The Distortion Magnifier

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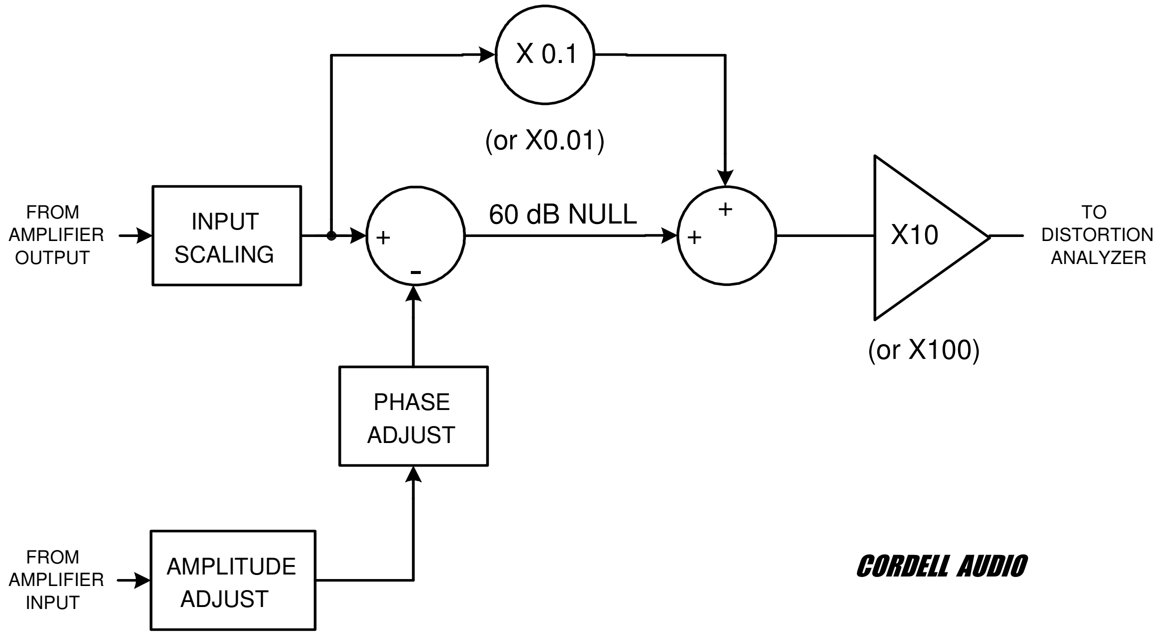
The Distortion magnifier described here provides ways of measuring very low levels of THD and IM distortions. These techniques go beyond the straightforward use of a THD or IM analyzer.

Features and issues

- Operates by subtracting input from scaled, phase-matched output of DUT
- Useable with THD analyzer, or spectrum analyzer or other instruments
- Greatly enhances the dynamic range of THD and spectrum analyzers
- Coarse and fine amplitude and HF phase adjustment
- LF phase adjustment is optional
- Selectable magnification of 1X (bypass) 10X or 100X
- Balanced differential inputs from DUT amplifier
- Eliminates issue of distortion and noise inherent in the test source
- It is as good as the op amps it uses
- Avoids noise issues in source and in THD analyzer
- Does not avoid noise introduced by DUT
- DUT noise rejection is the job of the spectrum analyzer
- Also valuable for use with PC-based THD and spectrum analyzers
- Op amps are used: NE5532 or LM4562
- 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 Under Test (AUT) and the THD analyzer. By subtracting the sinusoidal test input applied to the AUT from the scaled-down output of the AUT, the distortion of the AUT is magnified by a controlled factor of 10 or 100.

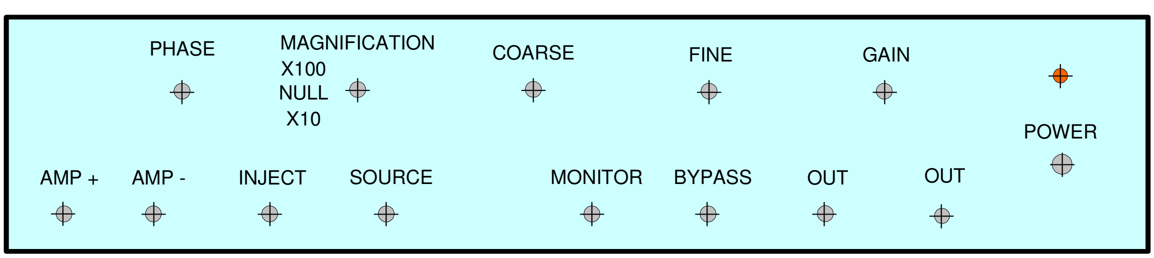
A block diagram of the DM is shown in Figure 1. The DM is fed the source sinusoid and the output of the amplifier under test. These input and output signals of the amplifier under test are scaled to be of equal amplitude, adjusted for exact opposite phase, and subtracted. A selectable amount of the signal from the AUT 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. Typically this process results in a relative magnification of the distortion by a factor of ten or one-hundred.



