TÜBİTAK
MARMARA BİLİMSEL VE ENDÜSTRİYEL ARAŞTIRMA ENSTİTÜSÜ

ELEKTRONİK ARAŞTIRMA BÖLÜMÜ

EXTENSION OF THE SIMPLIFIED REAL FREQUENCY TECHNIQUE AND A DYNAMIC DESIGN PROCEDURE FOR DESIGNING MICROWAVE AMPLIFIERS

B.S. Yarman

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EXTENSION OF THE SIMPLIFIED REAL FREQUENCY TECHNIQUE AND A DYNAMIC DESIGN PROCEDURE FOR DESIGNING MICROWAVE AMPLIFIERS

B.S. YARMAN

ABSTRACT

The simplified real frequency technique, which is qualitatively shown to offer better design performance over the other available techniques for broadband matching networks with lumped elements, is extended to incorporate distributed network elements. Besides the computer program is now developed utilizing a dynamic procedure (instead of the existing prodecure) for designing microwave amplifiers. Thus, it is possible to design such networks with lumped, distributed and mixed elements, as well. The effectiveness of this technique in the design of single stage and multi stage amplifiers are demonstrated with several examples. It is therefore, expected to be useful in the design of active and passive networks.

DESIGN OF MATCHING NETWORKS WITH COMMENSURATE TRANSMISSION LINES

The Simplified Real Frequency Technique (SRFT) proposed by Yarman and Carlin [1]-[3] is useful in the design of broadband matching networks or equalizers between an arbitrary load and a complex generator (Fig. 1), The design procedure utilizes measured data from the generator and the load networks. It does not require a priori decisions about the algebraic form of the transfer function or circuit topology. With the use of an optimization procedure, it yields almost optimum and physically realizable matching networks.

At microwave frequencies, distributed matching networks employing transmission line elements may be required. In such cases SRFT can be readily implemented with the use of Richards' transformation [4]. The remaining procedure is essentially similar to that given in [2], except that the lossless reciprocal equalizer now consists of commesurate transmission line sections.

Referring to Fig. 1, Let us assume that equalizer E consists of n cascaded transmission lines, all of equal length and the same propogation constant β. In this case, the scattering parameters e_{11} and e_{22} of E are Bounded Real (BR) rational functions of exp ($j\beta l$). On the application of Richards' transformation [4], e_{11} and e_{22} become rational functions of the Richards' variable λ ;

$$\lambda = \tanh(j\beta l) = \Sigma + j\Omega \qquad (1)$$

but the transfer scattering coefficient e_{21} may not always be a rational function of λ. However, it remains BR for $\mathrm{Re}\lambda \geq 0$. Carlin [5] proves that necessary and sufficient condition for e_{21} to represent a cascade of n lossless βl type lines is that

$$0 \leq |e_{21}(j\Omega|^2 = \frac{(1+\Omega^2)^n}{G(\Omega^2)} \leq 1 \ ; \quad \infty \leq \Omega \leq \infty \qquad (2)$$

where $G(\Omega^2)$ is an even positive polynomial of degree 2n. Hence $e_{21}(\lambda)$ is given by the explicit factorization of (2) in λ domain.

That is,

$$e_{21}(\lambda) = \frac{(1-\lambda^2)^{n/2}}{g(\lambda)} \qquad (3)^*$$

where $g(\lambda)$ is a Hurwitz polynomial of degree n and formed on the Left Half Plane (LHP) roots of $G(-\lambda^2)$ (i.e. $G(-\lambda^2) = g(\lambda)g(-\lambda)$). It is clear that $e_{21}(\lambda)$ is irrational when n is odd.

If the input reflection coefficient e_{11} is assummed to have the following form

$$e_{11}(\lambda) = \frac{h(\lambda)}{g(\lambda)} = \frac{\sum_{k=o}^{n} h_k \lambda^k}{\sum_{k=o}^{n} g_k \lambda^k} \qquad (4)$$

then, the remaining scattering parameters e_{ij} are also implicitly expressed in terms of $h(\lambda)$ as in [1]-[3].

