Positive Feedback Terminates Cables

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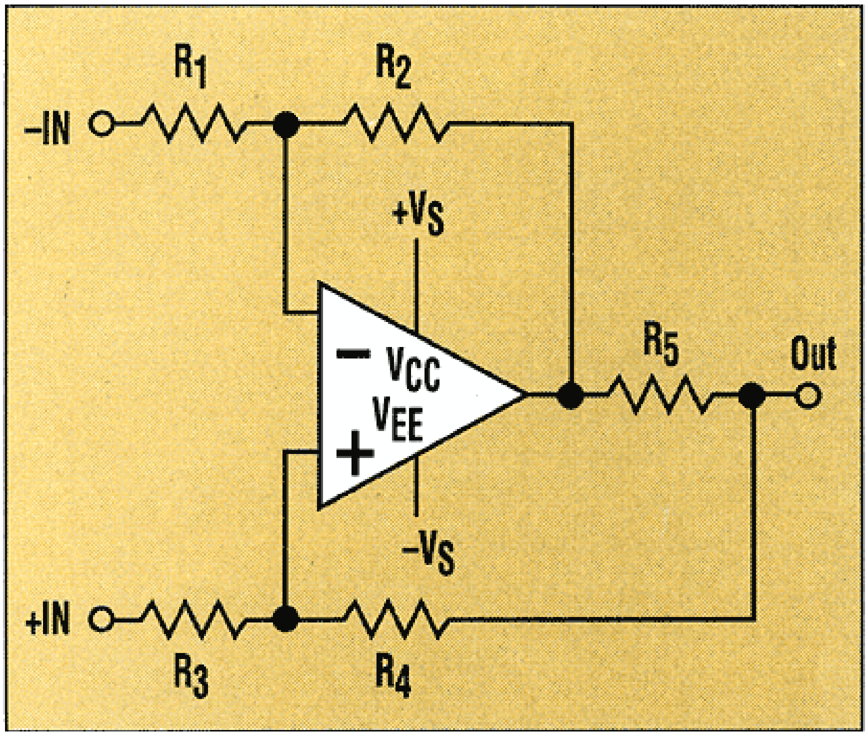
Positive feedback along with a series output resistor can provide a controlled output impedance from an op-amp circuit, with lower losses than would result from using an actual resistor. The circuit is useful when driving coaxial cables that must be terminated at each end in their characteristic impedance, which is often 50 Ω. Adding a 50-Ω series resistor on the op amp's output obviously reduces the available signal swing.

As can be seen in Figure 1, the circuit is an adaptation of the Improved Howland Current Pump, which is usually designed to maximize output impedance. It uses the positive feedback to provide a multiplication of the current sense resistor's value. For example, with R1 = R2 = R3 = 1 kΩ, and R4 = 1.2 kΩ, the circuit supplies a 50-Ω output impedance with only 5 Ω of real resistance to lose voltage swing through.



1. Coupling positive feedback with a series output resistor provides a controlled output impedance from an op-amp circuit, reducing losses that would otherwise occur with an actual resistor. The circuit is an adaptation of the Improved Howland Current Pump.

