Instrumentation Requirements for THD+N Measurements

Important criteria for high-quality harmonic distortion measurement instruments include the following:

- The generator must have extremely low residual distortion. There is no practical method to separate distortion in the generator from distortion introduced in the device under test, so the generator distortion must be well below the lowest distortion value that is to be measured. Generally, a margin of 10 dB or greater is desired in order that the generator distortion not contribute to the reading.
- The residual distortion in the input stages and notch filter circuitry of the analyzer must also be lower than the lowest values to be measured.
- The analyzer input circuitry should have a high CMRR to reject common-mode noise.
- The analyzer must have a selection of band-limiting filters to control the noise bandwidth of the measurement.
- For ease and speed of operation, the instrument should have autoranging input stages, auto set level, automatically-tuning and nulling notch filters, and autoranging of the stages following the notch filter.
- The instrument detector must be true rms-responding for accuracy, since the signal measured often is largely noise or a complex combination of several harmonics.

Intermodulation Distortion (IMD)

All intermodulation distortion techniques use a stimulus signal more complex than a single sine wave. The most widely-used IMD techniques in professional audio, broadcast, and consumer audio use two sine waves as the stimulus signal. With two sine waves of frequencies F_1 and F_2 as the stimulus signal, a non-linear DUT output will consist of the original two sine waves plus an infinite number of IMD products given by the equation

$$m \cdot F_1 \mp n \cdot F_2$$

where *m* and *n* are all possible integers. The "order" of any particular IMD product is the sum of *m* and *n*. Thus, the order of some IMD products are as in the following table:

$F_2–F_1$	2nd order (even)
F_1+F_2	2nd order (even)
$2F_1–F_2$	3rd order (odd)
$F_1–2F_2$	3rd order (odd)
$2F_1+F_2$	3rd order (odd)
$3F_1–F_2$	4th order (even)
$3F_1+2F_2$	5th order (odd)

and so on.

The terms "odd" and "even" refer to whether the sum of (m+n) is an odd or even number. As in the case of harmonics, odd order IMD products are produced by symmetrical non-linearities in the device transfer function and even-order IMD products by non-symmetrical non-linearities.

A potential advantage of IMD measurements versus harmonic distortion measurements is that the test can be arranged so that many distortion products fall within the audio band, permitting linearity measurements of band-limited devices.

SMPTE/DIN IMD

The most common IMD measurement standards in the professional, broadcast, and consumer audio fields are the SMPTE and DIN methods. SMPTE (Society of Motion Picture and Television Engineers) standard RP120-1983 and DIN (Deutsches Institut fur Normung e.V.) standard 45403 are similar. Both specify a two-sine wave test signal consisting of a low-frequency high-amplitude tone linearly combined with a high-frequency tone at ¼ the amplitude (–12.04 dB) of the low frequency tone. The SMPTE specification calls for 60 Hz and 7 kHz as the two frequencies. The DIN specification permits several choices in both low and high frequency selection; 250 Hz and 8 kHz are a commonly-used set of frequencies which comply with the DIN specification. Other SMPTE-like or DIN-like signals are also sometimes used, such as 70 Hz and 7 kHz. Figure 25 shows such a signal in both time and frequency domain representations.

When such a two-tone test signal is fed to a non-linear device, intermodulation products appear as a family of sidebands around the high-frequency tone. The spacing between the high frequency tone and the first pair of sidebands (2nd-order sidebands, $F_2±F_1$) is equal to the low frequency tone; the second pair of sidebands (3rd-order sidebands, $F_2±2F_1$) are spaced at twice the low frequency tone from the high frequency tone, etc. The percentage of

