Broadbanding The Mark III Antenna On 80 Meters

BY COMMANDER PAUL H. LEE*, W3JHR

The Mark III, originally designed to cover the 3.8 to 4.0 mc portion of the 80 meter band can be made to cover the entire 3.5 to 4.0 mc. The article below illustrates the use of the Smith Chart to devise the corrective network that broadbands the Mark III.

An earlier issue of this magazine[1] described the Mark III DX Antenna. In the first three months after the appearance of that article in print, I received over two hundred letters from readers inquiring about various aspects of antenna design. Many readers wished to be able to use the Mark III over the whole 80 meter band, and wondered how the s.w.r. over the whole band could be improved. It was originally designed to cover only the 3.8-4.0 mc range. Some computation and a few neat tricks with that handy tool, the Smith Chart,[2] have resulted in the information contained herein.

Use of the Smith Chart makes the solution of a problem such as broadbanding the Mark III 80 meter feed quite easy. The input impedance of the Mark III 80 meter feed versus frequency is tabulated below (tuned for 3.9 mc):

Frequency	*Impedance*	*Normalized Value 51 ohm basis* $(R + jx)$
3.5	$6.64+j5.6$	$.13+j.11$
3.6	$11.20+j7.66$	$.22+j.15$
3.7	$18.30+j9.69$	$.36+j.19$
3.8	$29.60+j10.20$	$.57+j.20$
3.9	$51.00+j0$	$1.00+j0$
4.0	$58.80-j33.10$	$1.15-j.65$

These normalized values of $R+jx$ are plotted on the chart in fig. 1 as curve "A", giving a complete picture of impedance versus frequency in the range of interest. It may be seen that the 2.0:1 s.w.r. circle includes that portion of the curve between 3.8 and 4.0 mc, but that the s.w.r. at 3.5 mc is horrible, being about 7.5:1.

If the Mark III were tuned for 1:1 s.w.r. at the center of the band, 3.75 mc, the curve would lie wholly within a 4:1 s.w.r. circle. The high s.w.r. at the extreme portions of the band is due to the Q of the feed point of the antenna, which is about 12. We can do something to improve this s.w.r. situation by adding several components to the matching network, as we shall see. The techniques used herein are currently employed in the design of shipboard antenna matching networks for Naval use, where it is required that an antenna be matched to a transmission line over a very wide frequency range, with s.w.r. of 2.5:1 or so.

The equivalent circuit of the Mark III feed, as tuned for 3.9 mc, is shown in fig. 2A. As may be seen, it is a simple L network whereby the 9 ohm antenna feed point resistance R_a is matched to the 51 ohm line. The series inductive arm of the network is made of two parts as shown in fig. 2B. One of these is the positive reactance of the antenna feed point X_a, which is $+j113$ ohms. The other part is the negative reactance of the series capacitor, which at 3.9 mc is $-j93.4$ ohms Thus the series arm is the sum of the two, or $+j19.6$ ohms. The shunt arm of the L network is $-j23.8$ ohms. (These are true values, not normalized.)

Mismatching the L Network

Our first step is to intentionally mismatch the L network in order to raise its input impedance, by a factor of 1.9, to a new Z_o of 96.9 ohms. We also tune it for the center of the band, 3.75 mc. The reasons for this will be seen later when the shape and location of the final input impedance curve are plotted and seen on the Smith Chart.

The new values for the L network of input $Z_o = 96.9$ ohms at 3.75 mc are shown in fig. 3A and 3B. The antenna feed point impedance is $9 + j108.5$ at this frequency. Antenna resistance for all practical purposes remains at $R_a = 9$ ohms, whereas the reactance changes somewhat, with frequency. The negative reactance of the series capacitor must now be $-j78.5$ ohms, and that of the shunt capacitor must be $-j32$ ohms. The series arm of the L network is the sum of $-j78.5$ and $+j108.5$ ohms, or $+j30$ ohms, as shown in fig. 3A. The L network was computed from the formulae and charts in Terman's *Radio Engineer's Handbook*.

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*5209 Bangor Drive, Kensington, Maryland.

[1] Lee, P. H., "The Mark III DX Antenna," *CQ*, December 1962, page 43.

