THE T MATCH: AN INTEGRATED MATCH FOR CPW-FED SLOT ANTENNAS

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Abstract— **A new, compact way to match slot antennas to a coplanar waveguide (CPW) feed is presented. Added to its advantages of flexibility, reduced size and increased bandwidth of the matched antenna, a good analytical approximation of its behavior is possible. An equivalent circuit and procedures for its design are presented. As a demonstration of the possibilites of the method, a set of T-matched antennas has been built and measured at S-band.**

Keywords— **CPW, slot antenna, antenna matching.**

1. Introduction

The slot T-match is a generalization of the folded slot dipole (as the wire T-match is a generalization of the folded wire dipole) and its behavior can be deduced either making a parallel with the wire case [1] or directly applying Booker's formula, that relates input impedance of complementary planar structures in free space:

$$Z'_{\text{in}} = \frac{\eta^2}{Z_{\text{in}}} \tag{1}$$

where η is the free space impedance. The slot T-match, indeed, is the complementary structure of the classic wire T-match.

It is also related to the T-shaped coaxial feed for a cavity backed slot, which is a classic slot feeding system, well known for its wideband characteristics [2].

2. Geometry of the match

Like its wire counterpart, the T-match circuit most suited to antennas with symmetric input branches. The direct complementary image has been slightly modified to fit into the width of the slot antenna and obtain a more compact structure (fig. 1).

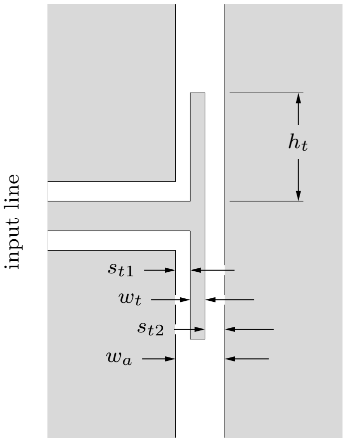

Figure 1: Geometrical parameters of the T-match. Slots represented in white, metal in grey.

3. Equivalent circuit and design parameters

The equivalent circuit is based on division of the field in the input branches in two modes, which, following the convention in [1], we shall call *antenna* and *transmission line* modes. The first is symmetric (field on both sides of the T has the same direction) and the second is antisymmetric; when speaking of CPWs, these are called, respectively, even and odd mode [3].

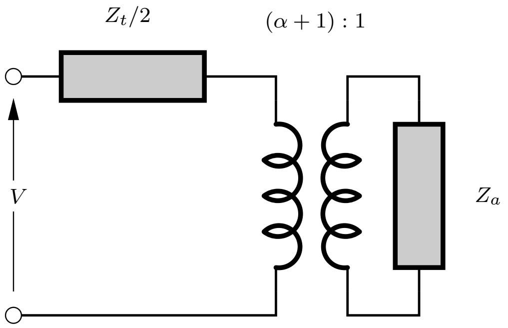

Figure 2: Equivalent circuit for CPW T-match.

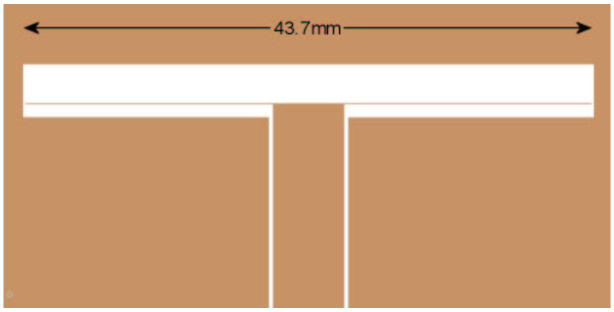

Figure 3: T matched slot dipole. Slots represented in white.

