EE345S Real-Time Digital Signal Processing Lab   Spring 2006

Data Conversion

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Some figures are from Ken C. Pohlmann, *Principles of Digital Audio*, McGraw-Hill, 1995.

Lecture 10

Image Halftoning

- **Handout J on noise-shaped feedback coding**
  - Different ways to perform one-bit quantization (halftoning)
  - Original image has 8 bits per pixel original image (pixel values range from 0 to 255 inclusive)
- ***Pixel thresholding*: Same threshold at each pixel**
  - Gray levels from 128-255 become 1 (white)
  - Gray levels from 0-127 become 0 (black)

No noise shaping

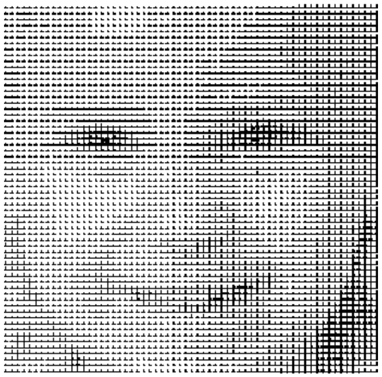
- ***Ordered dither*: Periodic space-varying thresholding**
  - Equivalent to adding spatially-varying dither (noise) at input to threshold operation (quantizer)
  - Example uses 16 different thresholds in a 4×4 mask
  - Periodic artifacts appear as if screen has been overlaid

No noise shaping

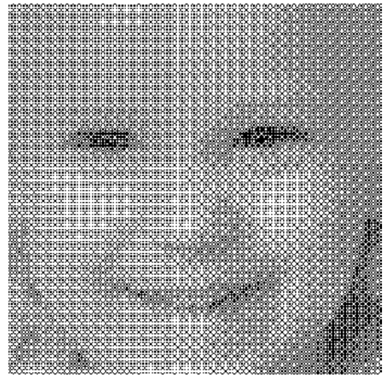
Image Halftoning

- ***Error diffusion*: Noise-shaping feedback coding**
  - Contains sharpened original plus high-frequency noise
  - Human visual system less sensitive to high-frequency noise (as is the auditory system)
  - Example uses four-tap Floyd-Steinberg noise-shaping (i.e. a four-tap IIR filter)
- **Image quality of halftones**
  - Thresholding (low): error spread equally over all freq.
  - Ordered dither (medium): resampling causes aliasing
  - Error diffusion (high): error placed into higher frequencies
- **Noise-shaped feedback coding is a key principle in modern A/D and D/A converters**

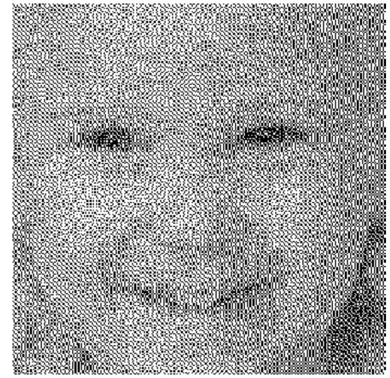
Digital Halftoning Methods



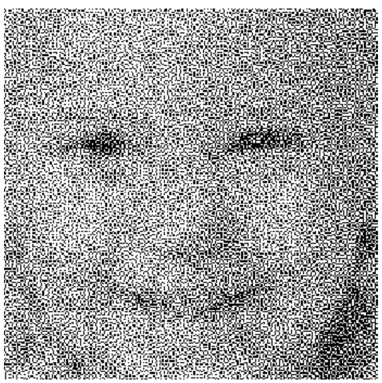
Clustered Dot Screening
AM Halftoning



Dispersed Dot Screening
FM Halftoning

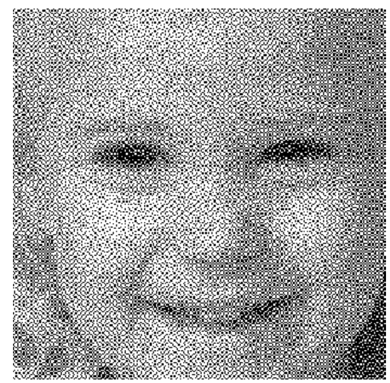


Error Diffusion
FM Halftoning 1975



Blue-noise Mask
FM Halftoning 1993

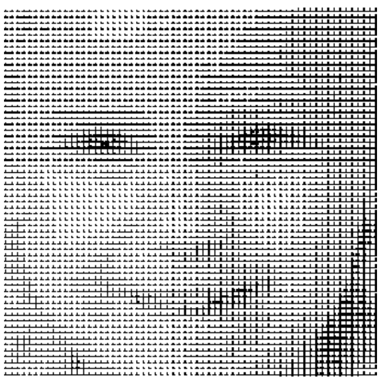
Green-noise Halftoning
AM-FM Halftoning 1992

