Analog multiplier works over large frequency range

Hubert Houtman - September 16, 1999

Schottky-diode double-balanced mixers are common elements in analog and digital telecommunications circuits that operate at radio and microwave frequencies. Transistor analog multipliers, such as log-antilog, MOS, and variable-transconductance types, are usually limited to frequencies of much less than 1 GHz. In the circuit in Figure 1, an MBD301 hot-carrier Schottky-diode bridge forms the core of a four-quadrant analog multiplier and, therefore, can operate over a much larger frequency range than can transistor analog multipliers. This highly sensitive double-balanced modulator provides a high-quality output with low spurious-response level. Using the proper high-frequency circuit and IC techniques, you can use this type of circuit for digital and analog communications, radar, product detection, AGC circuits, and phase detectors in the radio and microwave bands.

Figure 1 An MBD301 hot-carrier Schottky-diode bridge forms the core of a four-quadrant analog multiplier that performs continuous computations of the product of arbitrary input signals A and B.
Like many double-balanced mixers and analog multipliers, this circuit has an amplifier, the MAX4223, for the IF. This differential amplifier is the only essential amplifier in the circuit; the MAX4224s are two 10-dB amplifier stages. If you use a balun transformer with a center-ta-grounded secondary in place of the dual AD8056, inputs A and B can be radio or microwave frequencies. With the input amplifiers shown, however, the frequency range for Input A is limited to about 100 MHz. You can use fast transistor amplifiers for the input and the output amplifiers to achieve system bandwidths greater than 1 GHz. You can also use a fast buffer amplifier-such as the MAX4405, which has a 75W output-at Input B for improved port isolation.

This four-quadrant analog multiplier is a quarter-squares multiplier based on the identity:

\[(A+B)^2-(A-B)^2=4AB.\]

The MAX4223 differential amplifier, which has a 1-GHz bandwidth, registers \((A+B)^2\) from the left bridge while subtracting \((A-B)^2\) from the right bridge to form the product:

\[\frac{V_{\text{OUT}}}{K}=AB,\]

where the constant, \(K\), is 12 mV. You can add the carrier at the differential amplifier's input for amplitude modulation as necessary.

The differential output across the 1-kW resistor of each diode bridge is a precisely symmetric, even function of the voltage across it: \(A+B\) for the left bridge and \(A-B\) for the right bridge. Consequently, the bridge's \(V_{\text{OUT}}\) contains only even terms of the combined Taylor series due to the four diode currents. The constant terms cancel out because the MAX4223 subtracts the bridge outputs, so the dominant term is the square term. Higher order even terms do not contribute, provided that inputs A and B stay at less than approximately 150 mV. For large inputs, each bridge behaves as a full-wave rectifier; the diodes become forward-biased with resistance smaller than the 1-kW load, and the parabolic branches ultimately degenerate into straight lines that the load resistor dominates. Therefore, the multiplier is unusable with such large inputs.

The circuit includes a balanced, double current-mirror network that supplies the diode bridge with four bias currents. A single 1-kW potentiometer controls the current, and four 3.9-kW resistors accurately distribute equal, balanced currents to the two bridges while preventing crosstalk between the bridges. These four resistors also isolate the diode bridges from the transistors, thereby improving system bandwidth.

Without this bias-current network, the bridge requires an approximately 5-MW load resistor for parabolic behavior. This value precludes this design's use in high-frequency circuits because the currents are extremely small and the time constants are very long when you connect the bridge to an amplifier input of a few picofarads. With the 1-kW load for the bridge and no bias network, the bridge output has a pronounced flat bottom around the origin. Fortunately, with the bias current of 1.08 mA in each 3.9-kW resistor, the Schottky diodes become forward-biased into partial conduction with 340 mV for each path, and the bridge yields an accurate and symmetric square-law output with a low source resistance. You can use one such bridge with the differential amplifier as a fast squarer for frequency-doubling and square-law detection, for example. With slightly more current, you can make the load resistor as little as 50W.
Figure 2 A quarter-squares multiplier test pattern on an X-Y oscilloscope illustrates good linearity and balanced behavior in all four quadrants. (Horizontal = Input A at 10 mV/div; vertical = $V_{\text{out}}$ at 20 mV/div.)

The multiplier test pattern in Figure 2 results from a 5-kHz sine wave on both Input A and the horizontal input and a 20-kHz square wave from a 100W source set at 0-, 6-, 12-, 18-, and 24-mV amplitude levels at Input B. Over this range of inputs, this multiple exposure shows that the analog multiplier exhibits linear behavior with errors of less than 1% of full scale. In Figure 3a, Trace A shows a double-sideband, suppressed-carrier output resulting from a -28 dBm, 20-kHz square-wave carrier, and Trace B results from a 20-kHz sine-wave carrier. Trace C shows the 2-kHz modulation signal on Input A. Figure 3b shows double-sideband suppressed-carrier output signals at Input B frequencies of 10 MHz (Trace A), 25 MHz (Trace B), and 120 MHz (Trace C) using a 600-kHz sine-wave modulator at Input A. Trace D shows that same signal as Trace C but at 5 nsec/division, to show that the rise time of the multiplier in this breadboard version is just a few nanoseconds. (DI #2413)
square-wave carrier at Input B (a) and outputs with input frequencies as large as 120 MHz (b).

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