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SINGLE & DOUBLE STUB MATCHING TECHNIQUES

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Abstract: The purpose of this paper is to make a comparative study on bandwidth enhancement techniques of impedance matching networks that help to overcome the bandwidth constraint of transmission line. Impedance matching between transmission lines and antennas is an important and fundamental concept in microwave theory. As it achieve maximum power transfer. It is frequently performed with Smith charts. In many cases, loads and termination for transmission lines in practical will not have impedance equal to the characteristic impedance of the transmission line. This result in high reflections of wave transverse in the transmission line and correspondingly a high VSWR due to standing wave formations, so to overcome this, is to introduce an arrangement of transmission line with matching network.
Keywords: Smith chart, stub tuner, impedance matching, reflection coefficient, bandwidth

I. Introduction

In this paper, we will try to focus on narrowband single stub and double stub matching .We will use Smith Chart tool for solving impedance matching problems. The matching procedure is also referred to as "tuning".

Practical reasons will be discussed in paper, make it more convenient in many transmission line problems to work in admittance terms. [3] Thus when we design a stub, we are seeking to find the stub length which will provide a particular susceptance. We can obtain any desired susceptance by using either a short circuit or open circuit stub of suitable length. Again, practical reasons suggest variable stubs should be short circuited.

1) Why Impedance Match?

>Maximum power is delivered and power loss is minimum.
>To improve signal to noise ratio as in sensitive receiver components such as LNA, antenna, etc.
>Impedance matching in a power distribution network will reduce amplitude and phase errors.

2) Single and Double Stub Tuners

>A simple form of variable impedance matching device is the single stub tuner. It consists of a transmission line with a stub of short or open circuit that can be used as the reactive element in the impedance matching method.
>A double stub tuner provides variable distance from the load, and is widely used in laboratory practice as a single frequency matching device. In actual design practice, it is replaced by more compact and broadband approaches.

3) How long?

Make stub as short as possible for wider bandwidths, preferably less than $\lambda/2$. But if the stub is too short for precise cutting, a bit over $\lambda/2$ is acceptable. Stub length will decides the bandwidth

4) Series or shunt?

Physical construction usually dictates the choice. For balanced feeders like twin ribbon cables, series insertion is easy to make. But for coax, series is difficult.

5) Open or short stub?

If there is a choice, choose the one that makes the stub length shortest, preferably less than $\lambda/4$ if possible. For micro strips, open stubs are easier to make. For coax, short stubs are less radiating from ends.

6) Basic Idea

The matching network is ideally lossless and is placed between a load and a transmission line, as shown in figure1 to avoid unnecessary loss of power, and is usually designed so that the impedance seen looking into the matching network is Z_0.

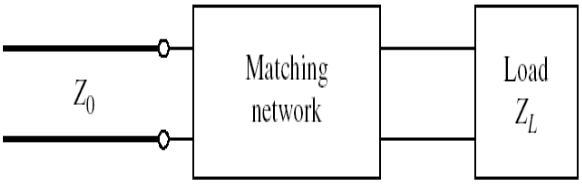

Figure 1 matching network[2]

II. Literature view

For lossless transmission lines:

$$\frac{Z_L}{Z_0} = \frac{Z_L \cosh|\gamma l| + Z_0 \sinh|\gamma l|}{Z_0 \cosh|\gamma l| + Z_L \sinh|\gamma l|}$$

A line is terminated in its characteristic impedance which is complex for an arbitrary lossy line that is if $Z_L = Z_0$, then above equation shows that $Z_L = Z_0$ for any value of l .That is the input impedance becomes independent of line length. This is an important practical property, and the line is said to be matched.

Stubs

In coaxial cable or two-wire line applications, the stubs are obtained by cutting appropriate lengths of the main line. Shorted stubs are usually preferred because opened stubs may radiate from their opened ends. However, in microwave integrated circuits employing micro strip lines, radiation is not as a major concern because of their smaller size, and either opened or shorted stubs may be used. The single stub tuner is perhaps the most widely used matching circuit and can match any load. However, it is sometimes inconvenient to connect to the main line if different loads are to be matched. In such cases, double stubs may be used, but they cannot match all loads. Triple stubs can match any load. [4]

Characteristic impedance Zo:

It is ratio of the voltage to current of the forward travelling wave, assuming no backward wave. It is real but lossless impedance. $Zo = \sqrt{(L/C)}$, where L is inductance per unit length and C is capacitance per unit length. [1]

Voltage standing wave ratio (VSWR):

It is the ratio of the maximum voltage amplitude to the minimum voltage amplitude which is at λ/4 from the maximum point. VSWR is given by [1]

$$\text{VSWR} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

III. Main finding

A. Smith chart approach

- The Smith Chart is a clever tool for analyzing transmission lines
- The outside of the chart shows location on the line in wavelengths
- The combination of intersecting circles inside the chart allow us to locate the normalized impedance and then to find the impedance anywhere on the line
- The first step in analyzing a transmission line is to locate the normalized load impedance on the chart

- Next, a circle is drawn that represents the reflection coefficient or SWR. The center of the circle is the center of the chart. The circle passes through the normalized load impedance
- Any point on the line is found on this circle. Rotate clockwise to move toward the generator (away from the load)
- The distance moved on the line is indicated on the outside of the chart in wavelengths
- Also note that exactly opposite to the normalized load is its admittance. Thus, the chart can also be used to find the admittance. We use this fact in stub matching[6]

