Application Note 24 A Simplified Test Set for Op Amp Characterization

Literature Number: SNOA637
A Simplified Test Set for Op Amp Characterization

INTRODUCTION

The test set described in this paper allows complete quantitative characterization of all dc operational amplifier parameters quickly and with a minimum of additional equipment. The method used is accurate and is equally suitable for laboratory or production test—for quantitative readout or for limit testing. As embodied here, the test set is conditioned for testing the LM709 and LM101 amplifiers; however, simple changes discussed in the text will allow testing of any of the generally available operational amplifiers.

Amplifier parameters are tested over the full range of common mode and power supply voltages with either of two output loads. Test set sensitivity and stability are adequate for testing all presently available integrated amplifiers.

The paper will be divided into two sections, i.e., a functional description, and a discussion of circuit operation. Complete construction information will be given including a layout for the tester circuit boards.

FUNCTIONAL DESCRIPTION

The test set operates in one of three basic modes. These are: (1) Bias Current Test; (2) Offset Voltage, Offset Current Test; and (3) Transfer Function Test. In the first two of these tests, the amplifier under test is exercised throughout its full common mode range. In all three tests, power supply voltages for the circuit under test may be set at ±5V, ±10V, ±15V, or ±20V.

POWER SUPPLY

Basic waveforms and dc operating voltages for the test set are derived from a power supply section comprising a positive and a negative rectifier and filter, a test set voltage regulator, a test circuit voltage regulator, and a function generator. The dc supplies will be discussed in the section dealing with detailed circuit description.

The waveform generator provides three output functions, a ±19V square wave, a −19V to +19V pulse with a 1% duty cycle, and a ±5V triangular wave. The square wave is the basic waveform from which both the pulse and triangular wave outputs are derived.

The square wave generator is an operational amplifier connected as an astable multivibrator. This amplifier provides an output of approximately ±19V at 16 Hz. This square wave is used to drive junction FET switches in the test set and to generate the pulse and triangular waveforms.

The pulse generator is a monostable multivibrator driven by the output of the square wave generator. This multivibrator is allowed to swing from negative saturation to positive saturation on the positive going edge of the square wave input and has a time constant which will provide a duty cycle of approximately 1%. The output is approximately −19V to +19V.

The triangular wave generator is a dc stabilized integrator driven by the output of the square wave generator and provides a ±5V output at the square wave frequency, inverted with respect to the square wave.

FIGURE 1. Functional Diagram of Bias Current Test Circuit

The triangular wave generator is a dc stabilized integrator driven by the output of the square wave generator and provides a ±5V output at the square wave frequency, inverted with respect to the square wave.

The purpose of these various outputs from the power supply section will be discussed in the functional description.
BIAS CURRENT TEST

A functional diagram of the bias current test circuit is shown in Figure 1. The output of the triangular wave generator and the output of the test circuit, respectively, drive the horizontal and vertical deflection of an oscilloscope.

The device under test, (cascaded with the integrator, A), is connected in a differential amplifier configuration by R, R, R, and R. The inputs of this differential amplifier are driven in common from the output of the triangular wave generator through attenuator R and amplifier A. The outputs of the device under test are connected to the feedback network through resistors R and R, shunted by the switch S and S.

The feedback network provides a closed loop gain of 1,000 and the integrator time constant serves to reduce noise at the output of the test circuit as well as allowing the output of the device under test to remain near zero volts.

The bias current test is accomplished by allowing the device under test to draw input current to one of its inputs through the corresponding input resistor on positive going or negative going halves of the triangular wave generator output. This is accomplished by closing S or S on alternate halves of the triangular wave input. The voltage appearing across the input resistor is equal to input current times the input voltage of the oscilloscope. The vertical separation of the traces representing the two input currents of the amplifier under test is equivalent to the total bias current of the amplifier under test.

The bias current over the entire common mode range may be examined by setting the output of A equal to the amplifier common mode range. A photograph of the bias current oscilloscope display is given as Figure 2. In this figure, the total input current of an amplifier is displayed over a ±10V common mode range with a sensitivity of 100 nA per vertical division.

The bias current display of Figure 2 has the added advantage that incipient breakdown of the input stage of the device under test at the extremes of the common mode range is easily detected.

If either or both the upper or lower trace in the bias current display exhibits curvature near the horizontal ends of the oscilloscope face, then the bias current of that input of the amplifier is shown to be dependent on common mode voltage. The usual causes of this dependency are low breakdown voltage of the differential input stage or current sink.

OFFSET VOLTAGE, OFFSET CURRENT TEST

The offset voltage and offset current tests are performed in the same general way as the bias current test. The only difference is that the switches S and S are closed on the same half-cycle of the triangular wave input.

The synchronous operation of S and S forces the amplifier under test to draw its input currents through matched high and low input resistors on alternate halves of the input triangular wave. The difference between the voltage drop across the two values of input resistors is proportional to the difference in input current to the two inputs of the amplifier under test and may be measured as the vertical spacing between the two traces appearing on the face of the oscilloscope.