[2] Smith, P. H., "Transmission Line Calculator," *Electronics*, January 1939 Amis, P. C., "Antenna Impedance Matching-Part I," *CQ*, November 1963 page 63, Part II, December 1963, page 33.

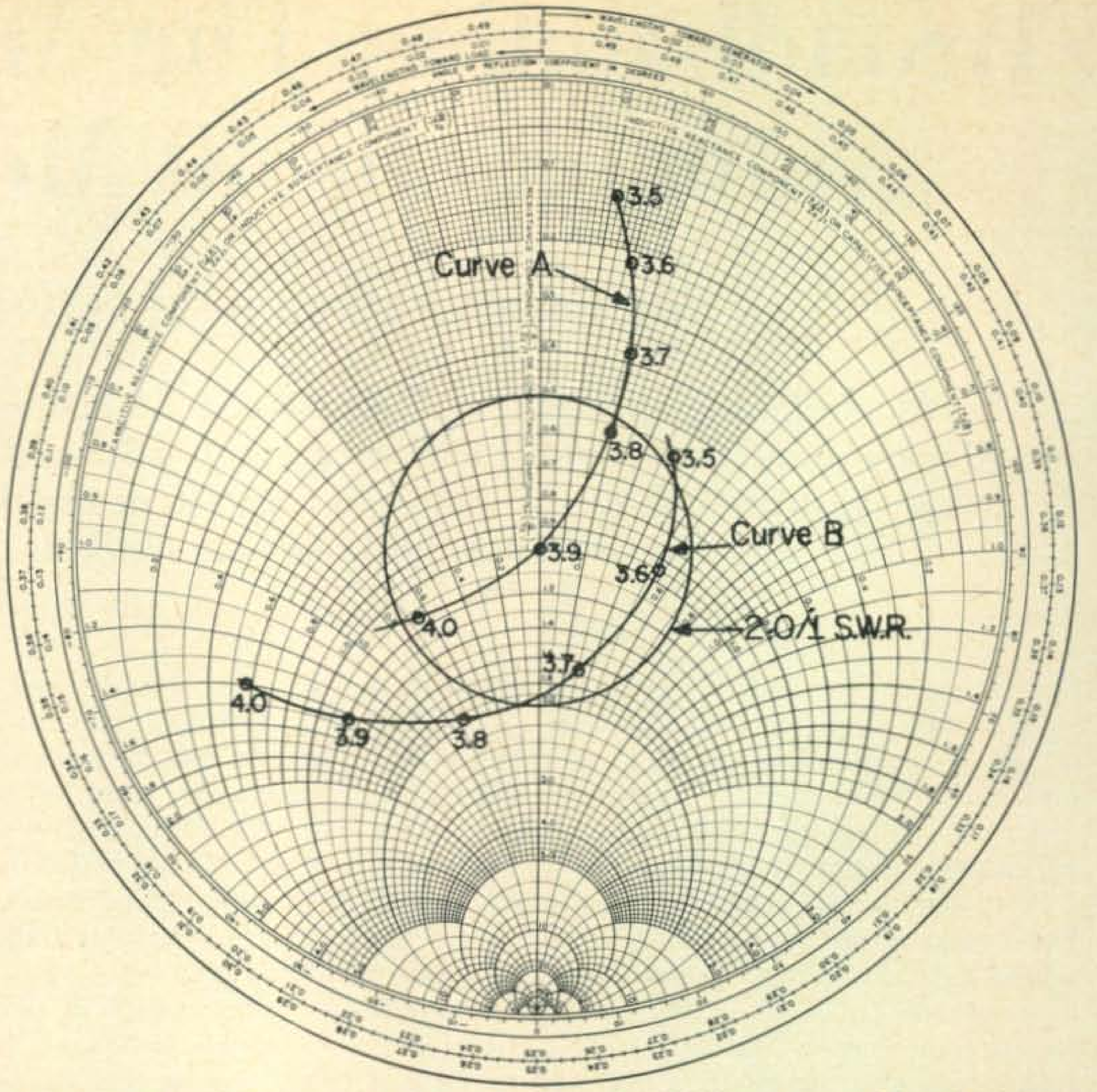

Fig. 1 — Curve A plotted on the Smith Chart above is with the Mark III antenna tuned to 3.9 mc. The 2:1 s.w.r. circle includes only frequencies from 3.8 to 4.0 mc. Curve B was developed with new values in the L network (fig. 3) and is positioned properly to be folded back on itself by the use of additional networks components.

