

BUILD THIS



**How good
is your amplifier?
Our inexpensive
THD analyzer
will let
you know.**

JOHN F. KEIDEL

HAVE YOU EVER WONDERED EXACTLY how good an amplifier is, or whether it actually measures up to the manufacturer's specification of its Total Harmonic Distortion, or THD? Or are you curious if the amplifier you've designed is better or worse than a store-bought one? If the answer is yes to any of those questions, then you should build our inexpensive THD analyzer. You can use it to test "home-brew" amplifier breadboard circuits or commercial equipment such as stereo receivers, preamps, and power amps. The analyzer uses an ultra-pure 1-kHz test signal to measure THD at a user-selected

voltage level for voltage amplifiers, or a desired power level for checking power amps up to 600 watts. It will detect THD levels down to 0.005 percent! It features a built-in one-percent THD calibrator, a full array of input and output processing controls, and uses your digital multimeter (DMM) as a readout device.

Circuit description

As shown in Fig. 1, an NE5534N low-noise, low-distortion op-amp, IC1, is configured as a Wien Bridge sine-wave oscillator. Carefully matched RC values (R2-C1 and R3-C2) in the frequency-selective positive feedback network contribute to its low distortion level. Resistor R1 and bulb LMP1 form the stabilized negative feedback network that provides a constant-amplitude output signal. DC offset control R4 keeps DC current out of LMP1, which minimizes second harmonic distortion content. Filter network R6-C6 further reduces any residual distortor-

tion. After passing through fixed and variable attenuators, plus a buffer amp (IC2), the signal emerges at output jack J1.

The output signal from J1 drives the input of the device under test (DUT), usually an amplifier. The DUT's output, which includes some degree of distortion, is applied to the input of the analyzer at jack J2. The fundamental frequency (1 kHz) is then removed from the output signal of the DUT, leaving only harmonic distortion components.

Combination notch/high-pass filter circuits IC3 and IC4 (both TLO74's) perform the removal function. One feature of IC3's three-stage RC active filter is that it maintains a constant 45-dB notch depth over its full tuning range. The filter is connected in series with an identical second filter (IC4), to provide a 90-dB notch of the fundamental signal. The resultant frequency response of the combined filters is 27 dB down at 20 Hz, which helps suppress 60-Hz hum and

