6.1: A 1.2GS/s 15b DAC for Precision Signal Generation

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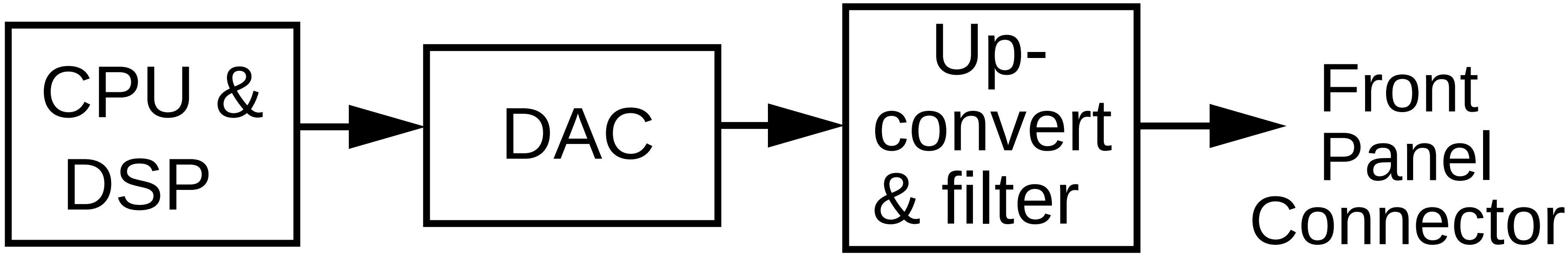
DAC Use in Direct IF for RF Instruments

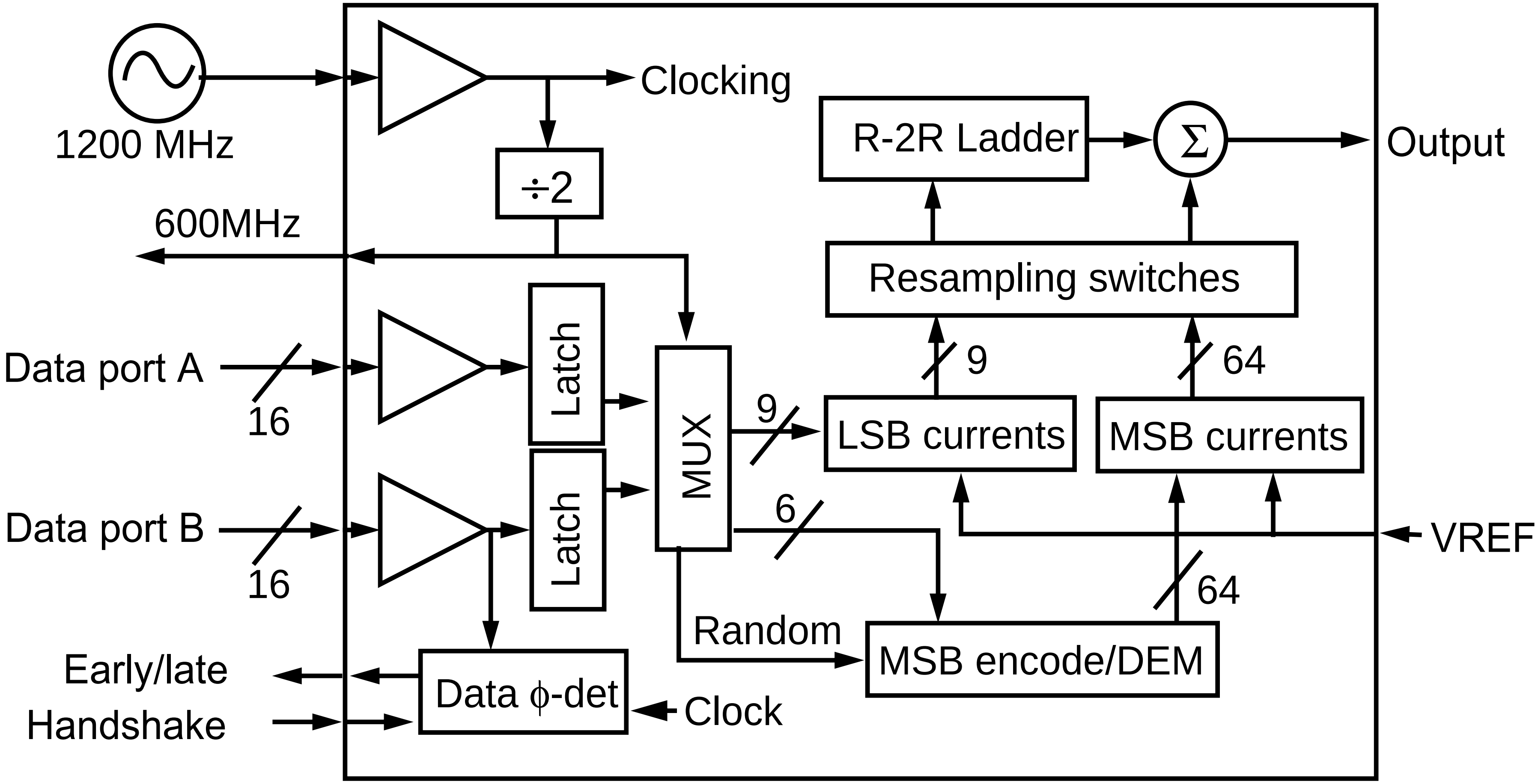


- Use DSP to get complex modulation formats
- Maintain instrument-class signal fidelity
- Cover as wide a bandwidth as possible, up to 80% of Nyquist typically.
- Cost, power, size not as important as for mobile applications
- Only a single up-conversion required

Goals for this DAC

- Requirements for wide-band IF generation:
    - At least 80MHz of bandwidth
    - Spurious signals < -80dBc
    - Signal-to-noise > 80dB in an 80MHz bandwidth
    - Center frequency about 300MHz or higher
- Path not taken: Sigma-delta
- Additional uses that require Nyquist implementation:
    - Arbitrary waveform generation -- as fast as possible
    - Very wide band up-conversion -- as fast as possible