These new values for the *L* network components produce a new input impedance curve as frequency is varied. This is curve "B" in fig. 1. Note that the resistance components at 3.5 and 4.0 mc are equal, at .57, and that the highest resistance component, 2.0, appears at about 3.77 mc. The impedance values are also shown here in tabular form:

Frequency	*Normalized Impedance*
3.5	$.57+j.38$
3.6	$.95+j.53$
3.7	$1.67+j.30$
3.8	$1.96-j.75$
3.9	$1.20-j1.42$
4.0	$.57-j1.39$

Bending the Curve

We now have a curve which is properly placed on the Smith Chart to be amenable to being twisted back on itself like a pretzel by the insertion of a series differential network consisting of series positive and negative reactance, of such values as to cause their sum to be negative at 3.5 mc and positive at 4.0 mc. It is our purpose to cause the ends of the curve to move within the 2:1 s.w.r. circle, and to bring the whole curve as close to 1:1 s.w.r. as possible. We cannot make it perfect, but it will be usable over the whole 3.5-4.0 mc band.

Inspection of curve B in fig. 1 shows that addition of $-j.55$ at 3.5 mc and $+j1.60$ at 4.0 mc will accomplish the desired result. The following set of simultaneous equations for the series network is used to compute the values of series X_L and X_C:

Where *a* is 4.0 mc; $+j1.60 = +jX_{La} - jX_{Ca}$, and *b* is 3.5 mc; $-j.55 = +jX_{Lb} - jX_{Cb}$

Taking the ratio of frequencies 3.5/4.0 into account and solving, we find that X_{Lb} is +7.90