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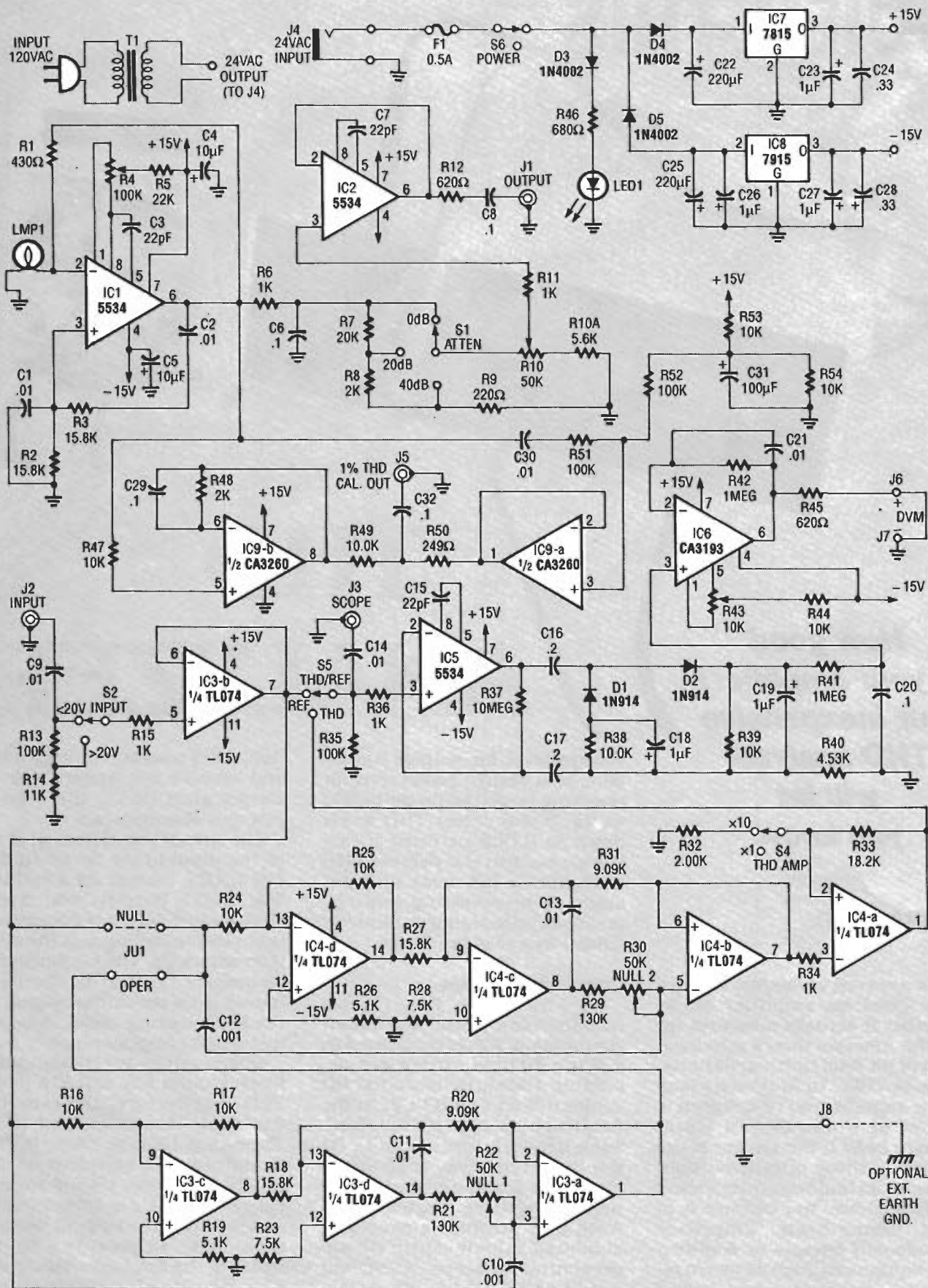


FIG. 1—SCHEMATIC DIAGRAM of the simple THD analyzer. An NE5534N op-amp (IC1) is configured as a Wien Bridge sine wave oscillator. Carefully matched RC values in the frequency-selective positive feedback network contribute to the low distortion level. Resistor R1 and incandescent bulb LMP1 form the stabilized negative feedback network that provides a constant-amplitude output signal.

other low-frequency noises. Above the 90-dB notch frequency, the response is flat (± 0.5 dB) from 2 kHz to 100 kHz.

When S4, the THD/REF switch, is in the THD position, a signal containing only THD components is channeled through from the output of the $\times 1/\times 10$ THD amp (IC4) to the input of the AC-to-DC converter, IC5. Although both polarities of the applied signal are rectified by this circuit, only the positive averaged signal is fed to the low-pass filter R41-C20. The output buffer, IC6, is a CA3194 precision op-amp, stable enough to provide accurate volt, millivolt, and microvolt DC level output signals to an external DVM.