Regarding the antenna mode, the effect of the T can be quite accurately described as an impedance transforming effect, given the fact that the magnetic current on the antenna is divided unevenly between the two slots (of witdh s_{t1} and s_{t2}) of the T matching circuit, the degree of unevenness depending mostly on the ratio s_{t1}/s_{t2}. The magnetic current division factor, α, remains approximately constant over the first resonances of any antenna, at least as far as the division in two modes and the equivalent circuit itself remain valid. As an approximate expression for α, that for the wire T-match has been used [1], using equivalent widths for the slots. Here, it represents, as stated, a *magnetic* current division factor.

The electric current is the same for both slots, per definition of the antenna mode. The Z_a parameter of the equivalent circuit is the input impedance of the antenna before the T-match is inserted, and usually has to be computed numerically, using a full-wave analysis program.

The transmission line mode adds the reactive part corresponding to two parallel-connected, open-circuited transmission lines of length h_t to the input impedance of the antenna. An asymmetrical CPW (ACPW) must be considered: its analysis, and the associated formulas, are available in the literature [4].

This considerations allow us to propose the equivalent circuit shown in figure 2.

4. MATCHING OF BASIC ANTENNAS

In the most basic matching method, the reactance of the T is set to be zero at the resonant frequency of the antenna. This is controled with the length parameter h_t, which should then be $\lambda/4$. Therefore, the antenna is used at its typical resonant frequency (say where $l = \lambda/2$ for a slot dipole) and, there, only its resistance changes (is reduced) with the addition of the T.

The resistance can then be adjusted with the ratio of slots in the asymmetrical CPW, s_{t1}/s_{t2}.

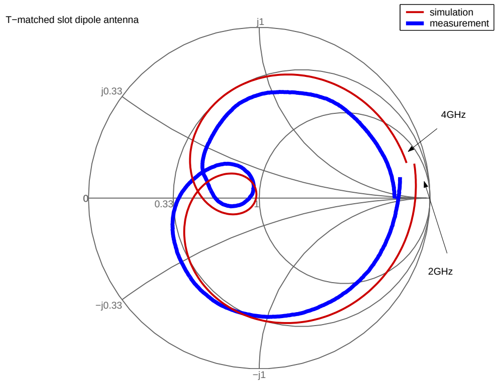

Figure 4: S_{11} of the T matched slot dipole.

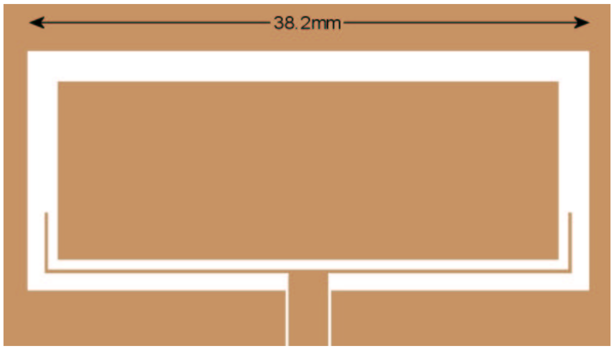

Figure 5: T matched slot loop.

As an example, fig. 3 shows a simple T-matched slot dipole. The input impedance after optimization is compared with measurements in fig. 4. Adjustment of Z_a and l in the equivalent circuit was enough to achieve optimal agreement with measurements. This and all the following examples were built on Duroid RT/5870 ($\epsilon_r = 2.33$) substrate.

As another basic example, a slot loop antenna (fig. 5) was designed. In this case, the dimensions obtained with the approximate expressions for the model pa-

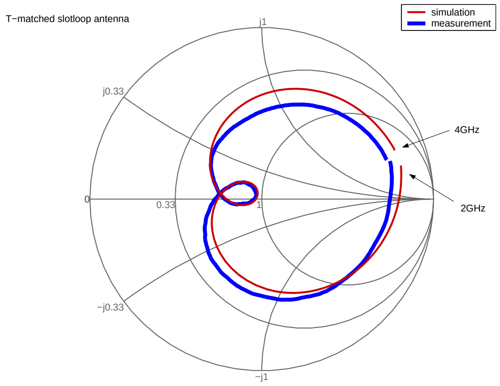

Figure 6: S_{11} of the T matched slot dipole.