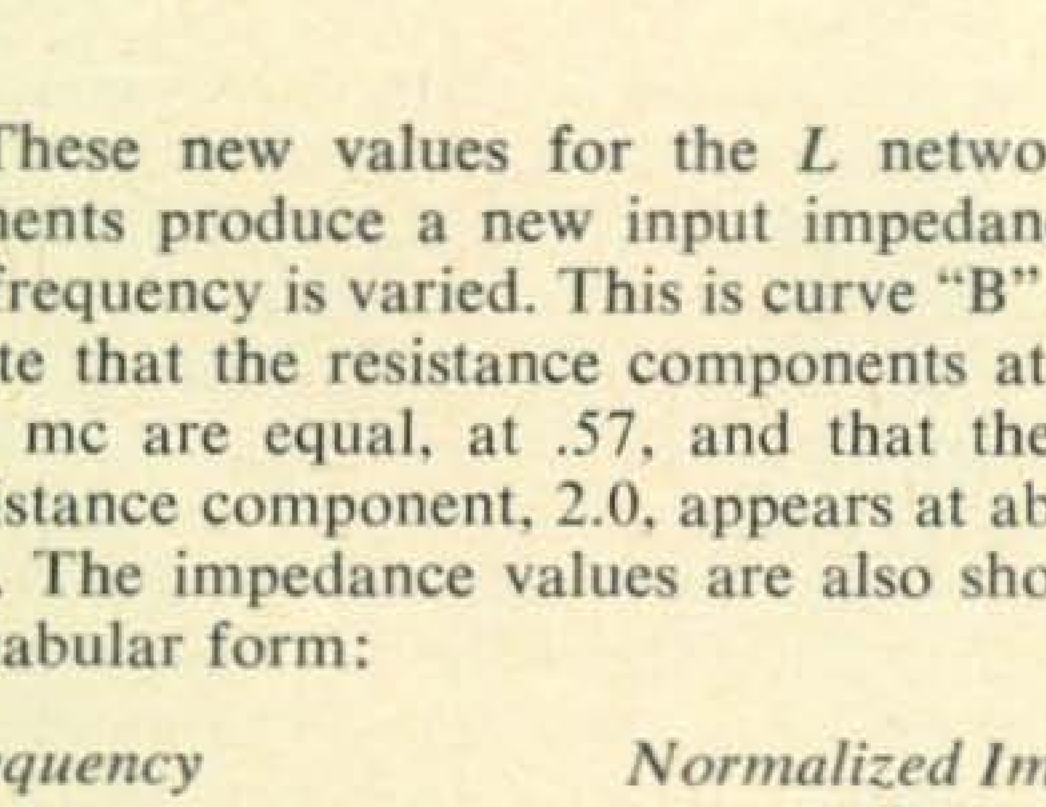

Fig. 2—The equivalent circuit for the Mark III feed tuned to 3.9 mc is shown in (A). Equivalent circuit (B) shows the negative reactance of the series capacitor which provides, in a series resultant, $-j19.6$ ohms.

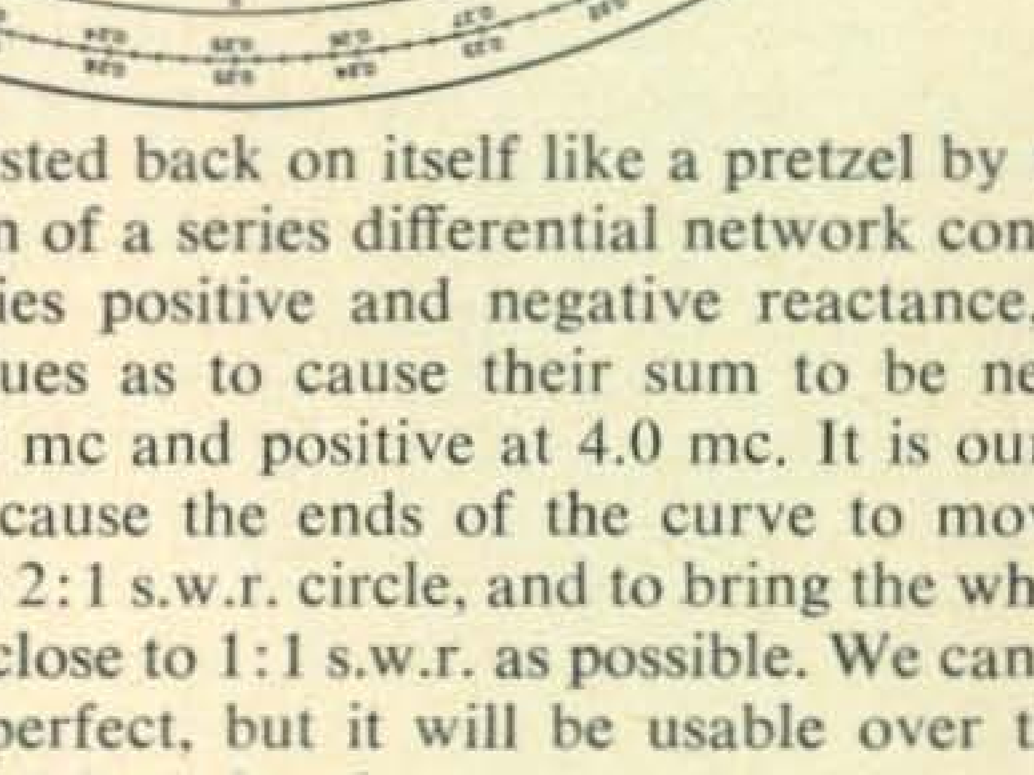

Fig. 3—The equivalent circuit showing the new values for the L network is shown in (A). Equivalent circuit (B) shows the negative series reactance of $-j78.5$ thus giving the resultant $+j30$ as shown in (A).

