What is a polyphase filter bank ?

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Spectral Analysis
using
Polyphase Filter Bank

April 26, 2007

Polyphase filter bank

- What is polyphase filter bank ?
- What are the problem of a pure DFT-based spectral analysis ? Spectral leakage.
- Explain how DFT can be seen as a polyphase filter, and can be improved to avoid the DFT problems.
- How to design PFB ? → Matlab+VHDL toolbox to migrate the algorithm to FPGA

DFT spectral analysis: DFT as a filter bank

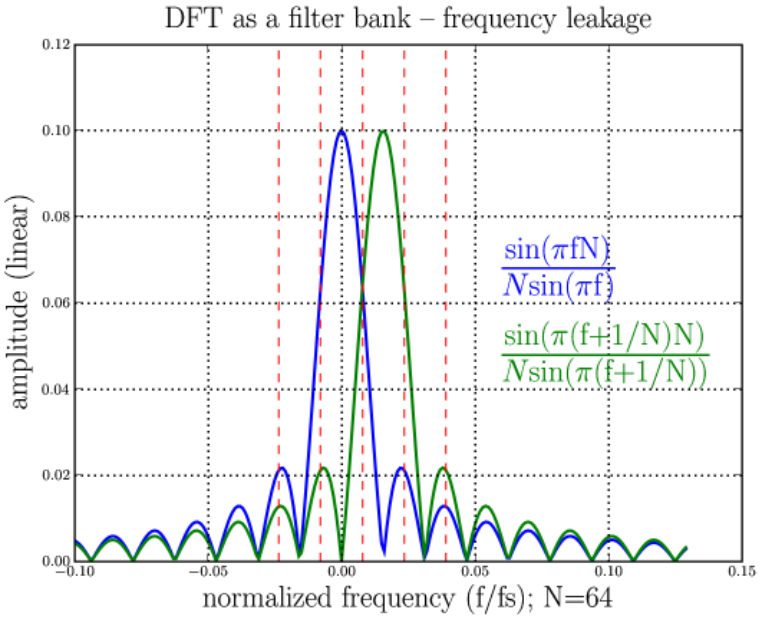
Each Fourier coefficient can be seen as the output of a linear filter (continuous-time convolution operator). For example:

$$X[0] = \frac{1}{N}\sum_{i=0}^{N-1} x[i] = x(t) * \varphi_0(t)$$

X[0] is the output of the convolution of x(t) by the distribution $\varphi_0(t)$

$$\varphi_0(t) = \frac{1}{N}\sum_{i=0}^{N-1} \delta(t - iT)$$

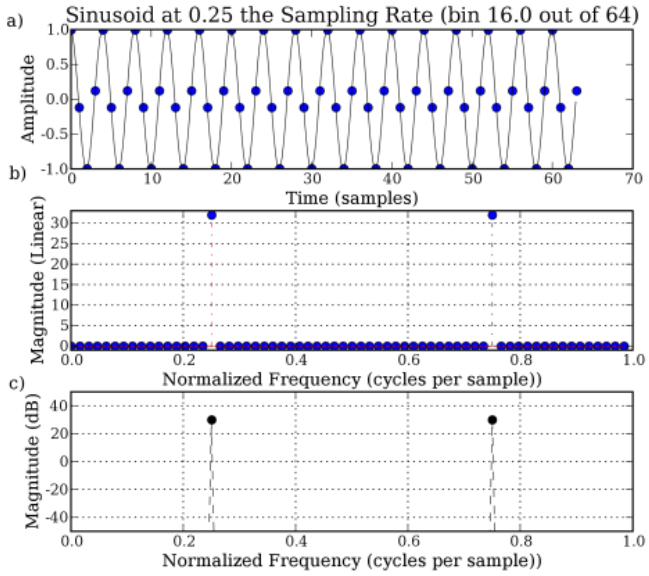
$$\Phi_0(f) = \frac{1}{N}\frac{\sin(\pi f N T)}{\sin(\pi f t)} e^{-j\pi f (N-1)T}$$

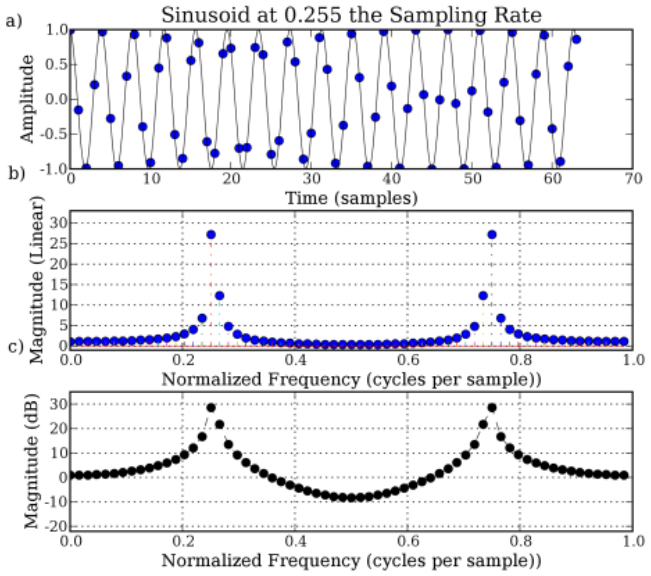


DFT spectral analysis: DFT as a filter bank

- Discrete Fourier Transform can be seen as a set of N identical filters, equally spaced in frequency with step $1/NT=f_s/N$
- Spectral resolution:

