Administrivia

- Oral timeslot Doodle has been posted
  - Most students have grabbed a slot
- Need to arrange sit-down signup as well (upcoming)
- Come prepared to labs!
  - In particular lab 4.
- Low # of reflection submissions (24, 17, 17)
  - Common reasons, or just coincidence?

Specifications and dynamic range

DAT116, Dec 3 2018

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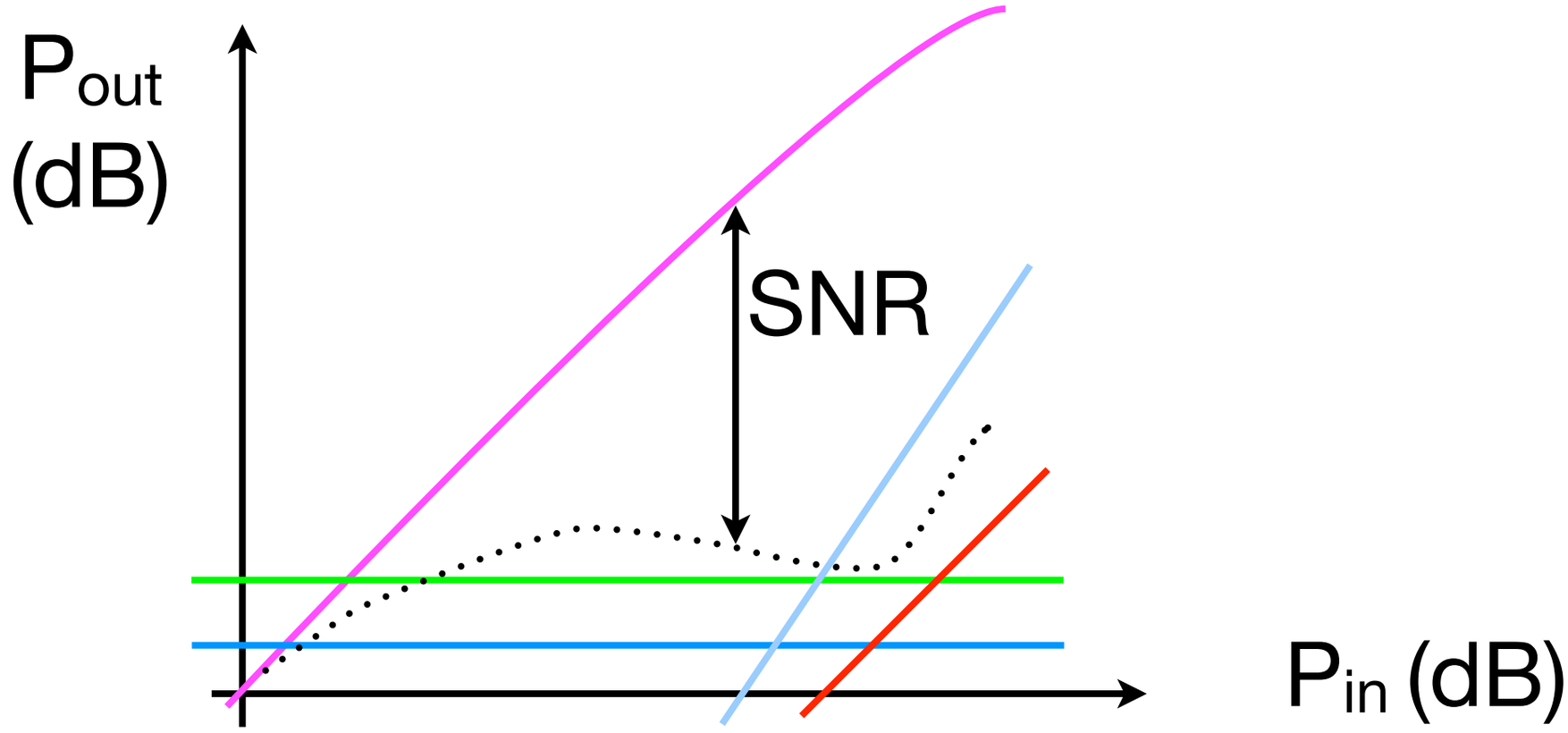
Conversion phenomena

