Volume 50, Number 4, 2009

ACTA TECHNICA NAPOCENSIS
Electronics and Telecommunications

A PSPICE MODEL FOR T MATCHING CIRCUITS

Ioana SĂRĂCUȚ Victor POPESCU
Technical University of Cluj-Napoca,
G.Baritiu Street 26-28, Cluj-Napoca, phone 0264-401803
E-mail: Ioana.Saracut@bel.utcluj.ro, Victor.Popescu@bel.utcluj.ro

Abstract: In electronics, impedance matching is an engineering technique employed in circuit design for matching unequal source and load impedances. This can be done by inserting a matching circuit between the source and a load. For given values of the source resistance, load resistance, the modulus of the coupling factor and the frequency at which the matching is achieved, four different circuit result. In this paper, we simplified the calculation of the reactances of the elements and presented a PSpice model that can be used to model any of the four matching circuits. Hence the model can be used as an impedance matching circuit without the need to calculate the nature and the values of its elements. Then we compared the time and frequency behaviors of a circuit that uses this PSpice model to the case when the same circuit doesn't use it.

Key words: *propagation, matching circuit, working frequency, reflected wave.*

I. INTRODUCTION

When sending power down a transmission line, it is desirable to maximize the power transferred from the source to the load and minimize the power reflected back to the source. This can be ensured by making the load impedance equal to the characteristic impedance of the transmission line, in which case the transmission line is said to be *matched*. Ensuring the source impedance matches the characteristic impedance will maximize power transfer from the source to the transmission line.

Impedance matching can be accomplished by inserting a *matching circuit* between the source and the load. In order to reduce the power loss, the elements of a matching circuit are purely reactive (non-dissipative). The matching circuits are frequency-selective therefore they perform the matching only at the working frequency and roughly around it.

Consider a T matching circuit that matches the internal resistance R_g of a voltage source to a load R_s , as depicted in *Figure 1*.

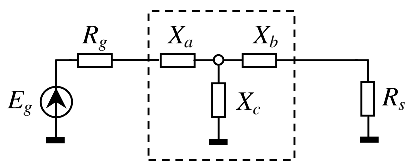

Figure 1. The T matching circuit connected between the source resistance Rg and the load Rs

The transversal reactance (X_c) and the longitudinal reactances (X_a and X_b) are given by:

$$\begin{aligned} X_a &= \pm R_g \sqrt{K_T^2 - 1} - X_c \\ X_b &= \pm R_s \sqrt{K_T^2 - 1} - X_c \\ X_c &= K_T \sqrt{R_g R_s} \end{aligned} \qquad (1)$$

where K_T is the coupling factor, which satisfies the coupling condition: $|K_T| \geq 1$. It has been proved [1] that the two signs (±) in the expressions of X_a and X_b must be the same.

If one knows the frequency at which the matching is achieved (the working frequency f), reactances allows calculating values of the elements. Depending on the sign of the reactances, the elements of the matching circuit can be either coils or capacitors.

For given values of R_g, R_s, $|K_T|$ and f, four different two-ports result, each of them having three reactive elements, two of the same nature and the third of opposite type. All the four circuits perform the matching, but they have different frequency characteristics and introduce different phase differences at the working frequency f.

The phase difference φ introduced by a T matching circuit is related to the coupling factor by the relation:

$$K_T = \frac{1}{\sin\varphi} \qquad (2)$$

In this paper we will present how we simplified the calculation of the three reactances and thus they will no longer depend on K_T, but only on R_g, R_s and φ. Then we implemented these new relations to create an OrCAD part which can be used to simulate *any* of the four matching circuits. As an example, we simulated one of the

Manuscript received on October 05, 2009; revised on November 12, 2009

matching circuit and we compared the time results and frequency characteristics with the case when the load is not matched to the source.

II. THE PART MATCH_T

It has been proved [1] that the modulus of the phase difference introduced by the matching circuit is less than *90º* if the coupling factor and the sign ± are either both positive or both negative. And if they are of different sings, then the phase difference in modulus is grater than *90º* .