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* *Note that $e_{12} = e_{21}$ by reciprocity.*

Since E is lossless, it follows that

$$e_{22}(\lambda) = -e_{11}(\lambda)\,\frac{e_{21}(\lambda)}{e_{21}(-\lambda)} = -\frac{h(-\lambda)}{g(\lambda)} \qquad (5)$$

and

$$\begin{aligned} G(-\lambda^2) &= g(\lambda)g(-\lambda) = h(\lambda)h(-\lambda) + (1-\lambda^2)^n \\ &= G_o + G_1\lambda^2 + \cdots + G_n\lambda^{2n} \qquad (6) \end{aligned}$$

In (4), the coefficients G_k are given in terms of the coefficients of $h(\lambda)$:

$$\begin{aligned} G_o &= h_o + 1 \\ G_k &= h_k^2 + 2\sum_{j=1}^{k} h_{(j-1)}\, h_{(2k-j+1)} + (-1)^k \frac{n!}{k!(n-k)!}\ , \ k = 1,2,\ldots,(n-1) \\ &\vdots \\ G_n &= h_n^2 + (-1)^n \qquad (7) \end{aligned}$$

Now, the Transducer Power Gain (TPG) $T(\omega)$

$$T(\omega) = T_g \frac{|e_{21}|^2 |l_{21}|^2}{|1-e_{11}S_G|^2 |1-\hat{e}_{22}S_L|^2} \qquad (8)$$

of the doubly terminated structure can be generated in terms of the coefficients h_k. In this process, the common denominator polynomial for all e_{ij} is computed by the explicit factorization of (6). In (8), the terms T_g, l_{21} and $\hat{e}_{22}$ are given as follows

$$\begin{aligned} T_g &= 1 - |S_G|^2 \\ |l_{21}|^2 &= 1 - |S_L|^2 \\ \hat{e}_{22} &= e_{22} + \frac{e_{21}^2 S_G}{1-e_{11}S_G} \qquad (9) \end{aligned}$$

where S_G and S_L are the real normalized generator and load reflection coefficients respectively. Thus, the coefficients h_k are unknown for the matching problem and they can be determined with the use of nonlinear optimization techniques, or linear programming techniques described in [6], such that, TPG is optimum in the specified band according to the definitions given in [6] and [7].

Richards' extraction is then utilized on $e_{11}(\lambda)$ or $e_{22}(\lambda)$ to obtain the distributed matching network consisting of cascaded commensurate line sections. The computer program is implemented in such a way that it is possible to realize the matching networks partly with lumped elements and partly with distributed elements by exchanging the network elements properly. It, thus, provides greater flexibility in circuit design.

It should be noted that the performance of the matched system associated with (2) may be improved by choosing a more general generic form for $e_{21}(\lambda)$ (e.g. $|e_{21}(j\Omega)|^2 = \dfrac{\Omega^q(1+\Omega^2)^n}{G_{n+q}}$; q is a positive integer)

Inclusion of any form of $|e_{21}|^2$ in our procedure is straighforward, provided the coefficients G_k given by (7) are revised properly. However the resulting matching networks coming from more complex forms of $|e_{21}|^2$ may be difficult to realize practically.

A DYNAMIC PROCEDURE FOR DESIGNING MICROWAVE AMPLIFIERS

The extended simplified real frequency technique is combined with a dynamic design procedure presented below, rather than the existing sequential procedure proposed in [1]-[3] to design microwave amplifiers.

Referring to Fig.2a, in the sequential procedure, the input matching network is first designed when the output of the active device is resistively terminated. Next, the output matching network is developed after removing the resistive termination. At this stage, overall TPG is optimized (Fig.2c). The above procedure is repeated several times until the desired gain level is reached.

The new dynamic design procedure consists of two major steps:

(a) The input matching network is first designed when the output is terminated in a hypothetical perfect match S_0. Clearly, S_0 is the function of input matching network as well as the active device. At this stage, $\tilde{T}(\omega)$ the gain under perfect match conditions, is optimized (Fig. 2b).

(b) Next, the hypothetical match S_0 is removed and the output matching network is designed (Fig. 2c). At this stage, the transducer power gain $T(\omega)$ is optimized, which approaches to $\tilde{T}(\omega)$.

