THE APPLICATION OF DSP TECHNOLOGY IN HF/VHF/UHF RADIO SYSTEMS

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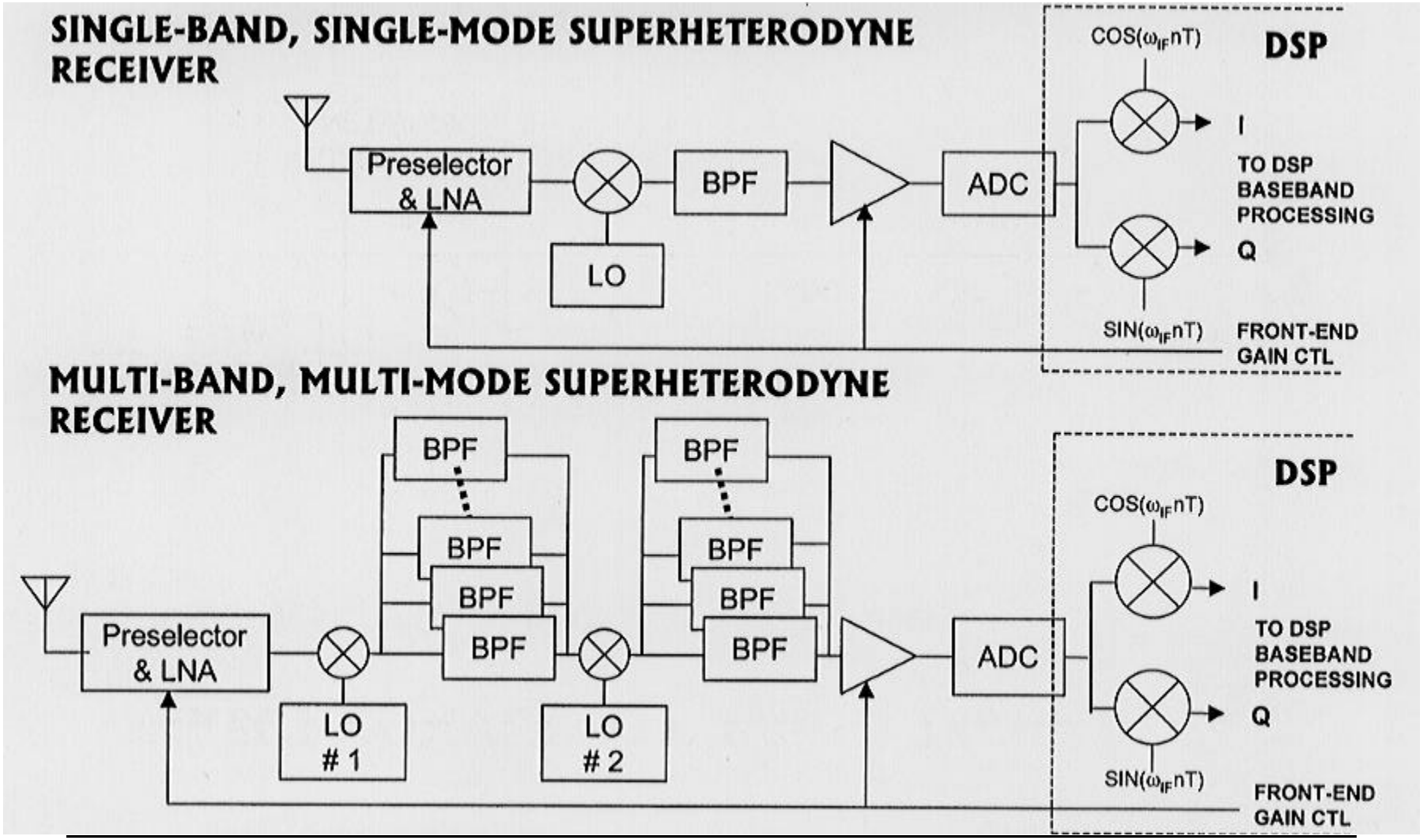
PRESENTATION AGENDA

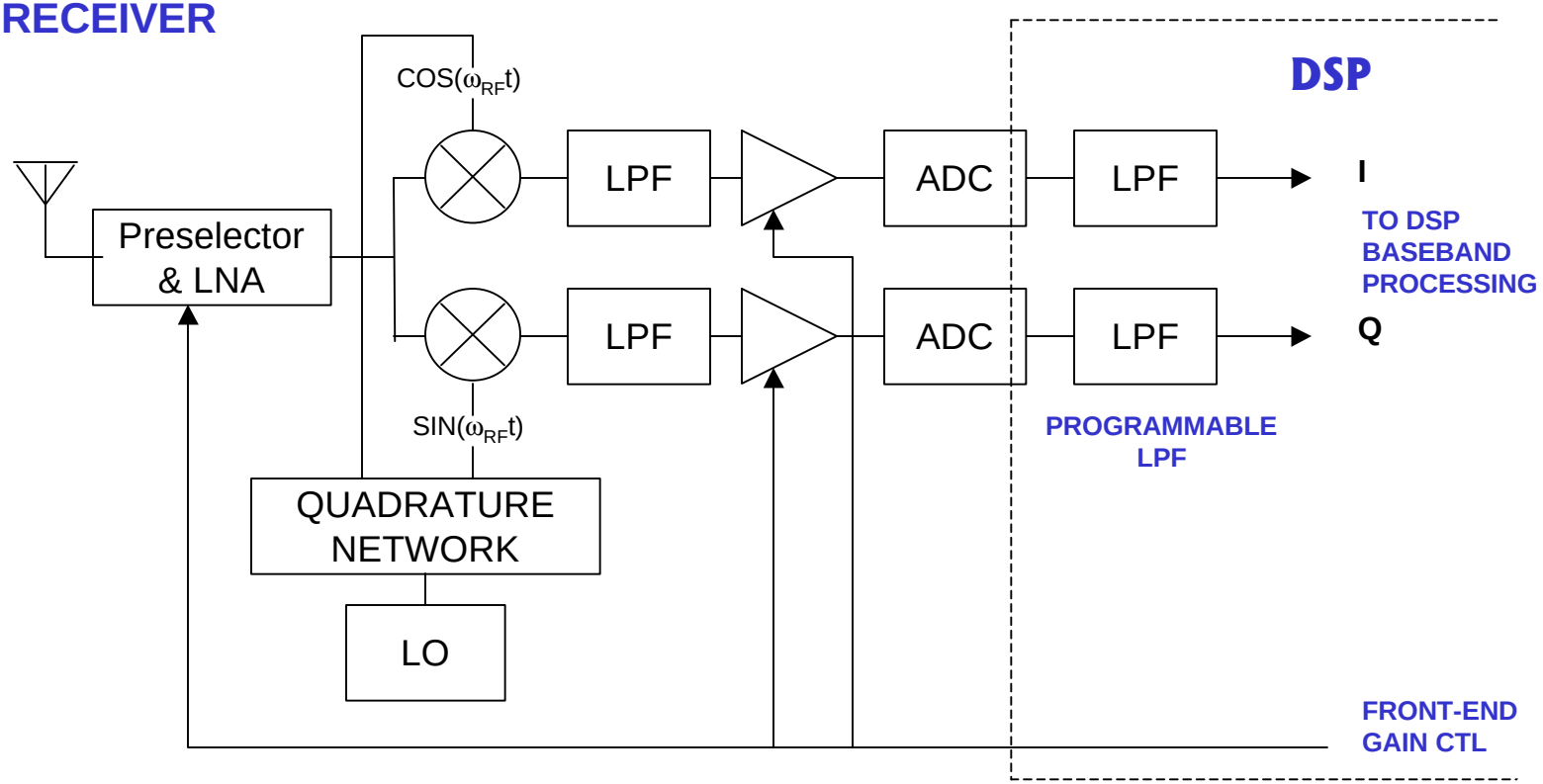
- Superheterodyne Radio Technology
- Direct Conversion Radio (DCR) Technology
- Critical DSP Radio Performance Issues
- Tricks of the DSP Trade
- Future DSP Radio Technology

