OPTIMIZING TRANSMISSION LINE MATCHING CIRCUITS

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Abstract

When designing transmission line matching circuits, there exist often overlooked, additional, not much used, degree of choice in the selection of the transmission line impedance. In this work are presented results of CAD analysis for the two element transmission line matching networks, demonstrating that selecting matching circuits transmission lines with higher impedance, than usually used 50 or 75 ohms, can in most cases substantially decrease the physical dimension of the final matching circuit. Computer program, analyzing the influence of the matching line impedance on the length of the matching elements was developed and results are presented. It appears, that it is advantageous to choose matching circuits with high characteristic impedance. This results in a reduced dimension of the matching circuits.

1. Introduction.

When designing high frequency circuits, we have, in addition to the selection of various parameters, make also the decision about the characteristic impedance of matching networks and other elements in the circuit. As far as an "external" impedance is concerned, we usually have to accept the standard 50 or 75 ohms transmission lines, respectively. This limitation fortunately does not apply to the impedances of the "internal" lines. Due to this fact, we often have a wide choice regarding the impedance of these "internal" lines. There may be also an additional advantage when selecting "internal" lines with higher impedance. Noticing that many types of microwave and high frequency transistors in the stripline package do have fairly narrow connecting terminal strips, we can choose the "internal" connecting line with the same width (i.e. often with higher impedance than 50 ohms), reduce the transition effect, and therefore further improve the match over a wider bandwidth. Typical situation with "external" and "internal" lines for a transistor amplifier matching with microstrip lines is shown in Fig.1. From the above reasons, it may be of interest to investigate the influence of the impedance of the transmission lines on the amplifier performance and, as is done in this work, also on the final dimension of the matching circuits in amplifiers. For simplicity the analysis is done only for two element transmission line matching circuits, using short lengths of the transmission line and a stub, which is a terminated transmission line. Bandwidth of the amplifier realized with such basic input and output matching network is, depending on the used stub, that may be open or shorted on the end, usually in range between 5 to 20%. This value can be higher, in case if we deliberately mismatch one or another side of the amplifier, like in the case of a low noise or other type of desired performance.

In the course of the analysis we have to take in the consideration the input and output impedance of the transistor, which may be of FET or BJT type. Those two types do have basically different characteristics and behavior. For the low power transistors, investigated here, we can deduce from the manufacturer data some general conclusions. For example, FET's input and output impedances do have capacitive character up to a very high frequency. In contrast, the bipolar transistors (BJT), do change input impedance from capacitive to inductive with increasing frequency, and the output impedance is in general inductive, although at higher gains and frequencies may became also capacitive. Also the output impedance of the BJT's varies much more than the FET's, indicating that selection of the matching network is more critical in their case.

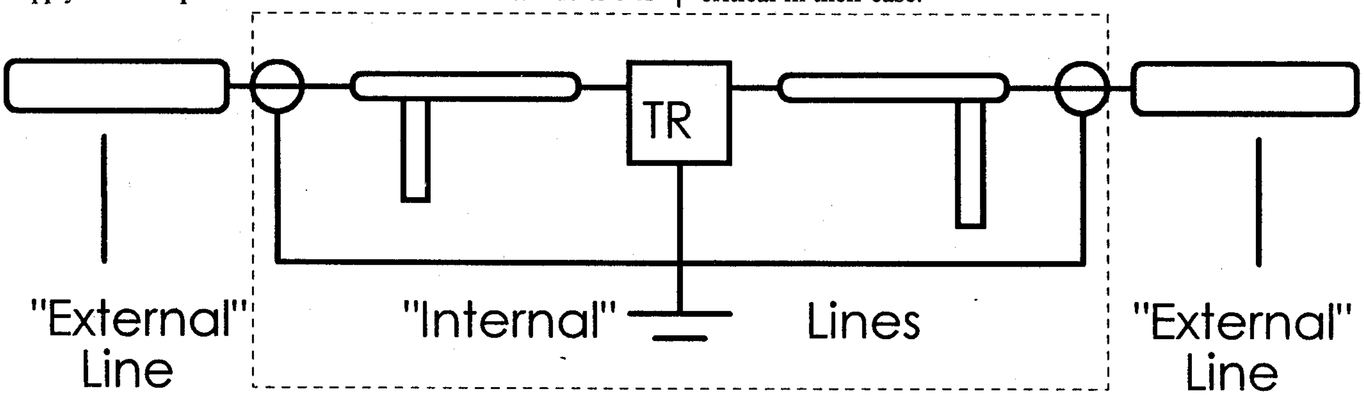

Fig.1. Transistor amplifier with "internal" microstrip matching lines having another impedance than the "external" lines.

