S Parameter Computation and Their Use for Electromagnetic Energy Wireless Transmission

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ABSTRACT

This paper present the correct way of defining S parameters, based on linear electrical circuits, and the practical use of these parameters in obtaining efficient processes for transmitting the information and of the electromagnetic energy wireless transfer from emitter-receiver signal transmission point of view. Here are presented, also, two procedures for calculating these parameters, one based on modified nodal analyses, the second one based on state equations method. S parameters generation algorithm has the same structure for both computation procedures. The computation procedures for S parameters use the most advanced analogue circuit simulation programs, such as: Cadence, Advances Design System, Ansoft Extractor Q3D, Feko, ECAP, SYSEG etc. Finally, there are presented a few illustrative examples that certify the validity of the used computation procedures.

Indexing terms/Keywords

linear electrical circuits, S parameters, electromagnetic energy wireless transfer, modified nodal analyses, Advances Design System, Ansoft Extractor Q3D .

Academic Discipline And Sub-Disciplines

Circuits and Systems, Electrical Engineering

SUBJECT CLASSIFICATION

Circuits Theory

TYPE (METHOD/APPROACH)

Nodal analyses method, , state equations, electromagnetic energy wireless transfer, Circuit Symbolic Analysis Program (CSAP), SYmbolic STATE Equation Generation (SYSEG)

INTRODUCTION

In order to characterize linear devices, in harmonic state, there are used, at low and medium frequencies, the following parameters: Z, Y, H, T etc. When these devices function at high frequencies, these parameters can no longer be used, because they require particular branches to be short-circuited or open so that the voltages and the current from the circuits to be measured or computed. For example, to compute the input impedance of a two-port circuit, one has to short-circuit the output port, which practically makes impossible the measurement at high frequencies. In this case, the equipment is not able to measure the total voltage and the total current from the ports of the circuit. Also, many active circuits, such as the transistors, tunnel diodes, often have a stable functioning when the circuit is short-circuited or open. The logic variables that should be used at these frequencies are the transversal waves.

The scattering parameters – denoted by S, are complex quantities, function of frequency, associated to a multi-port linear system functioning in harmonic state. Initially, S parameters have been used in long transmission line theory, for their definition being used the transmitted direct and inverse voltage wave. In general, S parameters can be defined in information transmission systems, such as microwave (waveguides) systems, where these parameters can be studies using the circuit theory. There are many ways to introduce these parameters [1 - 3] which makes their interpretation and understanding often to be difficult.

S parameters do not have a direct correspondent in electric circuit theory, because this does not contain circuit elements in which there are as propagation means the waveguides. But, in electric circuit theory, there are reasonings similar to the ones for microwave circuits, by introducing the concept of power wave, terminology which comes from their significance that is related to the dependence between the active power absorbed by a load connected to a port and the working frequency [4]. There are conversion formulas between S parameters and the classical parameters corresponding to the circuit theory (impedance Z, admittance Y, H parameter, fundamental parameters), but the literature should be careful studied because, due to a wrong understanding of the significance, some formulas are useless (e.g. the formulas from [5], article criticized in [6]). The understanding of S parameters is especially important for high-frequency applications that include the active and passive components from the passive integrated circuits [7], inclusive the microelectromechanical systems (MEMS), as well as wireless power transfer systems [8].

This paper present the correct way of defining S parameters using electrical circuits theory, and the practical use of these parameters in obtaining efficient processes for transmitting the information and of the electromagnetic energy wireless transfer from emitter-receiver signal transmission point of view. There are also presented some procedures for computing these parameters. The computation procedures use the most advanced computation programs, such as Cadence [9, 11, 12, 22], ADS [15, 19, 20, 24], Ansoft Extractor Q3D [23, 25], Feko [10] etc. In chapter 2 there is presented the correct formulation, based on electrical circuit theory, of S parameters for a linear passive two-port in harmonic state. Chapter 3 is dedicated to automated computation procedures for S parameters, one method based on modified nodal analyses and the other on state equations method. In this chapter there is also presented the practical use of this parameters for obtaining efficient processes for transmitting the information and for electromagnetic energy wireless transfer from emitter-receiver signal transmission point of view. Finally, there are presented a few illustrative examples that certify the validity of the used computation procedures.

$\underline{S}$ PARAMETER FORMULATION (DEFINITION)

The Scattering parameters $\underline{S}$ - are used to compute the efficiency of signal transmission for microwave networks and for Transfer Power Wireless Systems (TPWS). There are efficient techniques to measure the $\underline{S}$ parameters, such as Vector Network Analyzer (VNA)) [13 – 15, 24, 25], reason that recommends the use of these parameters in obtaining an efficient information transmission and propagation and an efficient wireless electromagnetic energy transfer.

To define in a correct manner the scattering parameters S for a two-port structure, let’s consider the circuit given in Fig. 1.

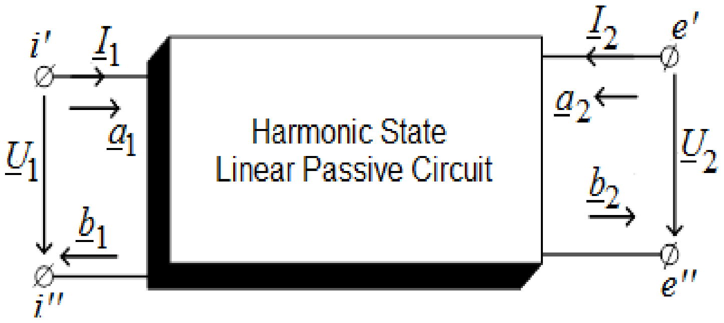


Fig 1: Circuit used to define S parameters.

where Z0 is a real positive variable, called – characteristic impedance.

By similarity with the wave equation, the solution $\underline{a}_1$ ($\underline{a}_2$) represents the incident wave from port i’ – i’’ (e’ – e’’), and $\underline{b}_1$ ($\underline{b}_2$) is the reflected wave at the same port. For linear circuits, the variables associated to each port can be considered as a superposition of incident (direct) waves and of reflected (indirect) waves [9, 11, 23].