SUPERHETERODYNE RADIO TECHNOLOGY



DIRECT CONVERSION RADIO TECHNOLOGY

MULTI-BAND, MULTI-MODE DIRECT CONVERSION RECEIVER



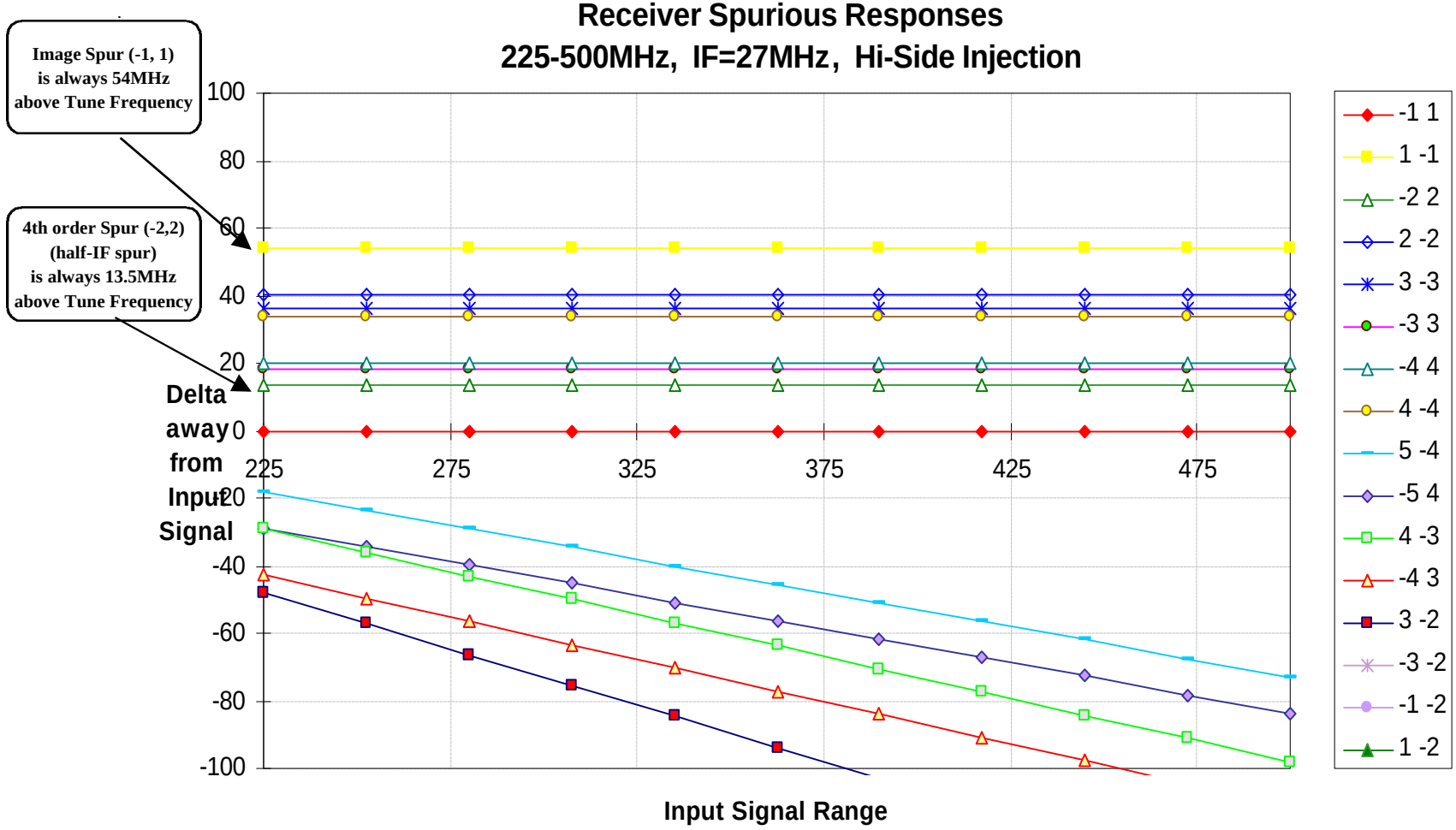
MODULAR AVIONICS RADIO WAVEFORMS

Waveform	Frequency	BW
SINCGARS	30-88MHz	25KHz
VOR	108-118MHz	18KHz
ILS (MB,LOC,GS)	75,108-112,329-335MHz	36KHz
VHF/UHF (Clear Voice Com & Data)	30-400MHz	8.33KHz, 18KHz
HAVE QUICK, HAVE QUICK II	225-400MHz	25KHz,36KHz
SATURN	225-400MHz	36KHz
Link 4	225-400MHz	70KHz
Link 11	225-400MHz	70KHz
SATCOM (DAMA)	240-317MHz	8KHz, 36KHz
Constant Source (T-A/B, TIBS, TRAP)	240-270MHz	8KHz, 36KHz
IFF / TCAS (XPND / INT)	1030,1090MHz	10.0MHz
Link 16 / JTIDS	969-1206MHz	3.0MHz
TACAN	962-1213MHz	400KHz
Weapons Data Link	1500-1900MHz	10.0MHz
HF	*2-30MHz*	*3, 6KHz*

DCR PRO'S AND CON'S

- DCR Offers Lower Cost / Size / Power for a Wide Frequency Coverage Radio
  - How do you build a 2 to 3000 MHz Superheterodyne?
  - Single Synthesizer DCR, 1-Loop at RF Carrier Frequency
  - Single Frequency Translator DCR, RF to BB & BB to RF
  - All DCR components are suitable for integration
    - MMIC's & ASIC's
  - Spurious Responses are well behaved (No Crossovers)
- DCR May be the only "practical" near-term technology for low-power PCMCIA Radio
- DCR *REQUIRES* DSP Calibration of Analog Circuits
  - Phase & Gain error, Rcvr DC Offset, Xmtr LO Leakage
  - DCR DSP is more complex but can be digital VLSI

