6. Modulation Synthesis

- *Modulation*, in electronic and computer music implies one aspect of the *carrier signal* being modified by a *modulator signal*.
- *Modulation products*, or *sidebands*, begin to get noticeable whenever the frequency of modulation rises above the audible bandwidth.
- Modulation synthesis is more efficient in achieving complex spectrums.

Bipolar and Unipolar Signals

- Bipolar signals have a positive and negative excursion around zero.
- Unipolar signals only have either a positive or negative excursion.
- Unipolar signals can be conceptualized as a bipolar signal to which a constant has been added.
- The difference between ring modulation and amplitude modulation, is that the former modulates two bipolar signals, while the later modulates a bipolar signal with a unipolar.

Ring Modulation

- Ring modulation is a form of amplitude modulation.
- Formula for determining the value of a simple ring-modulated signal $RingMod$ at time t:

$$RingMod_t = C_t * M_t$$

- If frequency of modulator M is below $20\,Hz$, the amplitude of C varies at the frequency of M.
- If the frequency of M is in the audible range, the timbre of C changes.
- For each sinusoidal component of C, M adds a pair of *sidebands*.

- If C and M are in an integer ratio, the sidebands are harmonic, otherwise they're inharmonic.
- Sidebands in signal multiplication derive from a trigonometric identity:

$$\cos(C) * \cos(M) = 0.5 * [\cos(C - M) + \cos(C + M)]$$

- Ring Modulation can also be understood as a case of *convolution*.
- As an example, let assume C is a $1000\ Hz$ sine and M is a $400\ Hz$ sine. We'll have bands at $1400\ Hz\ (C\ +\ M)$ and $600\ Hz\ (C\ -\ M)$.

Negative Frequencies

- Negative frequencies are a biproduct of a modulation where M has a frequency higher than C. As an example, given $C\ =\ 100\ Hz$ and $M\ =\ 400\ Hz$, $C\ +\ M\ =\ 500$, while $C\ -\ M\ =\ -300$.

Application of RM

- Modification of sampled carrier by sinewave modulator.
- Creation of pure synthetic sounds.

Analog Ring Modulation and Frequency Shifting

- Digital RM, in general tends to always sound the same, whereas analog RM, due to its circuits and components, tend to sound different, or to present a "character" of their own.
- Silicon or germanium diodes within the system, would introduce extraneous frequencies.

Amplitude Modulation

- As in ring modulation, the amplitude of the carrier varies with the modulator signal. The difference between RM and AM, is that in AM the modulator is a unipolar signal.
- A common example of AM happens when an envelope is applied to a sinewave. The envelope, being unipolar (with values ranging from 0 to 1) acts as the modulator, and the sine, being bipolar, as the carrier.
- We can apply an envelope to a signal by multiplying the two waveforms:

$$AmpMod_t = C_t * M_t$$

- Just like in RM, a pair of sidebands is generated for every sinusoidal component of the carrier and modulator.
- The difference in spectrum, from RM, is that AM contains the carrier frequency as well.

AM Instruments

- To implement AM, we simply restrict the modulator to a unipolar signal (between 0 and 1).