

# Two New Devices Help Reinvent the Signal Generator

By David Hunter

In the past, the most difficult part of an arbitrary waveform generator was designing the output stage. Typical signal generators offer output ranges from 25 mV to 5 V. To drive a 50-Ω load, traditional designs used high-performance discrete devices, a large number of integrated devices in parallel, or an expensive ASIC, with designers spending countless hours to create a stable, high-performance output stage with a wide programmable range. Now, advancements in technology have produced amplifiers that can drive these loads, reducing output stage complexity while decreasing cost and time to market.

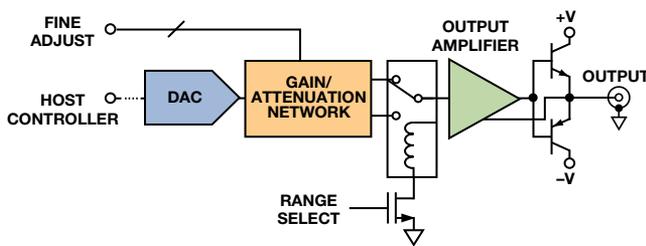


Figure 1. A typical signal generator model.

When using general-purpose signal generators, a frequency is entered, a button is pressed, and the instrument produces a new frequency. Next, the desired output power is entered, and another button is pressed. Relays click as they switch internal networks to adjust the output level. This discontinuous operation is required to compensate for the lack of a wide programmable range. This article proposes a new architecture that also solves this half of the problem with the output stage design.

The two key components that solve this front-end design challenge are: a high-performance output stage that provides high speed, high voltage, and high output current; and a variable-gain amplifier (VGA) with continuous linear-in-dB tuning. This design targets 20-MHz performance, with 22.4-V amplitude (+39 dBm) into a 50-Ω load.

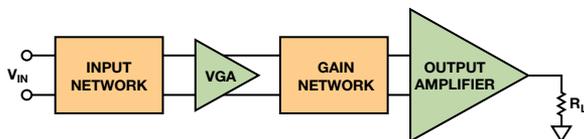


Figure 2. The smaller, simpler, signal generator output stage.

## New Compact Output Stage

The initial signal may come from a digital-to-analog converter (DAC) for a complex waveform, or from a direct-digital synthesis (DDS) device for sine-wave generation. In either case, its specifications and power adjustment capabilities may not be ideal. The first requirement is to provide attenuation or gain using a VGA. The gain provided by many VGAs is limited, however, and is seldom enough to be useful for this application.

If the output of the VGA can be set to a target level, then no matter what the input is, the output can be forced to a *known* amplitude. For example, if the desired output amplitude is 2 V,

and the power output stage has a gain of 10, then the output amplitude of the VGA should be regulated to 0.2 V. When the output stage is correctly designed, the output amplitude is ultimately set by the output of the VGA. Unfortunately, most VGAs become the bottleneck due to their limited programmable range.

A typical, high-quality signal generator offers an output amplitude range of 25 mV to 5 V. This 46-dB adjustable range exceeds the capabilities of most commercially available VGAs. The AD8330 was the first VGA to achieve a 50-dB range, but the bar was raised further with the AD8338, a new low-power VGA with an 80-dB programmable range. Under ideal conditions, the output amplitude of a classic signal generator could then range from 0.5 mV to 5 V, without the use of relays or switched networks. The full range would be continuously adjustable, free of the discontinuities associated with switches and relays. In addition, eliminating the relays increases instrument lifetime and system reliability.

Modern DACs and DDS devices often have differential outputs, requiring designers to use a transformer, lose half of the signal with a single-ended connection, or add a differential-to-single-ended converter. The AD8338 provides a natural fit, having a fully differential interface, as shown in Figure 3. For a sine-wave application, the DAC would be replaced with a DDS.

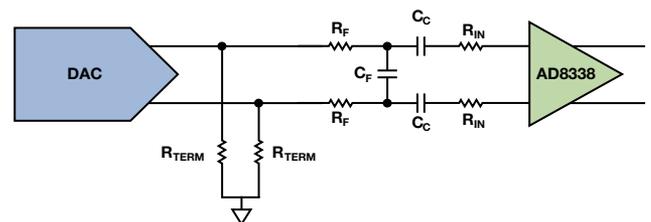


Figure 3. Example of a network that interfaces a DAC to the AD8338.

