BNL-99258-2013-TECH

C-A/AP/106;BNL-99258-2013-IR

Computer Aided Design of Stub Tuners for Impedance Matching

S. Zheng

September 2003

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

DISCLAIMER

C-A/AP/#106
September 2003

Computer Aided Design of Stub Tuners For Impedance Matching

S. Zheng, and J. M. Brennan

Collider-Accelerator Department
Brookhaven National Laboratory
Upton, NY 11973

Computer Aided Design of Stub Tuners
For Impedance Matching

S. Zheng and J. M. Brennan

I Introduction

In RF and microwave circuit design, a common situation is to match a load with arbitrary impedance Z_L to an input circuit with a different impedance Z_S. Several techniques for this impedance matching are available. Among them, quarter wavelength transmission line with characteristic impedance given by $Z_0 = \sqrt{Z_L Z_S}$ is well known. This method, however, is difficult to implement in high power applications since Z_0 obtained from the impedance equation is usually a non-standard value.

Another matching technique, namely stub tuner [1], can be used to solve the problem. This method uses two pieces of transmission lines, thus the impedance of the matching transmission lines can be arbitrarily chosen and commercially available cables are usually used to form the matching network. This stub tuner was proposed to replace the old quarter wavelength matching cable in the RHIC 28 MHz accelerating PA input circuits. The design of the stub tuner using MATLAB is given in this note.

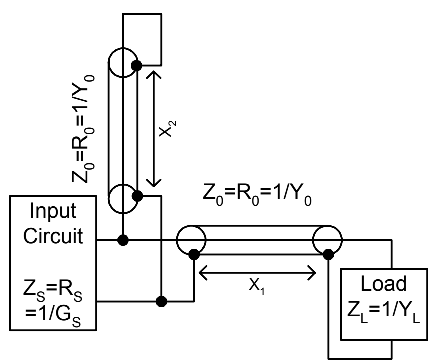

Fig. 1 A stub matching network.

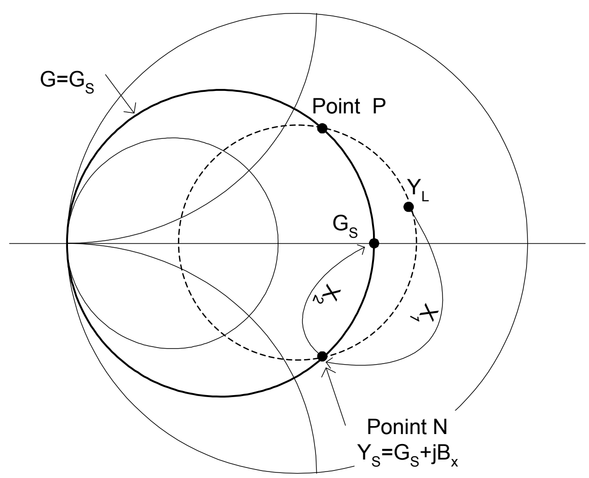

Fig. 2 Smith chart explanation of the stub tuner.

II Stub length calculation

A stub tuner is shown in Fig. 1, where X_1 and X_2 are the normalized length of the matching cables, and the shunt-connected transmission line is shorted at one end. The input circuit is assumed to be a lossless transmission line with a characteristic impedance R_S or a circuit with a pure resistive output impedance R_S.

The basic idea of the stub tuner is to transform the load admittance Y_L (normalized to Y_0) to a point $Y_x = G_S + jB_x$ on the admittance circle $G=G_S$ of the smith chart using cable

X_1, and then compensate the susceptance part B_x by the shorted stub X_2 to obtain a match to the input admittance G_S, as shown in Fig. 2.

Without consideration of the shorted stub, the admittance looking from the source end of X_1 is (Assume lossless matching cable):

$$Y_x = \frac{Y_L + j\tan(2\pi X_1)}{1 + jY_L\tan(2\pi X_1)}. \tag{1}$$

Let $Y_x = G_S + jB_x$ and $Y_L = G_L + jB_L$. Solving $\tan(2\pi X_1)$ from the above equation one gets:

$$\begin{aligned}\tan(2\pi X_1) = &\frac{(G_S - G_L)(B_L G_S + G_L B_x) - (B_x - B_L)(G_L G_S - B_L B_x - 1)}{(G_L G_S - B_L B_x - 1)^2 + (B_L G_S + G_L B_x)^2} \\ &+ j\frac{(G_S - G_L)(G_L G_S - B_L B_x - 1) + (B_x - B_L)(B_L G_S + G_L B_x)}{(G_L G_S - B_L B_x - 1)^2 + (B_L G_S + G_L B_x)^2}\end{aligned} \tag{2}$$

Since $\tan(2\pi X_1)$ can not be complex, the imaginary part of the above equation must be zero, and thus B_x is solved:

$$B_x = \pm\sqrt{\left(\frac{B_L{}^2}{G_L} + G_L + \frac{1}{G_L} - G_S\right)G_S - 1}. \tag{3}$$

A match can be obtained as long as B_x's are real. Here B_x has two values. The positive one is indicated by point P in Fig. 2. It is an inductive point and needs a capacitive shorted stub (longer than a quarter wave length) to compensate it to G_S. The negative point (point N in Fig.2) is a capacitive point and needs an inductive stub (shorter than quarter wavelength) for compensation. However, if the initial point Y_L is inside the $G=G_S$ circle, the total length of the two pieces of cables with a capacitive stub may be shorter than that with an inductive stub.