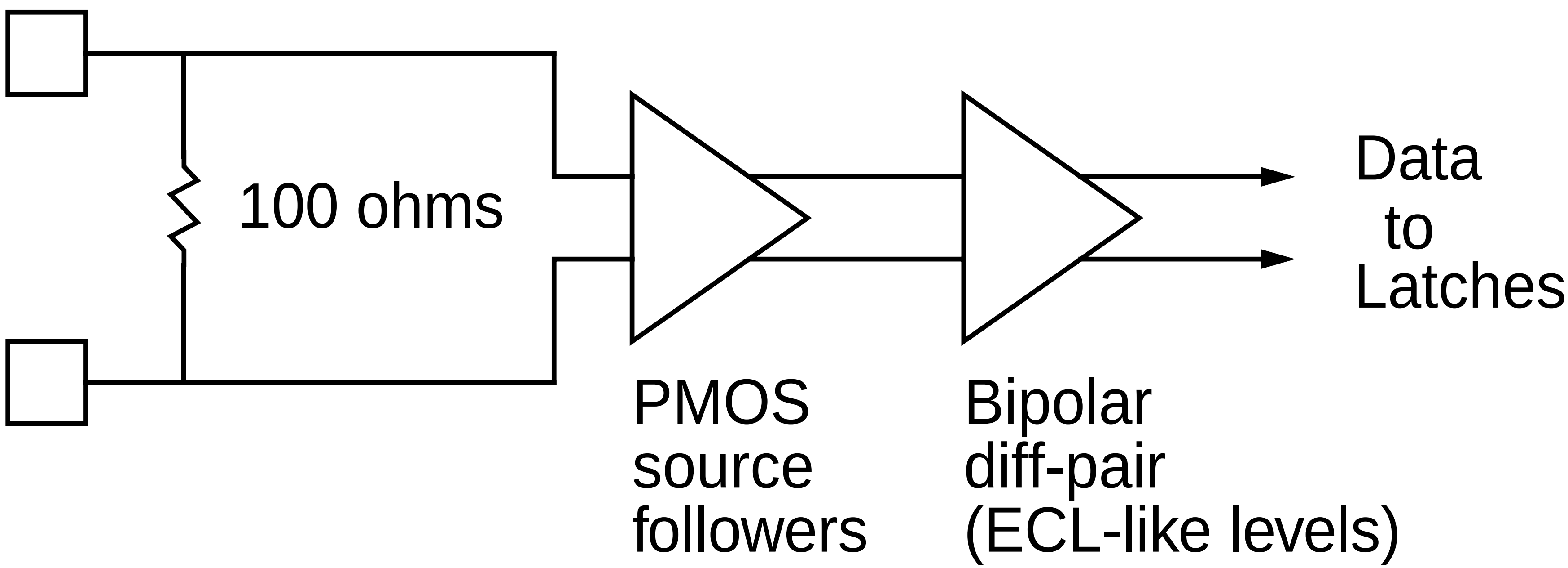
Block Diagram



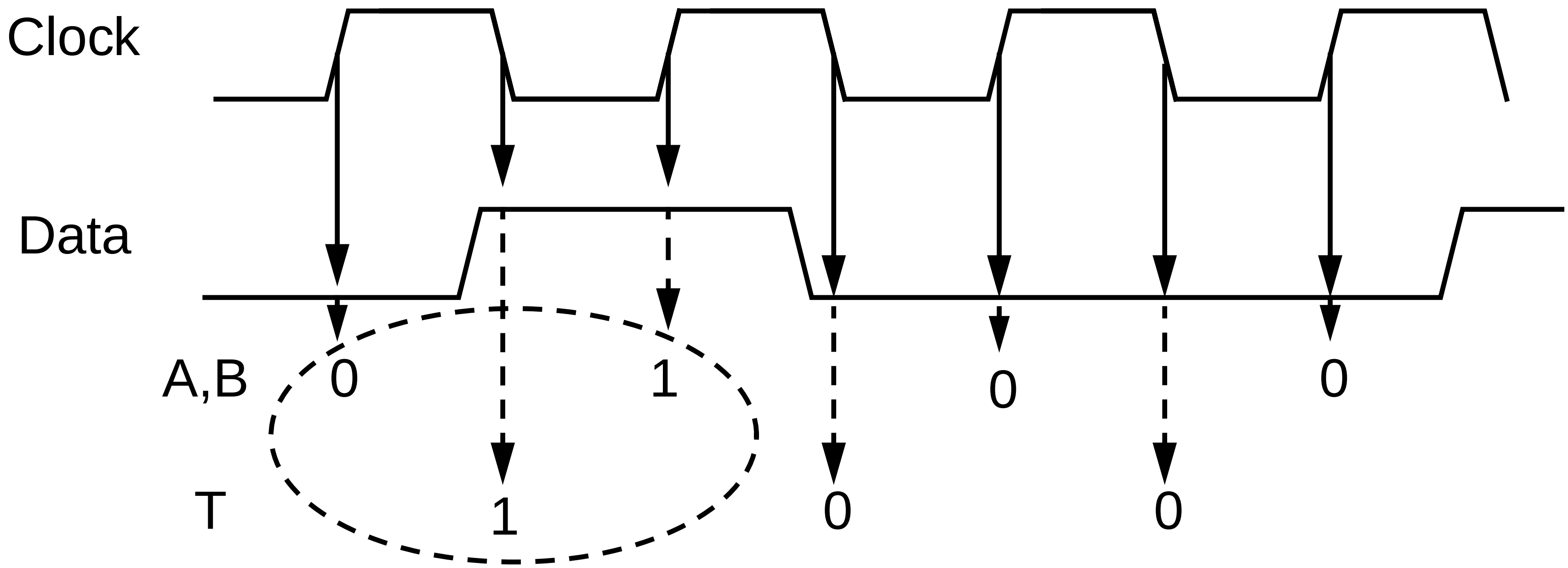
- 15-bit resolution, 1200 MSample/sec, 0 dBm output power
- Output is duplicated to get NRZ waveform

Input Data Buffer

- As flexible as possible
  - LVDS main interface spec
  - Should handle ECL/PECL levels as well
  - Should provide on-chip terminations (50-ohm, diff)
- 1200 MHz and greater receive rate



Input Data Timing Mechanism

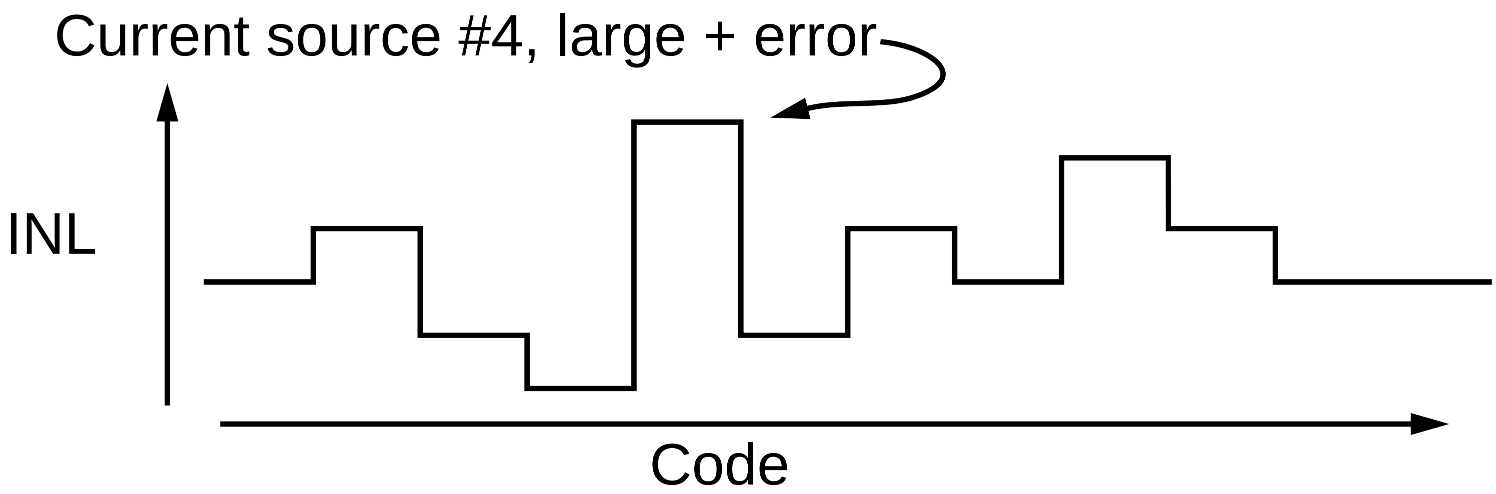


A-T-B sequence 0-1-1, so the data is “early”

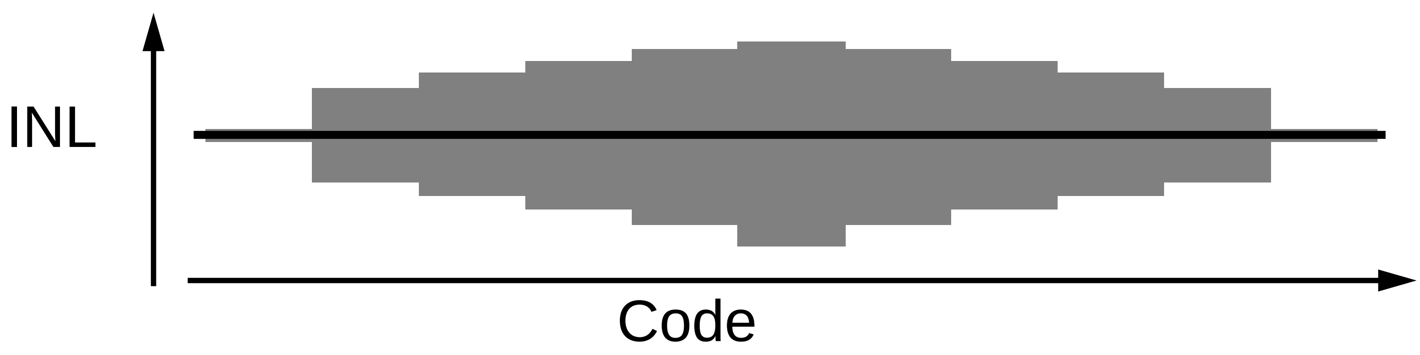
- Data and clock must be aligned at 1200 MSa/s with 100-ps accuracy (one-port mode)
- A-T-B scheme from serial links techniques