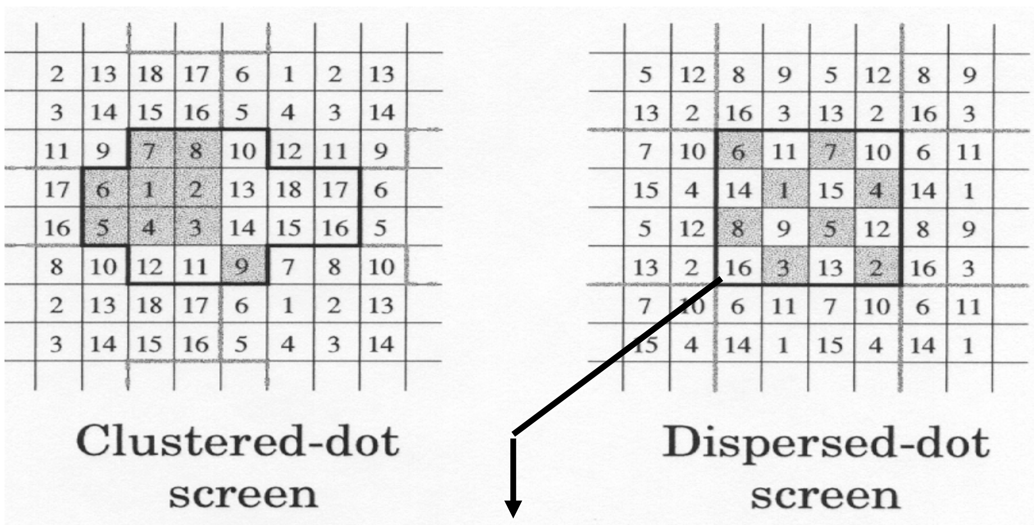


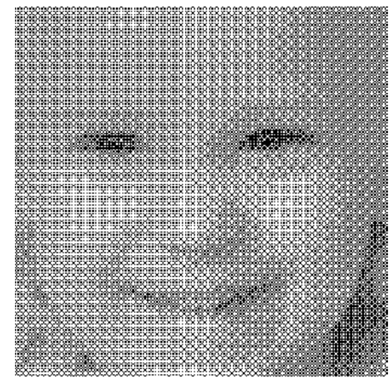
Direct Binary Search
FM Halftoning 1992

Screening (Masking) Methods

- **Periodic array of thresholds smaller than image**
  - Spatial resampling leads to aliasing (gridding effect)
  - Clustered dot screening produces a coarse image that is more resistant to printer defects such as ink spread
  - Dispersed dot screening has higher spatial resolution





