Digital Direct-Sequence Spread-Spectrum Receiver Design Considerations

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Wireless Systems Applications of Direct-Sequence Spread-Spectrum

- Cellular
- PCS
- Cordless Telephones
- Wireless LANs
- GPS

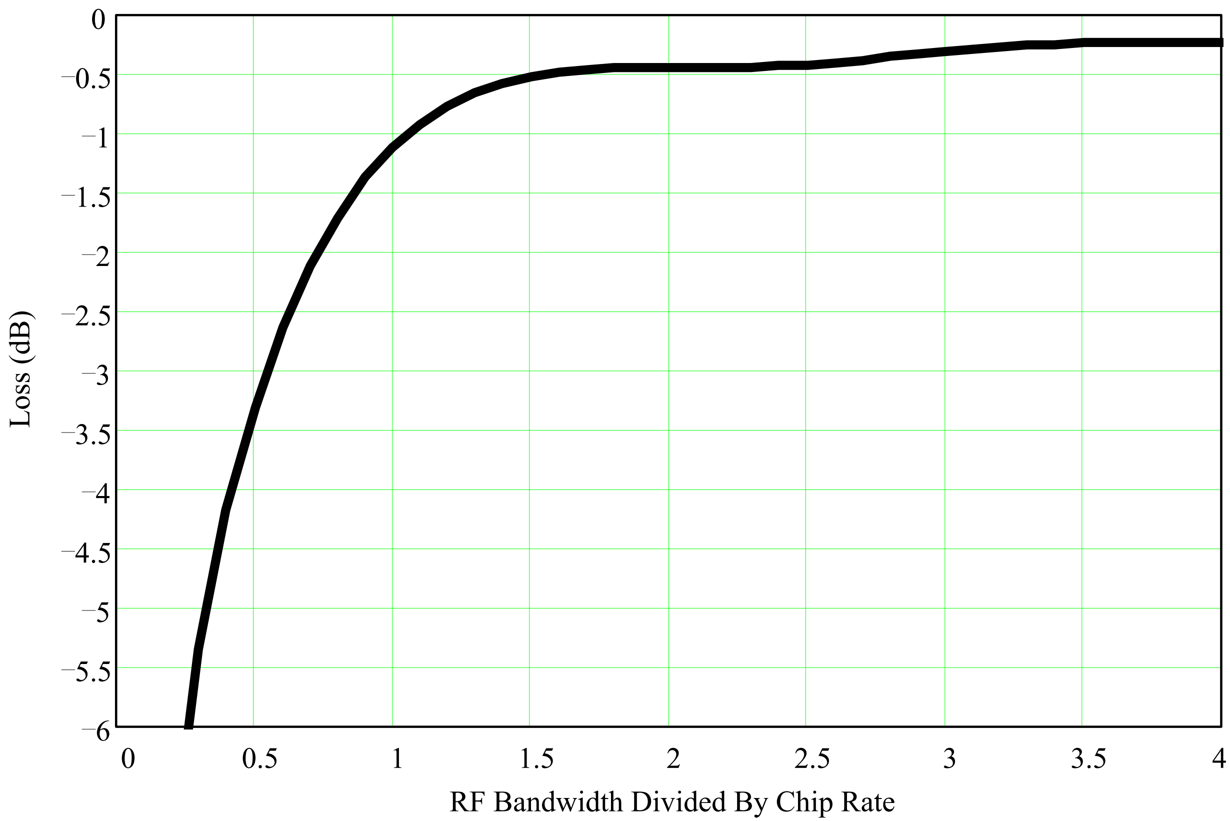
Key Receiver Design Trades

- Bandlimiting
- Sampling
- Quantization

Bandlimiting

- Truncates signal which reduces C/N_0
- Reduces the noise spectral density in the data bandwidth which increases C/N_0
- Assumptions
  - Bandlimited AWGN
  - Long PN-code
  - Large processing gain
  - Ideal filter with linear phase
  - Zero carrier phase error