Dynamic Element Matching

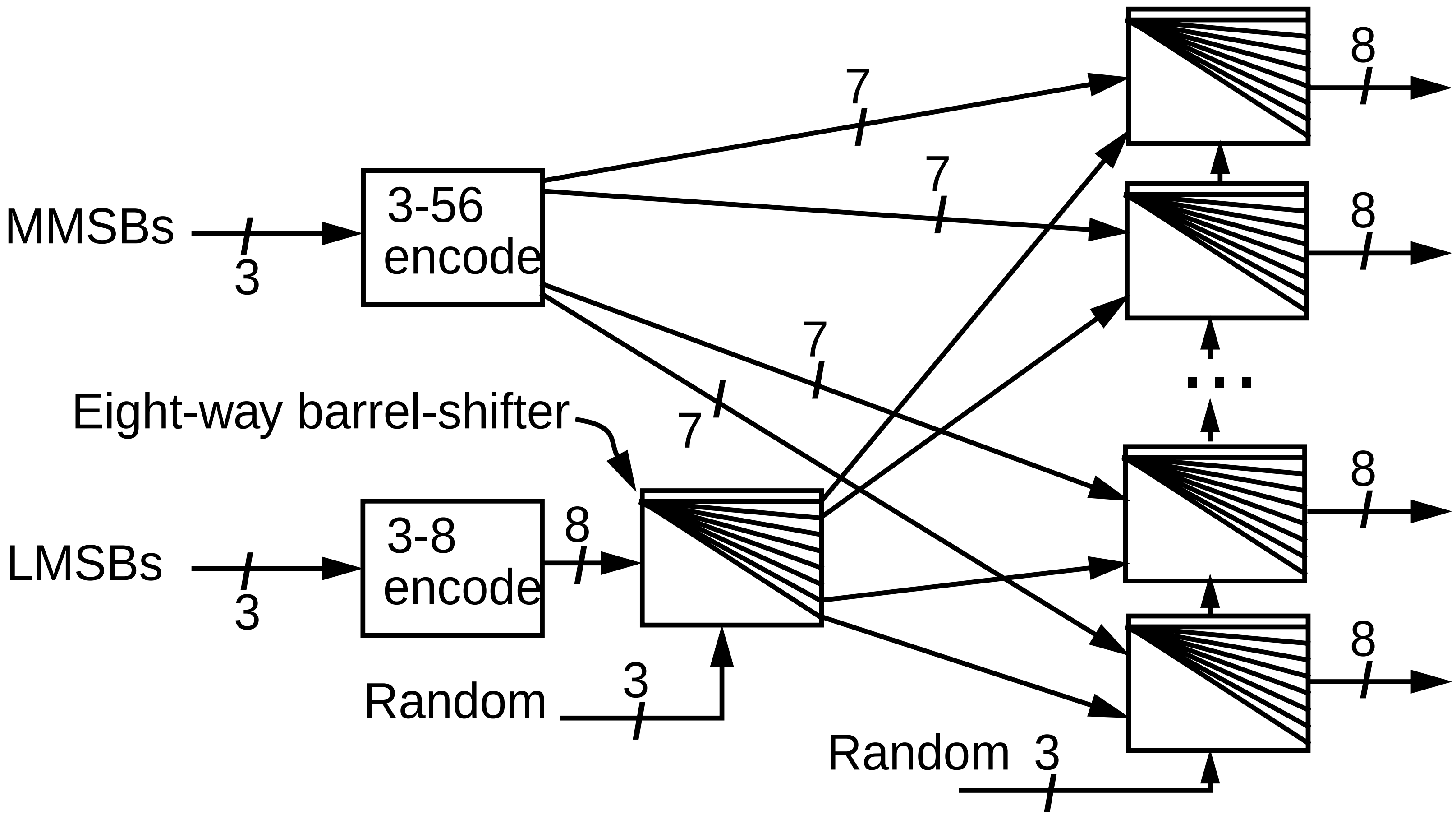
- In Nyquist DACs, current source mismatches can cause nonlinearities:



- If currents are chosen randomly the nonlinearities are converted into white noise:



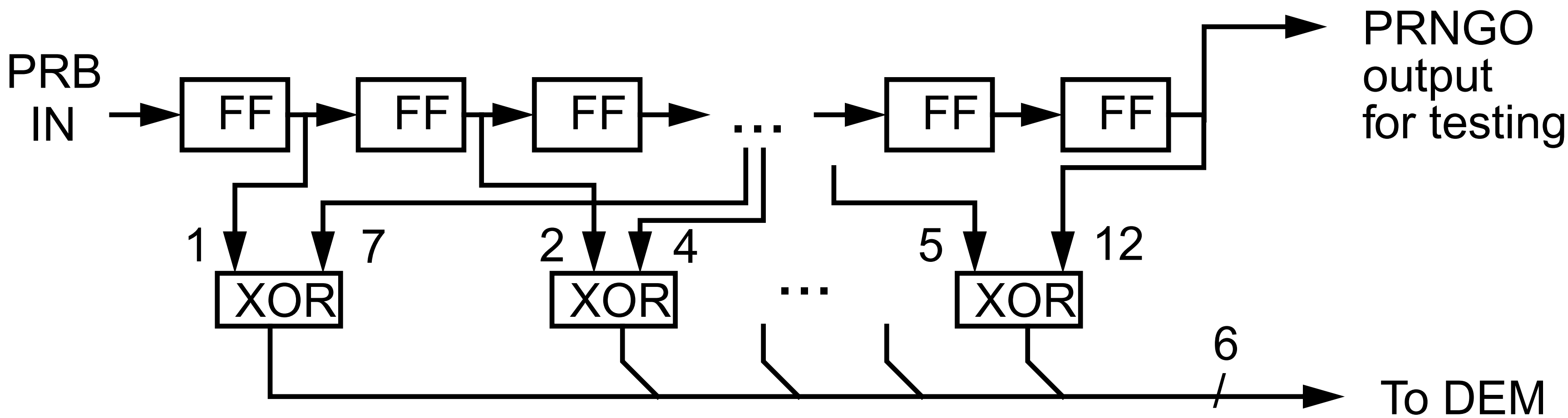
MSB Current Source Randomization



- MSB requests are binary -- convert to a unary weighted code, then scramble 64 requests
- Any request may use any current source

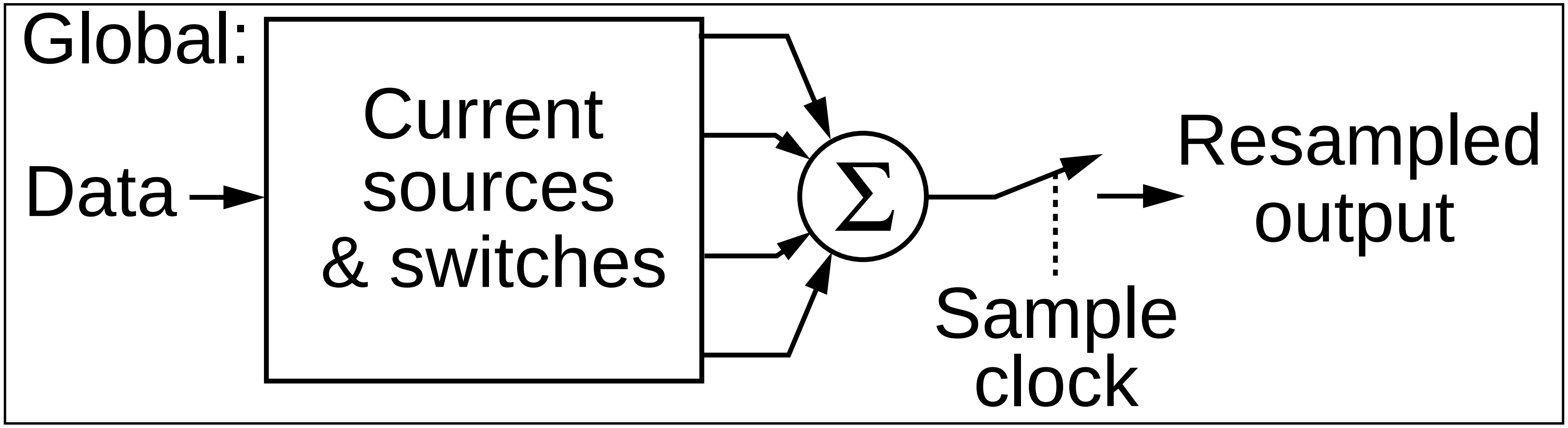
Random Bit Generation

- Six random bits are needed on each cycle
- Prefer to have these controlled externally
- Use XORs to create other phases of the sequence:

