The Distortion Magnifier

Bob Cordell

Measuring the very low distortion of modern amplifiers, preamplifiers and even op amps can be difficult with all but the most expensive test equipment. At the same time, sophisticated test functionality has become available to the hobbyist in the form of PC-based instrumentation that employs computer sound cards. This equipment, and reasonably-priced conventional analog test equipment, needs a means to improve its sensitivity and measurement floor.
The Distortion Magnifier (DM) described here provides ways of measuring very low levels of THD and IM distortions. These techniques go beyond the straightforward use of a THD or IM analyzer.

The Basic Idea

The Distortion Magnifier operates by subtracting the input of the amplifier under test from a scaled-down version of its output, leaving only the distortion products. One tenth of the amplifier output is then added back into the signal. The result is an output signal whose relative distortion has been magnified by a factor of ten. If only one percent of the amplifier's output is added back into the signal path, then the DM will have magnified the relative distortion level by a factor of 100. Key to this process is accurate level and phase matching of the source and amplifier output signal to be subtracted. The DM will work with any THD analyzer, spectrum analyzer or other type of measurement equipment, such as PC-sound card arrangements. The DM will enhance the dynamic range of the measuring equipment by 20 or 40 dB.
Because its operation is based on a signal subtraction process, the DM does not magnify the distortion or noise in the source test signal. This effectively increases the dynamic range of the source oscillator in the same way that it increases the dynamic range of the measurement equipment.

Features

- Coarse and fine amplitude and HF phase adjustment
- Selectable magnification of 1X (bypass) 10X or 100X
- Balanced differential inputs from DUT amplifier
- Reduction of relative distortion and noise inherent in the test source
- Measurements below –140 dB are achievable

The most straightforward use of the Distortion Magnifier (DM) is with a conventional THD analyzer. In this case, the DM is placed between the amplifier being tested (DUT) and the THD analyzer. By subtracting most of the sinusoidal test input applied to the DUT from the scaled-down output of the DUT, the distortion of the DUT is magnified by a controlled factor of 10 or 100.

A block diagram of the DM is shown in Figure 1. The DM is fed the source sinusoid and the output of the amplifier under test. The input and output signals of the amplifier under test are scaled to be of equal amplitude, adjusted for exact phase match, and subtracted. A selectable amount of the signal from the DUT is then added back to the result so that there is some known value of the fundamental for the subsequent THD analyzer to lock onto. This process results in a relative magnification of the distortion by a factor of 10 or 100.

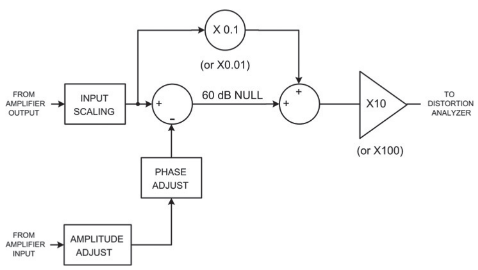

Figure 1, The distortion magnifier

If the THD analyzer normally has a residual measuring capability (measurement floor) of 0.001 percent, and if the DM is set to a magnification of 10X, then the combined instruments are capable of a measurement floor of 0.0001 percent as long as the distortion and noise contributed by the DM are less than that amount. In such an arrangement, when the THD analyzer is reading 0.001%, the actual distortion of the DUT is 0.0001%.

A typical front panel layout of the DM is shown in Figure 2. Balanced inputs are available for the signals from the DUT, while a single-ended input receives a copy of the source signal applied to the DUT. An additional input allows the injection of a known "distortion" test signal into the signal path for calibration purposes. A monitor output is provided that supplies a copy of the received DUT output signal attenuated by a factor of 10. Four potentiometers provide coarse and fine control of gain and phase matching for the nulling adjustment. A three-position switch allows selection of 10X or 100X distortion magnification, or the nulling mode. A second switch allows the gain in the signal path to be increased by a factor of 10 to restore the level of the fundamental to its nominal value when in the X100 magnification mode. A third switch allows the magnification process to be bypassed, effectively providing an X1 magnification function that is useful for reference purposes.

Amplitude and Phase Matching

The most fundamental operation in the DM is the creation of a null by subtracting the test signal input from a scaled-down version of the output of the DUT. The objective is to achieve a 60 dB (or better) null in this process. This requires accurate phase and amplitude matching, so both coarse and fine amplitude and phase adjustments are desirable. The DM is set up to accommodate DUT gains from about 10 to about 35.

