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Broad-Band Coupling of High-Q Resonant Loads

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***Abstract*—Considering the method of broad-band coupling a series resonant *RLC* load to a resistive source using a uniform quarter-wave transmission-line inverter, it is shown that the 3-dB bandwidth of the network insertion loss reckoned with respect to a 0-dB loss attains a maximum for a particular value of the center frequency insertion loss in the range 0–3 dB. The center frequency loss and the corresponding value of the maximum 3-dB bandwidth are calculated for various loads and the results graphically presented.**

I. Introduction

THERE ARE a number of applications in microwave engineering practice where broad-band circuitry is required. Swept-frequency and communication circuits are two such examples. The high-Q impedance behavior of the load imposes a limit on the range of frequencies over which a given circuit can be operated. In many practical situations, the problem can be reduced to the broad-band coupling of a resonant load to a resistive source. Quantitatively, this requires that the network insertion loss [1] be kept below a specified limit over as large a band of frequencies as possible.

A method of solution, suggested by Reeder and Sperry [2], for broad-band coupling of a series *RLC* resonant load to a resistive source is to use a uniform quarter-wave transmission-line inverter as the coupling network, and to select the characteristic impedance of the line to achieve maximal flatness of the insertion loss versus frequency curve with a view to obtain maximum bandwidth. Though the method approximately achieves maximal flatness of the insertion loss curve, it has no control over the actual level of the curve. If the center frequency loss turns out to be greater than a specified limit, for instance 3 dB, then flattening the insertion-loss curve loses its purpose. By using a quarter-wave transmission-line inverter and selecting its characteristic impedance for maximal flatness of the insertion loss curve, the center frequency loss can be seen to assume values greater than 3 dB [2] for small values of the normalized load resistance.

In some applications, it is more important to achieve a low center frequency insertion loss than it is to obtain a specific bandpass response, such as a maximally flat or specified ripple. Rather, it may be desired that the network insertion loss is simply less than a maximum value, say 3 dB, over the largest possible bandwidth. In this case, one would determine the bandwidth for a given maximum insertion loss with respect to 0 dB, not with respect to the network center frequency insertion loss. Although the maximum allowed insertion loss may be

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selected arbitrarily, this paper assumes a 3-dB maximum allowed loss, and measures the network operating bandwidth with respect to a 0-dB loss.

It is shown that, using a quarter-wave transmission line for coupling a series RLC resonant load to a resistive source, the 3-dB bandwidth (reckoned with respect to a 0-dB loss) attains a maximum for a value of center frequency insertion loss in the range 0–3 dB. The value of the center frequency loss, for which the bandwidth is maximum, and the value of the maximum bandwidth are calculated for various values of load parameters, and the results graphically presented.

II. Broad-Band Coupling

Consider the network of Fig. 1, which uses a lossless quarter-wave uniform transmission line to couple a series RLC load resonant at a frequency f_0 to a resistive source. Let the load impedance be represented by

$$Z_L = R_L + j2\pi fL + (j2\pi fC)^{-1} = R_L(1 + jQF)$$

where $Q = (2\pi f_0 L/R_L)$, and $F = [(f/f_0) - (f_0/f)]$, f being the operating frequency. The input impedance Z_{in} at the left-hand end of the line in Fig. 1 is given by

$$Z_{in} = \frac{Z_0(Z_L + jZ_0 \tan\theta)}{(Z_0 + jZ_L \tan\theta)} \tag{1}$$

where Z_0 is the characteristic impedance of the line, and $\theta = (\pi f/2f_0)$ is the transmission phase. Normalizing the input impedance Z_{in} with respect to the source resistance R_g, (1) can be written as

$$z_{in} = (Z_{in}/R_g) = (x_1 + jy_1)/(x_2 + jy_2)$$

where

$$x_1 = rz_0, \qquad y_1 = rz_0QF + z_0^2 \tan\theta$$
$$x_2 = z_0 - rQF \tan\theta, \qquad y_2 = r\tan\theta$$

in which $r = (R_L/R_g)$ and $z_0 = (Z_0/R_g)$ are, respectively, the normalized load resistance and the normalized characteristic impedance of the line. The network reflection coefficient Γ and insertion loss $L(f)$ are then given by

$$\Gamma = (z_{in} - 1)/(z_{in} + 1)$$

and

$$L(f) = \left[1 - |\Gamma|^2\right]^{-1} = \frac{(x_1 + x_2)^2 + (y_1 + y_2)^2}{4(x_1x_2 + y_1y_2)}. \tag{2}$$

