ACCELERATOR DEPARTMENT
(AGS)

JLW-4

Internal Report

BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, L.I., N.Y.SOME PROPERTIES OF STUB TUNERS
WHICH CAN BE DISPLAYED ON SMITH CHARTS

J. L. Walters

May 9, 1962

That the Smith chart is useful in studying stub tuners is well known, and what follows here is either similar to or a slight amplification of material appearing in Ragan¹.

The following properties will be shown.

1. The $\frac{1}{4}$ wavelength-spaced double stub tuner cannot tune a load which appears at stub 1 (the one nearer the load) with a conductive component greater than the characteristic admittance. (Among those excluded here are all resistive loads of less than 50 ohms)
2. For the $\frac{3}{8}$ wavelength spacing admittances cannot be tuned which appear at stub 1 with a conductive component greater than twice Y_0 .
3. A $\frac{5}{12}$ wavelength spacing tuner will match any admittance which appears at stub 1 with a real part less than 4 times Y_0 . The resistive loads which cannot be tuned are those of less than $12\frac{1}{2}$ ohms (for a 50 ohm line).
4. Any double stub tuner can match any finite load if the distance to the load can be changed by $\frac{1}{4}$ wave length.
5. A triple stub tuner of any equal spacing can match any finite load.
6. The $\frac{1}{4}$ wavelength spaced double stub tuner cannot be tuned by making successive moves which reduce VSWR. For any other spacing the process is convergent.

¹ Ragan, G.L. "Microwave Transmission Circuits" McGraw-Hill 1948 pp. 472-478

Facsimile Price \$	1.60
Microfilm Price \$	-.80
Available from the Office of Technical Services Department of Commerce Washington 25, D. C.	

MASTER

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

7. If VSWR is measurable, it should be possible to adjust a double stub tuner with 3 or 4 moves and a triple stub tuner with 4 or 5 moves.

To any complex admittance (or impedance) with positive real part there corresponds a point on the Smith chart. The right half plane is so mapped into a circle that the transformation,

$$Y_2 = Y_0 \frac{Y_1 + j Y_0 \tan \theta}{Y_0 + j Y_1 \tan \theta}$$

is a rotation about the center of the circle of 2θ . This transformation gives the admittance Y_2 , which appears when a lossless transmission line of characteristic admittance Y_0 is terminated by an admittance Y_1 at an electrical distance θ .

Figure 1 shows a Smith chart on which some circles of constant VSWR have been drawn. A typical point, $0.2 + j0.7$ has been labeled Y_1 . Adding negative susceptance to Y_1 will change the combined admittance in the direction of arrow a along the $G = 0.2$ circle. If the measuring point is moved along the line toward the generator, Y_1 will be transformed to values lying on the $VSWR = 7$ circle in direction b. Adding pure conductance will change the total admittance along the $B = 0.7$ circle as indicated by arrow c. The stub tuning problem becomes that of moving from an admittance point such as Y_1 to the center of the chart via paths like a and b only.

Consider as the first example the double stub tuner with $1/8$ wave length spacing. Assume that both stubs are set at their $\frac{1}{4}$ wave positions so that they are adding no susceptance; point 1 is the admittance seen at stub 1.

If short 1 is moved in from its $\frac{1}{2}$ wave position, the negative susceptance which is thereby added to Y_1 will produce a new combined admittance lying on the $G = 0.2$ circle in direction a. It can be seen that moving the short $180 - 110 = 70$ Smith chart degrees, (which is 35 electrical degrees, or 0.098 wavelengths as read from the outer scale), will put the combined admittance on the real axis minimizing the VSWR to a value of 5. This is shown on Figure 2 as point 2.

This combined admittance, Y_2 , at stub 1, will appear as Y_3 at stub 2. To find Y_3 , follow the VSWR = 5 circle for 90° cw, which is equivalent to going $1/8$ wavelength toward the source. $Y_3 = 0.42 + j0.93$. The short in stub 2 may be moved to minimize VSWR. An inward movement of 43° (electrical) will add 0.93 of negative susceptance to produce Y_4 on the real axis. At stub 1 Y_4 will be transformed to Y_5 by a 90° CCW path along the VSWR = 2.5 circle. The short at stub 1 can be moved out to supply enough positive susceptance to move back to a lower VSWR at point 6 on the real axis. Y_6 is transformed to Y_7 at stub 2 where the short can be moved in to produce Y_8 on the real axis and so on. By moving one short and then the other in directions to always reduce VSWR, the center of the chart can be approached. This method of adjustment is quite useful when working at wavelengths of 10 cm or less; a $3/8$ inch coax double stub tuner fits in the palm; the shorting plungers; resemble hypodermic syringes and are easily moved. The stub tuners which are used in the 200 MC, $3\frac{1}{8}$ inch coax system of the LINAC are adjusted by means of a handwheel. The screw is $\frac{1}{2} \times 13$ and the wavelength is 1.5 meters. In the example just given, total motions of the shorts was 279° . This is equal to $(150)(13)(279)/(2.54)(360) = 595$ turns of the handwheel. If a VSWR is measureable, the Smith chart can be used to move to a match by a more direct route as shown in Figure 3. Notice the $3/4$ circle; this is

part of the $G=1$ circle which has been rotated about the origin $1/8$ wavelength. If the admittance can be moved to this circle, it will appear at stub 2 on the $G=1$ circle where adding susceptance will bring it directly to the origin. To move from $Y = 0.2 + j0.7$ to $Y = 1.0$ directly requires a total motion of the shorts of 76° . An exploratory trip to the real axis must be made to find the location of Y_1 . This can be done as follows starting with both shorts at the $\frac{1}{2}$ wave positions:

1. Measure VSWR. The position of Y_1 is somewhere on the circle of that VSWR, for example VSWR = 7.3
2. Move the short at stub 1 enough to change the VSWR; if moving the short in (towards the main line) decreases VSWR, Y_1 must lie on the upper, or $+jB$ semicircle, and conversely.
3. Move the short to minimize VSWR; the motion of the short required to do this gives; ΔB so that Y_1 lies at one of the intersections of the appropriate B curve and the VSWR circle. The size of Δvswr can be used to determine which of the two intersections. With the location of Y_1 known, stub 1 can be used to move to the rotated $G=1$ circle and then directly to the center.

