TRANSMISSION LINE MODEL FOR
SLOT-COUPLED MICROSTRIP REFLECTARRAY ANTENNAS

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Abstract: A transmission line model is adopted for the analysis of slot-coupled microstrip reflectarrays. The current on the equivalent impedance for the single radiating element is used to obtain the reflectarray phase design curve. Computational costs are drastically reduced with respect to theoretical full-wave analysis. Numerical and experimental validations are presented on the phase curve useful for the design of a 10 GHz slot-coupled reflectarray prototype.

INTRODUCTION
A fundamental task in microstrip reflectarrays design is the determination of an appropriate phase distribution on the radiating elements giving a field pattern with prescribed features. The required phase curve can be obtained as a function of the element resonant size or using stubs with different lengths [1-2]. A novel structure has been recently proposed by the authors [3] which is based on slot-coupled array elements having the same resonant size. Microstrip lines with different lengths are adopted as coupling elements to introduce the correct phase distribution on the array [3]. This multi-layer structure significantly reduces interference effects on the scattered field due to phase tuning elements usually located on the patches side. As a matter of fact, the prescribed field is obtained without changing the geometry of the reflecting surface. A transmission line model [4] is adopted in this paper for the analysis of slot-coupled microstrip reflectarrays. Patch elements printed on a thin dielectric substrate are represented by a transmission line modeling the fundamental TEM mode propagation. The remaining part of circuit includes two transformers coupling the aperture to the upper patch and the lower microstrip line, respectively. This equivalent transmission line model is used to obtain the reflectarray phase design curve with reduced computational costs when compared to full-wave analysis methods. Numerical validations are presented on the scattered field of a 10 GHz slot-coupled reflectarray element. Results are compared with moment-method analysis and measurements.

TRANSMISSION LINE MODEL
The analysis is addressed to the structure in fig.1, where a square patch slot-coupled to a phase tuning microstrip line is used as single reflectarray element [3].

The transmission line approach [4], adopted to model the structure, is reported in fig.2. A fundamental TEM mode propagation is assumed for the $L \times L$ square patch, as given by the upper transmission line terminated on the $Y_S$ admittance loads. Two transformers are used for modeling the coupling of the aperture to the patch and microstrip line, respectively. The transformation ratio $n_1$ is given as [4]:

$$n_1 = \frac{L_n}{L}$$

Figure 1 Slot-coupled single element geometry.
while the second transformation ratio $n_2$ can be approximated by the expression [4]:

$$n_2 = \frac{L_a}{\sqrt{W_m h}}$$  \hspace{1cm} (2)

The equivalent impedance $Z_{AB}$ is computed by the formula [4]:

$$Z_{AB} = \frac{n_2^2}{n_1^2 Y_{patch} + Y_{ap}}$$  \hspace{1cm} (3)

where the aperture admittance $Y_{ap}$ including the stored energy near the slot is numerically evaluated by a full-wave simulation.

The total current flowing through the impedance $Z_{AB}$ is proportionally related to the scattered field [5], so that it can be used to obtain the phase design curve for the microstrip reflectarray.

**NUMERICAL AND EXPERIMENTAL RESULTS**

The circuital analysis approach is numerically validated by computing the current on the impedance $Z_{AB}$ for a 10 GHz single element of dimension $L = 8.2$ mm, printed on a Diclad 870 substrate with $\varepsilon_r = 2.33$ and thickness $t = 0.762$ mm. A rectangular slot with $L_a = 5$ mm is used for coupling the patch to a microstrip line of variable length $0.68 \text{ mm} \leq L_m \leq 8 \text{ mm}$ and width $W_m = 1.16$ mm, printed on Diclad 870 substrate. The scattered field obtained from the transmission line analysis is reported under figs. 3(a) and 3(b) for the amplitude and phase, respectively. A good agreement results from comparison with full-wave moment-method analysis. As a further validation of the proposed transmission line analysis, a comparison with experimental results is presented in fig.4, where the reflection from the ground plane is included to obtain the reflectarray phase curve [2].

**CONCLUDING REMARKS**

A novel structure for reflectarray antennas based on slot-coupled microstrip patches is analyzed by a transmission line model. The current flowing through the single element equivalent impedance is used to obtain the phase curve required for reflectarray design. This circuital analysis significantly reduces computational costs with respect to traditional full-wave methods. Numerical and experimental validations are presented on the phase design curve for a 10 GHz reflectarray prototype.
Figure 3 Amplitude (a) and phase (b) of the scattered field for a 10 GHz slot-coupled reflectarray element.

Figure 4 Comparison between transmission line analysis and experimental results for a 10 GHz reflectarray phase curve.

REFERENCES