A Novel Approach for Broadband Antenna Matching Network Design

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ABSTRACT

In this paper, a novel method for interstage matching network design in the smith chart is presented. This technique is based on matching the reflection coefficients between input of interstage matching network and S22 of the first transistor with considering input VSWR and the gain of the complete amplifier (or output of the complete amplifier if the matching is applied to the output of the interstage matching network). Also, the novel locus of constant gain and VSWR of interstage matching network are presented in the smith chart.

Keywords: Broadband antenna, Antenna matching, Matched network.

I. INTRODUCTION

In any system that uses RF circuits, a matching network is necessary to transfer the maximum amount of power between a source and a load. In most systems, such as wireless devices, there is a bandwidth of operation specified. As a result the purpose of the matching network is to provide maximum power transfer over a range of frequencies. While the L section matching approach (conjugate match), guarantees maximum power transfer, it does so only at a single frequency.

II. BROADBAND MATCHING DESIGN

The theoretical limitation of available bandwidth for a given reflection coefficient was analyzed by Fano [4]. In this theory, a minimum reflection increases as the system requires wider bandwidth (Figure 2). Since a Q-factor relates the ratio of load reactance and resistance, this theory also demonstrates that Q-Bandwidth product remains constant if same reflection coefficient is assumed.

Table 1: Comparison of Matching Solution

<table>
<thead>
<tr>
<th>Number of Tuned Circuit (n)</th>
<th>Percent Bandwidth Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (=2 lumped elements)</td>
<td>100 (from n = 1)</td>
</tr>
<tr>
<td>2</td>
<td>20 (from n = 2)</td>
</tr>
<tr>
<td>3</td>
<td>9 (from n = 3)</td>
</tr>
<tr>
<td>4</td>
<td></td>
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</tbody>
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This concept can be understood by following the graphical method using Smith Chart [6]. Ellipse 1 in Figure 3 represents a constant Q trajectory. A simple design is one L-C matching that uses one series inductor and one shunt capacitor to match the load to a reference resistance such as 50 Ohm. Ellipse 2 in Figure 3 however, utilizes a 3 L-C section matching, and a smaller Q path, which is translated to a wider bandwidth.

Figure 3: Impedance Path on Smith Chart (1) n = 1, (2) n = 3

2.1 Smith Chart

The Smith chart, invented by Phillip H. Smith (1905–1987),[7][8] is a graphical aid or nomogram designed for electrical and electronics engineers specializing in radio frequency (RF) engineering to assist in solving problems with transmission lines and matching circuits.[9] Use of the Smith chart utility has grown steadily over the years and it is still widely used today, not only as a problem solving aid, but as a graphical demonstrator of how many RF parameters behave at one or more frequencies, an alternative to using tabular information.

Figure 4: Most basic use of an impedance Smith chart. A wave travels down a transmission line of characteristic impedance Z0, terminated at a load with impedance ZL and normalised impedance z = ZL/Z0. There is a signal reflection with coefficient Γ. Each point on the Smith chart simultaneously represents both a value of z (bottom left), and the corresponding value of Γ (bottom right), related by z = (1 + Γ)/(1 – Γ)

The Smith chart can be used to simultaneously display multiple parameters including impedances, admittances, reflection coefficients, scattering parameters, noise figure circles, constant gain contours and regions for unconditional stability, including mechanical vibrations analysis.[10] [11] The Smith chart is most frequently used at or within the unityradius region. However, the remainder is still mathematically relevant, being used, for example, in oscillator design and stability analysis.[12]

As impedances and admittances change with frequency, problems using the Smith chart can only be solved manually using one frequency at a time, the result being represented by a point. This is often adequate for narrow band applications (typically up to about 5% to 10% bandwidth) but for wider bandwidths it is usually necessary to apply Smith chart techniques at more than one frequency across the operating frequency band. Provided the frequencies are sufficiently close, the resulting Smith chart points may be joined by straight lines to create a locus.

A locus of points on a Smith chart covering a range of frequencies can be used to visually represent:

- How capacitive or how inductive a load is across the frequency range.
- How difficult matching is likely to be at various frequencies.
- How well matched a particular component is.

The accuracy of the Smith chart is reduced for problems involving a large locus of impedances or admittances, although the scaling can be magnified for individual areas to accommodate these.

2.2 Specify Frequency and Impedance

We are first building a matching network with a bandpass response, so specify the center frequency and the bandwidth of match.

Centre frequency(fc) = 400 \times 10^6 Hz

Bandwidth of matching network(Hz) = 120 \times 10^6 Hz

Here we specify the source impedance, the reference impedance and the load impedance. The load Zl is modeled as a series R-L circuit. We could instead measure the impedance of the load and use that directly.

Source impedance (ohm) (Zs) = 50;

Reference impedance (ohm) (Z_0) = 50;

Load resistance (ohm) (RL) = 40

Load inductance (Henry) L = 12 \times 10^{-8}

Now we use smith chart to shows the variation in the load reflection coefficient with frequency. Input reflection coefficient closer to centre of the Smith chart means a better matching performance. This plot shows that the load reflection coefficient is far away from this point and so, there is an impedance mismatch.
Figure 5: Smith Chart of Source When No Matching Network

We can confirm this mismatch by plotting the transducer gain as a function of frequency.

As the plot shows, there is approximately 10 dB power loss around the desired region of operation (340 – 460 MHz). As a result, the antenna needs a matching network that operates over a 120 MHz bandwidth that is centered at 400 MHz.

2.3 Design the Matching Network

The matching network must operate between 340 MHz and 460 MHz, so you choose a bandpass topology for the matching network which is shown in Figure 7.

Figure 7: Matching Network (Band pass topology)

The approach you take here is to design an odd order, 0.5 dB Chebyshev low pass (LP) prototype and then apply a lowpass to bandpass transformation to obtain the initial design for the matching network [1]. Figure 7 shows the resulting matching network topology. You now need to enter the order desired and the associated coefficients. This is a single match problem [3], i.e. the source is purely resistive while load is a combination of R and L, so we can begin by choosing a five element prototype network.

The topology demands an LP prototype that begins with a series inductor. If the topology chosen is an LC bandpass pi then you would begin with shunt C for the LP prototype.

2.4 Optimize the Designed Matching Network

We are now optimizing the matched network components (i.e. value of inductor and capacitor) so that the value of reflection coefficient should be minimum and near to the centre of smith chart.

Figure 8: Smith Chart for Optimizing Reflection Coefficient

2.5 Update the Matching Network Elements with Optimal Values

Once we get the optimum values of inductor we can update these values for designing the matchnetwork in MATLAB we can use different method for optimizing and updating these values.

2.6 Analyse and Display Optimization Results

Use the analyze method in MATLAB to perform frequency domain analysis on the circuit under two scenarios:

- With the optimized matching network.
- Without a matching network.

Figure 9: Smith Chart Comparing Values of Reflection Coefficient without Matching Network and with Matching Network
The optimized matching network improves the performance of the circuit. In the passband (340 MHz to 460 MHz), the input reflection coefficient is closer to the centre of the Smith chart.

Plot the power delivered to load, with the matching network, using the plot method of the rfckt object of MATLAB.

**Figure 10:** Power Delivered To Load (Matching Network vs. No Matching Network).

### III. CONCLUSION

The matching plays a vital role in the wide-band performance of compact antenna systems. Moreover, different matching networks affect the bandwidths of antenna correlation and matching efficiency in different ways. In this paper, we are comparing the power level and reflection coefficients of the transmitting signal with and without applying matching network, the comparison is shown in Figure 9 and Figure 10.

### REFERENCES