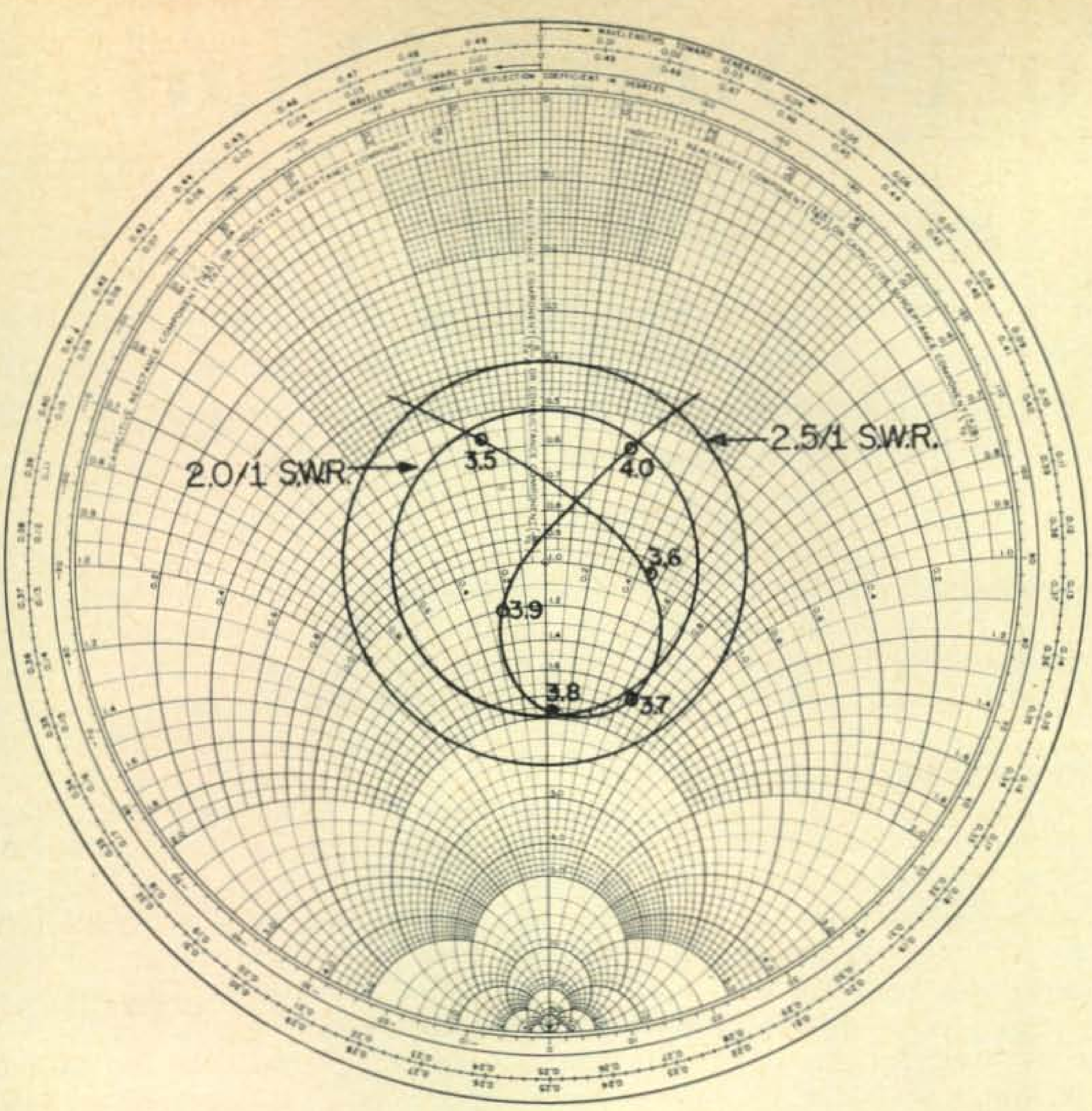

Fig. 4—Curve B of fig. 1 has been bent back on itself as shown above and the 3.5 to 4.0 mc portion lies completely within the 2:1 s.w.r. circle. While not perfect, it is usable over the entire 80 meter band and for those who wish to work outside the band (MARS) it is also usable.

and X_{Cb} is —8.45. Computing them for all the frequencies of interest, we find the following:

Frequency	X_L	X_C	*Sum*
3.5	+7.90	—8.45	— .55
3.6	+8.12	—8.20	— .08
3.7	+8.38	—8.00	+ .38
3.75	+8.49	—7.89	+ .60
3.8	+8.60	—7.78	+ .82
3.9	+8.80	—7.60	+1.20
4.0	+9.03	—7.40	+1.63