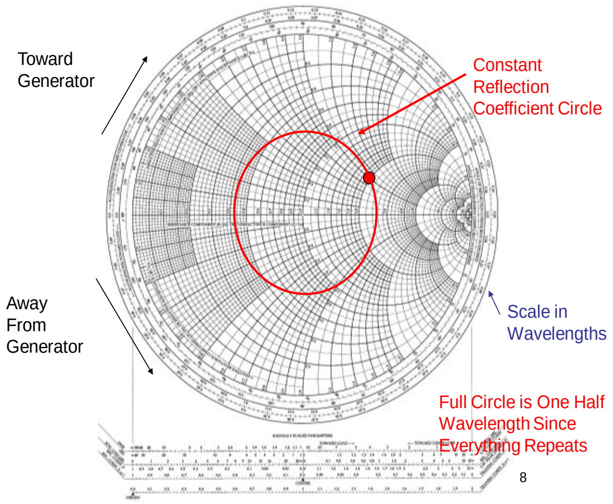

Figure 2 Smith chart evaluation [10]

B. Stub matching

Two complex networks can be conjugate matched for maximum power transfer by inserting single/multiple stubs in series or shunt configuration. In each case, we extend the transmission line to match the real part of Z_L to line while reactive stubs are used to cancel out the imaginary part of Z_L[4] .It is used to overcome the drawback of LC matching network ,which is cannot operated above 1GHz.

C. Design Considerations of Matching Network

Factors used for selecting a matching network.

• **Complexity:** A simpler impedance transformation network is usually cheaper, more reliable, and less lossy than a more complex design.

• **Bandwidth:** Typical matching network gives match only for narrow band of frequencies. For a larger bandwidth complexity is increases, for which instance multi-section transformers are used

• **Implementation:** Shunt stubs are easier to implement than series stubs.

• **Adjustability:** Some applications may require adjustments e.g. we cannot attach a short shunt very close to antenna as it may disturb the radiation pattern of the antenna besides problems to accommodate. [2]

D. Single stub matching

The single stub tuner use as matching network attached to the transmission line at a particular location. It can be shorted or open circuit section. Why an open or shorted section? Because these are easy to fabricate, the length can easily be made adjustable and little to no power is dissipated in the stub. Two adjustable parameters are the distance d and the value of susceptance or reactance provided by the shunt or series stub.

There are two design parameters for single stub matching:

- The location of the stub with reference to the load d stub
- The length of the stub line l stub[4]

Advantage:

- Easy fabrication in micro strip or strip line form, where open-circuit stub is preferable. While short-circuit stub is preferable for coax or waveguide.
- Lumped elements are not required
- Two adjustable parameters are the distance *d* and the value of susceptance or reactance provided by the shunt or series stub.

Disadvantage:

- An open circuit single stub is difficult to realize.
- single stub tuner is that it must be placed at the proper distance from the load, which is a variable that is difficult to adjust in practice

Circuit representation:

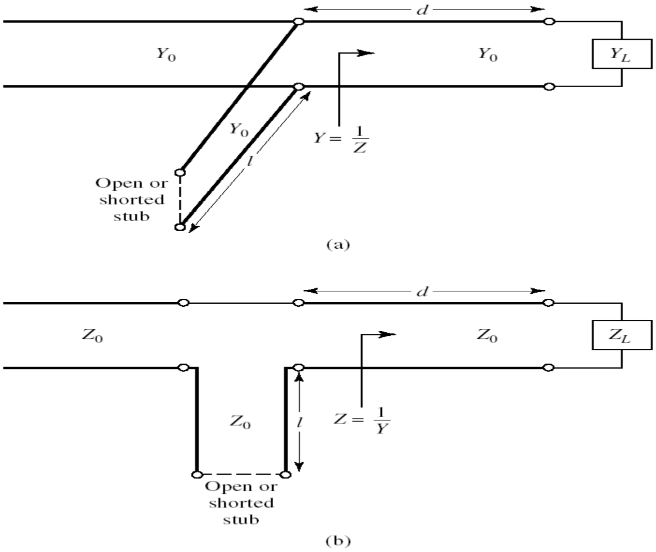

Figure 3 single stub tuning circuit (a) shunt stub (b) series stub [3]

Example1: A lossless line of characteristic impedance of 50W is to be matched with load 50/2 + (2+√3j) W by means of lossless short circuit stub having impedance of 100W. Find stub position and length of the stub.

Solution:

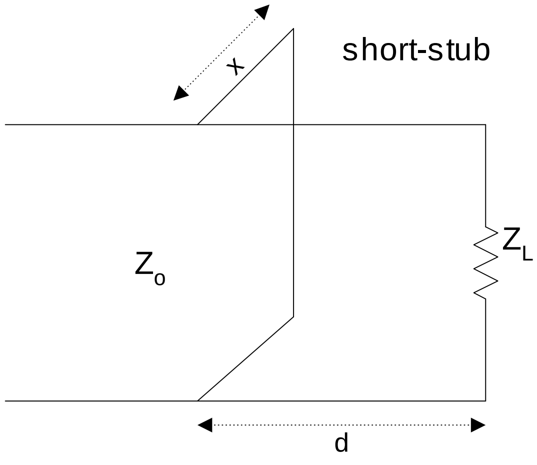

Figure 4: circuit representation of shunt short stub [3]

1. The normalized load impedance Z_L= 0.11-j0.208
2. SWR circle intersects the 1+jb circle at both points
   y_1 = 1.0+-j2.9
   y_2 = 1.0-j2.9

Reading from towards the generator scale can obtain:
   d_1= 0.019λ
   d_2= 0.081λ.

