) appended for more realistic models of the circuit components.

Total radiation efficiency and diversity gain for the original full length case, reduced length case and the optimized reduced length case are computed and measured in the reverberation chamber. Results are shown in Fig. 9-11. As can be seen in Fig. 9-10 the total radiation efficiency of the optimized reduced length antenna is significantly improved compared to the reduced length case, which dropped about 10 dB compared to the original full length antenna. The correlation between the antennas elements have after optimization been reduced from a maximum of 0.64 in the frequency interval for the full length case to less than 0.15 for the optimized case. This is a significant improvement which also results in a very high diversity gain, see Fig. 11. Actually, in Fig. 11 the diversity gain is in a wide frequency interval close to 10, which is the maximum achievable diversity gain for this diversity scheme (two antennas and selection combining) at given cumulative probability level (1%).

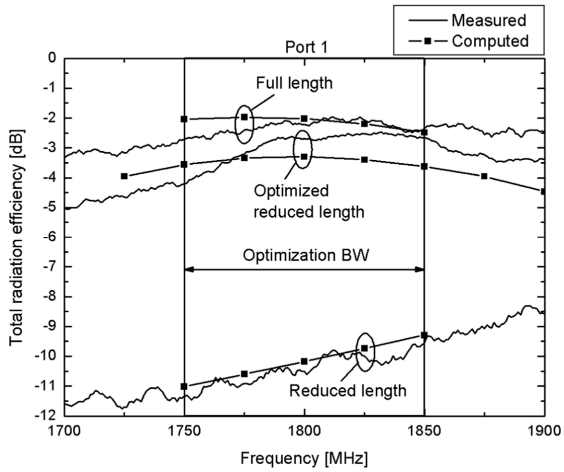

Fig. 9. Total radiation efficiency of port 1 for original full length, reduced length and optimized reduced length antenna.

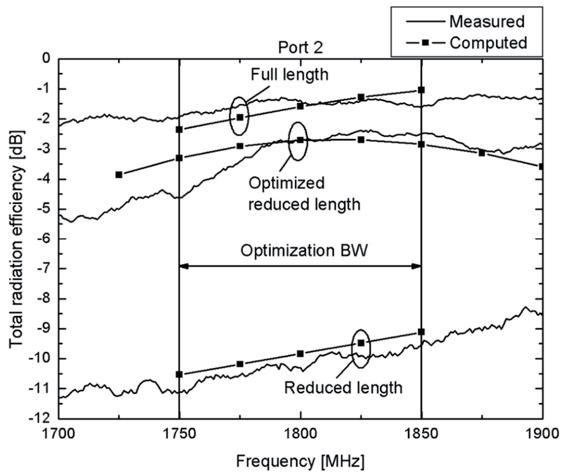

Fig. 10. Total radiation efficiency of port 2 for original full length, reduced length and optimized reduced length antenna.

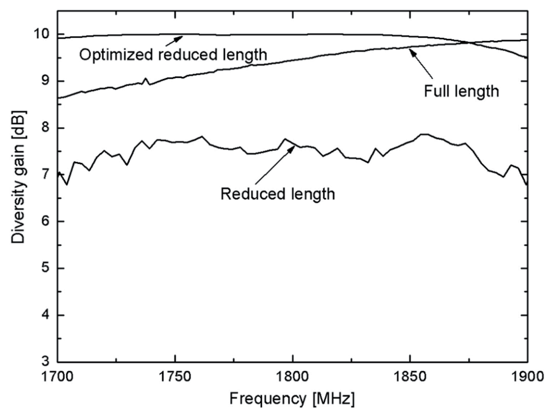

Fig. 11. Measured diversity gain for original full length, reduced length and optimized reduced length antenna.

To point out the importance of realistic models of circuit components this problem was optimized once more, now without the small resistors previously connected in series with the complex impedances. As the reader should remember, the purpose of those resistors was to avoid a theoretical solution to the problem which cannot be matched with measurements. Now, without the resistive components the optimizer will work on a slightly different problem and therefore find a slightly different optimum (other component values). The measured results of the first port of the antenna are shown in Fig. 12 for both the case optimized with resistors present and for the case optimized without resistors. In this figure it can be seen that the measured result is significantly degraded for the case which is optimized without resistors. The reason for this, as already mentioned, is the wrong optimum solution found by the optimizer when complex impedances are modeled as ideal, i.e. lossless.