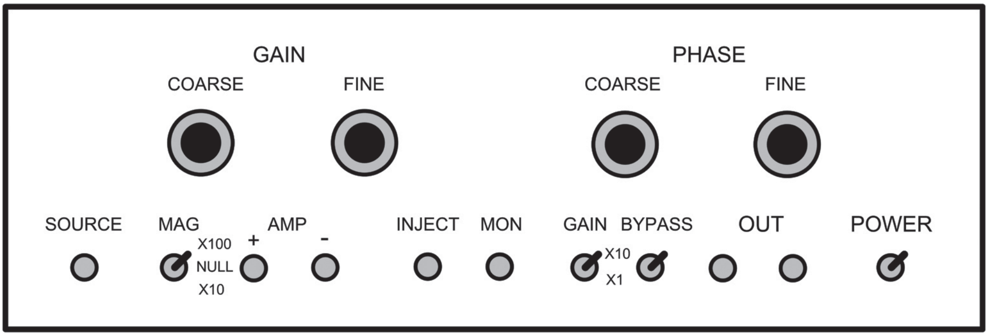

Figure 2: Example front panel layout for the DM

High-frequency phase matching is achieved with an adjustable single-pole LPF roll-off in the test signal input path. The LPF emulates the phase and delay characteristics of the DUT, at least in the neighborhood of the test signal frequencies and their harmonics. More complex phase matching networks could be used, but have thus far proved unnecessary.

The DM could also incorporate an adjustable low frequency phase matching network to compensate for the usual high-pass characteristic of an AC-coupled DUT (e.g., a 3-dB corner at, say 5 Hz) to enable more accurate nulls to be achieved when implementing low-frequency THD measurements. This has not been incorporated into the DM at this time.

The first-order phase compensation networks incorporated into the current DM are only an approximation to the phase match that is accurate at the given test frequency used when the null adjustment is made. If a distortion measurement is made at 20 kHz and then the measurement is to be carried out at 10 kHz, some re-adjustment of the null may be necessary.

The phase compensation approximation will also be less accurate for cancellation of harmonics of the test signal that are present in the sine wave source. Great improvement in immunity to sine wave source distortion will still be had, but for this reason it is still desirable to employ a low-distortion sine wave source for best results.

The Nulling Process

The nulling process is an iterative exercise between the phase and amplitude matching controls, but it actually converges quite quickly. Nulling is accomplished by monitoring the output of the DM with an AC voltmeter while the mode switch in the "null" position. In this position, no fraction of the DUT test signal is added back into the signal path. The fine amplitude and phase controls are set to their mid position and the coarse amplitude and phase controls are adjusted for a good minimum. Adjustment of the fine controls is then iterated until a null of at least 60 dB is achieved. A more advanced version of the DM would incorporate a built-in logarithmic amplitude display to make the nulling adjustment easier.

DUT Input Channel

The DUT input channel is shown in Figure 3. The balanced input from the DUT at J1A and J1B is applied to a differential amplifier (U1A) with a gain of 0.1 (the right side of dual RCA connectors will be referred to as the B connector). Most power amplifiers have a single-ended output, in which case the negative half of the balanced input is simply connected to the speaker return terminal at the amplifier. The balanced inputs can be swapped for power amplifiers that are inverting. The use of balanced inputs on the DM for receiving the output of the DUT is important even when the DUT is not a balanced amplifier. This is so because we want to reject any noise or distortion introduced by testing ground loops or stray magnetic fields. Input resistors R1 and R2 are 2-watt metal film types to minimize any heating-induced distortions.

A calibrated amount of "distortion" can be injected at J3A from a signal generator to check overall system distortion measurement accuracy and scaling. This signal will be attenuated to 1/1000 of the DUT output. So if you inject the same level as the DUT output, which is 100%, the 1/1000 attenuation should make for a "distortion" indication of 0,1%. If the DUT produces 20V RMS and you inject a "distortion" calibration signal of 2V RMS you should get an indication of 0,01%. The signal injected can be of any desired frequency and need not be related to the main test signal.