The center frequency value L_0 of the insertion loss in (2) can be obtained as

$$L_0 = L(f_0) = (r + z_0^2)^2/4rz_0^2. \tag{3}$$

For a given load and L_0 $(1 \leqslant L_0 \leqslant 2)$, the value of z_0 can be obtained from solving (3), as

$$z_0^2 = r\left[(2L_0 - 1) \pm 2\sqrt{L_0(L_0 - 1)}\,\right] \tag{4}$$

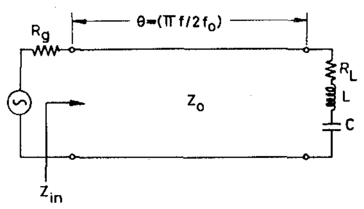

Fig. 1. Coupling of a series resonant load to a resistive source using a quarter-wave transmission-line inverter.

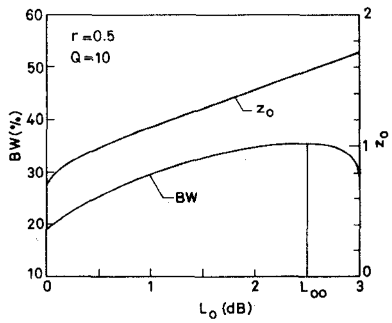

Fig. 2. Curves of z_0 and 3-dB bandwidth for $r = 0.5$ and $Q = 10$, as L_0 (dB) is varied from 0 to 3 dB.

and the 3-dB bandwidth of the insertion loss in (2) can be computed using the value of z_0 in (4). If one is interested in broad-band coupling, one can continuously vary L_0 (dB) in the range 0–3 dB, and locate the value of center frequency loss L_{00} for which the 3-dB bandwidth (reckoned with respect to 0-dB loss) is maximum. The existence of L_{00} can be argued as follows. It is a known fact that lower insertion loss can be traded for increased bandwidth. Therefore, as the value of L_0 (dB) is increased from zero, the insertion loss, using the larger value of z_0 obtained from (4) in (2), can be initially expected to become more and more flat [2] and later possess a Chebyshev ripple response, thereby giving a larger 3-dB bandwidth. At the other end, as the value of L_0 (dB) approaches 3 dB, the value of the 3-dB bandwidth (reckoned with respect to 0-dB loss) must approach zero or maximum. Based on these two observations, it can be concluded that the 3-dB bandwidth (reckoned with respect to 0 dB loss) must attain a maximum for some value of center frequency loss in the range $0 < L_0$ (dB) $\leqslant 3$ dB, that value of loss being denoted by L_{00}. For a given load, the insertion loss curve having maximum bandwidth will exhibit a single minimum or ripple according as the center frequency loss L_{00} (dB) is less than or equal to 3 dB.

III. Results

The above procedure of finding z_0 from (4) and the 3-dB bandwidth of the insertion loss in (2) for $r = 0.5$ and $Q = 10$, as the center frequency loss is varied from 0 to 3 dB, is implemented on a computer and the results graphically shown in Fig. 2. The 3-dB bandwidth is expressed as a percentage of the center frequency f_0 in Fig. 2. It can be seen from this figure, that the 3-dB bandwidth attains a maximum at a center frequency loss given by L_{00}.

The procedure for finding the center frequency loss L_{00}, the maximum 3-dB bandwidth of the insertion loss in (2), and the corresponding value of z_0 is repeated for various sets of values of load parameters r and Q, and the results shown in Fig. 3. For broad-band coupling a given load to a source of specified internal resistance, the value of the normalized characteristic impedance z_0 of the line and the resulting maximum 3-dB bandwidth and L_{00} can be read from Fig. 3.

The results obtained here cannot be directly compared with those of [2] because the 3-dB bandwidth in [2] is measured with respect to a floating center frequency loss, whereas the 3-dB bandwidth here is measured with respect to 0-dB loss (irrespective of the center frequency loss) for reasons mentioned earlier. However, the bandwidths obtained here are greater than those obtained in [2] at higher values of r for any Q. These larger bandwidths result from the fact that the conditions used here are not restricted to a specified insertion loss frequency response characteristic.

