COMPUTER-AIDED DESIGN OF

BROAD-BAND ACTIVE MATCHING NETWORKS

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Abstract

Described is a computer-aided technique of designing active matching networks using distributed constant circuit elements. The merits and limitations of various performance indices which have been used are discussed. Some sample designs are presented.

Introduction

Analytical approaches in the literature have shown that it is only possible to match a given complex impedance function to a resistive generator to within a constant deviation from a perfect match; the greater the bandwidth being considered the larger the deviation.[1,2,3] Thus, if one is interested in matching a complex impedance (such as an electrically small antenna) to a transmission line over a broad-band (2 to 1 or greater) some other technique must be used.

By introducing active elements, relatively simple matching networks, consisting of distributed constant elements, can produce an effective match of electrically small antennas over a relatively broad-band (3 to 1).

The general approach to the problem and some of the early results were presented in a paper by Trick and Vlach[5]. This paper describes some changes, additions and improvements to this approach which have been made since these publications.

Design Technique

The technique involves representing all elements of the matching network by their respective transformation of T matrices normalized to a common reference impedance (50 ohms is usually used). The basic elements of the matching network are (a) the active device [transistor(s)], (b) a length of transmission line having a characteristic impedance Z_L and a length ℓ_L, (c) a shorted or open shunt stub having a Z_s and ℓ_s, (d) an input normalization matrix (ML), and (e) an output normalization matrix (MR). These normalization matrices characterize respectively the source and the load. The S-parameters (scattering matrix) of the transistor and complex source or load impedances are measured values over the frequency range of interest (every 10 MHz from 150 → 450 MHz in our case). The matching network is constructed from these basic building blocks and a composite scattering matrix, S_T, is obtained (see Figure 1).

The S-parameters of this composite scattering matrix characterize the whole network including the complex terminating impedances, and are defined in terms of the variables of the distributed constant matching elements (Z_{L1}, ℓ_{L1}, Z_{S1}, ℓ_{S1}, etc.). For example, $|S_{T21}|^2$ represents the power delivered to the 50 ohm transmission line from the complex source relative to the maximum power available from the source (usually greater than 1 for an active matching network). S_{T11} and S_{T22} are the input and output reflection coefficients and $|S_{T12}|^2$ is the power going backwards through the network (since the transistor is unidirectional, S_{T12} is small).

These composite S-parameters are utilized in various ways to create error functions which can be minimized by an optimization routine (a modified version of Rosenbrock's direct search minimization procedure in our case).[6] An error function can be made to stress various aspects of the design, gain flatness, maximum power transfer, optimum noise match and various combinations of these features.

For a compromise between gain flatness and good match the following error function has been used:

$$E = \sum_{i=1}^{n} \{b\left|\,|S_{T21}^{\,i}|^2 - |S_{T21}^{\,v}|^2\right|^d + a(|S_{T11}^{\,i}|^2 + |S_{T22}^{\,i}|^2)\}. \qquad (1)$$

where $(|S_{T21}^{i}|^2 - |S_{T21}^{v}|^2)$ is the deviation at each frequency, i, of the power gain $|S_{T21}^{i}|^2$, from an average power gain $|S_{T21}^{v}|^2$, and $|S_{T11}^{i}|^2$ and $|S_{T22}^{i}|^2$ are the reflection losses at the input and output ports, and a, b, and d are weight factors.

If one wants to stress maximum constant gain over a band a good error function is:

$$E_f = \sum_{i=1}^{n} \left|G_{max}(f_{max}) - |S_{T21}^{\,i}|^2\right|^d \qquad (2)$$

where $G_{max}(f_{max})$ is the maximum gain of the active device at the maximum frequency being considered.

If one wants maximum power transfer the following error function can be used:

$$E_{\substack{max\\power}} = \sum_{i=1}^{n} \left|10 \log_{10} \frac{G_{max}^{\,i}}{|S_{T21}^{\,i}|^2}\right|^d \qquad (3)$$

where maximum gain of the active device is obtained from its measured S-parameters by

$$G_{max} = \frac{|S_{21}|^2}{(1 - |S_{11}|^2)(1 - |S_{22}|^2)} \qquad (4)$$

When optimum noise performance of the active device is desired, it is best to utalize a two step procedure. As an example, consider the case of a receiving antenna feeding a 50 ohm transmission line through a matching network consisting of an L section, a transistor, and a second L section, see Figure 2. The first step is to design the first L section to provide the best noise performance of the transistor (the transistor is presented with its optimum source impedance in the low noise sense). The error function is

$$E_{noise} = \sum_{i=1}^{M} \left|T_e^{\,i} - T_{eo}^{\,i}\right|^d \qquad (5)$$

or

$$E_{noise} = \sum_{i=1}^{n} \left[(T')^i \frac{[(R_s^i - R_o^i)^2 + (X_s^i - X_o^i)^2]}{R_o^i R_s^i} \right]^d \qquad (6)$$

where R_o^i and X_o^i are the optimum and R_s^i and X_s^i are the actual source resistances and reactances at each frequency i. The constant (T') is a measure of how sensitive the actual noise temperature, T_e^i, is to a good match. R_o^i, X_o^i, T_{eo}^i and (T') are all measured values. The second L section is then designed to provide maximum constant gain or maximum power transfer.