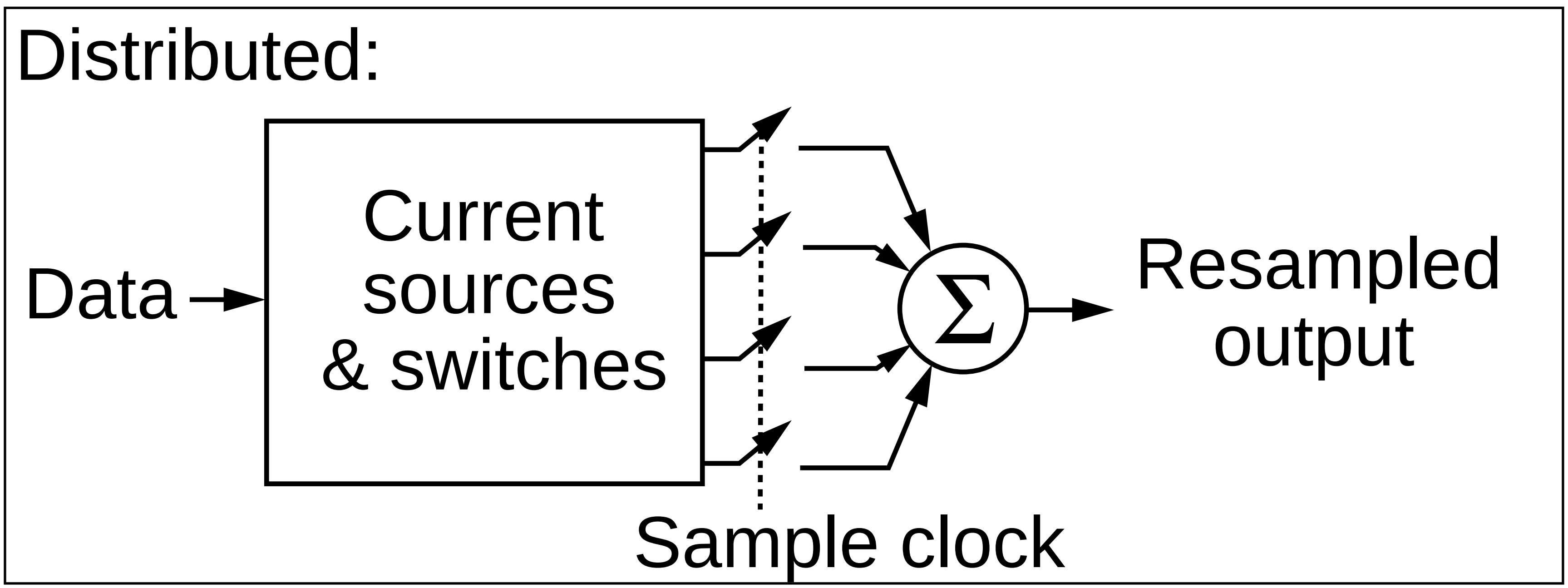


- Use different tap spacings to get different sequences

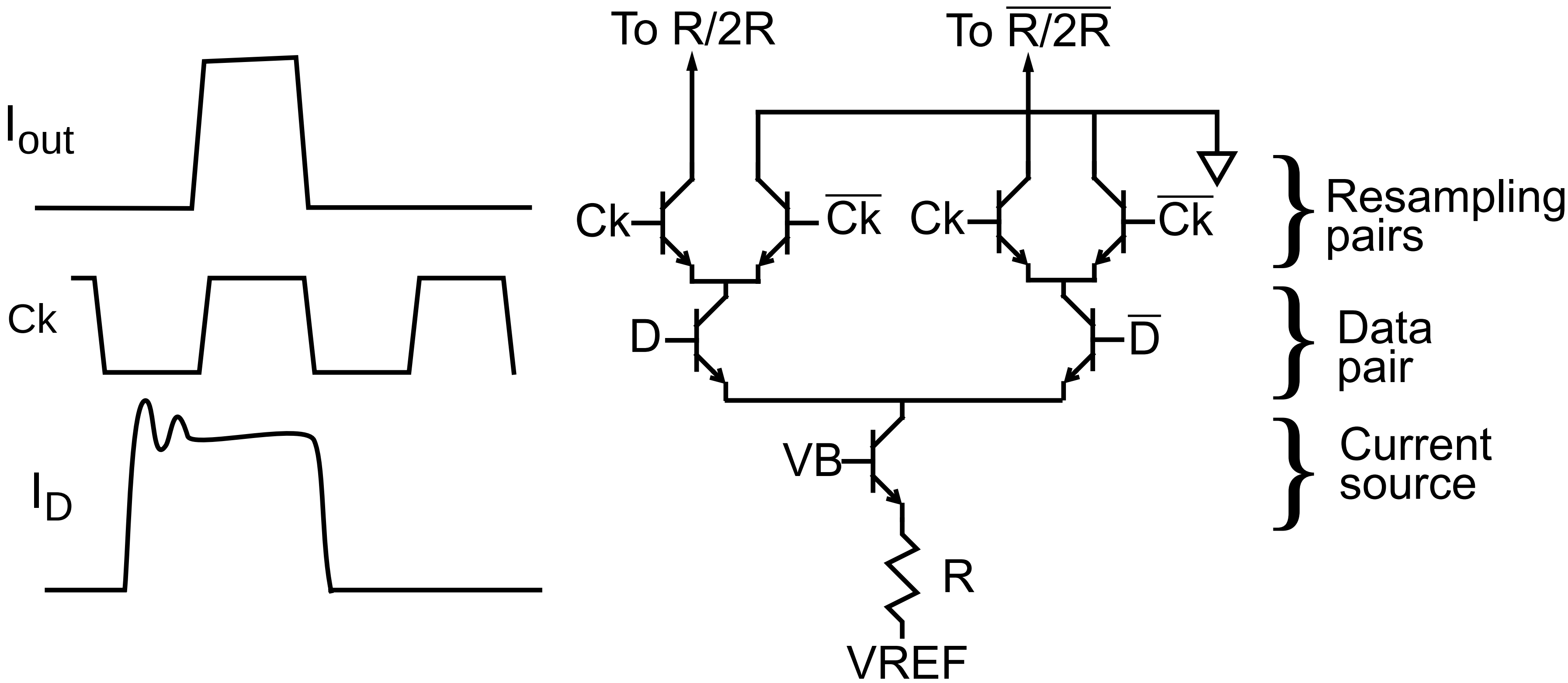
Global vs. Distributed Output Resampling