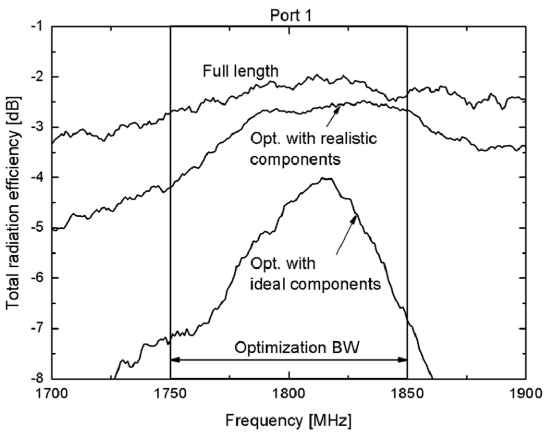

Fig. 12. Measured total radiation efficiency of the first port. The importance of realistic component models is illustrated by the difference between optimization of ideal components models and realistic component models.

5. Conclusions

A method for efficiently analyzing and optimizing multi-port antennas based on the use of a port response matrix and embedded element patterns has been presented. This has been implemented in software which uses data from commercial full-wave EM codes and communicates with a circuit simulator for fast evaluation of antenna parameters for arbitrary port loadings. The method is especially useful for optimization which was demonstrated by two simple examples.

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References

[1] KARLSSON, K., CARLSSON, J., BELOV, I., KILDAL, P.-S. Software for optimizing multi-port antennas based on precomputed embedded element patterns from commercial codes. In *Proceedings of EMB07*. Lund (Sweden), October 18–19, 2007.

[2] KARLSSON, K., CARLSSON, J., BELOV, I., NILSSON, G., KILDAL, P.-S. Optimization of antenna diversity gain by combining full-wave and circuit simulations. In *Proceedings of EuCAP 2007*. Edinburgh (UK), Nov. 11–16, 2007.

[3] CARLSSON, J., KARLSSON, K. Analysis and optimization of multi-port antennas by using circuit simulation and embedded element patterns from full-wave simulation. In *Proceedings of IEEE AP-S International Symposium and URSI Science Meeting*. San Diego (USA), July 5-11, 2008.

[4] WHEELER, H. A. Fundamental limitations of small antennas, *Proc. I.R.E.*, Dec. 1947, pp. 1479-1484.

[5] CHU, L. J. Physical limitations of omni-directional antennas. *J. Appl. Phys*., 1948, vol. 19, pp. 1163-1175.

[6] POZAR, D. M. Microstrip antennas. *Proceedings of the IEEE*, Jan. 1992, vol. 80, no. 1, pp. 79-91.

[7] ROWELL, C. R., MURCH, R. D. A capacitively loaded PIFA for compact mobile telephone handsets. *IEEE Trans. Antennas Propagat*., May 1997, vol. 45, no. 5, pp. 837-842.

[8] KATSIBAS, K. D., BALANIS, C. A., TIRKAS, P. A., BIRTCHER, C. R. Folded loop antenna for mobile hand-held units. *IEEE Trans. Antennas Propagat*., Feb. 1998, vol. 46, no. 2, pp. 260-266.

[9] FUJIMOTO, K., HENDERSON, A., HIRASAWA, A., JAMES, J. R. Small antennas. *Research Studies press*, Letchworth England, 1987.

[10] JOHNSON, J. M., RAHMAT-SAMII, Y. The tab monopole. *IEEE Trans. Antennas Propagat*., Jan. 1997, vol. 45, no. 1, pp. 187-188.

[11] CHEN, Z. N., AMMANN, M. J., QING, X., WU, X. H., SEE, T. S. P., CAI, A. Planar antennas. *Microwave Magazine*, IEEE, Dec. 2006, vol. 7, no. 6, pp. 63-73.

[12] LINDBERG, P., SENGUL, M., CIMEN, E. G., YARMAN, B. S., RYDBERG, A., AKSEN, A. A single matching network design for a dual band pifa antenna via simplified real frequency technique. In *Proceedings of EuCAP 2006*. Nice (France), Nov. 6–10, 2006.