3. The stub length for tuning z_1 to 1 requires
   l_1 = 0.478λ,

And for tuning z_2 to 1 needs
   l_2 = 0.022λ

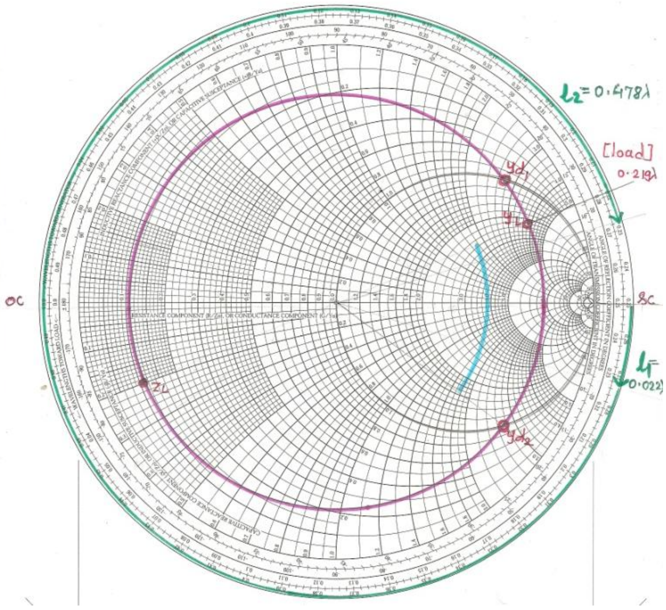

Figure 5: Short circuited stub in shunt [3]

Example 2 For load impedance Z_L=60-j80W design single open circuited shunt stub tuning network to match load of line 50W

Solution:

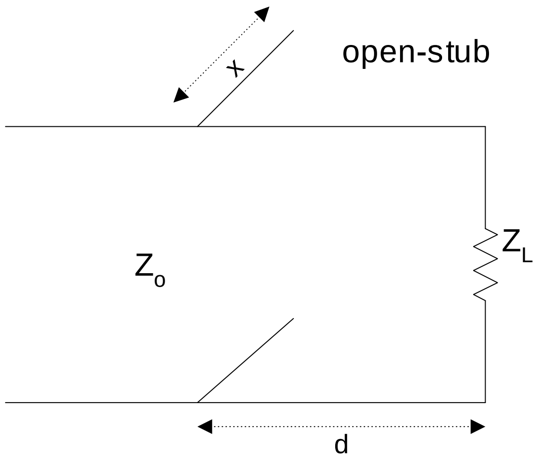

Figure 6: circuit representation of shunt open stub[3]

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1. The normalized load impedance Z_L= 1.2-j1.6.
2. SWR circle intersects the 1+jb circle at both points
   y_1 = 1.0+j1.5
   y_2 = 1.0-j1.5.

Reading from towards the generator can obtain:
d_1= 0.11λ
d_2=0.26λ.

3. The stub length for tuning y_1 to 1 requires
   l_1 = 0.34λ,

And for tuning y_2 to 1 needs
l_2 = 0.156λ

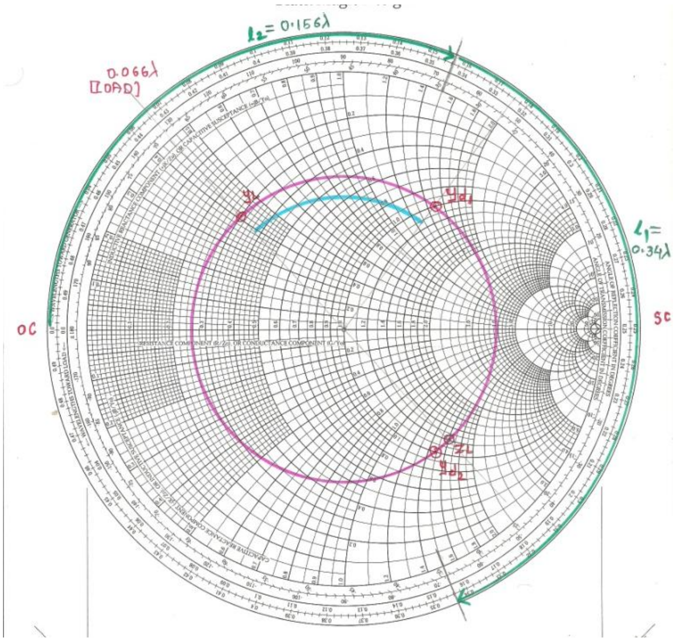

Figure 7: open circuited stub in shunt [3]

Example 3: For the load impedance of 100+j80Wdesign single short circuited series stub tuning network to match load line of 50W

Solution:

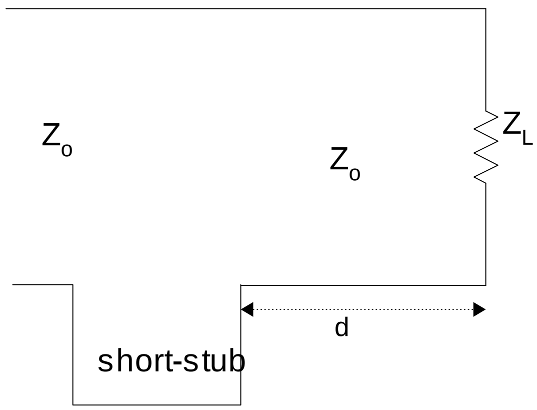

Figure 8: circuit representation of series short stub[3]

1. The normalized load impedance Z_L= 2+j1.6
2. SWR circle intersects the 1+jx circle at both points
   z_1 = 1.0-j1.35
   z_2 = 1.0+j1.35

Reading from towards the generator can obtain:
  d_1= 0.036λ
  d_2=0.38λ.