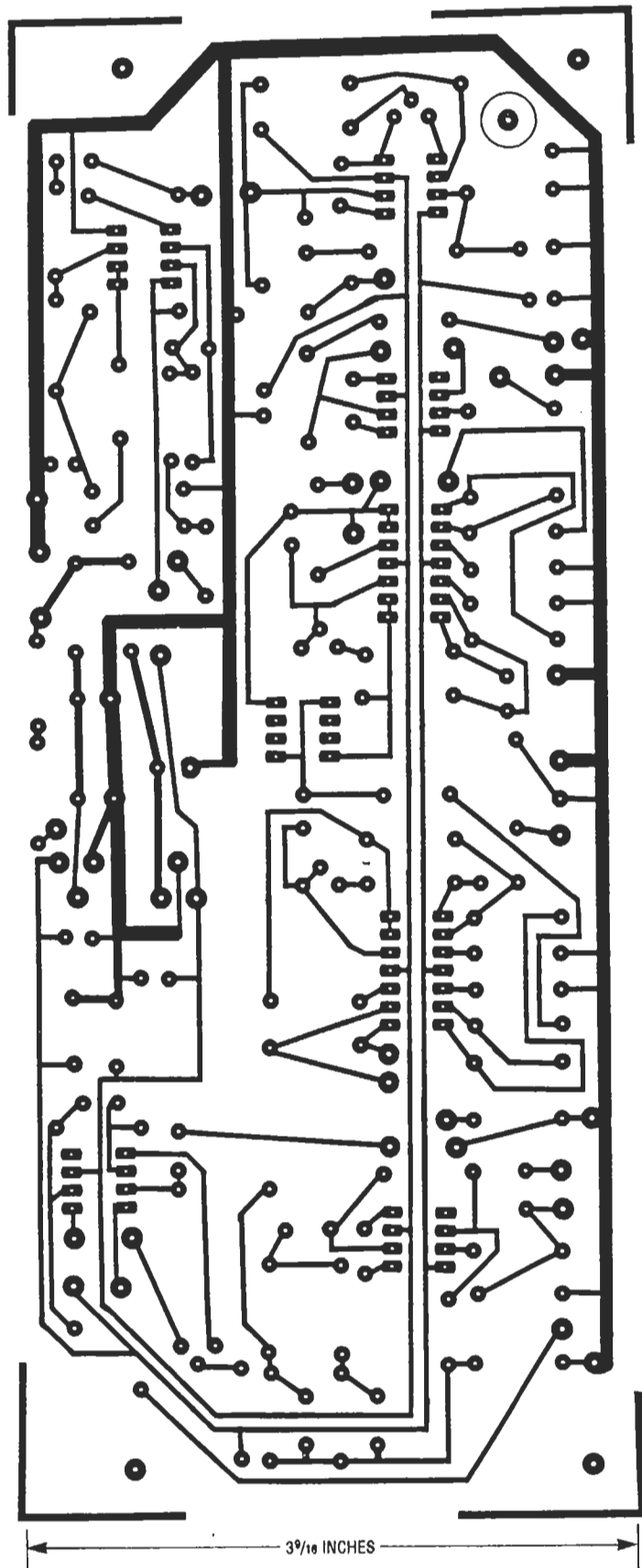
Dual op-amp IC9, a CA3260, serves as a calibrator. The first stage affords precision half-wave rectification of the master oscillator's signal. That same applied signal is AC coupled by C30 to the second stage, biased at $\frac{1}{2} V_{CC}$, for linear transfer to its output. Voltage divider R49-R50 mixes a very small portion of half-wave output at pin 7 of IC9 with a much larger full sine wave seen at pin 1. Since the signal swings slightly more positive from its quiescent level than it does in the negative-going direction, it is considered to have a specific amount of second harmonic distortion. That amount, by design, is one percent.

Wall transformer T1 feeds half-wave power diodes D4 and D5 through connector J4, fuse F1, and power switch S5. Capacitors C22 and C25 are the principal filters for the positive and negative supplies, respectively. Smaller filters, C23 and C27, along with high-frequency transient suppressors C24 and C28, are included at the output side of regulators IC7 (a 7815 +15-volt regulator) and IC8 (a 7915 -15-volt regulator).

Construction

Breadboard assembly of the analyzer is not recommended, although a seasoned builder may wish to attempt it. It's best to either make your own PC board from the foil pattern we've provided, or order one from source mentioned in the parts list.

Mount all components as shown in Fig. 2. Check orienta-



FOIL PATTERN for the THD meter shown actual size.

tion of all polarized parts as you install them, and the use of IC sockets is suggested. All power-

line wiring, including the LED1 indicator, uses two wires plus a shield. Connect the shield wires