The magnitudes of the new variables have dimension $\sqrt{AV}$, which shows that the square of these modules have the dimensions of an electrical power. Usually, the reference impedance is equal to the module of the load impedance. From equation (1) results:

$$\begin{aligned} \underline{a}_1 + \underline{b}_1 &= \frac{1}{\sqrt{Z_0}}\underline{U}_1, \quad \underline{a}_1 - \underline{b}_1 = \sqrt{Z_0}\,\underline{I}_1 \\ \underline{a}_2 + \underline{b}_2 &= \frac{1}{\sqrt{Z_0}}\underline{U}_2, \quad \underline{a}_2 - \underline{b}_2 = \sqrt{Z_0}\,\underline{I}_2 \end{aligned} \tag{2}$$

and solving function of the new variables, we obtain:

$$\begin{aligned} \underline{a}_1 &= \frac{1}{2}\left(\frac{1}{\sqrt{Z_0}}\underline{U}_1 + \sqrt{Z_0}\,\underline{I}_1\right) = \frac{1}{2\sqrt{Z_0}}\left(\underline{U}_1 + Z_0\,\underline{I}_1\right) \\ \underline{b}_1 &= \frac{1}{2}\left(\frac{1}{\sqrt{Z_0}}\underline{U}_1 - \sqrt{Z_0}\,\underline{I}_1\right) = \frac{1}{2\sqrt{Z_0}}\left(\underline{U}_1 - Z_0\,\underline{I}_1\right) \end{aligned} \tag{3}$$

respectively

$$\underline{a}_2 = \frac{1}{2}\left(\frac{1}{\sqrt{Z_0}}\underline{U}_2 + \sqrt{Z_0}\,\underline{I}_2\right) = \frac{1}{2\sqrt{Z_0}}\left(\underline{U}_2 + Z_0\,\underline{I}_2\right)$$
$$\underline{b}_2 = \frac{1}{2}\left(\frac{1}{\sqrt{Z_0}}\underline{U}_2 - \sqrt{Z_0}\,\underline{I}_2\right) = \frac{1}{2\sqrt{Z_0}}\left(\underline{U}_2 - Z_0\,\underline{I}_2\right) \tag{4}$$

The scattering parameters S of a two-port structure (Fig. 1) satisfy the following equations between the incident and the reflected signals:

$$\underline{b}_1 = \underline{S}_{11}\underline{a}_1 + \underline{S}_{12}\underline{a}_2$$
$$\underline{b}_2 = \underline{S}_{21}\underline{a}_1 + \underline{S}_{22}\underline{a}_2 \tag{5}$$

The four S parameters, associated to a linear two-port circuit (Fig. 1), are defined below:

The reflection parameter from port 1 - <u>S</u>11

$$\underline{S}_{11} = \left.\frac{\underline{b}_1}{\underline{a}_1}\right|_{\substack{\underline{a}_2=0 \Leftrightarrow \underline{U}_2=-Z_c\underline{I}_2 \\ \underline{Z}_s=Z_c,\underline{U}_1=\underline{E}_i-Z_c\underline{I}_1}} =$$
$$= \left.\frac{\underline{U}_1 - Z_c\,\underline{I}_1}{\underline{U}_1 + Z_c\,\underline{I}_1}\right|_{\substack{\underline{a}_2=0 \Leftrightarrow \underline{U}_2=-Z_c\underline{I}_2 \\ \underline{Z}_s=Z_c,\underline{U}_1=\underline{E}_i-Z_c\underline{I}_1}} =$$
$$= \frac{\underline{E}_i - 2Z_c\,\underline{I}_c}{\underline{E}_i} = 1 - 2\underline{A}_{1i} \tag{6}$$

where $\underline{A}_{1i} = \left.\frac{Z_c\,\underline{I}_1}{\underline{E}_i}\right|_{\underline{U}_2=-Z_c\underline{I}_2,\underline{Z}_s=Z_c}$ is the voltage transfer factor (amplification), computed when at input port i′ - i” is connected in series a t.e.m. Ei with input impedance Zi = Zc, and at output port 2 (e' – e'') is connected an impedance Ze = Zs = Zc;

The transmission parameter from port 1 to port 2 - <u>S</u>12

$$\underline{S}_{12} = \left.\frac{\underline{b}_1}{\underline{a}_2}\right|_{\substack{\underline{a}_1=0 \Leftrightarrow \underline{U}_1=-Z_c\,\underline{I}_1 \\ \underline{Z_i}=Z_c,\underline{Z}_s=Z_c}} =$$
$$= \left.\frac{\underline{U}_1 - Z_c\,\underline{I}_1}{\underline{U}_2 + Z_c\,\underline{I}_2}\right|_{\substack{\underline{a}_1=0 \Leftrightarrow \underline{U}_1=-Z_c\,\underline{I}_1 \\ \underline{Z_i}=Z_c,\underline{Z}_s=Z_c}} =$$
$$= \frac{-2Z_c\,\underline{I}_1}{\underline{E}_e} = -2\underline{A}_{io} \tag{7}$$

,

where $\underline{A}_{io} = \left.\frac{Z_c\,\underline{I}_1}{\underline{E}_o}\right|_{\underline{U}_1=-Z_c\underline{I}_1,\underline{Z}_s=Z_c}$ is the voltage transfer factor (amplification), when the characteristic (reference) impedance Zc is connected to the input port i′ - i” (Ei being zero) and at output port e' – e'' e=is connected the impedance Zs = Zc in series with t.e.m. Eo;

The transmission parameter from port 2 to port 1 - S21

$$\underline{S}_{21}=\left.\frac{\underline{b}_2}{\underline{a}_1}\right|_{\substack{\underline{a}_2=0\Leftrightarrow\underline{U}_2=-Z_c\underline{I}_2\\ \underline{Z}_i=Z_c,\underline{Z}_s=Z_c,\underline{U}_1=\underline{E}_i-Z_c\underline{I}_1}}=$$

$$=\left.\frac{\underline{U}_2-Z_c\underline{I}_2}{\underline{U}_1+Z_c\underline{I}_1}\right|_{\substack{\underline{a}_2=0\Leftrightarrow\underline{U}_2=-Z_c\underline{I}_2\\ \underline{Z}_i=Z_c,\underline{Z}_s=Z_c,\underline{U}_1=\underline{E}_i-Z_c\underline{I}_1}}=$$

$$=\frac{-2Z_c\underline{I}_2}{\underline{E}_i}=-2\underline{A}_{oi} \qquad (8)$$

,

where $\underline{A}_{oi}=\left.\frac{Z_c\underline{I}_2}{\underline{E}_i}\right|_{\underline{U}_2=-Z_c\underline{I}_2,\underline{Z}_i=Z_c,\underline{Z}_s=Z_c}$ is the voltage transfer factor (amplification) from output to input, under the circumstances mentioned in (8).