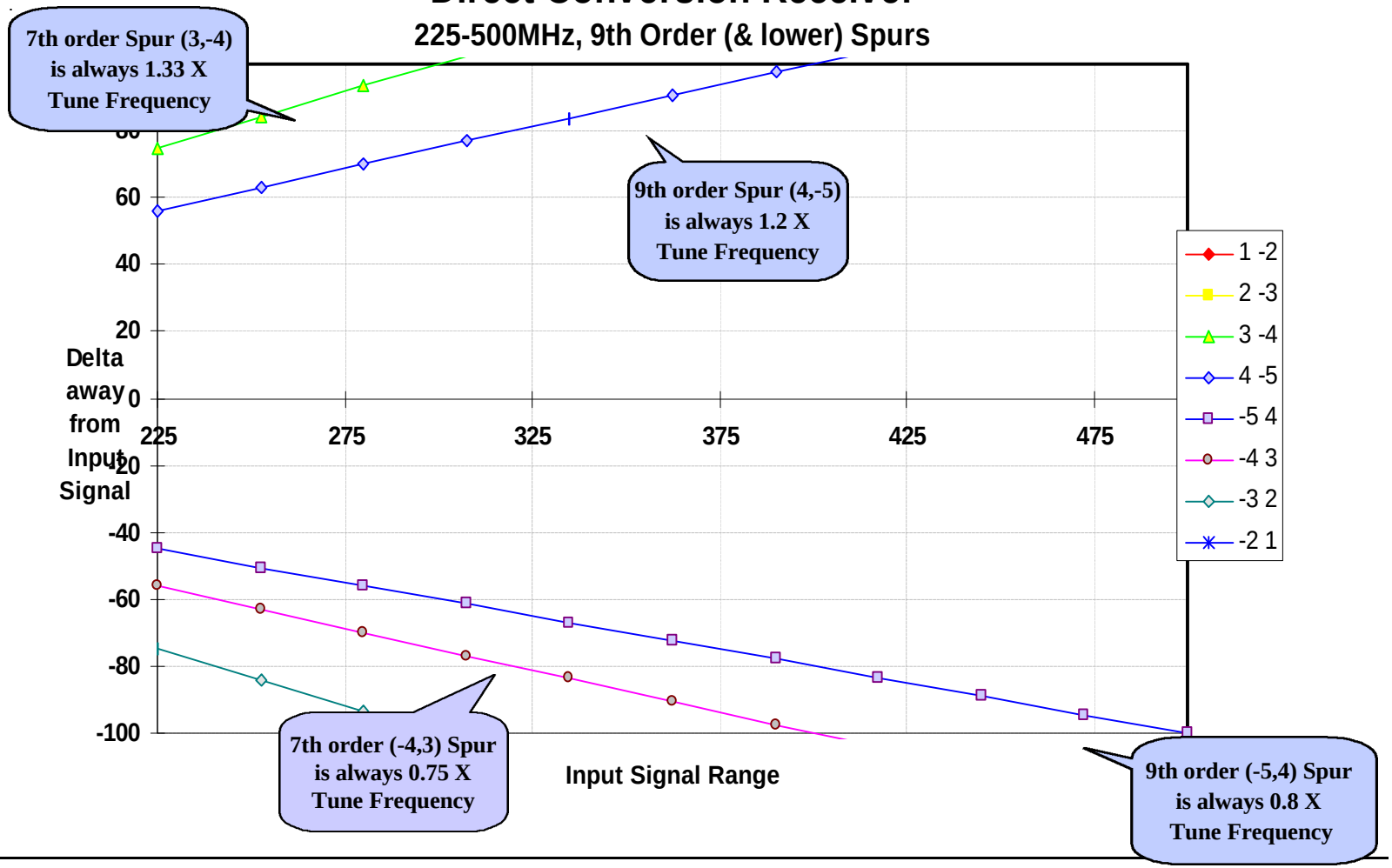
UHF SUPERHET SPURS



UHF DCR SPURS

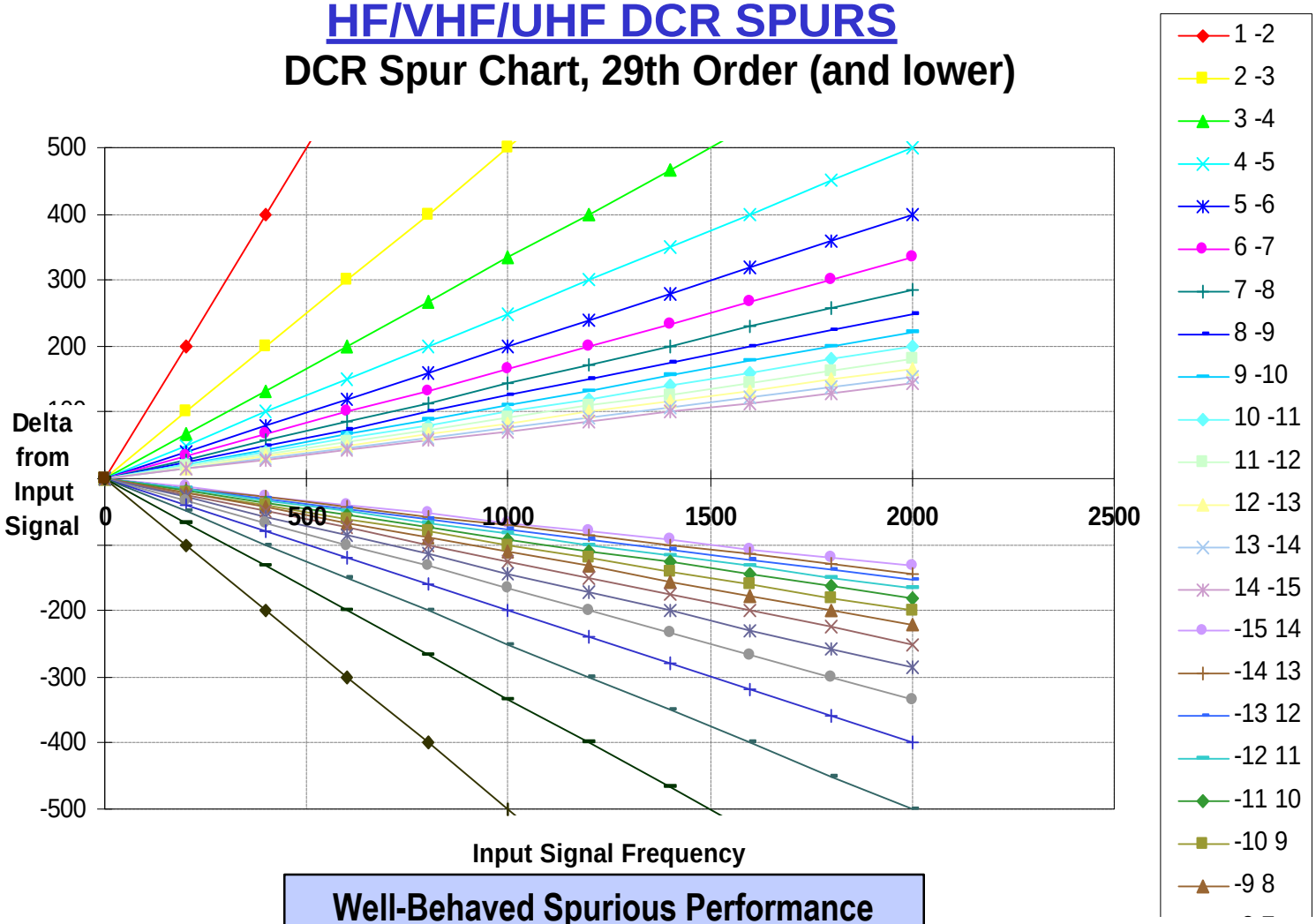
Direct Conversion Receiver

225-500MHz, 9th Order (& lower) Spurs



HF/VHF/UHF DCR SPURS

DCR Spur Chart, 29th Order (and lower)