Preference for open or shorted stub matching may be influenced by biasing or other requirements. It is important to keep length of stubs such, that we avoid the area, where the stub impedance is changing too rapidly for reliable realization of such stub. This factor alone may decide for open or shorted stub match. In this contribution is also shown, that the impedance of the lines and stubs does play an important role in the final length of the lines, therefore the right selection of the line impedance can result in reduction of the element dimensions in the final circuit. Note that in the matching network it is possible to use one impedance for the transmission line and another for the stub, and also different impedances at the input and output resulting in another degree of freedom.

2. Matching for minimal size.

Considering that in most cases the optimal matching requires the maximum transfer of power between complex impedance (device input or output), and the real impedance of the connecting transmission lines (50 or 75 ohm in most cases), we could, for the moment, limit our discussion to such situation, and consider only transmission lines with practically realizable values.

Using this approach, we usually analyze amplifier matching at one frequency and for one value of line impedance. To analyze matching at other values of impedance requires new set of calculations. We could also decide to realize match with different values of line impedance at the input or output of the device, as well as combining, say open stub match at the input with shorted stub at the device output or vice versa.

For all such cases CAD can prove very valuable tool, because we can analyze various solutions in relatively short time, particularly when using graphical display facilities, and choose the best one for given application. Program for this type of analysis was developed and some results for selected representative types of the transistors are shown. Considering that actual matching networks will use one or another type of microstrip or stripline transmission lines with presently available substrate materials, having relative permeability between approximately 2.2 to 10, we may easily realize lines with impedances in the range between 20 and 150 ohms. Lower or higher values do represent manufacturing problems, because the line width became too wide to realize on a given substrate, or too narrow for reliable fabrication and etching. For that reason, the calculations were limited to the above values of line impedance, thought in many cases it is possible to calculate matching networks for wider range of values, if desired, by changing the computational limits. Note here that there are exceptional cases where the match at certain low or high range of impedances is not realizable at all.

As one representative case was chosen Motorola bipolar transistor MRF 571 with noise figure 2.5 dB @ 2 GHz, which was analyzed at various frequencies up to 2 GHz. Similar analysis was done for Motorola N-channel dual-gate GaAs FET transistor MRF 966 having noise figure 1.2 dB @ 1GHz, and capable operation up to 2 GHz. At frequencies where any device was potentially unstable, the gain was chosen marginally lower (.5-1 dB), than the maximum stable gain (MSG) of the transistor. For all other cases, the matching line lengths were calculated for the maximum gain. In all resulting graphs the lengths of lines are plotted in fraction of the free space wavelength versus characteristic impedance of matching line.

The result for the input and output line lengths for the low power bipolar transistor MRF 571 are similar at all frequencies; the lengths of input and output transmission lines are mostly decreasing, when increasing the impedance of the matching circuit lines. Typical representative results for transmission line match are shown in Fig. 2a and 2b. At he chosen frequency of 1GHz the device is unconditionally stable with gain 14.05 dB. Note, that the transmission line associated with the open stub (LO), is at the input always longer, than the transmission lines associated with the shorted stub (LS), but the shorted stub (SS), is always shorter than open stub (OS). In this case, the preferable choice of the matching circuit will be the transmission line with shorted stub, because the length of the open stub is nearly always above .167 lambda (60 degrees), where, as mentioned above, the impedance of stubs varies too rapidly for its reliable realization, fine adjustment and manufacturing. The output of the bipolar transistor exhibits a relatively small variation of the impedance, but, with the exception of the lowest frequencies, the natural choice here will be longer line with shorted stub, because the open stub is again uncomfortably long at all line impedances.