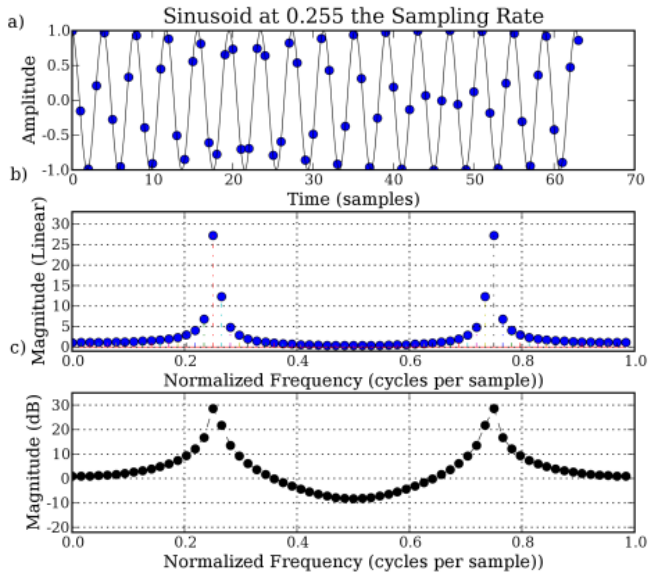
  A pure sine wave $\sin(2\pi f_0 t)$ with $f_0 \neq k f_s/N$ contributes to all X[k] !!! → frequency bin leakage

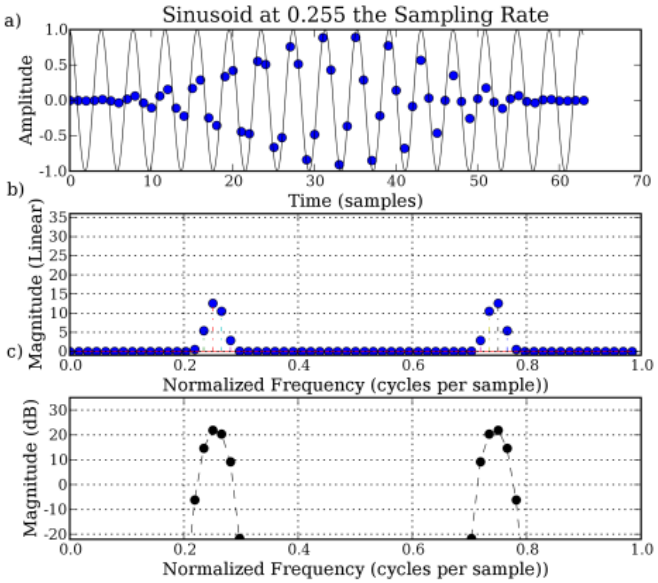




DFT spectral analysis: windowed DFT

- the simplest method to reduced spectral leakage, is to multiply input data with a window function (which is equivalent to convolving its spectrum by the frequency response of the window function).





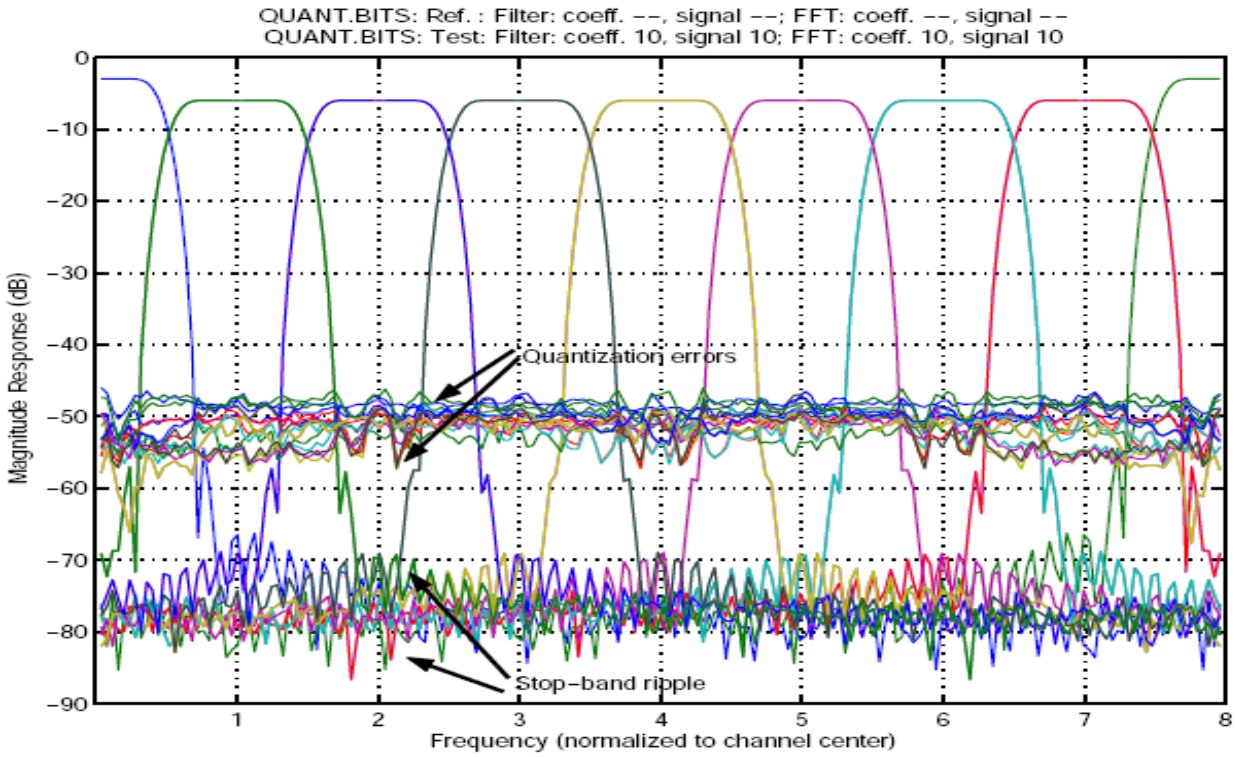
Problem: the windowed DFT **improves the spectral leakage** but **decrease the resolution**. Is it possible to improve spectral leakage without decreasing resolution ? **YES → Polyphase DFT filter bank**