- Ideal
  - # bits
  - Sample rate, aliasing
- Non-ideal
  - noise
  - jitter
  - nonlinearities

Manifestations



- Desired signal
- Thermal noise
- Quantization noise
- Sampling jitter
- Harmonics (2f, 3f, …)
- Other stuff…

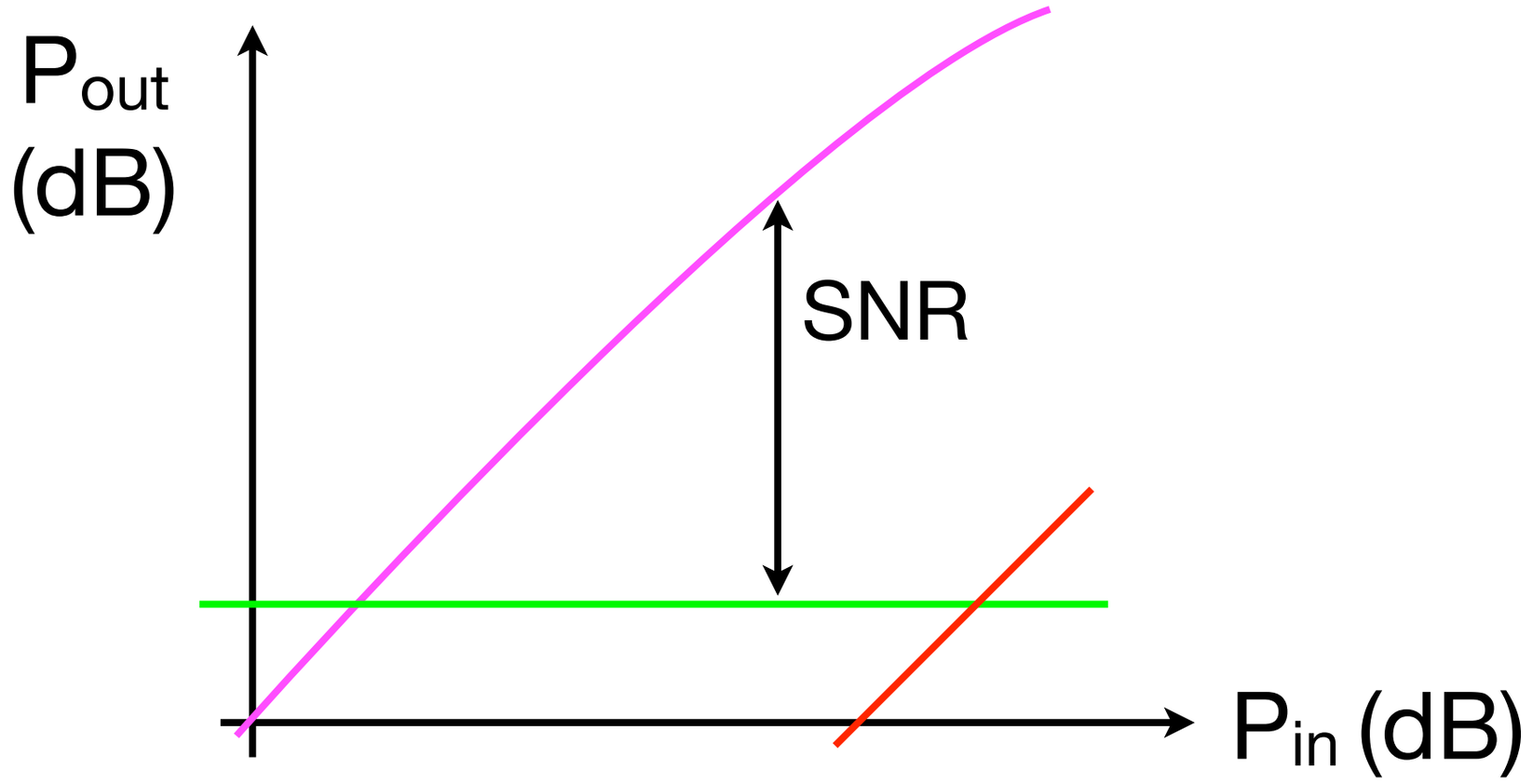
Limits

- Small end
  - Noises
- Big end
  - Nonlinearities
- All over
  - Jitter

- Reading: Maloberti Ch. 2

Performance measures

Signal to Noise Ratio (SNR)

