Floating a Source Output

by George D. Pontis

To provide the greatest versatility in both benchtop and systems applications, the 8903A Audio Analyzer's built-in source is floating. This lets the user eliminate ground-loop errors, sum signals, and add dc offsets to the source output.

Previous designs used a separate, isolated power supply for the source circuits. This method is straightforward and offers very good low-frequency common-mode rejection. However, there are several reasons why this arrangement is not used in the 8903A.

The biggest problem with the floating power supply approach is interfacing with the digital programming lines. Since only three of the thirteen attenuator lines have relay isolation and none of the nineteen oscillator lines can be floated, over thirty lines must be coupled in some manner. One solution is to float only the final output stage. This eliminates the need for couplers, but requires a high-performance differential-input amplifier to reject the common-mode signal that appears at the input of the floating stage. Since a floating power supply is still required, the cost of this approach is relatively high.

The 8903A solves this problem with a single-ended-to-differential output converter. This circuit, shown in Fig. 1, operates on the instrument's ground-referenced $\pm15V$ supplies and requires only two operational amplifiers. A precise combination of negative feedback, positive feedback, and cross-coupling yields a symmetrical differential output with infinite common-mode rejection and a well-defined output impedance.

An analysis of this circuit is generally a tedious procedure because of the number of components involved. However, the high degree of symmetry in the circuit can be exploited to great advantage by using the relations $R2/R1 = R12/R11$, $R3 = R7$, $R6 = R10$, and $R4 = R5 = R8 = R9$. From these relationships, one can derive the expression $R2/R1 = (2R6 + R4)/2R3$, which is a necessary condition for achieving an infinite common-mode output impedance. Then it is easy to calculate the differential output impedance and the open-circuit voltage gain. The resulting equations can be manipulated to find suitable values. For the resistor values used in the 8903A, the associated gain is 1.125 and the output impedance is 480 ohms. The output is further padded with a 120-ohm resistor to yield the desired 600-ohm output impedance.

It would have been possible to use resistors that gave an output impedance of exactly 600 ohms instead of 480 ohms, but this would have required setting up and stocking a supply of several extra odd resistor values. As it is, the circuit is realized using 0.1%, 25-ppm resistors that are also used elsewhere in the instrument.

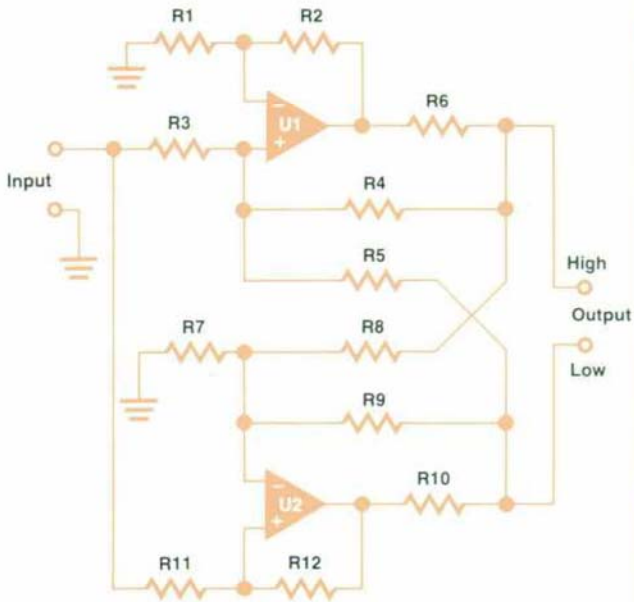

Fig. 1. *Single-ended-to-differential output converter provides a floating output for the 8903A's internal oscillator.*

The easiest way to see how this circuit works is to eliminate either the inverting (low) or noninverting (high) half of the circuit by shorting the respective output to ground. Fig. 2 shows the reduced circuit when the low half is grounded. If R4 is disconnected, the circuit will have a forward gain of about one, and an output impedance of 276 ohms. R4 works in conjunction with R6 to provide voltage and current feedback that causes the gain and the output impedance to rise.

