1 Preamble

- **Deliver sound wave (or electrical signal) to a system**
- **If the system reproduces the waveform <u>faithfully</u>, the signal is <u>undistorted</u>**
- **If the shape of the waveform is <u>altered</u>, the signal is <u>distorted</u>**

2 Three Types of Distortion

- **Frequency**
- **Transient**
- **Amplitude**

3 FREQUENCY DISTORTION

- **Panel A: Transfer function (amplitude response) of a system is the output when the input has equal amplitude at all frequencies.**
- **Panel B: No distortion at output of system**
- **Panels C & D**
  - **<u>NOT</u> all frequencies reproduced the same**
  - **System was frequency selective; filtering occurred**
  - **Signal underwent f<u>requency distortion</u>**

4 FREQUENCY DISTORTION

- **The three functions in panels B, C, & D describe the <u>system transfer function</u>, or <u>amplitude response</u>, of the system**
- **The amplitude response reveals evidence of frequency distortion**
- ***Linear systems*** **(A_{in} A_{out}) produce frequency distortions.**

5 Effects of Rise-Decay Time on Amplitude Response

- **Amplitude rises over time from zero to max, and falls over time from max to zero**
- **Panel A shows <u>amplitude envelope</u> in the time domain**
- **Panel B shows <u>amplitude spectrum</u> in the frequency domain (frequency spread)**
- **Initiation & termination of signal produces <u>transients</u>**

6 Effects of Rise-Decay Time on Amplitude Response

- **The longer the rise-fall time, the less the transient distortion**
- **ANSI S3.6-1989**
  - **>> Time from -20 dB to -1 dB shall not be less than 20 ms**

7 TRANSIENT DISTORTION

- **<u>A</u> sine wave of infinite time.**
- **<u>B</u> sin of finite time. (100 ms)**
- **<u>C</u> sin of short time. (4 ms)**
- **Energy spread to surrounding frequencies, and amplitude spectrum is <u>continuous</u>**
- **Why?**
  - **Its duration is <u>finite</u>**
- **Nulls at <u>integer multiples of reciprocal of duration</u> and width of each <u>lobe</u> is inversely proportional to duration**
- **(1/.1=10 and 1/.004=250)**

8 AMPLITUDE DISTORTION

- **Panel A: Do some of the instantaneous amplitudes of the input signal exceed the limits of linearity of the system?**

☑ Yes

- What is the result?

☑ The instantaneous amplitudes at or near maximum amplitude are "clipped off"-- output amplitude is not proportional to input amplitude -- the signal has been peak clipped; distortion

- Panel B: more severe peak clipping; more severe distortion

9 AMPLITUDE DISTORTION

- The distortion is called amplitude distortion; Why?

☑ Amplitude is the waveform parameter that was altered

- Amplitude distortion is also called nonlinear distortion; Why?

☑ The distortion arose from operating on the nonlinear portion of the I / O function

10 Effects of Amplitude, or Nonlinear, Distortion on Amplitude Spectrum

- Input signals in panels A & B are sinusoids
- Output signals are what kind of sound waves?

☑ Complex periodic waveforms

- At what frequencies should you expect to see energy in a complex periodic waveform?

☑ Harmonics

- Thus, amplitude, or nonlinear, distortion also can be called harmonic distortion (if the input waveform is sinusoidal)

11 Effects of *Amplitude*, *Nonlinear*, or *Harmonic* Distortion on Amplitude Spectrum

- The figure displays the output spectrum from a nonlinear system
- At the input, f = 100 Hz
- At the output, note energy at harmonics of f_0

12 Amplitude Response and Dynamic Range

- Panel A: I / O functions for several driving frequencies from .1 kHz to 10 kHz
  - » On each I / O function, location of the filled dot identifies point of maximum permissible harmonic distortion
- Panel B: The dots from I / O functions are connected and redrawn in the frequency domain to form the upper curve
  - » That defines the amplitude response of the system
  - » Electrical noise floor (ENF) of system is shown by lower curve

13 Amplitude Response and Dynamic Range

- Dynamic range is distance in decibels from ENF to amplitude response at maximum
- Does ENF vary with frequency?

☑ Yes

14 What should you know?

15 Intermodulation Distortion

- Driving signal is complex
- Experience nonlinear distortion
- Result called intermodulation distortion

16 Intermodulation Distortion

- Suppose input signal has two frequency components
  - ♦ f_1 = 100 Hz
  - ♦ f_2 = 110 Hz
- Frequency components of output signal include two types of distortion products:

- Harmonics
- Combination Tones
  - >> Difference tones
  - >> Summation tones

17 **Intermodulation Distortion**

- 1. Harmonics of each frequency component
  - $1f_1$ = 100 Hz & $1f_2$ = 110 Hz
  - $2f_1$ = 200 Hz & $2f_2$ = 220 Hz
  - $3f_1$ = 300 Hz & $3f_2$ = 330 Hz, etc.

18 **Intermodulation Distortion**

- 2. Difference tones:
  - $|1f_1 - f_2|$ = 10 Hz
  - $|2f_1 - f_2|$ = 90 Hz
  - $|3f_1 - f_2|$ = 190 Hz, etc.

19 **Intermodulation Distortion**

- 3. Summation tones:
  - $1f_1 + f_2$ = 210 Hz
  - $2f_1 + f_2$ = 310 Hz
  - $3f_1 + f_2$ = 410 Hz, etc.

20 **Combination Tones**

- Equation 7.3 defines frequencies of all harmonics, difference tones, and summation tones
  - $mf_1 \pm nf_2$, where
  - m and n are assigned all integer values

21 **Linear Systems**

- Linear systems alter only the amplitudes and phases of a signal
- They do produce frequency distortion
- “Frequency response” of an audio device might be described as
  - 100 Hz to 10,000 Hz
  - Flat ± X dB

22 **Linear Systems**

- Panel A: Input-Output (I/O) function of linear system
  - As input amplitude increases (e.g., 5 dB), output amplitude increases proportionally (5 dB)
  - Output amplitude need not equal input amplitude; the change is a proportional one
- Panel B: The characteristics of the input sine wave are preserved faithfully in output sine wave; Why?
  - ☑ The system is linear