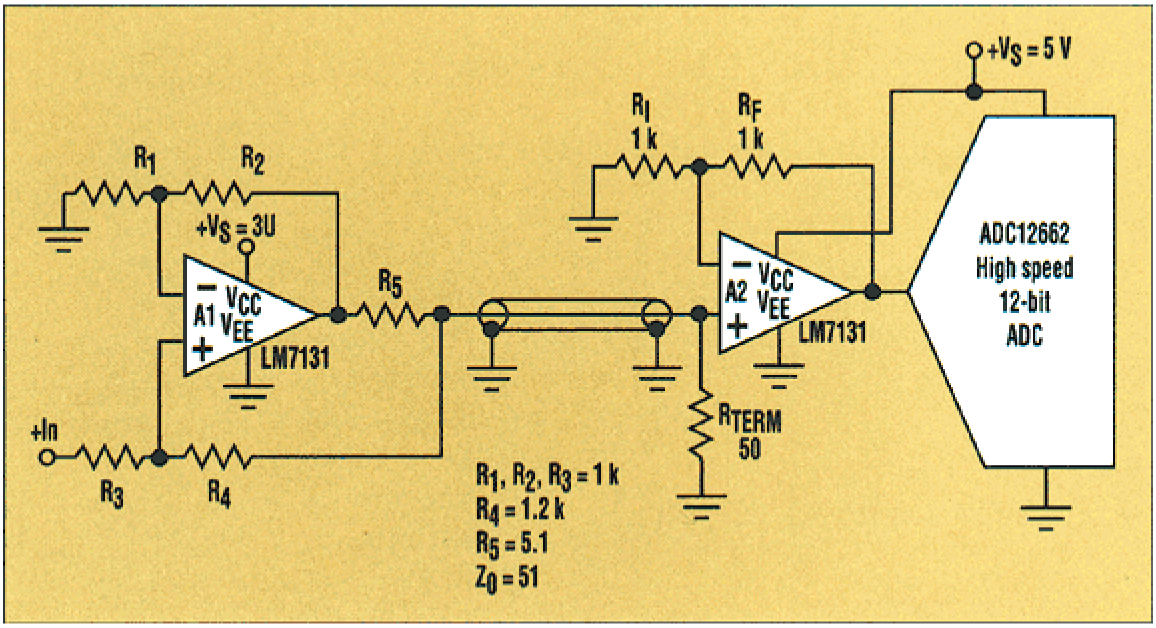
Adding positive feedback has the effect of multiplying circuit gain by the same ratio as it multiplies the sensing resistor (the example values given had a gain of about 10). Keep in mind that loading will cause the output voltage to drop to half (that's proof of the concept), so the loaded gain is half the unloaded gain. Available voltage swing remains essentially unimpaired. This can be a valuable feature, especially in low-voltage circuits like those used with National Semiconductor's LM7131. This part can provide 4-V pulses into a 150-Ω cable on 5-V supplies, but back termination would typically halve that. This technique maintains the full 4-V capability.

The circuit tolerates capacitive loads well, better than just the op amp alone. The inductive portion of any load is what could cause stability problems. Note that coax cable is a transmission line and isn't considered purely inductive or capacitive. Load inductance will manifest itself as overshoot or undershoot in pulse response. If the overshoot is less than 40% of the total peak-to-peak amplitude of the pulse, then the circuit has adequate phase margin.

Setting the desired gain involves pegging the values of the negative feedback resistors. Remember that the gain will ultimately be multiplied by an amount equal to what the series output resistor R5 is being multiplied. For convenience, the input leg of the positive feedback (R3) can be set equal to R1. The following equation solves for R4:

where Z is the desired output impedance. AOL is the open-loop gain of the op amp.

An example demonstrates the value of this technique (Fig. 2). A1 is National's LM7131 in a battery-operated portable device operating at 3 V. At the 3-V supply, the LM7131 is specified for a maximum swing of 2 V. Using positive feedback for back termination makes this entire voltage swing available. At the receiving end, another LM7131 provides gain to present a 0- to 4-V input to a high-speed 12-bit ADC.



2. The value of the technique demonstrated in Figure 1 is shown in this application, which uses National Semiconductor's LM7131 in a battery-operated piece of portable equipment operating at 3 V.

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Wideband low-voltage op amps have become widely available since the original Idea For Design was written. We also have seen an increasing use of ever-lower supply voltages. Presently, the region around 2.4- to 2.5-V total supply voltage is quite common. Soon, we will witness demands to run these analog systems at 1.8 V or lower. All of these factors contribute to making this circuit technique even more valuable today.

One critical detail, though, that wasn't covered in the original article involves the tolerance considerations of the resistors. It's well known that the Improved Howland Current Pump in its purest form can be quite sensitive to component variation. Just how sensitive it is depends on how close one operates it to the point where it becomes a true infinite-output impedance-current source. The back-termination circuit described here is operating far enough away from that point, so you can avoid using trimming potentiometers as long as you use resistors of sufficient precision.