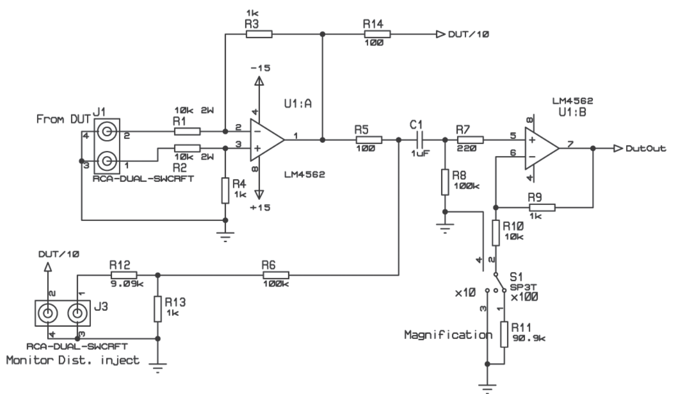

Figure 3, The DUT input channel

J3B provides a MONITOR output equal to 1/10 the level of the DUT. This output is also fed to the main output of the DM (Figure 5) when the DM is in BYPASS mode.

The single-ended and scaled DUT signal is then passed through near-unity-gain amplifier U1B. In the "null" mode, MAGNIFICATION switch S1 is in its center open position and the gain of this stage is exactly unity. Under this condition the gain and phase controls are adjusted for the deep null.

For measurements with a magnification factor of 10 or 100, the injection of a little bit of extra signal from the DUT is simply accomplished by increasing the gain of this stage ever so slightly to either 1.1 or to 1.01 by moving the swinger of S1 to a position that will engage a feedback shunting resistance (R10 or R10+R11) to work against feedback resistor R9.

Source Input Channel

The source input channel (J5, Figure 4) takes a copy of the signal that was applied to the input of the power amplifier DUT and adjusts its amplitude and phase to achieve a near-perfect null at the subsequent summer (which actually performs a subtraction).

Figure 4 shows the source input channel. It comprises a single op amp, U2A, that acts as both a gain control and a buffer. The non-inverting amplifier formed by U2A has a nominal gain of 1.3. This nominal gain is offset by R16 and R18 so that the nominal overall gain of the channel is approximately unity. This corresponds to a DUT with a gain of 20 (26 dB). Coarse gain pot RV1 allows the gain to be varied to accommodate power amplifier gains ranging from about 10 to 35. Fine gain control pot RV2 enables precise adjustment to achieve a deep null.

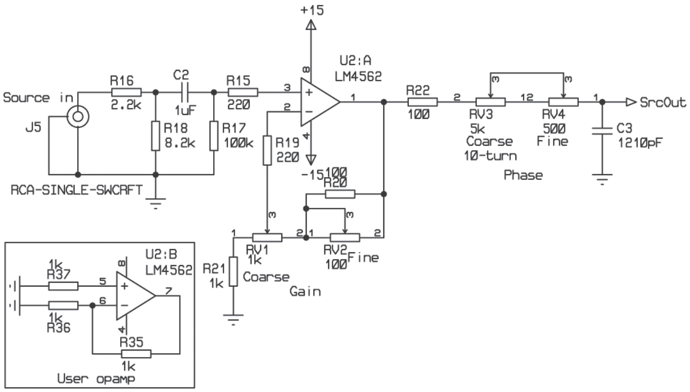

Figure 4, The source input channel

The buffered output of U2A goes to the phase-compensation low-pass filter. Potentiometers RV3 and RV4 provide the series resistance, while C3 provides the shunting capacitance. The single pole is nominally at about 48 kHz when the pots are centered. With both pots set to their minimum resistance, the pole is above 1 MHz. For most applications the lowest frequency available for the pole is unnecessarily low, but this can accommodate some vacuum tube amplifiers of limited bandwidth (for which a distortion magnifier would probably be unnecessary).

Summer and Output Amplifier

The summer and output amplifier circuit is shown in Figure 5. The summer is where the subtraction for the null takes place. Here the output of the source input channel is subtracted from the output of the DUT input channel. This circuit also provides selectable gain for the resulting difference signal for generating the output of the DM.

Differential amplifier U3B performs a subtraction of the DUT and source channel signals. It is arranged in such a way that the output is zero when the signal from the DUT channel is exactly twice the signal from the source channel (the factor of two here relates to the nominal gain of the DUT being 20).

The output amplifier is implemented by U3A. It provides a gain of either 10 or 100, corresponding to the magnification factors of 10 and 100. This gain keeps the amplitude of the fundamental (as seen by the THD analyzer) the same whether the DM is in the BYPASS mode (see S3) or in either of the magnification modes. The only thing that changes among these three modes is the effective amount of distortion magnification. The amount of fundamental at the output of the DM will remain at 1/10 the level at the output of the DUT.

