A NOVEL HIGH FREQUENCY SINGLE-SIDEBAND TRANSMITTER USING CONSTANT-ENVELOPE MODULATION

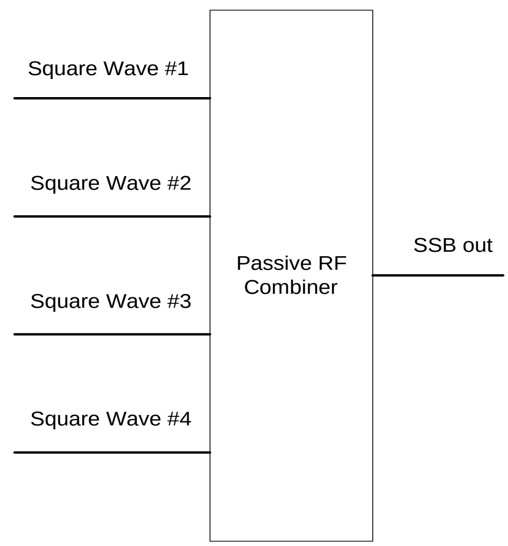
Richard L. Campbell
TriQuint Semiconductor
2300 NE Brookwood Parkway
Hillsboro, OR 97124

ABSTRACT

A technique for single-sideband generation has been developed that obtains the desired output as the sum of three or more constant envelope signals. The summation may be performed by a passive summing network, or in space as the output of an antenna array in a particular direction. This paper describes a practical implementation of the technique, with lower sideband output at 7.2 MHz. Four constant-envelope signals from hard-limiting differential amplifiers drive a passive combiner to obtain +16 dBm peak-envelope-power lower-sideband. All undesired outputs are suppressed more than 30 dB. System requirements for high-power high-efficiency operation are discussed.

INTRODUCTION

The basic concept for the low-power SSB transmitter described in this paper is illustrated in figure 1. N constant envelope signals at the same average frequency, with information contained only in the zero crossing times, are combined in a passive network to produce a single-sideband suppressed carrier output. Two obvious applications are the elimination of the need for linearity in radio-frequency stages of a generalized transmitter and the elimination of the need for conventional digital-to-analog conversion in DSP based radio transmitters. The proof-of-concept transmitter described here is for lower-sideband voice, but the technique may be used for frequency translation of any band-limited signal.



Basic Four-Branch Constant Envelope-to-SSB Generator
Figure 1

THEORY

The theory for obtaining linear single-sideband output as the sum of N constant-envelope signals is covered in detail in a separate paper [1]. A brief overview is presented here.

Each of the N constant-envelope signals may be initially generated as a double-sideband suppressed-carrier signal using a conventional balanced modulator. A carrier is then added

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with a phase shift of 90 ^{o} relative to the suppressed carrier in the DSB term. This is a standard method of generating narrow-band phase-modulation.

When the carrier is not large relative to the DSB amplitude, there are envelope variations. These envelope variations may be approximated using J_n, a Bessel function of the first kind. If the envelope variations are eliminated (for example by passing the signal through a limiter), distortion sidebands are produced. The amplitude of the nth pair of distortion sidebands introduced by limiting is J_n [3]. A constant-envelope single-sideband generator with N=3 suppresses the carrier and one sideband. Using N=4 allows suppression of the 3rd harmonic of the carrier as well. In general, as N increases, suppression of higher order products is obtained, and the phase and amplitude accuracy required for a given level of carrier and opposite sideband suppression is relaxed.

The complete expression for the sum of 4 constant-envelope signals with single-tone modulation is:

$$\Sigma J_i(a_1)\cos[i(\omega_1 t - 0)]\cos(\omega_0 t - 0) + J_0(a_1)\cos(\omega_0 t - \pi/2)$$

$$+ \Sigma J_i(a_1)\cos[i(\omega_1 t - \pi/2)]\cos(\omega_0 t - \pi/2) + J_0(a_1)\cos(\omega_0 t - \pi)$$

$$+ \Sigma J_i(a_1)\cos[i(\omega_1 t - \pi)]\cos(\omega_0 t - \pi) + J_0(a_1)\cos(\omega_0 t - 3\pi/2)$$

$$+ \Sigma J_i(a_1)\cos[i[\omega_1 t - 3\pi/2)]\cos(\omega_0 t - 3\pi/2) + J_0(a_1)\cos(\omega_0 t - 0)$$

When a_1 is nearly equal to 1, the constant envelope signal is reasonably well approximated by the just the J_0 (carrier) J_1 (DSB sidebands) and J_2 (first set of distortion sidebands) terms.