Offset voltage is measured as the vertical spacing between the trace corresponding to one of the two values of source resistance and the zero volt baseline. Switch S and Resistor R are a base line chopper whose purpose is to provide a baseline reference which is independent of test set and oscilloscope drift. S is driven from the pulse output of the function generator and has a duty cycle of approximately 1% of the triangular wave.

Figure 3 is a photograph of the various waveforms presented during this test. Offset voltage and offset current are displayed at a sensitivity of 1 mV and 100 nA per division, respectively, and both parameters are displayed over a common mode range of ±10V.

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**FIGURE 2. Bias Current and Common Mode Rejection Display**

**FIGURE 3. Offset Voltage, Offset Current and Common Mode Rejection Display**
TRANSFER FUNCTION TEST

A functional diagram of the transfer function test is shown in Figure 4. The output of the triangular wave generator and the output of the circuit under test, respectively, drive the horizontal and vertical inputs of an oscilloscope.

The device under test is driven by a ±2.5 mV triangular wave derived from the ±5V output of the triangular wave generator through the attenuators R11, R12, and R1, R3 and through the voltage follower, A7. The output of the device under test is fed to the vertical input of an oscilloscope.

Amplifier A7 performs a dual function in this test. When S7 is closed during the bias current test, a voltage is developed across C1 equal to the amplifier offset voltage multiplied by the gain of the feedback loop. When S7 is opened in the transfer function test, the charge stored in C1 continues to provide this offset correction voltage. In addition, A7 sums the triangular wave test signal with the offset correction voltage and applies this sum to the input of the amplifier under test through the attenuator R1, R3. This input sweeps the input of the amplifier under test ±2.5 mV around its offset voltage.

Figure 5 is a photograph of the output of the test set during the transfer function test. This figure illustrates the function of amplifier A7 in adjusting the dc input of the test device so that its transfer function is displayed on the center of the oscilloscope face.

The transfer function display is a plot of V_in vs V_out for an amplifier. This display provides information about three amplifier parameters: gain, gain linearity, and output swing.

Gain is displayed as the slope, ΔV_{OUT}/ΔV_{IN} of the transfer function. Gain linearity is indicated change in slope of the V_{OUT}/V_{IN} display as a function of output voltage. This display is particularly useful in detecting crossover distortion in a Class B output stage. Output swing is measured as the vertical deflection of the transfer function at the horizontal extremes of the display.
DETAILED CIRCUIT DESCRIPTION

POWER SUPPLIES

As shown in Figure 6, which is a complete schematic of the power supply and function generator, two power supplies are provided in the test set. One supply provides a fixed ±20V to power the circuitry in the test set; the other provides ±5V to ±20V to power the circuit under test.

The test set power supply regulator accepts +28V from the positive rectifier and filter and provides +20V through the LM100 positive regulator. Amplifier A1 is powered from the negative rectifier and filter and operates as a unity gain inverter whose input is +20V from the positive regulator, and whose output is −20V.

The test circuit power supply is referenced to the +20V output of the positive regulator through the variable divider comprising R7, R8, R9, R10, and R26. The output of this divider is +10V to +2.5V according to the position of S2a and is fed to the non-inverting, gain-of-two amplifier, A2. A3 is a LM100 positive regulator. Amplifier A1 is powered from the negative rectifier and filter and operates as a unity gain inverter whose input is +20V from the positive regulator, and whose output is −20V.

The test circuit power supply is referenced to the +20V output of the positive regulator through the variable divider comprising R7, R8, R9, R10, and R26. The output of this divider is +10V to +2.5V according to the position of S2a and is fed to the non-inverting, gain-of-two amplifier, A2. A3 is a

NOTE: All resistor values in ohms.
All resistors 1/4 W, 5% unless specified otherwise.
FUNCTION GENERATOR

The function generator provides three outputs, a ±19V square wave, a −19V to +19V pulse having a 1% duty cycle, and a ±5V triangular wave. The square wave is the basic function from which the pulse and triangular wave are derived, the pulse is referenced to the leading edge of the square wave, and the triangular wave is the inverted and integrated square wave.

Amplifier A5 is an astable multivibrator generating a square wave from positive to negative saturation. The amplitude of this square wave is approximately ±19V. The square wave frequency is determined by the ratio of R20 to R22 and by the time constant R21C10. The operating frequency of this feedback network is high enough so that the integrator action at the square wave frequency is not degraded. The function test. This disconnects A7 from the output of the device under test, these resistors are connected to the output of the common mode driver amplifier, A6.

Amplifier A6 is a dc stabilized integrator driven from the amplitude-regulated output of A5. Its output is a ±5V triangular wave. The amplitude of the output of A5 is determined by the square wave voltage developed across D3 and D4, and the time constant R43C14. DC stabilization is accomplished by the feedback network R24, R25, and C15. The ac attenuation of this feedback network is high enough so that the integrator action at the square wave frequency is not degraded.

