ANTENNA MATCHING BY GRAPHIC METHOD

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Introduction

I will present a simple way of antennas matching by graphic method.

For efficient transmission of RF energy from transmitter to the antenna, it is needed to do the matching between the antenna and transmitter in a way that minimize power reflection. Matching is done by solenoids and capacitors, in other words with appropriate inductance and capacity for example: using coaxial cables stubs. Output stage of transmitter usually has 50 ohms same as coaxial cable, but antenna mainly has a different and complex impedance **Z** with active part **R** and reactive part **jX**.

Matrix of graphic method is rectangular coordinate system where y-axis represents reactive component of impedance **jX** and x-axis represents active component of impedance **R**.

This graphic method determines elements of network matching between two impedances. The main advantage of this method is that everything is presented linear and directly to enable us much easier work.

In this way we follow impedance flow from coaxial cable to antenna and we can adopt it by **L, C** elements that we have, or make a new configuration **L**, **T** or **Π** that suits as the best.

Here I will show the example of matching one value of antenna impedance with **L**, **T** and **Π** network only to demonstrate the principles. In practice that choice depends of what do we want antenna to be, for example galvanic grounded or we prefer low-pass network because of higher harmonics. We have to take into account sizing of L and C elements considering voltage sag that will occur and the current that will flow through them depending on power that will be transferred through the network. Sometimes we also have to take into account phase shift, caused by our matching ex. at the phasing of two or more antennas.

Terminology Glossary

First we will define following terms:

$Z = R \pm jX$ – complex impedance

$\bar{Z} = R \mp jX$ – conjugated complex impedance, which differs only in algebraic sign of reactive part **Z**

R -resistance

+jX - inductive reactance

-jX - capacity reactance

$$X_L = 2\pi f L \qquad L = \frac{X_L}{2\pi f}$$

$$X_C = \frac{1}{2\pi f C} \qquad C = \frac{1}{2\pi f X_C}$$

On the diagram, impedance value moving vertically upward determines **serial adding of inductive reactance +jX,** while moving downwards determines **serial adding of capacity reactance -jX.**

Impedance circle is designed by drawing a line through point which represents value of impedance and also represents / through the central point - **origin (0, 0)** of coordinate system R-X. Than we must found the centerline of that line and the point where centerline cuts R axis is the center of impedance circle.

Impedance circle must always go through point that represents value of impedance and through the central point - **origin (0, 0)** of coordinate system R-X.

Moving on impedance circle is determined by **parallel adding of inductive or capacity reactance** depending on which point of the reactive **axis jX** curve or function crosses the line and make an intercept.

We trace a line through conjugated impedance value and through new value of impedance that we are trying to achieve and that intercept on **jX axis** represents the value of parallel added reactance **Xp** that is needed for the targeted value of impedance.

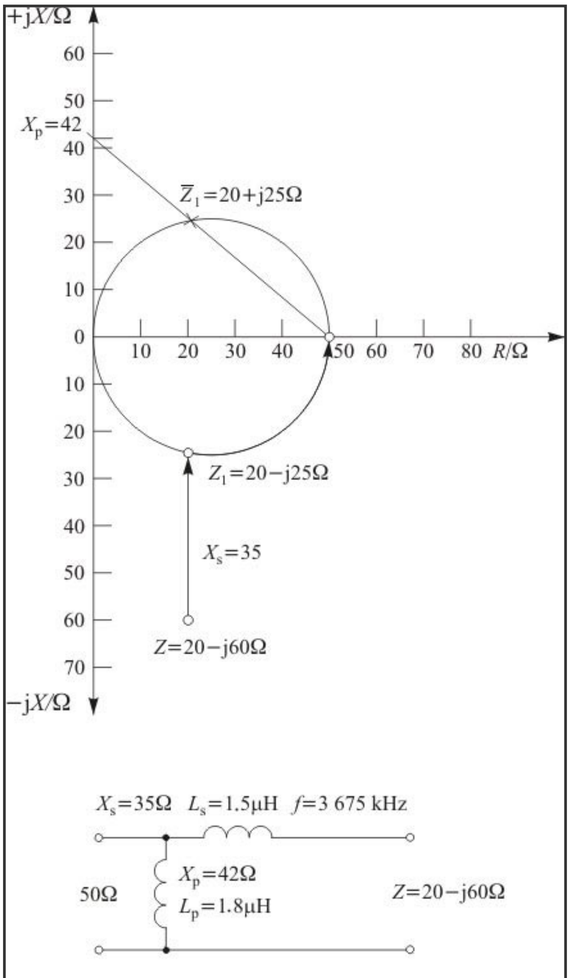
Calculation of antenna matching

L –matching network

On the figure 1 is shown example of matching vertical antenna to 50 Ohm's cable.