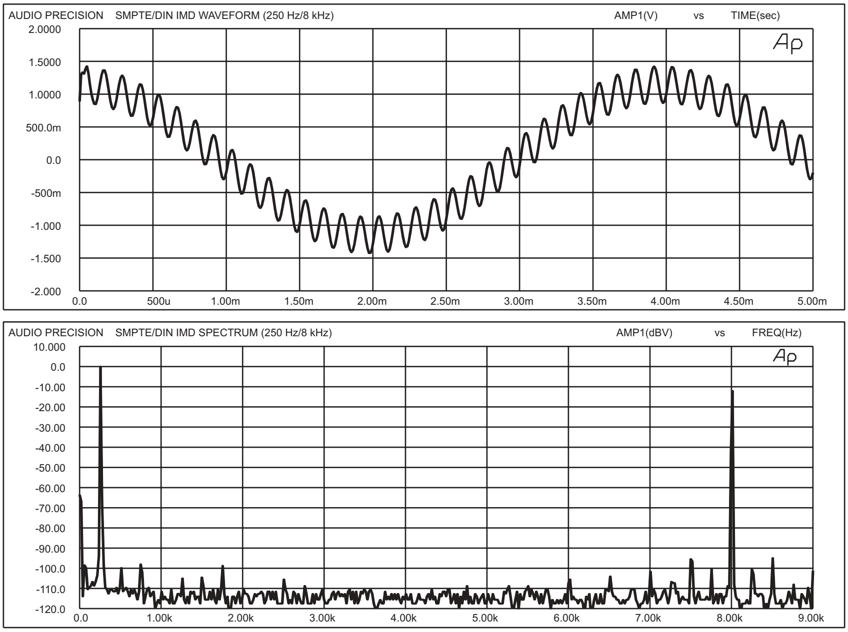

Figure 25. SMPTE/DIN IMD signal, time domain and frequency domain.

intermodulation distortion is defined as the percentage of amplitude modulation which these sidebands represent of the high frequency "carrier."

A typical SMPTE or DIN IMD analyzer has a simplified block diagram as shown in Figure 26. A high-pass filter first eliminates the low-frequency tone. The remaining signal is basically an amplitude-modulated signal, and is fed to an AM demodulator. The output of the demodulator consists of the sidebands translated down to baseband; for example, with a SMPTE test resulting in 2nd- and 3rd-order IMD products, the upper and lower sidebands would be translated down by the demodulator to 60 Hz and 120 Hz components. A low-pass filter follows the demodulator to remove any residual high-frequency "carrier," and the remaining signal is measured by a true rms detector. The detector output is calibrated in percentage amplitude modulation of the "carrier."

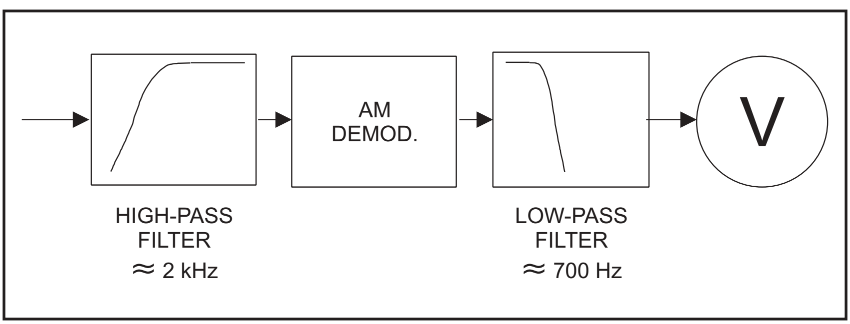

Figure 26. Block diagram, SMPTE/DIN analyzer.

SMPTE and DIN intermodulation testing has several advantages for testing audio devices. Like most intermodulation test signals, the more complex test signal is a step closer to simulating actual program material. The spectral balance between the higher-amplitude low frequency tone and lower-amplitude high frequency tone is also somewhat similar to music and voice spectral distribution. Many SMPTE/DIN IMD analyzers have a bandwidth after the demodulator of about 700 Hz, so at least second and third order IMD products will be measured if the low-frequency tone is below approximately 250 Hz. This makes the technique sensitive to both even and odd order distortion mechanisms. With a final noise bandwidth of about 700 Hz, the technique is substantially less sensitive to noise than THD+N with noise bandwidths of 20 kHz or greater. The use of a low frequency tone causes the IMD products to fall within a fairly narrow band around the high frequency tone, so the SMPTE and DIN techniques can be used to explore the linearity of band-limited systems quite close to their band-limiting frequency.

