

# Letters

## Explicit Microwave Rotary Phase Shifter Calibration Algorithm

P. I. SOMLO

A microwave rotary phase shifter calibration method described previously<sup>1</sup> requires the device under test (DUT) to be connected in tandem with a 2-state phase stepper (flap) of initially unknown phase shift  $F$  to form an arm of a phase bridge circuit. The measurement is carried out by setting the DUT sequentially to a series of cardinal points,  $\alpha_{oi}$ ,  $i=1, \dots, M$ , equally spaced around the dial. At each, the phase bridge is balanced, and after introducing the flap, the new setting  $\alpha_{fi}$  of the DUT needed to return the phase bridge to balance is found.

The advantages of the method are that no standard phase shifter is required; that since the method is not a buildup method, errors are not cumulative; and that the phase bridge need not have any long-term stability. The algorithms previously described for data reduction are both iterative.

A new algorithm is presented here that provides an explicit solution for the  $M$  unknowns.

We represent the DUT's error by a Fourier series as a function of dial setting, and solve for the  $M-1$  Fourier coefficients,<sup>2</sup> plus the (initially unknown) phase shift of the flap,  $F$ .

The relationship between the true phase shift,  $\alpha_{true}$ , and the dial setting,  $\alpha$ , of the DUT is defined as

$$\begin{aligned} \alpha_{true} &= \alpha + \text{corr} \\ &= \alpha + \sum_{m=1}^{M/2-1} [A_m \cos(m\alpha) + B_m \sin(m\alpha)] \\ &\quad + A_{M/2} \cos\left(\frac{M}{2}\alpha\right). \end{aligned} \quad (1)$$

Because the difference between the corresponding pairs of readings is the phase shift of the flap, we may write

$$(\alpha_{fi} + \text{corr}_{fi}) - (\alpha_{oi} + \text{corr}_{oi}) = F, \quad i=1, \dots, M.$$

This with (1) leads to a set of simultaneous equations:

$$\begin{aligned} \sum_{m=1}^{M/2-1} A_m [\cos(m\alpha_{fi}) - \cos(m\alpha_{oi})] \\ + B_m [\sin(m\alpha_{fi}) - \sin(m\alpha_{oi})] \\ + A_{M/2} \left[ \cos\left(\frac{M}{2}\alpha_{fi}\right) - \cos\left(\frac{M}{2}\alpha_{oi}\right) \right] - F = \alpha_{oi} - \alpha_{fi}, \\ i=1, \dots, M \end{aligned} \quad (2)$$

which may be readily solved by matrix inversion.

It is worthwhile noting that the error may also be obtained by deconvolving the observed data,  $\alpha_{oi} - \alpha_{fi}$ , with an odd impulse pair of baseline  $F$ , but the method given here is simpler.

## Corrections to "High-Frequency MESFET Noise Modeling Including Distributed Effects"

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In the above paper<sup>1</sup> Figs. 5, 6, and 8 were partially illegible owing to poor reproduction. These figures are reprinted here.

The paper also contains an inconsistency in notation concerning the source resistance. The resistance  $R_s$  used in equations (5), (6), and (A1) is identical to the element  $R_{gs}$  shown in Fig. 7.

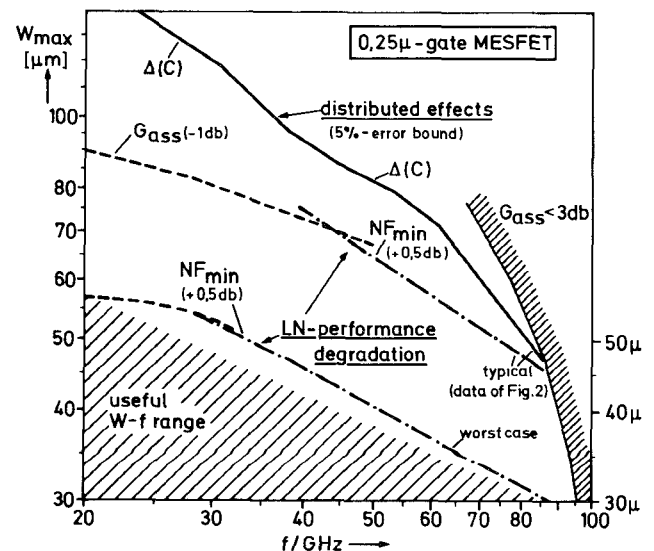


Fig. 5.

Manuscript received July 28, 1989.

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<sup>1</sup>P. I. Somlo *et al.*, "The absolute calibration of periodic microwave phase shifters without a standard phase shifter," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-20, pp. 532-537, Aug. 1972.

<sup>2</sup>There is no constant term in the Fourier series because this would represent a fixed offset phase shift. With the phase shifter used in the differential mode this offset cancels out. Also (for  $M$  even), the highest harmonic in the error spectrum has only two points per period, and therefore is represented by only a cos term.

Manuscript received July 27, 1989.

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<sup>1</sup>W. Heinrich, *IEEE Trans. Microwave Theory Tech.*, vol. 37, pp. 836-842, May 1989.