Input impedance of the MRF 966 FET is, as expected, varying with frequency relatively little. But also

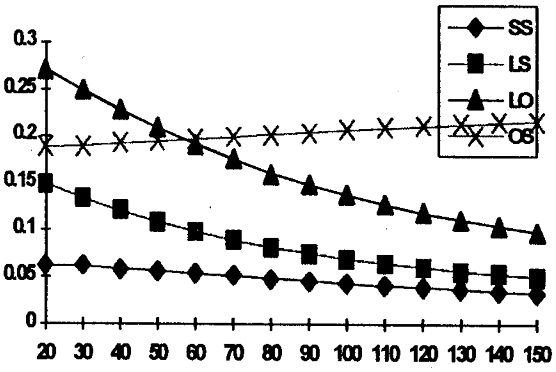

Fig.2a. MRF571-OUTPUT MATCH @ 1 GHz
OUTPUT IMPEDANCE = 17.57-j73.95, G=14.05dB

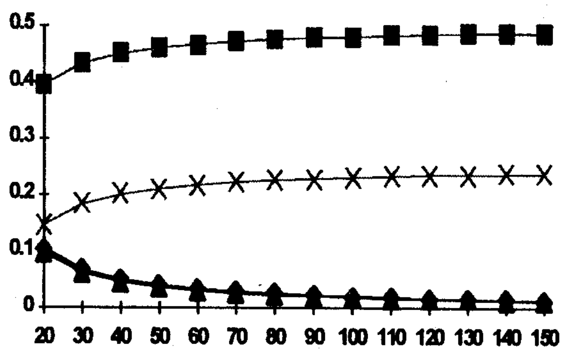

Fig.2b. MRF571-INPUT MATCH-@ 1 Ghz
INPUT IMPEDANCE = 2.887+j.56, K=1.03

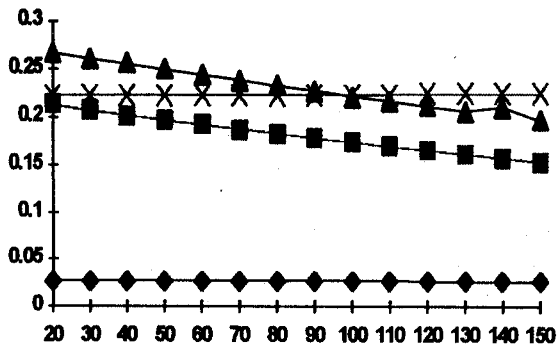

Fig.3a. MRF966-OUTPUT MATCH @ 1 GHz
OUTPUT IMPEDANCE = 46.43-j285.3, G=19.9dB

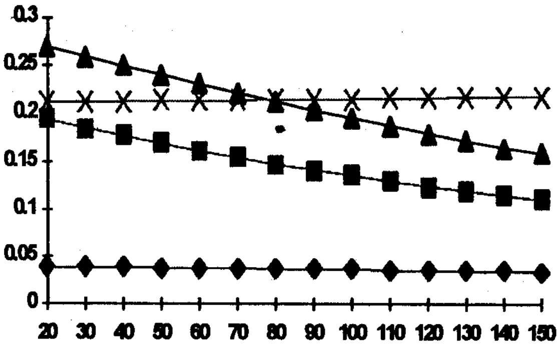

Fig.3b. MRF966-INPUT MATCH @ 1 GHz
INPUT IMPEDANCE = 31.18-j164.41, K=1.499

in this case the calculated length of the open stub is too long for reliable realization at all transmission line impedances, therefore the line with shorted stub will be preferable for matching. Considering that the FET output behaves in a similar manner, the above reasoning is also valid for the output matching network. Results for FET are shown in Fig. 3a and 3b. Results at all other frequencies are again similar to the result at 1000 MHz.To verify the effect in high frequency low power devices from other manufacturer, additional analysis was made for NEC bipolar transistor NE 02135 (similar to MRF 571) having noise figure 2.4 dB @ 2GHZ and for MESFET transistor NE 72084 having noise figure .8 dB @ 4 GHz, used for satellite low noise amplifiers. The results for comparable transistors were similar. Results for some representative frequencies are presented in Fig.4 and 5 below.

From Fig.4. we could see that the length of lines changes more rapidly for NE 02135 device, which is, in contrast to MRF571, at both frequencies potentially unstable. This itself could contribute to the little different behavior.