To demonstrate that the output is truly floating, we ground the input and apply a test source to both outputs. Ideally, the current flow from the test source should be zero. Fig. 3 shows a block diagram and the reduced circuit for this test. Here it can be quickly calculated that the output of U1 will rise just enough over that of the test source to make the current through R6 cancel the current through R4 and R8. Note that the current flowing through sources V1 and V2 is supplied by the other half of the circuit, which is not shown.

timum match between the filter configuration and the variable resistive element is not straightforward.

Let's go through the alternatives and the tradeoffs. Switchable resistor networks have good distortion and noise characteristics but do not provide continuous tuning coverage and require extensive switching circuitry. Photoresistors can be driven over a large resistance range and provide continous tuning. However, the noise and distortion they add to a signal are greater than the required level of 90 dB below the signal level. They can be used as fine-tuning elements if coupled only partially into the circuit. These devices can also be slow and are awkward to control rapidly, reducing the tuning speed. Finally, they tend to vary significantly from device to device and with time and temperature, making compensation difficult.

Four-quadrant analog multipliers also do not have the 90-dB performance necessary, but they too can be lightly coupled into the circuit for fine tuning. These devices are fast, inexpensive, and easy to drive. There are many variations on this type of circuit, some of which can be obtained in integrated form. Those most suitable use a differential pair of bipolar transistors as a variable gain element by varying the common-mode current.

Light bulbs as variable resistive devices are relatively linear but are slow and have a limited dynamic range. Thermistors, diodes and other nonlinear devices would all be useful only for fine-tune applications. The drive and compensation circuitry for all of these alternatives would be complex and the overall performance marginal.

The tuning elements selected were switchable resistor

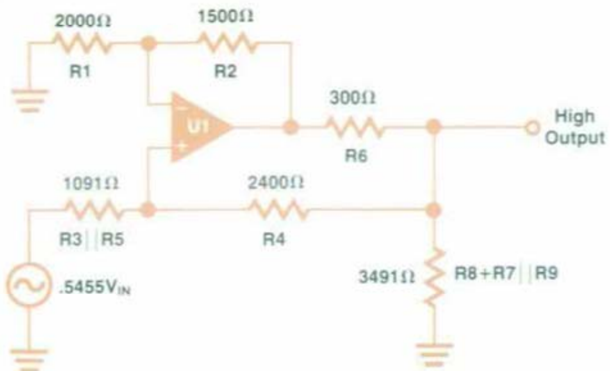

Fig. 2. *Eliminating the inverting side of the circuit of Fig. 1 by shorting the low output to ground results in this reduced circuit.*

In practice it was found that parasitic effects and the electromagnetic-interference (EMI) filters degrade the circuit balance when the frequency approaches 100 kHz. However, each board is tested for a minimum of 50 dB common-mode rejection at 1 kHz. A typical unit has greater than 40 dB rejection at 100 kHz. Also, a 10-kΩ resistor internally ties the low output to the chassis ground. This provides a reference for the output when no external load is connected. Without this resistor, the common-mode output voltage is indeterminate.

One initial concern about the circuit was difficulty of troubleshooting problems, such as one of the resistors drifting out of tolerance, causing poor common-mode rejection. This problem was solved by implementing the following test procedure. First, the input to the floating amplifier is set to exactly 1.00V rms using the special functions built into the 8903A. Then, the technician shorts the low side to ground and measures the potentials at several circuit nodes. The measured values can be compared to the calculated values published in a table in the 8903A manual. A second set of measurements can be made, if necessary, with the high side grounded. By observing the deviations between the measured and calculated values, it is easy to locate the faulty component.