Sample Design

As an example of the application of the design technique, the simulated impedance of a slot antenna was matched to a 50 ohm load over a 3 to 1 band (150 to 450 MHz). A Smith Chart plot of the simulated slot impedance is shown in Figure 3. Figures 4 and 5 compare the conjugate mismatch loss of the slot without the matching network, to gain of the slot-matching network combination, for the cases of maximum constant gain and maximum power transfer, without and with noise optimization. Figure 6 shows curves of noise figure as a function of frequency for the cases of maximum constant gain and maximum power transfer before noise optimization and the improvement in noise figure after noise optimization.

Conclusions

This paper describes a practical technique of utilizing a computer and a minimization procedure to design active matching networks. Due to the flexibility of this technique, it can be applied to a large variety of network configurations and design objectives.

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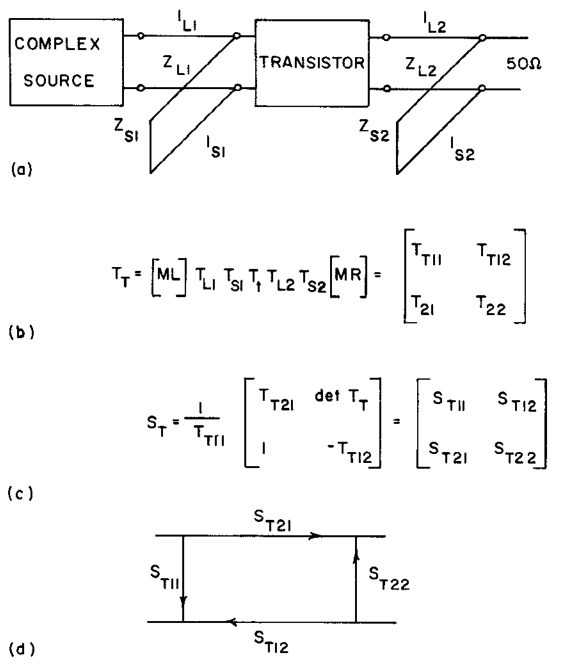

FIG. 1 A SAMPLE ACTIVE MATCHING NETWORK CONSTRUCTED FROM THE BASIC CIRCUIT ELEMENTS AND THE RESULTING COMPOSITE T AND S MATRICES.

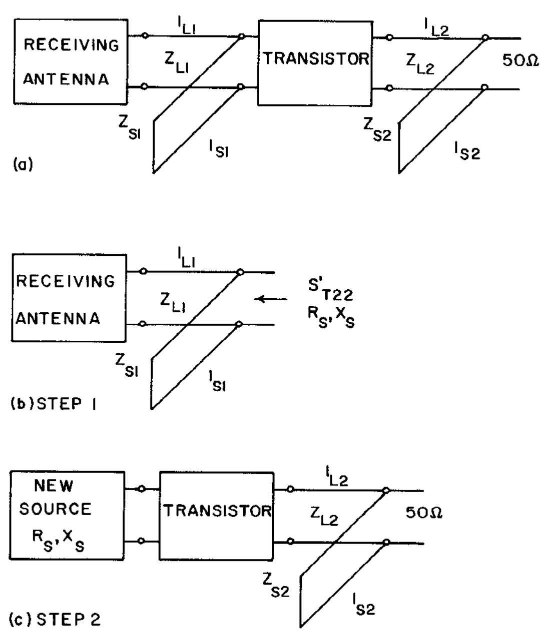

FIG. 2 AN EXAMPLE OF HOW A TWO STEP PROCEDURE IS USED TO DESIGN AN ACTIVE MATCHING NETWORK WHICH IS OPTIMIZED FOR NOISE.

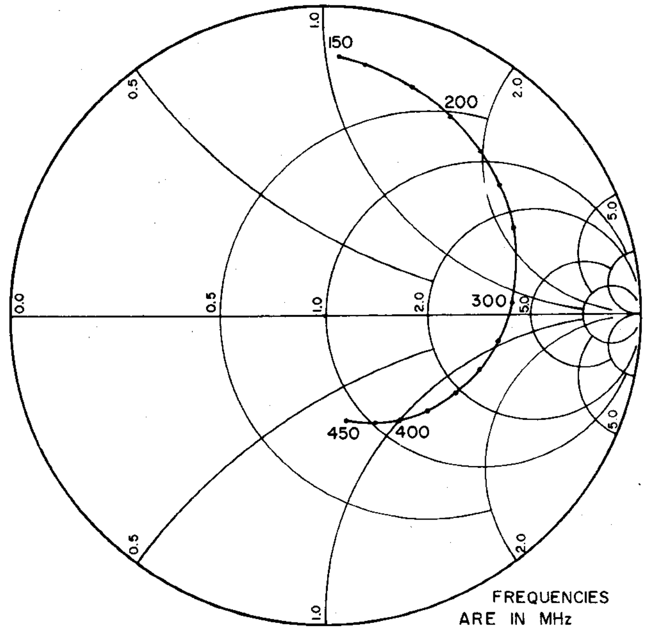

FIG. 3 A SMITH CHART PLOT SHOWING THE MEASURED IMPEDANCE AS A FUNCTION OF FREQUENCY (150 TO 450 MHz) OF A SIMULATED SLOT ANTENNA.

