

MODELING OF THE WIDEBAND FERRITE TRANSFORMER USING S PARAMETERS

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Abstract: This paper focuses on the modeling of ferrite transformers for directional couplers up to 1 GHz. Four port scattering parameters of ferrite transformer were measured. On the basis of measured data, transformer model was built for the lower UHF range. Those passive devices are suitable for a class of small signal amplifiers using a transformer and coupler lossless feedback. Using transformer indefinite S matrix overall dissipation loss was analyzed.

Keywords: S parameter measurement, ferrite transformer, modeling

1 INTRODUCTION

This paper shows a model of a ferrite transformer, which is the part of a ferrite directional coupler. In [1], a weakly coupled ferrite coupler was modeled like pure inductive reactive device, neglecting the parasitic capacitances and resistive losses up to 500 MHz.

Using transformer indefinite S matrix, overall dissipation losses were analyzed. Using matrix transformation indefinite Y matrix was calculated. This matrix is better for physical transformer model understanding and it is helpful for model element extraction. At the end, Y and Z two-port model was calculated in order to establish parameter extracting.

2 FERRITE TRANSFORMER S PARAMETERS MEASUREMENT

Two four-port port microstrip test yigs were built. One for S parameter measurements and second one for network analyzer calibration. Miniature double-aperture ferrite core (U17 SIFERRIT material dimension 2.5 x 3.6 x 2.1 mm) was used for wideband transformer realization. The ferrite transformer with the turn number ratio 0.5:4 is suitable for ferrite directional coupler building with coupler tap coupling about -15 dB.

3 FERRITE TRANSFORMER LOSS ESTIMATION

The ferrite transformer was measured like floating indefinite four-port element. The measured transformer reflexive S parameters results are shown on the Fig. 1. Fig. 2 depicts the transformer transmission parameters in polar form. Ferrite material used for fabrication of such transformers and couplers is of low losses. Let us investigate the ferrite transformer dissipation matrix, which elements are actually the rows of indefinite measured S matrix:

$$row_1 = 1 - |s_{11}|^2 - |s_{21}|^2 - |s_{31}|^2 - |s_{41}|^2 \quad (1)$$

$$row_2 = 1 - |s_{12}|^2 - |s_{22}|^2 - |s_{32}|^2 - |s_{42}|^2 \quad (2)$$

$$row_3 = 1 - |s_{13}|^2 - |s_{23}|^2 - |s_{33}|^2 - |s_{43}|^2 \quad (3)$$

$$row_4 = 1 - |s_{14}|^2 - |s_{24}|^2 - |s_{34}|^2 - |s_{44}|^2 \quad (4)$$

For lossless element each of the row_i ($i=1,2,3,4$), should be zero. Fig. 3 shows the frequency dependence of row_i like a measure of overall losses.