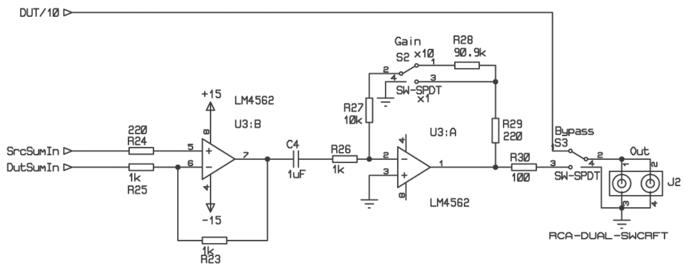

Figure 5: The summer and output amplifier

Powering the DM

Figure 6 shows the details of the ±15V power supply for the DM. A conventional bridge rectifier arrangement provides raw DC that is regulated by LM317/337 IC regulators (U4, U5). The DM can be powered from a center-tapped power transformer rated at 24V RMS or more from end to end, but this is marginal. The DM can also be powered from a 20V AC wall transformer rated at 10VA or more. In this arrangement power pins J6 and J8 are both connected to one side of the wall transformer secondary and ground is connected to the other side.

Using the Distortion Magnifier

For spectral THD measurement, the distortion residual from a THD analyzer is fed to a spectrum analyzer. The spectrum analyzer separates out the noise and any remaining fundamental from the various distortion products, yielding a much more sensitive arrangement. Even greater sensitivity can be had with the use of the Distortion Magnifier circuit in such an arrangement, as illustrated in Figure 7.

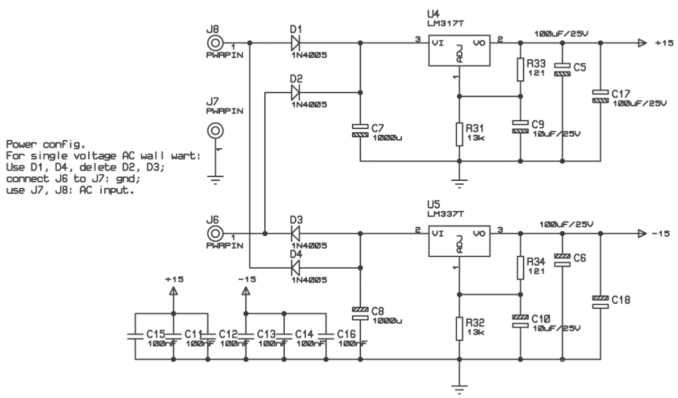

Figure 6: Power supply for the DM

Use of the DM allows a relative magnification of the distortion by a factor of 10 or 100. Note that distortion and noise in the sinusoidal source are also reduced in the same relative proportion as the magnification factor. As long as the DM is implemented with operational amplifiers with very low distortion (like the LM4562), the measurement floor of the resulting system is reduced by 20-40 dB. Given the ability of the spectrum analyzer to largely eliminate noise contributions, measurement floors of –140 dB or better are achievable.

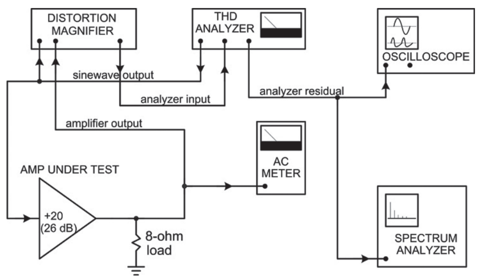

Figure 7: Arrangement for highly sensitive THD measurement

Use with Other Types of Distortion Tests

The Distortion Magnifier is also useful with more complex distortion tests such as twin-tone CCIF, SMPTE IM and DIM, where the test signal is not just a simple sinusoid. Many of these more complex tests rely on the use of a spectrum analyzer, where useable dynamic range is always at a premium.

The DM increases the useable dynamic range in such arrangements by 20 or 40 dB. Indeed, since the spectrum analyzer does not require a fundamental to lock onto, the DM can be operated in its full null mode, where none of the test signal is added back into the signal path. In this case, its magnification of the useable dynamic range can be on the order of 60 dB. In this case the actual magnitude of each harmonic as seen on the SA must be compared to the known output level of the DUT after appropriate scaling. Applying a small signal of known amplitude to the injection input can be helpful here.

Twin tone IM distortion is a good example of the use of the DM with more complex tests. CCIF IM is measured by summing two high-frequency tones, such as 19 kHz and 20 kHz, and applying the result to the amplifier under test. The output of the amplifier is then observed with a spectrum analyzer. This measurement can also benefit in the same way from the use of the Distortion Magnifier.