This technique can also be utilized to design multistage amplifiers. The matching networks are designed one at a time with the output of the active device terminated in a perfect match in a manner similar to that given in [2].

Finally, we demonstrate these design procedures with several examples.

Example 1 presents a design of a complete X-band (8.2-12.4 GHz) FET amplifier. Both the input and the output matching networks consist of distributed elements. These elements can be easily realized in microstrip lines. This example also illustrates the design with mixed elements.

In Example 2, a single-stage amplifier for the 6-16 GHz band is designed. The input and output matching networks are designed employing the dynamic design procedure discussed above. The use of iterations as in sequential technique did not yield further improvement of the design. A number of other computer programs such as COSMIC [8] and Super-COMPACT [9] have likewise not been able to improve upon the element values of the matching networks obtained with our technique. For comparison, the gain performance obtained with this technique is 7.35 ±0.33 dB and an independent design carried out using Super-COMPACT yields 6.81 ±0.5 dB.

A two-stage broadband FET amplifier is designed in Example 3. It is shown that the gain performance of the amplifier is reshaped, that is, the gain variation in the passband is reduced, when it is attempted to re-optimize the best amplifier design obtained with this technique by changing the element values of the matching network using COSMIC.

SUMMARY AND CONCLUSION

In this presentation, we have extended the algorithm of the simplified real frequency technique for broadband matching networks with lumped elements to incorporate commensurate transmission lines. Moreover, a new dynamic procedure to design microwave amplifiers has been discussed. By means of several examples, it has been shown that the new design technique yields superior amplifier performances over the other available CAD techniques

(e.g. Cosmic, Compact or Super Compact etc.).*

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REFERENCES

[1] B.S. Yarman and H.J. Carlin, "A Simplified Real Frequency Technique Appliable to Broadband Multistage Amplifiers", 1982 IEEE Int. Microwave Symposium Dallas, Tx., Digest, pp.529.

[2] B.S. Yarman, "A Simplified Real Frequency Technique for Broadband Matching a Complex Generator to a Complex Load", RCA Review vol.43, September 1982.

[3] B.S. Yarman and H.J. Carlin, "A Simplified Real Frequency Technique Applied to Broadband Multistage Microwave Amplifiers", IEEE Trans. MTT, vol. 30, No.12, December 12, 1982.

[4] P.I. Richards, "Resistor Transmission Line Circuits", Proc. IRE, vol.36, pp.2217-2220, Feb. 1948.

[5] H.J. Carlin, "Distributed Circuit Design with Transmission Line Elements", Proc. IEEE, vol.59, pp. 1059-1081, July 1981.

[6] B.S. Yarman, "Real Frequency Broadband Matching via Linear Programming", RCA Review, vol. 43, December 1982.

[7] H.J. Carlin and P. Amstutz, "On Optimum Broadband Matching", IEEE Trans. CAS, vol. 28, pp.401-405, May 1981.

[8] B.S. Perlman, et al, "Computer aided design and Testing of Microwave Circuits", RCA Engineer, vol. 27, No. 5, Sept/Oct. 1982, pp.76-86.

[9] Super Compact users Manualy Compact Engineering, Palo Alto, California.

* *Because of the space restrictions, we couldn't include the details of the examples. However more information can be obtained from the author.*

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[4] P.I. Richards, "Resistor Transmission Line Circuits", Proc. IRE, vol.36, pp.2217-2220, Feb. 1948.