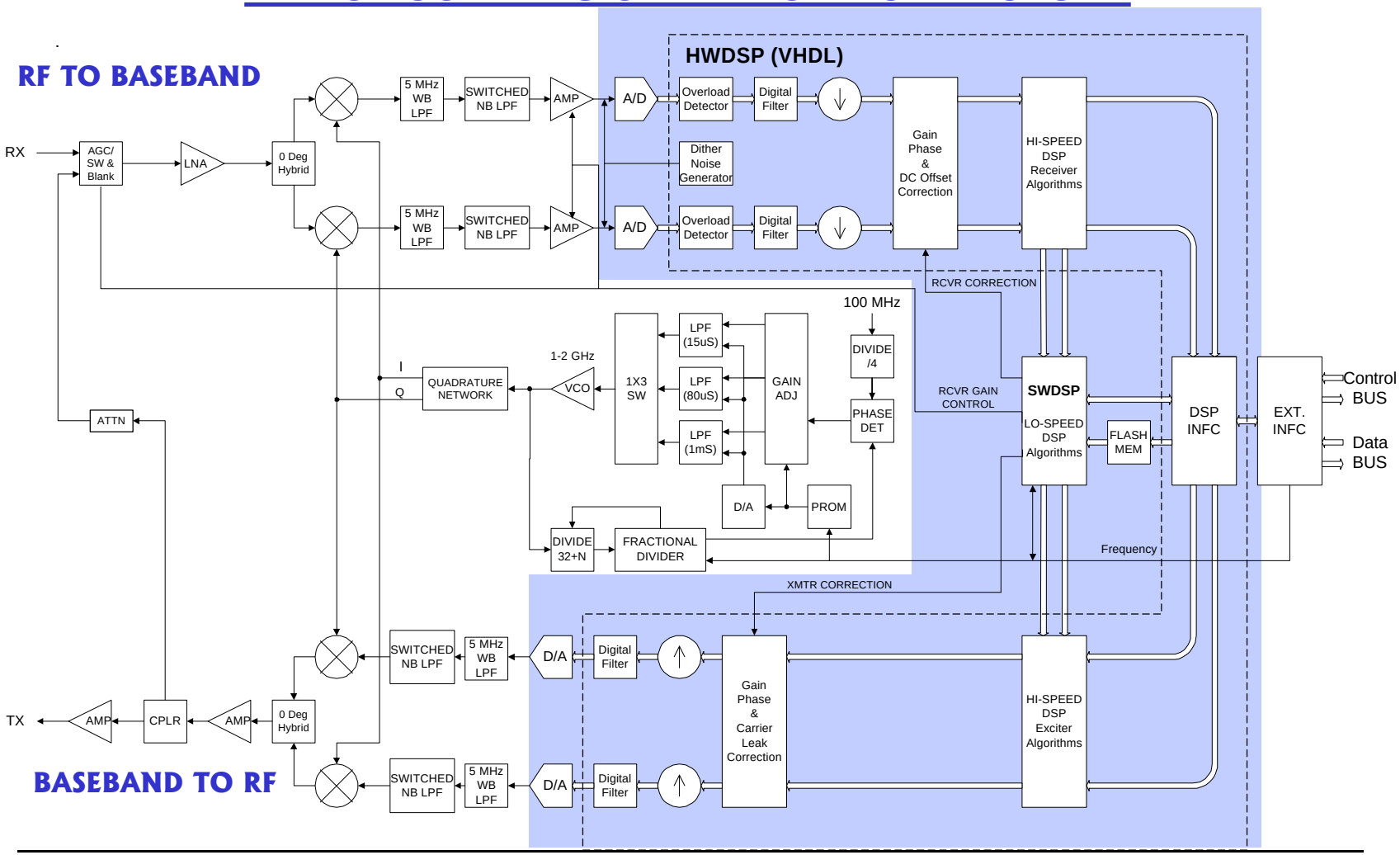


Well-Behaved Spurious Performance

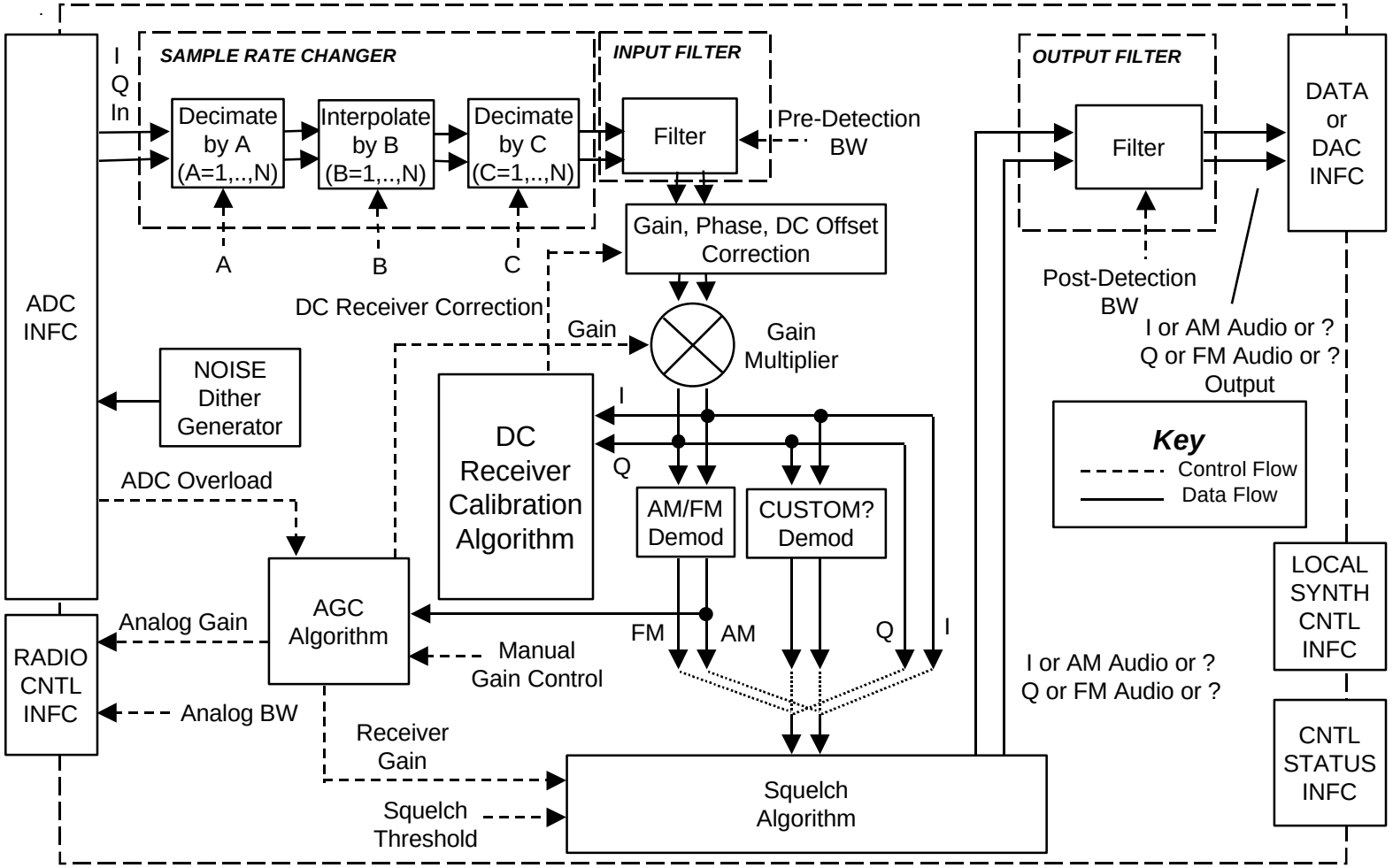
MODULAR AVIONICS RADIO CAPABILITIES

- Direct Conversion Receiver / Direct Conversion Exciter
  - **Multi-Band Receiver and Exciter: *30 MHz to 2000 MHz***
  - **Multiple Channel Bandwidths: *5 KHz to 10 MHz***
  - **3-Pitch SEM-E Form Factor (5" x 6" x 1.8"), reducing to 1-Pitch (5" x 6" x 0.6")**
  - **Custom MMICs and ASICs and FPGAs**
- 30-2000MHz Synthesizer:
  - **Single-Loop PLL, utilizing Fractional Division Technology**
  - **Continuous Freq. Coverage 30-2000MHz / 10 Hz resolution.**
  - **Fast Tune (*15uS*), Medium Tune (*80uS*), and Slow Tune (*1mS*) modes.**
  - **Eliminates need for Synthesizer in PA**
- Digital Signal Processing:
  - **Phase, Gain, and DC Offset Correction Algorithms**
  - **Exciter Phase, Gain, and Carrier Leak Correction Algorithms**
  - **Decimation/Interpolation, Channel Selectivity, & Baseband Selectivity Filtering**
  - **Automatic & Manual Gain Control Algorithms**
  - **I/Q and AM/FM Modulation and Demodulation Algorithms**
  - **Squelch Algorithms**
  - **Digital Baseband I/Q or AM/FM Interface for both Tx and Rcv**

DIRECT CONVERSION RADIO ARCHITECTURE



TYPICAL RECEIVER DSP ALGORITHMS



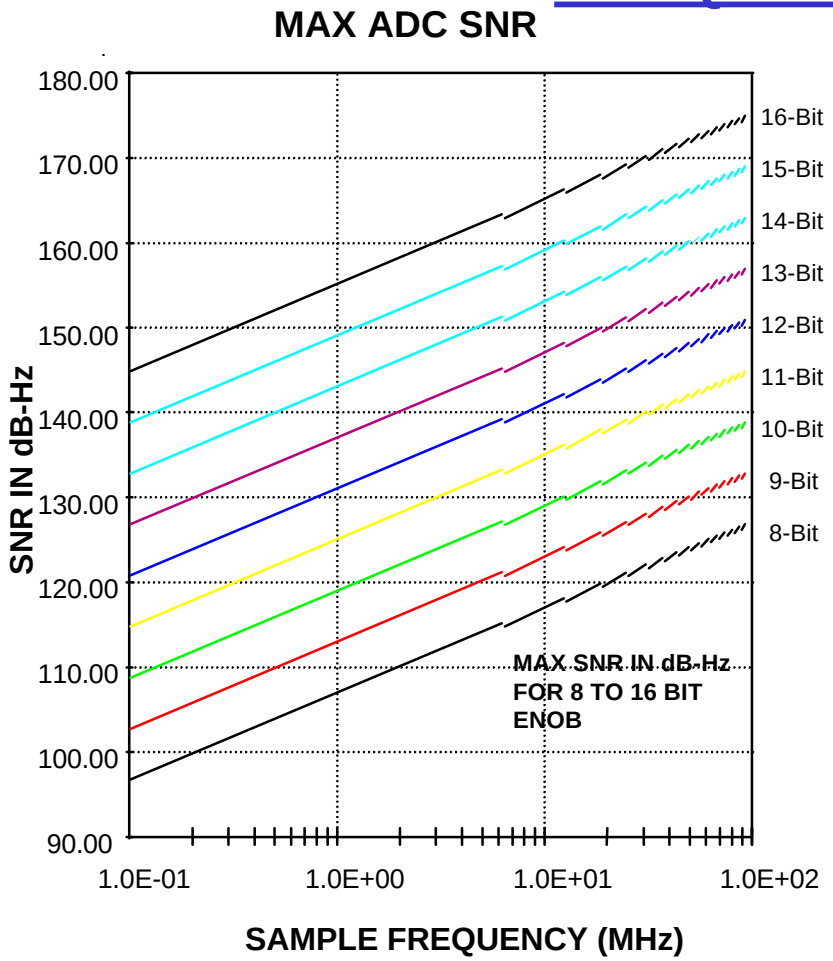
DCR CALIBRATION TECHNOLOGY

- Rapid & Accurate DCR Calibration Algorithms
  - Off-line/Factory/Pwr-up Calibration
    - e.g.
      - Calibrate entire Receiver and Exciter from 30 to 2000 MHz in less than 10 seconds
  - Tuning Event Calibration
    - e.g.
      - Calibrate DC Offset in 5 microseconds to support fast frequency hopping
  - Calibration Performance Requirements
    - e.g.
      - Calibrate Phase & Gain to -60 dBc Distortion
      - Phase error < 0.1 degree, Gain error < 0.01 dB
      - Calibrate DC Offset to preserve 80 dB SFDR

