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High-Frequency VGA Has Digital Control

Introduction

You can use variable-gain amplifiers (VGAs) in many types of systems, such as radio receivers, in which the input signal voltage depends on an uncontrolled variable, such as distance to the transmitter. In this type of system, you can use a VGA to ensure that the input signal amplitude matches the input voltage range of key components, such as ADCs and DACs, thereby maximizing the converters' dynamic range. The VGA in Figure 1 has high bandwidth, ranging from 115MHz at high gain to 225MHz at low gain, so you can use this circuit in the RF-signal path without degrading the signal. You can update the DAC in this circuit at 100MHz, but the level-shifter op amp limits the speed at which you can update the gain of the VGA to 3MHz. As configured, this VGA implements a calibration function with a 3MHz DAC update rate.

The VGA design comprises a three-transistor, long-tailed pair configuration comprising Q_1, Q_2, and Q_3. By changing the base voltage of Q_3, the DAC (IC_1) varies the emitter currents of the long-tailed pair. Changing Q_3's base voltage controls the gain according to the following equation, where K is a function of the emitter current and V_{B3} is the base voltage of Q_3:

$$G = KV_{IN}|V_{B3}|.$$

The gain control and bias-stability parameters of the circuit depend on transistor matching, so the circuit uses an HFA3102 matched, long-tailed array for Q_1 through Q_3. The usable range of V_{B3} is -0.8 to -4.4V, which corresponds to a gain range of 11.8 to -16.9dB, respectively. This gain span is a total of 28.7dB. The gain is proportional to R_4. Increasing R_4 increases the gain, but the gain span stays constant at approximately 28.7dB. Increasing the gain causes a corresponding decrease in the frequency response.

R_2, R_3, and the -5V supply form a bias circuit that sets V_{B3} to -4.4V when there is no DAC output current (the voltage across R_1 is zero), which occurs at a digital input of all ones. When the digital input is all zeros, the DAC output current is 20mA, which develops -1V across R_1. IC_2 level-shifts and amplifies this voltage to yield V_{B3} = -0.8V. The CA5160 works well as the level shifter because its low bias currents do not affect the DC performance, and its bandwidth enables the gain to change at a rate as high as 3MHz.

You should keep the video input signal level at about 25mV to prevent distortion. The signal path has an excellent frequency response because the HFA3102 is the only component in the signal path. A frequency response plot for V_{B3} = -3V (gain of 10dB) shows that the transfer function is well-behaved with no peaking and that the frequency response is 131MHz at the -3dB point. The DAC transfers the digital input to the internal registers on the rising edge of the clock pulses. This circuit uses the inverting DAC output to yield a positive increasing-transfer function, but you can obtain the inverse-transfer function by using the noninverting input (Table 1).

TABLE 1. VGA PERFORMANCE SUMMARY

PARAMETER	MINIMUM	MAXIMUM
Gain (dB)	-16.9	11.8
V_{B3} (V)	-4.4	-0.8
F_{-3dB} (MHz)	225	115
Digital Input/Inverting Output	0000 0000 0000	1111 1111 1111
Digital Input/Noninverting Output	1111 1111 1111	0000 0000 0000

If fast updates are unnecessary, you can use a slower DAC than IC_1. However, you may also have to redesign the interface circuit (IC_2 and associated components) if the DAC output voltage swing changes.

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