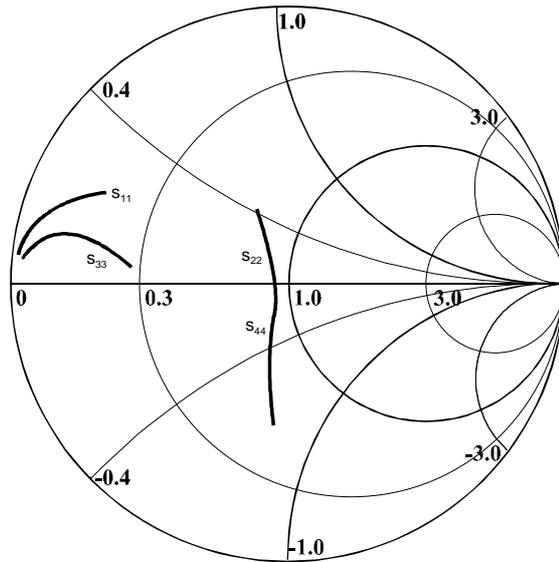


Figure 1. Ferrite transformer measured indefinite reflexive parameters

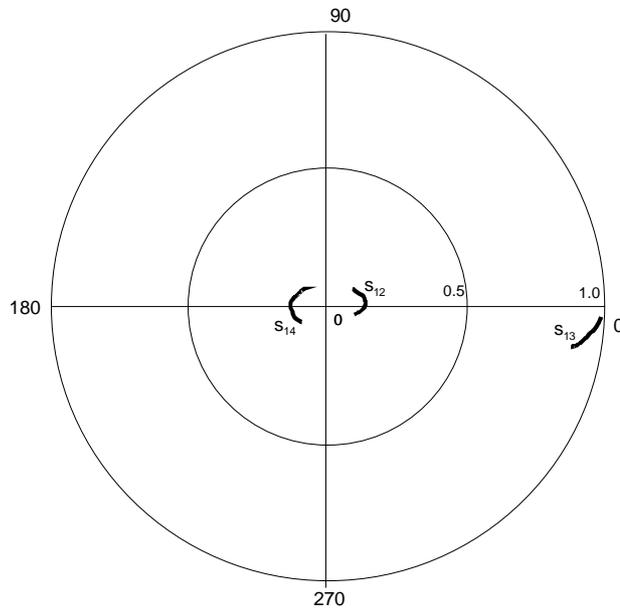


Figure 2. Ferrite transformer measured indefinite transmission parameters

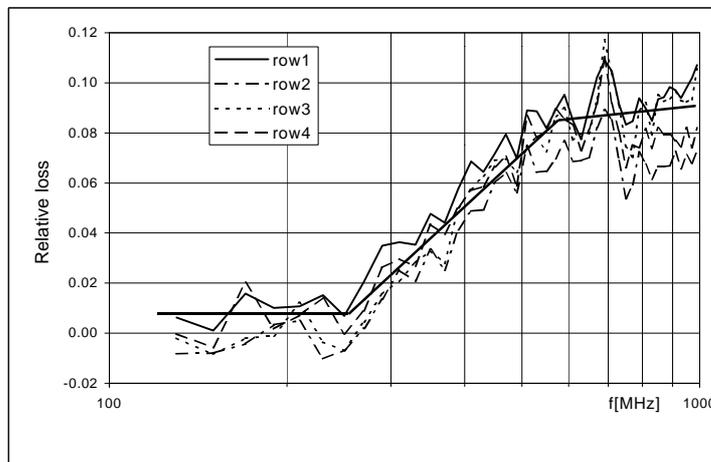


Figure 3. Frequency dependence of the transformer relative loss

In the frequency band between 250 and 500 MHz transformer shows hysteresis loss with linear operational frequency increase.

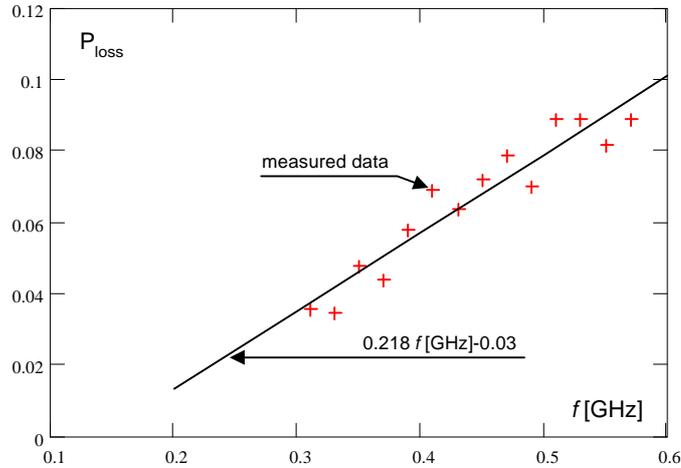


Figure 4. Curve fitting of measured results in hysteresis loss frequency band

Similar graph is shown on the Fig. 4. which presents losses in the ferrite coupler structure with tap coupling -15 dB. This coupler was built from two ferrite transformers and hysteresis losses are also apparent in frequency band between 220 and 500 MHz which is in good agreement with ferrite core type data.