Bandlimiting Loss



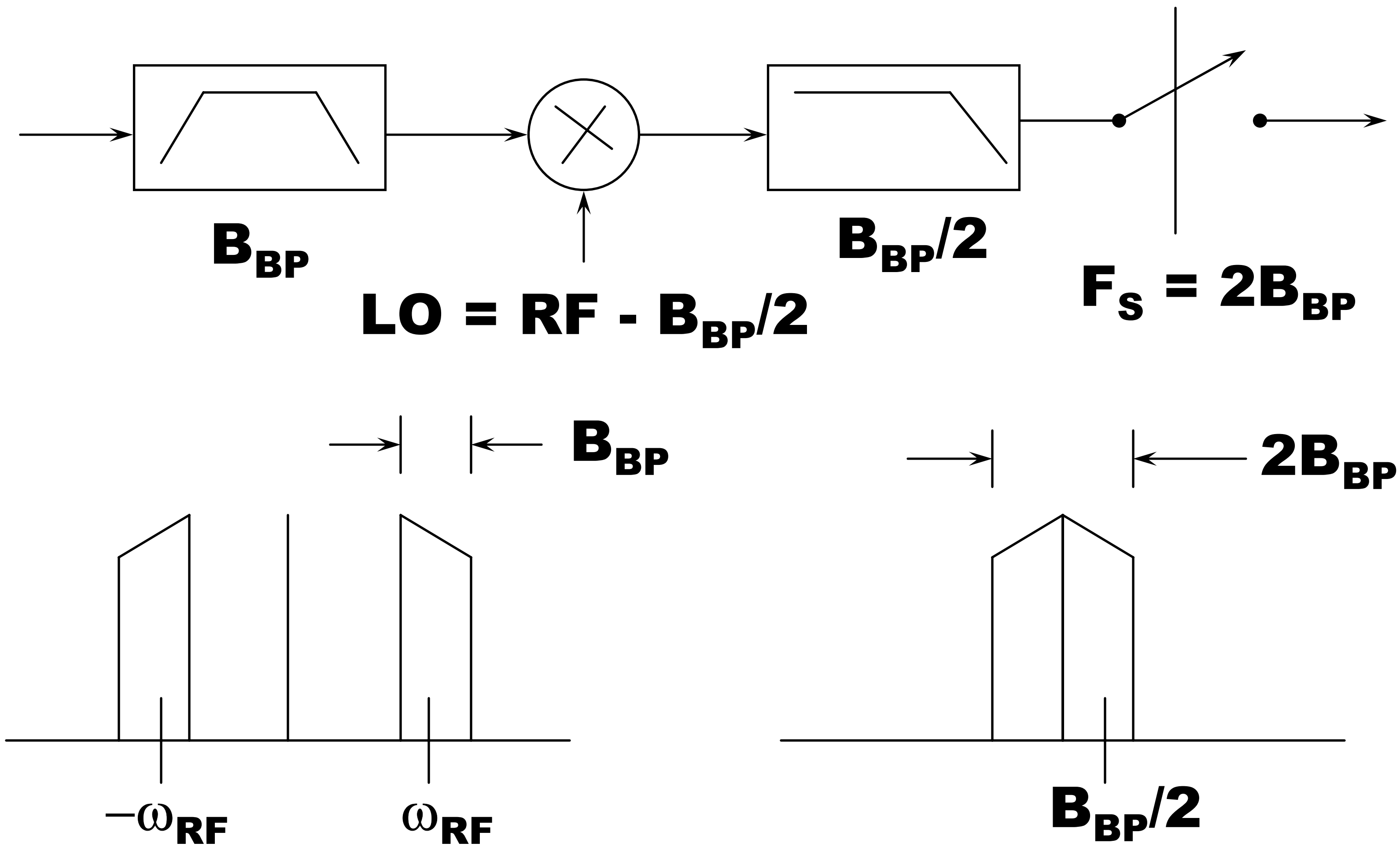
Nyquist Sampling Theorem

If a continuous signal $x(t)$ has a bandlimited Fourier transform $X(j\Omega)$, that is, $|X(j\,\Omega)| = 0$ for $|\Omega| \geq 2\pi F_c$, then $x(t)$ can be uniquely reconstructed without error from equally spaced samples $x(nT_S)$, $-\infty < n < \infty$, if $F_S \geq 2F_c$, where $F_S = 1/T_S$ is the sampling frequency