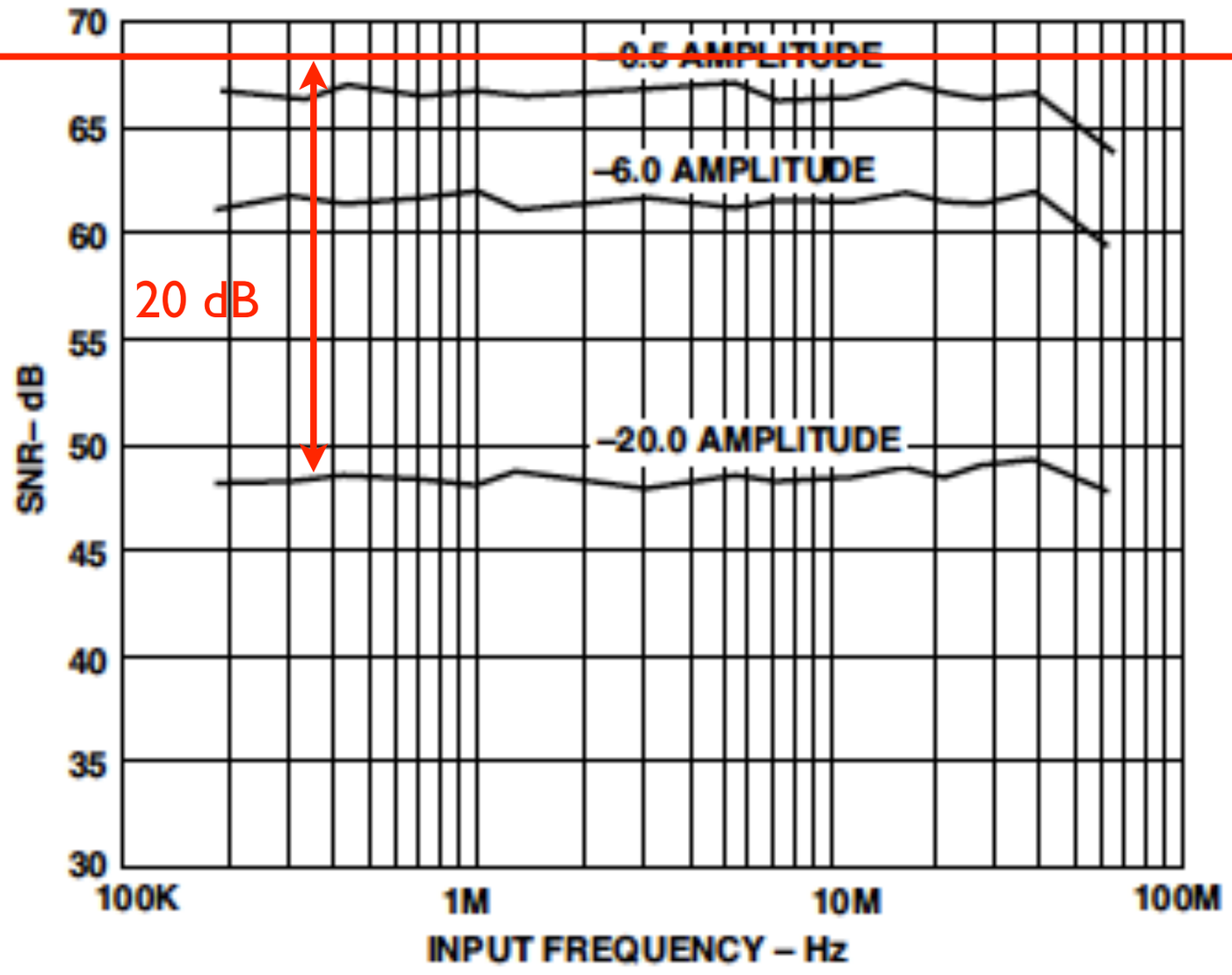


- Ratio of signal power to noise power (in dB): S / N
- Typically assumes single-sinewave input
- Must specify input level, frequency, and bandwidth!
- Most often, largest value across input levels is given