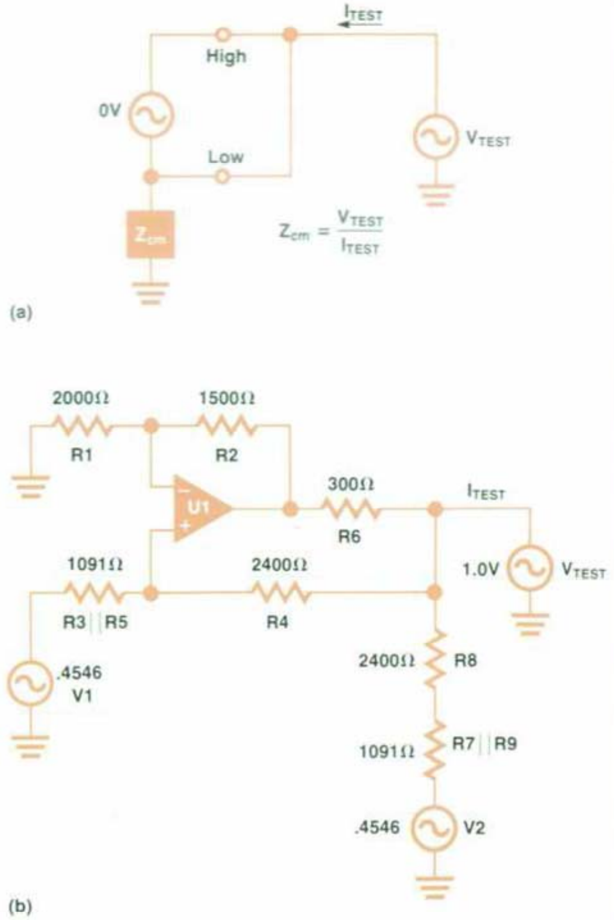

Fig. 3. *(a) To demonstrate that the output of the circuit is floating, the input is grounded and a voltage source is applied to both outputs. (b) Reduced circuit for this test (only half of the circuit is shown). Current through R6 cancels the current through R4 and R8. Current through V1 and V2 is supplied by the other half of the circuit (not shown). Thus no current is drawn from the test source.*

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Born in Los Angeles, California, George Pontis attended the University of California at Santa Barbara, receiving his BSEE degree in 1975. He joined HP in 1978 and contributed to the design of the 8903A Audio Analyzer. Formerly a contributing editor of Audio Magazine, he's a member of the Audio Engineering Society. He lives in Palo Alto, California and enjoys outdoor sports, especially tennis, skiing, and swimming.

networks for low-distortion coarse tuning, and a four-quadrant multiplier for fine tuning between the discrete steps of the switchable resistors. Since the four-quadrant multiplier is coupled into the circuit only enough for ±7% tuning, it does not contribute significantly to the overall noise and distortion. A resistor switching network is best implemented if one end of the network is dynamically kept at ground potential; this relieves many constraints on the switching network. To this end, a state-variable* notch configuration is used (see page 14). With this design, low-distortion tuning over a 10:1 frequency range is achieved. Capacitors are switched into the network to change frequency in three-octave bands and provide complete coverage of the frequency range of the analyzer.

To complete the fine-tuning path, a synchronous detector mixes the filter output waveform with the fundamental waveform. If any fundamental exists in the notch output, a dc current is generated to fine tune the notch. The critical parameters here are 100-dB dynamic range and rapid operation. A FET double-balanced mixer was selected. The input mixing signal that drives the FET is a square wave, rich in odd harmonics, so the circuit responds to odd-order harmonics as well as to the fundamental. This is the classical solution. A complete null may not be achieved if third, fifth, or higher-order odd harmonics are present. Total error can

*The name "state-variable filter" is a consequence of the fact that the equations that describe the system can be written in a form that fits the classical state-space description of a linear system, i.e., $\dot{\mathbf{x}} = \mathbf{Ax} + \mathbf{Bu}$, where $\mathbf{x}$ is the response (or state variable) of the system to an input $\mathbf{u}$.