A major feature of the AD8338 is the flexible input stage. As an input-VGA, it manipulates the input currents using the “H-amp” topology invented by ADI Fellow Barrie Gilbert. This design uses feedback to balance the input currents while maintaining the internal nodes at 1.5 V. Under normal conditions, using the 500-Ω input resistors, the maximum 1.5-V input signal produces a 3-mA current. If the input amplitude were larger, say 15 V, a larger resistor would be connected to the “direct” input pins. This resistor is sized such that the same 3-mA current is obtained:

$$\frac{15.00 \text{ V}}{3 \text{ mA}} = 5 \text{ k}\Omega \quad (1)$$

The single-ended 15-V signal would output 1.141 V differentially. In this case, at minimum gain, the AD8338 would provide 28.4-dB attenuation, so the maximum possible gain is +51.6 dB. As a low-power part, it has a 1.5-V typical output swing into a 1-kΩ load.

The power of the input VGA is that its total gain range can be located around different set points. First, determine the output level required to produce the signal generator's maximum output. Many commercial generators only provide a 250 mW rms (+24 dBm) maximum output power into a 50-Ω load (sine wave). This is not enough to cover applications that need more output power, such as testing high-output HF amplifiers or ultrasound pulse generation, for example.

Advances in current-feedback amplifier (CFA) technology mean that this no longer has to be a problem. The ADA4870 CFA can drive 1 A at 17 V on ±20-V supplies. For sine waves, it can output frequencies up to 23 MHz at full load, making it an ideal front-end driver for the next generation of general-purpose arbitrary waveform/signal generators.

For 50-Ω systems that are sensitive to reflections, the ADA4870 requires some passive devices to match the source impedance to the 50-Ω load: a resistive pad and a 1.5:1 RF autotransformer. Allowing 1 V of margin, 8-W peak power is obtained when the effective amplifier loading is 16 Ω. Alternatively, if reflections are not a concern, the resistive pad can be eliminated, and the autotransformer can be replaced with one with a 0.77:1 ratio. Without the resistive padding the output power increases to 16-W peak (28.3-V amplitude).

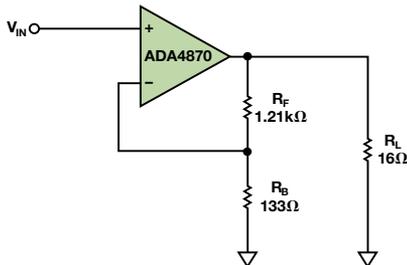


Figure 4. The basic connection for the ADA4870 for driving 16 Ω, gain = 10.

To optimize the output signal swing, the ADA4870 is configured for a gain of 10, so the required input amplitude is 1.6 V. The ADA4870 has a single-ended input, and the AD8338 has a differential output, so an AD8130 differential-receive amplifier, with its 270-MHz gain-bandwidth product and 1090-V/μs slew rate, provides both the differential-to-single-ended conversion and the required gain. The AD8338's output is constrained to ±1.0 V, so the AD8130 must provide an intermediate gain of 1.6 V/V. When combined, the three devices form a complete signal generator output stage.

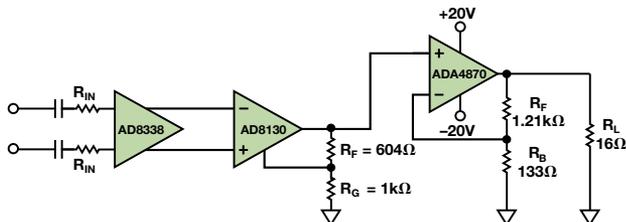


Figure 5. Signal generator output stage.

Two final steps are required to complete the design: configuring the input network for maximum input signal plus antialiasing, and designing the output network for an impedance transformation.

### The AD8338 Input Network

For this design, the differential output amplitude will be ±1.0 V. With factory default settings, the internal 500 Ω resistors, and maximum gain, the input amplitude would have to be 100 μV. Adding resistors to the direct-input

pins allows the designer to adjust this requirement. The gain range, as determined by the input resistors, is:

$$\text{Gain (dB)} = 80 \times (V_{\text{GAIN}} - 0.1) + 20 \log \left( \frac{19000}{R_P + R_N} \right) - 34 \quad (2)$$

Using 40.2-kΩ resistors at each input provides a good balance between noise power and input attenuation. With  $V_{\text{GAIN}} = 1.1 \text{ V}$  (maximum gain), the gain is:

$$\text{Gain (dB)} = 80 + 20 \log \left( \frac{19000}{80400} \right) - 34 = 33.5 \text{ dB} \quad (3)$$

In this case, the differential input only needs to be 21 mV.