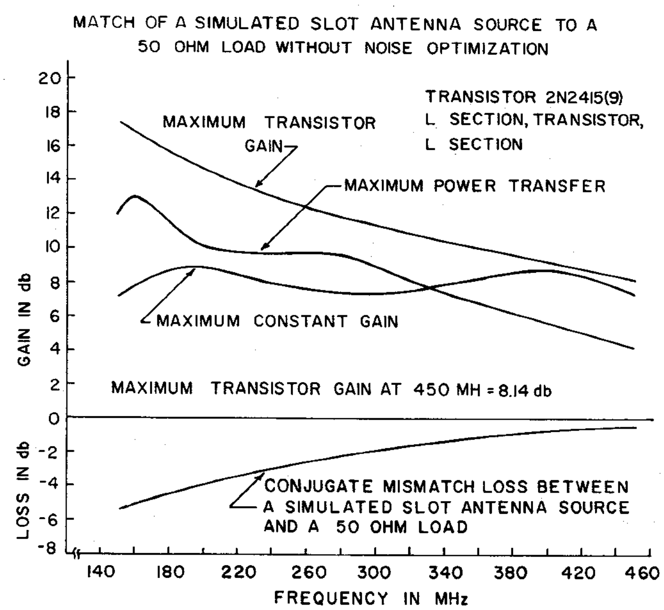

FIG. 4 CALCULATED CURVES COMPARING THE MATCH OF A SIMULATED SLOT ANTENNA SOURCE TO A 50 OHM LOAD WITH AND WITHOUT AN ACTIVE MATCHING NETWORK (NOISE NOT CONSIDERED).

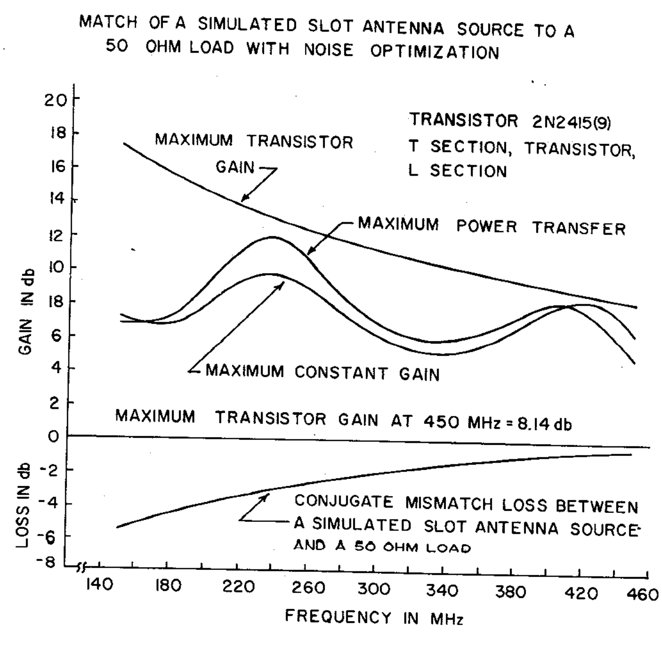

FIG. 5 CALCULATED CURVES COMPARING THE MATCH OF A SIMULATED SLOT ANTENNA SOURCE TO A 50 OHM LOAD WITH AND WITHOUT AN ACTIVE MATCHING NETWORK (NOISE CONSIDERED).

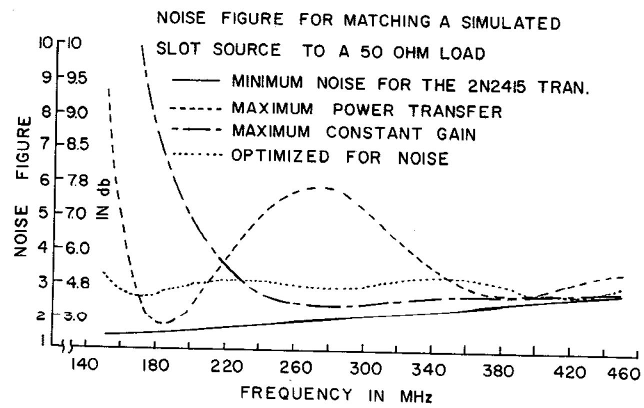

FIG. 6 CALCULATED CURVES COMPARING THE NOISE FIGURES OF A MAXIMUM CONSTANT GAIN, MAXIMUM POWER TRANSFER AND OPTIMIZED NOISE MATCH WITH THE MEASURED OPTIMUM NOISE OF THE TRANSISTOR [2N2415(9)], FOR A SIMULATED SLOT ANTENNA SOURCE AND A 50 OHM LOAD.