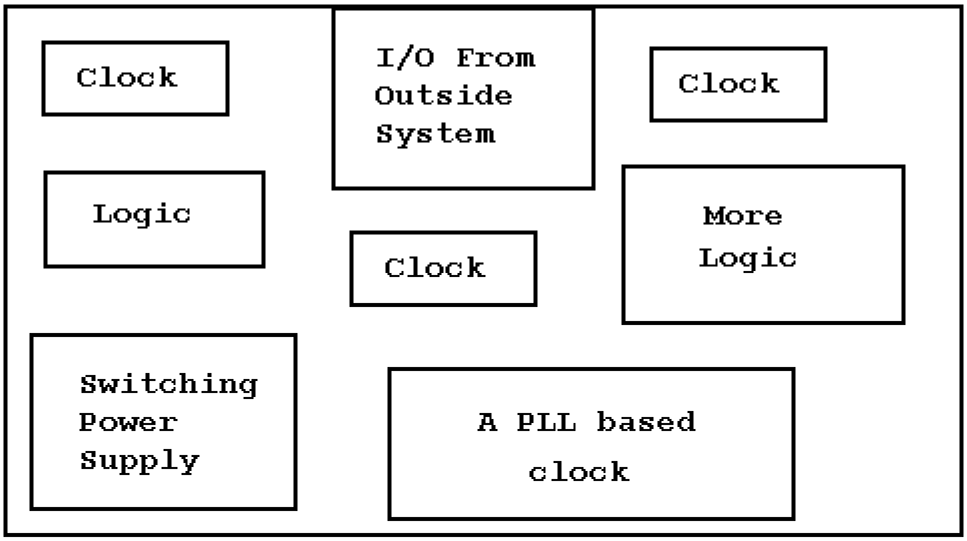
APPENDIX C
FFT-Based Jitter Analysis

- **Sources of periodic jitter**
- **A display of jitter**
- **Basic measurement and random measurements**
- **Effective sampling rate**
- **Variance of measurements**
- **Aliasing**
- **DSP procedure with graphs**
- **FFT graphs showing**
  -how padding improves graph
  -behavior of various windows
  -aliasing
  -low frequency jitter analysis

Sources of Periodic Jitter:

A Digital System;



Some causes of periodic jitter:

-crosstalk between clocks

-SPS ripple - Frequency modulates a PLL

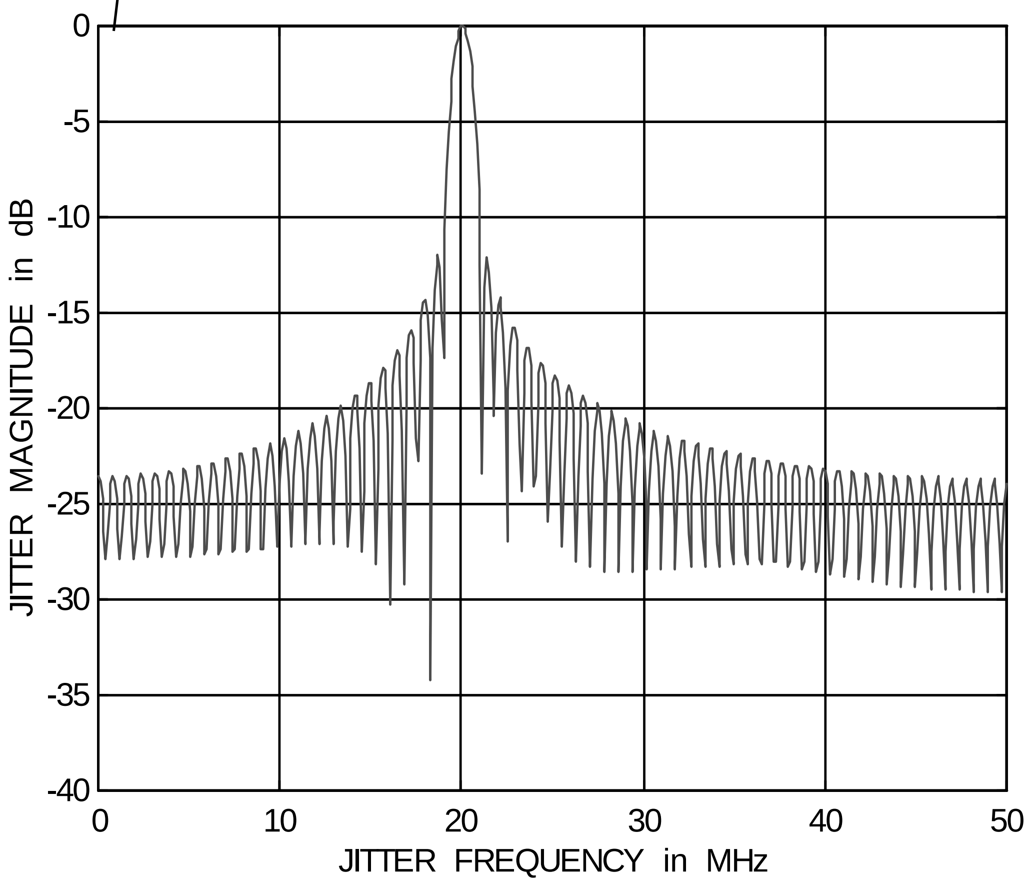
-crosstalk between a clock and a counter, which is driven by the same clock

-EMI coming in through I/O cables; a nearby radio station

A Frequency Domain Analysis Tool helps to diagnose a Digital System which has problems with Periodic Jitter.