Using this property and the relations (1), (2), we obtained the following expression for the three reactances, in terms of R_g, R_s and φ:

$$X_a = \frac{R_g \cos\varphi - \sqrt{R_g R_s}}{\sin\varphi}$$
$$X_b = \frac{R_s \cos\varphi - \sqrt{R_g R_s}}{\sin\varphi} \qquad (3)$$
$$X_c = \frac{\sqrt{R_g R_s}}{\sin\varphi}$$

The sign $\pm$ is no longer necessary here, because the condition $K_T < 0$ implies $\sin\varphi < 0$ and the signs (+) or (–) are given by $\cos\varphi$ as follows: $\cos\varphi > 0$ if $|\varphi| < 90^\circ$ and $\cos\varphi < 0$ if $90^\circ < |\varphi| < 180^\circ$.

Using the OrCAD program, we created the part named *Match_T*, based on the expression of the reactances given by (3). The internal schematic of *Match_T* is shown in *Figure 2* and its symbol is in *Figure 3*.

Each of the three reactances (X_a, X_b and X_c) was modeled by using a GAIN part, a parallel LC circuit and two voltage controlled switches. Each GAIN part controls two switches and each switch is connected to a coil or a capacitor. Depending on the sign of a GAIN part, the corresponding switches of the corresponding parallel LC circuit disconnect one of the two reactive elements, so that only one of them is connected at a time.

The values of the GAIN parts are as follows: $GAIN\_a = X_a$, $GAIN\_b = X_b$ and $GAIN\_c = \sin\varphi$ respectively, with X_a, X_b given by (3). The switches have the “on” resistance of *1μΩ* and the “off” resistance of *1TΩ*.

Using this one single part, all the four matching circuits can be simulated, depending on the four parameters of the part: the source resistance (R_g), the load resistance (R_s), the working frequency (*f*) and the phase difference (*p*). The default values of the parameters are shown in *Figure 3*.

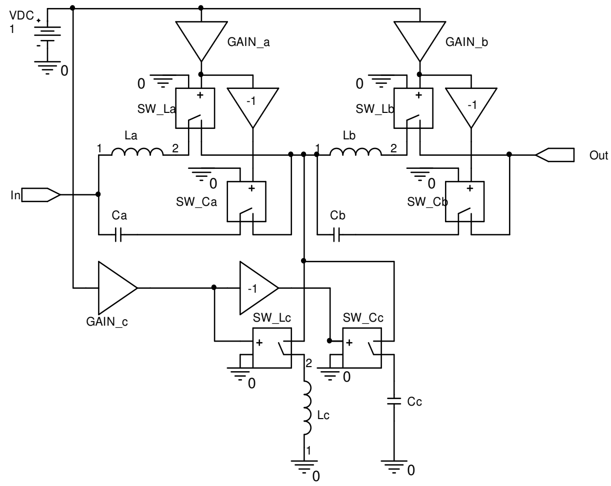

Figure 2. The internal schematic of the part Match_T

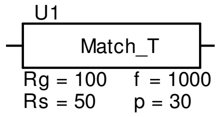

Figure 3. The symbol of the part Match_T

III. SIMULATION RESULTS

A circuit using the part *Match_T* was simulated, in order to perform the matching of a source resistance of *377Ω* (the wave impedance of an electromagnetic wave in vacuum) to a load resistance of *188.5Ω* (see the schematic shown in *Figure 4*). The working frequency *f* was set to *1MHz* and the phase difference induced by the matching circuit $\varphi = 30^\circ$.

For comparison, we also simulated the case when the load is not matched to the source resistance (the upper branch of the circuit).

The parts named *Diel_32* are each equivalent to *32* identical two-ports connected in series as a chain circuit. This is why we used them here, so we can observe the inverse waves. The two-ports have reactive elements therefore the whole chain introduce a certain delay that can be set by the user (the parameter *dx*). At the frequency of *1MHz* the wavelength in vacuum is *300m*, so if we set *dx=9.375* m, the total length modeled by a *Diel_32* block equals *32 x 9.375 m = 300 m*, i.e. equals exactly one wavelength.