Normalized length X_1 is obtained from the real part of (2):

$$X_1 = \frac{1}{2\pi}\tan^{-1}\left(\frac{(G_S - G_L)(B_L G_S + G_L B_x) - (B_x - B_L)(G_L G_S - B_L B_x - 1)}{(G_L G_S - B_L B_x - 1)^2 + (B_L G_S + G_L B_x)^2}\right). \tag{4}$$

The shunt-connected matching cable has an admittance of

$$Y_y = \frac{1}{j\tan(2\pi X_2)}. \tag{5}$$

Since it is used to compensate B_x obtained above, let it equal to $-jB_x$. Thus X_2 is obtained:

$$X_2 = \frac{1}{2\pi}\tan^{-1}\left(\frac{1}{B_x}\right). \tag{6}$$

For convenience, the normalized cable length of X_1 and X_2 can be converted to time delay TD:

$$TD = \frac{X}{f}. \tag{7}$$

Where X is the normalized length and *f* is the frequency.

III MATLAB implementation and test result

MATLAB code has been written to perform the above calculations. It takes the load impedance Z_L, the impedance of the input circuit R_S, and the matching cable impedance R_0 as the inputs, and gives the results for both inductive stub and capacitive stub. The code is given in Appendix I. A plot showing matching cable lengths vs. load resistance for the case of 28 MHz PA is given in Fig.3.

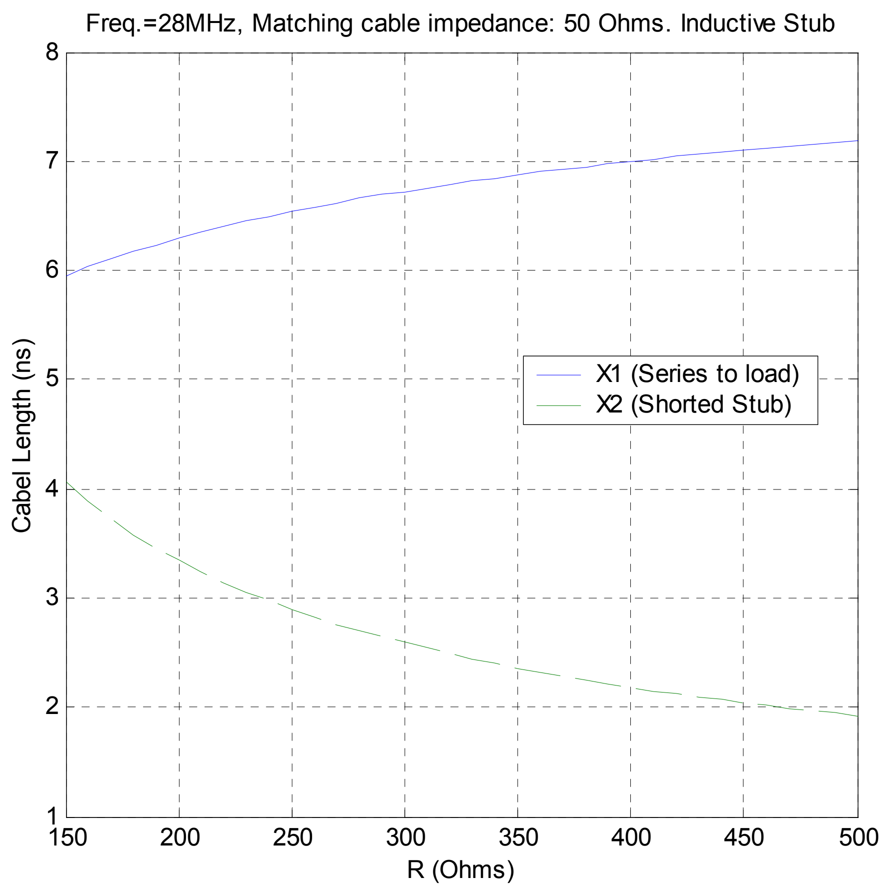

Fig. 3 Designing curves for the 28 MHz PA stub generated by MATLAB.

A stub tuner is made for a 28 MHz PA. The input resistance of the PA is about 300 Ω. From Fig. 3, the lengths of the stub cables are: X_1=6.7 ns, X_2=2.6 ns. The matched input impedance measured by Network Analyzer is shown in Fig. 4.