Jitter Spectrum

This is the 0 dB reference level for peak jitter in seconds, relative to jitter over one period of a clock

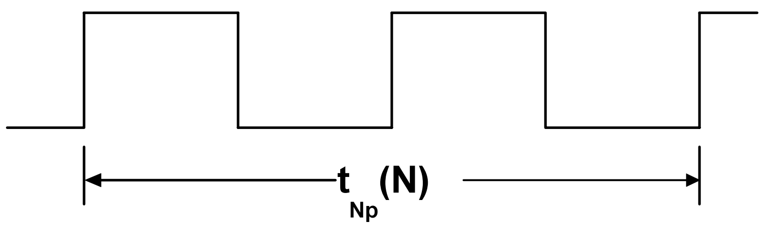


-Actual display will print the 0 dB reference level in seconds peak

Basic measurement and random measurements:

The basic measurement, $t_{Np}(N)$:

A Clock:

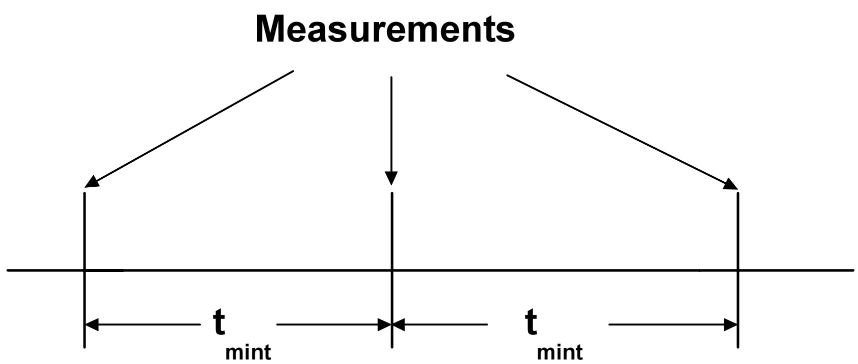


$t_{Np}(N)$ is the measured time interval of N periods of a clock

In this case N = 2

This is a real time measurement

Random measurements:



t_{mint} varies from 21us to 25us

t_{mint} is the measurement interval

Effective sampling rate:

Measurement schedule for $t_{Np}(N)$;

$N = \{1, 1*N_{step}+1, 2*N_{step}+1, ..., N_{max}\}$

N_{step} is the step size of N
N_{max} is the maximum value of N

Effective sampling rate; $f_s = \bar{f}_{clock}/N_{step}$

$\bar{f}_{clock}$ is the mean clock frequency

Variance of $t_{Np}(N)$:

$$VARIANCE[t_{Np}(N)] = (1/M_{meas}) \sum_{j=1}^{M_{meas}} [t_{Np}(N) - \bar{t}_{Np}(N)]^2$$

$\bar{t}_{Np}(N)$ is the mean value of $t_{Np}(N)$, for a given N

M_{meas} is the number of measurements taken for each N
M_{meas} is usually set from 100 to 10,000

$N = \{1, 1*N_{step}+1, 2*N_{step}+1, ..., N_{max}\}$

$$\bar{t}_{Np}(N) = (1/M_{meas}) \sum_{j=1}^{M_{meas}} t_{Np}(N)$$

Aliasing:

An alias is that which is not what it seems to be. An alias is a pretender.

If $f_{pj} > f_s/2$, the Nyquist frequency, the measured jitter frequency will be less than $f_s/2$,

f_{pj} is the periodic jitter frequency

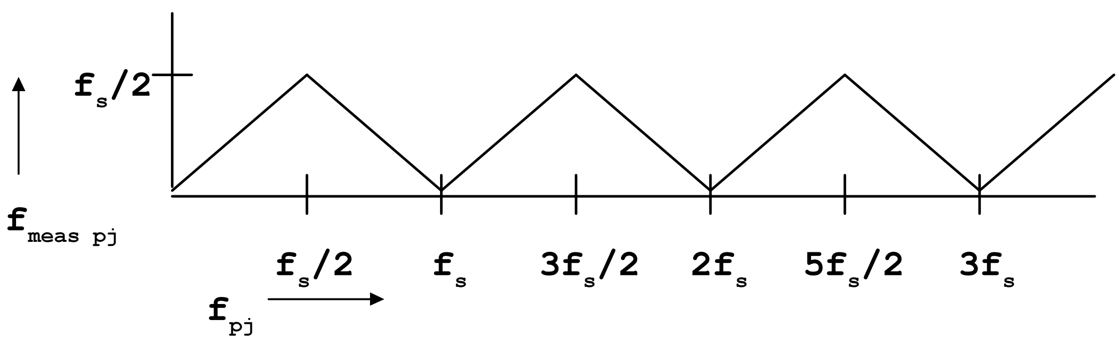
f_s is the effective sampling rate

$f_{meas\ pj}$ **= MINIMUM[ABS(k*fs-f_{pj})],**

ABS is the absolute value function

$f_{meas\ pj}$ is the measured periodic jitter frequency

k = {1,2,3...}



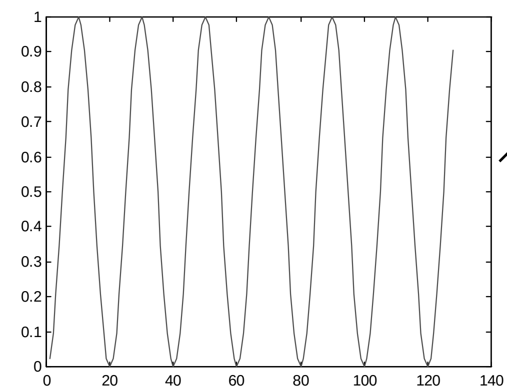
When $f_s=f_{clock}$ (N_{step}=1), the alias products are real

Example:

f_s **= 100MHz,** f_{pj} **= 260MHz (4th harmonic of 65MHz)**
$f_{meas\ pj}$ **= 40MHz, this is less than 50MHz, $f_s/2$**

calculation: $f_{meas\ pj}$ **= ABS(3*100 MHz-260 MHz)**
(k = 3)

Our Procedure to obtain a Frequency Domain display of Periodic Jitter:



VARIANCE[t_{Np}(N)]

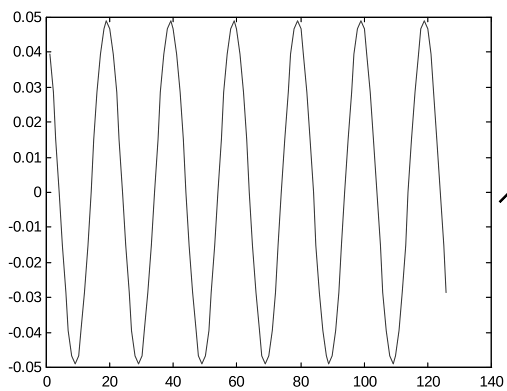
Measurement schedule: Nmax=128
Nstep=1

Jitter source is one sine wave.