The reflection parameter from 2 - S22

$$\underline{S}_{22}=\left.\frac{\underline{b}_2}{\underline{a}_2}\right|_{\substack{\underline{a}_1=0\Leftrightarrow\underline{U}_1=-Z_c\underline{I}_1\\ \underline{Z}_i=Z_c,\underline{Z}_s=Z_c,\underline{U}_2=\underline{E}_o-Z_c\underline{I}_2}}=$$

$$=\left.\frac{\underline{U}_2-Z_c\underline{I}_2}{\underline{U}_2+Z_c\underline{I}_2}\right|_{\substack{\underline{a}_1=0\Leftrightarrow\underline{U}_1=-Z_c\underline{I}_1\\ \underline{Z}_i=Z_c,\underline{Z}_s=Z_c,\underline{U}_2=\underline{E}_o-Z_c\underline{I}_2}}= \qquad (9)$$

$$=\frac{\underline{E}_o-2Z_c\underline{I}_2}{\underline{E}_o}=1-2\underline{A}_{2o}$$

where $\underline{A}_{2o}=\left.\frac{Z_c\underline{I}_2}{\underline{E}_o}\right|_{\underline{U}_1=-Z_c\underline{I}_1,\underline{Z}_s=Z_c}$ is the voltage transfer factor (amplification) when at port i′ – i″ is connected the characteristic impedance Zc (Ei being zero) and at output port e' – e'' there is connected the impedance Zs = Zc in series with t.e.m. Eo. The reflexion factor S11 and the transmission factor S21 can be measured using Vector Network Analyzer (VNA)) [13–15, 24–27].

S parameters generation, for analogue linear circuits and for nonlinear analogue circuits, piecewise linear functioning point, in precise conditions given by polarization and temperature corresponding to electronic circuits, can take place by small signal simulations. [15, 27].

S parameters are defined function of characteristic impedance which is in general equal to 50 Ω.

To generate S parameters for nonlinear circuits we use the simulator – Large-Signal S-Parameter Simulation (LSSP) [15], that uses the harmonic balance method. The simulation based o harmonic balance method is a large signal simulation for which the solutions include also the effects given by the nonlinearity of electronic components. S parameters for both small and large signals are defied as ratios between the incident and the reflected wave [15].

Usually, the most important S parameters are the reflexion parameter S11 and the transmission S21, because the reflected signals efficiency is $\eta_{11}\overset{d}{=}S_{11}^2\times 100\ (\%)$, and the transmission signals efficiency is $\eta_{21\_S_{21}}=S_{21}^2\times 100$ [1–15].

S PARAMETERS COMPUTATION PROCEDURE

To compute S parameters, for any two-port linear system or for different structures WPTS (Wireless Power Transfer Systems) one can use any analyses program for analogue circuits.

As follows, the parameters S will be automated generated, for any WPTS system, using either the software called Circuit Symbolic Analysis Program (CSAP), based on nodal modified equations, or the software SYmbolic STATE Equation Generation (SYSEG), which uses the state equations [9, 11, 12].

Because the results obtained using the two programs CSAP and SYSEG are identical, as follows, we present the computation algorithm for S parameters for series-series connection configuration resonator, when for nodal modified equation generation we used SCAP software [9, 11, 12].

For the other three connections of the resonator magnetically coupled: series-parallel, parallel-series, and parallel-parallel, when for nodal modified equation generation we used SCAP or SYSEG program, the algorithms for computing the S parameters have the same structure as the algorithm corresponding to the series-series connection. The validation of the results obtained with the programs SCAP and SYSEG took place by comparing the corresponding results with the ones obtained using ADS software [15].

S parameters computation algorithm description for series-series configurarion (RpoCMSS)

P1. Computation of parameters S11_ss and S21_ss

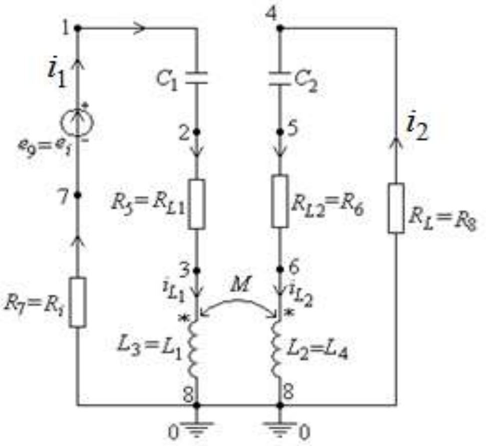


Fig. 2: The circuit used to generate the parameters S11_ss and S21_ss.

To compute the parameters S11_ss = 1.0 - 2.0*Zc*I1/Ei and S21_ss= - 2.0*Aoi is analysed in harmonic state the circuit given in Fig. 2, using SCAP or SYSEG program, when Ri = RL = Zc (Rc).

In the input file RCMSS_S11_S21.smb – for SCAP (RCMSS_S11_S21.dat – for SYSEG) were kept Ri and RL to be able to compute the efficiency of the active power transmission from port 1 to port 2: ç21_ss = 100*PRL_ss/P1_ss, where PRL _ss= RL*IRL_ss^2 and P1_ss = Re(Ei*conjugate(Ii_ss)). The signals transmission efficiency from port 1 to port: 2 $\eta_{21\_S_{21\_ss}} = 100.0 \cdot \underline{S}_{21} \cdot \underline{S}_{21}^{*}$ is computed for Ri = RL = Zc and obviously it is not identical to the active power transmission efficiency ç21_ss.

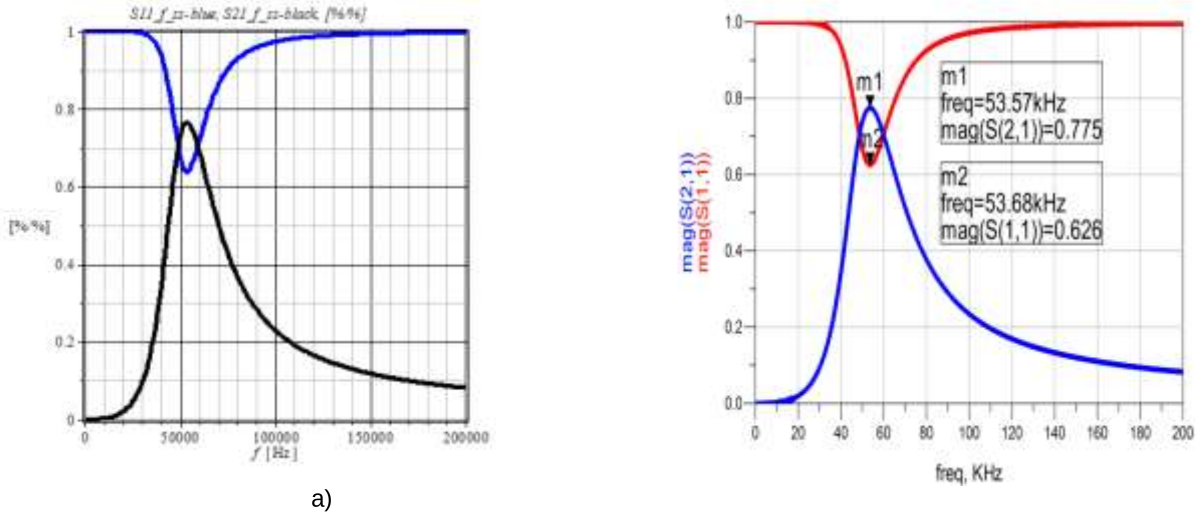
P1.1. For S11_ss parameter generation, firstly it is computed the input admittance $\underline{Y}_{ii} = \left.\frac{\underline{I}_1}{\underline{E}_i}\right|_{R_i=Z_c, R_L=Z_c}$, then by using the definition formula S11_ss = 1.0 - 2.0*Zc*Yii it is obtained the expression of reflection coefficient from port 1, function of the parameters of the circuits from Fig. 2 and of the frequency f;

