1 Summation of Sine Waves

2 1. A Sawtooth Wave

- A complex periodic wave with energy at <u>odd</u> and <u>even</u> harmonics that has a <u>spectral envelope slope</u> of - 6 dB / octave
- Amplitudes decrease as the inverse of the harmonic #
- dB = 20 $\log_{10} (1 / h_i)$, where h_i is the harmonic #
- dB = - 20 $\log_{10} h_i$

3 Sawtooth Wave

- <u>Absolute</u> voltage of any harmonic depends on voltage of f_0!
- dB = - 20 $\log_{10} h_i$
- <u>Relative level</u>, in dB, is independent of voltage of f_0!
  - ♦ 2nd = - 20 $\log_{10}$ 2 = - 6 dB
  - ♦ 3rd = - 20 $\log_{10}$ 3 = - 9.5 dB
  - ♦ 4th = ?
    - ☑ - 20 $\log_{10}$ 4 = - 12 dB

4 Summary of Sawtooth Wave

- A complex periodic wave
- Energy at odd & even integer multiples of f_0
- Spectral envelope slope of - 6 dB / octave
- dB = 20 $\log_{10} 1 / h_i$ = - 20 $\log_{10} h_i$

5 2. Square Wave

- A complex periodic wave with energy only at <u>odd</u> integer multiples of f_0 that has a spectral envelope slope of - 6 dB / octave
- Amplitudes decrease as the inverse of the harmonic #
- dB= 20 $\log_{10} (1/h_i)$ = - 20 $\log_{10} h_i$

6 Summary of Square Wave

- Complex periodic wave
- Energy only at <u>odd</u> integer multiples of f_0
- Spectral envelope slope of - 6 dB / octave
- dB = 20 $\log_{10} 1 / h_i$ = - 20 $\log_{10} h_i$

7 Summary of Square Wave

- What about the phase spectrum?
- Confusion among textbooks
  - ♦ Some will show the starting phase to be 0º; others as 90º
  - ♦ Each is correct, but all harmonics must have the same starting phase

8 3. Triangular Wave

- A complex periodic wave with energy only at <u>odd</u> harmonics
- What distinguishes the triangular wave from the square wave?
  - ☑ Slope of envelope is steeper for triangular wave

9 ## Triangular Wave

- Amplitudes decrease as the reciprocal of the square of the harmonic #
- dB= $20 \log_{10} 1/h_i^2$
  $= - 20 \log_{10} h_i^2$
  $= - 40 \log_{10} h_i$
- Why - 40?
  - ☑ Log Law 3

10 ## Summary of Triangular Wave

- Complex periodic wave
- Energy only at odd integer multiples of f_0
- Spectral envelope slope of -12 dB/octave
- $dB = 20 \log_{10} 1/h_i^2 = - 40 \log_{10} h_i$

11 ## 4. Pulse Train

- A repetitious series of rectangularly shaped pulses
- Each pulse has some width or duration (P_d)
- Is it periodic or aperiodic?
  - ☑ A line spectrum; it must be periodic

12 ## Pulse Train

- In this example, P_d = 2 ms
- The period (T) of the pulse is 10 ms
- 1/T defines the pulse repetition frequency (PRF): PRF = ?
  - ☑ PRF = 100 Hz

13 ## Pulse Train

- A complex periodic wave with harmonics at odd and even integer multiples of the pulse repetition frequency: 100, 200, 300, etc.
- Amplitude spectrum shows lobes and valleys (nulls)
- Nulls occur at integer multiples of reciprocal of P_d

14 ## Pulse Train

- Thus, nulls occur at $1/P_d$, $2/P_d$, $3/P_d$, etc.
  - ♦ 500 Hz, 1000 Hz, 1500 Hz
- Starting phases?
  - ♦ Below 1st null: 0^o
  - ♦ Between 1st and 2nd null: 180^o
  - ♦ Between 2nd and 3rd null: 0^o
  - ♦ and so forth

15 ## Why is White Noise Called Gaussian Noise?

- For white noise, the probability density function is a normal curve, or Gaussian distribution
- Spectral envelope slope of 0 dB/octave
- Starting phases in random array

16 ## 6. A Single Pulse

- P_d = 2 ms
- Is the waveform periodic?
  - ☑ It cannot be!
  - ☑ It is <u>aperiodic</u>, & the amplitude spectrum must, therefore, be <u>continuous</u>

17 ## MEASURES OF SOUND PRESSURE FOR COMPLEX WAVES

- Different equations required for different signals
- True rms meter vs. average-responding meter
- Only the true rms meter will correctly read the rms voltage of signals other than sinusoids

18 ## SIGNAL-TO-NOISE RATIO IN dB (dB S / N)

- It is the ratio of signal level to noise level
- dB S / N = 10 $\log_{10}(I_S / I_N)$
- If S = 70 dB and N = 66 dB
  - ♦dB S / N = 4 dB
- Why?

☑ dB S / N = 10 $\log_{10}(10^{-5} / 4 \times 10^{-6})$

= +4 dB

☑ dB S / N = 70 - 66

= +4 dB

☑ (Log Law 2)