ADC & DAC NOISE & DISTORTION SOURCES

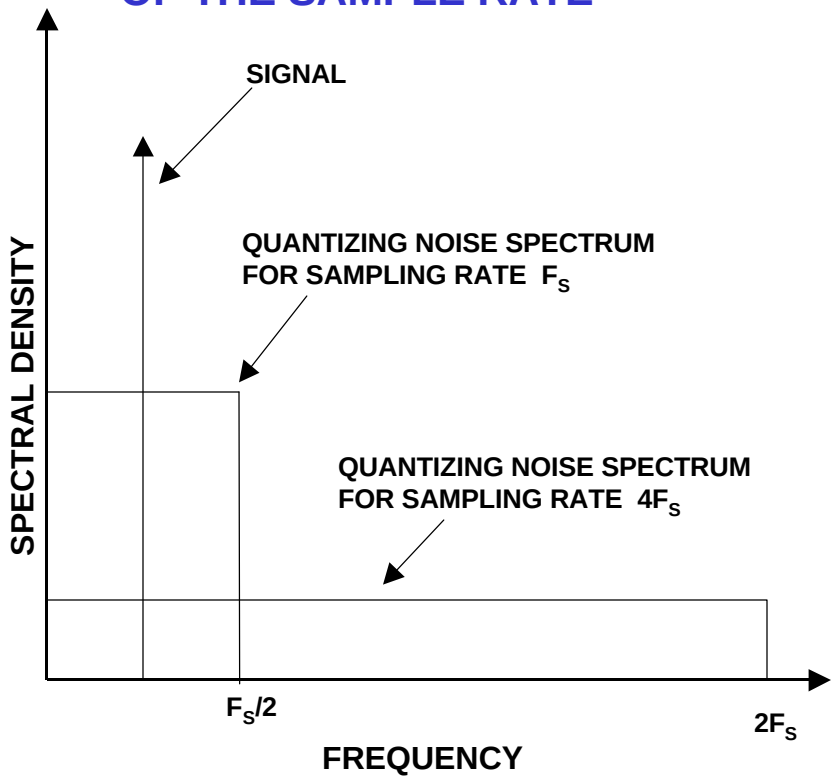
- Random Noise due to Quantization
  - Know your Effective Number of Bits (ENOB) !
- Phase Noise due to Sampler Aperture Jitter
- Harmonic & Intermodulation Distortion due to :
  - Non-Uniform Quantizer Step Sizes
  - Cubic & Quadratic Amplifier Transfer Curve
  - Slew Rate Limiting
  - Nonlinear Impedance
  - ADC Overload
  - Inadequate Quantizer Noise Dither
- Spurious Noise & Distortion due to :
  - Undesired Digital Noise Pickup
    - *The Sample Clock is a Local Oscillator & MUST BE CLEAN*
  - Aliasing (including Broadband Noise Aliasing in ADC!)

ADC QUANTIZING NOISE

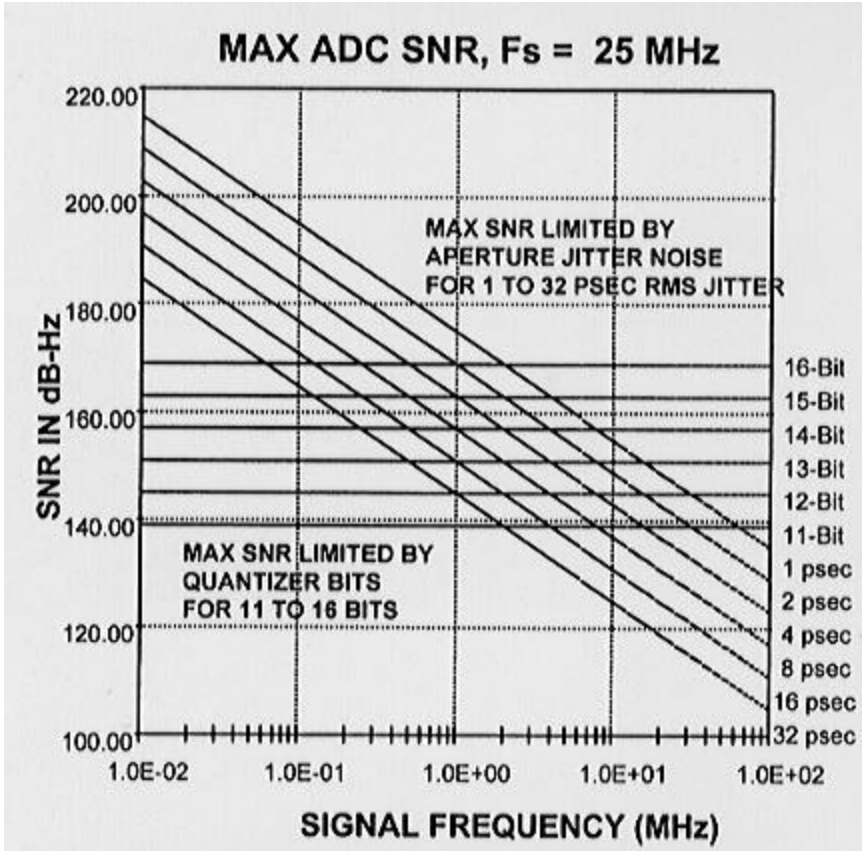


SNR INCREASES 6 dB PER BIT

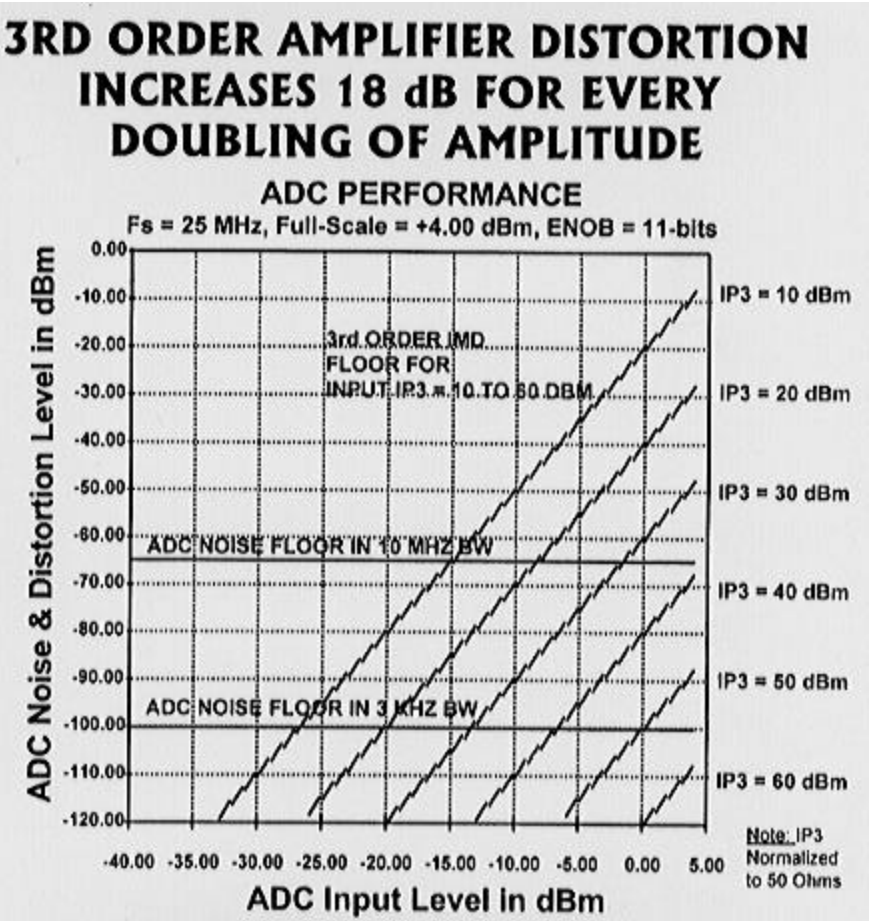
QUANTIZER NOISE DENSITY DECREASES 3 dB FOR EVERY DOUBLING OF THE SAMPLE RATE



ADC NOISE & DISTORTION SOURCES



APERTURE JITTER NOISE INCREASES 6 dB FOR EVERY DOUBLING OF JITTER, AMPLITUDE, OR FREQUENCY



QUANTIZER DISTORTION IS FIXED RELATIVE TO FULL-SCALE (e.g. -6 dB PER BIT)