SMPTE/DIN Instrument Criteria

A high-quality SMPTE/DIN IMD test set should have very low residual intermodulation distortion in both the generator and analyzer; values of –90 dB (0.003%) or lower are readily available. The analyzer detector should be true rms responding, since the signal may contain several frequencies and thus is non-sinusoidal. It is desirable that both the low frequency tone and the high frequency tone can be varied or selected across a substantial range, to permit SMPTE-like or DIN-like tests on bandwidth-limited systems. For example, voice-bandwidth systems can be tested with a low frequency tone of 300 Hz to 500 Hz and a high frequency tone of 3 kHz if the generator and analyzer architecture permit. Similarly, a 20 kHz band-limited system can be tested by placing the high frequency tone at about 19 kHz, which provides a good test of high frequency linearity while still allowing several low-order IMD products to fall within the band limit. Some audio test sets make it possible to sweep the high frequency tone across the audio spectrum above some limit such as 2.5 kHz.

"CCIF," Twin-Tone, Difference-Tone IMD

The stimulus signal for this type of intermodulation distortion testing consists of two equal-amplitude high frequency signals spaced rather closely together in frequency. Common signals are 13 kHz and 14 kHz for 15 kHz band-limited systems, and 19 kHz and 20 kHz for systems with a full audio bandwidth. Figure 28 shows this type of IMD signal in both time and frequency domains. While such a stimulus signal will produce an infinite number of IMD products across a wide spectrum according to the basic IMD equations shown earlier, it is common in practical IMD analyzers to simplify the instrument architecture by measuring only the low-frequency second-order product falling at F_2 - F_1. If the maximum frequency spacing permitted between the two tones

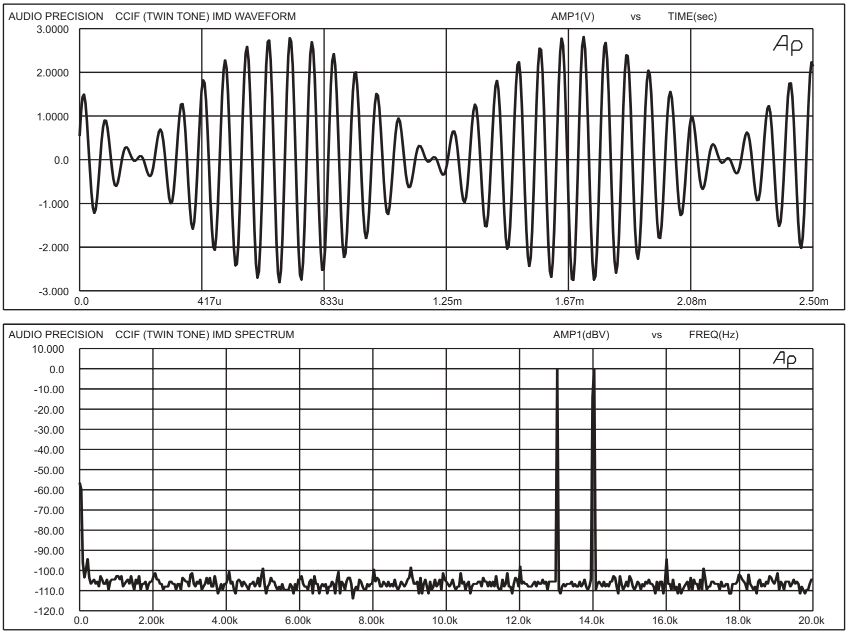

Figure 28. "CCIF" IMD signal, time domain and frequency domain.

is 1 kHz, the analyzer architecture can consist simply of a low-pass and/or bandpass filter at 1 kHz, followed by a voltmeter; see Figure 27.