ADC example

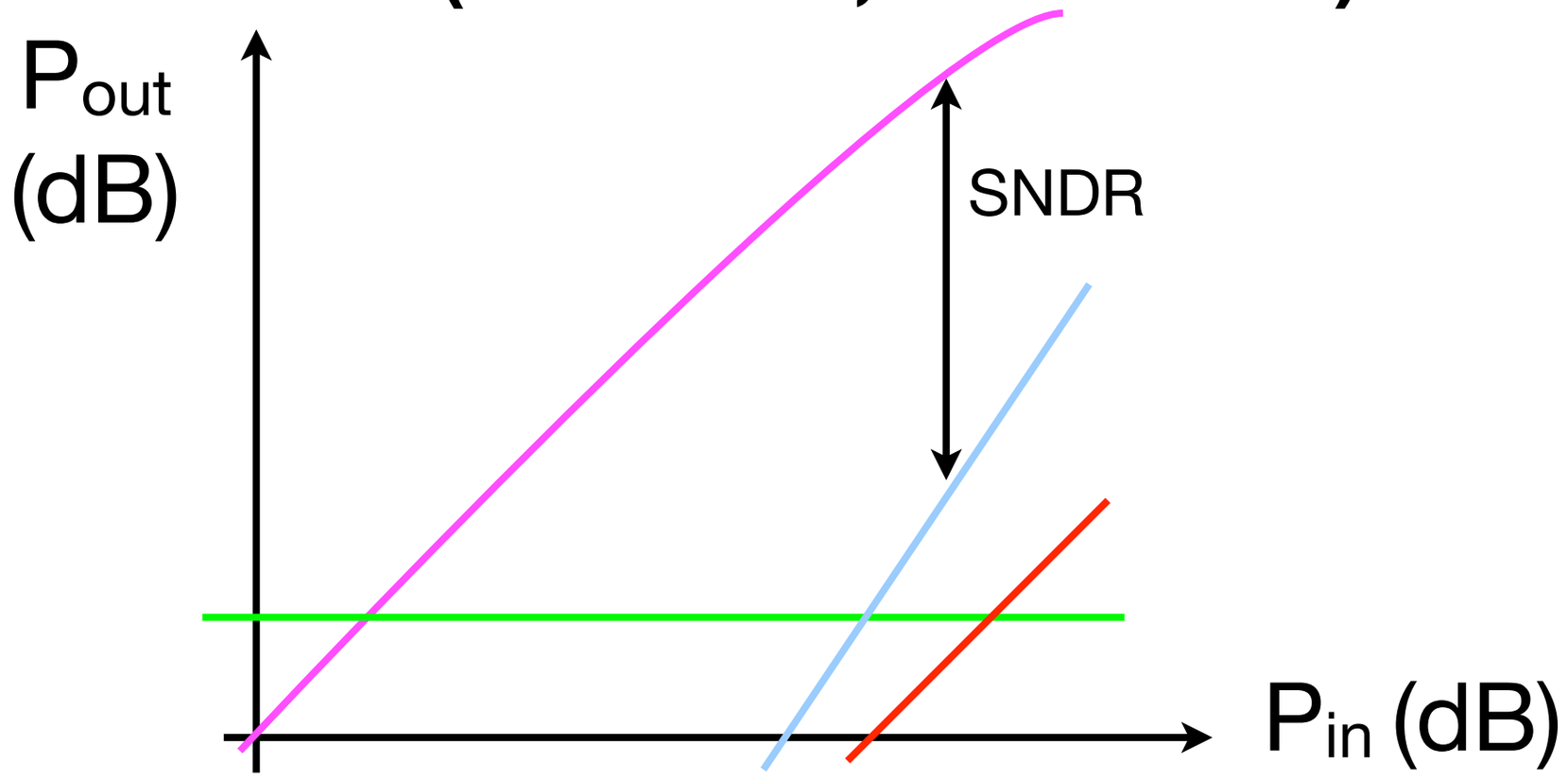
Resolution?

