MARE 502, Advanced Topics in Computer Music

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Outline of this Lecture

Recapitulation

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- What is additive synthesis?

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- What is the purpose of Csound's different signal rates?
- What is the difference between a harmonic and an inharmonic spectrum (analytically and perceptually)?
- What is additive synthesis?
- Multiple wavetable synthesis can closely approximate the sound of acoustical instruments (e.g., woodwinds and brass). What are principle differences between this technique and sampling?

Exercises I

Please conduct the following exercises individually. Don't hesitate to ask for help if necessary.

- Define a Csound orchestra containing a simple instrument that uses the `pluck` opcode (cf. Fig. 1.4 in Csound book). Check the documentation of `pluck` and make sure that a random sequence will be used for its f-table. Play a single note with this instrument.
- Change the instrument definition such that pitch and amplitude can be controlled in the score. Define a score that plays either a chord (e.g., a major triad with the frequencies 400 Hz, 500 Hz, and 600 Hz) and a scale (e.g., a major scale with the frequencies 400 Hz, 450 Hz, 500 Hz, 533 Hz, 600 Hz, 667 Hz, 750 Hz, 800 Hz). Remember that you might need to adapt the amplitude for multiple simultaneous notes.

Exercises II

Please conduct the following exercises individually. Don't hesitate to ask for help if necessary.

- Change the instrument definition such that the pitch can be given as a MIDI note number (keynumber) in the score. Use the value converter `semitone` (see the documentation for its use). You can compute the frequency with the following formula $refFreq * semitone(keynumber - refKey)$. Traditionally, the reference note for tuning is Concert A (keynumber 69) tuned at 440 Hz.
- Change the instrument definition such that the `pluck` opcode is used to synthesis a drum sound (see the documentation of `pluck`, argument `imeth`). Refine the instrument such that the 'roughness factor' (more pluck or more drum sound) can be controlled in the score.

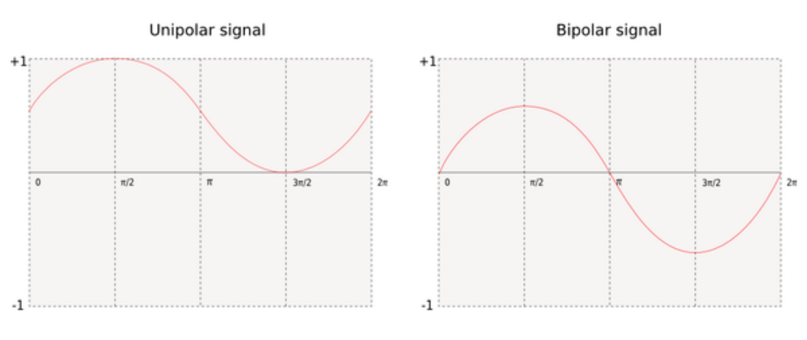
Exercises III

Additional exercise

- Read Csound book Chapter 4 *Optimizing Your Csound Instruments*

Bipolar and Unipolar Signals

- Bipolar signal has both negative and positive amplitude values
- Unipolar signal is only positive (or only negative)
- A bipolar signal can be converted into a unipolar signal by adding a constant offset



[1]

[1] Source: Wikibooks, Sound Synthesis Theory/Modulation Synthesis

Ring Modulation (RM) I

- RM is multiplication of two bipolar signals.
- Formula for computing sample at time t.

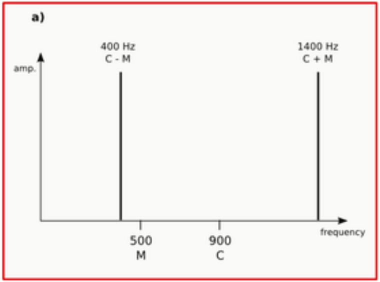
$$RingMod_t = Carrier_t * Modulator_t$$

Sidebands

- RM generates frequency spectrum with 2 sidebands: *sum* and *difference* of the carrier and modulator frequencies
- Carrier (and modulator) frequency are absent in result
- If ration of frequencies $Carrier/Modulator$ is integer ratio, then combination of sidebands, carrier and modulator form *harmonic* spectrum

Ring Modulation (RM) II

Examples



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[a] Source: Wikibooks, Sound Synthesis Theory/Modulation Synthesis

Ring Modulation (RM) III

Csound examples

RM-sine.csd, RM-buzz.csd

Amplitude Modulation (AM)

Differences between AM and RM

- In AM, carrier signal is unipolar instead of bipolar (as in RM)
- In AM, carrier frequency is preserved in result together with sidebands
- Loudness of sidebands is controllable by modulation index

Csound examples

AM.csd

Compositional Examples

Stockhausen (1970). *Mantra*. ($>$ 70 min)

Wolfgang von Schweinitz (1999). *KLANG auf Schön Berg La Monte YOUNG*. ($>$ 45 min)

Frequency Modulation (FM)

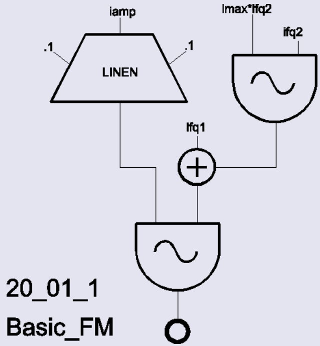
- FM modulates *frequency* of oscillator
  — RM and AM modulate amplitude of a signal
- Highly complex and dynamic timbres can be computed with very low processing cost
  — much cheaper than additive synthesis
- Amplitudes of resulting sidesbands hard to predict
  — far more complex than for AM and RM