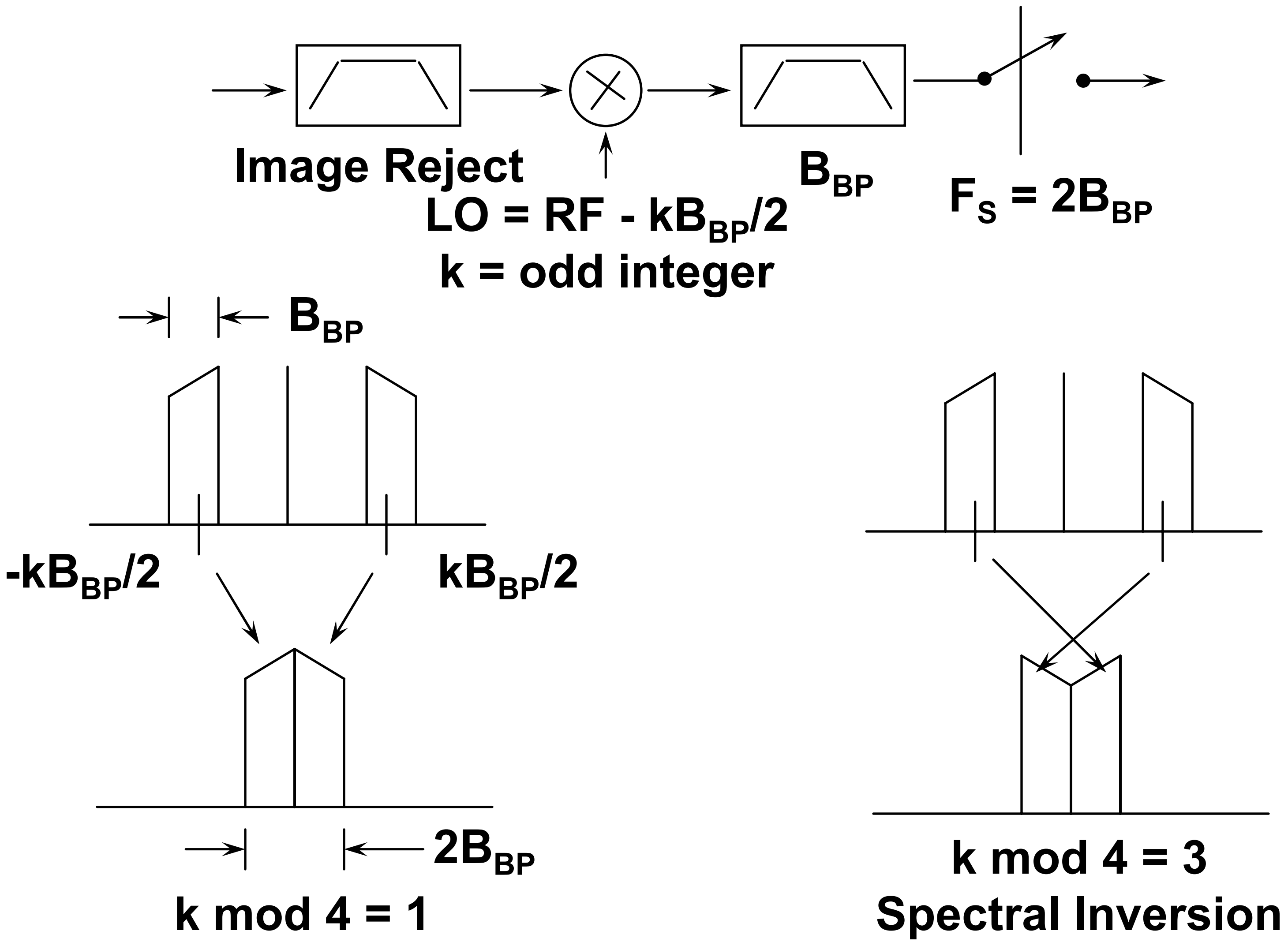
Sampling

- Direct application of sampling theorem to RF signals requires sampling rate in excess of twice the RF frequency
- Bandpass sampling allows a sampling rate consistent with information content
- Three basic bandpass sampling techniques
  - lowpass
  - integer-band
  - quadrature