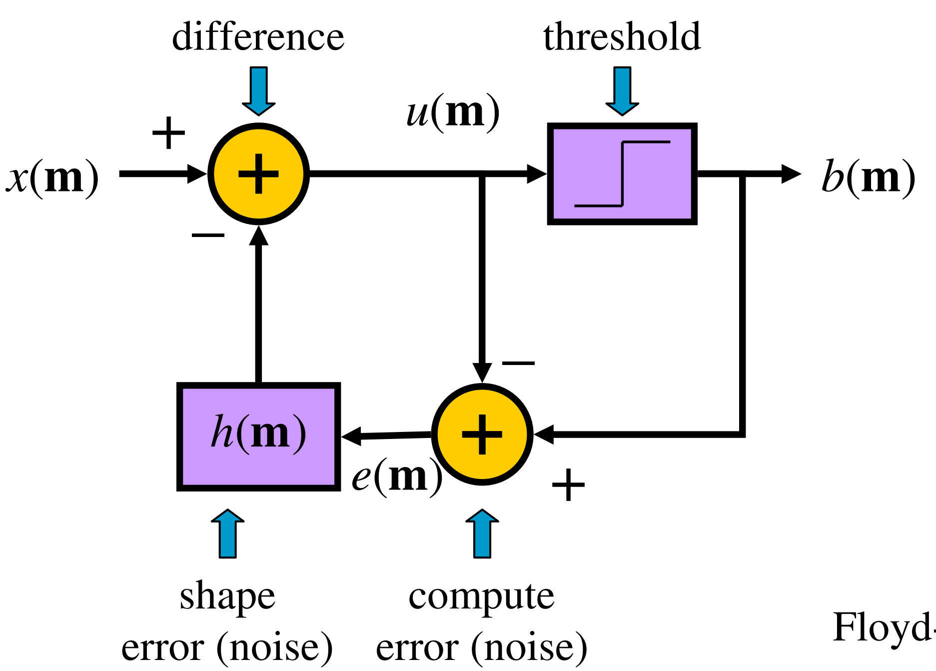


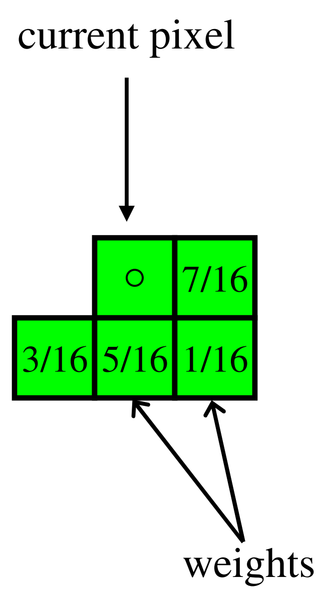
Thresholds =

$$\left\{\frac{1}{32},\frac{3}{32},\frac{5}{32},\frac{7}{32},\frac{9}{32},\frac{11}{32},\frac{13}{32},\frac{15}{32},\frac{17}{32},\frac{19}{32},\frac{21}{32},\frac{23}{32},\frac{25}{32},\frac{27}{32},\frac{29}{32},\frac{31}{32}\right\}*256$$

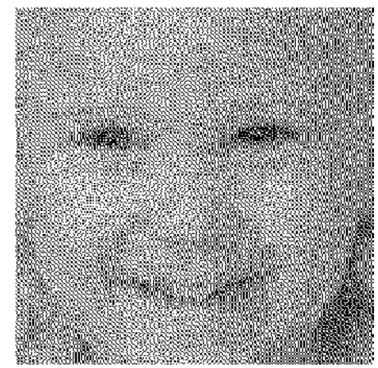
Grayscale Error Diffusion

- **Shapes quantization error (noise) into high frequencies**
- **Type of sigma-delta modulation**
- **Error filter $h(\mathbf{m})$ is lowpass**

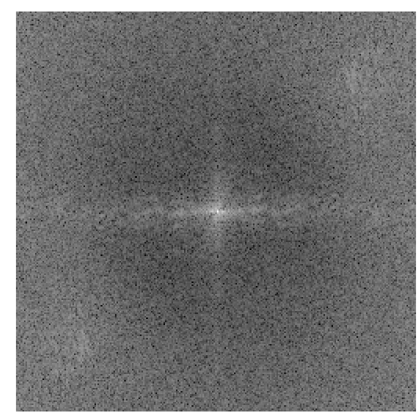




Floyd-Steinberg filter $h(\mathbf{m})$



Error Diffusion Halftone

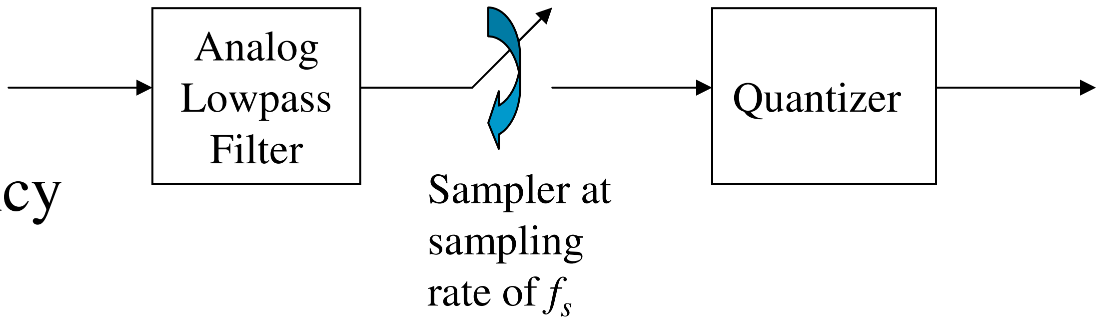


Spectrum

Old-Style A/D and D/A Converters

- **Used discrete components (before mid-1980s)**
- **A/D Converter**

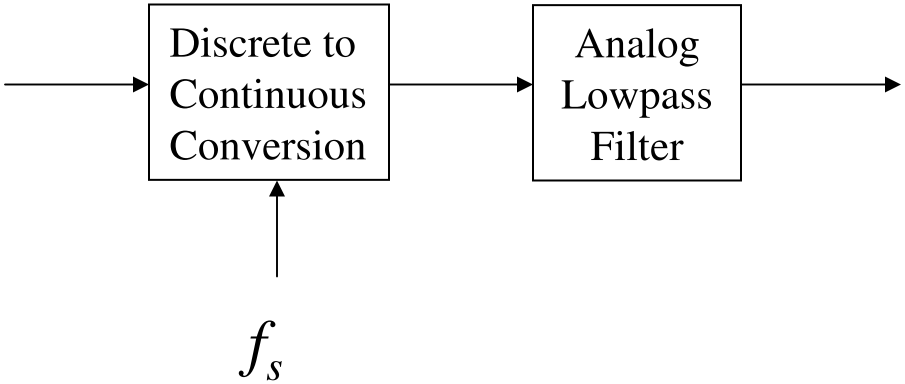
  Lowpass filter has stopband frequency of ½ f_s