When  $V_{\text{GAIN}} = 0.1 \text{ V}$ , the gain is:

$$\text{Gain (dB)} = 0 - 12.5 - 34 = -46.5 \text{ dB} \quad (4)$$

For the same 21 mV input, the output will be about 100 μV.

Factoring in the total gain of the AD8130 and the ADA4870, which amounts to 24.1 dB, the output amplitude of the ADA4870 will range from 1.6 mV to 16 V. After the resistive pad and autotransformer, the voltage on the output will range from 2 mV to 20 V.

Interfacing the AD8338 to a device such as a DDS requires accounting for the antialiasing and input attenuation. For example, the differential output AD9834C DDS requires 200-Ω resistors to ground for proper swing. Each output produces only half of the sine-wave signal, as shown in Figure 6.

Each output peaks at 0.6 V, making an effective input of ±0.6 V. The required attenuation is 26 dB. With 200-Ω resistors, the attenuation is easily achieved by creating a simple resistive divider. Since the signal does not swing uniformly, the peak of the signal should reach the expected attenuated value.

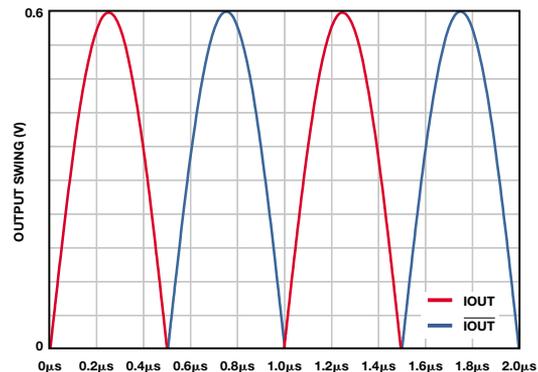


Figure 6. Output swing of the 9834C IOUT and  $\overline{\text{IOUT}}$ . Aliasing artifacts are not shown.

$$0.021 = 0.6 \left( \frac{R_{\text{BOT}}}{R_{\text{TOP}} + R_{\text{BOT}}} \right); R_{\text{TOP}} = 193 \text{ } \Omega \text{ and } R_{\text{BOT}} = 7 \text{ } \Omega \quad (5)$$

Using standard 6.98-Ω and 191-Ω resistor values will contribute 0.7% error.

Finally, some antialiasing will be necessary. With a 75-MSPS sample rate, the Nyquist-rate output would be 37.5 MHz, which exceeds the 20-MHz bandwidth of this design. Setting the antialiasing pole at 20 MHz, the required capacitor is:

$$C_{\text{FILT}} = \frac{1/R_{\text{BOT}}}{2\pi \times f} = \frac{0.142}{2\pi \times 20 \times 10^6} = 1100 \text{ pF} \quad (6)$$

This is a standard value, so the complete input network is as shown in Figure 7:

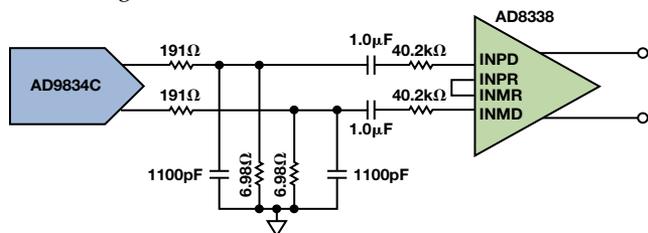


Figure 7. DDS + attenuation and filter network + AD8338.

This stage was constructed and measured. The overall variation was within  $\pm 0.6$  dB, as shown in Figure 8.

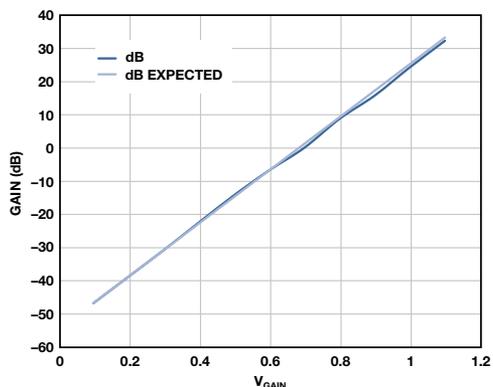


Figure 8. Calculated vs. measured gain for AD8338 configuration.