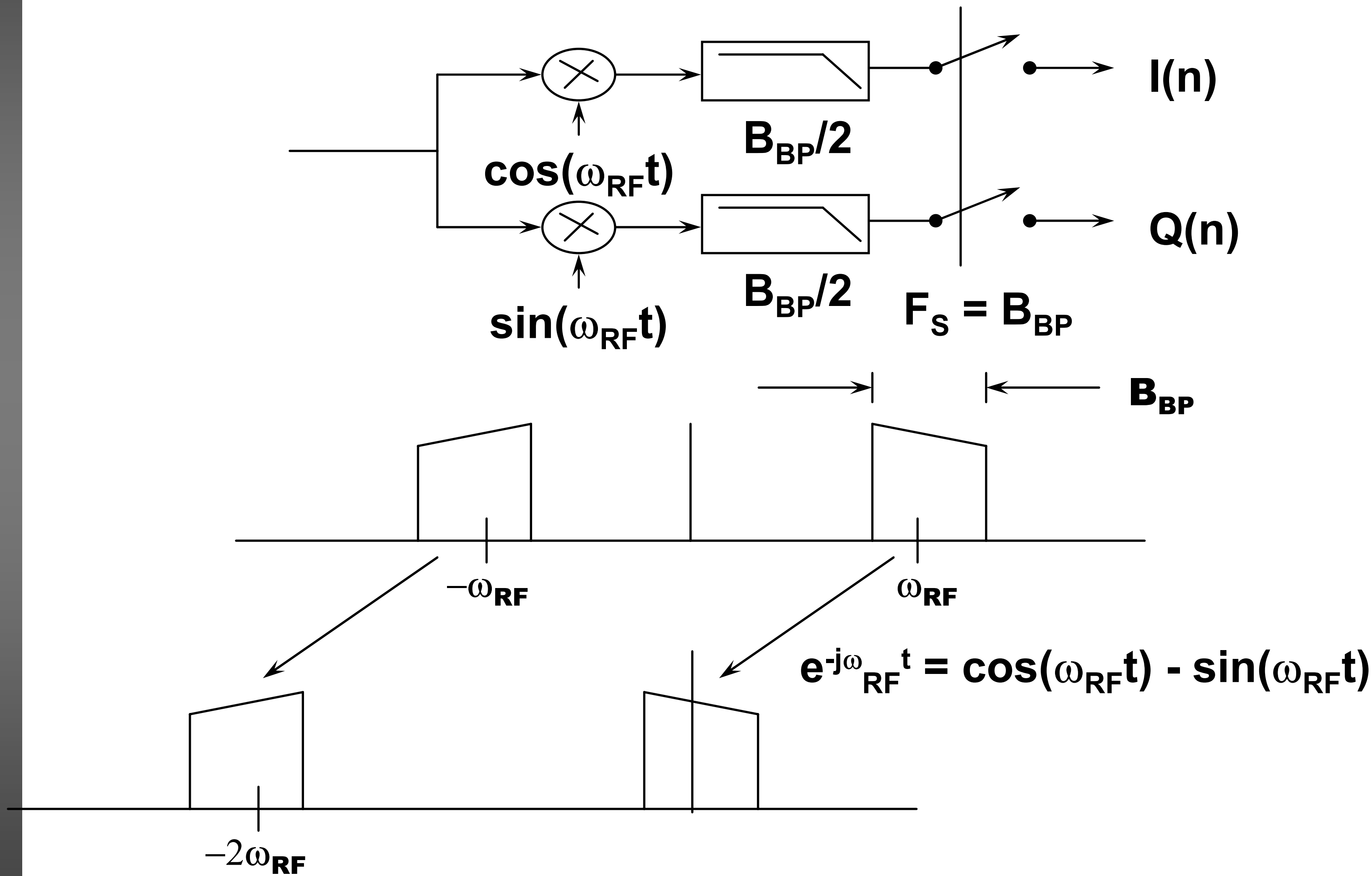
Lowpass Bandpass Sampling



Integer Band Bandpass Sampling



Quadrature Bandpass Sampling



Sampling Trades

	Lowpass	Integer Band	Quadrature
Hardware Complexity	1	1	x 2
Sampling Rate	x 2	x 2	1
DC Offsets	YES	NO	YES
Amplitude Balance	NO	NO	YES
Phase Balance	NO	NO	YES