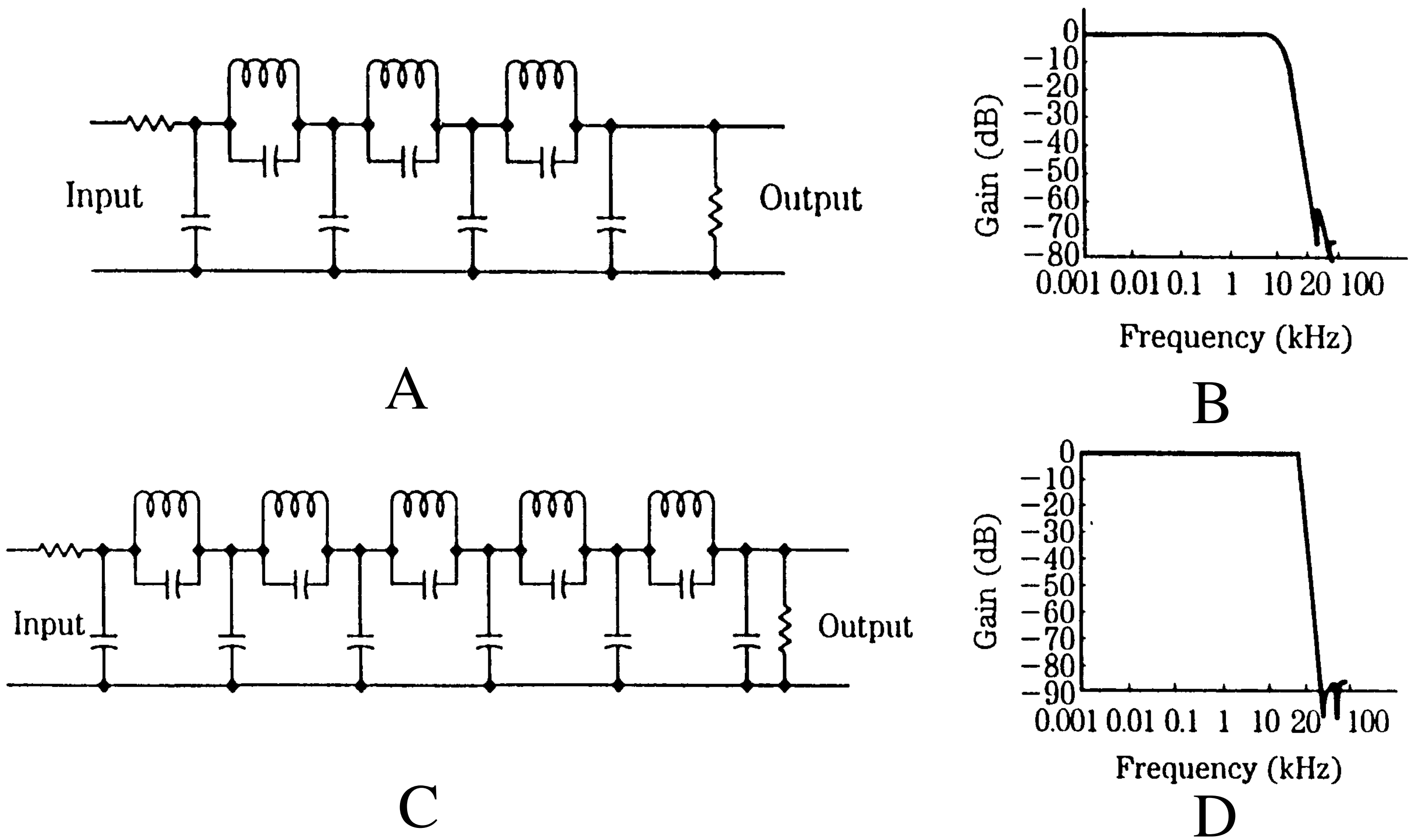
- **D/A Converter**

  Lowpass filter has stopband frequency of ½ f_s

  Discrete-to-continuous conversion could be as simple as sample and hold

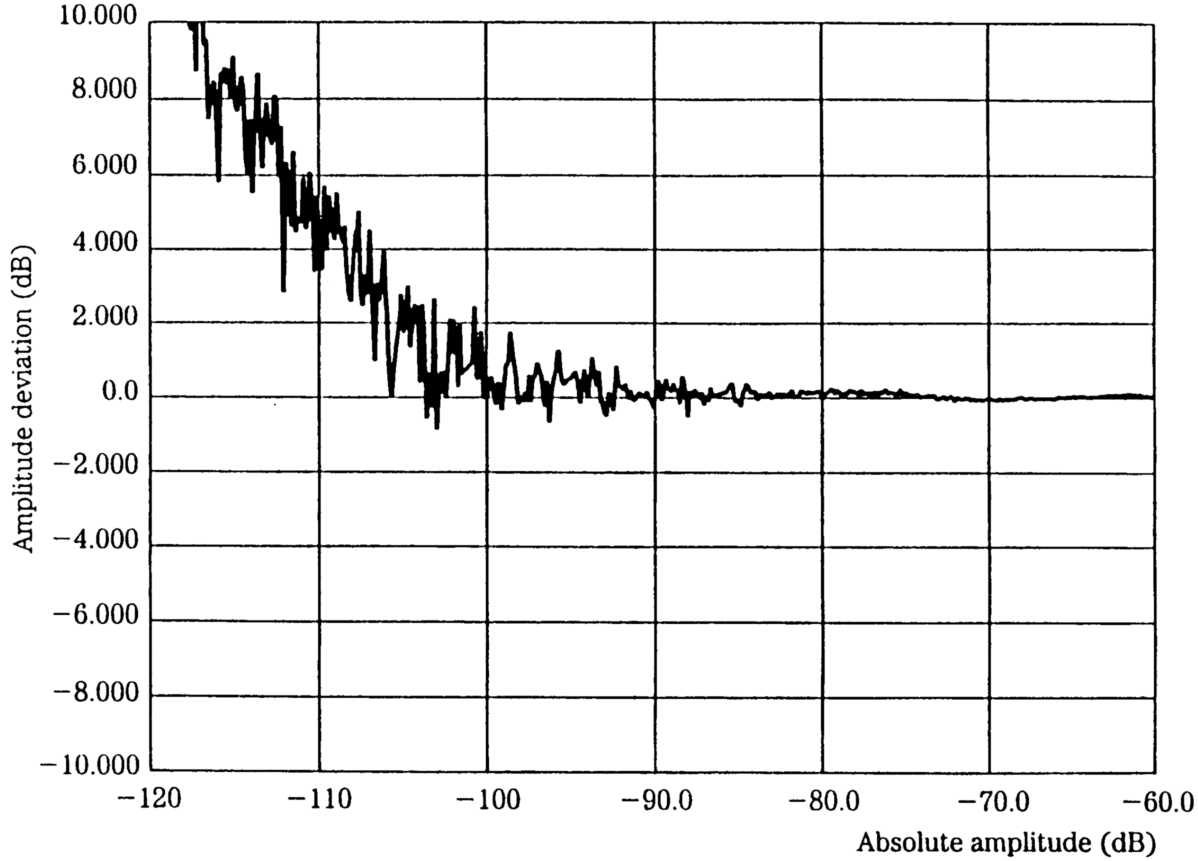


Cost of Multibit Conversion Part I: Brickwall Analog Filters



Pohlmann Fig. 3-5 Two examples of passive Chebyshev lowpass filters and their frequency responses. A. A passive low-order filter schematic. B. Low-order filter frequency response. C. Attenuation to -90 dB is obtained by adding