Magnitude is in seconds squared or "jitter squared" (power).

This is a display of the auto-correlation function of periodic jitter (one tone).

TIME in periods of 1/fs

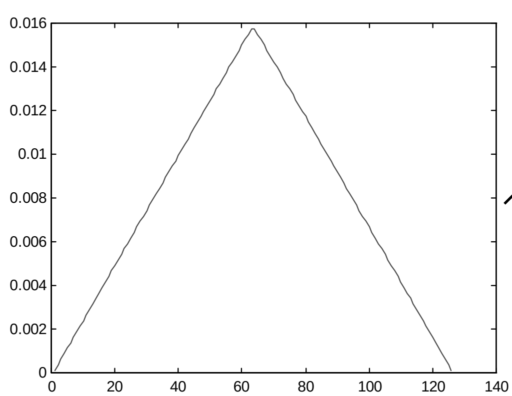


Second derivative of VARIANCE[t_{Np}(N)].

This normalizes the magnitude to jitter over one clock period.

Notice that the second derivative has shifted the phase 180 degrees.

Two data points have been lost by performing this function.



This is a window; in this case a triangular window.

The type of window selected determines the bandwidth and stop-band rejection of each FFT output point (bin).

The second derivative of VARIANCE is multiplied by this window.

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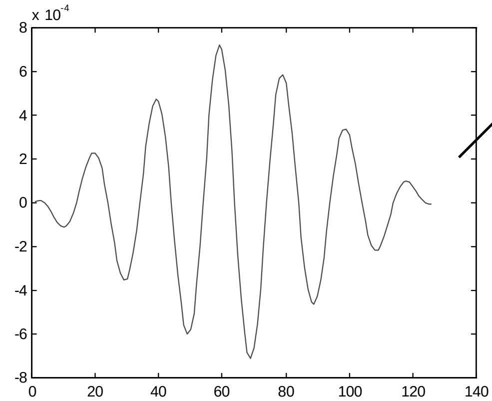
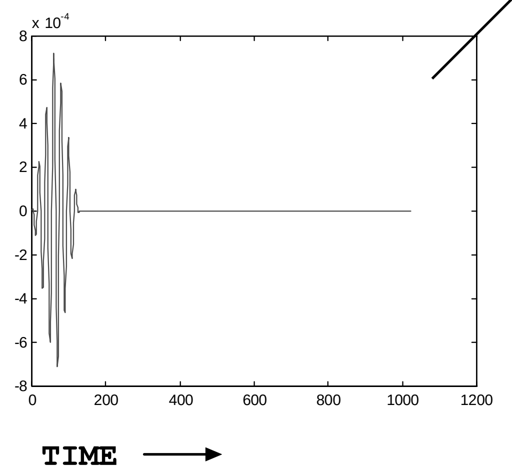


A graph of the window times the second derivative of VARIANCE(N).

Notice that the magnitude of the plot is tapered from the center to the ends.

We are still in the seconds squared domain (jitter power).

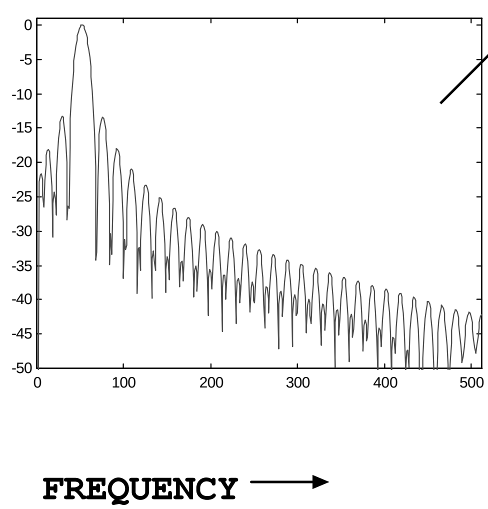


The data has been padded with zeros. The padding factor is 8.

898 zeros have been added to the end of the data record and now has a length of 1024, suitable for a Radix 2 FFT input.

Padding increases the frequency resolution of the FFT, resulting in a better looking display and it also has increased amplitude accuracy. It also reduces "picket fencing" error.

A Radix 2 FFT is executed:



The square-root of the FFT output bins is taken; we are now in the jitter domain (not jitter squared).

A $20*\log_{10}$ is performed and the display is plotted.

The magnitude of the display is in dB below the peak jitter level in seconds. Frequency is on the x-axis. The right-most bin is the Nyquist frequency ($f_s/2$). This is a display of one spectral line.