Also the FET transistor NE72084 is potentially unstable at frequencies well over 6GHz. Representative result at 2000 MHz is shown in Fig.5. and indicate that output behaves similarly like MRF966 FET, but in the input increasing the line impedance can actually increase the line lengths. In this case we will preferably use 50 ohm lines for the matching network. This transistor cannot be matched at higher frequencies by line impedances outside the 50 to 75 ohm area. Because this transistor was designed for low noise operation at higher frequencies, result for matching network dimensions at 6 GHz is also presented, showing that even with the device being potentially unstable, we can reduce the line dimensions by choosing higher impedance of the matching networks, particularly at the output. In the input we see that with impedances below 40 ohms is impossible to realize the match.

3. Conclusion.

Comparing the lengths of the matching transmission lines for few types of the devices in the selected range of impedances, evidently the capacitive impedances (i.e. FET's) do require shorter line lengths for matching, than the inductive impedances (i.e., BJT). The lengths of the matching transmission lines generally decrease with increasing value of their impedance. Choice of the characteristic impedance of the matching transmission lines can therefore indeed provide for the reduced dimensions of the matching circuit, and subsequently for the whole amplifier circuit stage. Note, that for some devices (see graph for NE 72084), there also exists a limit on the range of the line impedances which can provide for the match. In such case only a limited range of the transmission line impedances will be available for the realization of the match. Further, considering that the stub length of about .16 lambda is a maximum for a reliable realization, we are often limited to only one solution for a given matching situation.

It is therefore advantageous to investigate in each case and for any particular device if we could profit from the increase in transmission line impedance or not. This will often depend on the choice of open or shorted stub. In many cases, as demonstrated, higher transmission line impedance will result in smaller dimensions of the matching network. In the paper is clearly demonstrated that the single transmission line and stubs matching with nonstandard transmission line impedances could be simple and effective solution for the matching in narrow and middle band amplifiers. If we do not limit ourselves to the choice of the traditional 50 or 75 ohm transmission line impedances we could also reduce the final dimensions of the circuit. Another reduction of the circuit dimension could be achieved by selection of different impedance for the stub only.

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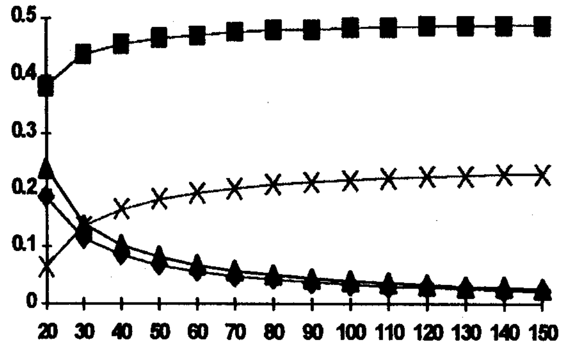