sections to increase the filter’s order. D. Steepness of slope and depth of attenuation are improved.

Cost of Multibit Conversion Part II: Low- Level Linearity



Pohlmann Fig. 4-3 An example of a low-level linearity measurement of a D/A converter showing increasing non-linearity with decreasing amplitude.

Solutions

- **Oversampling eases analog filter design**

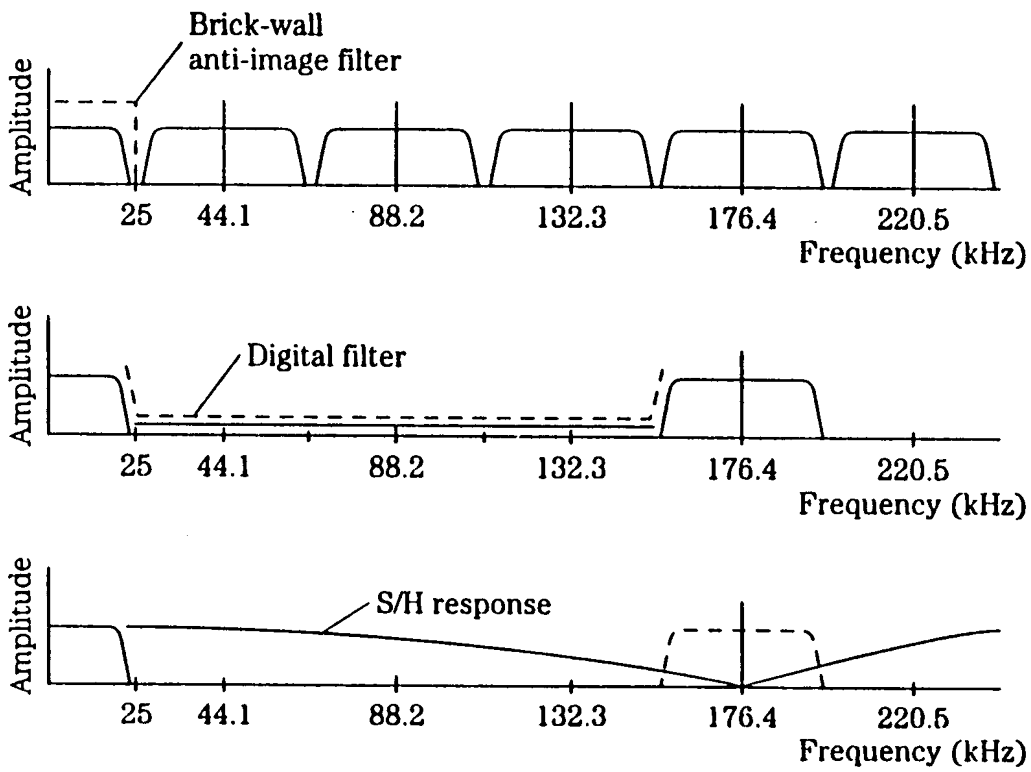
  Also creates spectrum to put noise at inaudible frequencies
- **Add dither (noise) at quantizer input**