Use with PC-based Test Equipment

Today's availability of PC-based instrumentation, often employing sound cards, has made many sophisticated measurement capabilities available at very low cost. Perhaps the best example of this is the spectrum analyzer function based on the FFT. In the past, conventional analog spectrum analyzers, like the HP 3580A, were very expensive.

PC-based instrumentation is limited in its performance capabilities by the quality of the sound card and the noisy environment in which it may reside. The Distortion Magnifier is thus a perfect complement to PC-based instrumentation. Not only does it magnify the distortion for better dynamic range, but it also provides a handy interface between the DUT and the input of the sound card.

If the DM is to be used with a sound card, it is a good idea to add an amplitude-limiting circuit to the output of the DM so as not to overload or damage the sound card. This could be as simple as adding two pairs of 1N4148 diodes connected in opposing polarity across the DM output at J2. This will limit the output to less than about 1.4V peak. One must watch for distortion added by this arrangement, however. A greater number of diodes in series, or low-voltage Zener diodes can be used to achieve higher limiting thresholds if the sound card can accommodate higher levels. More sophisticated limiting circuits can be imagined as well.

The performance of the DM is essentially as good as the performance of its op amps and their associated circuits. This applies to both noise and distortion. The objective is for the DM to have better noise and distortion performance than the DUT. This is not difficult with today's excellent op amps. Indeed, very impressive performance of the DM is achieved using the LM4562 op amps.
As noted above, the noise-dominated performance can be largely improved by the use of a spectrum analyzer, especially if it is set to a very small measurement bandwidth.

Building the Distortion Magnifier

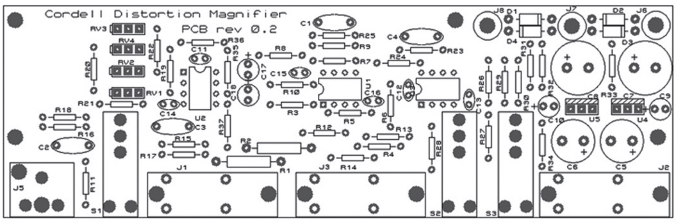

Figure 8

A PCB has been made available for the DM, which holds all the parts except the 4 potentiometers for the coarse and fine level and phase adjustments. The board layout is shown in Fig 8; building the unit using this board will virtually guarantee success. A bill of materials is at the end of the article and gives the Mouser order numbers for the switches and RCA jacks that fit the board. A semi-kit containing the PCB and some selected parts is available from Pilgham Audio, check their website at www.pilghamaudio.com.

Conclusion

The Distortion Magnifier should prove to be a useful addition to the bench of anyone doing serious distortion measurements. It can dramatically increase the dynamic range and sensitivity of both conventional analog distortion analyzers and those based on a PC-soundcard combination.

Bill of materials

Resistors: (all ¼ W metal film 1% except where noted)
R1,R2: 10k 2W
R3,R4,R9,R13,R21,R23,R25,R26,R35-R37: 1k
R5,R14,R20,R22,R30: 100 ohms
R6,R8,R17: 100k
R7,R15,R19,R24,R29: 221 ohms
R10,R27: 10k

R11,R28: 90.9k
R12: 9.09k
R16: 2.21k
R18: 8.25k
R31,R32: 13k
R33,R34: 121 ohms

Opamps:
U1-U3: LM4562, DIL08
Voltage regulators:
U4: LM317T, TO220
U5: LM337T, TO220

Potentiometers:
RV1: 1k; RV2: 100 ohms; RV3: 5k (preferably multiturn); RV4: 500 ohms

Switches:
S1: SP3T, NKK M2T13SA5G40-RO, Mouser # 633-M2T13SA5G40-RO
S2,S3: SPDT, NKK M2T12SA5G40-RO, Mouser # 633-M2T12SA5G40-RO

Capacitors:
C1,C2,C4: 1uF, 50V, film
C3: 1210pF, 50V, 5% film
C5,C6: 100uF/25V electrolytic
C7,C8: 1000u/35V electrolytic
C9,C10: 10uF/25V electrolytic
C11-C16: 100nF, 50V decoupling
C17,C18: 100uF/25V electrolytic

Connectors:
J1-J3: RCA dual, switchcraft PJRAS2X1S01X, Mouser # 502-PJRAS2XS01X
J5: RCA single, switchcraft PJRAS1X1S02X, Mouser # 502-PJRAS1X1S02X)

Diodes:
D1-D4: 1N4005 or eq.