3. The stub length for tuning z_1 to 1 requires
   l_1 = 0.148λ,

And for tuning z_2 to 1 needs
 l_2 = 0.352λ.

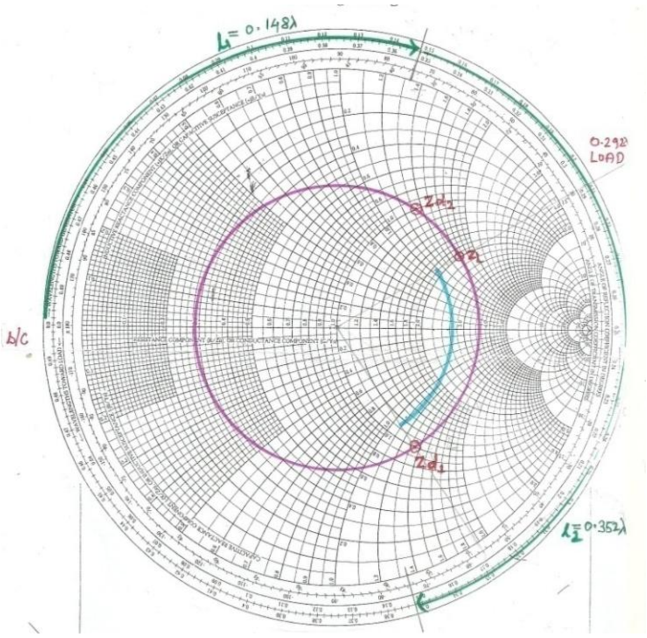

Figure 9: Short circuited stub in series [3]

BANDWIDTH CONSIDERATION

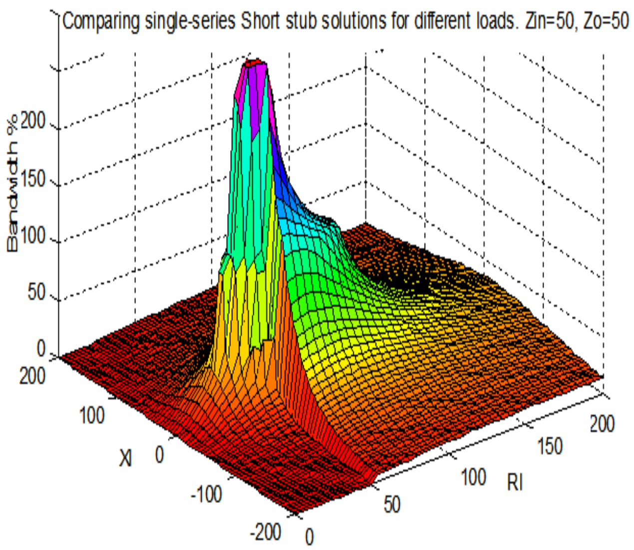

Figure10:3D plot of %bandwidth versus Z_L, (Zo = 50 Ω) [7]

When load impedance is equal to the 50+0j Ω, we observed a maximum (theoretically infinite) bandwidth because it equals the characteristic impedance giving a frequency independent match between load and transmission line.

Example 4: A load impedance $Z_{L=}$30-j40W is to be match with 50W line using single series stub tuner of characteristic impedance of 50W using open circuited stub.

Solution:

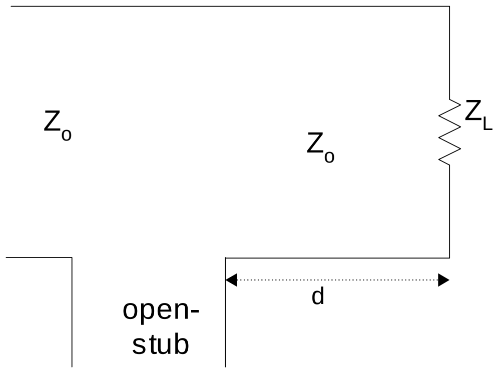

Figure 11: circuit representation of series open stub [3]

1. The normalized load impedance Z_L= 0.6-j0.8
2. SWR circle intersects the 1+jx circle at both points
   z_1 = 1.0+j1.2
   z_2 = 1.0+j1.2
Reading from towards the generator can obtain:
 d_1= 0.293λ
 $d_{2=}$0.459λ.
3. The stub length for tuning z_1 to 1 requires
   l_1 = 0.389λ,
And for tuning z_2 to 1 needs
 l_2 = 0.112λ.

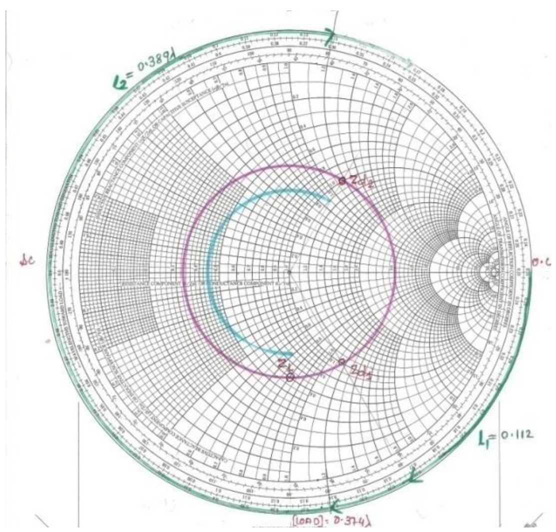

Figure 12: open circuited stub in series [3]