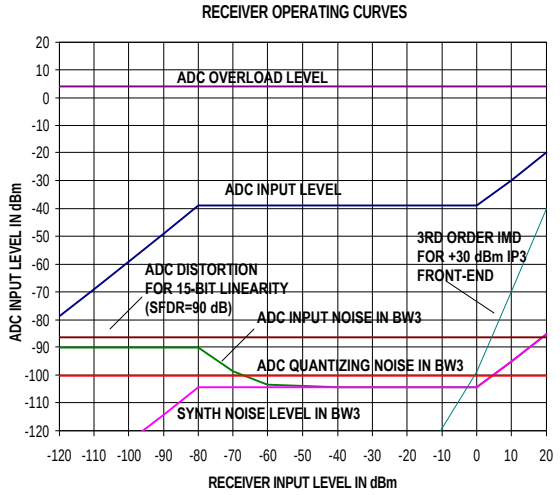
DSP RECEIVER DESIGN

- Set Analog Gain to meet sensitivity requirement
  - e.g. 10 dB SNR @ -113 dBm in 3 kHz BW
- Ensure ADC output noise has Uniform Density
  - Either amplify thermal noise or add out-of-band dither noise
- Keep analog gain high until Ultimate SNR is obtained
  - Control output level with DSP gain control
- Hold ADC level constant if Ultimate SNR is obtained
  - Reduce analog gain & hold DSP gain constant
- Detect out-of-band interference at ADC
  - Reduce analog gain & increase DSP gain to maintain output
- Use Spreadsheet to select ADC, set gain distribution, and analyze noise & distortion performance

DSP RECEIVER SPREADSHEET EXAMPLE

DSP RECEIVER GAIN DISTRIBUTION AND NOISE PERFORMANCE VHF/UHF RCVR, 36 kHz BW

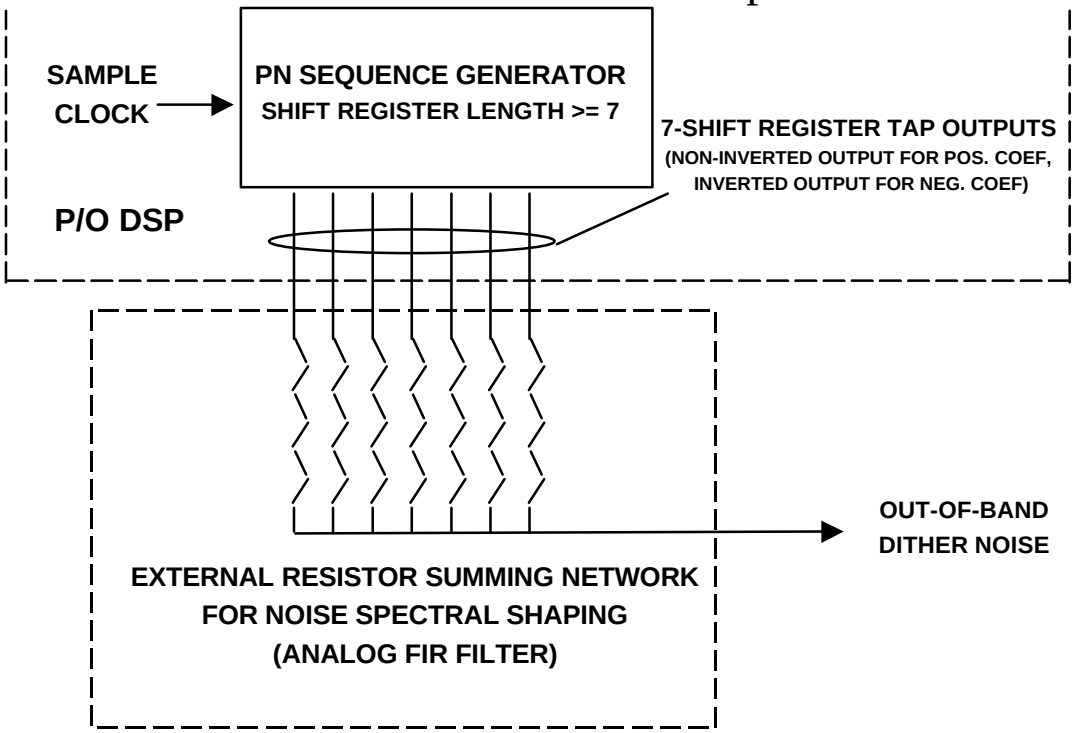
Analog RF/IF Front-End Noise Figure	8.00	dB		
Max. Receiver Antenna Signal Level	20.00	dBm		
A/D Converter Effective No. of Bits	11.00	bits	68.0	dB Max. A/D S/N in Nyquist BW
A/D Converter Full-Scale Level	0.50	V-pk =	4.0	dBm (full-scale sinewave level)
A/D Converter Sample Frequency	25,000.0	kHz	-62.2	dBm Min. A/D Input Noise (reqmt)
A/D Converter Input Bandwidth (BW1)	5,000.0	kHz	-68.0	dBm A/D Quant. Noise in BW1
DSP Pre-Detection (IF) Bandwidth (BW2)	36.0	kHz	-89.4	dBm A/D Quant. Noise in BW2
DSP Post-Detection (Audio) Bandwidth (BW3)	3.0	kHz	-100.2	dBm A/D Quant. Noise in BW3
Analog RF/IF Front-End AGC Threshold	-80.00	dBm		
Analog RF/IF Front-End AGC Range	81.00	dB		
Receiver AGC Threshold	-115.00	dBm	-16.00	dBm IQ Output Signal Level
Max. DSP Internal Gain	58.00	dB		
AM Modulation Percentage	80.00	%	-23.96	dBm AM Output Signal Level
FM Detector Sample Frequency	64.00	kHz		
FM Peak Deviation	8.00	kHz	-8.06	dBm FM Output Signal Level
Synthesizer Noise Density	-100.00	dBc-Hz	33.01	dB Max pre-A/D SNR in BW1
			54.44	dB Max pre-A/D SNR in BW2
			65.23	dB Max pre-A/D SNR in BW3