As shown on **figure 1**, we will adapt the antenna with the L-network and two inductances so called Inducti Match. In this way antenna is grounded and capacitors usage is avoided and antenna matching is simply done by solenoid.

We will assume that input impedance is **Z=20-j60 Ω** with frequency of **3675 kHz** (this numbers we can get by measuring with impedance meter ex. MFJ-259B or by calculations with antenna modeling programs as MMANA, NEC or we can get it from diagram).



L-matching network

Fig.1

First we construct circle with impedance of 50 Ohms (that is impedance of coaxial cable) and match the antenna to that value. From the picture we can see that we have to add, upward, in to the series inductive reactance **Xs** to come/make a **circle** with impedance of 50 Ohms (value Xs we read from X-axis). New value of impedance is **Z_1=20-j25 Ω.** Now we mark conjugated complex impedance **$\overline{Z}_1$=20+j25 Ω** on the circle and draw a line through **$\overline{Z}_1$** and **50 Ω** impedance that we are trying to achieve. Obtained intercept on X-axis represents the value of parallel added inductive reactance **+jXp**.

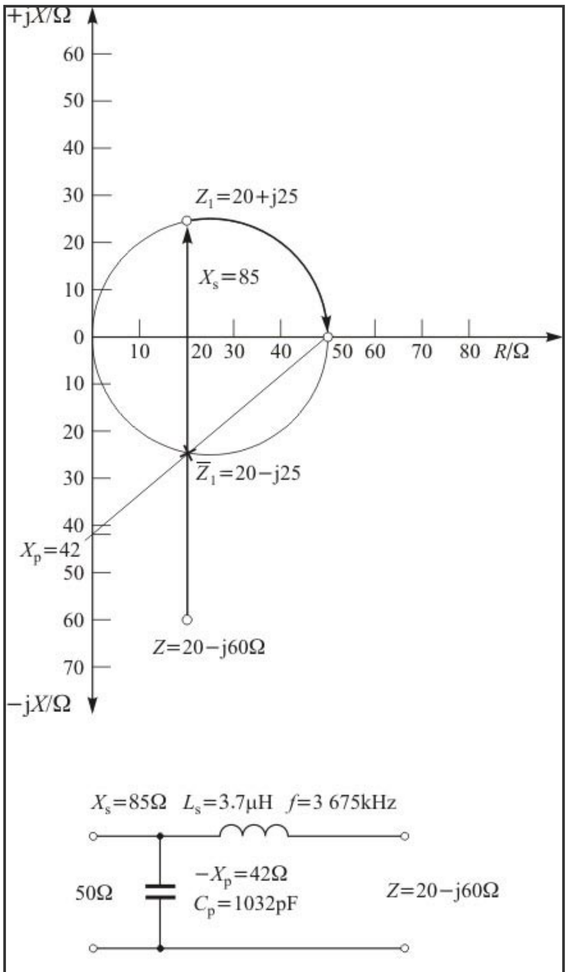
Therewith antenna matching is done.

Values of needed inductances can now be calculated from obtained inductive reactance **+jXs=35 Ω** and +**jXp =42 Ω.**

$$L_{ps} = \frac{X_{ps}}{2\pi f}$$

$$L_s = \frac{35}{2\pi \; 3.675 \; 10^6} = 1.52\mu H$$

$$L_p = \frac{42}{2\pi \; 3.675 \; 10^6} = 1.8\mu H$$



L-matching network

Fig.2

L-matching network can be also created with combination of inductance and capacity as shown on **figure 2 .**

Again, starting point is **circle with impedance of 50 Ohms** and antenna impedance **Z.** We add in series inductive reactance **Xs** and move to new impedance value **Z_1**. Than by parallel adding of capacity reactance **–Xp** we move on the circle with impedance of 50 Ohms until point, with **50 Ohms** value. The value of **–Xp** we define on **–X axis** by drawing a line through $\overline{Z}_1$ and **50Ω** impedance that we are trying to achieve.