- Switch must be very linear for the global case

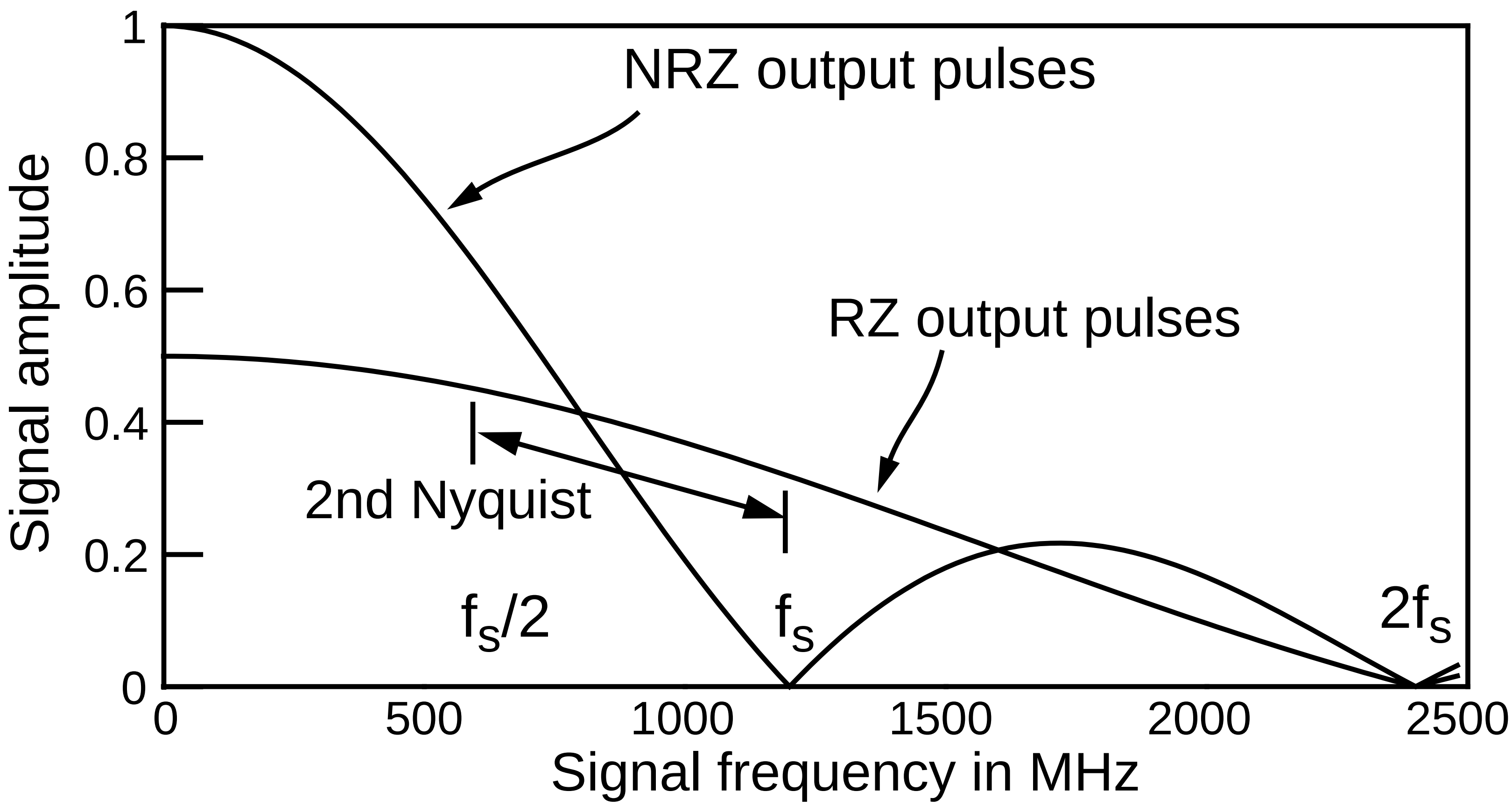


Distributed Output Resampling



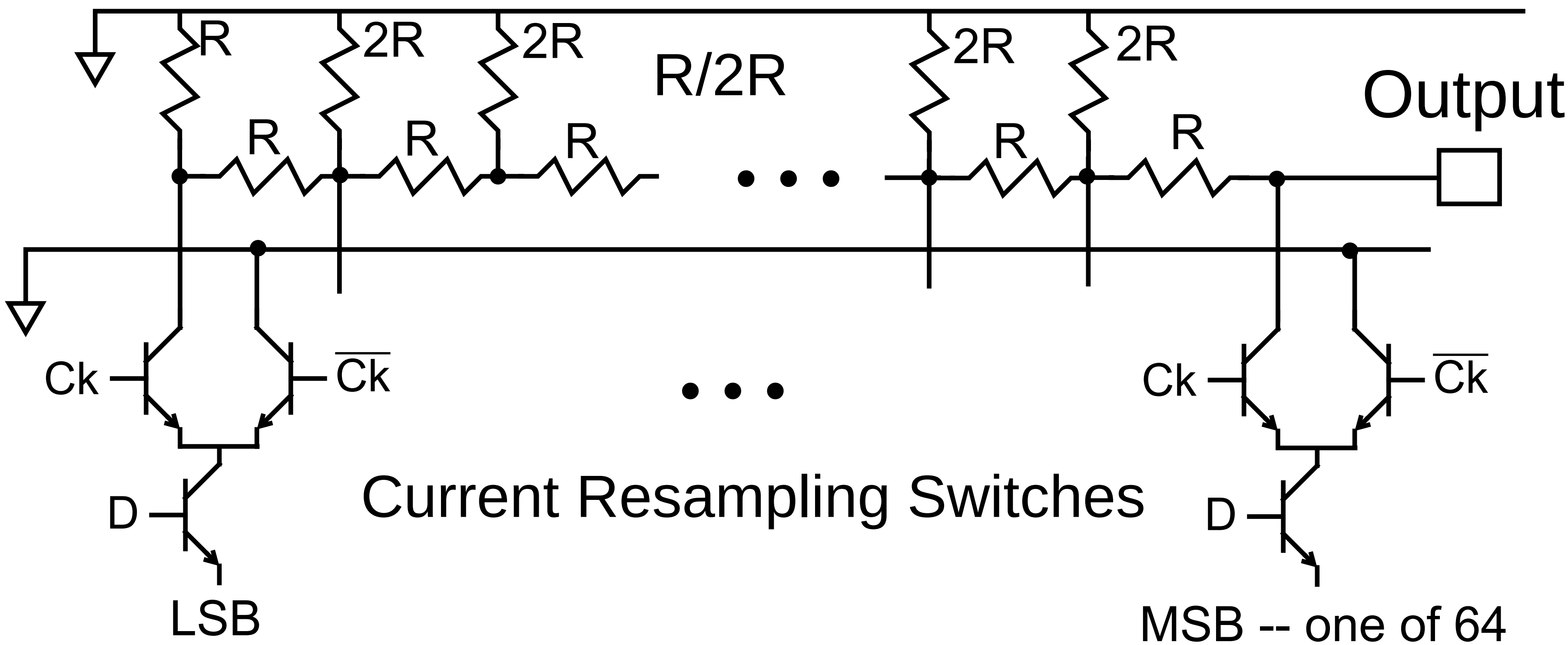
- Data arrives first and currents go into ground
- Ck switches settled current to the R/2R output
- Only units currents are switched, so the process is inherently linear

Sin(x)/x Roll-off

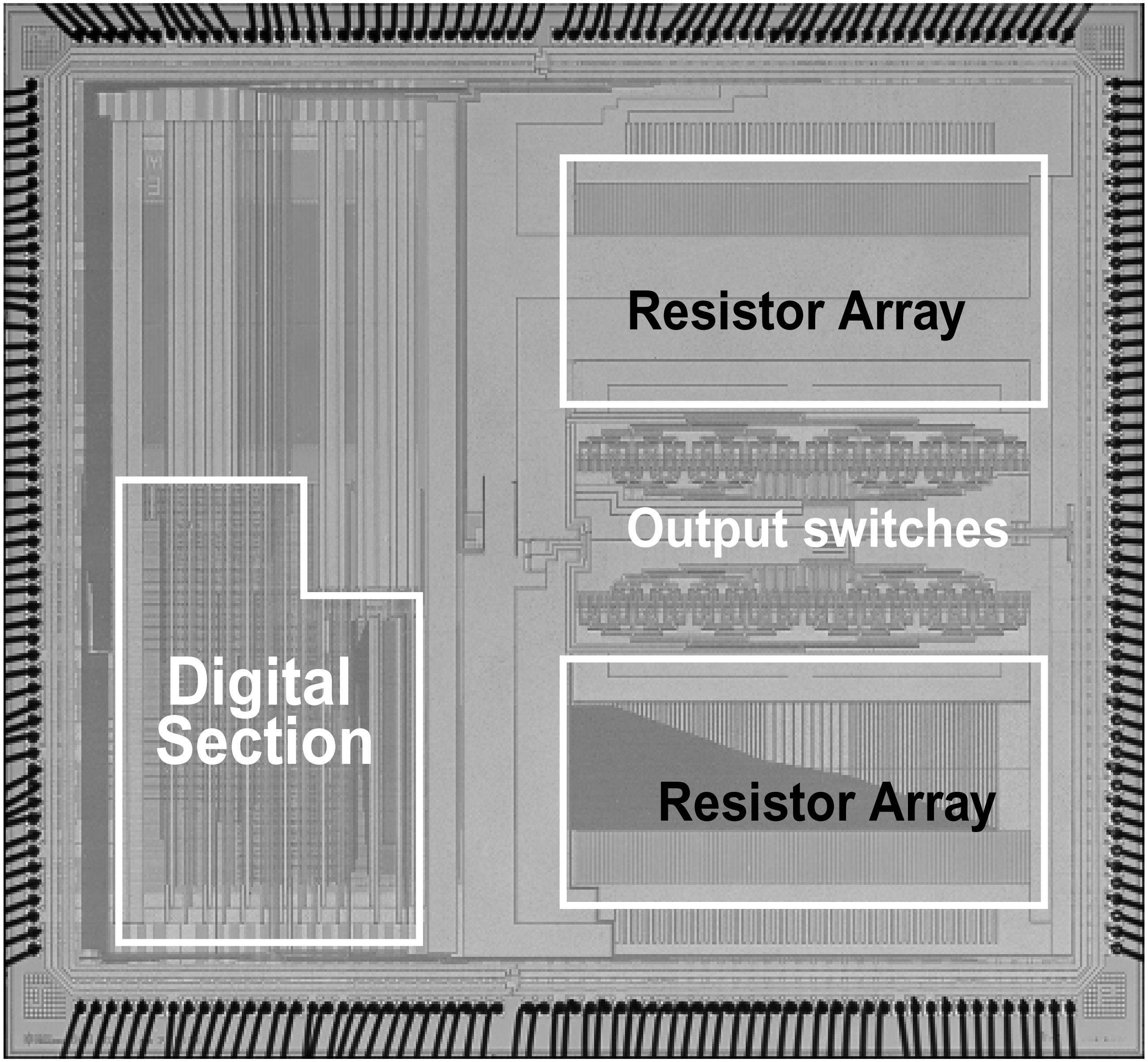


- With a “non-return-to-zero” waveform (NRZ), the first null is at 1200MHz
- With RZ (half-width pulses) there is more power at some frequencies, such as 900MHz