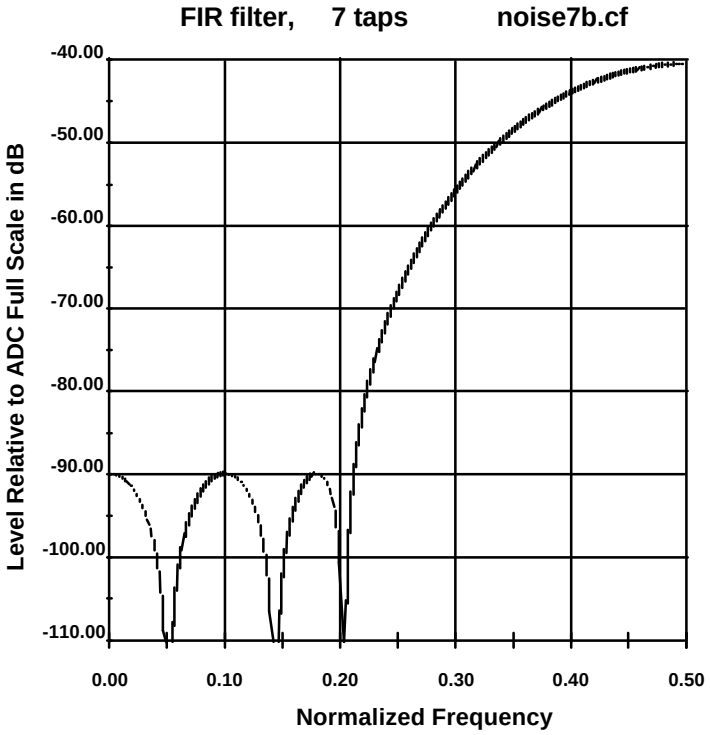


Antenna Signal Level (dBm)	Analog RF/IF Gain (dB)	A/D Signal Level (dBm)	Noise at A/D Input in BW1 (dBm)	Noise at A/D Input in BW2 (dBm)	Noise at A/D Input in BW3 (dBm)	Total Noise in BW2 (dBm)	Total Noise in BW3 (dBm)	IQ SNR in BW2 (dB)	IQ SNR in BW3 (dB)	AM SNR in BW3 (dB)	FM SNR in BW3 (dB)	DSP Internal Gain (dB)	IQ Output Level (dBm)	Total Noise Figure (dB)	Antenna Ovld Level (dBm)	Antenna Ovld/Sig Ratio (dB)
-120.00	41.00	-79.00	-58.01	-79.44	-90.23	-79.02	-89.81	0.02	10.81	2.85	0.31	58.00	-21.00	8.42	-37.0	83.0
-110.00	41.00	-69.00	-58.01	-79.44	-90.23	-79.02	-89.81	10.02	20.81	12.85	30.85	53.00	-16.00	8.42	-37.0	73.0
-100.00	41.00	-59.00	-58.01	-79.44	-90.23	-79.02	-89.81	20.02	30.81	22.85	41.09	43.00	-16.00	8.42	-37.0	63.0
-90.00	41.00	-49.00	-57.99	-79.42	-90.21	-79.01	-89.80	30.01	40.80	32.84	51.08	33.00	-16.00	8.43	-37.0	53.0
-80.00	41.00	-39.00	-57.84	-79.27	-90.06	-78.87	-89.66	39.87	50.66	42.70	60.94	23.00	-16.00	8.57	-37.0	43.0
-70.00	31.00	-39.00	-66.55	-87.98	-98.77	-85.63	-96.42	46.63	57.42	49.46	67.70	23.00	-16.00	11.81	-27.0	43.0
-60.00	21.00	-39.00	-71.04	-92.46	-103.26	-87.67	-98.46	48.67	59.46	51.50	69.74	23.00	-16.00	19.77	-17.0	43.0
-50.00	11.00	-39.00	-71.90	-93.33	-104.12	-87.93	-98.73	48.93	59.73	51.77	70.01	23.00	-16.00	29.50	-7.0	43.0
-40.00	1.00	-39.00	-72.00	-93.43	-104.22	-87.96	-98.75	48.96	59.75	51.80	70.03	23.00	-16.00	39.47	3.0	43.0
-30.00	-9.00	-39.00	-72.01	-93.44	-104.23	-87.96	-98.76	48.96	59.76	51.80	70.04	23.00	-16.00	49.47	13.0	43.0
-20.00	-19.00	-39.00	-72.01	-93.44	-104.23	-87.97	-98.76	48.97	59.76	51.80	70.04	23.00	-16.00	59.47	20.0	40.0
-10.00	-29.00	-39.00	-72.01	-93.44	-104.23	-87.97	-98.76	48.97	59.76	51.80	70.04	23.00	-16.00	69.47	20.0	30.0
0.00	-39.00	-39.00	-72.01	-93.44	-104.23	-87.97	-98.76	48.97	59.76	51.80	70.04	23.00	-16.00	79.47	20.0	20.0
10.00	-40.00	-30.00	-63.01	-84.44	-95.23	-83.24	-94.03	53.24	64.03	56.07	74.31	14.00	-16.00	85.20	20.0	10.0
20.00	-40.00	-20.00	-53.01	-74.44	-85.23	-74.30	-85.09	54.30	65.09	57.13	75.37	4.00	-16.00	94.14	20.0	0.0

NOISE DITHER GENERATION

- Digital Generation of Out-of-Band Noise Dither
  - Dither May Be Required in NB Modes to Ensure Uniform Quantizing Noise (e.g. to Linearize ADC Model)
  - Dither Reduces ADC Spurs & Distortion

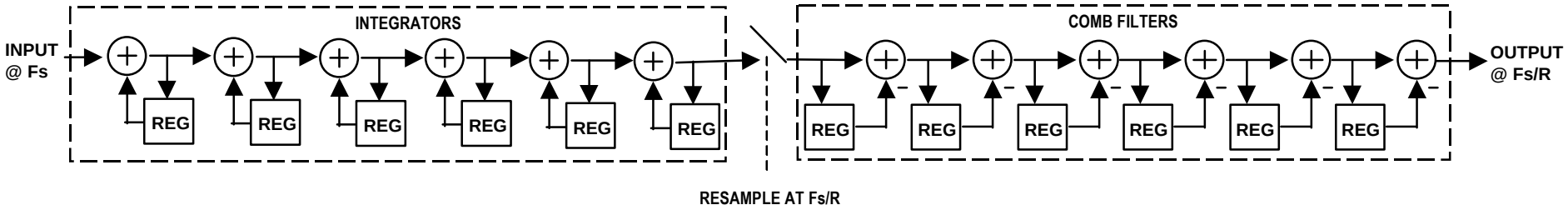




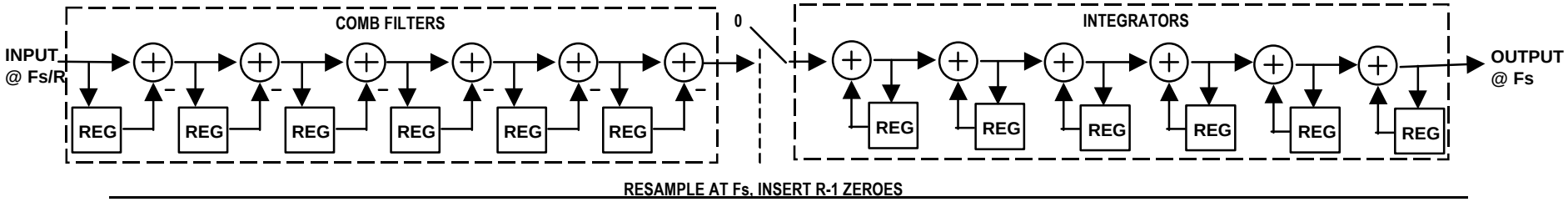
HI-SPEED (MULTIPLIER-LESS) DIGITAL FILTERING

- Decimation & Interpolation
  - Cascade-Integrator-Comb (CIC) Digital Filters
    - Linear Phase Response
    - Variable Decimation / Interpolation Ratio
    - Multiplier-less Design

CIC DECIMATOR (N=6, M=1, R=1,...,N) :

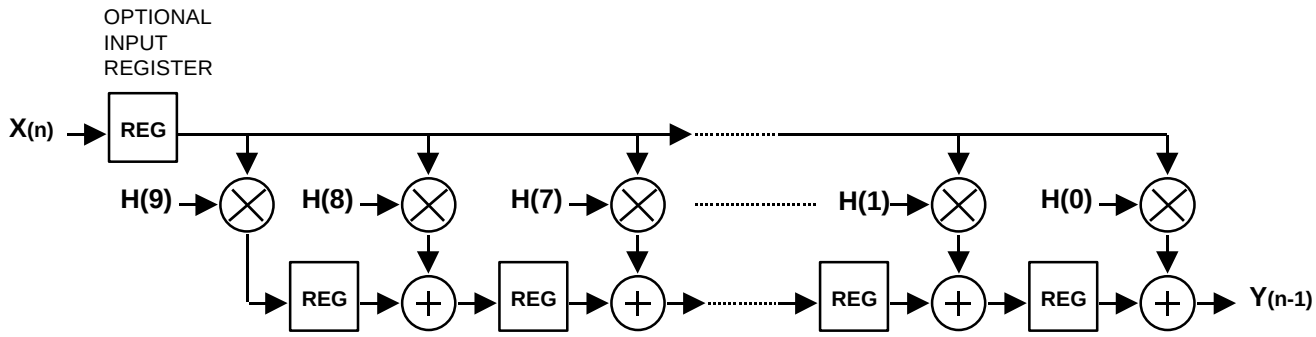


CIC INTERPOLATOR (N=6, M=1, R=1,...,N) :