### ADA4870 Output Stage

With the single-ended output provided by the AD8130, the ADA4870 will perform the final gain-of-10. Two resistors are needed to set this gain, and the stage is stable without external compensation. The only work that will be left is shaping the output network to conform to the application's need. There are three general implementations:

1. Direct output from amplifier to 50  $\Omega$
2. Padded, autotransformer output to 50  $\Omega$
3. Unpadded, autotransformer output to 50  $\Omega$

For a direct output, the amplifier output is tied directly to the output connector, without any network to transform the source, as shown in Figure 9. Perfect for the true-dc-connected source, this method doesn't use the device's full potential, yet still does better than the typical signal generator's 10-V output amplitude. In this case, the maximum peak power will be 5.12 W.

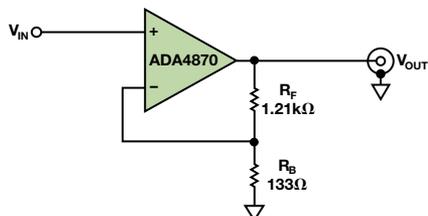


Figure 9. Connections for direct output drive.

With the padded design, the 16- $\Omega$  load is split between an 8- $\Omega$  series pad, and the filtered 1.5:1 autotransformer, as shown in Figure 10. In this mode, the low impedance of the design enables the designer to use  $6.25\times$  smaller values for the inductors than those used for 50- $\Omega$  designs. The low-pass filter and autotransformer convert the effective 8- $\Omega$  source impedance to a well matched 50  $\Omega$ . While the total peak output power will be 8 W, this design method is best suited to applications that need a matched 50- $\Omega$  source where reflections might be of concern, such as when long transmission lines are involved.

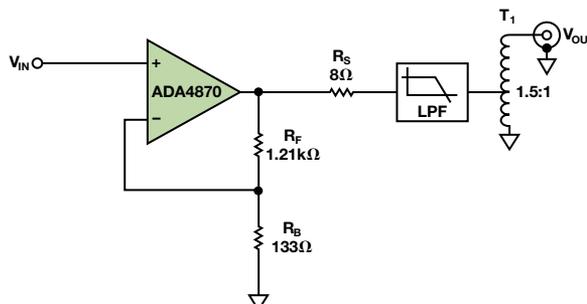


Figure 10. ADA4870 connections for padded-output design. Input impedance appears as 50  $\Omega$  to any reflections within the band of interest.

The last option, and probably the most useful for signal generators, skips the use of the 8- $\Omega$  pad, and permits twice the output power. An LC ladder filter is still recommended, as shown in Figure 11, but the ladder values will be  $3.125\times$  smaller than values which would be used for a 50- $\Omega$  system (design to 16- $\Omega$  nominal impedance). In this case, the autotransformer will use a 0.77:1 ratio. In this mode, the peak sine-wave output amplitude will be 28.3 V, and the ADA4870 will drive approximately 16 W into a 50- $\Omega$  load (8-W rms or 39 dBm).

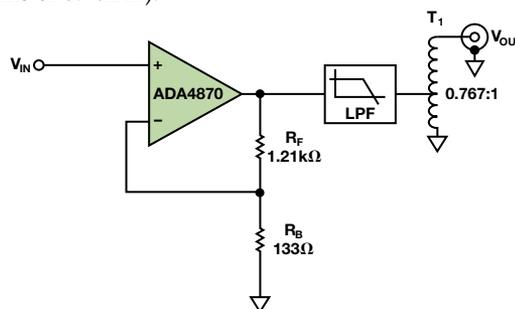


Figure 11. Connections for optimal power output for driving 50- $\Omega$  loads.

### The Total Solution

In the real world, simulations and equations are meaningless if they don't match the real world. It is thus important to build a complete system and measure its performance against expectations. Figure 12 shows the schematic of an actual padded-output design.