Operating frequency of the function generator may be varied by adjusting the time constants associated with A4, A5, and A6 in the same ratio.

TEST CIRCUIT

A complete schematic diagram of the test circuit is shown in Figure 7. The test circuit accepts the outputs of the power supplies and function generator and provides horizontal and vertical outputs for an X-Y oscilloscope, which is used as the measurement system.

The primary elements of the test circuit are the feedback buffer and integrator, comprising amplifier A3 and its feedback network C16, R37, R41, and R33, and the differential amplifier network, comprising the device under test and the feedback network R40, R42, R44, and R52. The remainder of the test circuit provides the proper conditioning for the device under test and scaling for the oscilloscope, on which the test results are displayed.

The amplifier A5 provides a variable amplitude source of common mode signal to exercise the integrator under test over its common mode range. This amplifier is connected as a non-inverting unity gain amplifier and receives its input from the triangular wave generator. Potentiometer R6 allows the output of this amplifier to be varied from ±0V to ±18 volts. The output of this amplifier drives the differential input resistors, R43 and R44, for the device under test.

The resistors R46 and R57 are current sensing resistors which sense the input current of the device under test. These resistors are switched into the feedback network as part of the switching sequence by the field effect transistors Q0 and Q1. Q0 and Q1 are driven from the square wave output of the function generator by the PNP pair, Q10 and Q11, and the NPN pair, Q20 and Q21. Switch sections S1a and S1d, select the switching sequence for Q0 and Q1, and hence for Q20 and Q21. In the bias current test, the FET drivers, Q8 and Q9, are switched by out of phase signals from Q10 and Q11.

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Amplifier A5 is an astable multivibrator generating a square wave from positive to negative saturation. The amplitude of this square wave is approximately ±19V. The square wave frequency is determined by the ratio of R20 to R22 and by the time constant R21C10. The output pulse of A5 is an approximately 1% duty cycle pulse from approximately −19V to +19V.

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Operating frequency of the function generator may be varied by adjusting the time constants associated with A4, A5, and A6 in the same ratio.
driven by the output of monostable multivibrator $A_5$, and shorts the vertical oscilloscope drive signal to ground during the time that $A_5$ output is positive.

Switch $S_3$, $R_{27}$, and $R_{28}$ provide a 5X scale increase during input parameter tests to allow measurement of amplifiers with large offset voltage, offset current, or bias current.

Switch $S_5$ allows amplifier compensation to be changed for 101 or 709 type amplifiers.

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**CALIBRATION**

Calibration of the test system is relatively simple and requires only two adjustments. First, the output of the main regulator is set up for 20V. Then, the triangular wave generator is adjusted to provide ±5V output by selecting $R_{adj}$. This sets the horizontal sweep for the X-Y oscilloscope used as the measurement system. The oscilloscope is then set up for 1V/division vertical and for a full 10 division horizontal sweep.

Scale factors for the three test positions are:

1. **Bias Current Display** (Figure 2)
   - $I_{bias}$ total: 100 nA/div. vertical
   - Common Mode Voltage: Variable horizontal

2. **Offset Voltage-Offset Current** (Figure 3)
   - $I_{offset}$: 100 nA/div. vertical
   - $V_{offset}$: 1 mV/div. vertical
   - Common Mode Voltage: Variable horizontal

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Note: All resistors 1/4W, 5% unless specified otherwise. *2N3819 matched for on resistance within 200 Ω. Select for $BV_{GS} > 45V$.

**FIGURE 7. Test Circuit**
3. **Transfer Function (Figure 5)**

\[
\text{Gain} = \frac{\Delta V_{\text{OUT}}}{\Delta V_{\text{IN}}}
\]

**CONSTRUCTION**

Test set construction is simplified through the use of integrated circuits and etched circuit layout. Figures 8, 9, 10 give photographs of the completed tester. Figure 11 shows the parts location for the components on the circuit board layout of Figure 12. An attempt should be made to adhere to this layout to insure that parasitic coupling between elements will not cause oscillations or give calibration problems.

**Table 1. Partial Parts List**

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁</td>
<td>Triad F-90X</td>
</tr>
<tr>
<td>S₁</td>
<td>Centralab PA2003 non-shorting</td>
</tr>
<tr>
<td>S₂</td>
<td>Centralab PA2015 non-shorting</td>
</tr>
<tr>
<td>S₃, S₄</td>
<td>Grayhill 30-1 Series 30 subminiature pushbutton switch</td>
</tr>
<tr>
<td>S₅, S₆</td>
<td>Alcoswitch MST-105D SPDT</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**

A semi-automatic test system has been described which will completely test the important operational amplifier parameters over the full power supply and common mode ranges. The system is simple, inexpensive, easily calibrated, and is equally suitable for engineering or quality assurance usage.
FIGURE 9. Front Panel

FIGURE 10. Jacks
FIGURE 11. Component Location, Top View
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