R/2R Ladder Design

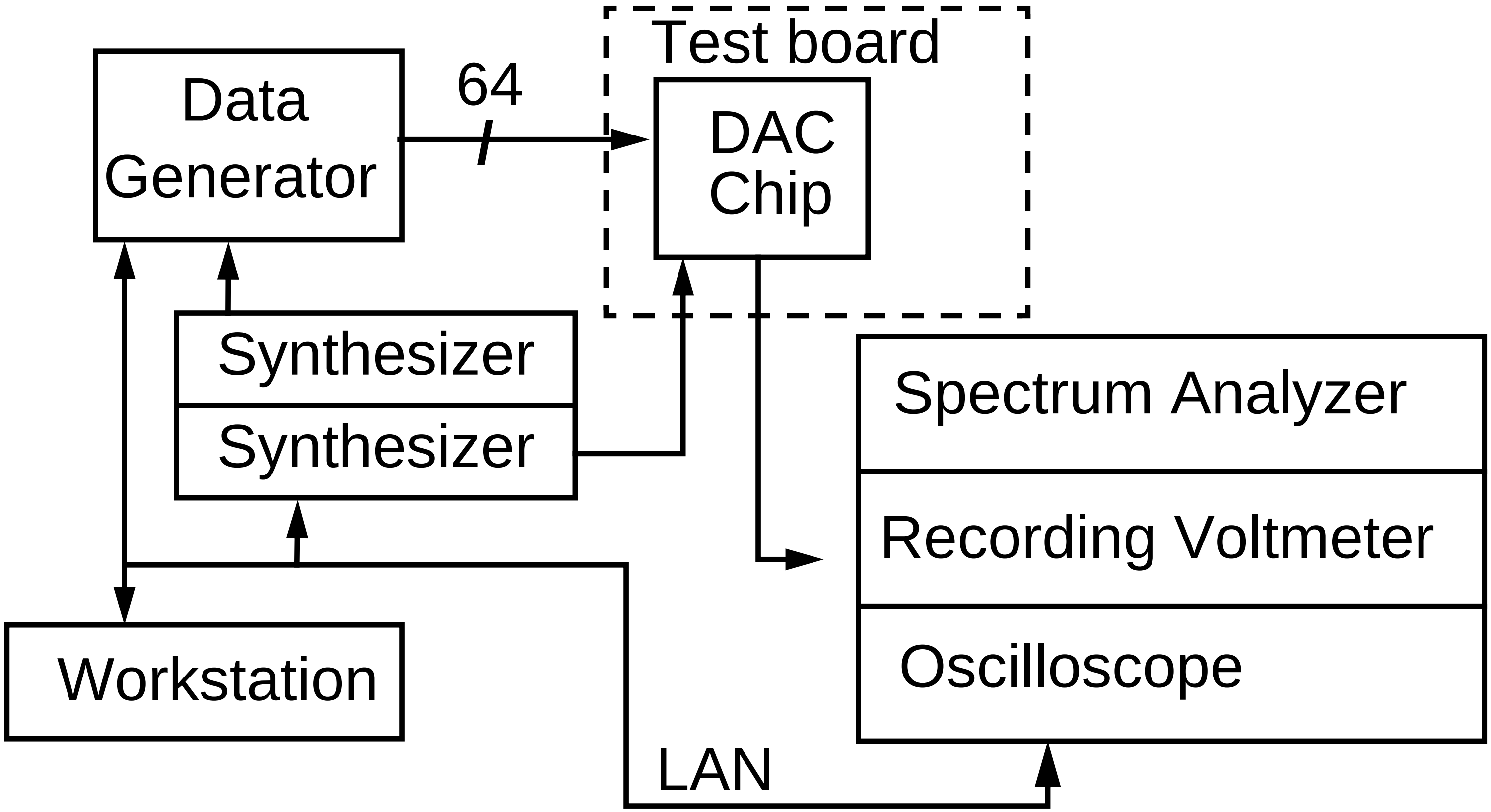


- Matching to 1/4 LSB of the 9-bit ladder
- Capacitance on the ladder delays the LSBs
- Currents at the output can be very high, causing heating and electromigration



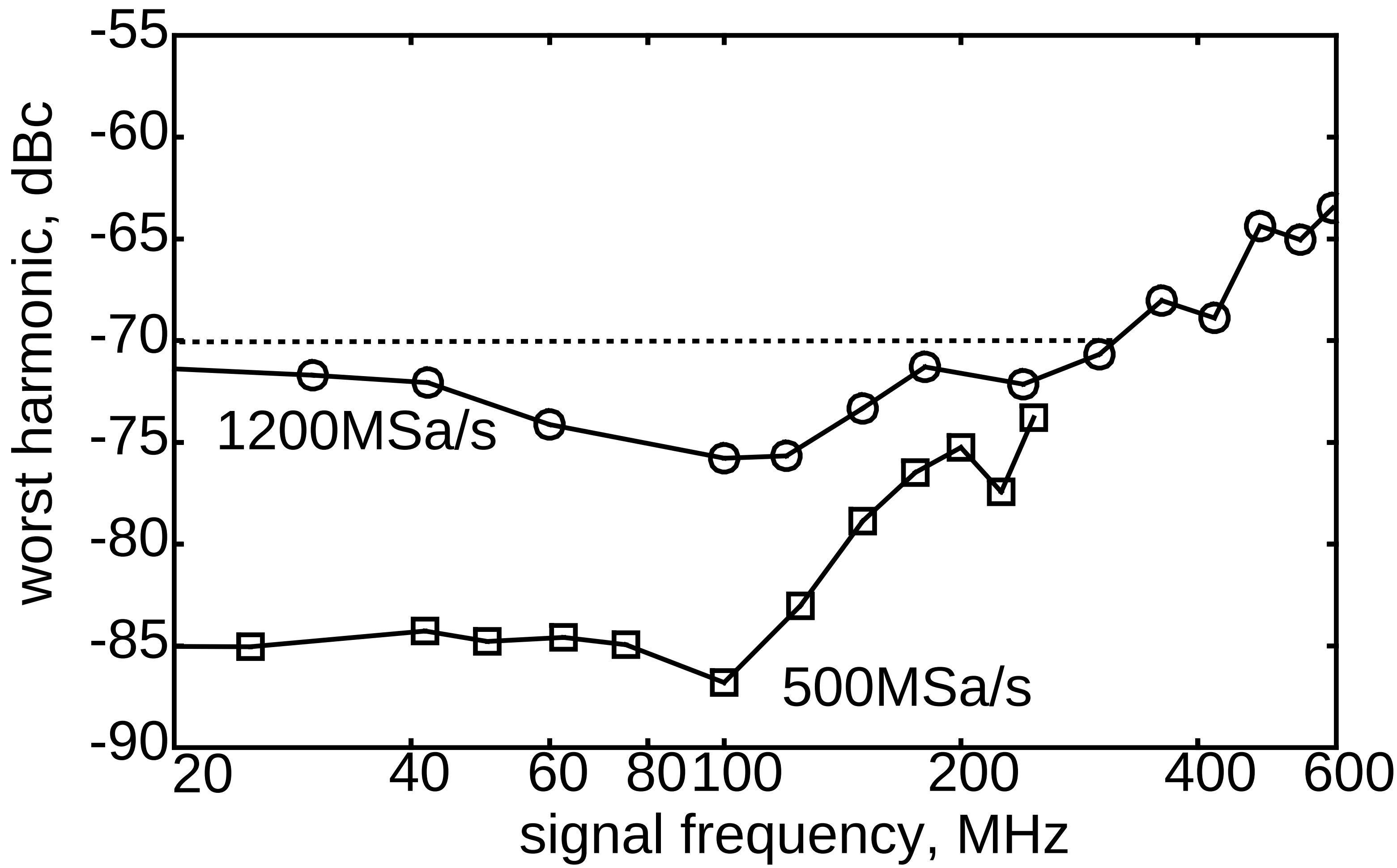
5 mm x 6 mm, 0.35-µm BiCMOS,40-GHz NPNs,
3.3V and -2V supplies, 6.5W total power