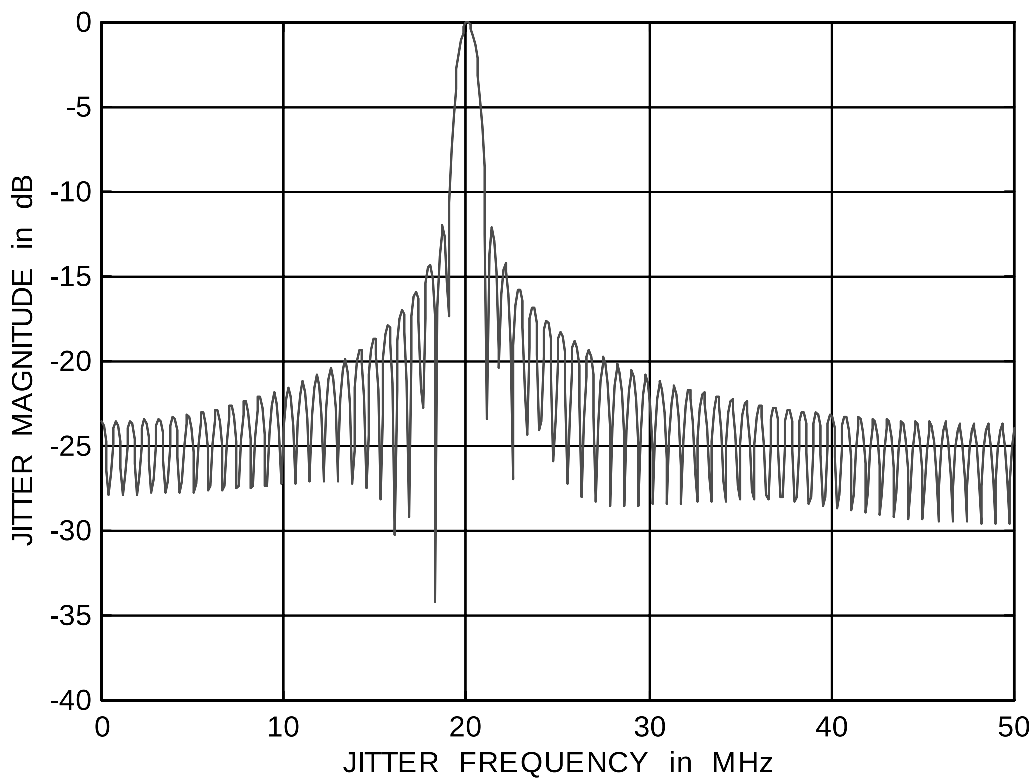
Jitter Spectrum

Nmax = 128 Nstep = 1

f_{clock} = 100 MHz f_s = 100 MHz
f_{pj1} = 20 MHz @ 0 dB

Kaiser-Bessel Window, alpha = 3
Padding Factor = 8

- shows characteristic of Kaiser-Bessel window with alpha set to 3



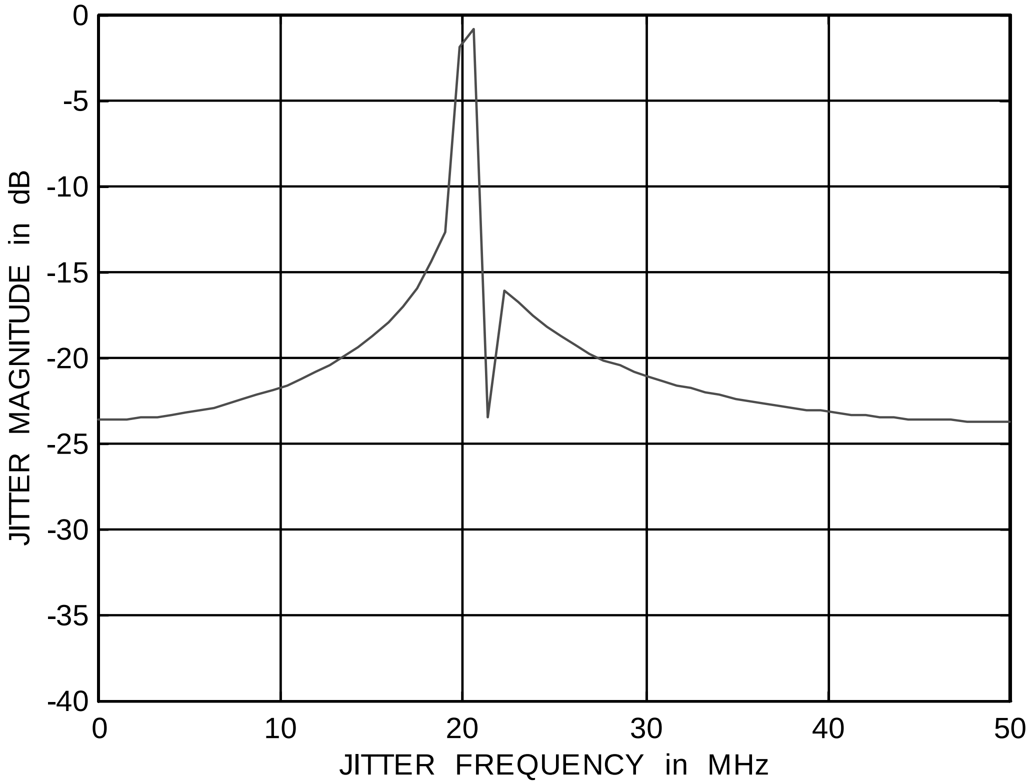
- Display has good resolution, padding factor is large enough: a larger padding factor will require a larger data processing time