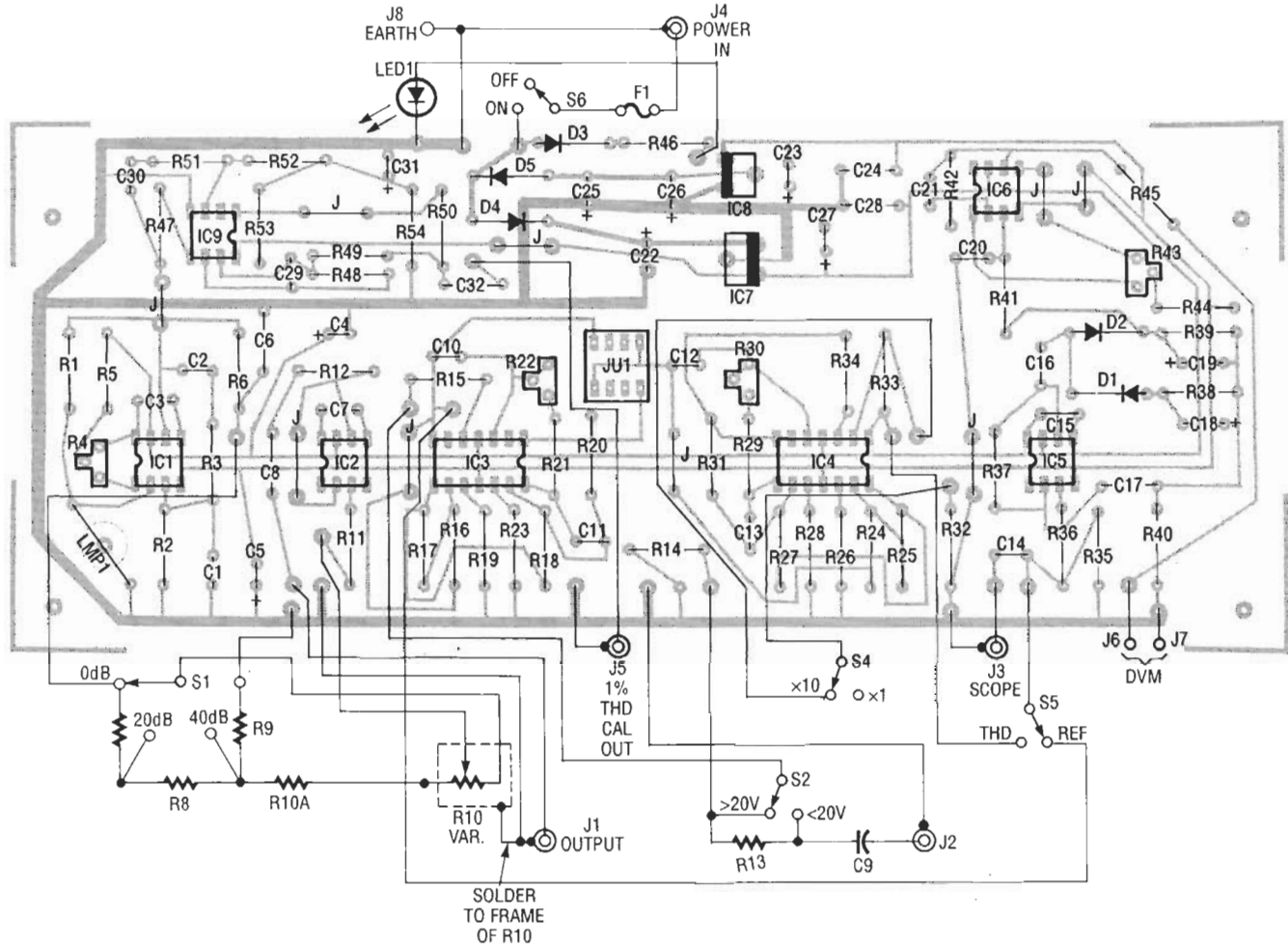


FIG. 2—PARTS PLACEMENT DIAGRAM. Note that JU1 is actually an 8-pin DIP socket in which a jumper is placed in either the far-left or -right side (see text). Also note the six components soldered to the front-panel-mounted controls.

together and then to ground, to prevent hum pick-up. Also, ground the frame of potentiometer R10. Bare ground wires for each BNC connector may be wrapped around the connector body prior to installing the retaining nut. The ground binding post (J8) on the rear panel provides an optional, external earth-ground connection when measuring microvolt-level THD signals. Just connect J8 to circuit ground. The grommet used to hold bulb LMP1 should have a 1/4-inch inside diameter. It is glued to the top side over the hole for maximum resiliency.