Figure 5 shows the direct path for Y_1 lying inside the $G=1$ circle.

Figure 6 shows the $G = 1$ circle, the rotated $G = 1$ circle and some of the other G circles for G greater than 1. If Y_1 lies inside the hatched area, adding susceptance will only move Y around inside the hatched area, and it will be impossible to get to rotated $G = 1$. The hatched area is enclosed by the G circle which is tangent to the rotated $G = 1$ circle; for the $1/8$ wave length case this is $G = 2.0$. Figure 7 shows how these inaccessible admittances are transformed when viewed at stub 2. Adding $+jB$ at stub 2 will move Y onto the rotated $G = 1$ circle and a third stub could be used to go to

the center along $G = 1$. Figure 8 shows a triple stub tuner direct path where stub 1 has been used to minimize VSWR.

Similar reasoning applies to other stub spacings. Figure 9 shows the circle of inaccessible admittances for $5/12$ wave length spacing; also shown are the rotated $G = 1$ circle and a direct path to the center. Figure 10 shows the path of successive reduction of VSWR. The numbers near the G circles indicate the stubs which are being changed. The net motions of the shorts at stubs 1 and 2 should add up to those shown in Figure 9, i.e. path 1,2 equals the total motion of stub 1; path 3,4 is the total movement of stub 2. Comparing Figures 9 and 3, it can be noted that in performing the same match a larger VSWR in the line between stubs has resulted than in the case of the $1/8$ wave length spacing. This effect becomes more pronounced as the spacing is decreased; actually this means as the spacing approaches $\frac{1}{2}$ wave. At $\frac{1}{2}$ wave spacing the rotated $G = 1$ circle coincides with the unrotated $G = 1$ circle, the circle of inaccessible admittances has shrunk to zero, but infinite VSWR is required in the interstub line for any matching. Figure 11 shows the rotated $G = 1$ circle for the $\frac{\lambda}{4}$ spacing, the region of inaccessible admittances, and the tuning path. Figure 12 shows that moving stub 1 to minimize VSWR puts the transformed admittance at stub 2 inside the shaded area and on the horizontal axis so that adding any susceptance will increase VSWR. Figure 13 shows the situation for a spacing just slightly less than $\frac{\lambda}{4}$. Both the direct path 1,2,3,4 and the path obtained by successively reducing VSWR are shown. It can be seen how slowly this process converges.

JLW:mo'n

5/9/62

Distr: AGS Linac Group

NAME	TITLE	DWG. NO.
SMITH CHART FORM 82BSPR (2-49)	Accelerator Department - JLN-4 5/9/62 KAY ELECTRIC COMPANY, PINE BROOK, N.J. ©1949 PRINTED IN U.S.A.	DATE

IMPEDANCE OR ADMITTANCE COORDINATES

Figure 1

BROOKHAVEN NATIONAL LABORATORY

BY _____ DATE _____ SUBJECT _____ SHEET No. _____ OF _____
 CHKD. BY _____ DATE _____ JOB No. _____
 DEPT. OR PROJECT Accelerator Dept. JLW-4 5/9/62

Figure 2
 $\frac{\lambda}{8}$ spacing
 Tuning trajectory obtained
 by minimizing VSWR

Figure 3.
 $\frac{\lambda}{8}$ spacing
 Minimum trajectory

BROOKHAVEN NATIONAL LABORATORY

BY _____ DATE _____

SUBJECT _____

SHEET No. _____ OF _____

CHKD. BY _____ DATE _____

DEPT. OR PROJECT _____

JOB No. _____

Accelerator Department JLNW 5/9/62

Figure 4
Determining the location
of an admittance

BROOKHAVEN NATIONAL LABORATORY

BY _____ DATE _____

SUBJECT _____

SHEET No. _____ OF _____

CHKD. BY _____ DATE _____

DEPT. OR PROJECT _____

JOB No. _____

Accelerator Department JLW-4 5/9/62

Figure 5 Trajectory for
Y₁ lying inside the G=1
circle - $\frac{\lambda}{8}$ spacing

Figure 6 Region
of inaccessible
admittances for $\frac{\lambda}{8}$
spacing

Fig. 7

Figure 8 trajectory
for $\frac{\lambda}{8}$ triple stub
tuner

BROOKHAVEN NATIONAL LABORATORY

BY _____ DATE _____ SUBJECT _____ SHEET No. _____ OF _____
 CHKD. BY _____ DATE _____ JOB No. _____
 DEPT. OR PROJECT Accelerator Department JLN-4 5/9/62

BROOKHAVEN NATIONAL LABORATORY

BY.....DATE.....

SUBJECT.....

SHEET No.....OF.....

CHKD. BY.....DATE.....

.....

JOB No.....

.....

DEPT. OR PROJECT Accelerator Department

JW-4 5/9/62

Figure 13 Slightly less than $\frac{\lambda}{4}$ spacing