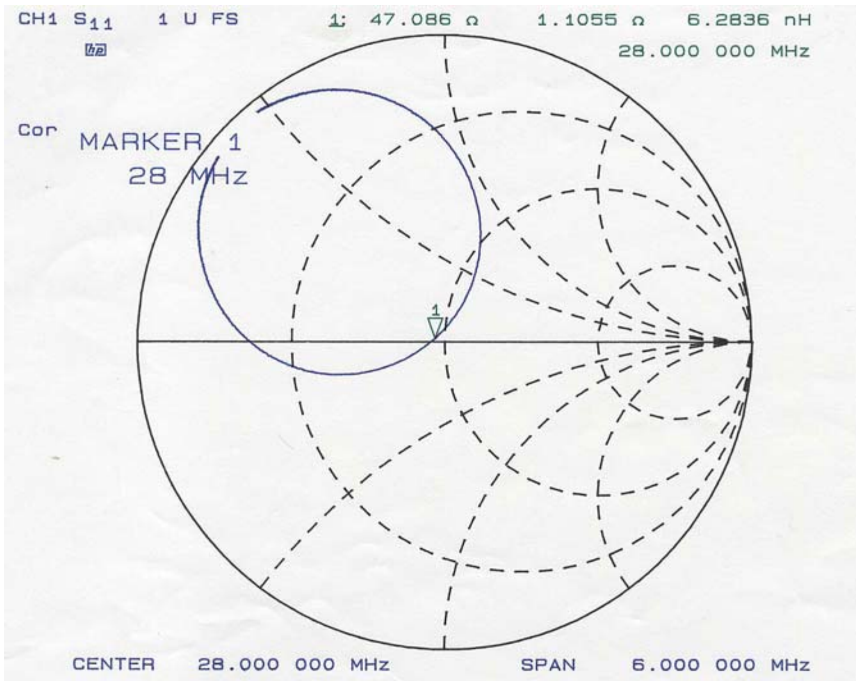

Fig.4 The 28 MHz PA input impedance looking from the stub tuner.

V Summary

A method of designing stub tuner is present. A MATLAB program is written to perform the calculation. The design has been verified by its application in the 28 MHz PA.

VI Reference

[1]John D. Kraus, "Electromagnetics," Third edition, McGraw-Hill Book Company, 1984.

Appendix MATLAB Program

```
function y=stub(zl,ri,r0)
%
%This program caculates the lengthes of the two cables in shorted-stub impedance matching.
%Lossless cables are assumed for the matching network.
%
%To call the function, 3 Arguments are to be specified:
```

```
%
%   zl  : Load impedance. If it's a complex number, using the form of "R+j*X";
%   ri  : The impedance of the input cable;
%   r0  : The impedance of the matching cables. This parameter can be omitted if it is the
%         same as that of the input cable.
%
%The output is the cable lengthes (in Wavelength) in a 2*2 matrix. The first row of the
%matrix shows the cable lengthes with a inductive stub (less than quater-wavelength long).
%The second row gives the lengthes with a capacitive stub. It has the following form:
%
%          X1_ind  X2_ind
%          X1_cap  X2_cap
%
%where X1 is the length of the cable series-connected from the load to the stub,
%X2 is the length of the stub. Choice between these two solutions can be made
%by picking up the one with the shoter total cable length or the one with a shoter stub length.
%
%Example:
%Suppose a load of 200 Ohms needs to be matched to an input impedance of 50 Ohms and
%the matching cables are 50 Ohms:
%
%   >> stub(200,50,50)
%
%   ans =
%
%       0.1762    0.0936
%       0.3238    0.4064


%Check the inputs.
if (nargin < 2)
   disp('***At least two arguments-load impedance (Ohms), and input cable impedance (Ohms)-are required !');
   return;
elseif (nargin == 2)
   disp('***The impedance of the matching cables are assumed to be equal to that of the input cable !');
   r0=ri;
end

if zl==ri
   disp('***The load impedance already matches the input impedance !');
   return;
end

%Constant caculations and transformation from impedances to admittances.
Yl=r0/zl;
Gl=real(Yl);
Bl=imag(Yl);
Gx=r0/ri;

%Caculation of the suceptance that needs to be compensated by the stub.
Bx_Sq=(Bl^2/Gl+Gl+1/Gl)*Gx-Gx^2-1;
if Bx_Sq<0
   disp('***No possible match can be found !');
   return;
```

```
end

%Inductive stub:
Bx=Bx_Sq^0.5;
TAN_BTX1=(Bx*(1-Gl^2-Bl^2)+Bl*(Bx^2+Gx^2-1))/((Gl*Gx-Bx*Bl-1)^2+(Bl*Gx+Bx*Gl)^2);
BTX1=atan(TAN_BTX1);
if BTX1<0
   BTX1=pi+BTX1;
end
X1=BTX1/(2*pi);

BTX2=atan(1/Bx);
X2=BTX2/(2*pi);
y_ind=[X1,X2];

%Capacitive stub:
Bx=-Bx_Sq^0.5;
TAN_BTX1=(Bx*(1-Gl^2-Bl^2)+Bl*(Bx^2+Gx^2-1))/((Gl*Gx-Bx*Bl-1)^2+(Bl*Gx+Bx*Gl)^2);
BTX1=atan(TAN_BTX1);
if BTX1<0
   BTX1=pi+BTX1;
end
X1=BTX1/(2*pi);

BTX2=pi+atan(1/Bx);
X2=BTX2/(2*pi);
y_cap=[X1,X2];

%Result matrix:
y=[y_ind;y_cap];

return;
```