In addition to the components that are soldered to the circuit board, also note that five resistors and one capacitor are soldered across the terminals of panel-mounted controls S1, R10, S2, and J2 (see Fig. 2).

Capacitors C1 and C2 must be matched to better tolerances

than their marked 1% values. If you don't own or can't borrow a capacitance meter, you can build and use the simple circuit shown in Fig. 3. Adjust the calibration potentiometer with any one of the four 0.01 μF capacitors (C1, C2, C11, or C13) inserted as C_x , to read 1.000 volt on your DMM's 2-volt DC range. (You can consider the reading to be 0.01000 μF .) Now measure the remaining three capacitors and select the two that are closest in value. Absolute value is not important; we simply want them to be the same value. However, if one capacitor measures 80 pF lower than another, you can solder an 82-pF mica capacitor on the underside of the PC board in parallel with the selected capacitor. The leftover 1% 0.01 μF capacitors can be used for C11 and C13 without having to be closely matched.

Likewise, resistors R2 and R3 must be close in value. Using

your DMM on its 20K resistance range, select two 15.8K resistors that are the closest in value. If the match is less than perfect, solder a small-value resistor in series with the lower value to raise it to the exact value of the higher one. You can mount two resistors in place of one by putting one through each hole in the board and soldering the raised ends together. Again, the leftover 1% 15.8K resistors can be used for R18 and R27 without having to be closely matched.

You may wish to build your own enclosure for the THD meter. A silk-screened front panel measuring 9 3/4 inches wide by 3 inches high can be purchased from the source mentioned in the parts list. If you decide to purchase the front panel, and build your own enclosure, build it to fit the front panel and drill several 1/4-inch holes in the top panel near the voltage regulators to allow heat to escape. Otherwise you can purchase the same enclosure used for the prototype; the exact

PARTS LIST

All resistors are 1/4 watt, 5%, unless otherwise indicated.

R1—430 ohms
 R2, R3, R18, R27—15,800 ohms, 1%, metal film
 R4—100,000 ohms, PC-mount potentiometer
 R5—22,000 ohms
 R6, R11, R15, R34, R36—1000 ohms
 R7—20,000 ohms
 R8, R48—2000 ohms
 R9—220 ohms
 R10—50,000 ohms, panel-mount potentiometer
 R10A—5600 ohms
 R12, R45—620 ohms
 R13, R35—100,000 ohms
 R14—11,000 ohms
 R16, R17, R24, R25, R38, R39, R49—10,000 ohms, 1%, metal film
 R19, R26—5100 ohms
 R20, R31—9090 ohms, 1%, metal film
 R21, R29—130,000 ohms
 R22, R30—50,000 ohms, PC-mount potentiometer
 R23, R28—7500 ohms
 R32—2000 ohms, 1%, metal film
 R33—18,200 ohms, 1%, metal film
 R37—10 megohms
 R40—4530 ohms, 1%, metal film
 R41, R42—1 megohm
 R43—10,000 ohms, PC-mount potentiometer
 R44, R47, R53, R54—10,000 ohms

R46—680 ohms
 R50—249 ohms, 1%, metal film
 R51, R52—100,000 ohms, 1%, metal film
Capacitors
 C1, C2, C11, C13—0.01 μ F, 100 volts, 1% Mylar
 C3, C7, C15—22 pF, 300 volts, mica
 C4, C5—10 μ F, 25 volts, tantalum
 C6, C8, C20, C29, C32—0.1 μ F, 50 volts, Mylar
 C9, C14, C21, C30—0.01 μ F, 50 volts, Mylar
 C10, C12—0.001 μ F, 100 volts, 1% Mylar
 C16, C17—0.2 μ F, 50 volts, Mylar
 C18, C19, C23, C27—1.0 μ F, 25 volts, tantalum
 C22, C25—220 μ F, 50 volts, electrolytic
 C24, C28—0.33 μ F, 50 volts, Mylar
 C26—1 μ F, 50 volts, tantalum
 C31—100 μ F, 25 volts, electrolytic
Semiconductors
 IC1, IC2, IC5—NE5534N low-noise op-amp
 IC3, IC4—TL074 quad low-noise op-amp
 IC6—CA3193E precision op-amp
 IC7—7815 positive 15-volt regulator
 IC8—7915 negative 15-volt regulator
 IC9—CA3260E dual MOSFET-input op-amp
 DI, D2—1N914 diode
 D3—D5—1N4002 diode