Jitter Spectrum

Nmax = 128 Nstep = 1

f_{clock} = 100 MHz f_s = 100 MHz
f_{pj1} = 20 MHz @ 0 dB

Kaiser-Bessel Window, alpha = 3
Padding Factor = 1



- **Display has poor resolution, padding factor is too small.**

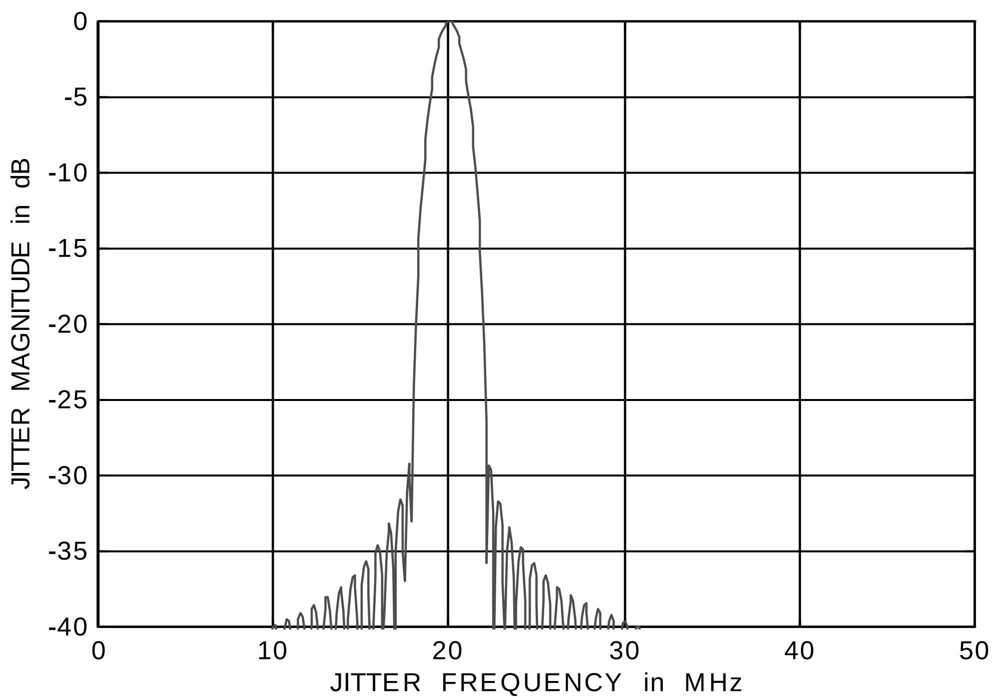
Jitter Spectrum

Nmax = 128 Nstep = 1

f_{clock} = 100 MHz f_s = 100 MHz
f_{pj1} = 20 MHz @ 0 dB

Kaiser-Bessel Window, alpha = 8
Padding Factor = 8

-shows characteristic of Kaiser-Bessel window with alpha set to 8



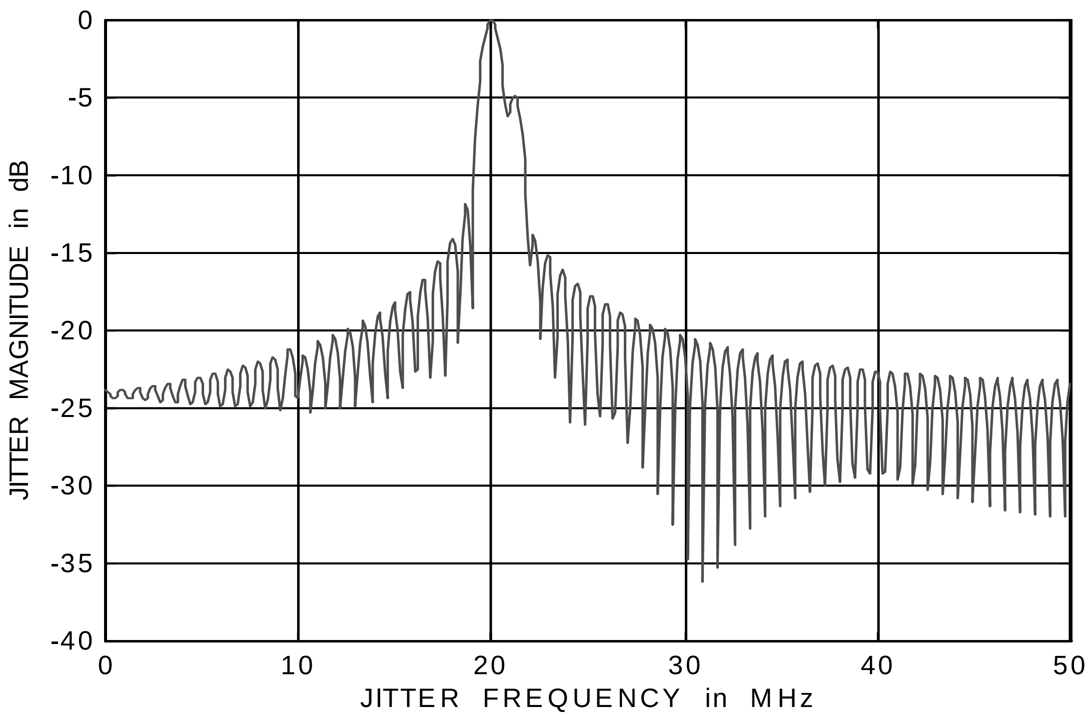
- **Note that with alpha set to 8 the central lobe is wider and the sidelobes are down more, compared with alpha set to 3**

Jitter Spectrum

Nmax = 128 Nstep = 1

f_{clock} = 100 MHz f_s = 100 MHz
f_{pj1} = 20 MHz @ 0 dB
f_{pj2} = 21 MHz @ -5 dB
f_{pj3} = 10 MHz @ -30 dB

Kaiser-Bessel Window, alpha = 3
Padding Factor = 8



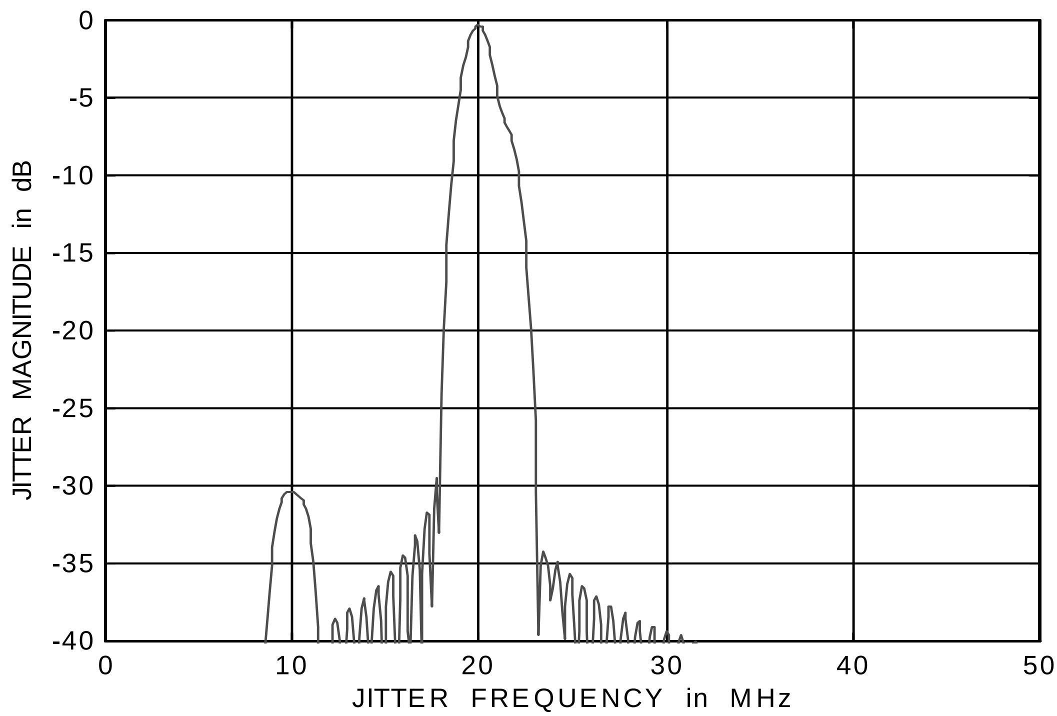
- **The 20 MHz and 21 MHz jitter components are resolved and the 10 MHz component is not seen with alpha set to 3.**