Fig.4a. NE02135-OUTPUT MATCH @ 1 GHz
OUTPUT IMPEDANCE = 7.53-j6.86, G=16dB

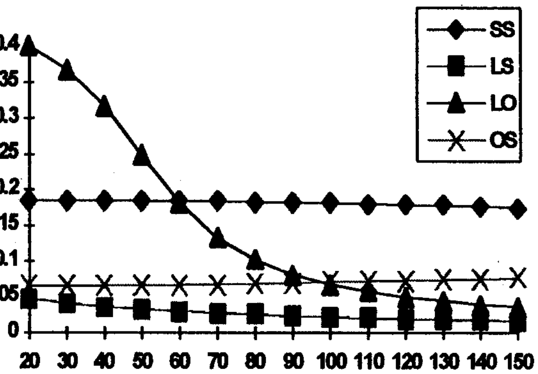

Fig.4b. NE02135-INPUT MATCH @ 1 Ghz
INPUT IMPEDANCE = 49.56-j21.85, K=.664

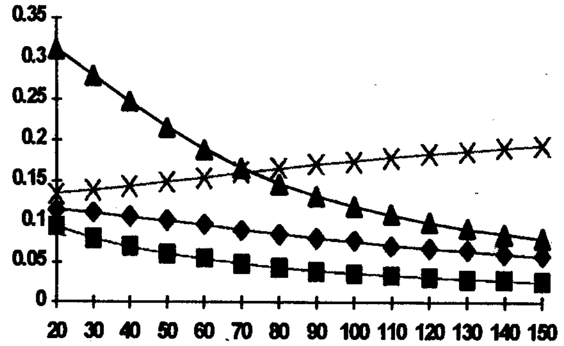

Fig.4c. NE02135-OUTPUT MATCH @ 1.5 GHz
OUTPUT IMPEDANCE = 4.47+j1.35, G=14dB

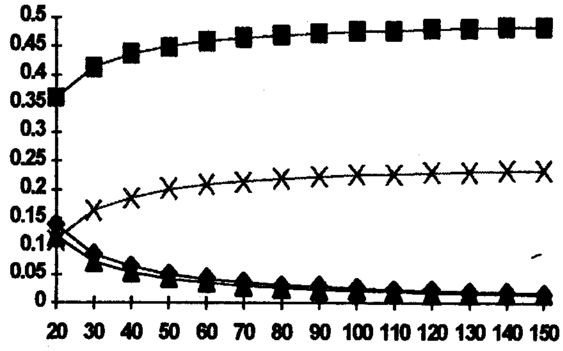

Fig.4d. NE02135-INPUT MATCH @ 1.5 GHz
INPUT IMPEDANCE = 30.34-j49, K=.89

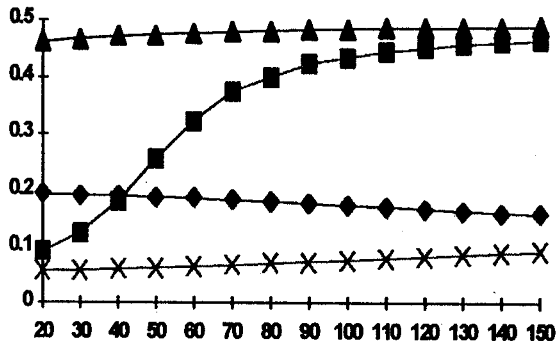

Fig.5a. NE72084-OUTPUT MATCH @ 2 GHz
OUTPUT IMPEDANCE = 48.42+j20.05, K=.244

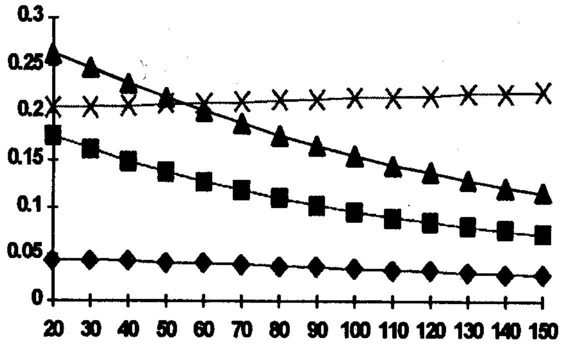

Fig.5b. NE72084-INPUT MATCH @ 2 GHz
INPUT IMPEDANCE = 15.7-j99.48

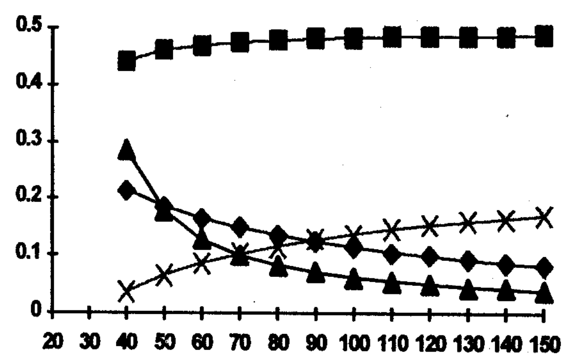

Fig.5c. NE72084-OUTPUT MATCH @ 6 GHz
OUTPUT IMPEDANCE = 36.23-j12.4, K=.618

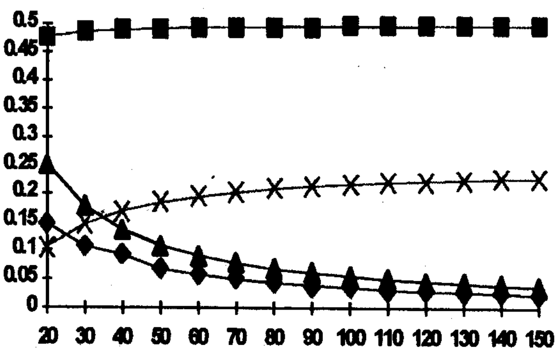

Fig.5d. NE72084-INPUT MATCH @ 6 GHz
INPUT IMPEDANCE = 8.08-j15.6, G=11dB