Csound example

Demonstration of evolution of sidebands when vibrato frequency and depth is increased:
01FMSynthesisVibratoToSideBands.csd

Basic FM

Flowchart

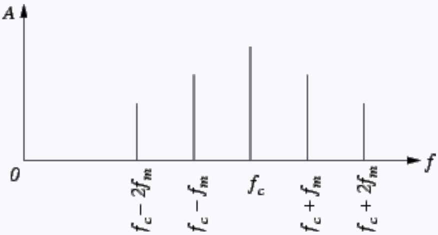


Csound example

BasicFM.csd

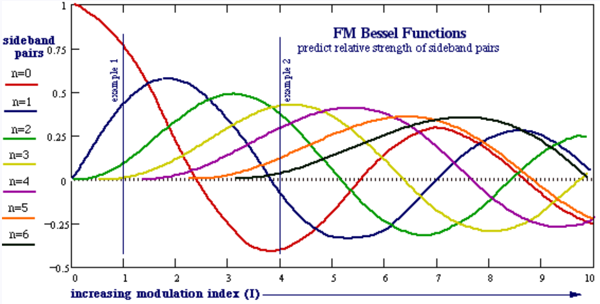
$C : M$ Ratio

- Ratio between carrier and modulator frequency
- Determines frequencies of sidebands
- If $C : M$ is simple integer ratio (e.g. $4 : 1$), then FM generates harmonic spectrum otherwise inharmonic spectrum
- Sideband frequencies are
  - C+M C+2M C+3M C+4M C+5M ...
  - C-M C-2M C-3M C-4M C-5M ...



Modulation Index

- *ModulationDepth*/*ModulationFrequency* (`imax` in BasicFM flowchart above)
- Affects overall amplitude of sidebands
- Exact amplitudes of individual sidebands vary according to a highly complex function (Bessel function of first kind and nth order)



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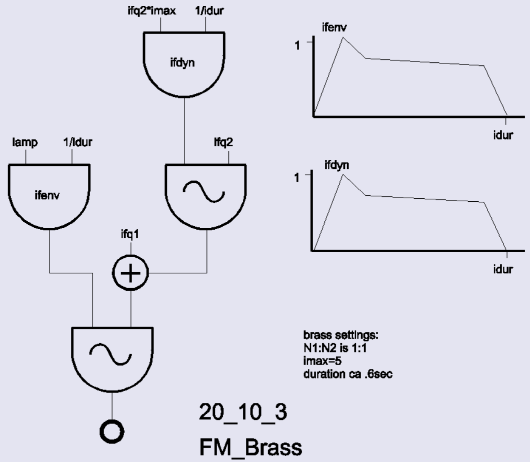
[2]Source: Introduction to Computer Music, Indiana University

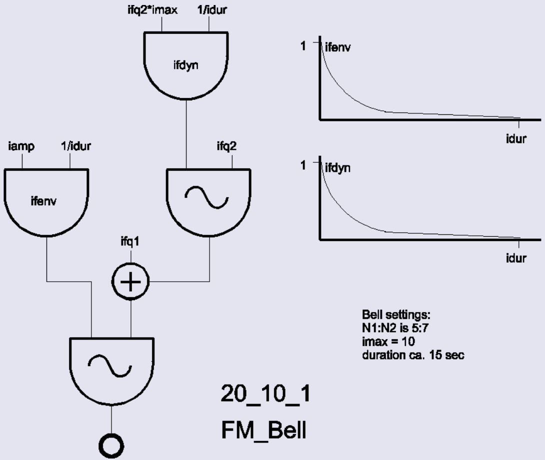
Emulating Acoustic Instruments with Basic FM I

Flowchart BrassFM.csd



Emulating Acoustic Instruments with Basic FM II

Flowchart BellFM.csd



Emulating Acoustic Instruments with Basic FM III

Csound examples

BrassFM.csd, BellFM.csd

Source

Chowning, J. (1973). The Synthesis of Complex Audio Spectra by Means of Frequency Modulation. *Journal of the Audio Engineering Society*, 21(7):526-534. Reprinted in C. Roads and J. Strawn, eds. (1985). *Foundations of Computer Music*. MIT Press, pp. 6-29.

Multiple-Modulator FM

Various extension of the basic FM have been developed, e.g., multiple modulators may modulate each other in a chain.

Csound example

DoubleModulatorFM.csd

Summary

- Practical exercises
- Amplitude and ring modulation
- Frequency modulation

Exercises for Next Week

Reading

- Read Csound book chapter 9: *FM Synthesis and Morphing in Csound: from Percussion to Brass*
- Optionally, also read
  - Amsterdam Catalog: FM Synthesis. `http://www.music.buffalo.edu/hiller/accci/20/20-index.txt.html`
  - Csound book chapter 12: *FM Synthesis in Csound*

Practical exercises

- Finish exercises given at beginning of session
- Somehow change example AM.csd such that modulation index (`imod`) changes at control rate modulated by an envelope. Parameters of the envelope should be controllable in the score
- Execute examples of Csound book chapter 9
- Explore sound possibilities of DoubleModulatorFM.csd