E. Application of single stub :

Antenna Matching Example:
Consider a 1-metre dipole antenna load which is used at a frequency not designed for. It is cheaper and easier to do a stub matching rather than to change the antenna structure. Suppose the frequency is to be changed from 120 MHz to 160 MHz [9]
Some initial experimental data of the normalized impedance at the dipole centre are plotted on the Smith chart, for 120, 125, 130… 160 MHz Matched at around 140 MHz (centre of chart). The circles represent constant Γ or VSWR and hence tell us about the bandwidth of this dipole**:**

VSWR=1.33 or |Γ| = 0.02 = 0.141 (2% power reflected)
Frequency range is 137 MHz to 144 MHz (orange circle)

VSWR=1.93 or |Γ| = √0.1 = 0.316 (10% power reflected)
Frequency range: 132 MHz to 151 MHz (green circle)

VSWR=6 or |Γ| = √0.5 = 0.7071 (50% power reflected) Too bad! Significantly mismatched (blue circle)

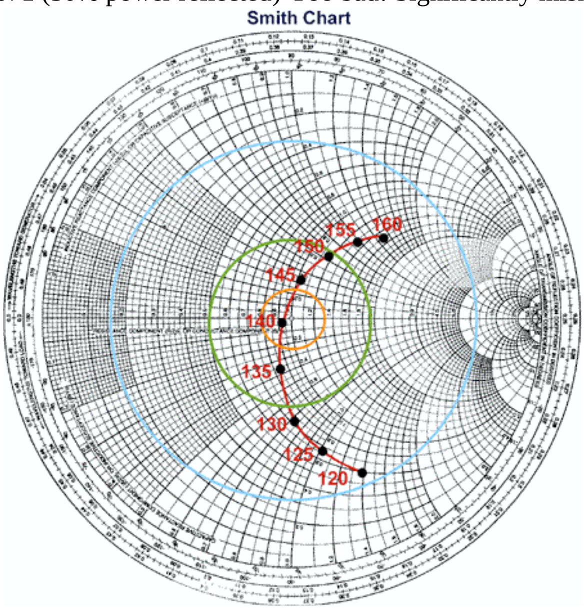

Figure 13: Smith chart, for 120, 125, 130…160 MHz Matched at around 140 MHz [9]

Matching Procedure:
We begin with the impedance at 120 MHz It is 44.8 – *j* 107Ω, normalized to 0.597 – *j* 1.43 for a 75Ω coax line. Rotate it clockwise (generator direction) until it reaches the circle corresponding to *r* = 1 (red circle). We see that

1. We need to insert a stub at 0.346λ from the antenna.
2. The normalized reactance at that point is *j* 1.86. So, we need to cancel this out. Cancellation requires a short- or open- circuit stub of appropriate length. [9]

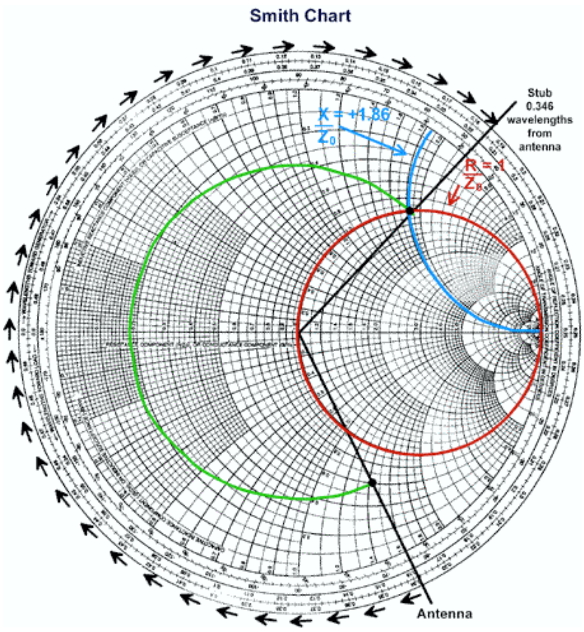

Figure 14: stub location from an antenna [9]

Finally, to get the match stub length, we use the Smith chart again. The outer circle corresponds to r = 0, i.e., pure reactance. The leftmost point is SHORT, and the rightmost is OPEN. On the chart, we find the reactance circle of $x = -1.86$
and find the length required from either the OPEN or SHORT point. Here, we need 0.328λ from the SHORT, or 0.078λ from the OPEN. (Rotate clockwise!) We choose the open-circuit stub. The required length is 0.078λ. **[**9]

Final circuit solution:

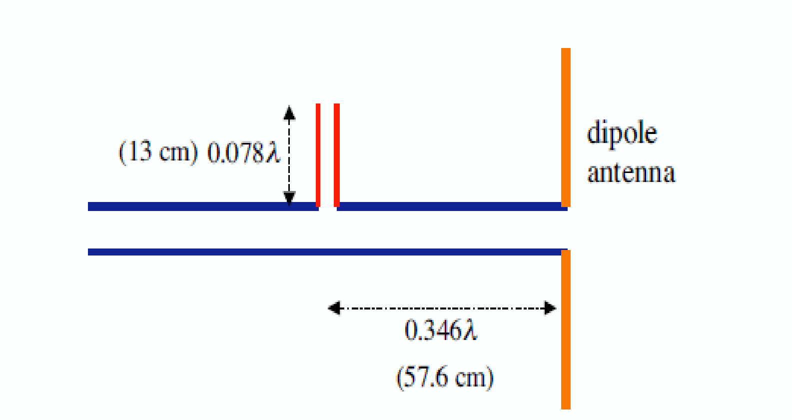

Figure 15: circuit solution for dipole antenna matching [9]

F. Double stub matching
Why we use double-stub tuning?

The single-stub tuner has one limitation: it must be placed at the proper distance from the load, which is a variable that is difficult to adjust in practice. The double-stub tuner uses two tuning stubs, partially removes the requirement for variable distance from the load, and is widely used in laboratory practice as a single frequency matching device.