This "twin tone" test permits stressing band-limited systems at their highest frequencies while still measuring an in-band IMD product. The most severe limitation of the simplified analysis technique is that it measures only the second order product. The simplified technique is thus not useful to measure distortion produced by non-linear transfer functions which are symmetrical about zero, such as the BH curves of magnetic tape; this method should not be used to measure tape recorders. The same twin-tone signal can be used with an FFT

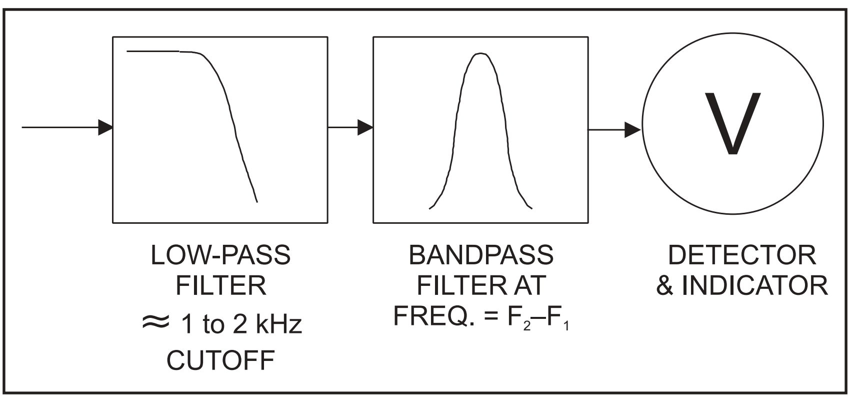

Figure 27. Block diagram, CCIF IMD analyzer.

analyzer or other selective analyzer to measure IMD products of all orders and thus yield more information, but analysis of such information requires more skill than the simple “one number” readout of the simplified analysis technique.

“CCIF” IMD Instrument Criteria

Both the generator and analyzer should have low residual intermodulation distortion. With the simplified analysis technique which measures only the low frequency second order product at F_2-F_1, the analyzer will profit from extremely narrow bandwidth. Analyzers which use both a low-pass filter and a one-third octave band-pass filter at the difference frequency can provide noise bandwidths of 200 Hz and less, reducing the region of noise-limited measurements to quite low levels. It is possible by this technique to provide analyzers with residual difference-frequency IMD and noise below –100 dB. It is desirable to be able to set the generator tone frequencies to different spacings across a wide frequency range in order to comply with various versions of this testing technique. Some test sets make it possible to sweep the two-tone pair across a wide frequency range above approximately 4 kHz, maintaining a constant spacing between the two tones, so that the analyzer can continuously display the second-order product as a function of tone pair center frequency.

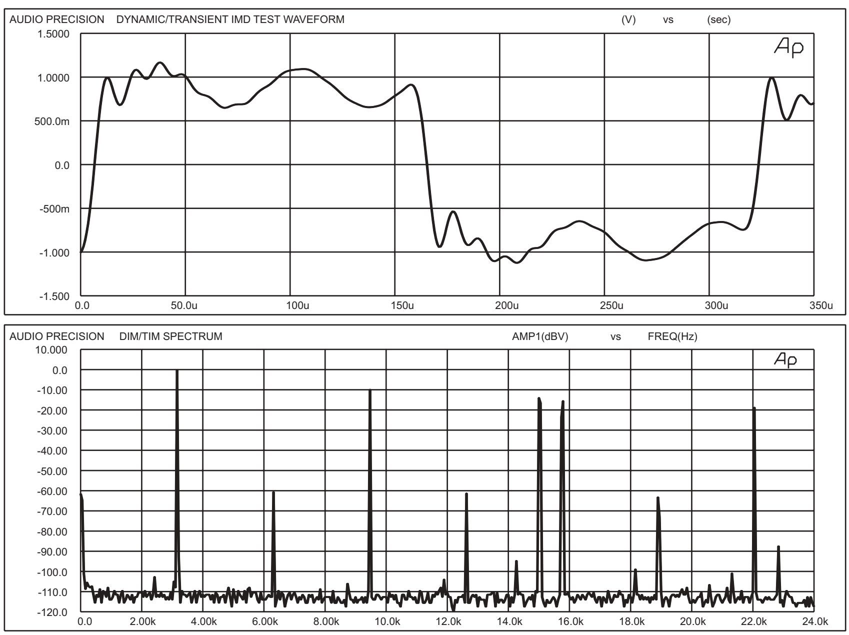

Figure 29. Dynamic/Transient IMD signal, time domain and frequency domain.