Hence the total delay will be exactly one period of the input signal (*1μs*).

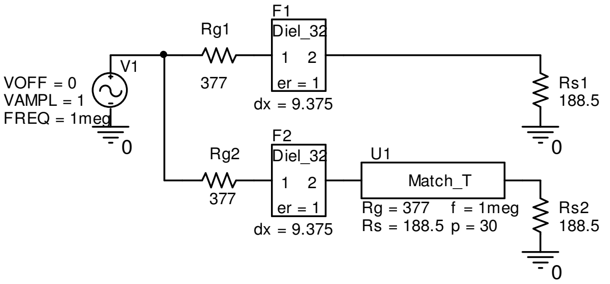

Figure 4. The circuit used for testing the part Match_T

Remember that the purpose of matching is to eliminate the reflected wave. To verify this, first we plotted the inverse wave (see *Figure 5*) for both situations: without (the upper graph) and with (the lower graph) the matching circuit.

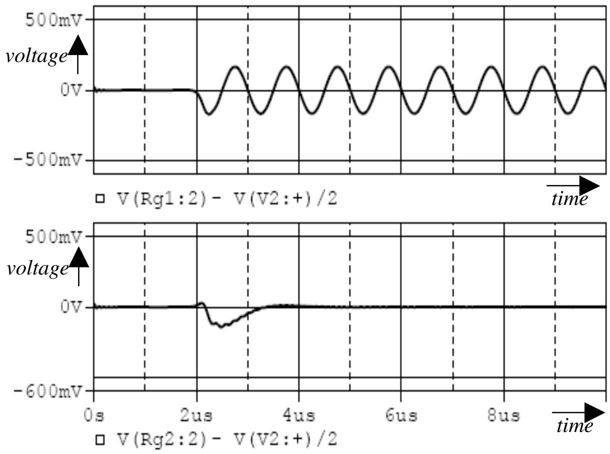

Figure 5. The inverse waves

Here the inverse wave is expressed as the difference between the voltage at the input of the delay line and half of the source voltage, according to the relations:

$$U_i = U_t - U_d \tag{4}$$

$$U_d = \frac{E}{2} \tag{5}$$

where U_i is the inverse wave, U_t is the transmitted wave and U_d is the direct wave (the voltage at the input of *Diel_32*). Because of the causality, the direct wave propagates at first as if there isn't any discontinuity in the circuit (as if the load resistance equals the characteristic impedance of the line), which is why U_d is here half of the source voltage (E).

On the upper plot it can be seen that at first the inverse wave is zero until the moment of $2\mu s$ ($2\mu s$ is the time necessary for the signal to propagate through the delay line and back). After this moment, the inverse wave is non-zero.

On the lower plot, the inverse wave is zero almost all the time, except for the transitory state between $2\mu s$ and $4\mu s$. As we expected, this is the effect of using a matching circuit.

In *Figure 6* we represented the voltages at the input of the delay lines. The upper plot shows the situation when R_s is not matched to R_g. It can be seen that in this case the amplitude of the signal is first of *0.5V* – see relation (5), then it decreases after $2\mu s$. The decreasing is due to the inverse wave (which it was seen in *Figure 5* – the upper plot).

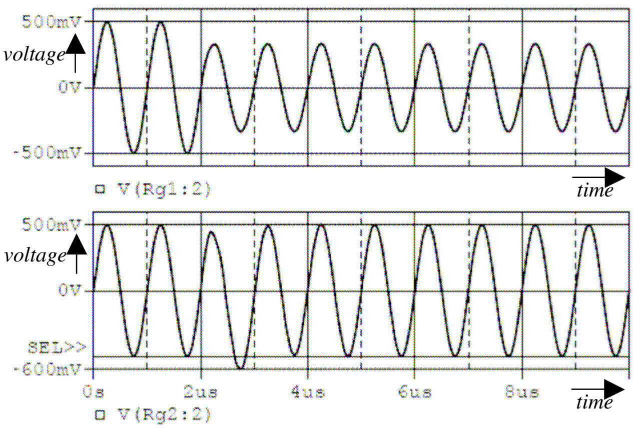

Figure 6. The inputs of the delay line

The case when we used a matching circuit is shown on the lower plot: the amplitude is constant over time, except for the transitory state that we mentioned above.