Advantage over single stub:

- Variable length of length d between load and stub to have adjustable tuning between load and the first stub.

- Shunt stubs are easier to implement in practice than series stubs.
- In practice, stub spacing is chosen as λ/8 or 3λ/8 and far away 0 or λ/2 to reduce frequency sensitive

Disadvantage:

- The double-stub tuner cannot match all load impedances. The shaded region forms a forbidden range of load admittances.
- Two possible solutions
- b_1, b_2 and b_1', b_2' with the same distance *d*.

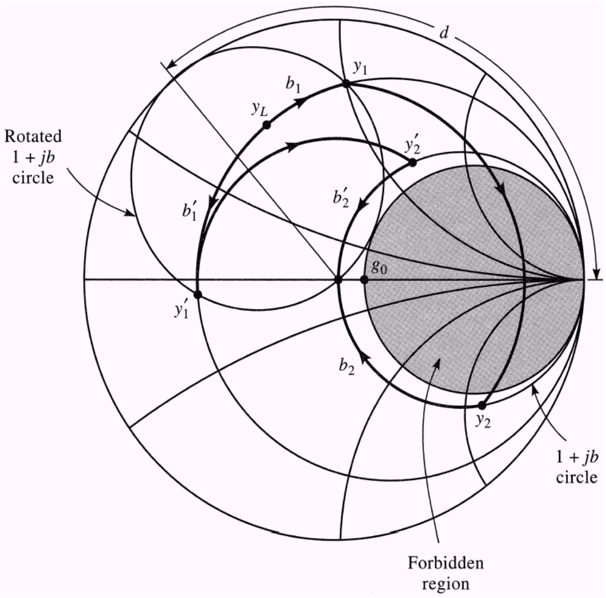

Figure 16: Forbidden region [3]

Circuit representation:

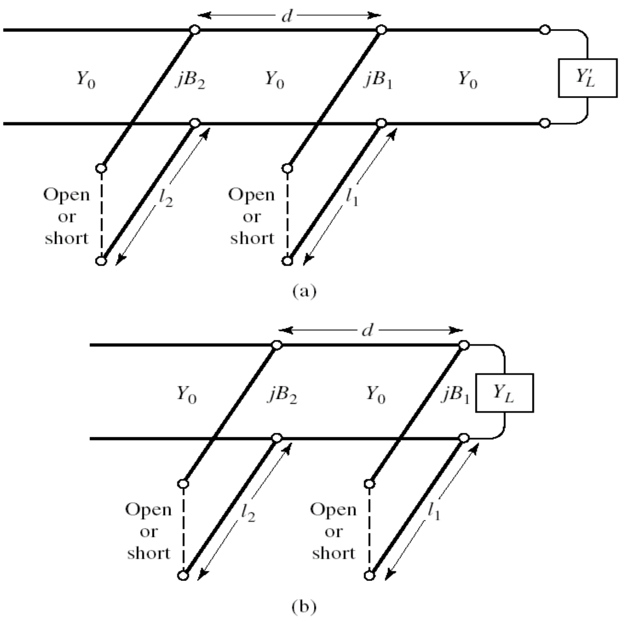

Figure 17: Double stub tuning (a) original circuit with load an arbitrary distance (b) equivalent circuit with load at the first stub [3]

Example 5: Match a load impedance Z_L = 60 - j 80 Ω to a
50 Ω line using a double-stub tuner. The stubs are short circuited are spaced λ/8apart. The match frequency is 2 GHz.

Solution:
1. The normalized load impedance Z_L= 1.2-j1.6
2. Y_L=0.32+j0.42, rotating this point by 0.4l towards the generator to get y_{d1}=0.32-j0.19
3. Rotating unit circle by λ/8 toward the load to get value of y_{11}=0.32+j0.34 and y_{11}'=0.32+j1.6
4. The susceptance of the first stubs are b_1=0.53j and b_1'=1.79j
5. Rotating y_{11} and y_{11}' by 90°on unity circle to get y_{d2}=1+j1.6 and y_{d2}'=1-j3.6
6. The length of the first open-circuited stubs are found as
   l_1 = 0.078λ,
   l_1'= 0.168λ,
And

7. The length of the second open-circuited stubs are found as
 l_2 = 0.27λ,
 $l_{2'}$ = 0.34λ.

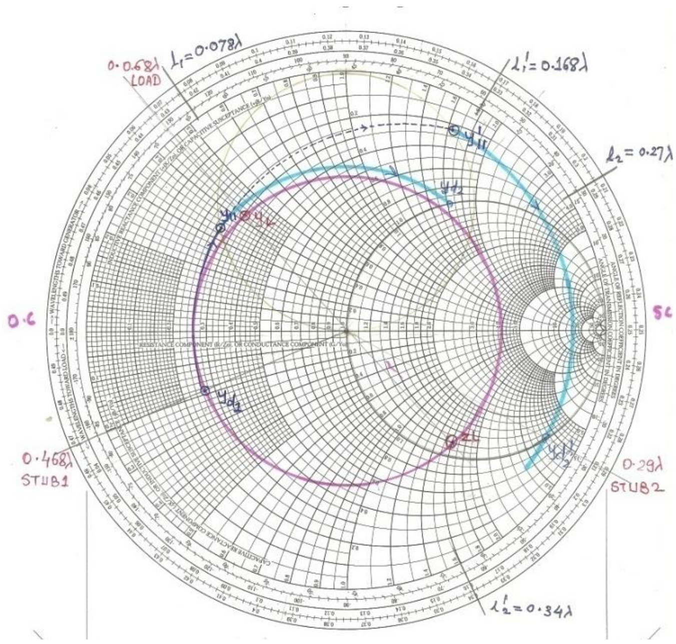

Figure 18: open circuited double stub in shunt [3]