≥11 bits



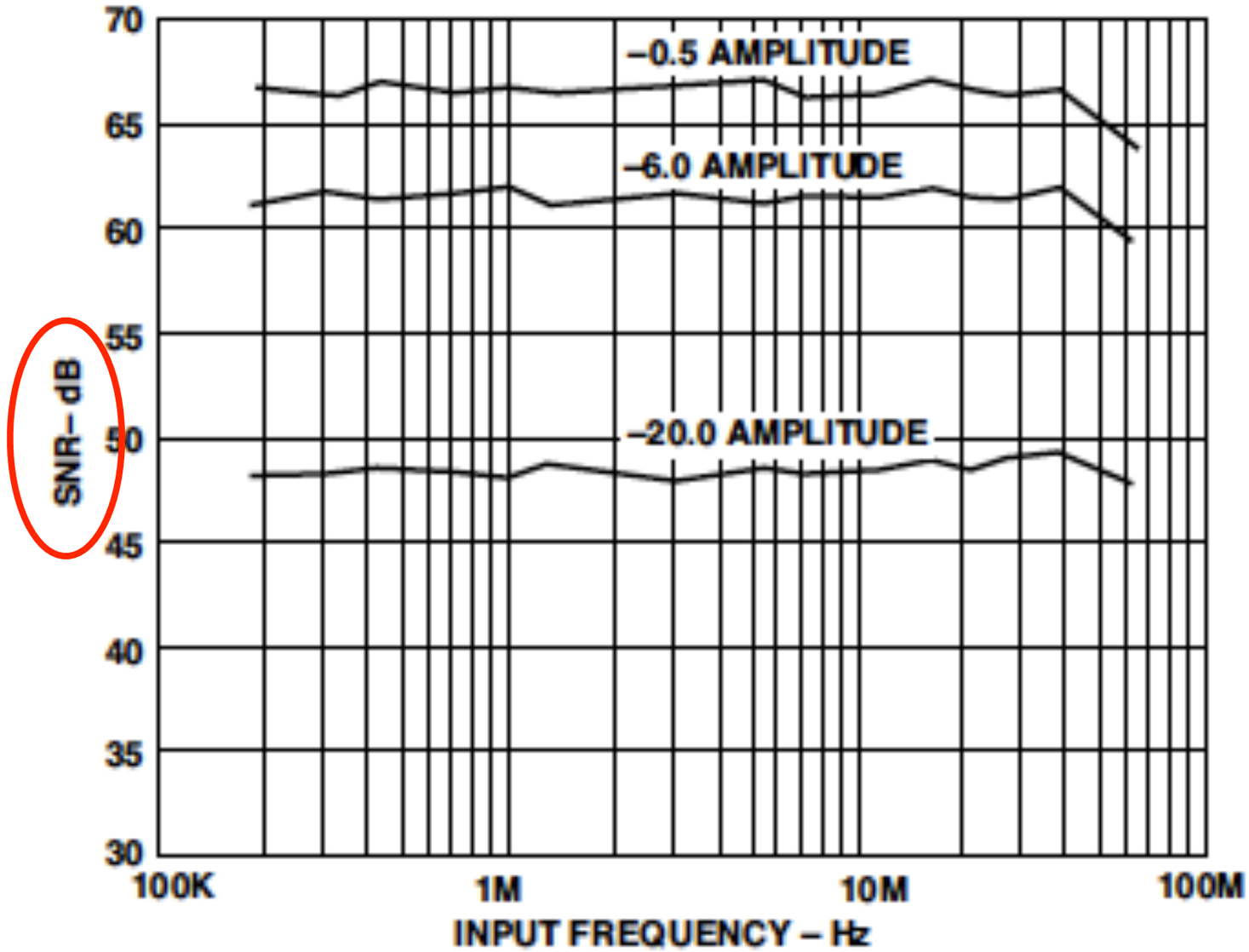
- SNR vs signal frequency at several amplitudes

Signal-to-Noise-and-Distortion Ratio (SNDR, SINAD)



- Explicitly include harmonics: SNDR = S / (N + D)
  - Sloppy terminology. “SNR” may include D too. Careful!
- Varies with level and frequency, just as SNR does
- Note: SNDR may shrink with increased power level!
- Beware measurement bandwidth!