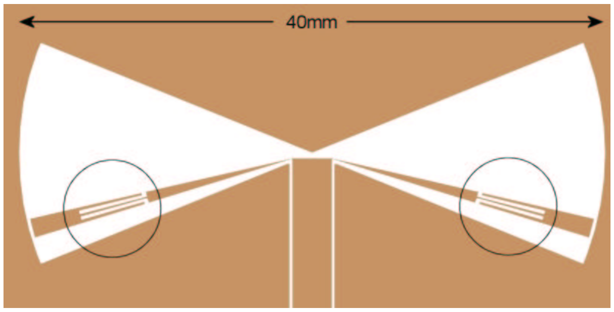

Figure 7: T matched slot bowtie antenna.

rameters were so good that no optimization was needed. A comparison of computed and measured input impedance is shown in fig. 6. The part of the antenna that the T-match modifies is proportionally smaller than in the slot dipole and so, the values of the Z_a parameter without and with the T-match are also closer than for the case of the dipole (the basic design procedure considers them equal).

It is worth saying that the radiation patterns are only slightly affected (the dipole) or no affected at all (the loop) with the addition of the T.

5. Advanced examples

A case in which the T-match was used for dual-band matching has been presented in [5]. There, two resonances of different peak resistance were used. As the impedance scaling factor remains constant over the whole band of interest, only the second resonance was matched at its peak resistance point. For the low frequency one, the zone immediately before resonance, where the resistance is lower and there is a strong positive reactance, was used. The T being much shorter than $\lambda/4$ at this low frequency, the capacitive reactance it presents is used to compensate it.

It is apparent that in this case the T-match was tailored to one particular antenna. However, it demonstrates a high degree of flexibility that could be of use in other instances.

As a last show-case of the method, a coplanar, T-matched bowtie antenna has been designed. The design procedure is similar to that of a dipole or loop, except that now, the transmision line whose impedance appears in the equivalent circuit (fig. 2) is not a regular, but instead a tapered ACPW. Here, the magnetic current division factor depends not on the width, but on the angle covered by the slots. Albeit in an approximate way, it is possible to obtain values good enough for a final optimization. However, the full length of the bowtie was not enough to make the impedance Z_t resonate at the same frequency as the bowtie antenna itself. Therefore, the electrical length of the T-match was extended with twin short-circuited inset stubs, which act as inductances at the frequency of operation (fig. 7). Simulated and measured input impedances are shown in figs. 8 and 9. In principle, a reduction of bandwidth is to be expected due to the use of the inset inductances. The results are, however, still remarkably good. It might well be that the simulation of such small geometrical details as the inset stubs be too much of a stress for the automatic discretization schemes existing in the full wave simulation software used (HP-Momentum). Homemade, specially tailored softwares should be used in these cases.

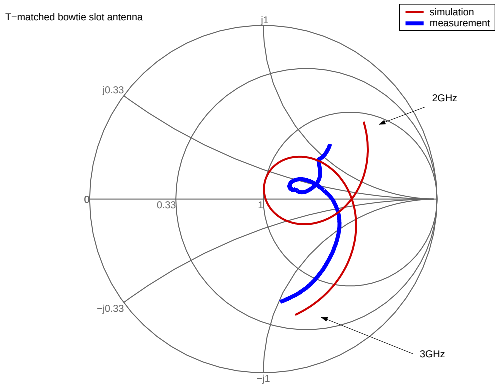

Figure 8: S_{11} of the T matched slot bowtie antenna.

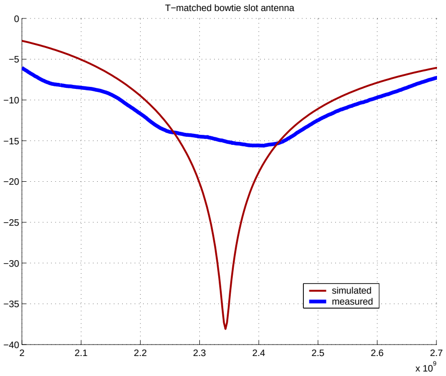

Figure 9: $10\log|S_{11}|^2$ for the T matched slot bowtie antenna.