Adding their sum to the values for curve B previously stated, we get:

Frequency	*Modified Z_o*
3.5	$.57-j.17$
3.6	$.95+j.45$
3.7	$1.67+j.68$
3.8	$1.96+j.05$
3.9	$1.20-j.22$
4.0	$.57+j.24$

These new values of Z_o are plotted in fig. 4, and one can see what has happened. The impedance curve is folded back on itself, and practically all of it lies within the 2:1 s.w.r. circle. Even the extremes at 3.5 and 4.0 mc are not too bad for those who wish to go outside the band limits for MARS operation. Now you can see why we raised the input Z_o, and balanced the curve about 3.75 mc.

Fig. 5—The new matching network shown above will permit the Mark III to operate over the 3.5 to 4.0 mc band with an s.w.r. of less than 2:1 at any point. The true reactances and component values are shown.

New Circuit

Figure 5 shows the new circuit diagram of the matching network with both true reactances and component values indicated. The true reactances are obtained by multiplying the normalized Z_o values by 51 ohms, and the component values are based upon a center frequency of 3.75 mc as stated above.

For those interested in voltage ratings of components, it should be stated that the series capacitors in the L and differential circuits should be rated for at least 2000 volts if a power of one kilowatt is contemplated. The shunt capacitor

[*Continued on page 94*]