LED1—Red light-emitting diode

Other components

S1—Panel-mount, 2-pole, 6-position switch
 S2, S4—S6—Panel-mount miniature SPDT toggle switch
 S3—Not used
 JU1—8-pin DIP socket or jumper block
 T1—120VAC/24VAC, 200 mA wall transformer
 J1—J3, J5—Panel-mount male BNC connector
 J4—Coaxial power input jack
 J6—J8—Panel-mount binding post
 LMP1—Incandescent bulb, #327
 F1—Fuse, 0.5A, 120 VAC

Miscellaneous: Project case (Jameco Electronics H2507), two 1/2-inch diameter instrument knobs, seven 8-pin IC sockets, (not including JU1), fuse holder, LED bezel, grommet, shielded cable, wire, solder, hardware, etc.

Note: The following items are available from Instrumex, P.O. Box 490, Blue Bell, PA 19422:

• Etched, drilled, and plated PC board and silk-screened plastic front panel (both to fit case mentioned above—\$25.00 + \$3.00 S&H)

PA residents must include 6% sales tax.

Allow 2-4 weeks for delivery.

model number is listed in the parts list, and the front panel is designed to fit it perfectly. Figure 4 shows the completed prototype.

Adjustments

Using a DMM on its millivolt-DC range, connect it between pin 6 of IC1 and ground. Adjust R4 for a reading of 000.0 mV on the meter. Next, set the INPUT switch (S2) to ">20V," the THD AMP switch (S4) to "x10," and the THD/REF switch (S5) to "THD." With the DMM still set to read millivolts DC, connect its leads across the + and - DVM binding posts (J6 and J7) and adjust R43 for a reading of 000.0 mV on the meter.

Filter-null adjustments may be made with an oscilloscope or DMM on its lowest AC voltage range (typically 2 volts). Insert a jumper in the JU1 jumper block (NULL-OPER) in the left-most position when facing the front panel (next to R22, or the "null" posi-

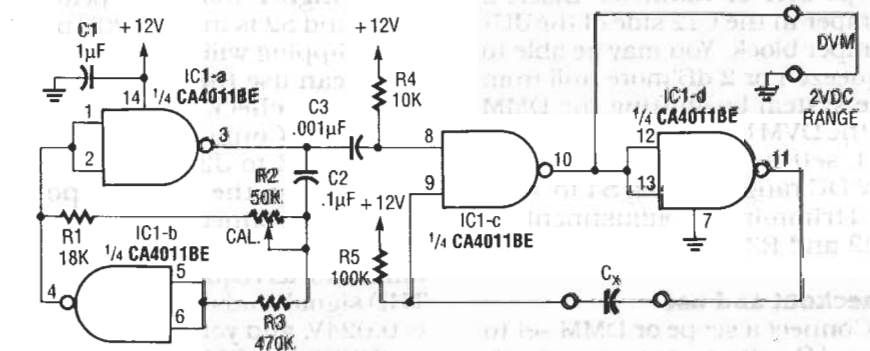


FIG. 3—HERE'S A ONE-IC CAPACITANCE TESTER used to match C1 and C2. See text for details.

tion). Connect a short coaxial cable between OUTPUT jack J1 and INPUT jack J2. With power on, and S2 in the "<20V" position, S4 in the x1 position, S5 in the "THD" position, and the rotary ATTEN-DB switch (S1) and VAR potentiometer (R10) in the minimum attenuation position, or fully counter-clockwise.

Connect a scope or voltmeter to

the IC4-pin-7 side of R31, and connect the ground lead to any ground in the area. If you're using a scope, set VOLTS/DIV switch (on the scope) to any position between 5 and 50 mV/div. Carefully adjust potentiometer R30 for the best null on a scope screen, or lowest reading on a meter.