Test System



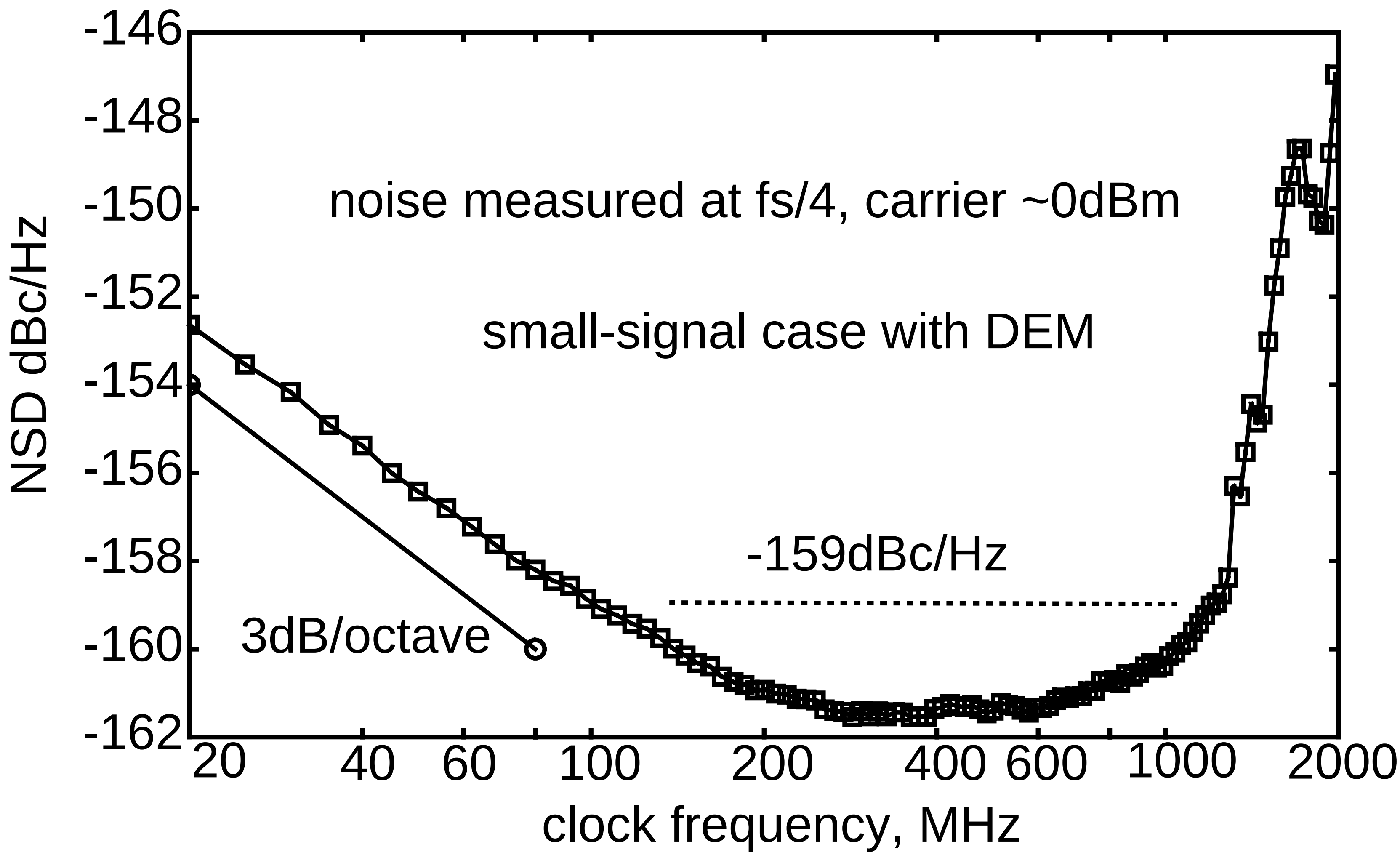
- Data generator goes up to 660/1320 MSa/s
- Voltmeter has sub-LSB accuracy
- Digital oscilloscope with 6GHz of bandwidth

Harmonic Distortion



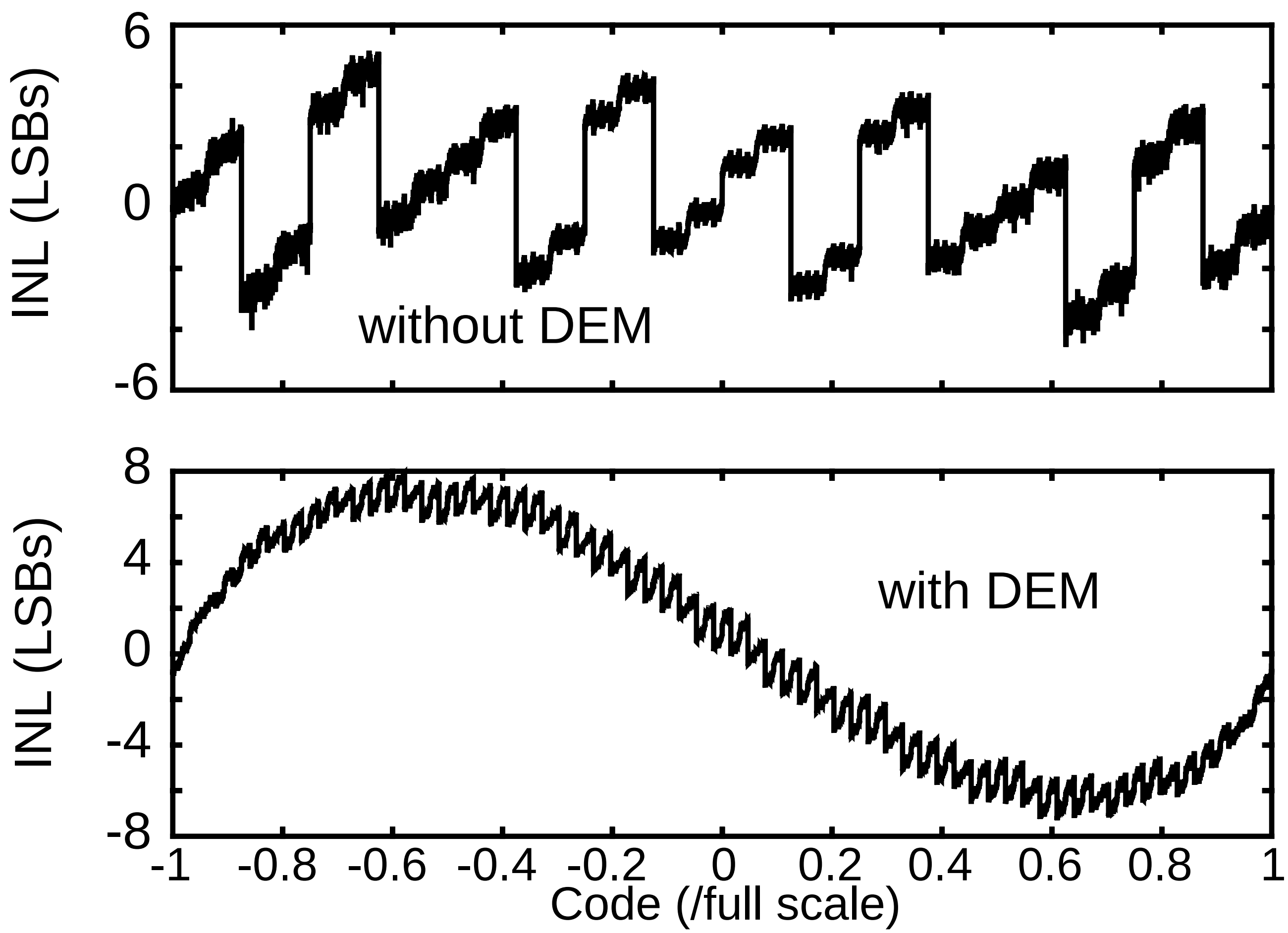
- < -80 dBc at low frequency and clock rate
- -70 dBc up to 300 MHz at 1200 MSa/s