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 AUT is 0.0001%.

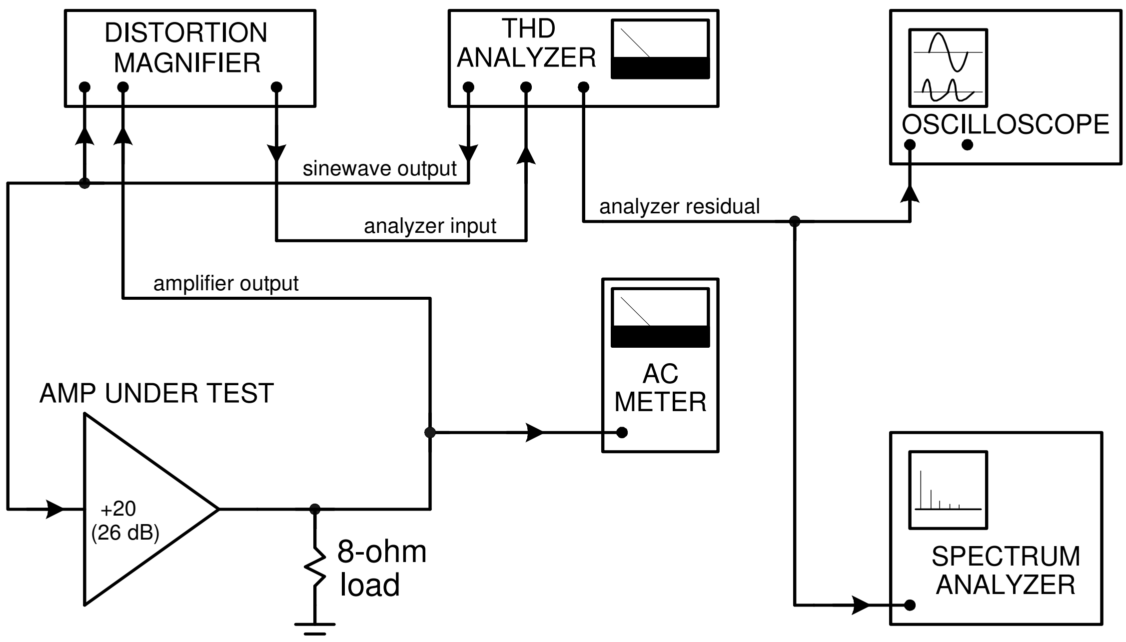
The front panel layout of the DM is shown in Figure 2.



For spectral THD measurement, the distortion residual from a THD analyzer is usually fed to a spectrum analyzer for spectral analysis. 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, illustrated in Figure 3.

Use of the DM typically results in a relative magnification of the distortion by a factor of ten or one-hundred. Given the ability of the spectrum analyzer to largely eliminate noise contributions, net measurement floors of –140 dB or better are achievable.



HIGHLY SENSITIVE THD MEASUREMENT

Consider a power amplifier that is producing 20 volts rms at its output with a THD of 0.001%. The distortion component will be on the order of 200 microvolts (100 dB down from the fundamental). The amplifier has a gain of 20, so the input is 1V rms. The output is scaled down in the DM by a factor of 20 to 1V rms, and the test signal input is then subtracted from it. That leaves a distortion component of 10 microvolts. If a distortion magnification of ten is desired, an amount of the fundamental equal to 0.1V is then added to this signal, and the result is fed through a gain of ten. The result is a 1V rms fundamental and a 100 microvolt distortion signal to be fed to the THD analyzer.

It can be seen that a 100 microvolt distortion signal on a 1-volt fundamental amounts to a signal with distortion down 80 dB, or 0.01 percent. The THD analyzer thus displays a THD value that is ten times the actual value. For a magnification of 100X, a 0.01V amount of fundamental would have been added back to the subtracted signal, and the result would have been multiplied by a 100X gain, resulting in a 1-Volt signal containing 0.1 percent THD.

Note that distortion and noise in the sinusoidal source are also reduced in the same relative proportion. As long as the DM is implemented with operational amplifiers with very low distortion, the distortion measurement floor of the resulting system is reduced by 20-40 dB.

Note also that the controlled magnification of the distortion, wherein some of the test signal is deliberately added back to the signal after the nulling process, provides the THD analyzer with a reliable amount of fundamental to lock onto with its auto-nulling circuits.

