CTP431: Fundamentals of Computer Music

Digital Sound Synthesis – Part 2

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Culture Technology

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Outlines

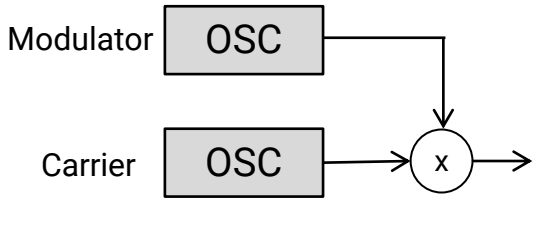
- Modulation synthesis
- Waveshaping synthesis
- Formant synthesis

Modulation Synthesis

- Modulation is originally from communication theory
  - Carrier: channel signal, e.g., radio or TV channel
  - Modulator: information signal, e.g., voice, video
- Types of modulation synthesis
  - Amplitude modulation (or ring modulation)
  - Frequency modulation
- Decreasing the frequency of carrier to hearing range can be used to synthesize sound
  - Generate new sinusoidal components
  - Modulation is non-linear processing

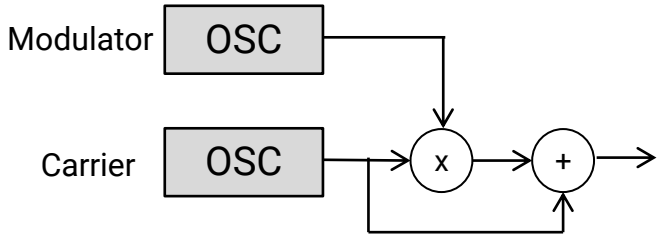
Ring Modulation / Amplitude Modulation

- Change the amplitude of one source with another source
  - Slow change: tremolo
  - Fast change: generate a new tone



$a_m(t)A_c\sin(2\pi f_c t)$

Ring Modulation

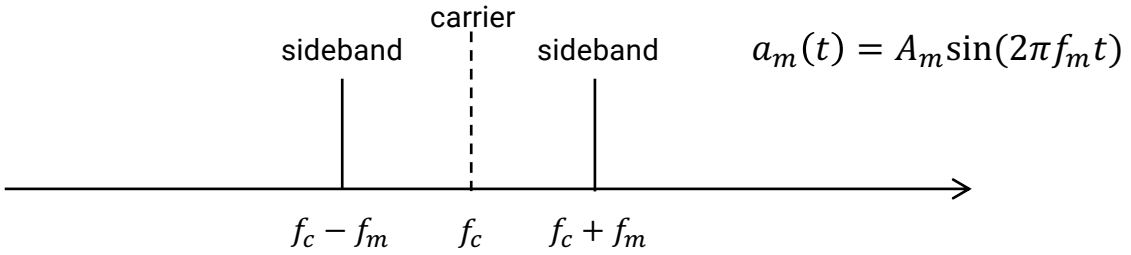


$(1 + a_m(t))A_c\sin(2\pi f_c t)$

Amplitude Modulation

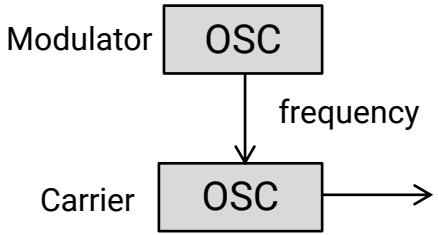
Ring Modulation / Amplitude Modulation

- Frequency domain
  - Expressed in terms of its sideband frequencies
  - The sum and difference of the two frequencies are obtained according to trigonometric identity
  - If the modulator is a non-sinusoidal tone, a mirrored-spectrum with regard to the carrier frequency is obtained



Frequency Modulation

- Change the frequency of one source with another source
  - Slow change: vibrato
  - Fast change: generate a new (and rich) tone
  - Invented by John Chowning in 1973 → Yamaha DX7