Jitter Spectrum

Nmax = 128 Nstep = 1

f_{clock} = 100 MHz f_s = 100 MHz
f_{pj1} = 20 MHz @ 0 dB
f_{pj2} = 21 MHz @ -5 dB
f_{pj3} = 10 MHz @ -30 dB

Kaiser-Bessel Window, alpha = 8
Padding Factor = 8



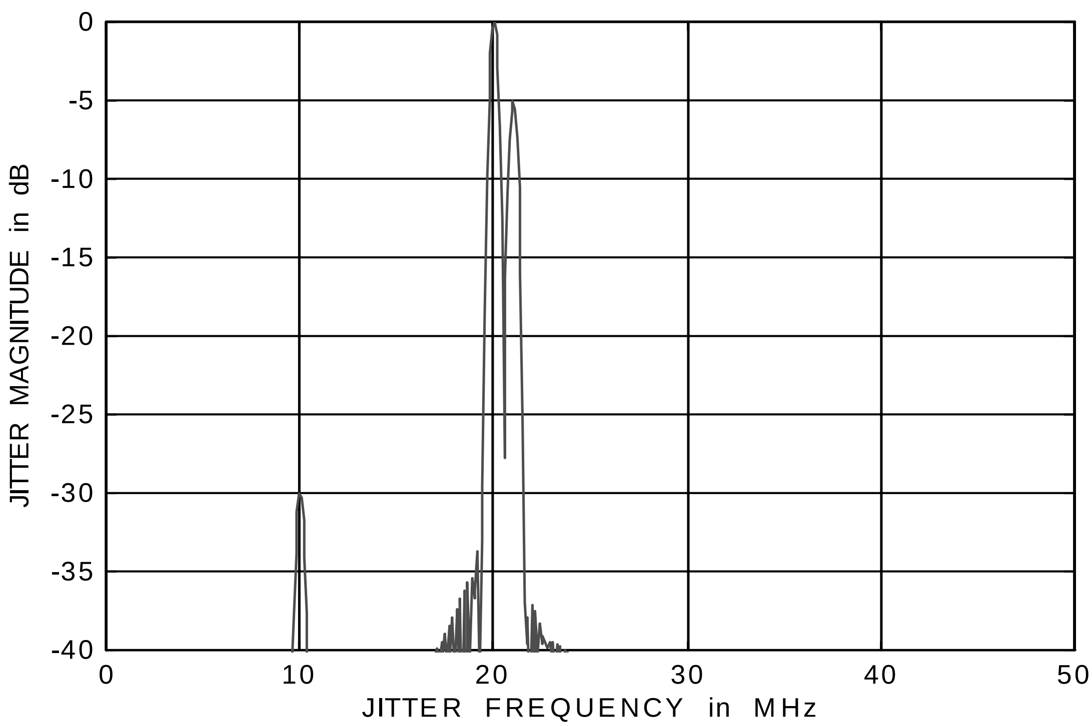
- **The 20 MHz and 21 MHz jitter components are not resolved and the 10 MHz component is seen with alpha set to 8**

Jitter Spectrum

Nmax = 512   Nstep = 1

f_{clock} = 100 MHz f_s = 100 MHz
f_{pj1} = 20 MHz @ 0 dB
f_{pj2} = 21 MHz @ -5 dB
f_{pj3} = 10 MHz @ -30 dB

Kaiser-Bessel Window, alpha = 8
Padding Factor = 2



- **All jitter components are resolved. Nmax is large enough, at the cost of increased measurement and data processing time.**

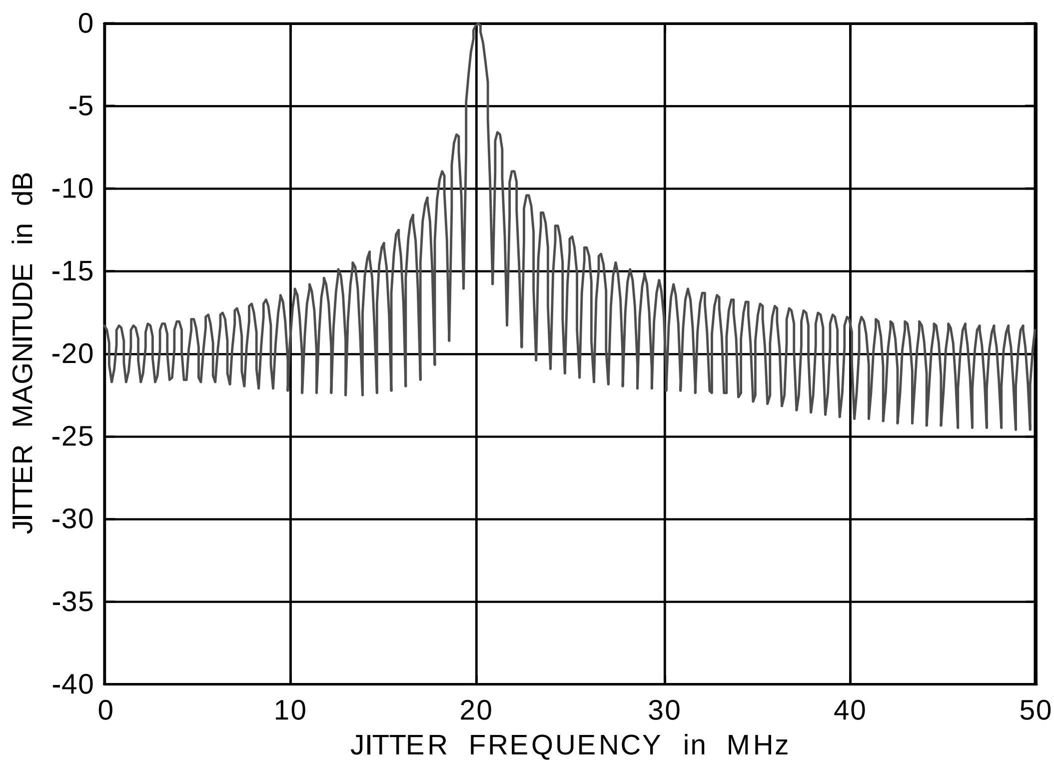
Jitter Spectrum

Nmax = 128 Nstep = 1

f_{clock} = 100 MHz f_s = 100 MHz
f_{pj1} = 20 MHz @ 0 dB

Rectangular Window
Padding Factor = 8

- **shows characteristic of Rectangular window; main sidelobes down ~ 7 dB**



- **This window has a constant magnitude as a function of N, this is like having no window.**