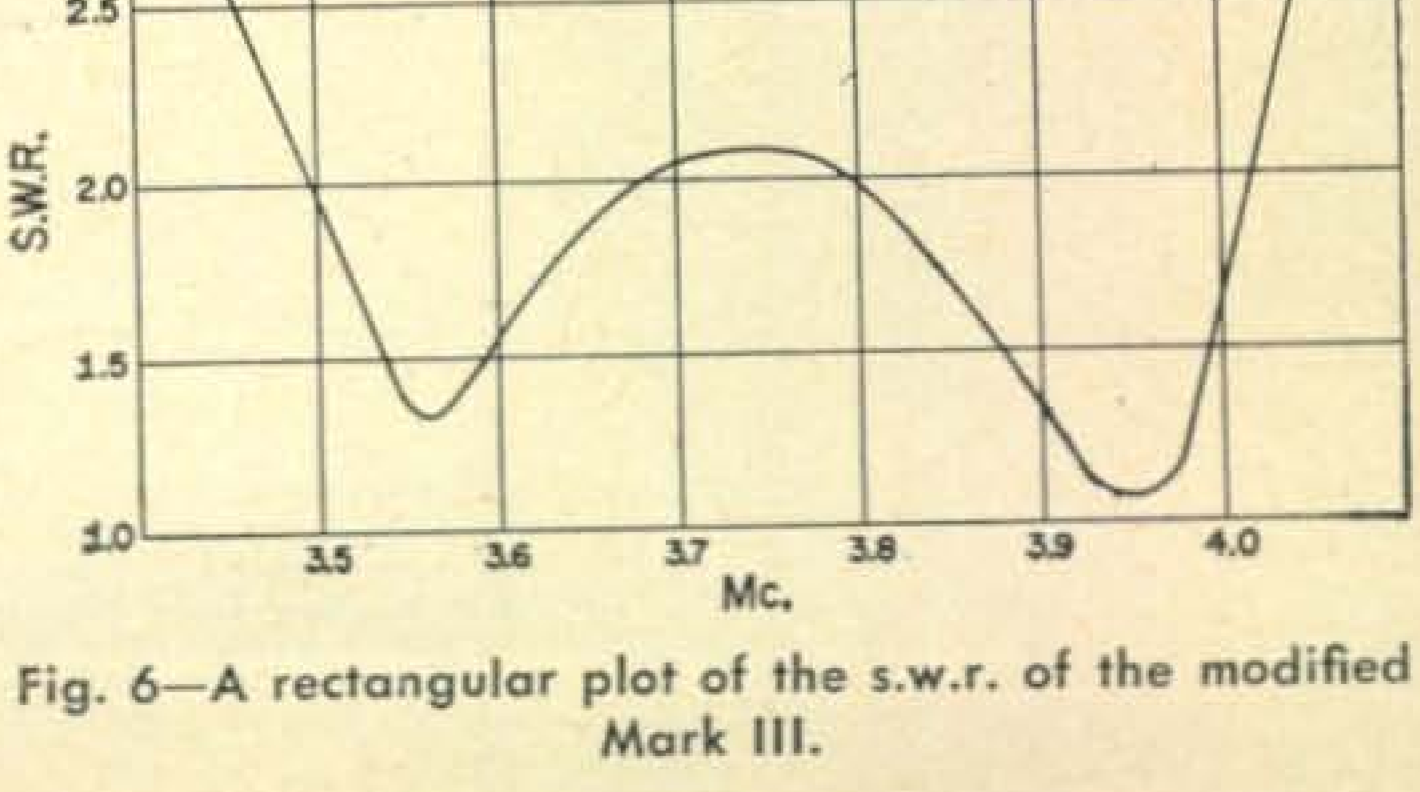

Fig. 6—A rectangular plot of the s.w.r. of the modified Mark III.

USA-CA [*from page 69*]

be transmitted via messages through the National Traffic System.

The nine members of the Net are K4PQL, K4MYO, K4ITV, W4JUJ, W4NLC, K4SDS, K4YNJ, W4ZAU and K4WVT. They are spread out over Virginia. Members will operate portable and mobile on weekends. Normal frequencies will be near 3537, 7030, and 14,075 kc. QSLs will be handled by K4MYO and s.a.s.e. will be required.

Good Will Acknowledgement

Last month we told a story of the need of the 30 members of the Harstad Radio Club, north of Arctic Circle in Norway, for books and magazines for their library . . . our thanks to Charles Folkes, Jr., Van Nuys, Calif., for sending the boys a complete back set of *CQ* to 1951. That's a lot of good reading material . . . like the man said . . . this USA-CA Program has international good will as one of its major purposes. And let's not forget in these trying hamdom times, we could stand a bit better local good will.

What's Cooking Department

Being worked out are details for a top-level Centennial and counties award program for state of Washington. It is expected the governor will affix his stamp of approval. In interim, start collecting all possible Washington counties in 1964 with possibility credit will be given for those worked during 1963. Here will be another example of CHC'ers working to achieve the highest amateur rapport with local, county and state officials to bring world-wide publicity and good will toward all who participate. More next issue.

Old Man, K6BX

Mark III Antenna [*from page 45*]

does not require such a high voltage rating, but it should be rated to carry at least 6 amperes at 4.0 mc. I have had many inquiries about my use of variable vacuums. I used them because they were available to me, and they are very stable under all conditions. Air variables may be used in the Mark III tuning unit, provided they are in a completely weatherproof box.

In the above computations we have neglected losses in the coils and capacitors. This is perfectly legal if we use good quality components. To allow for stray capacities, however, we should make the components variable over a portion of their range. Their approximate values may be found by measuring with an impedance bridge. The final adjustment will have to be made by use of either a General Radio r.f. bridge to check the input impedance, or with an s.w.r. meter which can be operated under power.

Summary

This technique of altering the input impedance of a tuning network or an antenna and twisting the curve back on itself like a pretzel on the Smith Chart can be applied generally to other antennas and matching networks, with certain limitations. The input impedance of the load being altered must be of *positive reactance at the lower frequency*, and of *negative reactance at the higher frequency*, like that in curve *B* of fig. 1. The differential series network which folds up the curve over itself can only be applied if such is the case. (A network of series X_L and X_C always looks more capacitive as frequency is lowered, and more inductive as frequency is raised.) If the load impedance is not as stated above, it must first be reversed in sign by a suitable transformation network before the series differential reactances can be applied.

A rectangular plot of s.w.r. versus frequency for the modified Mark III 80 meter feed is shown in fig. 6. At no time is the s.w.r. exactly 1:1, although it approaches it closely at several frequencies.