P1.2. To compute the S21_ss parameters, one generates, for the circuit given in Fig. 2, the voltage transfer factor (amplification) $\underline{A}_{oi} = \left.\frac{Z_c \underline{I}_2}{\underline{E}_i}\right|_{R_i=Z_c, R_L=Z_c}$, then using the definition formulae S21_ss= - 2.0*Aoi results the expression of the transmission coefficient from port 1 to port 2, function of the parameters given in Fig. .2 and the frequency f;

P1.3. Compute the expression of the signal transmission efficiency from port 1 to port 2: $\eta_{21\_S_{21\_ss}} = \underline{S}_{21} \cdot \underline{S}_{21}^{*}$;

P1.4. Compute the expressions of the efficiency ç21_f_ss for the following numerical values of the parameters form Fig.2 : C1=0.188e-06 F, C2=0.4e-06 F, L1=50.0e-06 H, L2=24.0e-06 H, M=8.4896e-06 H, RL1=0.0162 Ù, RL2=0.011 Ù, Ri=1.5 Ù; RL=6.0 Ù; Ei=100.0 V; $k = M / \sqrt{L_1 \cdot L_2} = 0.25$, parameters determined using ANSIS ANSOFT EXTRACTOR Q3D [23];

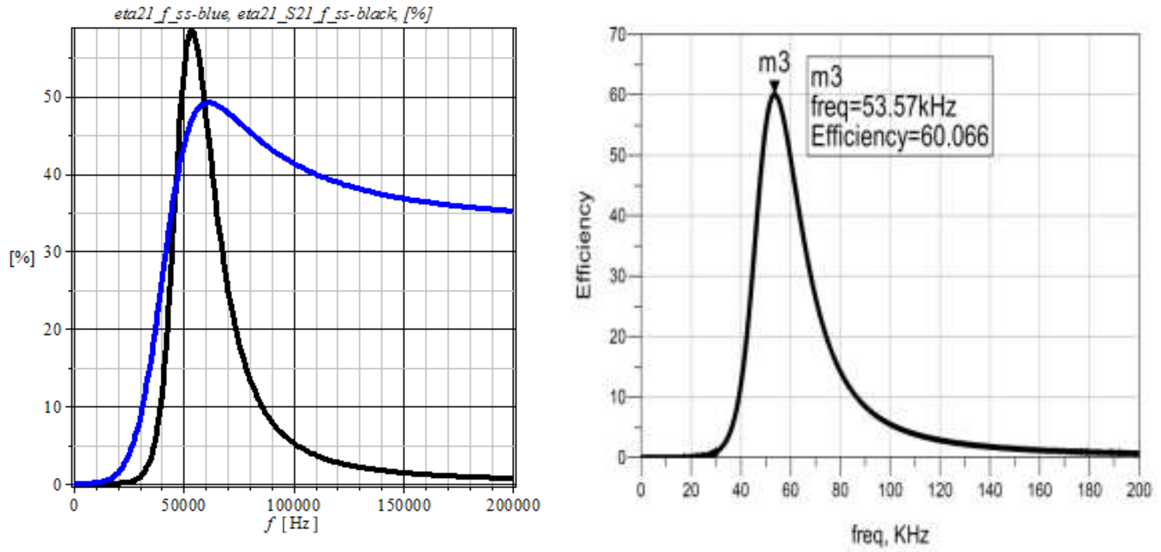
P1.5. For the values of the circuit parameters from step P1.4 and Zc=6 Ù there are presented in Fig. 3 a and b, the variations with respect to the frequency of the modules of the parameters S11_f_ss and S21_f_ss, computed using the programs ASINOM and SYSEG – Fig 3. a and resulted after using ADS program – Fig. 3, b. In Fig. 4, a and b are depicted the variation with respect to the frequency of the efficiencies eta21_f_ss and eta21_S21_f_ss, computed using the programs ASINOM and SYSEG – Fig. 4, a and the variation with respect to frequency of the efficiency eta21_S21_f_ss, computed using ADS – Fig.4, b.



a)

b)

Fig. 3: Variations with respect to frequency of the modules of parameters S11_f_ss şi S21_f_ss): a) Computed using ASINOM and SYSEG programs; b) Computed using ADS program.



a)

b)

Fig. 4: Variations with respect to frequency of the efficiencies eta21_f_ss and eta21_S21_f_ss: a) Computed using ASINOM and SYSEG programs; b) Computed using ADS program.

P2. Computation of parameters S12_ss and S22_ss

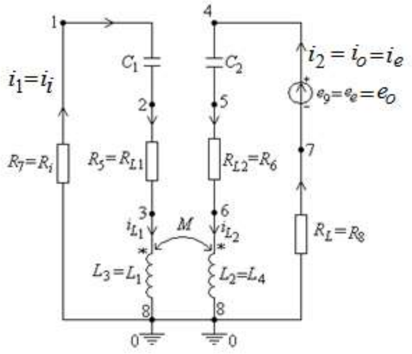


Fig. 5: The circuit used to determine the coefficients S12_ss and S22_ss.

For scattering parameters computation S12_ss = - 2.0*Aio and S22_ss= 1.0 - 2.0*A2o is analysed in harmonic state, using either SCAP or SYSEG program, the circuit given in Fig.5, powered at port e'-e'' with condition that Ri = RL = Zc (Rc).