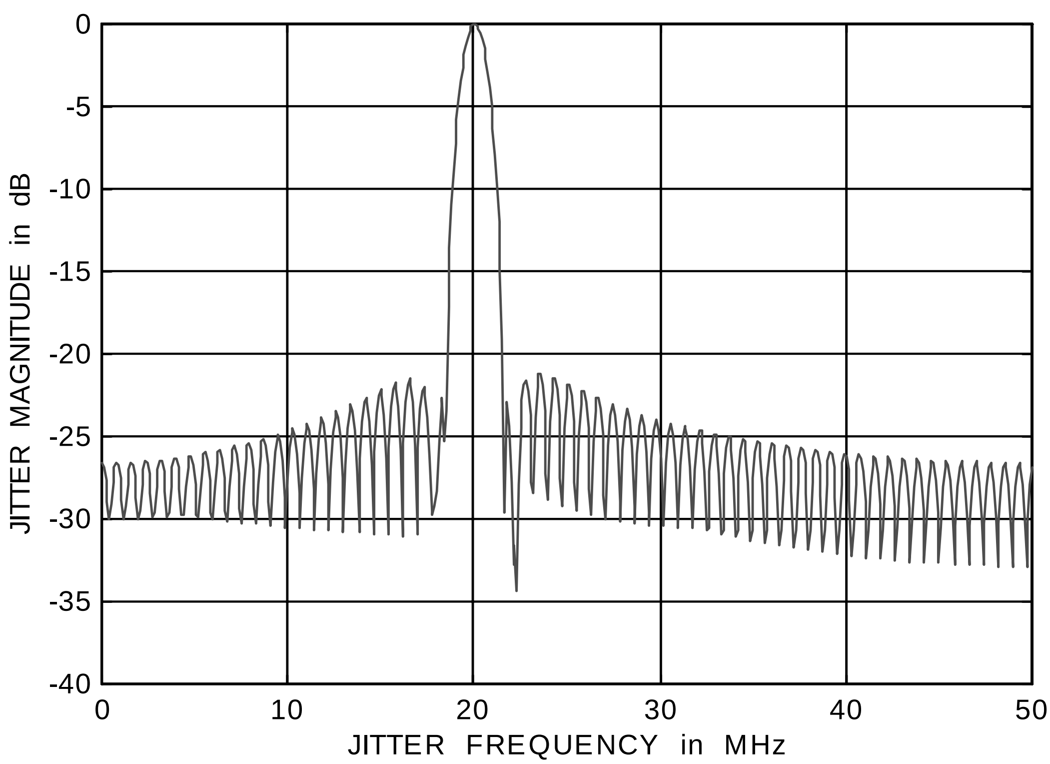
Jitter Spectrum

Nmax = 128 Nstep = 1

f_{clock} = 100 MHz f_s = 100 MHz
f_{pj1} = 20 MHz @ 0 dB

Hamming Window
Padding Factor = 8

- **shows characteristic of Hamming window; main sidelobes down ~ 22 dB**



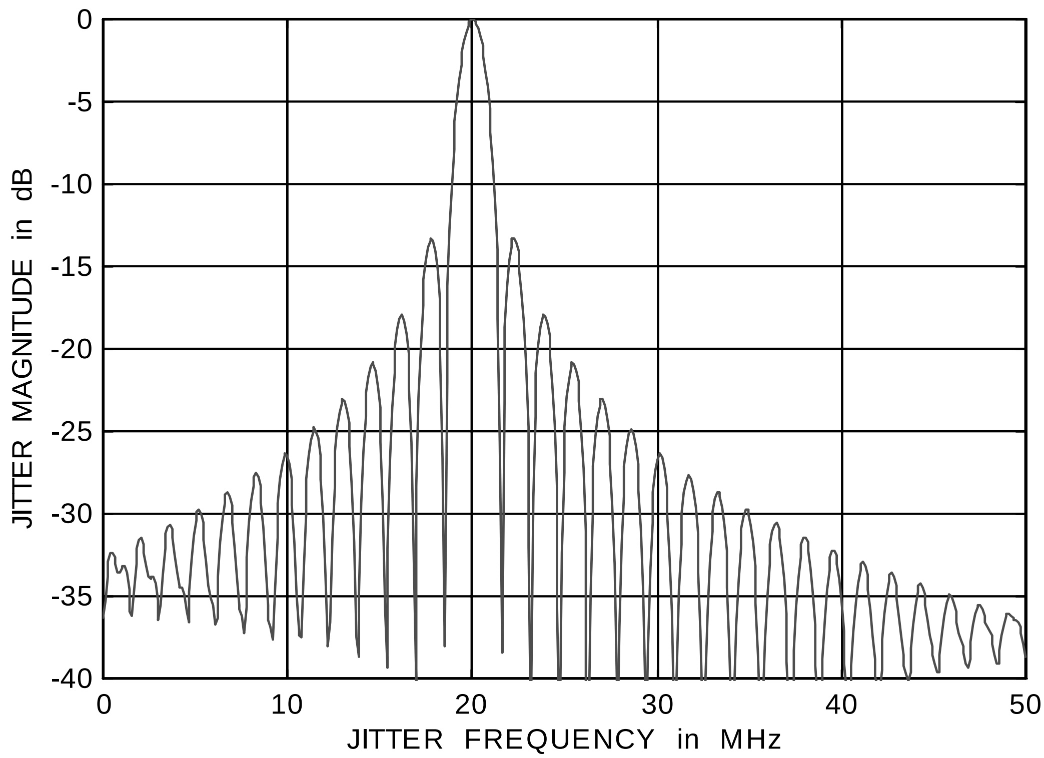
Jitter Spectrum

Nmax = 128 Nstep = 1

f_{clock} = 100 MHz f_s = 100 MHz
f_{pj1} = 20 MHz @ 0 dB

Triangular Window
Padding Factor = 8

-shows characteristic of Triangular window; main sidelobes down ~ 14 dB



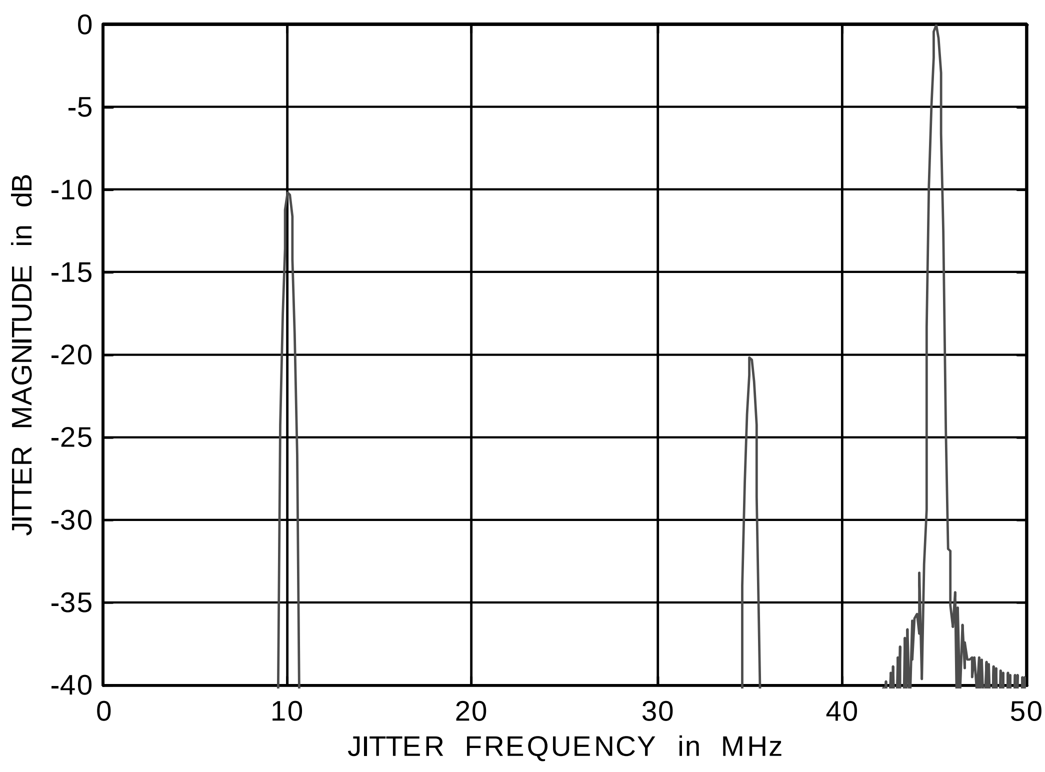
-The triangular window was used in an example earlier in this paper

Jitter Spectrum

Nmax = 512   Nstep = 1