  Breaks up harmonics (idle tones) caused by quantization
- **Shape quantization noise into high frequencies**

  Auditory system is less sensitive at higher frequencies
- **State-of-the-art in 20-bit/24-bit audio converters**

Oversampling	64x	256x	512x
Quantization	8 bits	6 bits	5 bits
Additive dither	2-bit Δ PDF	2-bit Δ PDF	2-bit Δ PDF
Noise shaping	5^{th} / 7^{th} order	5^{th} / 7^{th} order	5^{th} / 7^{th} order
Dynamic range	110 dB	120 dB	120 dB

Solution 1: Oversampling



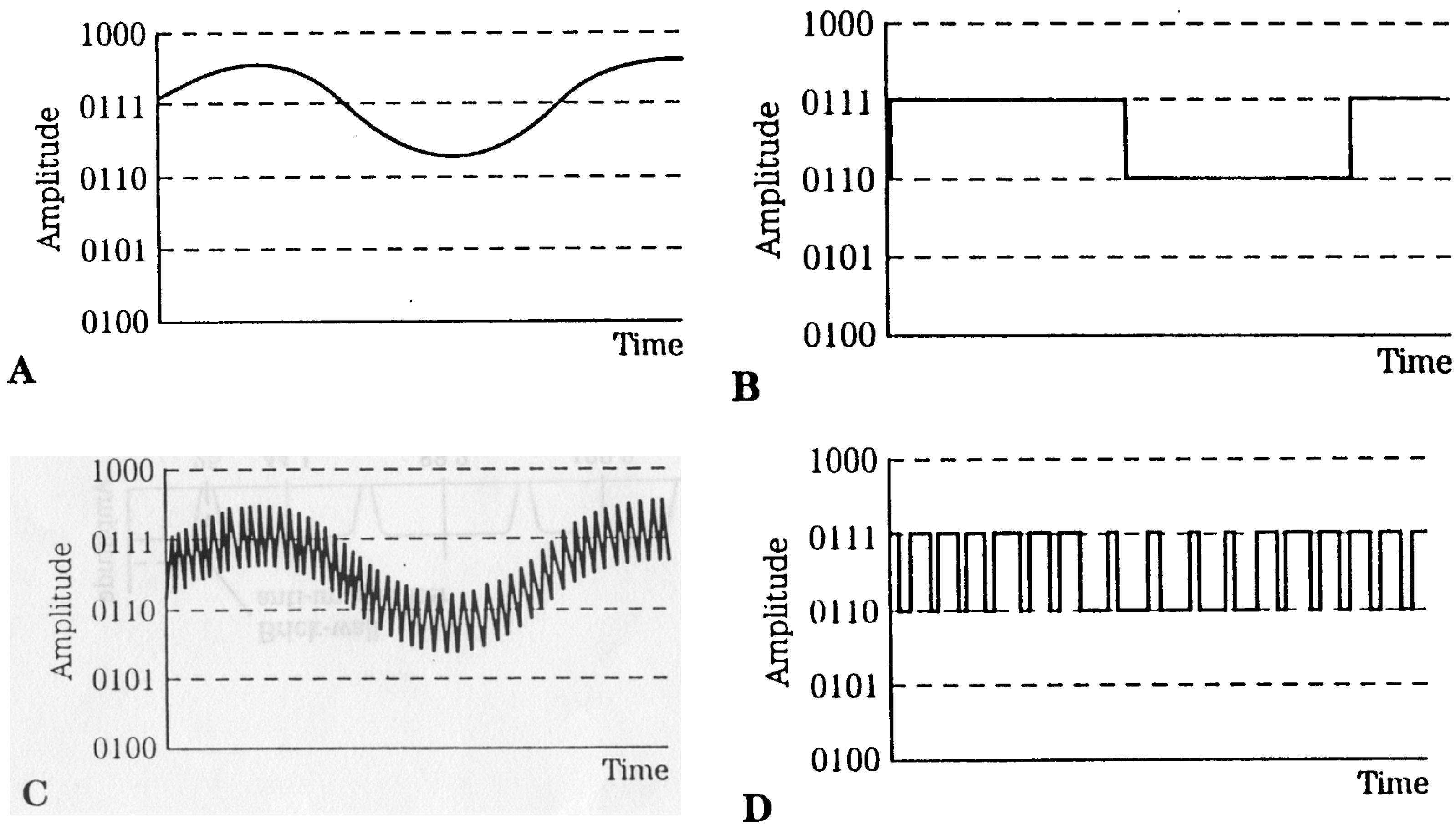
A. A brick-wall filter must sharply bandlimit the output spectra.