Quantizer Model

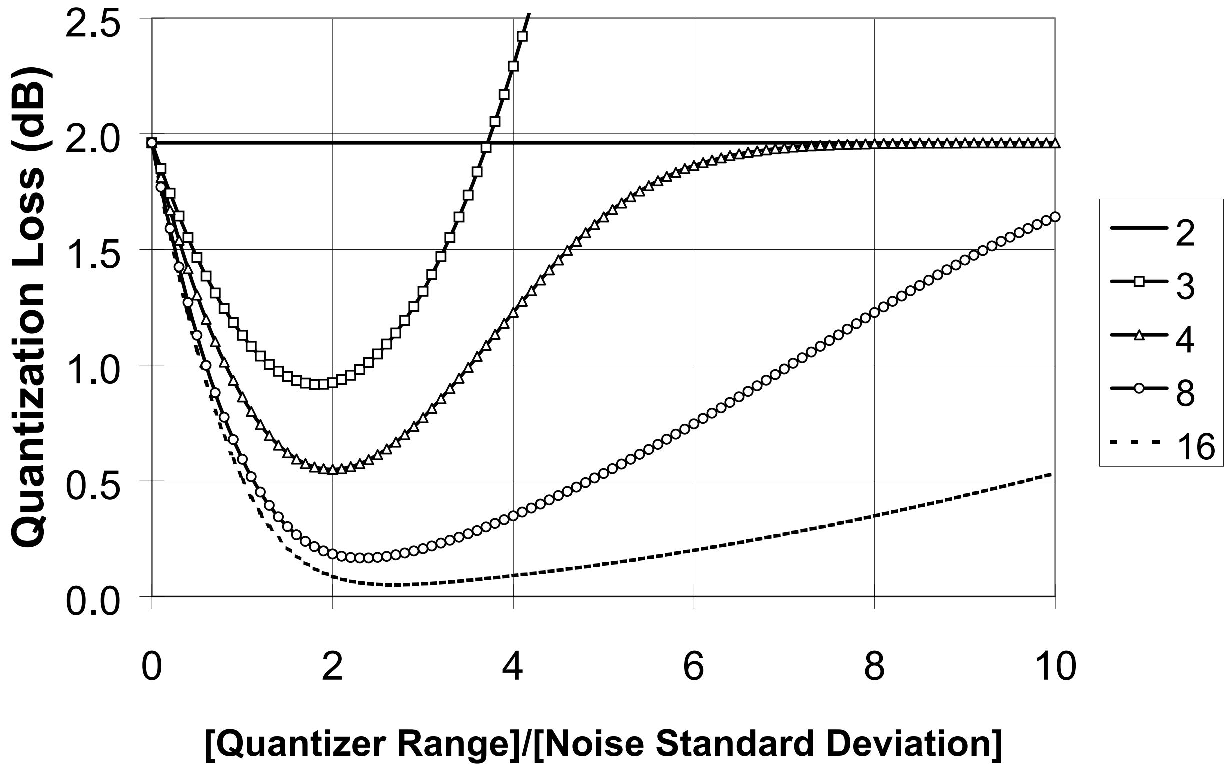
(L Quantization Levels, Range ±R)

Input = V	Output
$V < (-L/2+1)\ 2R/L$	-1
$(-L/2+1)\ 2R/L < V$	$-(L-3)/(L-1)$
• • • • • • •	• • • • •
$-2R/L < V < 0$	$-1/(L-1)$
$0 < V < 2\ R/L$	$1/(L-1)$
• • • • • • •	• • • • •
$(L/2-2)\ 2R/L < V < (L/2-1)\ 2R/L$	$(L-3)/(L-1)$
$(L/2-1)\ 2R/L < V$	1

