

### **Effect of {Relative} Phase on Tone Quality:**

Human ears **are** sensitive to phase information in the  $\sim 100 \leq f \leq 1500$  Hz range.

In a complex tone, there also exists subtle sound change(s) associated with the phase of higher harmonics **relative** to the fundamental. Due in part to **non-linear** response(s) in the ear (& auditory processing in brain) - *i.e.* the non-linear response associated with the firing of auditory nerves/firing of hair cells due to vibrations on the basilar membrane in the cochlea, from overall sound wave incident on one's ears. This is **especially** true for **loud** sounds!!! Non-linear auditory response(s) also become **increasingly** important with increasing sound pressure levels.

Please see/read Physics 406 Lecture Notes on “Theory of Distortion (I & II)” for details on how a non-linear system responds to pure and complex periodic signals.

### **Harmonic Spectrum:**

Please see above figure(s) for harmonic content associated with:

- a.) a pure sine wave
- b.) a symmetrical triangle wave
- c.) a sawtooth (= asymmetrical triangle) wave
- d.) a bipolar square wave

Musical instruments have **transient** response(s) – *i.e.* the harmonic content of the sounds produced by musical instruments changes/evolves in time.

How harmonics evolve in time is important.

How the harmonics build up to their steady-state values is important for overall tone quality, *e.g.* at the beginning of each note.

How the harmonics decay at the end of each note is also important - very often the higher harmonics decay more rapidly than lower-frequency harmonics, due to frequency-dependent dissipative processes.

### **Formants:**

Nearly all musical instruments have frequency regions that emphasize certain notes more so than others – these are known in musical parlance as **formants** – *i.e.* **resonances** – due to **constructive** interference of sound waves in those frequency regions. If resonances (constructive interference) exists within a given musical instrument for certain frequency range(s), there will also exist **anti-resonances** (destructive interference) for certain other frequency ranges, *e.g.* in between successive formants.