For this case, J_0 is approximately 1. Then the complete single-tone expression is:

$$J_1(a_1)\cos(\omega_1 t - 0)\cos(\omega_0 t - 0)$$
$$+ J_2(a_1)\cos[2(\omega_1 t - 0)]\cos(\omega_0 t - 0)$$
$$+ \cos(\omega_0 t - \pi/2)$$

$$+ J_1(a_1)\cos(\omega_1 t - \pi/2)\cos(\omega_0 t - \pi/2)$$
$$+ J_2(a_1)\cos[2(\omega_1 t - \pi/2)]\cos(\omega_0 t - \pi/2)$$
$$+ \cos(\omega_0 t - \pi)$$

$$+ J_1(a_1)\cos(\omega_1 t - \pi)\cos(\omega_0 t - \pi)$$
$$+ J_2(a_1)\cos[2(\omega_1 t - \pi)]\cos(\omega_0 t - \pi)$$
$$+ \cos(\omega_0 t - 3\pi/2)$$

$$+ J_1(a_1)\cos(\omega_1 t - 3\pi/2)\cos(\omega_0 t - 3\pi/2)$$
$$+ J_2(a_1)\cos[2(\omega_1 t - 3\pi/2)]\cos(\omega_0 t - 3\pi/2)$$
$$+ \cos(\omega_0 t - 0)$$

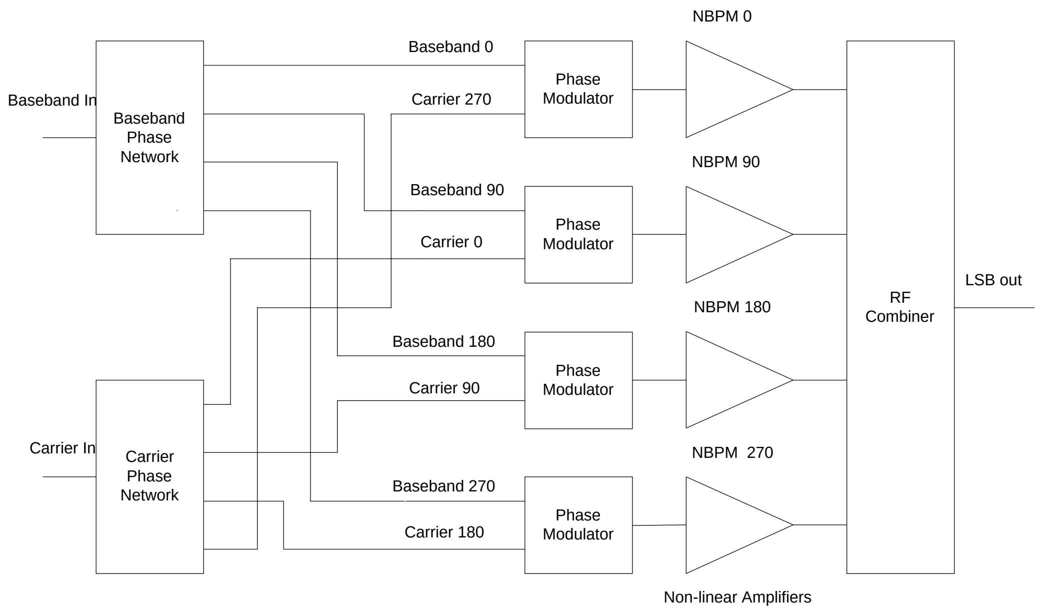
After some algebraic and trigonometric manipulation this reduces to:

$$= 2J_1(a_1)\cos(\omega_1 - \omega_0)t$$

which is just the original modulating single-tone, frequency shifted to (ω_1-ω_0). The carrier, opposite sideband, and all of the J_2 distortion products have canceled in the final summation.

CIRCUIT OVERVIEW

The passive combiner in Figure 1 is an additive summer and low-pass structure that may be implemented in any number of conventional ways. The novel portion of the circuit is the signal processor used to generate the four constant-envelope signals. These four signals may be generated using either analog or digital signal processing. In this application, they are generated entirely in conventional analog circuitry to facilitate understanding. A complete block diagram of the SSB generator is shown in figure 2.



Complete Block Diagram of Four-Branch Fourth Method SSB Generator

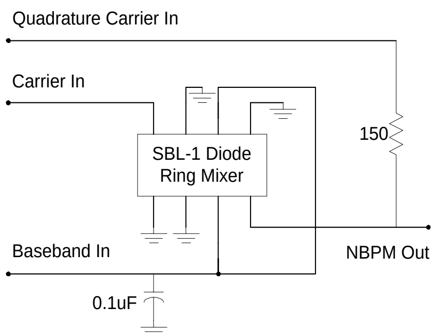
Figure 2

Each block in figure 2 is a textbook analog circuit. Spurious output performance of the SSB generator is determined by the amplitude and phase balance of the baseband signals, and phase accuracy of the four carrier signals.