IV. Example

Let the parameters of the load be given by $r=0.5$ and $Q=15$. Suppose that it is desired to couple this load over as wide a band of frequencies as possible using a quarter-wave line. The center frequency loss L_{00} for this case using Fig. 3(c) is read as 1.9 dB, and the normalized characteristic impedance of the line from Fig. 3(a) is obtained as $z_0=1.4$. The 3-dB bandwidth for this case is 20.6 percent, which is about 1.7 times larger than would be obtained if the transmission-line network were designed to give a true center frequency impedance match (i.e., $z_0=0.707$, $L_0=0$ dB).

V. Conclusions

Considering the method of broad-band coupling a series resonant RLC load to a resistive source using a quarter-wave transmission-line inverter, it is shown that the 3-dB bandwidth (reckoned with respect to 0-dB loss) of the network insertion loss can be maximized for a value of center frequency loss in the range 0 to 3 dB. A computational procedure for finding the center frequency loss for which the 3-dB bandwidth attains this maximum is outlined. The values of center frequency insertion loss and the maximum 3-dB bandwidth have been calculated for various sets of values of load parameters, and the results graphically presented. An example has been worked out illustrating the use of these results.

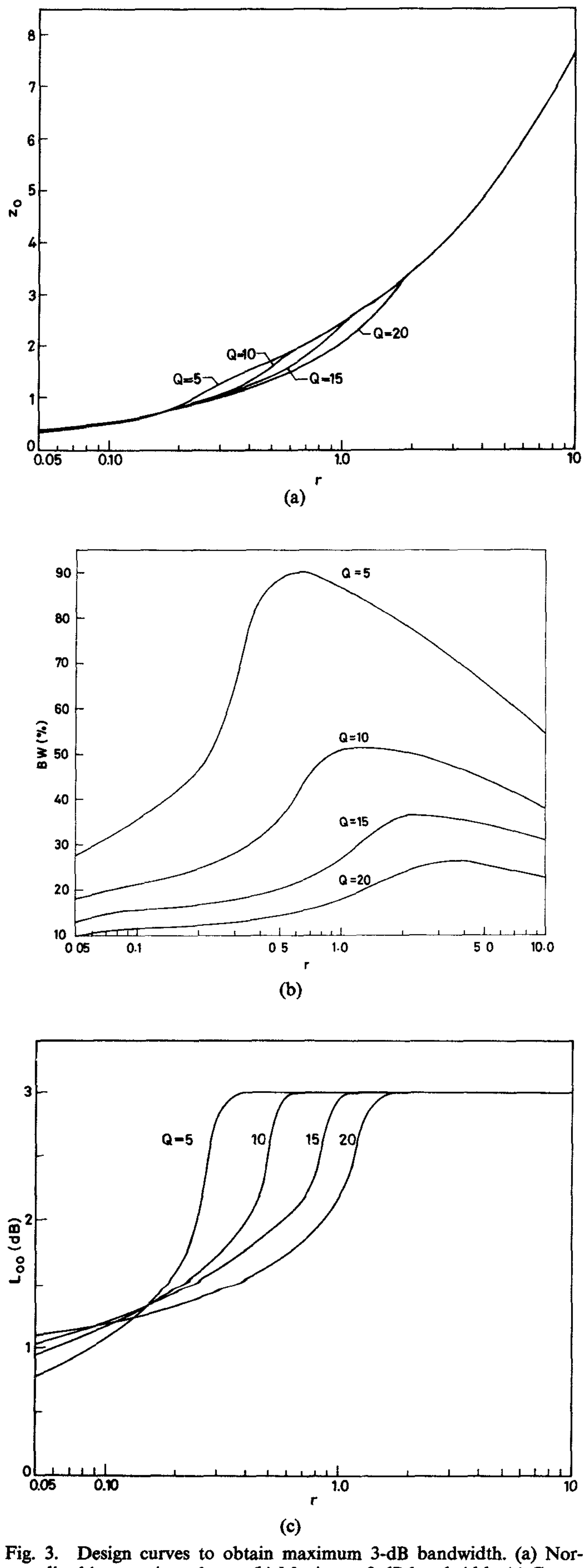

Fig. 3. Design curves to obtain maximum 3-dB bandwidth. (a) Normalized inverter impedance. (b) Maximum 3-dB bandwidth. (c) Center frequency insertion loss versus normalized load resistance.

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