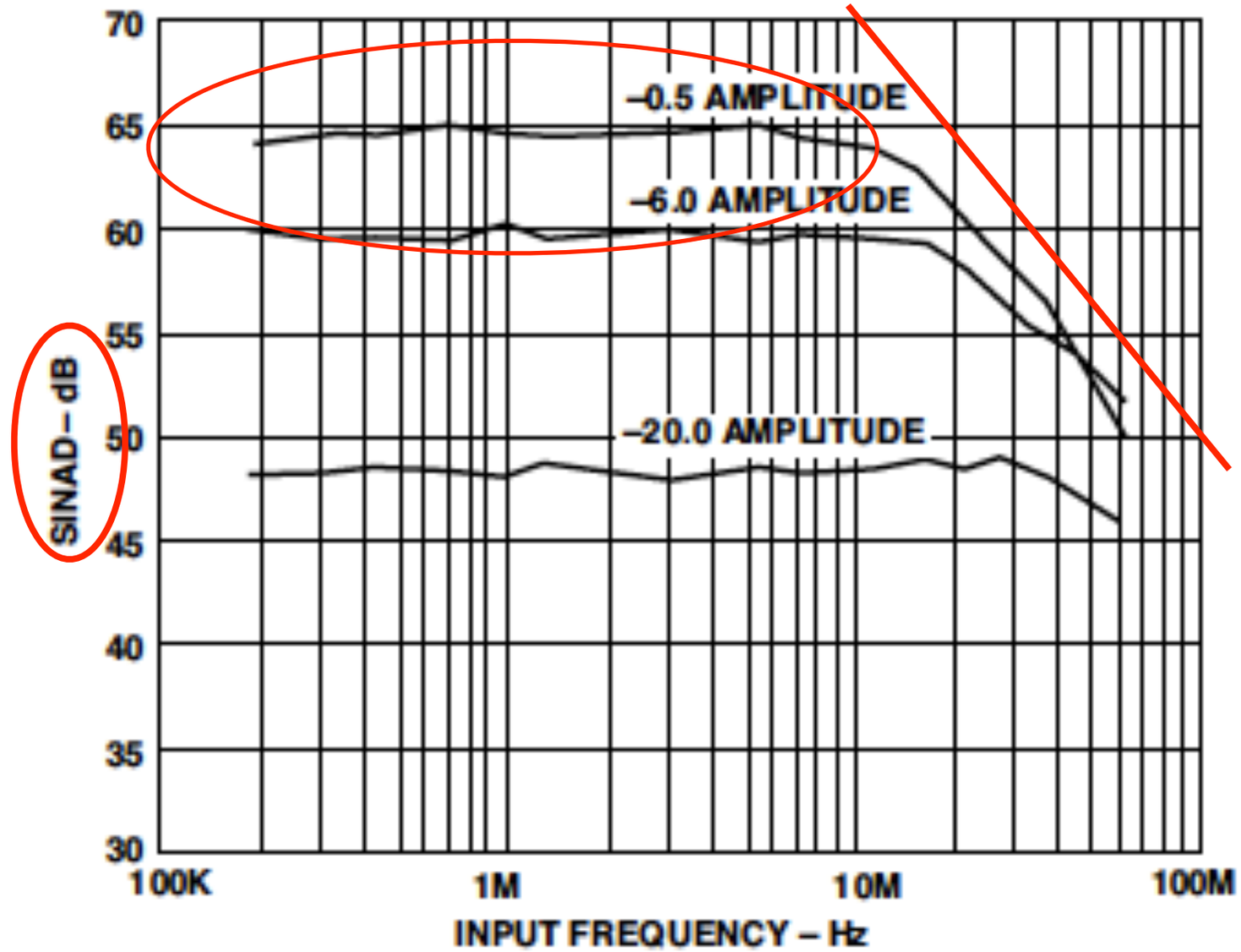
ADC example



- SNR vs frequency for several amplitudes