In the file RCMSS_S12_S22.smb (RCMSS_S12_S22.dat) were kept Ri and RL in order to be able to compute the active power transmission efficiency from 2 to port 1 ç12_ss = 100*P1_ss/P2_ss, where P1 _ss= Ri*I1^2 and P2_ss = Re(Eo*conjugate(I2)). The signals transmission efficiency from port 2 to port 1 $\eta_{12\_S_{12}\_ss} = 100.0 \cdot \underline{S}_{12} \cdot \underline{S}_{12}^{*}$ is computed for Ri = RL = Zc and it is obviously not identical to the active power transmission efficiency ç12_ss.

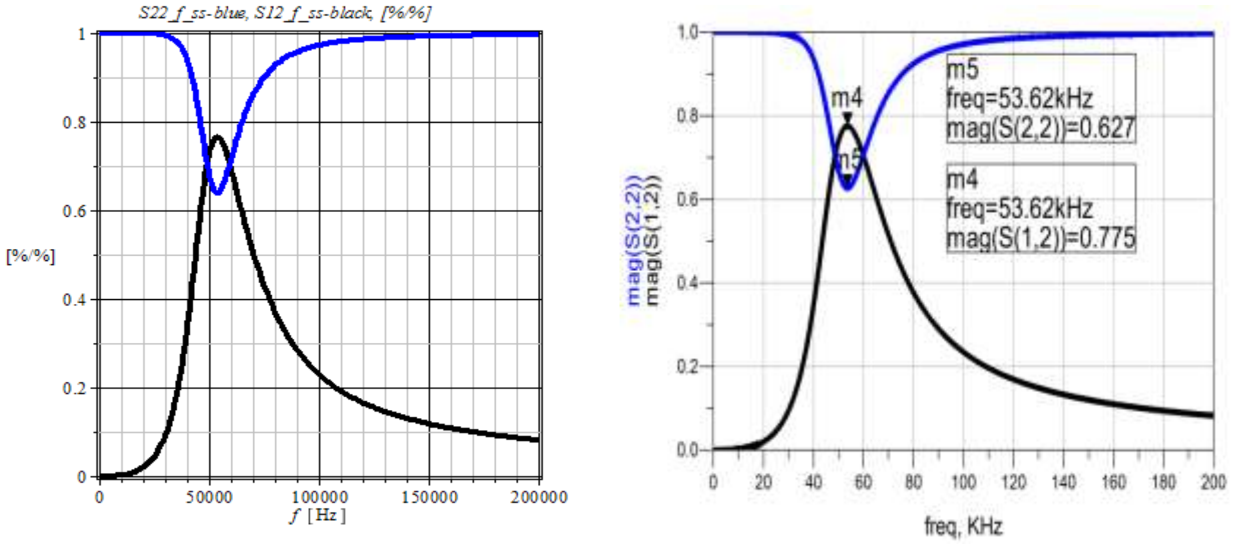
P2.1. To generate the parameter S12_ss we compute first the voltage amplification $\underline{A}_{io} = \left.\frac{Z_c \underline{I}_1}{\underline{E}_o}\right|_{R_i = Z_c, R_L = Z_c}$, then by using the definition formula S12_ss= - 2.0*Aio results the transmission coefficient expression from port 2 to port 1, function of the circuit parameters from Fig. 5 and the frequency f.

P2.2. To compute the parameter S22_ss is generated from the circuit Fig. 5, the voltage transfer $\underline{A}_{2o} = \left.\frac{Z_c \underline{I}_2}{\underline{E}_o}\right|_{R_i = Z_c, R_L = Z_c}$, then using the definition S22_ss= 1.0 - 2.0*A2o results the expression of the reflexion form port 2, function of the circuit parameters from Fig. 5 and the frequency f.

P2.3. Compute the expression of the signal transmission efficiency from port 2 to port $\eta_{12\_S_{12}\_ss} = \underline{S}_{12} \cdot \underline{S}_{12}^{*}$.

P2.4. Compute the expressions of the efficiency ç12_f_ss for the following numerical values of the parameters form Fig.2 : C1=0.188e-06 F, C2=0.4e-06 F, L1=50.0e-06 H, L2=24.0e-06 H, M=8.4896e-06 H, RL1=0.0162 Ù, RL2=0.011 Ù, Ri=1.5 Ù; RL=6.0 Ù; Ei=100.0 V; $k = M / \sqrt{L_1 \cdot L_2} = 0.25$, parameters determined using ANSIS ANSOFT EXTRACTOR Q3D [23];

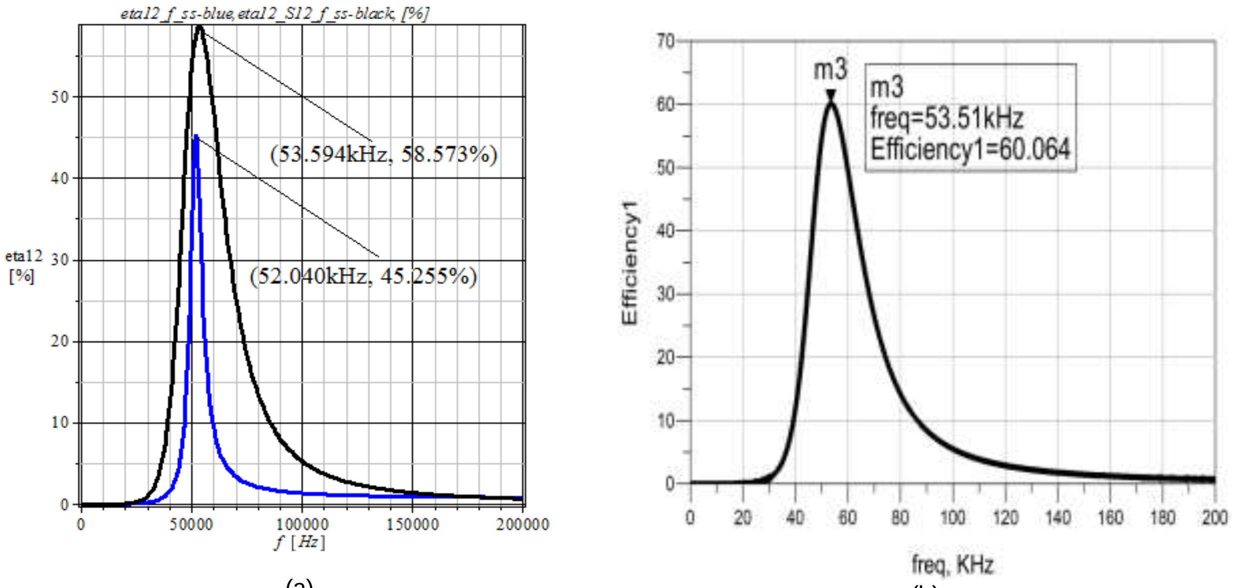
P2.5. For the values of the circuit parameters from step P2.4 and Zc=6 Ù there are presented in Fig. 6 a and b, the variations with respect to the frequency of the modules of the parameters S12_f_ss and S22_f_ss computed using the programs ASINOM and SYSEG – Fig 7. a and resulted after using ADS program – Fig. 6, b. In Fig. 7, a and b are depicted the variation with respect to the frequency of the efficiencies eta12_f_ss and eta12_S12_f_ss, computed using the programs ASINOM and SYSEG – Fig. 7, a and the variation with respect to frequency of the efficiency eta12_S12_f_ss, computed using ADS – Fig.7, b.