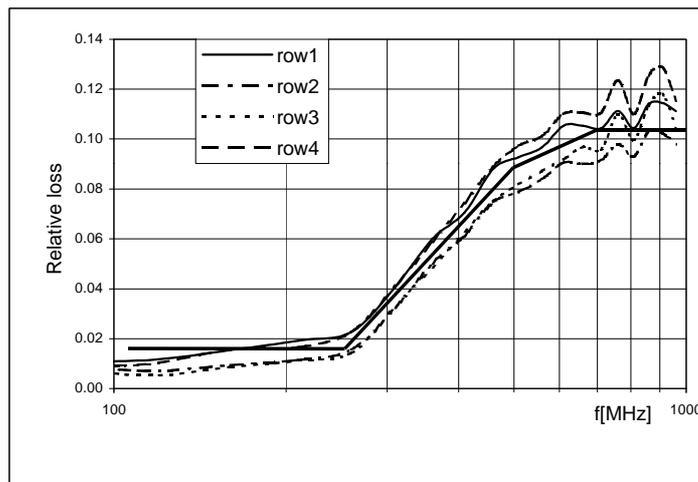


Figure 5. Frequency dependence of the ferrite coupler relative loss

4 TRANSFORMER MODELING

For successful extraction of model elements, it is a good idea to transform S matrix to Y (or Z) matrix. Transformer two-port S parameters were also measured and converted to Z parameters. Transformer model (Fig. 6) was designed like modification of ideal transformer with addition of losses in wire and ferrite core like equivalent resistances R1, R2. Because of small transformer dimensions parasitic inductance and interwindings capacitances was negligible. Model elements extraction was made in two steps: from 130 MHz up to 210 MHz and 210 up to 810 MHz. Equivalent circuit parameter extraction results are shown in Table 1.

$$L_{11} = L_1 - M_{12} \quad (5)$$

$$L_{22} = L_2 - M_{12} \quad (6)$$

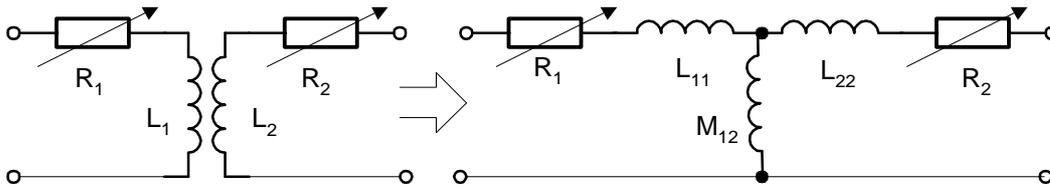


Figure 6. Ferrite transformer model

Table 1. Elements of ferrite transformer equivalent circuit

Equivalent circ. element	Frequency band 130 - 210 MHz	Frequency band 210 - 810 MHz
R_1 [Ω]	0.17	1.91
L_1 [nH]	17.82	17.82
R_2 [Ω]	3.45	36.95
L_2 [nH]	126.52	126.52
Max. error	Mag[dB]	≤ 0.84
	Phas.[$^\circ$]	≤ 8

5 CONCLUSIONS

This paper analyses a real model of a ferrite transformer that can be used in the GHz range as well, depending of the ferrite size, its shape and permeability and the configuration of its windings. Within the frequency range up to 500 MHz the hysteresis loss in the ferrite core is most important and it increases with frequency. The relative measure of losses are established from indefinite four port matrix (measured S parameters). Using two-port measured S matrix, and calculated Z matrix, transformer parameter extraction was made from the simple circuit model. In this model variable resistance with frequency dependent values depicts hysteresis losses including losses in copper as well.

LITERATURE

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