B. With four-times oversampling, images appear only at the oversampling frequency.

C. The output sample/hold (S/H) circuit can be used to further suppress the oversampling spectra.

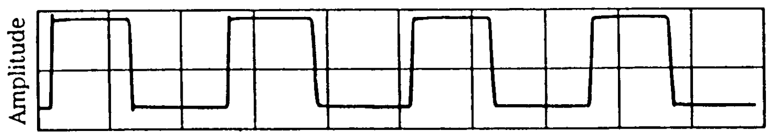
Pohlmann Fig. 4-15 Image spectra of nonoversampled and oversampled reconstruction. Four times oversampling simplifies reconstruction filter.

Solution 2: Add Dither

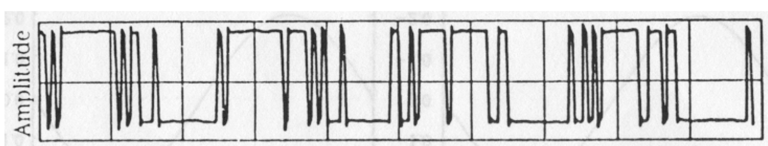


Pohlmann Fig. 2-8 Adding dither at quantizer input alleviates effects of quantization error.
A. An undithered input signal with amplitude on the order of one LSB.
B. Quantization results in a coarse coding over two levels. C. Dithered input signal.
D. Quantization yields a PWM waveform that codes information below the LSB.

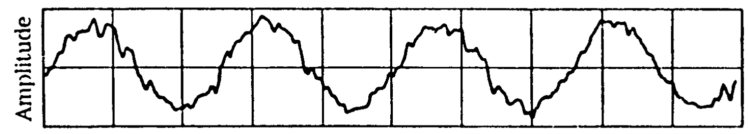
Time Domain Effect of Dither



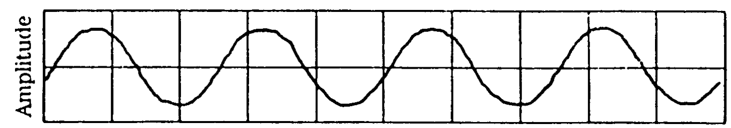
A A 1 kHz sinewave with amplitude of one-half LSB without dither produces a square wave.



B Dither of one-third LSB rms amplitude is added to the sinewave before quantization, resulting in a PWM waveform.



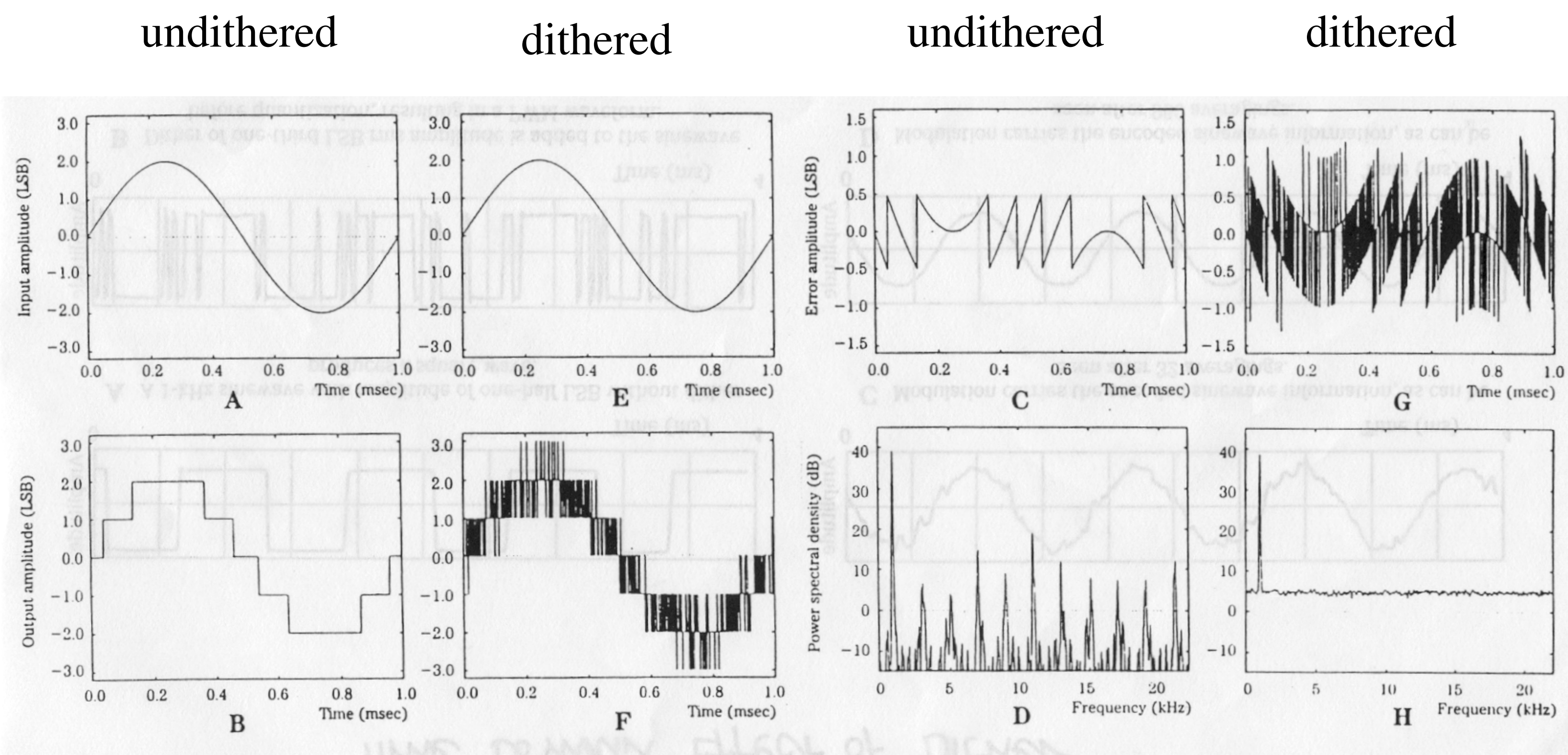
C Modulation carries the encoded sinewave information, as can be seen after 32 averagings.