HI-SPEED (MULTIPLIER-LESS) DIGITAL FILTERING

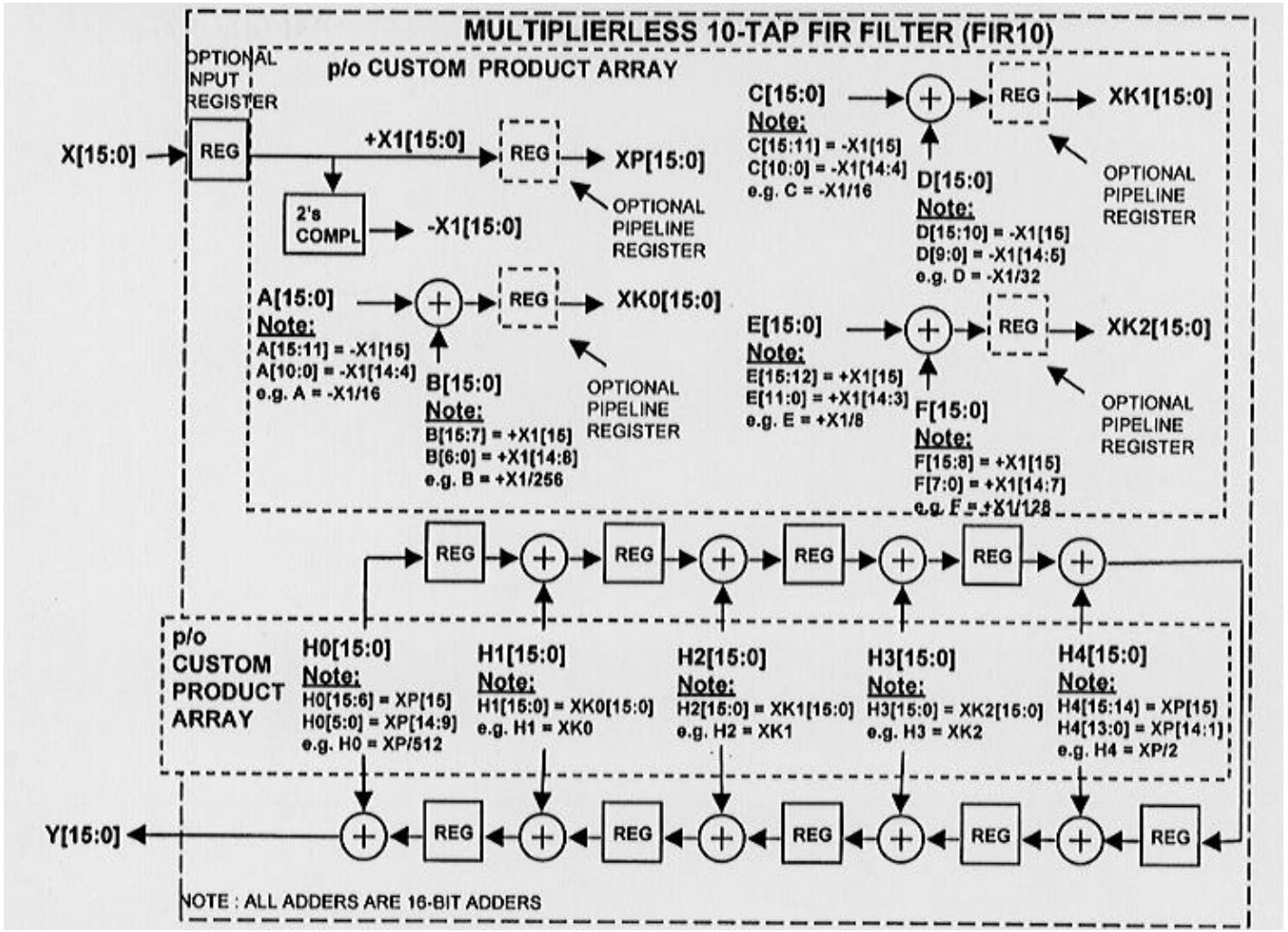
- FIR Digital Filtering
  - Selectivity Filtering
  - CIC Frequency Response Correction
    - CIC Passband Rolloff Compensation
    - CIC Alias Suppresion (Selectivity Filtering)
  - Multiplier-less Designs Possible
  - e.g.



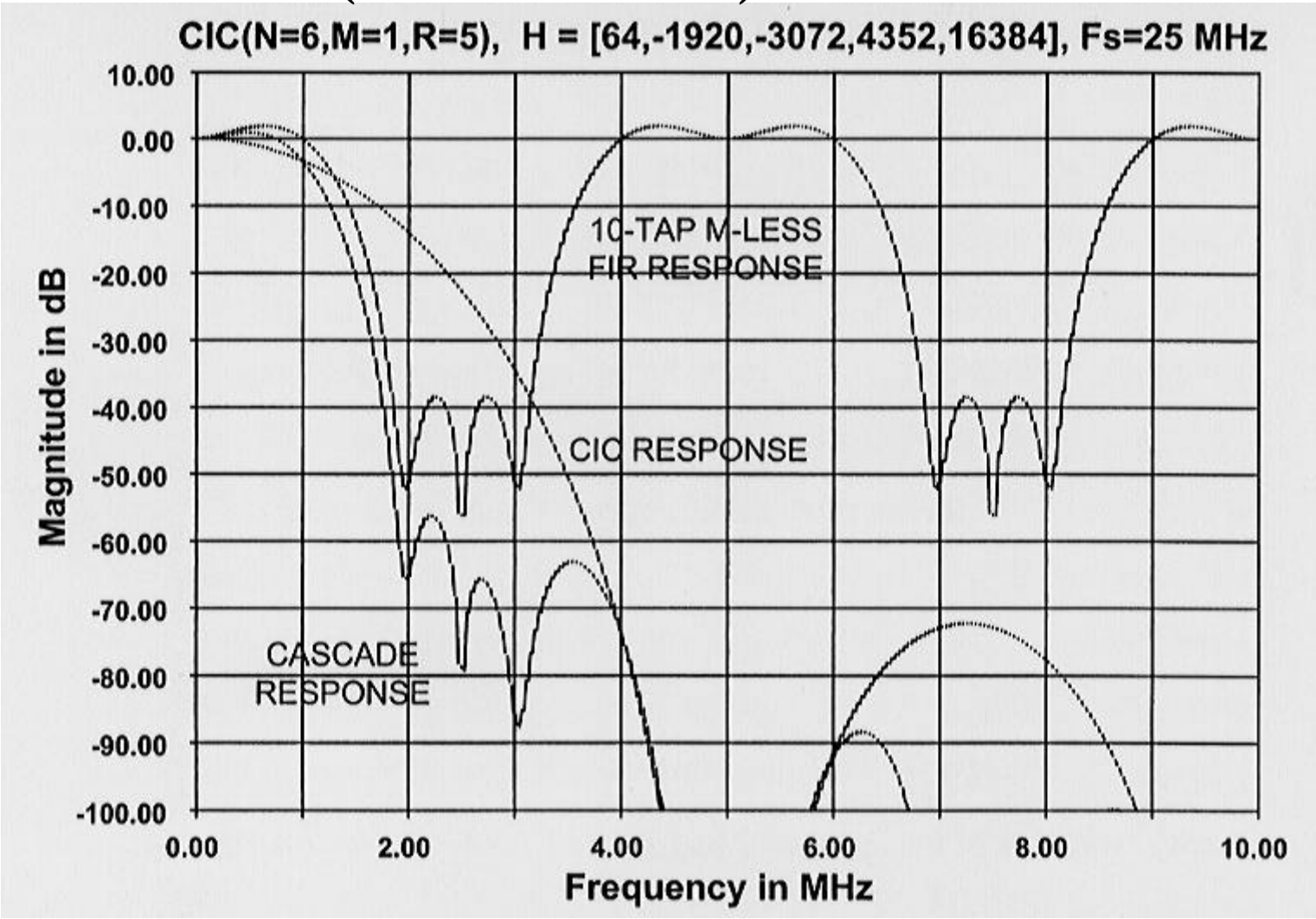
10-TAP MULTIPLIER-LESS LINEAR PHASE FIR FILTER EXAMPLE

$H(0) = H(9) = 0.001953125 = 2^{-9}$
$H(1) = H(8) = -0.058593750 = 2^{-8} - 2^{-4}$
$H(2) = H(7) = -0.093750000 = -2^{-5} - 2^{-4}$
$H(3) = H(6) = 0.132812500 = 2^{-7} + 2^{-3}$
$H(4) = H(5) = 0.500000000 = 2^{-1}$

HI-SPEED (MULTIPLIER-LESS) DIGITAL FILTERING



HI-SPEED (MULTIPLIER-LESS) DIGITAL FILTERING



FUTURE DSP RADIO TECHNOLOGY