A PSPICE MODEL FOR T MATCHING CIRCUITS

Ioana SĂRĂCUT   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.

\[
X_a = \pm R_g \sqrt{K_T^2 - 1} - X_c
\]
\[
X_b = \pm R_s \sqrt{K_T^2 - 1} - X_c
\]
\[
X_c = K_T \sqrt{R_g R_s}
\]

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 \( \varphi \) introduced by a T matching circuit is related to the coupling factor by the relation:

\[
K_T = \frac{1}{\sin \varphi}
\]

In this paper we will present how we simplified the calculation of the three reactances and thus they will no longer depend on \( R_g \), but only on \( R_s, K_T \) and \( \varphi \). 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
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 signs, then the phase difference in modulus is greater 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 \( \phi \):

\[
X_a = \frac{R_g \cos \phi - \sqrt{R_g R_s}}{\sin \phi} \quad X_b = \frac{R_g \cos \phi - \sqrt{R_g R_s}}{\sin \phi} \quad X_c = \frac{\sqrt{R_g R_s}}{\sin \phi}
\]

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

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 (\( X_a, X_b, X_c \)) 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: \( \text{GAIN} \_a = X_a \), \( \text{GAIN} \_b = X_b \) and \( \text{GAIN} \_c = \sin \phi \) respectively, with \( X_a, X_b \) given by (3). The switches have the “on” resistance of \( 1\mu\Omega \) and the “off” resistance of \( 1\Omega \).

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.

III. SIMULATION RESULTS

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

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 \( 32 \times 9.375 \) m = \( 300 \) m, i.e. equals exactly one wavelength.

Hence the total delay will be exactly one period of the input signal (\( 1\mu\text{s} \)).
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.

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:

\[ U_i = U_t - U_d \]  
\[ U_d = \frac{E}{2} \]  

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 \( R_c \). 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).

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 than 90º, the bandwidth is narrower.

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