Inasmuch as the Mark III is already sufficiently broadened on 7 and 14 mc, even enough to permit MARS operation on frequencies at some distance outside the bands, no changes have been made in the feed for those two bands. The only other change in the Mark III since the original article has been the removal of the 21 mc feed. The vertical pattern was not good for DX on that band. Removal of the 21 mc feed caused the feed point for 14 mc to move down the mast about 3 feet. This is the only change. The antenna has performed well for 20 months as of the date of writing, and no further changes are contemplated. ■

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40 M. Vertical *[from page 40]*

out. One week after loading ours up for the first time, we had worked 12 countries and numerous stateside QSOs on 40 meters. A check of the reports given by all contacts since the vertical went into operation shows an average signal strength of 8-plus. Unimpressed? Well, maximum power here is 135 watts p.e.p.

Perhaps the greatest satisfaction has arisen from saying "Antenna here is a quarter-wave vertical with a counterpoise ground system, all home-brew, OM." To which the guy will reply, "Tell me more, Dave, it sounds interesting." And you've got a good QSO sewed-up. Total cost here, $14.75. How can you miss? ■

Class C Linear *[from page 35]*

a strictly linear exciter—no compression, clipping, or a.l.c.[6] *etc*. More than half the time, not counting pauses, such an envelope has a peak to r.m.s. power ratio 8 db or greater. Since 8 db is about a 2.5 amplitude ratio, if the peak is at the p.e.p. (*i.e.*, no flat-topping), the same r.m.s. value is produced by a constant signal of 1/2.5 of the peak amplitude where the efficiency is also 1/2.5 or 40% of the p.e.p. efficiency. For these very unfavorable conditions (existing most of the time) this amounts to average efficiencies of approximately 40% of 30% (p.e.p. eff.) or 12% for Class A, 40% of 60% or 24% for Class B, and 40% of 80% or 32% for a Class C linear. It's been said many times before but bears repeating—i.e. by comparison, a two-tone signal, which has a 3 db peak r.m.s. ratio, would show 21% for Class A, 42% for Class B, and 56% Class C average efficiencies which look (and are) *lots* higher than voice signals! A.l.c. and/or audio compression will help keep the peaks up at the p.e.p. level, but they can't beat the 8 db Peak/Ave. ratio down because they can't change short interval envelope shapes. A good clipper is the most immediate, practical way to reduce the peak to average envelope ratio, and a good one improves *both* intelligibility and efficiency. The efficiency pay-off for clipping & a.l.c. is greatest of course in the Class C case due to the higher p.e.p. efficiency.

An alternate form for the Clamp tube of fig. 1 is shown in the circuit of fig. 4. A similar version of this was also in the *CQ Sideband Handbook* section (page 154). The 6BL7, V_2, is a dual triode with the first half as a d.c. amplifier, the second as a cathode follower d.c. screen driver or modulator. W6EDD has recently developed this circuit to drive a pair of 4W300B's in a Class C Linear. Its use solves an objection to the circuit of fig. 1 by eliminating R_4 because it has to be a rather husky resistor since the current is high under static conditions. A second problem solved is that if the filament should burn out in the fig. 1 case, or V_2 inadvertently left out of the socket, full screen voltage is applied to the amplifier tube which would certainly be rough! Still another advantage is that the cathode follower of fig. 4, being a low impedance device, will give better assurance of linearity against any non-linear screen grid loading.

Part II of this article will cover the construction and adjustment of a Class C linear amplifier.

[To be continued]

The Dow ECO *[from page 37]*

20 may endanger the crystal. Find out from either a smart old-timer or a smart newcomer what tubes this applies to. Also, operate the screen of electron-coupled crystal oscillators at a maximum of 100 to 150 volts unless special precautions have been taken in the design.

Check the oscillator against a stable standard, such as a continuously-running crystal oscillator or the b.f.o. of a stable receiver. If it is good, use it and enjoy it. Yet, in honesty, remember that much of what you have done was pioneered by Lieutenant Jennings B. Dow, USN, ex-W3TL.

Postscript

Experimenting with oscillators is a most rewarding experience. Comparisons are easy to make between one test and the next.

The principle is basically understood, yet there is much in the subject of oscillators for the ham to improve and invent—for instance a good *and exact* mathematics of how those blinking things work in Class C.

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[6] A.l.c. does not normally affect envelope shape (linearity) providing the time constant is greater than 50 ms.