f_{clock} = 100 MHz f_s = 100 MHz
f_{pj1} = 45 MHz @ 0 dB
f_{pj2} = 90 MHz @ -10 dB
f_{pj3} = 135 MHz @ -20 dB

Kaiser-Bessel Window, alpha = 8
Padding Factor = 2



- **The 45MHz jitter is at 45MHz. The 90MHz jitter is aliased to 10MHz. The 135MHz jitter is aliased to 35MHz.**

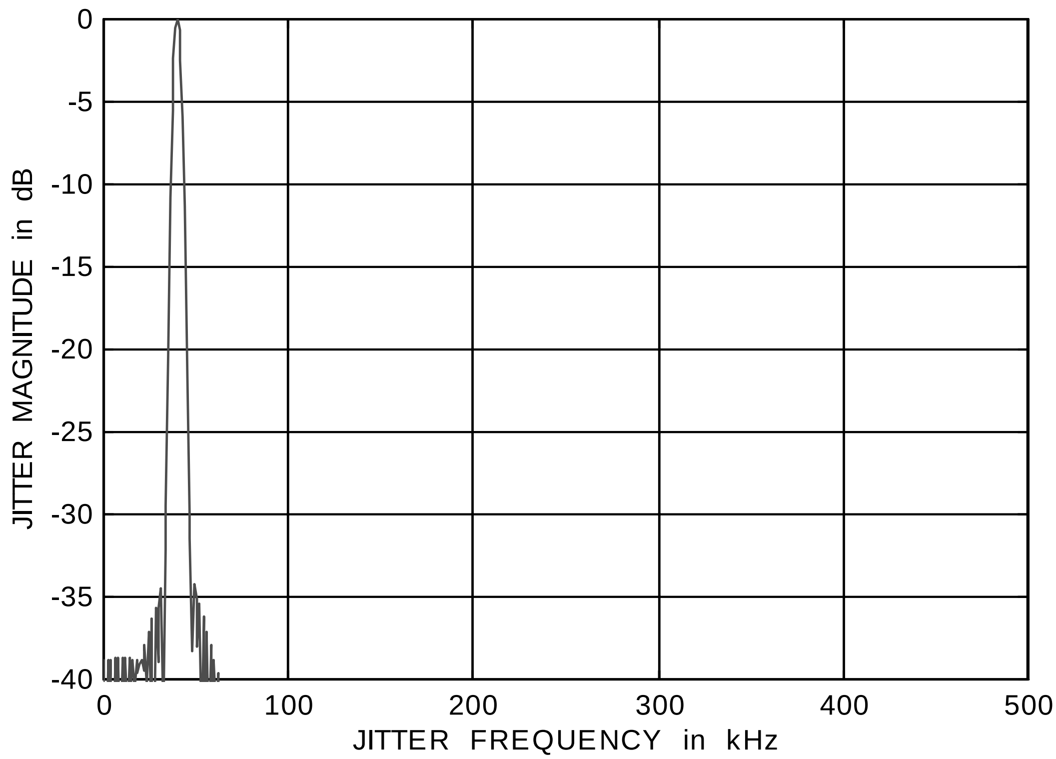
Jitter Spectrum

Nmax = 51 200   Nstep = 100

f_{clock} = 100 MHz f_s = 1 MHz
f_{pj1} = 40 kHz @ 0 dB

Kaiser-Bessel Window, alpha = 8
Padding Factor = 2

- **This setting of Nstep allows the display of low frequency jitter and saves data acquisition time and data processing time. Watch out for aliasing.**



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