Example 6: The terminating impedance Z_L=100+j100Wand the characteristic impedance of the line as well stub is 50W the first stub is placed at 0.4laway from the load .the spacing between two stub are 3l/8 deter mine length of short circuited stub when the match is achieve.

Solution:
1 .The normalized load impedance Z_L= 2+j2
2 .Y_L=0.25-j0.25, rotating this point by 0.4l towards the generator to get y_{d1}=0.55-j1.02
3. Rotating unit circle by 3λ/8 toward the load to get value of y_{11}=0.55-j0.1 and y_{11}'=0.55-j1.9
4. The susceptance of the first stubs are b_1=0.1j and b_1'=0.88j
5. Rotating y_{11} and y_{11}' by 270° on unity circle to get
   y_{d2}=1-j0.75 and y_{d2}'=1+j2.6
6. The length of the first open-circuited stubs are found as
   l_1 = 0.375λ,

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l_1'= 0.135λ,

And

7. The length of the second open – circuited stubs are found as

l_2 = 0.35λ,

$l_{2'}$ = 0.058λ.

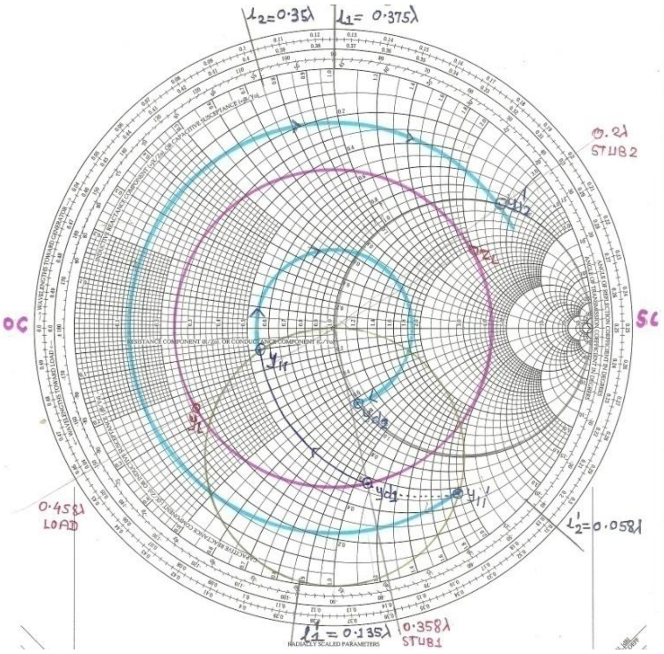

Figure 19: short circuited double stub in shunt [3]

BANDWIDTH CONSIDERATION:

In order to get a clear picture about the variation of bandwidth with varying load keeping the distance of the stubs constant i.e. d =l/ 8 and distance between load and its first nearest stub = 0.

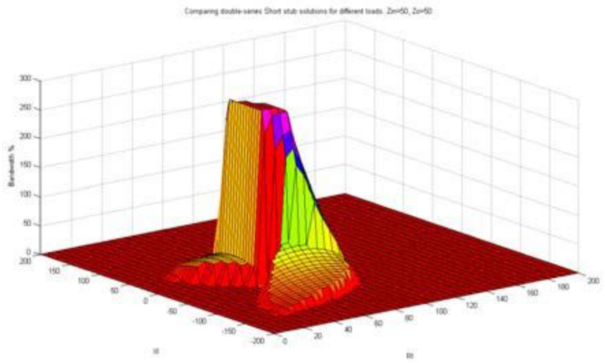

Figure 20: 3D representation of %bandwidth versus complex Impedance for double stub matching (Zo = 50Ω)[7]

Apparent from the 3D graph is a higher bandwidth for short shunt double stub matching as shown in example 5, using the similar values of input and characteristic impedances of 50Ω as for series short single stub. However in this case the matched region, giving very high bandwidth, is more flattened indicating its broadband nature and less degree of sensitivity to load variations. The graph shows a maximum of bandwidth occurring in the area near Z_L = 50, whereas the region of totally zero bandwidth indicates the forbidden region.

The forbidden region has been shaded, in figure 15 which shows the range of load impedances that cannot be matched using the double stub configuration [4], as their real part circles would never intersect the rotated input impedance real part circle .Therefore one never finds a value for the first stub in the double stub matching system that can be matched for load impedance in the forbidden region which is overcome with the help of triple stub.

G .Triple stub matching and optimization

In triple stub configuration, the aim of third stub is to transform Z_L falling in forbidden region to Z_{Lnew} outside the forbidden region, so that matching could be done easily. We define an auxiliary variable: I-Value for triple stub matching It is the imaginary part of impedance seen looking towards the load into third-stub extended by transmission line after disconnecting the left part (double stub network) of matching system [4].