ADC example

INL



20 dB / dec

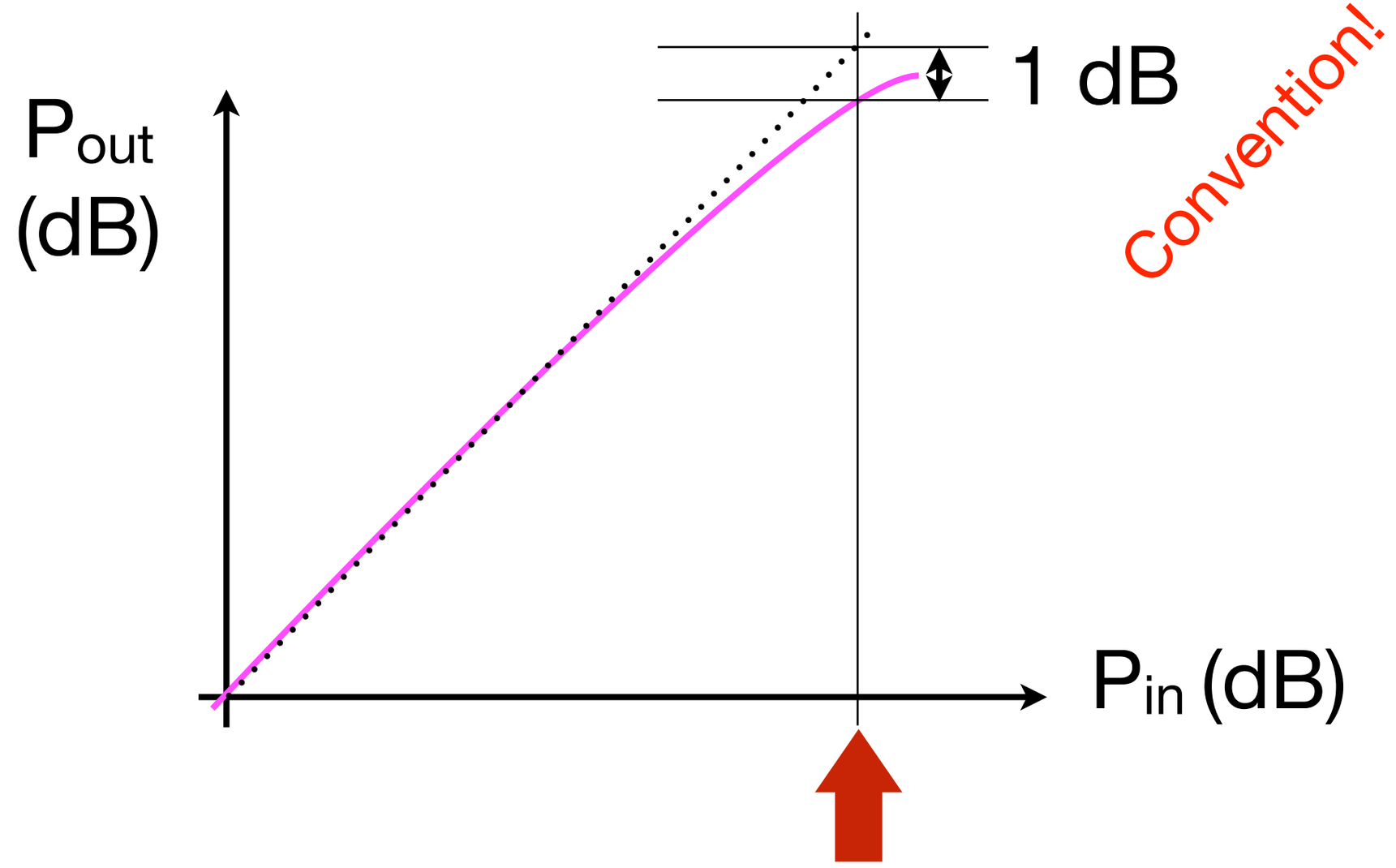
Jitter?
Distortion?
Raw-gain limit?