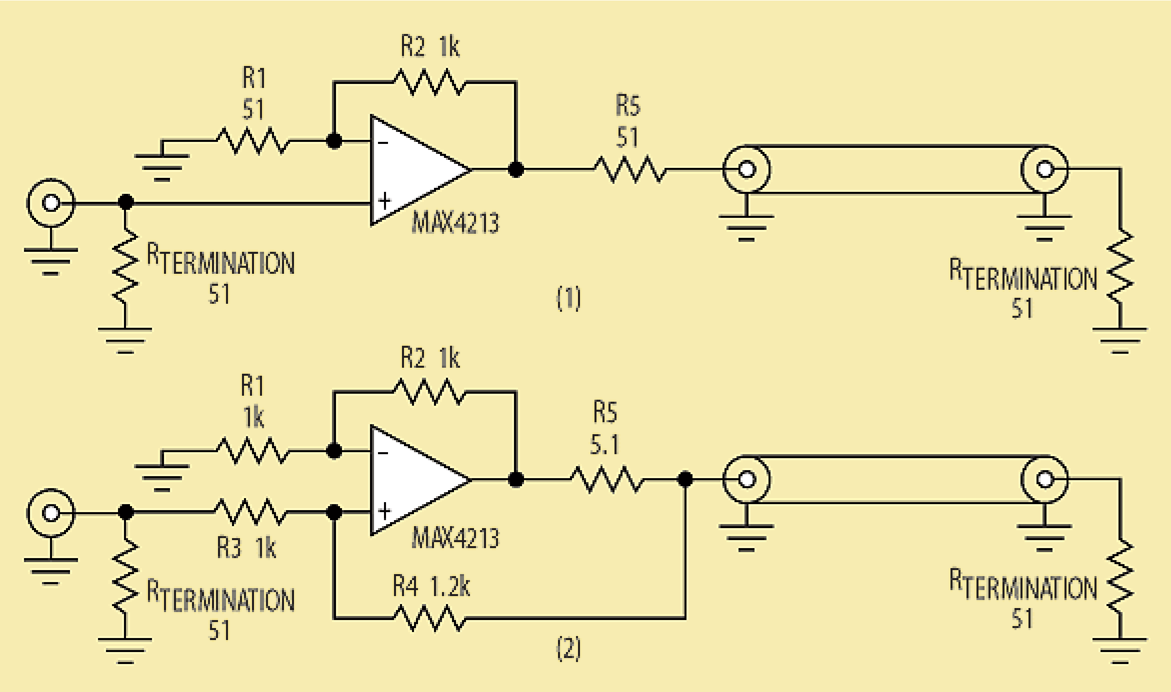
Note that the original article contained an error in the equation to determine R4. This reprint of the original Idea For Design has the correct version of that equation.

OUTPUT IMPEDANCE (Z_O) VERSUS R4

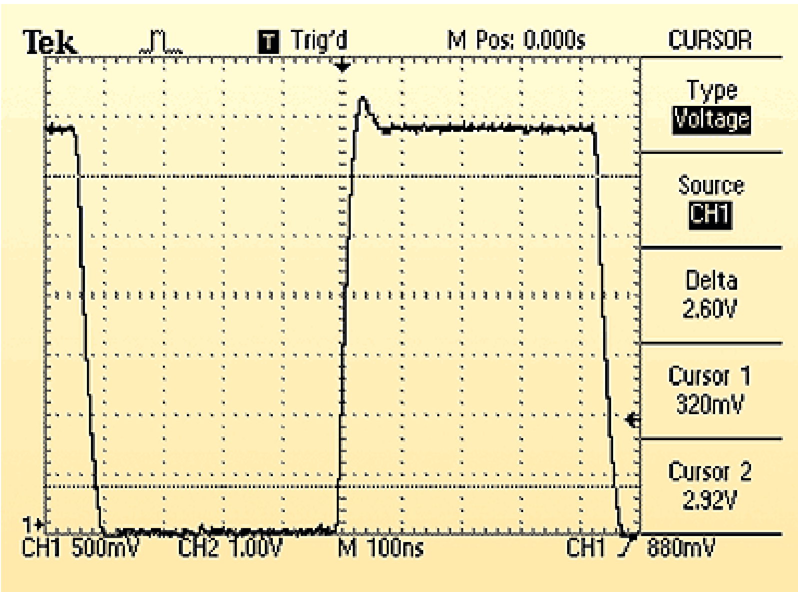
R4 (k V)	Z_O	R4 tolerance	Z_O variation	Z_O variation from 50 V
1.1979	55.50813	1%	5.53%	6.75%
1.2221	50.00675	1%	4.93%	23.83%
1.1858	58.796	2%	11.78%	13.07%
1.2342	47.68226	2%	9.35%	8.30%
1.1495	71.85118	5%	36.60%	38.18%
1.2705	41.95617	5%	20.23%	19.32%
0	25.0004	10%	#DIV/0!	2109.62%
1.331	35.20297	10%	33.07%	32.30%
1.21	52.59901	—	0.00%	1.15%