The measured radiation patterns for the bowtie are shown in fig. 10.

6. Conclusions

The T-match has been demonstrated as an useful, flexible matching method for CPW-fed antennas. With the method proposed, the real and imaginary parts of the input impedance can be adjusted with a certain independence. An equivalent circuit has been proposed and justified. Even when the parameters of this circuit cannot be analytically computed, it still describes very well the behavior of the matched antenna.

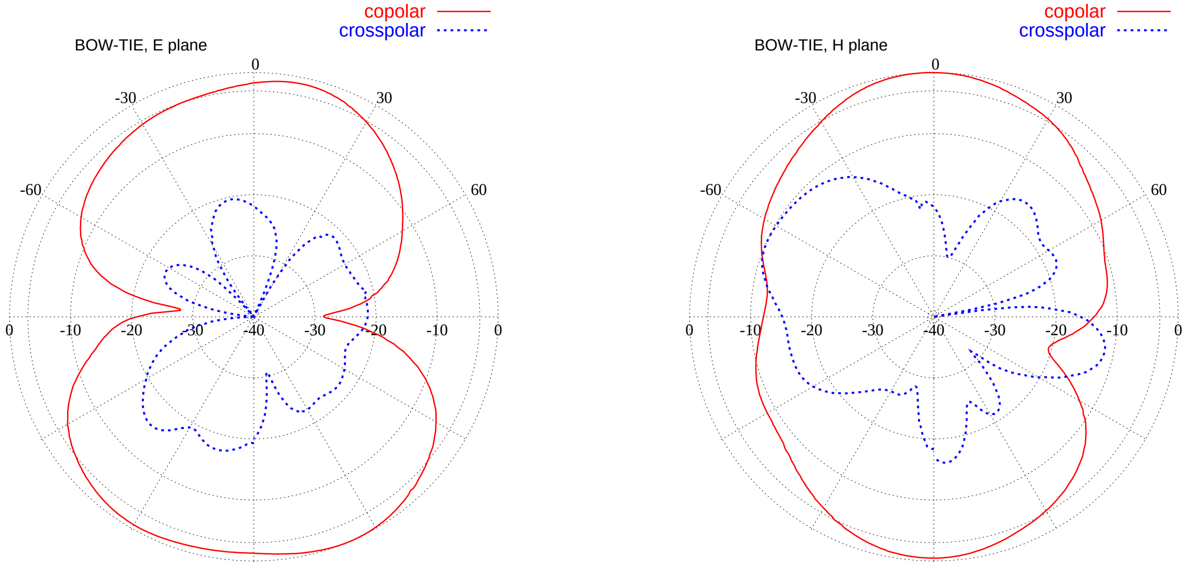

Figure 10: Radiation patterns for the T-matched bowtie slot antenna (2.4 GHz).

The practical limits of what can or not be matched with an inset T are given by:

- The ratio between the input resistance of the antenna and the characteristic impedance of the line to which it is to be matched. If the required magnetic current division factor is too large, fabrication tolerances may not allow to fabricate the antenna with some minimum accuracy.
- The place the T has to be fitted inside the antenna. Some antennas do not resonate at the required frequency, therefore requiring a longer T-match than what can be fitted into the antenna. In this case, we can chose a point at which the input impedance of the antenna shows still some positive reactance, so the T-match can be shorter, and adjust the current division factor accordingly.

The last point can mean, in some instances, that antenna and match cannot be separately designed; a certain compromise has to be made if the match is at all possible.

All the examples shown here are fed by 50 Ω CPW lines. For this case, input impedances between 70 and 1000 Ω can be matched without difficulties.

We have also shown how when problems are encountered, they can still be solved with some ingenuity.

7. Acknowledgements

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