(a)

(b)

Fig. 6: Variations with respect to frequency of the modules of parameters S22_f_ss and S12_f_ss: a) Computed using ASINOM and SYSEG programs; b) Computed using ADS program.

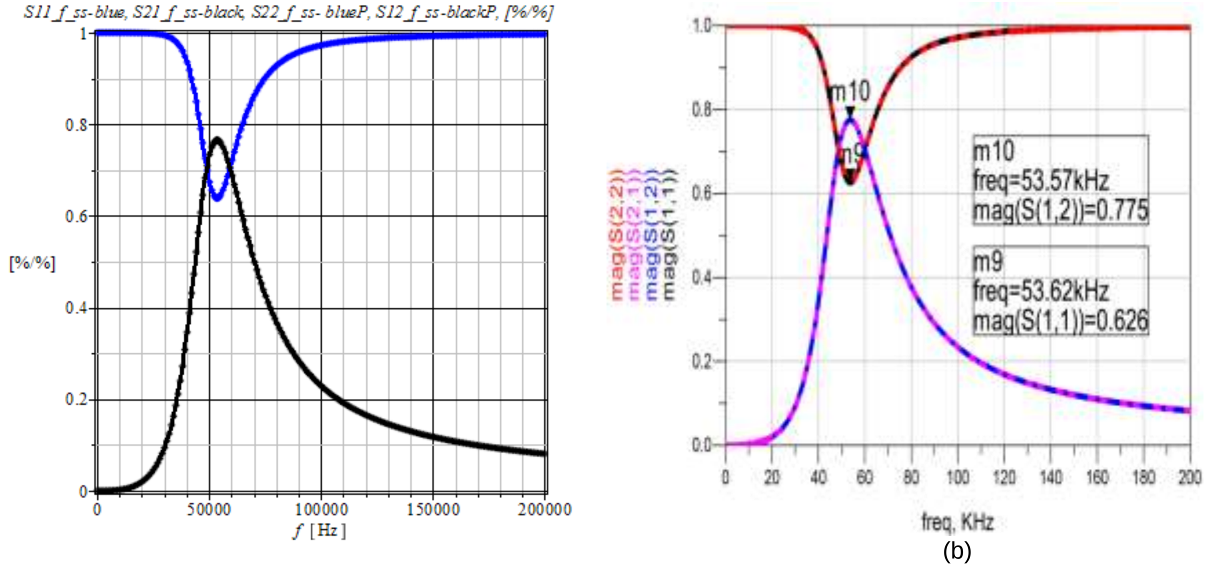


(a)

(b)

Fig. 7: Variations with respect to frequency of the efficiencies eta12_f_ss and eta12_S12_f_ss: a) Computed using ASINOM and SYSEG programs; b) Computed using ADS program.

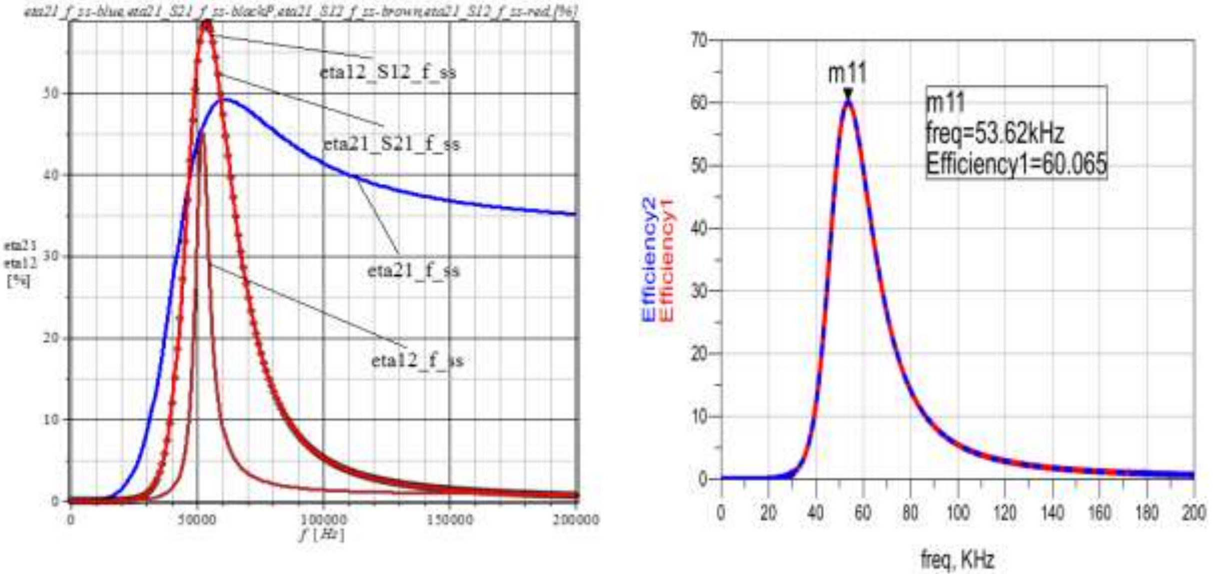
P.3. For the values of the parameters of the circuit from P1.4 and P2.4 and Zc=6 Ù are presented, in Fig. 8, a and b, the variations with respect to frequency of the modules of the parameters S11_f_ss, S21_f_ss, S22_f_ss and S12_f_ss, computed with the programs ASINOM and SYSEG – Fig. 8, a and the results of the simulation using ADS program– Fig.8, b. In Fig.9, a and b are given the efficiencies variation function of frequency eta21_f_ss, eta21_S21_f_ss, eta12_f_ss and eta12_S12_f_ss, computed using ASINOM and SYSEG – Fig.9, a and the variation with frequency of the efficiencies eta21_S21_f_ss and eta12_S12_f_ss, computed with ADS – Fig.9, b.