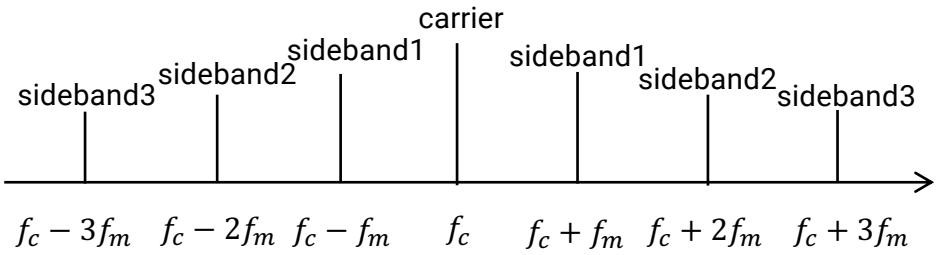
$$A_c \sin(2\pi f_c t + \beta \sin(2\pi f_m t))$$

$$\beta = \frac{A_m}{f_m}$$ Index of modulation

Frequency Modulation

- Frequency Domain
  - Expressed in terms of its sideband frequencies
  - Their amplitudes are determined by the Bessel function
  - The sidebands below 0 Hz or above the Nyquist frequency are folded

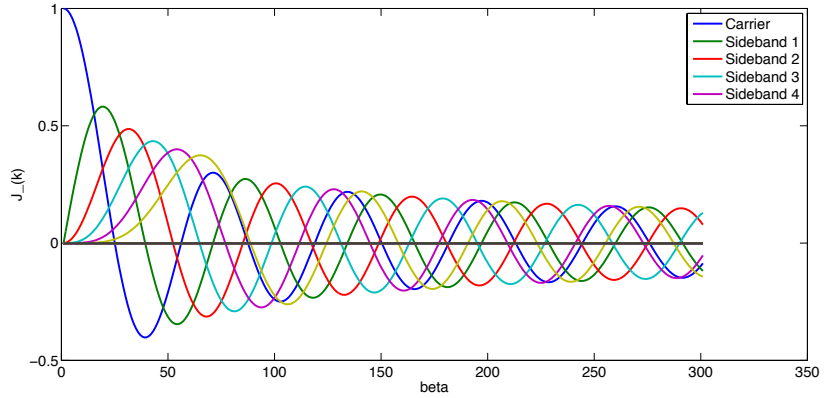
$$y(t) = A_c \sum_{k=-\infty}^{k=-\infty} J_k(\beta)\cos(2\pi(f_c + kf_m)t)$$



Frequency Modulation

- Bessel Function

$$J_k(\beta) = \sum_{n=0}^{\infty} \frac{(-1)^n (\frac{\beta}{2})^{k+2n}}{n!(n+k)!}$$



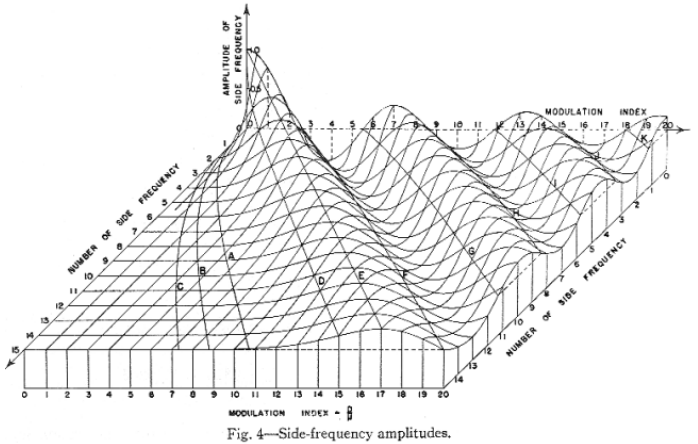
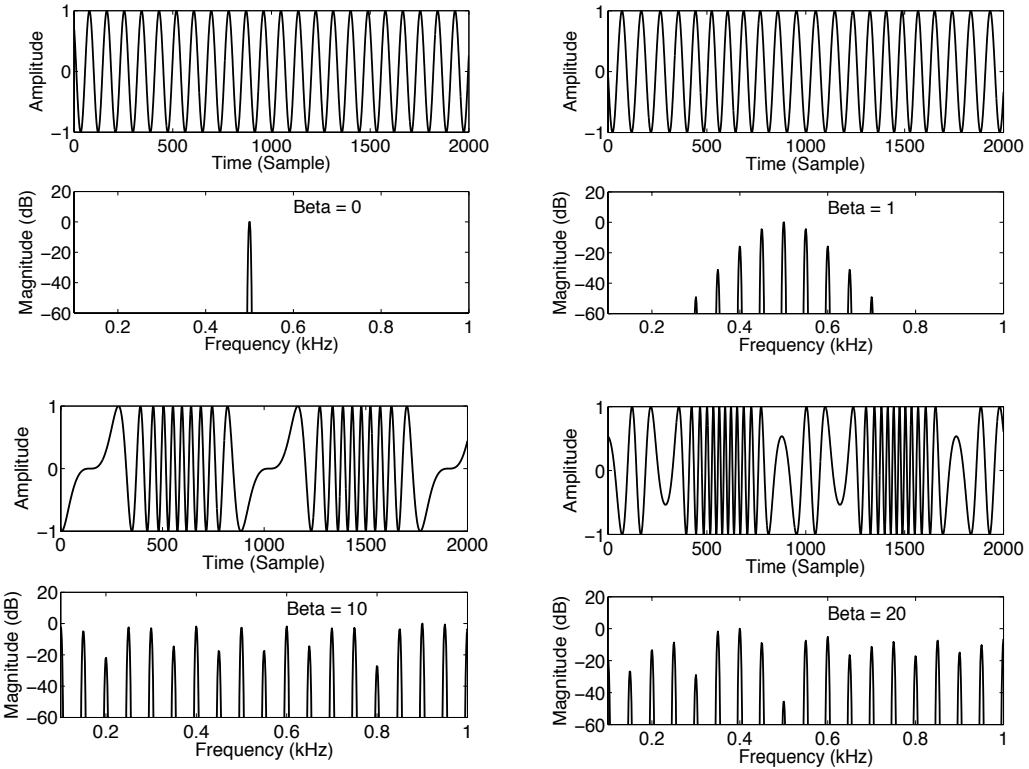


