

A Combined Single Sideband Hybrid AM-PM Signal

It is known¹ that two unique upper sideband signals which are AM-PM modulated by a single sinusoid may be written as

$$\begin{aligned} s_1(t) &= A_1 \exp[-\hat{f}_1(t)] \cos[\omega_c t + f_1(t)] \\ s_2(t) &= A_2 \exp[\hat{f}_2(t)] \cos[\omega_c t - f_2(t)] \end{aligned} \quad (1)$$

where " $\hat{}$ " denotes the Hilbert transform. Now define the two modulating functions $f_1(t)$ and $f_2(t)$ to be identical except for modulation index, such that

$$f_i(t) = \Delta\phi_i \sin[\omega_m t + \phi(t)]. \quad (3)$$

A combination signal $s(t)$ may now be synthesized by subtracting the second signal from the first. Then

$$\begin{aligned} s(t) &= s_1(t) - s_2(t) \\ &= \sum_{n=0}^{\infty} \frac{A_1 \Delta\phi_1^n - (-1)^n A_2 \Delta\phi_2^n}{n!} \cos[(\omega_c + n\omega_m)t + n\phi(t)] \end{aligned} \quad (4)$$

which follows directly from (2) and (3) of the earlier work.¹ The combination signal exhibits desirable characteristics not found in any of the single unique models.

In the single models the residual carrier power P_c is fixed by

$$P_c = \frac{A^2}{2}. \quad (5)$$

The power residing in the first-order sideband P_1 is

$$P_1 = \Delta\phi^2 \cdot \frac{A^2}{2}. \quad (6)$$

Likewise, for the second-order sideband

$$P_2 = \frac{\Delta\phi^4}{4} \cdot \frac{A^2}{2}. \quad (7)$$

The ratios of the various component powers are

$$\frac{P_1}{P_c} = \Delta\phi^2 \quad (8)$$

$$\frac{P_2}{P_c} = \frac{\Delta\phi^4}{4} \quad (9)$$

$$\frac{P_2}{P_1} = \frac{\Delta\phi^2}{4}. \quad (10)$$

Examination of (8)–(10), inclusive, shows that the ratios of component powers are fixed by choice of one signal parameter, modulation index, for the single model case.

For the combination case the residual carrier power is

$$P_c = \frac{(A_1 - A_2)^2}{2}. \quad (11)$$

The first- and second-order sideband powers are, respectively,

$$P_1 = \frac{(A_1 \Delta\phi_1 + A_2 \Delta\phi_2)^2}{2} \quad (12)$$

$$P_2 = \frac{(A_1 \Delta\phi_1^2 - A_2 \Delta\phi_2^2)^2}{8}. \quad (13)$$

The component power ratios are

$$\frac{P_1}{P_c} = \left[\frac{A_1 \Delta\phi_1 + A_2 \Delta\phi_2}{A_1 - A_2} \right]^2 \quad (14)$$

$$\frac{P_2}{P_c} = \frac{1}{4} \left[\frac{A_1 \Delta\phi_1^2 - A_2 \Delta\phi_2^2}{A_1 - A_2} \right]^2 \quad (15)$$

$$\frac{P_2}{P_1} = \frac{1}{4} \left[\frac{A_1 \Delta\phi_1^2 - A_2 \Delta\phi_2^2}{A_1 \Delta\phi_1 + A_2 \Delta\phi_2} \right]^2. \quad (16)$$

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¹ J. H. Painter, "Single-sideband hybrid AM-PM signal models," *Proc. IEEE (Letters)*, vol. 54, p. 440, March 1966.

Whereas in the single model case the three component power ratio equations were fixed by choice of only one parameter, it is seen that for the combination case four parameters are available for optimization of the various ratios. In fact, sufficient adjustable parameters are available to add further constraints, such as, perhaps, maximization of the total of the three component powers.

For a signal consisting of a phase-shift-keyed sinusoidal subcarrier modulated onto a sinusoidal carrier, the combination signal and the equations which result offer as flexible an approach to single sideband signal synthesis as previously was obtained for double sideband synthesis.²

JOHN H. PAINTER
Military Electronics Div.
Motorola, Inc.
Scottsdale, Ariz.

² J. H. Painter, "Synthesis techniques for a class of phase-modulated signals," *Proc. 1965 Conf. on Aerospace (Suppl.)*, vol. AS-3, pp. 264–269.

Automatic Display of C-V Curves for Metal-Insulator-Semiconductor (MIS) Structures

MIS capacitors, because of the ease of fabrication, simplicity of structure, and the sensitivity of their C-V characteristics to physical properties, can advantageously be used as a test vehicle for the study of the influence of process parameters on properties of insulating films on semiconductors, and insulator-semiconductor interfaces. The essential difference between an experimentally determined high-frequency C-V characteristic and one computed for an identical structure without surface states is the voltage due to the total charge in surface states.^{1–3} By comparing the measured voltage for a given value of capacitance with its "ideal" value, one can determine the total charge that can be trapped in surface states during the measurement period and the surface state density as a function of surface potential.

C-V measurements are normally carried out on a point by point basis using a capacitance bridge. Then the data have to be plotted. Such a procedure is extremely cumbersome, time-consuming, and subject to frequent error. To eliminate this problem an experimental arrangement has been developed which allows the automatic and rapid measurement of C-V characteristics of MIS structures at 1 MHz over a wide range of bias and sweep speed and under a variety of experimental conditions. The apparatus consists of essentially standard laboratory equipment, provides a graphical output, and makes possible the rapid study of certain problems in MIS-physics. For the comparison between experimental and theoretical C-V curves a computer program in FORTRAN has been developed. This program, together with a detailed description of the measuring circuit, and a discussion of the various applications, will be given in a forthcoming publication.⁴ We shall outline here only the principle of operation of this apparatus,⁵ and its main applications.

Essentially, the magnitude of an impedance is determined, eliminating thereby the need for a phase sensitive detector. A sawtooth voltage is applied to the MIS capacitor to provide a smoothly vary-

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¹ L. M. Terman, "An investigation of surface states at a silicon/silicon oxide interface employing metal-oxide-silicon diodes," *Solid-State Electronics*, vol. 5, pp. 285–299, September–October 1962.

² K. Lehovec, A. Slobodskoy, and J. L. Sprague, "Field effect capacitance analysis of surface states on silicon," *Phys. Stat. Sol.*, vol. 3, pp. 447–464, 1963.

³ K. H. Zaininger, and G. Warfield, "Limitations of the MOS capacitance method for the determination of semiconductor surface properties," *IEEE Trans. on Electron Devices*, vol. ED-12, pp. 179–193, April 1965.

⁴ —, "Automatic display of MIS capacitance vs bias characteristics," to be published in *RCA Rev.*, September 1966.

⁵ The computer program and detailed circuit diagrams can be obtained from the author upon request.