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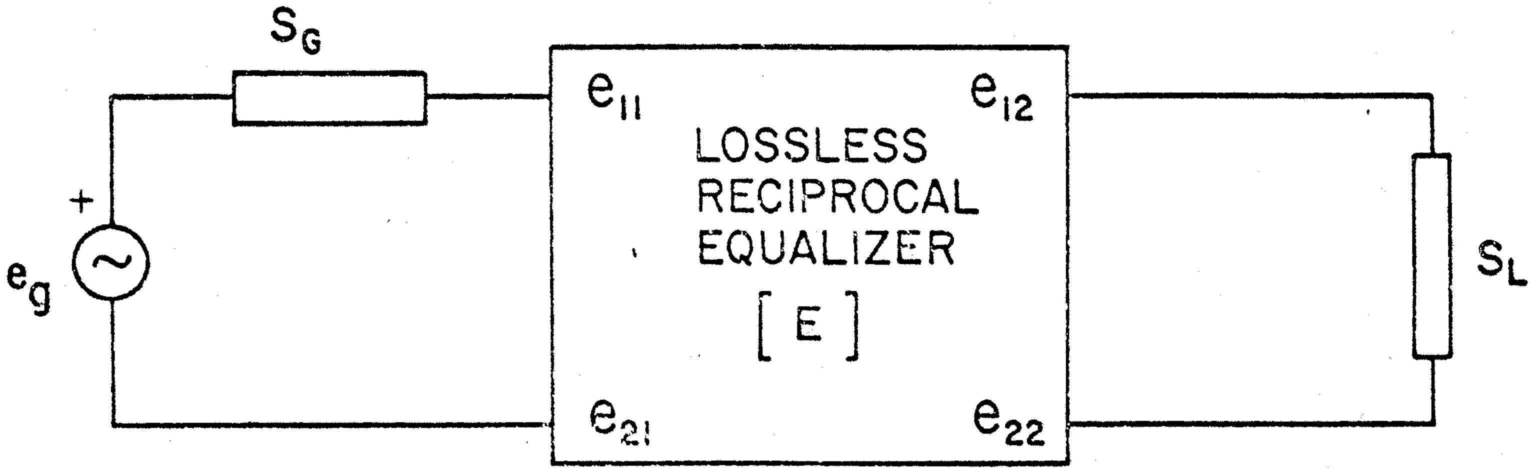
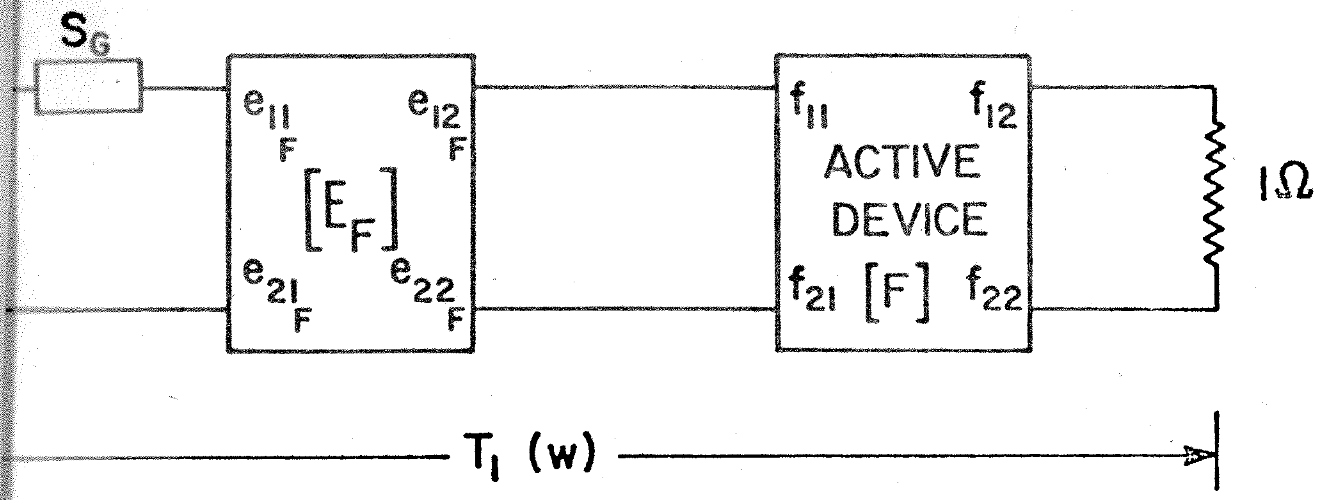