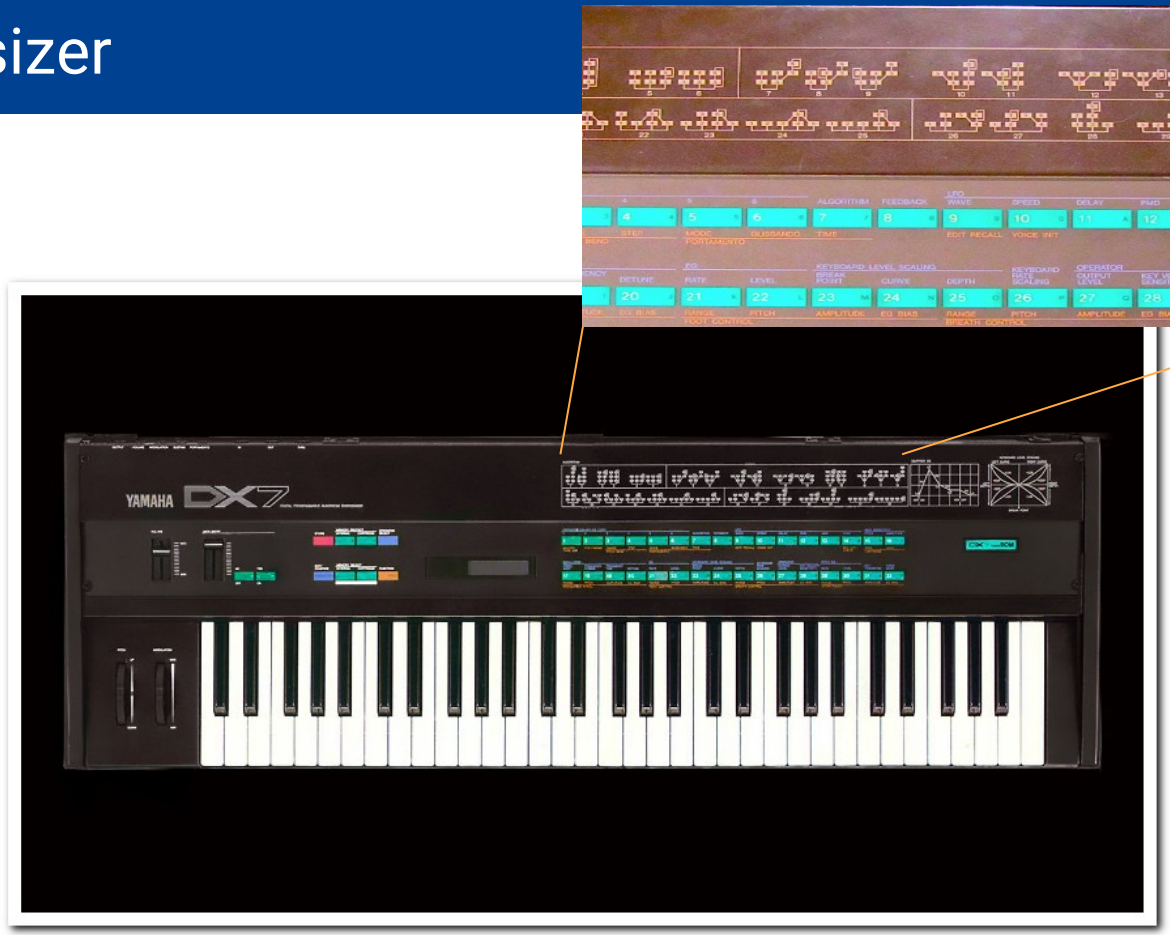
Fig. 4—Side-frequency amplitudes.

