Intermodulation Distortion

When the sum of two sine waves is applied to the input of an ideal amplifier, its output signal consists of a sum of only two sine waves. If the amplifier is not ideal, its output signal contains sine wave components at frequencies other than those of the input signal. This is called intermodulation distortion. Let the frequency components of the input signal be denoted by f_1 and f_2. In general, the frequency components of the output intermodulation components will be $(nf_1 \pm mf_2)$, where n and m are positive integers.

As an example, let the instantaneous amplifier output voltage be given by

$$v_O = Av_I + Bv_I^2 \tag{1}$$

where v_I is the input voltage and $B = 0$ for an ideal amplifier. For $B \neq 0$, the amplifier is said to have a second-order non-linearity. In general, amplifiers exhibit more non-linear terms than just second-order. Let $v_I = V_1 \sin \omega_1 t + V_2 \sin \omega_2 t$, where $\omega_1 > \omega_2$. It follows that v_O is given by

$$\begin{aligned} v_O &= A\left(V_1 \sin \omega_1 t + V_2 \sin \omega_2 t\right) + B\left(V_1 \sin \omega_1 t + V_2 \sin \omega_2 t\right)^2 \\ &= A\left(V_1 \sin \omega_1 t + V_2 \sin \omega_2 t\right) + v_D \end{aligned} \tag{2}$$

where v_D is the distortion component given by

$$\begin{aligned} v_D &= 0.5\left(V_1^2 + V_2^2\right) - 0.5V_1 \cos 2\omega_1 t + 0.5V_2 \cos 2\omega_2 t \\ &\quad + V_1 V_2 \cos\left(\omega_1 - \omega_2\right) t - V_1 V_2 \cos\left(\omega_1 + \omega_2\right) t \end{aligned} \tag{3}$$

The first term in the expression for v_D represents a dc term. It can be interpreted as a perturbation in the dc bias at the amplifier output. The second and third terms represent harmonic distortion components at the frequencies $2\omega_1$ and $2\omega_2$. The third and fourth terms represent intermodulation distortion terms at the frequencies $\omega_1 - \omega_2$ and $\omega_1 + \omega_2$. Non-linear terms of higher than second order generate more intermodulation distortion terms. For example, a cubic term in Eq. (3) would cause intermodulation terms at $2f_1 + f_2$, $2f_1 - f_2$, $f_1 + 2f_2$, and $f_1 - 2f_2$.

A widely used standard for measuring intermodulation distortion is the SMPTE (Society of Motion Picture and Television Engineers) standard. It specifies that the amplifier input signal be the sum of two sine waves, one at 60 Hz and the other at 7 kHz. The amplitude of the 60 Hz term is specified to be greater than the amplitude of the 7 kHz term by a factor of four. Thus the input signal is of the form $v_I(t) = V_1 [\sin(2\pi 60t) + 0.25 \sin(2\pi 7000t)]$, where V_1 is a constant. Fig. 1 shows a simplified block diagram of a SMPTE intermodulation distortion analyzer. The amplifier output signal is first high-pass filtered to remove the 60 Hz term. The remaining 7 kHz term is envelope detected. This detects the amplitude modulation on the 7 kHz term caused by the 60 Hz term. The output of the envelope detector is read on a meter that is calibrated to read the percent intermodulation distortion.

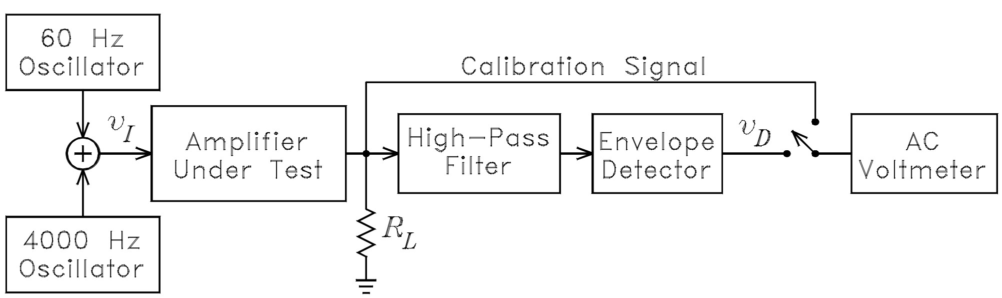

Figure 1: Diagram of intermodulation distortion analyzer.

To illustrate how the intermodulation distortion analyzer works, consider an amplifier with crossover distortion. Fig. **??**(a) illustrates its v_O versus v_S characteristics. The IM test waveform is shown in Fig. 2(a). Fig. 2(b) shows the waveform of the amplifier output. Note that the amplitude of the high-frequency component is decreased when the signal goes through zero. Fig. 2(c) shows the signal after the low-frequency sine wave is filtered out. The amplitude modulation on the high-frequency sine wave is clearly visible. This amplitude modulation is detected by the envelope detector in Fig. 1 and is read on an ac voltmeter. The envelope detector consists of a full-wave rectifier and low-pass filter. The output of the rectifier is shown in Fig. 2(d). The output of the envelope detector is shown in Fig. 2(e) The amplifier output signal is used as a calibration signal for the voltmeter so that the distortion can be read as a percent of the output signal.

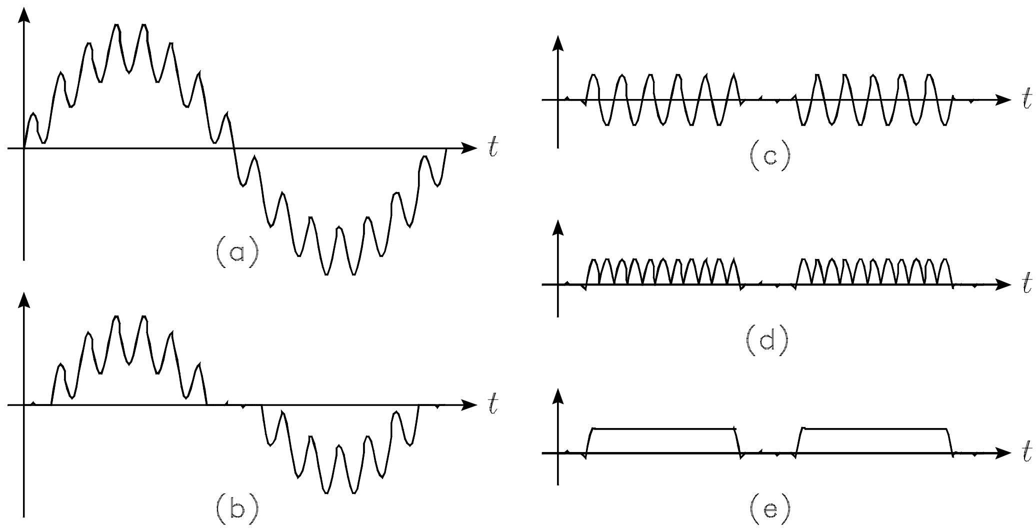

Figure 2: (a) IM test waveform. (b) Amplifier output voltage. (c) Output of high-pass filter. (d) Output of full-wave rectifier in envelope detector. (e) Output of envelope detector.