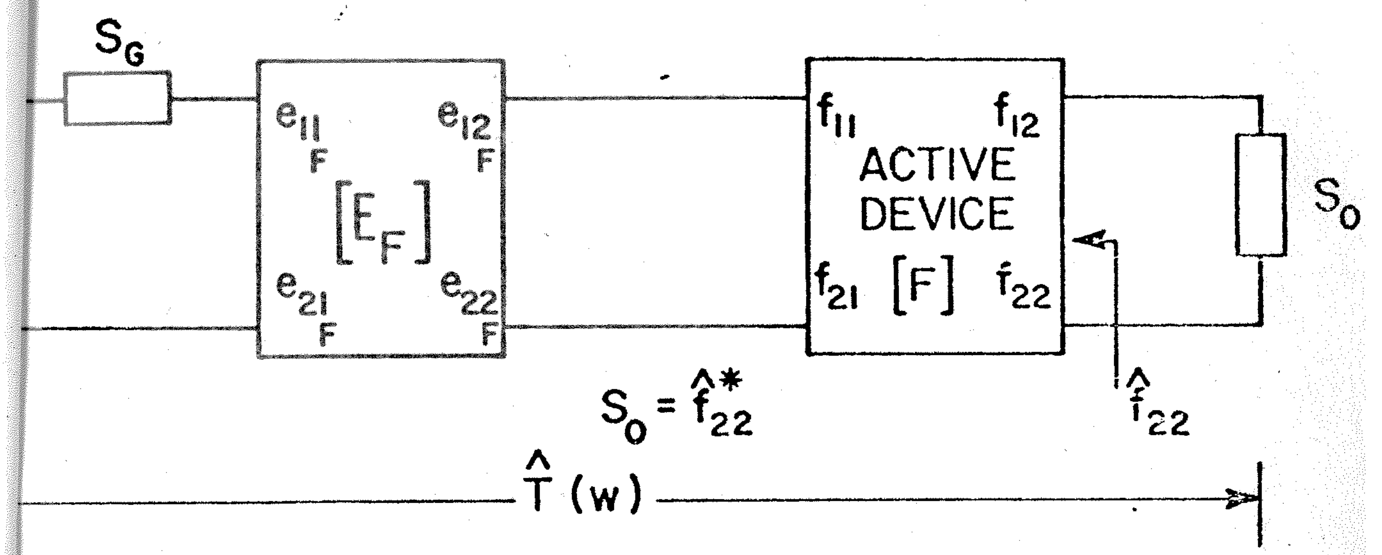
Figure 1

Generalized Broadband Matching Problem

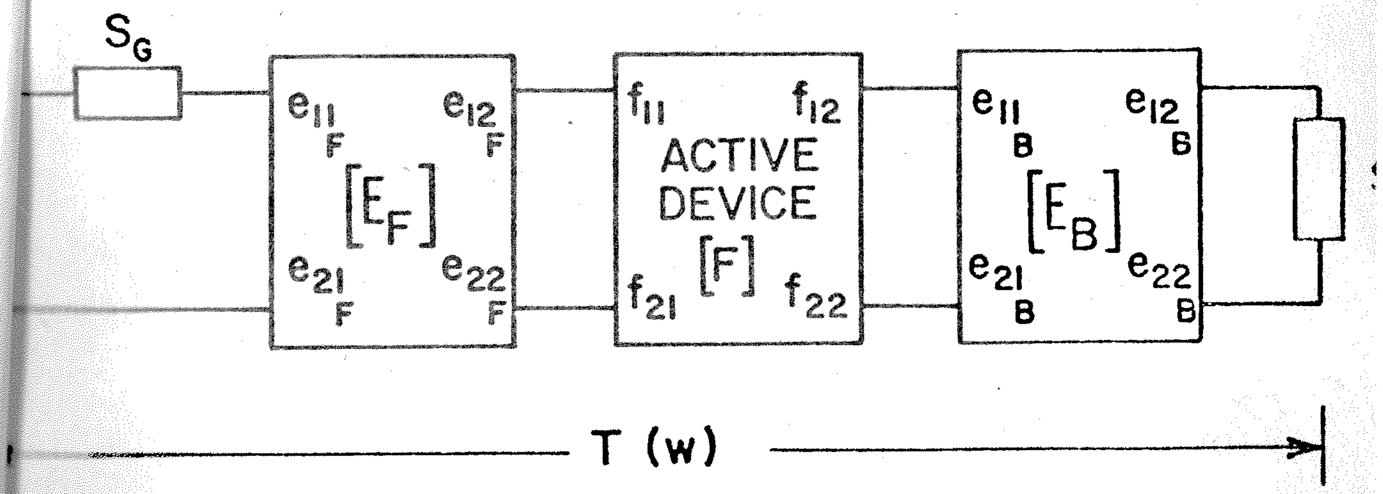
Figure 2



(a) Development of the input matching network as a first step in sequential design procedure.