Therewith antenna matching is done.

From obtained values **-Xp=42 Ω** and **Xs=85 Ω** we can now calculate needed capacity and inductance.

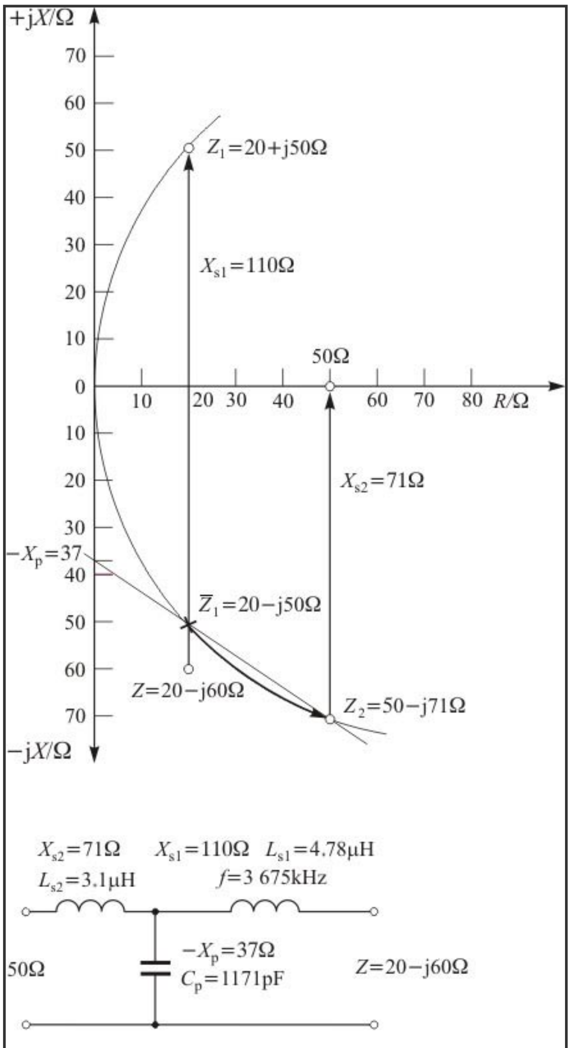
$$C_p = \frac{1}{2\pi\, f\, X_p} = \frac{1}{2\pi\, 3.675\, 10^6\, 42} = 1032\text{pF}$$

$$L_s = \frac{85}{2\pi\ \ 3.675\ 10^6} = 3.7\mu\text{H}$$

T-matching network

Let's show antenna matching with **T-network** with parallel added capacity as shown on **figure 3 .**

We add in series inductive reactance **Xs** and move to new impedance value $\mathbf{Z_1}$ on circle with impedance $\mathbf{Z_1}$. Then we mark conjugated complex impedance $\overline{\mathbf{Z}}_1$ on the circle and draw a line through $\overline{\mathbf{Z}}_1$ and new $\mathbf{Z_2}$ impedance. Obtained intercept on **–X axis** determines the value of parallel added capacity reactance **Xp**. As we choose impedance $\mathbf{Z_2}$ with active reactance of **50 Ω**, it is only left to add in series inductive reactance **Xs** and antenna matching is done.