(b)

(a)

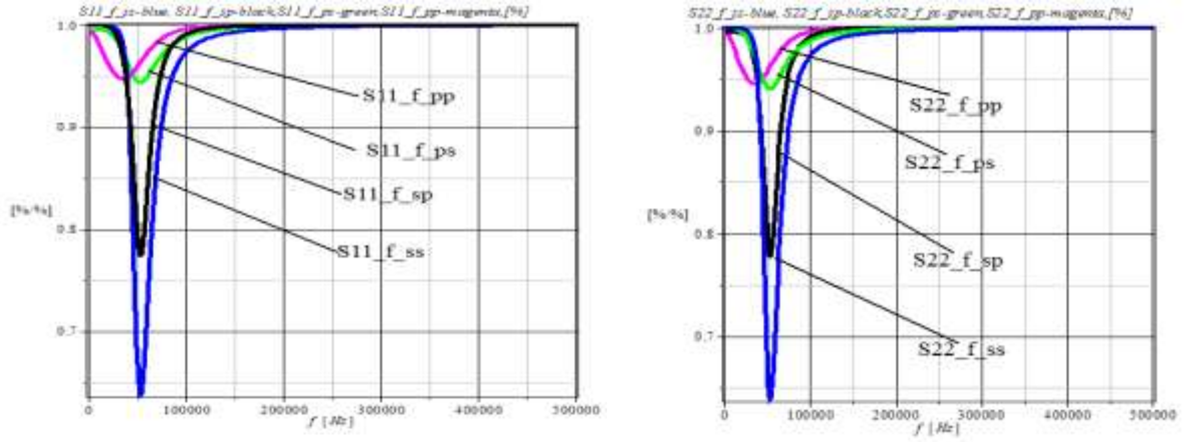
Fig. 8: Variations with respect to frequency of the modules of parameters S11_f_ss, S21_f_ss, S22_f_ss and S12_f_ss : a) Computed using ASINOM and SYSEG programs; b) Computed using ADS program.



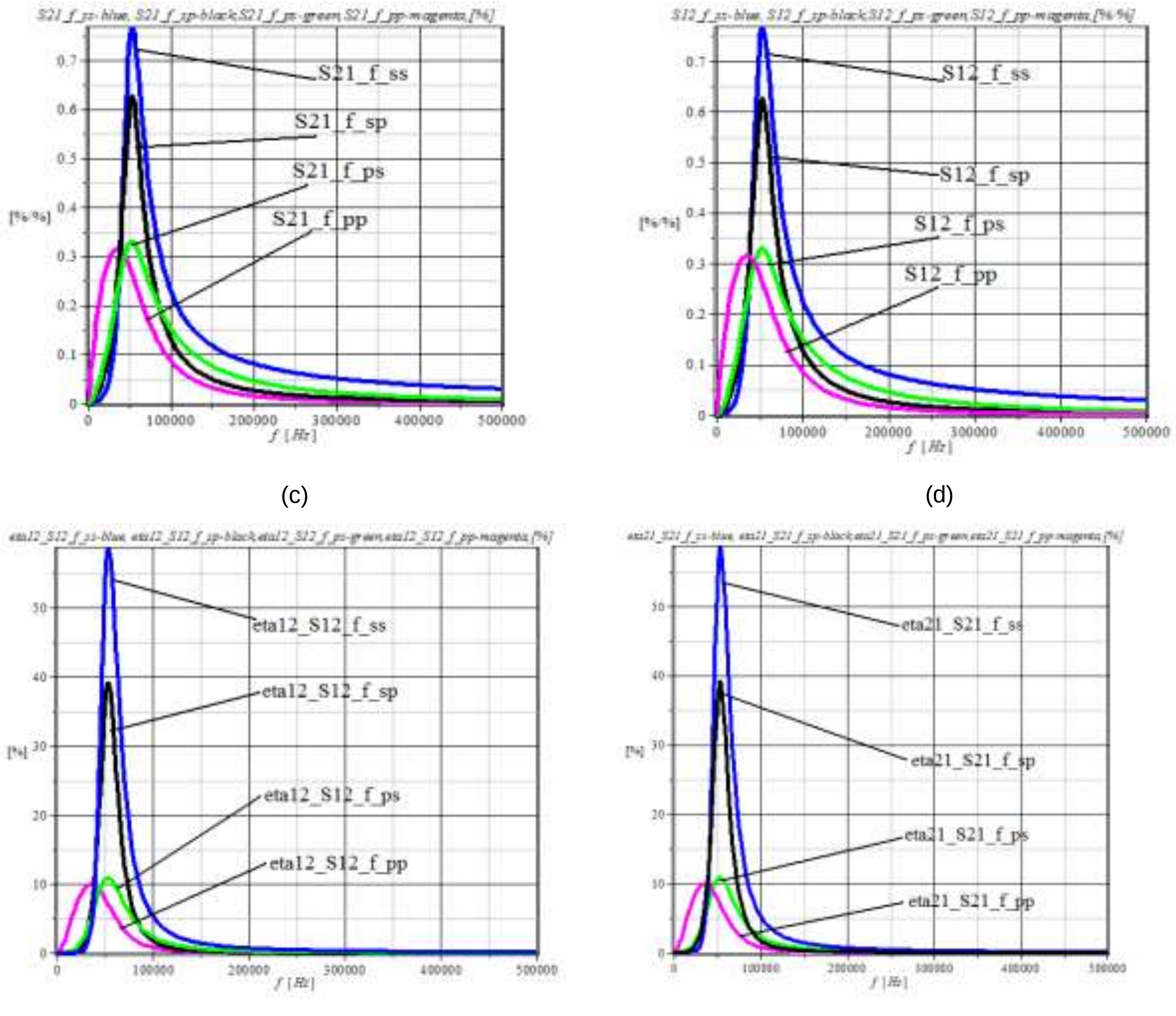
(a) (b)

Fig. 9: Variations with respect to frequency of the efficiencies eta21_f_ss, eta21_S21_f_ss, eta12_f_ss and eta12_S12_f_ss: a) Computed using ASINOM and SYSEG programs; b) Computed using ADS program.

In Fig.10, a-f and in Fig. 11 are presented the variations with frequency, for the four connections (ss, sp, ps ºi pp) of the magnetic coupled resonators, of the magnitudes $|\underline{S}_{11}|, |\underline{S}_{22}|, |\underline{S}_{21}|, |\underline{S}_{12}|, \eta_{21\_S_{12}}, \eta_{21\_S_{21}}$ and, respectively η_{21}. The computation of these magnitudes were doe for the following values of the parameters corresponding to the analysed magnetic coupled resonator: C1=0.188e-06 F, C2=0.4e-06 F, L1=50.0e-06 H, L2=24.0e-06 H, M=8.4896e-06 H, RL1=0.0162 Ù, RL2=0.011 Ù, Ri=1.5 Ù, RL=6.0 Ù, Ei=100.0 ºi kn=0.25.