In *Figure 7* we made a comparison of the gain characteristics for some different values of the phase difference introduced by the matching circuit: *-120º*, *-30º* , *30º* and *120º*.

First, it can be seen that all the gain characteristics have a maximum at the working frequency (*1MHz*).

Also notice that if the modulus of the phase difference is less than *90º*, then the matching is performed in a wider bandwidth around the working frequency and when the modulus of the phase difference is grater then *90º*, the bandwidth is narrower.

We also observed that the matching circuits having an inductive coupling ($\varphi = 30°$ and $\varphi = 120°$) have a tendency to a high-pass characteristic, while those with a capacitive coupling ($\varphi = -30°$ and $\varphi = -120°$) have a tendency to a low-pass characteristic.

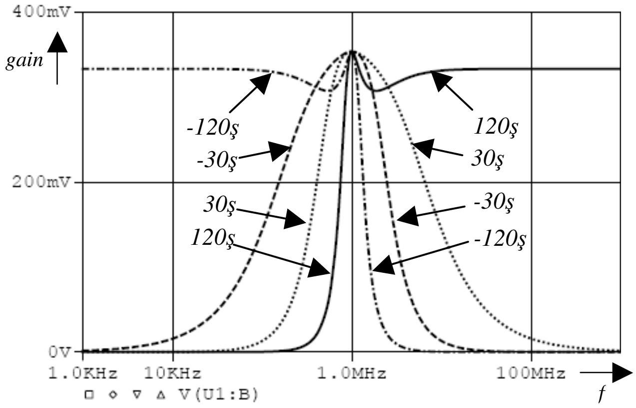

Figure 7 – Comparison between the gain-frequency characteristics for

IV. CONCLUSIONS

The proposed model can be used to simulate all four T matching circuits that result for given values of R_g, R_s, $|K_T|$ and *f*. Using this model is easy because the parameters to be indicated are exactly the design data: the load resistance, the source resistance, the desired phase shift and the working frequency. When used together with the parts of type *Diel_xx*, the direct and reflected waves in a circuit can clearly be observed. In conclusion, the presented model *Match_T* is a very useful tool in studying the phenomena related to the problem of impedance matching.

REFERENCES

[1] V. Popescu, "*Semnale, circuite şi sisteme. Partea a III-a: Teoria circuitelor* ", Casa Cărții de Știință, Cluj-Napoca, 2003.
[2] I. Sărăcuț, E. Szopos, V. Popescu, M. Topa, "*Semnale, circuite şi sisteme – Îndrumător de laborator IV*", Casa Cărții de Știință, Cluj-Napoca, 2003.
[3] G. Matthaei, L. Young, E.M.T. Jones, "*Microwave Filters, Impedance-Matching Networks and Coupling Structure*", BookMart Press, North Bergen, NJ, USA, 1885.
[4] B.K. Chung, "*Variability Analysis of Impedance Matching Network*", Microelectronics Journal, vol. 37, no. 11, pp. 1419-1423, November 2006.
[5] M.C. Tavares, J. Pissolato and C.M. Portela, "*Mode Domain Multiphase Transmission Line Model–Use in Transient Studies*", IEEE Transactions on Power Delivery, vol. 14, no. 4, pp. 1533-1544, 1999.
[6] A. Budner, "*Introduction of Frequency-Dependent Line Parameters into an Electromagnetic Transients Program*", IEEE Transactions on Power Apparatus and Systems, vol. PAS-89, no. 1, pp. 88-97, 1970.
[7] C. Christopoulos, "*The Transmission-Line Modeling Method*", IEEE Press, Piscataway, NJ, 1995.
[8] A. Maffucci, G. Miano, F. Villone, "*An Enhanced Transmission Line Model for Conductors with Arbitrary Cross Sections*", IEEE Transaction on Advanced Packaging, vol. 28, no. 2, pp. 174-188, May 2005