The table displays values for R4 varying from the nominal standard value of 1.21 kΩ for a 1% resistor, and the corresponding resultant output impedance. This chart indicates that the output impedance (ZO) varies approximately 5% for every 1% variation in R4. Using 2% resistors will keep the back termination within 12% of its value at the nominal value for R4. It should be noted that while 52 Ω was used for this discussion, there are 50- and 53.5-Ω coaxial cables available as well. The objective is to achieve good pulse fidelity and keep overshoot within limits. Keeping 12% tolerance will fulfill this requirement.

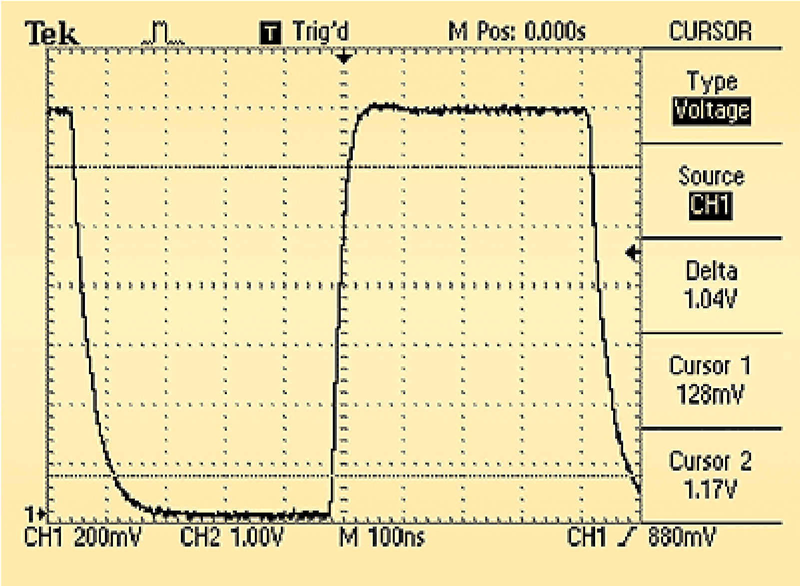
Some scope waveforms make it easy to compare the two circuits shown in Figure A. All tests were done with 15 ft. of RG-58 coaxial cable on the output. Figure A1 is a conventional circuit, while Figure A2 uses active back-termination. Figure B depicts Figure A1, the conventional circuit with no termination, showing a slight overshoot. Figure C shows the same circuit properly terminated. Likewise, Figure D is the output of Figure A2, the active back-termination circuit, with an unterminated output. Finally, Figure E is the output of the active back-termination circuit when it's terminated properly.