Use with other types of distortion tests

The Distortion Magnifier is also useful with more complex distortion tests such as twin-tone CCIF 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.

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, applying the result to the amplifier under test, and viewing the output of the amplifier with a spectrum analyzer. This measurement can also benefit in the same way from the use of the Distortion Magnifier. The DM effectively increases the useable dynamic range of the spectrum analyzer by 20 or 40 dB. Indeed, most types of distortion measurement can benefit in the same way.

Performance limits

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 AUT. This is not difficult with today’s excellent op amps. Indeed, very impressive performance of the DM is achieved using 5534-class op amps.

As noted above, the issue of noise-dominated performance (as dominated by either the AUT or the DM or the measuring instrument), can be largely reduced by the use of a spectrum analyzer, especially if it is set to a very small measurement bandwidth.

Balanced inputs

The use of balanced inputs on the DM for receiving the output of the AUT is important even when the AUT is not a balanced amplifier. This is so because we want to reject any noise or distortion introduced by testing ground loops or stray distortive magnetic fields.

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 AUT. 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 AUT gains from about 10 to about 35.

High-frequency phase matching is achieved with an adjustable single-pole LPF roll-off in the test signal input path. The LPF seeks to emulate the phase and delay characteristics of the AUT, at least in the neighborhood of the test signals 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 AUT (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 nulling process

The nulling process is an iterative exercise between the phase and amplitude matching controls, but it actually converges quite quickly. The process is carried out by monitoring the output of the DM with an AC voltmeter with the mode switch in the “null” position. In this position, no fraction of the input 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 minima. Adjustment of the fine controls is then iterated until at least a 60 dB null is achieved.

A more advanced version of the DM would incorporate a built-in logarithmic amplitude display to make the nulling adjustment easier.

In principle it is possible to incorporate auto-nulling into a more advanced version of the DM, similar in operation to the way auto nulling works in a THD analyzer. However, any such auto-nulling would have to be implemented very carefully so as not to impair the distortion and noise performance of the DM.

Note that 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 was 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 sinewave source. Great improvement in immunity to sinewave source distortion will still be had, but for this reason it is still desirable to employ a low-distortion sinewave source for best results.

Use with PC-based test equipment

Today's availability of PC-based instrumentation, often based on 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 AUT and the input of the sound card.

DUT input channel

The amplifier DUT input channel comprises a balanced input stage that scales the input down by a factor of ten. This scaling down is done because the DM is primarily intended for use in measuring power amplifiers. The input channel also includes a distortion injection input, where a test signal (typically a sinewave) can be injected to verify calibration of the overall distortion measurement system.

Finally, the DUT input channel incorporates the circuitry whereby a small amount (either 1% or 10%) of the source signal can be added into the signal path so as to provide a known amount of DUT signal for purposes of establishing the DUT magnification factor. The amount injected during the nulling process is zero.

The addition of source signal into the signal path is actually accomplished by very slightly increasing the gain of an amplifier stage as compared to its (unity) gain when in the nulling mode. For a magnification of 20 dB, the gain of this stage is increased by a factor of 1.1. For a magnification of 40 dB, the gain of this stage is increased by a factor of 1.01.

The DUT input channel is shown in Figure 4. The balanced input from the AUT is applied to a differential amplifier (U1) with a gain of 0.1. 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. Input resistors R1 and R2 are 2-watt metal film types to minimize any heating-induced distortions.

The balanced inputs can be swapped for power amplifiers that are inverting.

J5 provides a MONITOR output equal to 1/10 the level of the AUT. This output is also fed to the main output of the DM when in BYPASS mode.

A calibrated amount of “distortion” can be injected at J4 from a signal generator to check overall system distortion measurement accuracy and scaling. That signal sees a relative attenuation of 1000:1 compared to the amplifier output signal (R9 against R6).

The single-ended and scaled AUT signal is then passed through near-unity-gain amplifier U2B. 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 AUT 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 (R13 or R13+R12) to work against feedback resistor R14.

Source input channel

The source input channel takes 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 5 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 R18 and R15 so that the nominal overall gain of the channel is approximately unity. This corresponds to an AUT with a gain of 20 (26 dB). Coarse gain pot P1 allows the gain to be varied to accommodate power amplifier gains ranging from about 10 to 35.

The buffered output of U2A goes to the phase-compensation LPF. Potentiometers P3 and P4 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 unnecessary).

Summer and output amplifier

The summer is where 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 the output of the DM.

The summer and output amplifiers are shown in Figure 6. 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 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 all 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 AUT.