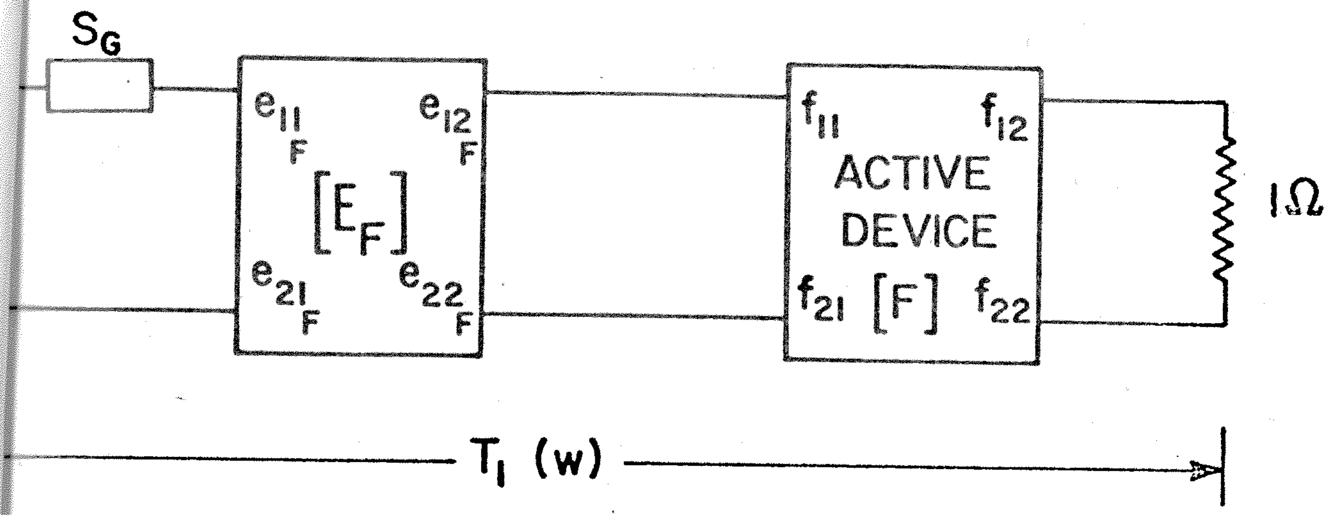


(b) Development of input matching network in dynamic design procedure



(c) Development of output matching network

Figure 2