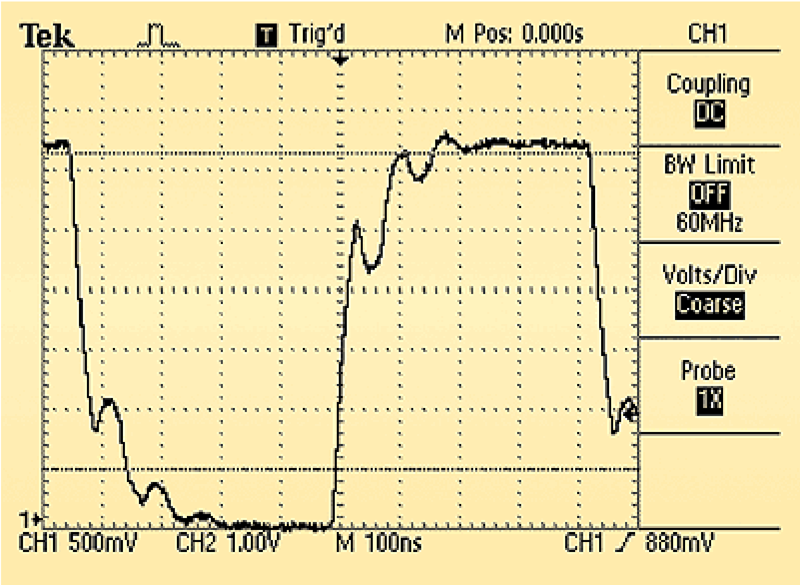
A. Two circuits were used to obtain the scope waveforms, a conventional circuit (1) and an active back-termination configuration (2). Notice that all of the waveforms are taken at the load (far) end of the 15 ft. of coax cable. RG-58 cable was used for these tests.



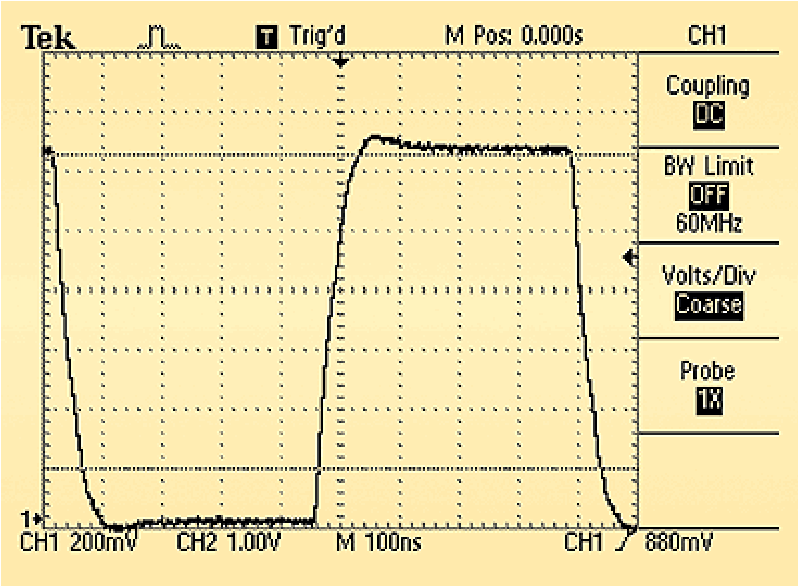
B. When unterminated, the waveform of the conventional amplifier measured at the far end of the coaxial cable exhibits a slight peak.



C. The peak in the waveform disappears when the conventional amplifier is properly terminated. But, note the change in vertical scale factor due to halving the amplitude.



D. This waveform results when the active termination circuit isn't terminated. The poor signal fidelity is probably the result of using positive feedback under conditions it's not suited for.



E. With the proper termination, the active termination circuit produces a much better waveform. Also, the waveform's amplitude isn't halved, as is the case when the conventional circuit is terminated.

The observed differences in pulse response between the two circuits can be attributed to a couple of things. First is the difference in impedance levels at the input nodes of each circuit. The impedances of the conventional circuit are on the order of 50 Ω at each node, while the active termination circuit is on the order of 500 Ω.

Second, the active termination circuit runs the op amp at half the closed loop gain-compared to the conventional circuit. This results in voltage differences at the inputs of half as much under slew conditions. The behavior of the unterminated active back-termination circuit is no doubt a consequence of using positive feedback under conditions that it's not intended to perform well under. Nonetheless, the active back-termination circuit shows good pulse fidelity when terminated. Most importantly, the active circuit makes available the full output-voltage swing of the amplifier.