Noise Spectral Density



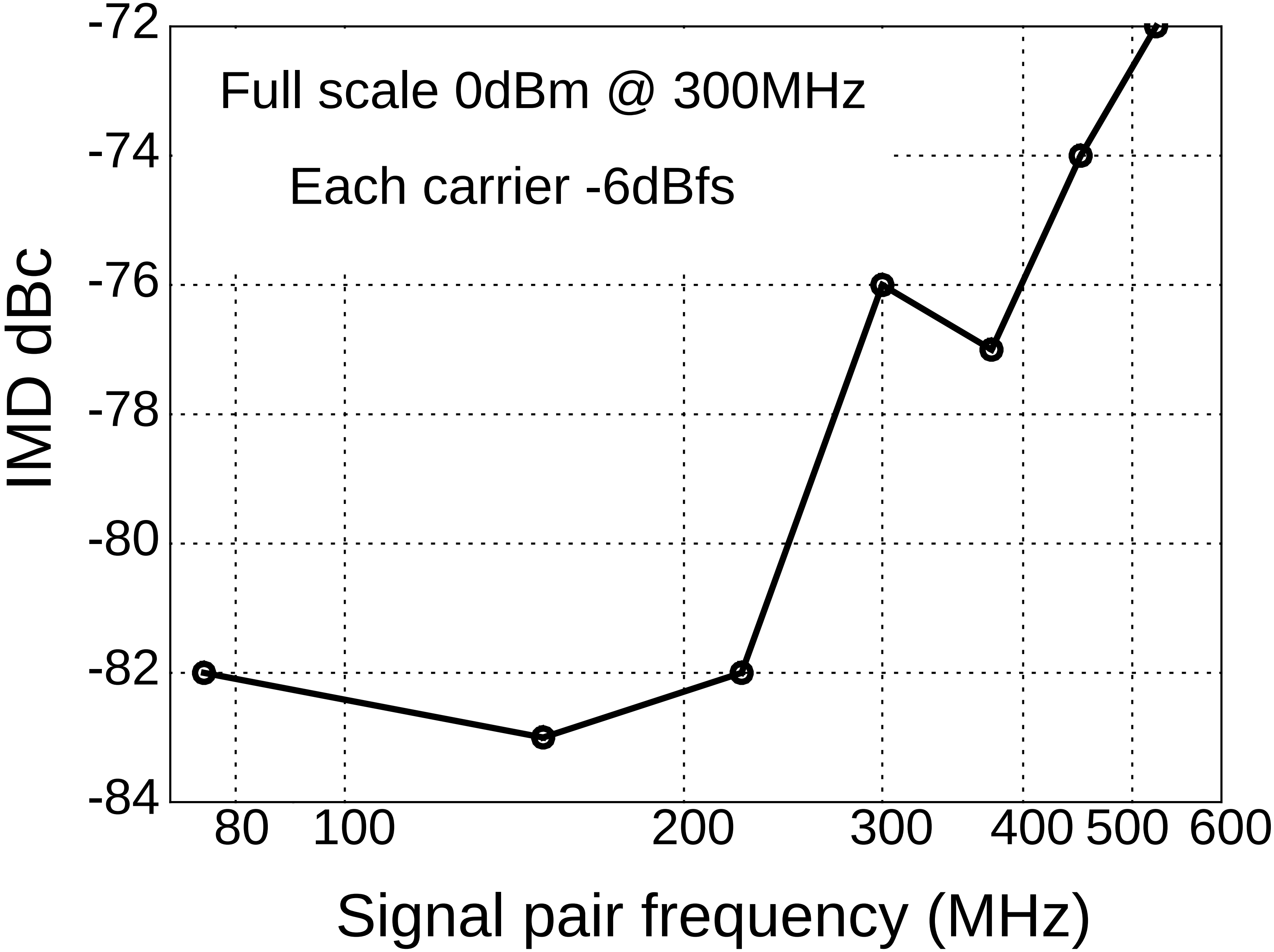
- -159 dBc/Hz is 80 dB SNR in an 80 MHz BW
- The chip clocks to beyond 2000 MHz

Integral Nonlinearity (INL)



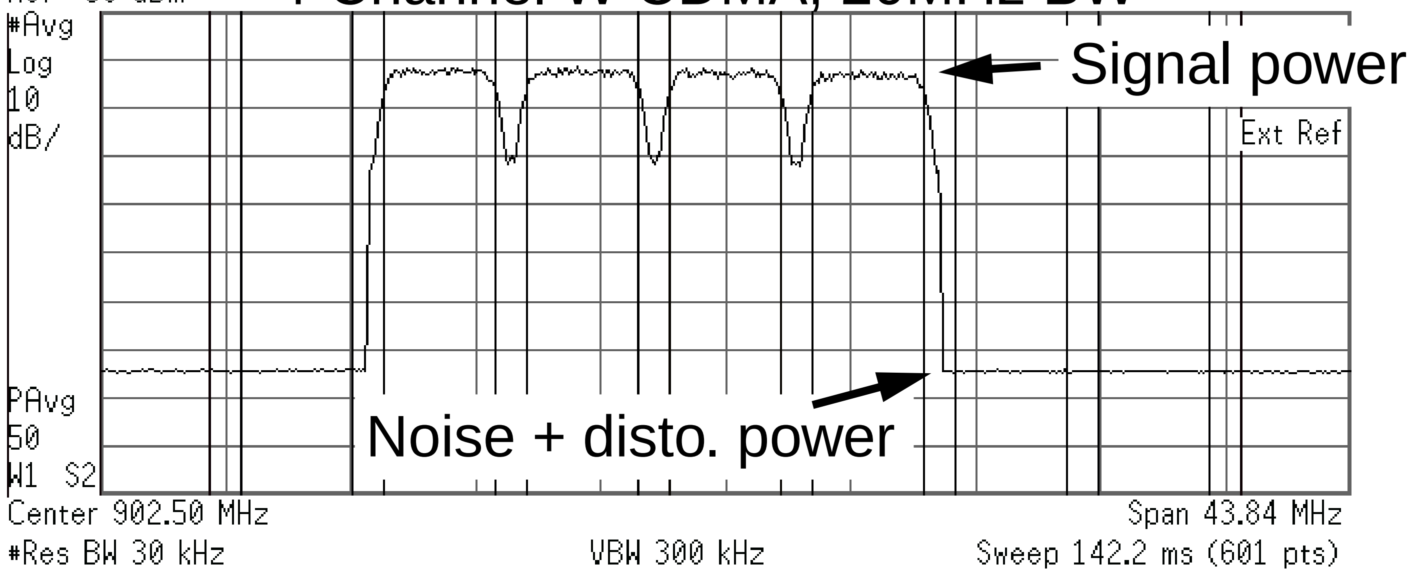
- DEM reduces DNL 3x but adds 3rd-order distortion
- May be from transients in the current sources

Two-Tone IMD vs. Frequency



Adjacent Channel Power Ratio (ACPR)

4-Channel W-CDMA, 20MHz BW



RMS Results	Freq Offset	Ref BW	Lower dBc	Lower dBm	Upper dBc	Upper dBm
Carrier Power	5.000 MHz	3.840 MHz	0.32	-21.80	-0.44	-22.56
-22.12 dBm /	10.00 MHz	3.840 MHz	0.43	-21.69	-71.07	-93.19
3.84000 MHz	15.00 MHz	3.840 MHz	-69.01	-91.13	-71.27	-93.39
	20.00 MHz	3.840 MHz	-69.26	-91.38	-71.72	-93.84

- At 300 MHz, ACPR is -72 dBc
- At 900 MHz, ACPR is -69 dBc
  - RZ for better high-frequency performance

Summary

- 1200 MSa/s spec’ed, operation to 2000 MSa/s
- -69 dB ACPR in 2nd Nyquist band (900 MHz)
- Distributed resampling improves performance by 6 dB
- Dynamic element matching improves DNL