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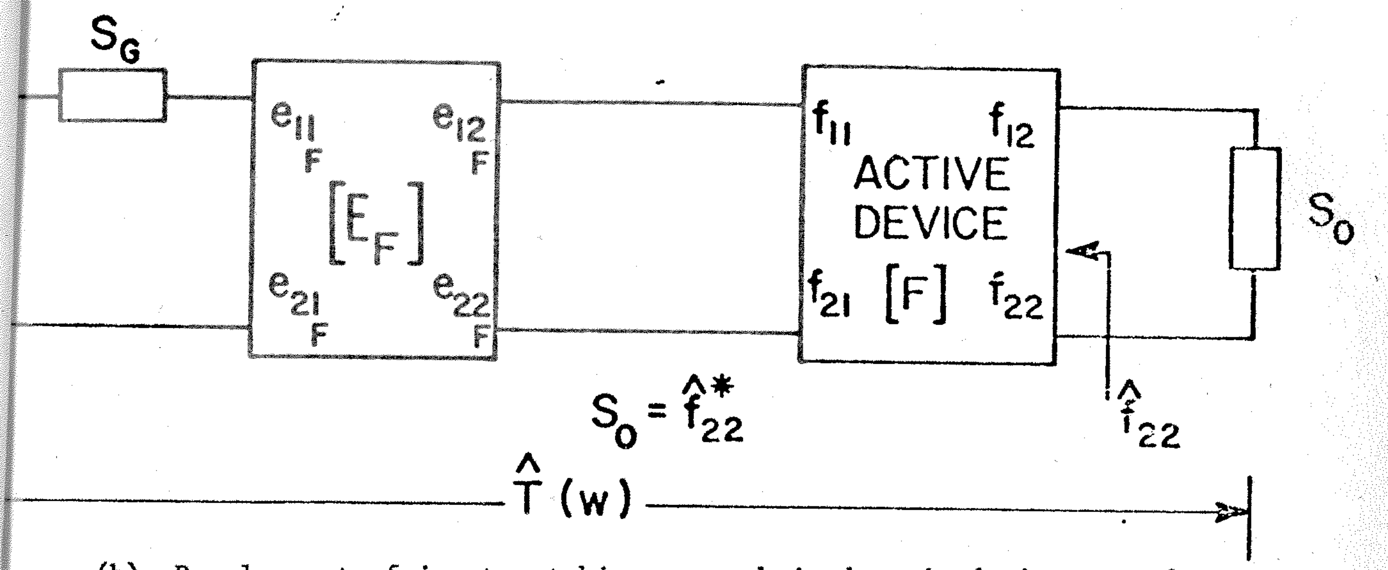

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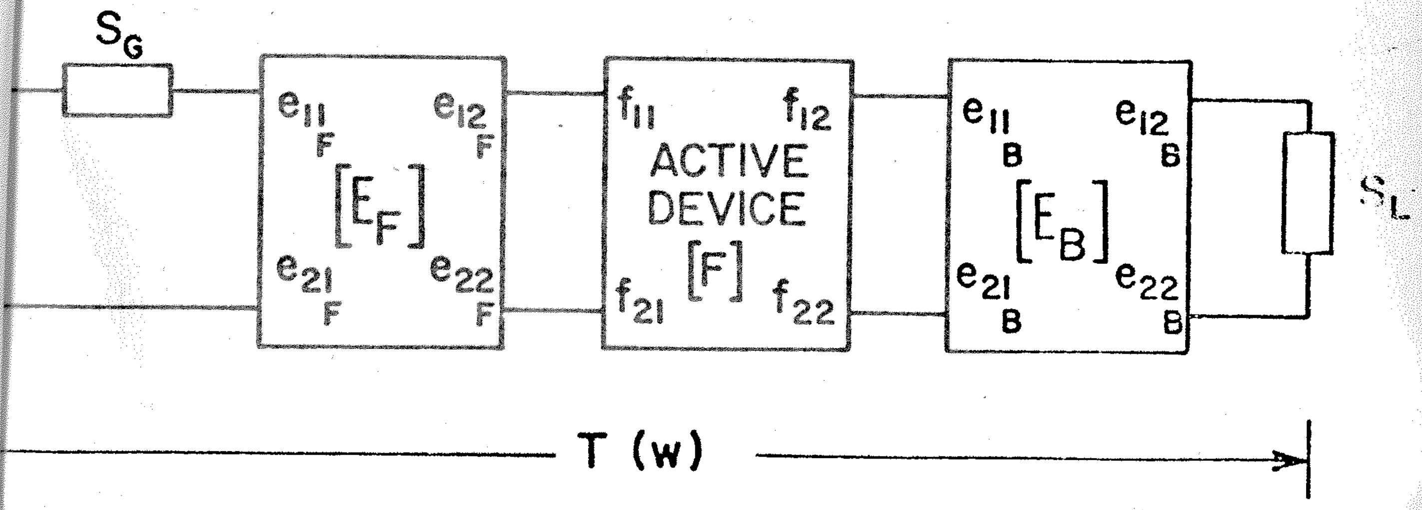

(c) Development of output matching network