T-matching network

Fig.3

From obtained values **Xs1=110 Ω, Xs2=71 Ω** and **-Xp=37 Ω** we can now calculate values of needed capacity and inductance.

$$L_{s1} = \frac{110}{2\pi\ \ 3.675\ 10^6} = 4.78\mu\text{H}$$

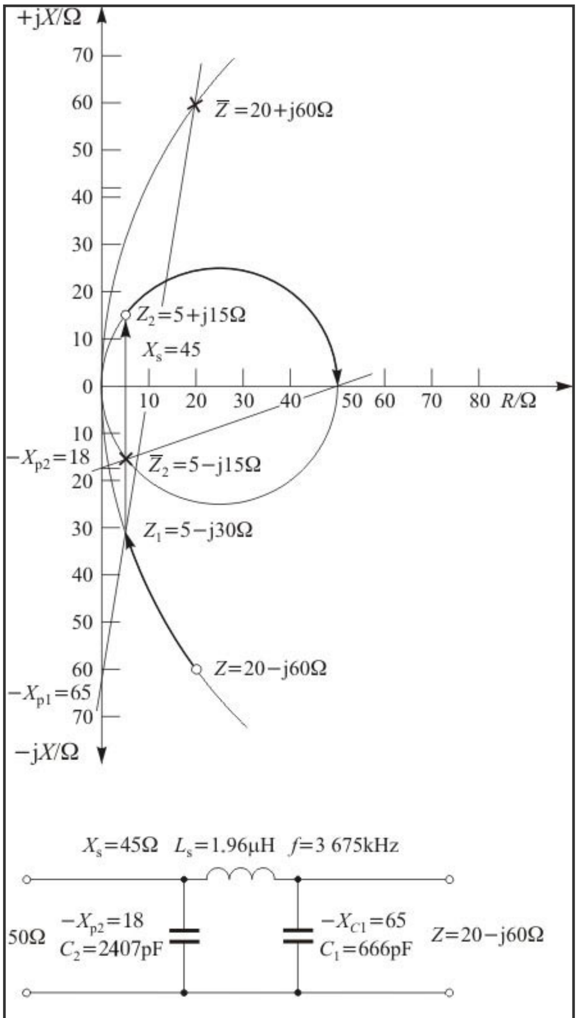
$$C_p = \frac{1}{2\pi\ \ 3.675\ 10^6\ 37} = 1171\text{pF}$$

$$L_{s\,2} = \frac{71}{2\pi\ \ 3.675\ 10^6} = 3.1\mu\text{H}$$

Π -matching network

Figure 4. show the same impedance matching but with **Π-network.**

Again, starting point is **circle with impedance of 50 Ohms** and **circle with impedance Z.** We move to the new impedance value $\mathbf{Z_1}$, then draw a line through conjugated complex impedance



Π-matching network

Fig.4

$\overline{Z}_1$ and Z_1 impedance that we are trying to achieve. Obtained intercept on **–X axis** determines the value of parallel added capacity reactance -**Xp1**. From point Z_1 we move upwards to point Z_2 and that represents serial added inductive reactance **Xs**.

From new impedance value Z_2 on circle, with impedance of 50, we draw a line through conjugated complex impedance $\overline{Z}_2$ and **50Ω** impedance and obtained intercept on **–X axis** determines the value of parallel added capacity reactance -**Xp2** so antenna matching is done.

From obtained values **-Xp1=65 Ω, Xs=45 Ω** and **-Xp2=18 Ω** we can now calculate values of needed capacity and inductance.

$$C_{p1} = \frac{1}{2\pi\ 3.675\ 10^6\ 65} = 666\text{pF}$$

$$L_s = \frac{45}{2\pi\ 3.675\ 10^6} = 1.96\mu\text{H}$$

$$C_{p2} = \frac{1}{2\pi\ 3.675\ 10^6\ 18} = 2407\text{pF}$$

If value of one of impedances is too big, for example Z=500 + j 600 Ω, in the first step we choose the proportions of values on axes R-X, in the way they can fit to the paper and after that we pass to more detailed ratio. Also if reactive part of impedance is too big, but we do not want to change the ratio, we can compensate it with serial added reactive reactance, with opposite sign, and then draw that new value of impedance and do the matching forward as described. For drawing we can use the mill-metric scaled paper.

The results of L, C elements calculations shown here are the decimal numbers with two decimals without rounding off, so that we can see the calculation method.

From these examples is obvious that we can follow the matching course and adjust it according to L, C elements that we have available. Where appropriate, we can also choose the network profile.

We can see how much and in which direction certain elements affect matching and what elements we can choose as fixed and what as variable ones.

This will help for easier understanding different schemes of antenna matching, antenna tuners, input or output circuits for linear amplifier matching and similar.

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