The Effect of Modulation Index



$$f_c = 500, \; f_m = 50$$

FM Synthesizer



Yamaha DX7 (1983)

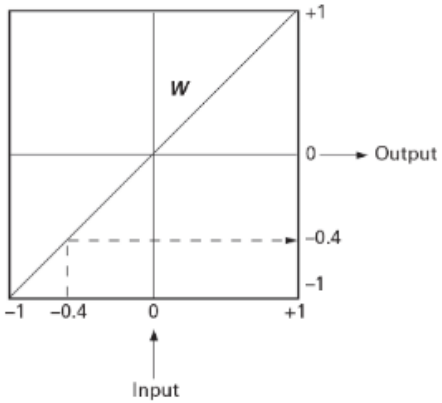
Examples

- Sound Examples
  - Bell
  - Wood
  - Brass
  - Electric Piano
  - Vibraphone

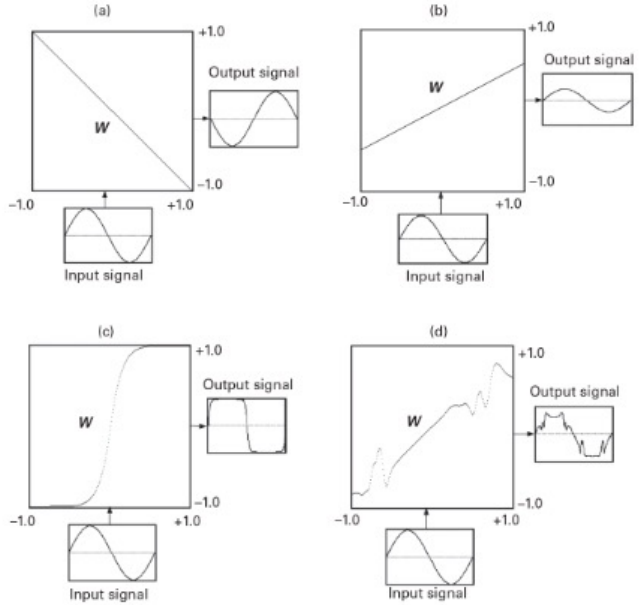
- Web Audio Demo
  - http://www.taktech.org/takm/WebFMSynth/

Waveshaping Synthesis

- Generate a rich sound spectrum by distorting a sine waveform by shaping a new waveform by a non-linear transfer function
  - Also, called “distortion synthesis”



x-to-y mapping



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Waveshaping Synthesis

- Examples of transfer function: $y = f(x)$
  - $y = \frac{x'}{1+|x'|} \rightarrow x' = g \cdot x$
  - g is the gain and it controls the harmonics
- Chebyshev polynomial: $T_{k+1}(x) = 2x \cdot T_k(x) - T_{k-1}(x)$
  - $T_k(\cos(x)) = \cos(kx)$
  - T_k generates the kth harmonics
  - Any harmonic distribution can be generated with a combination of T_k
    - $5T_1(x) + T_2(x) + 4T_3(x) + 3T_5(x)$

$$T_0(x) = 1$$
$$T_1(x) = x$$
$$T_2(x) = 2x^2 - 1$$
$$T_3(x) = 4x^3 - 3x$$
$$\dots$$