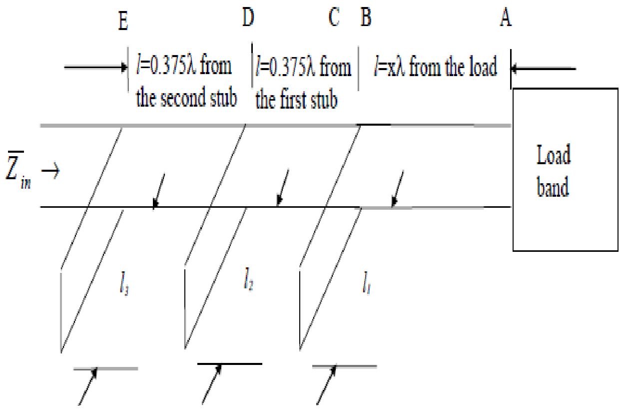

Figure 21: circuit representation of triple stub [5]

Considered the case if the triple stub in matching, a single frequency to the centre of the smith chart. In this section, the emphasis will be placed on determining the value of the VSWR circle that a band of frequencies lays within, when the centre of the band is matched to the centre of the Smith chart using the single frequency triple stub matching. The triple stub may be employed over the double stub, to ensure matching can occur for all impedances which may be encountered Similar to the double stub, at the higher microwave frequencies due to the small wavelengths involved, the distance between the stubs may be fixed at 0.375l. Figure shows a schematic of the triple stub with the 0.375lfixed separation between the stubs, and the variable distance x l of the first stub from the impedance band of frequencies.

BANDWIDTH CONSIDERATION:

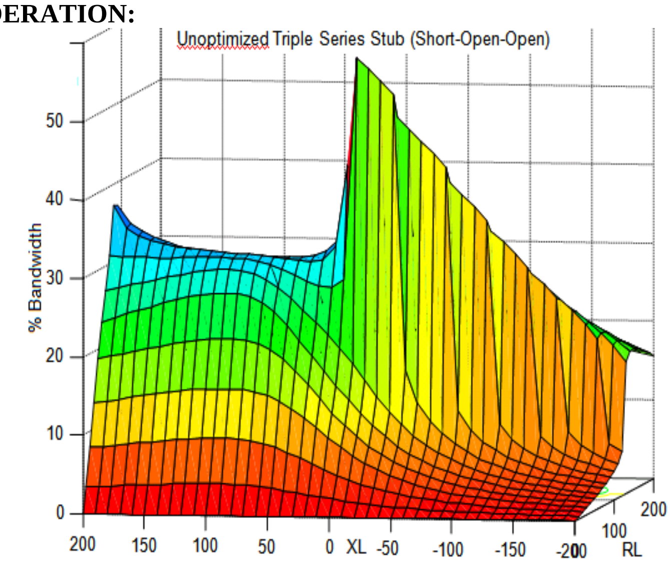

Figure 22: 3D plot of %bandwidth vs. ZL for unoptimized triple stub matching (Zo = 50Ω) [7]

It is obvious from the 3D level curves figure 22 that Optimized triple-stub system show broadband results even for relatively large values of $|Z_L|$ which is a quality absent in single and double stub systems.

IV. Problem analysis

For frequencies up to approximately 1 GHz, matching networks containing lumped elements (L-networks) may be used. The circuit elements (capacitors and inductors) must be small enough relative to wavelength so that the normal circuit equations for voltage and current are valid. This is used for narrowband frequency impedance matching. We can obtain any value of reactance or susceptance with the proper length of short-circuited or open-circuited transmission line, we may use these transmission line stubs as matching networks. A single stub network suffers from the disadvantage of requiring a variable length of t line between the load and the stub. This may not be a problem for fixed transformation network, but would pose some difficulty if an adjustable tuning network is desired.

Short-circuited or open-circuited transmission line, we may use these transmission line stubs as matching networks. A single stub network suffers from the disadvantage of requiring a variable length of l line between the load and the stub. This may not be a problem for fixed transformation network, but would pose some difficulty if an adjustable tuning network is desired.

A quarter-wave transformer (QWT) is a simple and useful circuit for matching real load impedance to a transmission line. An additional feature is that it can be extended to multi-section design for broader bandwidth. Although quarter-wave transformer can in theory used to match complex Impedance, it is more common to use it to match real impedance. At the operating frequency for, the electrical length of the matching section is l/4. But at other frequencies the length is different, so a perfect match is no longer obtained. The quarter wave transformer has a limited bandwidth, like other transformation methods and the transmission line must be placed between the load and the feed line. For applications requiring more bandwidth than a single quarter wave section can provide, multi-section transformers can be used [3] [4]

V. Conclusion

A general problem in a microwave system is to any information or power from a generator to a load by means of a transmission line. In this case, it is preferable to match the generator and the load to transmission line separately. Another method of matching is the matching of the impedance seen at the input port to the source impedance and the matching of the impedance seen at the output port to the load impedance. So, the matching problem of the system reduces to two separate matching to a transmission line. A well-known solution to this problem is the so called stub matching where open or short circuited transmission lines are used. The single, double, and triple-stub matching techniques are used.

This increases the power transferred to the load from the source. And overcome the bandwidth constraint of transmission line also the mismatch at the load transmission line connection decreases the strength of the line upon breakdown. Single stub is easier to implement but provides 0 degree of freedom as change in Z_L changes the position of stub. In double stub, we have 1 degree of freedom, thus allowing fixed stub positions and in case of triple stubs, the cardinality of solution set for a particular configuration increases from 2 to infinity. Triple stub can be greatly optimized for optimal bandwidth

VI. References

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