The baseband audio processor and carrier generator circuits are entirely conventional and were selected for this proof-of-concept design to make maximum use of existing circuitry and available parts. The baseband phase network is a conventional bandpass microphone amplifier driving a pair of op-amp all-pass networks to obtain 90 ^{o} phase shift to within 1^{o} accuracy over the 300 Hz to 4000 Hz passband. This network has been described previously as part of a conventional phasing-method SSB generator [2]. Each output drives an op-amp follower and inverter to obtain the four bandpass audio signals evenly spaced at 0 ^{o} 90 ^{o} 180 ^{o} and 270 ^{o}.

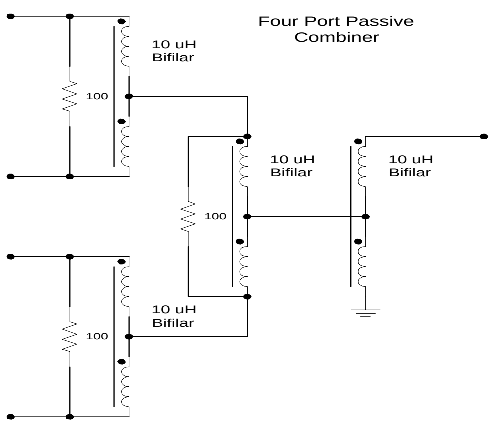
The carrier generator consists of a Pierce quartz-crystal oscillator driving an RC phase shift network. The outputs of the RC phase shift network drive a pair of 74HC04 CMOS hex-inverters configured as limiter/buffer and inverter to provide the four carrier outputs at 0 ^{o} 90 ^{o} 180 ^{o} and 270 ^{o}. Each output is transformed to 50 Ω in an LC pi-network with a variable capacitor on the output to provide phase trim on each channel. There are no amplitude trim adjustments in the system, as it may be shown that they are redundant in a four-branch SSB generator.

The narrow-band phase modulators are critical, as they must preserve the relative phase and amplitude of each carrier and baseband component. One modulator circuit that works well is illustrated in figure 3. The output of this modulator is approximately constant-envelope when the quadrature carrier level is large relative to the sidebands. Each of the four modulators is followed by a broadband symmetrical-limiting differential amplifier to obtain the four constant-envelope signals. The 150Ω quadrature carrier resistor provides the appropriate carrier level when driving a 50Ω load.



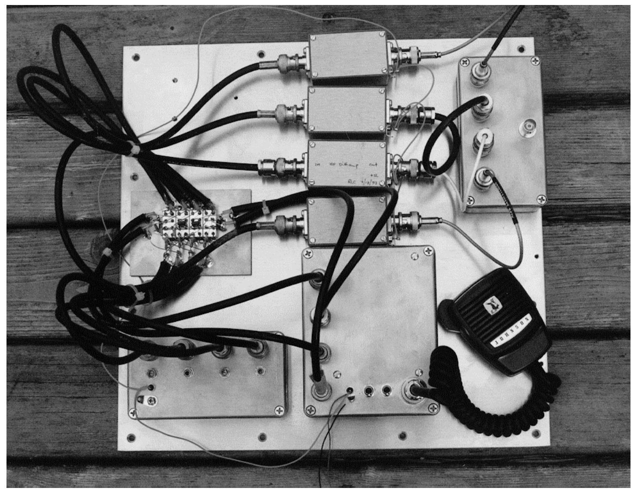
Narrow Band Phase Modulator
Figure 3

The four-port combiner shown in figure 4 connects to the antenna through a pi-network low-pass filter. In this low-power transmitter, the upper sideband and carrier components are dissipated in the 100 Ω resistors. In a higher power design, efficiency may be improved by removing the 100 Ω terminating resistors.



Four-Port Passive Combiner
Figure 4

Figure 5 is a photograph of the low-power 7.2 MHz prototype single-sideband transmitter. The baseband audio processor is at bottom center, the four-output carrier generator is in the lower left corner, the four narrow-band-phase-modulators are on the "ugly board" just above the carrier generator, the four limiting amplifiers are at top center, and the passive combiner is in the top right corner. Peak output power is +16 dBm, with carrier, opposite sideband, and higher order distortion products suppressed more than 30 dB.



Photograph of 7.2 MHz Low-Power Lower Sideband Transmitter
Figure 5

References:

1. Campbell, Richard, "A Fourth Method of Single Sideband Generation," submitted to IEEE Transactions on Microwave Theory and Techniques, September, 1997. In review.

2. Campbell, Rick, "A Multimode Phasing Exciter for 1 to 500 MHz," in QST, volume LXXVII Number 4, April 1993, pp. 27-31.

3. Kahn, Leonard R., "Comparison of Linear Single-Sideband Transmitters with Envelope Elimination and Restoration Single-Sideband Transmitters," in Proceedings of the IRE, volume 44 number 12, December 1956, The Institute of Radio Engineers, Inc. pp. 1706-1712.