[13] DIALLO, A., LUXEY, C., THUC, P. L., STARAJ, R., KOSSIAVAS, G. Study and reduction of the mutual coupling between two mobile phone PIFAs operating in the DCS1800 and UMTS bands. *IEEE Trans. Antennas Propagat*., Nov. 2006, vol. 54, no. 11, part 1, pp. 3063-3074.

[14] RAHOLA, J., OLLIKAINEN, J. Analysis of isolation of two-port antenna systems using simultaneous matching. In *Proceedings of EuCAP 2007*. Edinburgh (UK), Nov. 11–16, 2007.

[15] LAU, B. K., ANDERSEN, J. B., KRISTENSSON, G., MOLISCH, A. F. Impact of matching network on bandwidth of compact antenna arrays. *IEEE Trans. Antennas Propagat.*, Nov. 2006, vol. 54, no. 11, pp. 3225-3238.

[16] KILDAL, P.-S., ROSENGREN, K. Correlation and capacity of MIMO systems and mutual coupling, radiation efficiency and diversity gain of their antennas: Simulations and measurements in reverberation chamber. *IEEE Communications Magazine*, Dec. 2004, vol. 42, no. 12, pp. 102-112.

[17] ROSENGREN, K., KILDAL, P-S. Radiation efficiency, correlation, diversity gain and capacity of a six monopole antenna array for a MIMO system: theory, simulation and measurement in reverberation chamber. *Proceedings of IEE, Microwaves, Optics*

and Antennas, Feb. 2005, vol. 152, no. 1, pp. 7-16. (See also Erratum published in August 2006).

[18] KELLEY, D.F. Embedded element patterns and mutual impedance matrices in the terminated phased array environment. In *Proceedings of IEEE AP-S International Symposium*. Washington D.C., USA, July 2005, vol. 3A, pp. 659-662.

[19] NAGEL, L. W., PEDERSON, D. O. SPICE (Simulation Program with Integrated Circuit Emphasis), Memorandum No. ERL-M382, University of California, Berkeley, Apr. 1973.

[20] POZAR, D. M. *Microwave Engineering.* 3rd ed. John Wiley & Sons, Inc., 2005.

[21] HO, C-W., RUEHLI, A. E., BRENNAN, P. A. The modified nodal approach to network analysis. *IEEE Trans. Circuits Syst.*, June 1975, CAS-25, no. 6, p. 504 – 509.

[22] KILDAL, P.-S., *Foundation of Antennas*. Studentlitteratur 2000, ISBN 91-44-01318-3.

[23] BLANCH, S., ROMEU, J., CORBELLA, I. Exact representation of antenna system diversity performance from input parameter description. *Electronics Letters*, 1 May 2003, vol. 39, no. 9, pp. 705-707.

[24] KILDAL, P.-S., ROSENGREN, K., BYUN, J., LEE, J. Definition of effective diversity gain and how to measure it in a reverberation chamber. *Microwave and Opt. Lett*., 2002, vol. 34, pp. 56-59.

[25] KILDAL, P.-S., ROSENGREN, K. Electromagnetic analysis of effective and apparent diversity gain of two parallel dipoles. *IEEE Antennas and Wireless Propagation Letters*, 2003, vol. 2, no. 1, pp. 9-13.

[26] SCHWARTZ, M., BENNETT, W. R., STEIN, S. *Communications Systems and Techniques*. NewYork : McGraw-Hill, 1965.

[27] JIN, N., RAHMAT-SAMII, Y. Advances in particle swarm optimization for antenna designs: Real-number, binary, single-objective and multi-objective implementations. *IEEE Trans. Antennas Propagat.*, March 2007, vol. 55, no. 3, part 1, pp. 556 to 567.

[28] ROBINSON, J., RAHMAT-SAMII, Y. Particle swarm optimization in electromagnetics. *IEEE Trans. Antennas Propagat*., Feb. 2004, vol. 52, no. 2, pp.397-407.

[29] HORN, J., NAFPLIOTIS, N., GOLDBERG, D. E. A niched Pareto genetic algorithm for multiobjective optimization, Evolutionary Computation, 1994. IEEE World Congress on Computational Intelligence., *Proceedings of the First IEEE Conference on*, vol. 1, pp. 82-87, 27-29 June, 1994.

[30] CST Microwave Studio; http://www.cst.com/

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