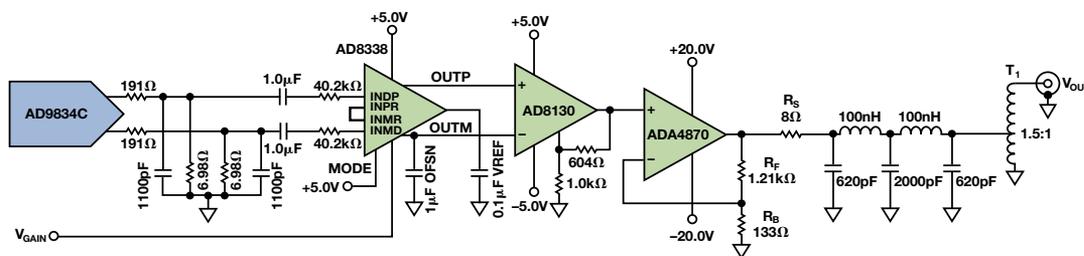
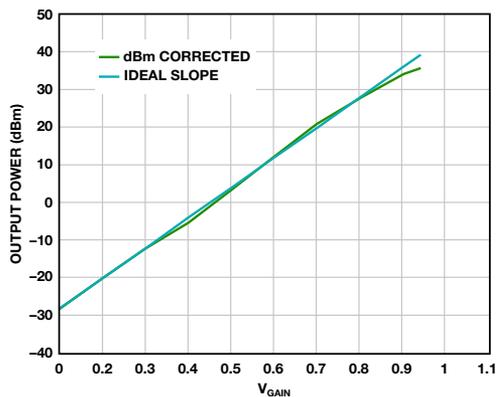


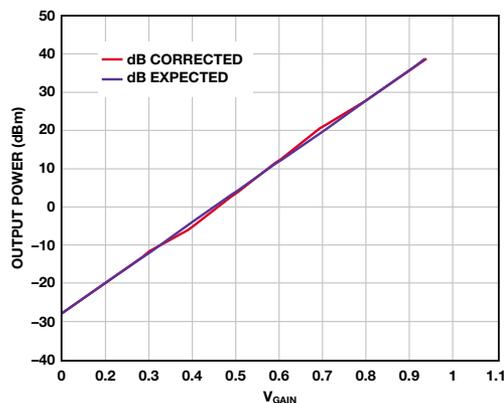
Figure 12. Simplified, complete schematic.

Figure 13 shows measured results without a filter. The system has a  $\pm 1$ -dB gain conformance worst case up to the 2.75 W rms (5.5-W peak) output power (P1dB compression point at 34 dBm). Most notably, the total gain range exceeded 62 dB, offering 16 dB more range than many standard generators.



**Figure 13.** Padded, unfiltered, output power results. Without the filter, system exhibits a P1dB point at 36 dBm.  $F_{TEST} = 14.0956$  MHz.

The gain range can be improved with better filtering at the DDS output, as well as by reducing system noise. Figure 14 shows the same measurements with a filter. The filtered output does not suffer the same P1dB level, producing a full +36 dBm output into a 50- $\Omega$  load. The overall gain linearity is better ( $\leq 0.65$  dB), with errors only present around midscale.



**Figure 14.** Measured output with a 5<sup>th</sup> order low-pass filter ( $f_c = 20$  MHz).  $F_{TEST} = 14.0956$  MHz.

If even higher output powers were required for particular modes of operation, multiple output amplifiers could

be used to drive a specialty transformer for the given application. Alternatively, the design methods described here could be applied to lower supply systems, as long as the methods described here are used within the constraints of the alternate designs.

Note that the upper end of the measurement stopped at  $V_{GAIN} = 0.9375$  V as a result of accumulated input attenuation and gain errors. This can be resolved by trimming the initial attenuation network to account for the total system errors. Once corrected, the total system gain range increased to 74 dB.

## Conclusion

By pairing a high-performance VGA and a high-performance, high-output CFA, a simple front end for a new generation of signal generator can be constructed. Total PC board area and cost are reduced due to the high integration of these parts.

For additional versatility, a log amplifier, such as the [AD8310](#), can be used in a closed-loop feedback system. With this addition, working in conjunction with a DDS like the [AD9834C](#), the designer can incorporate various forms of envelope modulation, such as frequency shift keying (FSK), on-off keying (OOK), and phase-shift keying (PSK), as an intrinsic feature, offering countless options through the novel use of two fundamental blocks.

## References

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[MT-060 Tutorial. Choosing Between Voltage Feedback and Current Feedback Op Amps.](#)

[MT-072 Tutorial. Precision Variable Gain Amplifiers.](#)

[MT-073 Tutorial. High Speed Variable Gain Amplifiers.](#)



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