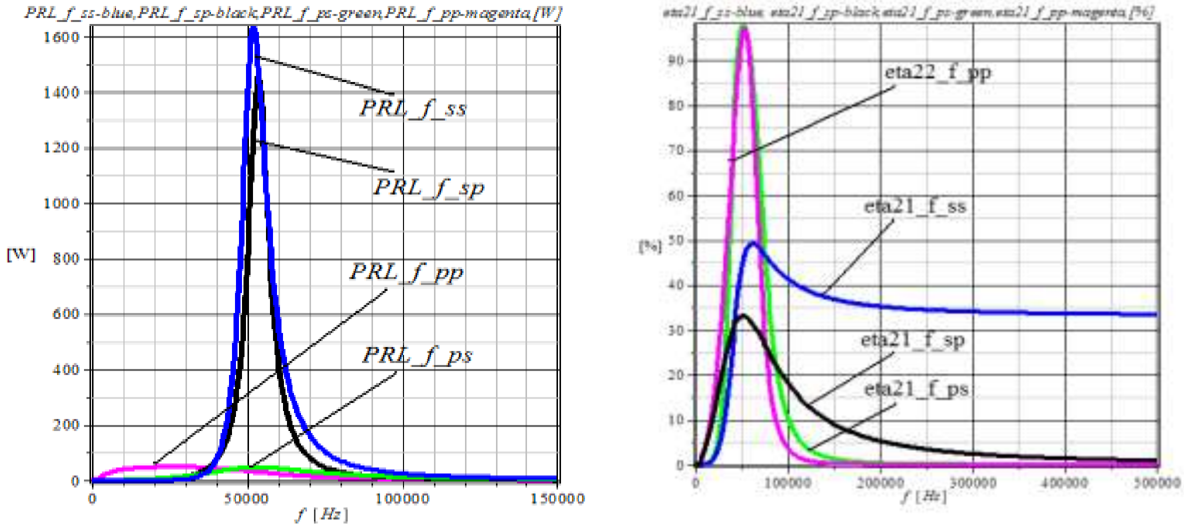
(a) (b)



(c) (d)

(e) (f)

Fig.10: Variation with respect to the frequency for the four connections, of the magnitudes: a) Parameter abs(S11); b) Parameter abs(S22); c) Parameter abs(S21); d) Parameter abs(S12); e) Efficiency η21_S12_f_ss; e) Efficiency η21_S21_f_ss .



(a) (b)

Fig. 11: Variation with frequency of the active power PRL_f_ss given by the load – (a) and of the input-output active power transmission efficiency η21_f_ss– (b), for the four connections.

CONCLUSIONS

Transfer Power Wireless Systems (TPWS) is a new technology, used when electromagnetic energy transmission is not possible for certain reasons (difficult allowable places, recharging implant batteries, etc.), through the conductors. The energy transfer using this procedure can take place at any distance for which the electromagnetic field is strong enough, such that to allow a reasonable energy. This is possible if booth the emitter and the receiver operate at resonance, because the resonant systems exchange energy much efficient that the non-resonant ones.

Modern applications of telecommunications systems (transfer of information) is based on the propagation of electromagnetic waves, but the radiating antenna technology is not suitable for power transfer efficiency because its efficiency is highly reduced (a large part of the energy is lost through dispersion into the environment).

The scattering parameters S are very useful for computing the signals transmission efficiency between two magnetic coupled resonators: $\eta_{21\_\underline{S}_{21}} = 100.0 \cdot \underline{S}_{21} \cdot \underline{S}_{21}^{*}$ from emitter to transmitter (from input to output) and $\eta_{21\_\underline{S}_{12}} = 100.0 \cdot \underline{S}_{12} \cdot \underline{S}_{12}^{*}$ from the de la transmitter to emitter (from output to input). These efficiencies are not identical with the input to output active power transmission efficiency (from emitter to transmitter) defied as: $\eta_{21} = 100.0 \cdot P_{R_L} / P_1$, where $P_{R_L} = R_L I_{R_L}^2$ is the active power given by load, and $P_1 = Re\left(\underline{E}_i \cdot \underline{I}_i^{*}\right)$ represents the active power given by the emitter's power source.

In general, the active power transmission efficiency η_{21} has maximum values smaller than the efficiencies $\eta_{21\_\underline{S}_{21}}$ and $\eta_{21\_\underline{S}_{12}}$, affirmation contradicted by the simulation performed using with SCAP, SYSEG and ADS programs. For series-series connection case, for a relatively small (100 mm) the efficiency η_{21} has the corresponding maximum value bigger than the values corresponding to $\eta_{21\_\underline{S}_{21}}$ and $\eta_{21\_\underline{S}_{12}}$. The frequencies values corresponding to extreme points of the three efficiencies are practically identical.

The accuracy of defining the scattering parameters S, based on analogue circuit theory in complex harmonic state, in relationships (6) – (9), is confirmed by the results obtained using the ADS program, which has sub-routines specific for S parameters generation.

The algorithms for generating S parameters for the four connection types (ss, sp, ps and pp), presented in this paper, computes very fast these parameters and analyses their dependence on the parameters corresponding to the magnetic coupled resonators, on frequency and on reference impedance Z0 = Zc. The algorithms are based on circuit's state equations – SYSEG program and on modified nodal equations – SCAP program;

The values corresponding to $\eta_{21\_\underline{S}_{21}}$ and $\eta_{21\_\underline{S}_{12}}$ are identical no matter if the magnetic coupled resonator is or not symmetrical and no matter is the connection type between the emitter and receiver,

The variations wit frequency of the active power PRL given by the load, of the modules corresponding to the four S parameters and to the three efficiencies η_{21}, $\eta_{21\_\underline{S}_{21}}$ and $\eta_{21\_\underline{S}_{12}}$ depend greatly on the connection type of the two magnetic coupled resonators. The biggest extreme values are obtained for series –series connection, followed by the series – parallel connection.

The frequencies values corresponding to the maximum values of the active power PRL given by the load, of the modules of the four parameters S and of the three efficiencies η_{21}, $\eta_{21\_\underline{S}_{21}}$ and $\eta_{21\_\underline{S}_{12}}$ are pretty close.

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