D Modulation carries the encoded sinewave information, as can be seen after 960 averagings.

Pohlmann Fig. 2-9 Dither permits encoding of information below the least significant bit.
Vanderkooy and Lipshitz.

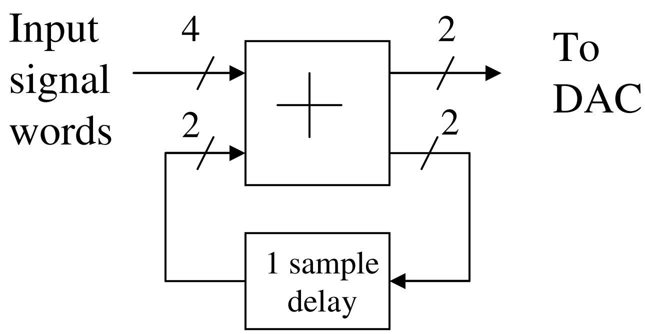
Frequency Domain Effect of Dither



Pohlmann Fig. 2-10 Computer-simulated quantization of a low-level 1- kHz sinewave without, and with dither. A. Input signal. B. Output signal (no dither). C. Total error signal (no dither). D. Power spectrum of output signal (no dither). E. Input signal. F. Output signal (triangualr pdf dither). G. Total error signal (triangular pdf dither). H. Power spectrum of output signal (triangular pdf dither) Lipshitz, Wannamaker, and Vanderkooy

Solution 3: Noise Shaping

We have a two-bit DAC and four-bit input signal words. Both are unsigned.



Assume input = 1001 constant

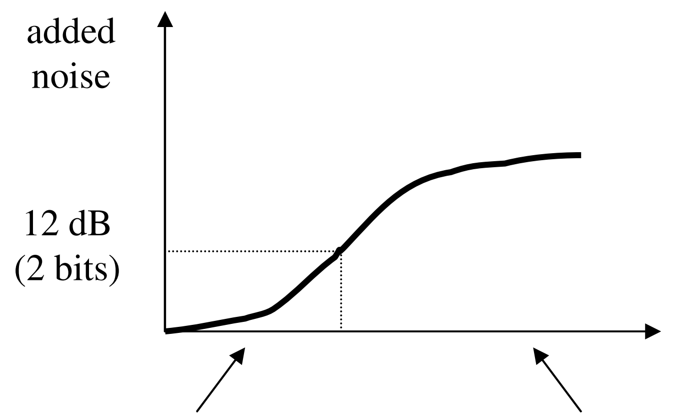
	Adder Inputs		Output	
Time	Upper	Lower	Sum	to DAC
1	1001	00	1001	10
2	1001	01	1010	10
3	1001	10	1011	10
4	1001	11	1100	11

Periodic

Average output = 1/4(10+10+10+11)=1001

⇨ 4-bit resolution at DC!

Going from 4 bits down to 2 bits increases noise by ~ 12 dB. However, the shaping eliminates noise at DC at the expense of increased noise at high frequency.



If signal is in this band, you are better off!

Let's hope this is above the passband! (oversample)