Transfer the test probe to the

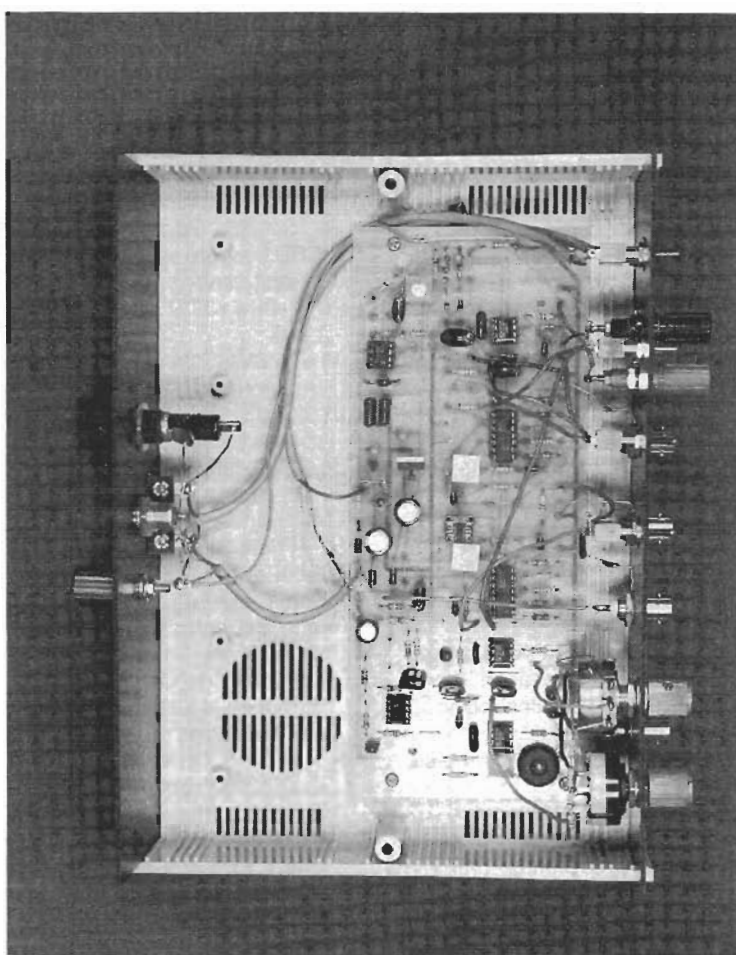


FIG. 4—THE COMPLETED PROTOTYPE. Notice how the incandescent bulb (LMP1) is protected from damage by a rubber grommet.

IC3-pin-1 side of R20. Adjust R22 for a minimum reading on the scope CRT or voltmeter. Insert a jumper in the C12 side of the JU1 jumper block. You may be able to squeeze 1 or 2 dB more null from the system by shifting the DMM to the DVM binding posts (J6 and J7), setting the meter to its 200 mV DC range, setting S4 to $\times 10$, and trimming the adjustments of R22 and R30.

Checkout and use

Connect a scope or DMM set to read AC volts to output jack J1. Rotate S1 and R10; the output signal voltage should vary accordingly. Remember that the controls are attenuators, not gain controls, so maximum signal occurs in the counterclockwise position.

Check the INPUT P-P switch S2 by applying the signal from J1 to J2, setting S5 to "REF," and measuring the AC output at J3. The output signal should be maximum with S2 in the $<20V$ position and minimum in the $>20V$

position. It's important to note that if the input signal to J2 goes much higher than 20V peak to peak, and S2 is in the $<20V$ position, clipping will begin to occur.

You can use the analyzer's calibrator to check all remaining functions. Connect a coaxial cable from J3 to J2. Set all toggle switches to the upright positions, and connect your DMM to J6 and J7 set to read DC volts or millivolts, as required. Now, if the THD signal reads 24.0 mV, which is 0.024V, and you switch the S5 to "REF," the DMM should then read 2.40V, or a number very close to that. When the resulting fraction (0.024/2.4) is multiplied by 100 it should produce a THD percent figure of one percent.