Assumptions

- Bandlimited AWGN, SNR << 1
- No code phase error between reference and received codes
- Doppler phase shift over matched filter integration interval is small
- Matched filter integration interval less then code period
- Matched filter integrates over large number of code chips

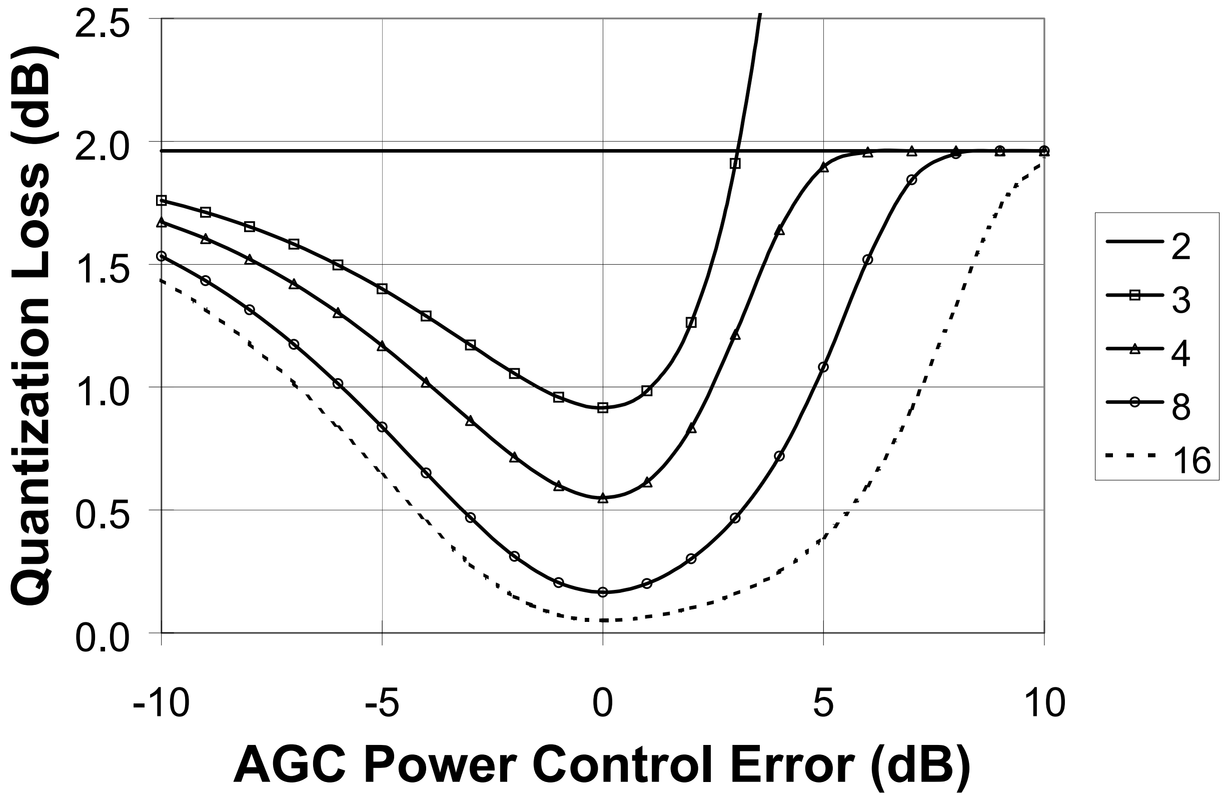
Quantizer Loss for Various Numbers of Levels



Minimum Quantizer Loss

Number of Quantizer Levels	Minimum Quantization Loss	Quantizer Range at Minimum Loss
2 (1-bit)	1.96 dB	---
3	0.92 dB	$\pm 1.84\ \sigma_n$
4 (2-bit)	0.55 dB	$\pm 1.99\ \sigma_n$
8 (3-bit)	0.17 dB	$\pm 2.34\ \sigma_n$
16 (4-bit)	0.05 dB	$\pm 2.68\ \sigma_n$

Quantization Loss vs. AGC Power Control Error for Various Numbers of Levels



Real World Effects

- Non-rectangular filters
- Filter passband ripple and phase non-linearity
- Finite sampler aperture
- Quantizer non-symmetry and hysteresis