Polyphase DFT filter bank

- Design a band-pass FIR filter to avoid frequency leakage

the band-pass width should be the same as the frequency bin of a N-length FFT operator

- Shift the filter by one frequency bin.
- A pure sinusoide brings a contribution to only one frrequency bin without polluting other bins.



Polyphase DFT filter bank: implementation

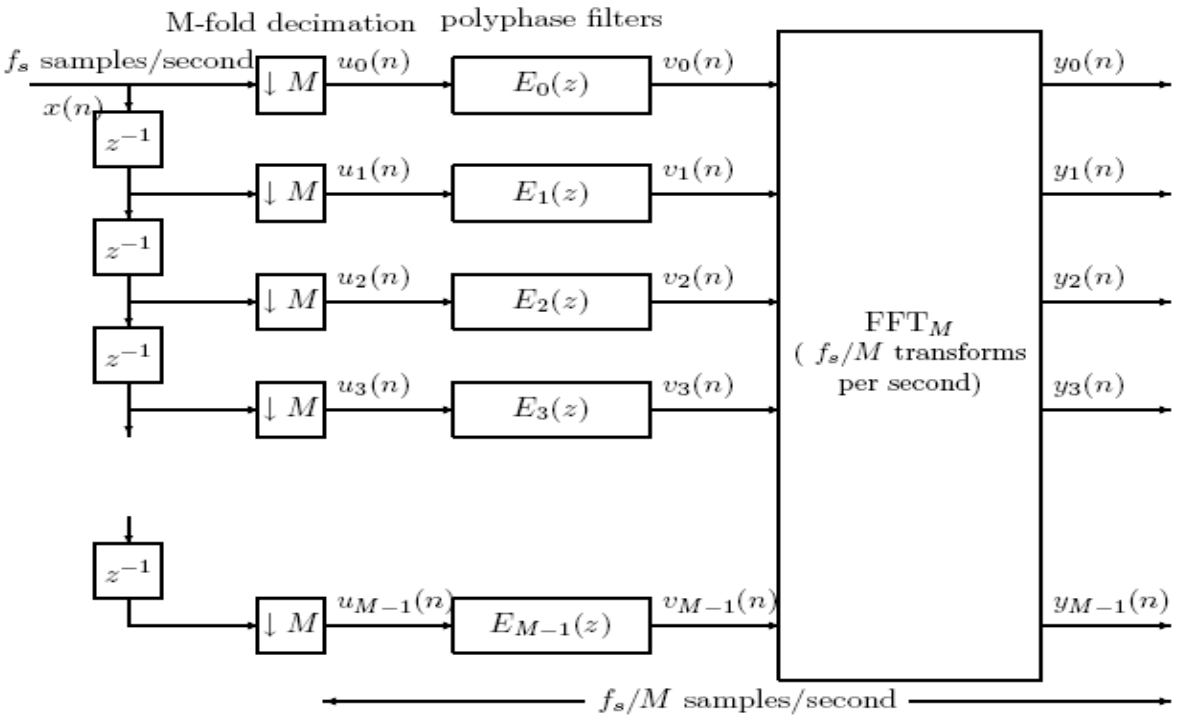


Figure 9: **Block diagram of a polyphase/DFT filter bank.**

- DFT spectral analyzer complexity: $5N\log_2 N$
- PFB spectral analyzer complexity: $N*(5\log_2 N+2k)$
  where k is the taps-number (usually a small number 4 to 8)