Figure 5 shows the test setup for THD measurements. Say that we are measuring percent THD of a 50-watt amplifier that's connected to an 8-ohm power resistor load. By ohms law, it will take 20 volts across 8 ohms to produce 50 watts. Now let's say

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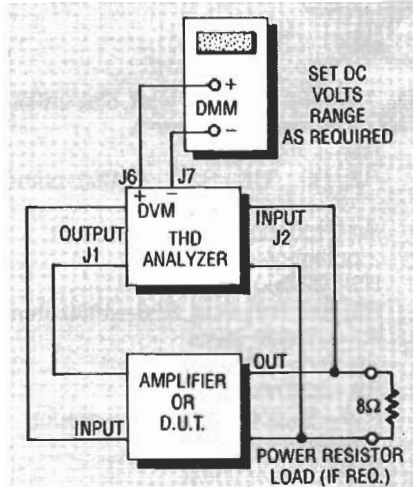


FIG. 5—BLOCK DIAGRAM OF TEST setup. Most THD measurements can be made in this manner.

THD MEASUREMENT

When a pure or undistorted sine wave is applied to a circuit containing vacuum tubes, transistors, or op-amps, which is used to provide linear transfer of the signal, some degree of distortion always appears at the output.

As the near-perfect sine wave travels through the device under test (DUT), its shape is altered due to inherent nonlinearities within the circuit. Waveform alteration is the equivalent of adding harmonics, or multiples of the fundamental frequency, in varying phases and amplitudes to the fundamental signal. It can be shown mathematically and by measurement that these spurious harmonic components are vested within the output signal's waveshape.

Spectrum analyzers are used to sweep over the frequency range of interest, separating the fundamental and its harmonics into individual signals. It provides a CRT display of these various signals, including odd and/or even harmonics in their proper amplitudes and frequency locations relative to the fundamental. Similar instruments use digital signal processing techniques rather than a sweep method to provide more in-depth data including phase angles.

Wave analyzers are essentially tuned filters that include a measurement window that is manually frequency shifted through the range of interest. It offers meter-read-out amplitude measurements of the various harmonics relative to the fundamental frequency.

THD analyzers are used to notch out the fundamental from the DUT's output signal leaving only the harmonic components intact. It then measures the sum total of the residual signals in terms of their RMS or average values, and compares them to the overall amplitude of the output signal which is taken as a 100 percent reference. The ratio of the THD measurement to the reference, multiplied by 100, equals the percent THD. R-E

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we drive the input of the amplifier with a 1-volt pure sine wave and we obtain the 20 volts required at the output. Since 20 volts RMS is 56 volts peak-to-peak, S2 must be set to $>20V$. With S5 in "THD" position a reading of 1.4 mV (0.0014V) DC is obtained. In the "REF" position we read 2.00V. Always read the range on the DMM that affords the best resolution. Now make the calculation: $0.0014/2.00 \times 100$ equals 0.07 percent THD.

Voltage amplifiers are measured in the same manner, but without the requirement of a load resistor. Such amplifiers will probably show lower THD voltage readings. If the THD voltage is too low on the DMM's mV range, set S4 to " $\times 10$." In this case, however, divide the displayed THD voltage by 10. For example, 0.8 mV on the meter is read as 0.08 mV, since it was amplified 10 times to 0.8 mV.

If the measured THD percent is three times or more greater than the analyzer's measurement "floor," no correction of the measured value is required. If it's less than three times, a good approximation of the true THD percent is given by the formula $D(DUT) = \sqrt{D^2(\text{measured}) - D^2(\text{floor})}$. That means if you measure a preamp's THD at 0.005%, and the measurement floor is 0.004%, the true THD of the preamp is 0.003%.

Depending upon the depth of the notch and how closely the RC's in the oscillator's frequency selective network are matched, the "floor" should typically be 0.003 to 0.005%. You can check the "floor" value in the same way you measured the 1% THD calibrator, explained earlier. Instead of using the calibrator signal, feed in a maximum signal level from output J1. If you use the $\times 10$ position, it may be necessary to connect J8 to an external earth ground.

Finally, you should know that THD measurements above 10 percent are less accurate than those below 10 percent, since the reference includes distortion plus the fundamental—not just the fundamental.

R-E