- SINAD vs frequency for several amplitudes

Effective # of bits (ENOB)

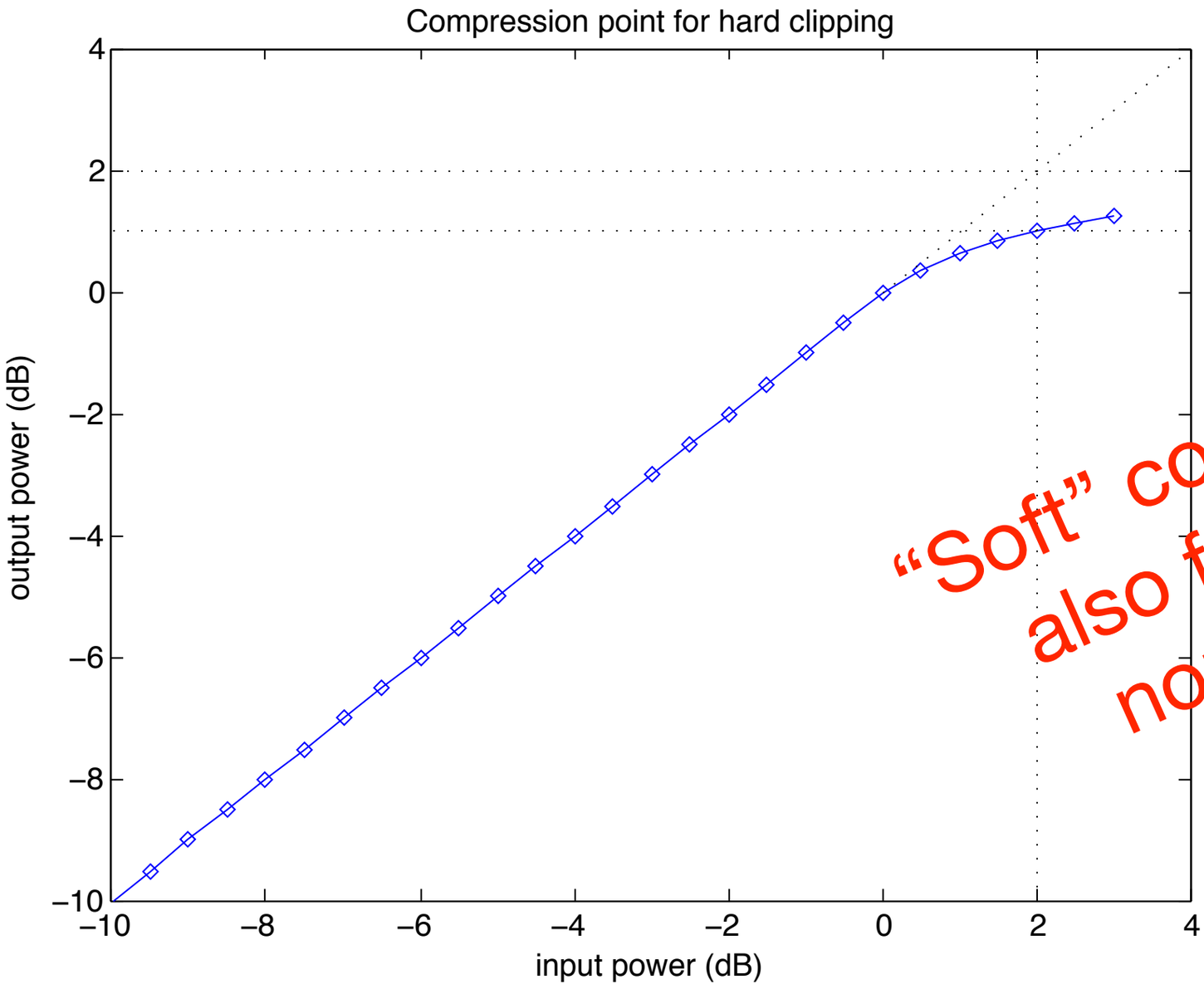
- Relate total noise and distortion to a hypothetical “perfect” converter
- ENOB = ($SINAD_{dB}$ – 1.76) / 6.02
  - Should be close to actual # of bits
  - May be difficult, esp. at high speeds
    - See previous slide!

Compression point



- Maximum “useful” input level

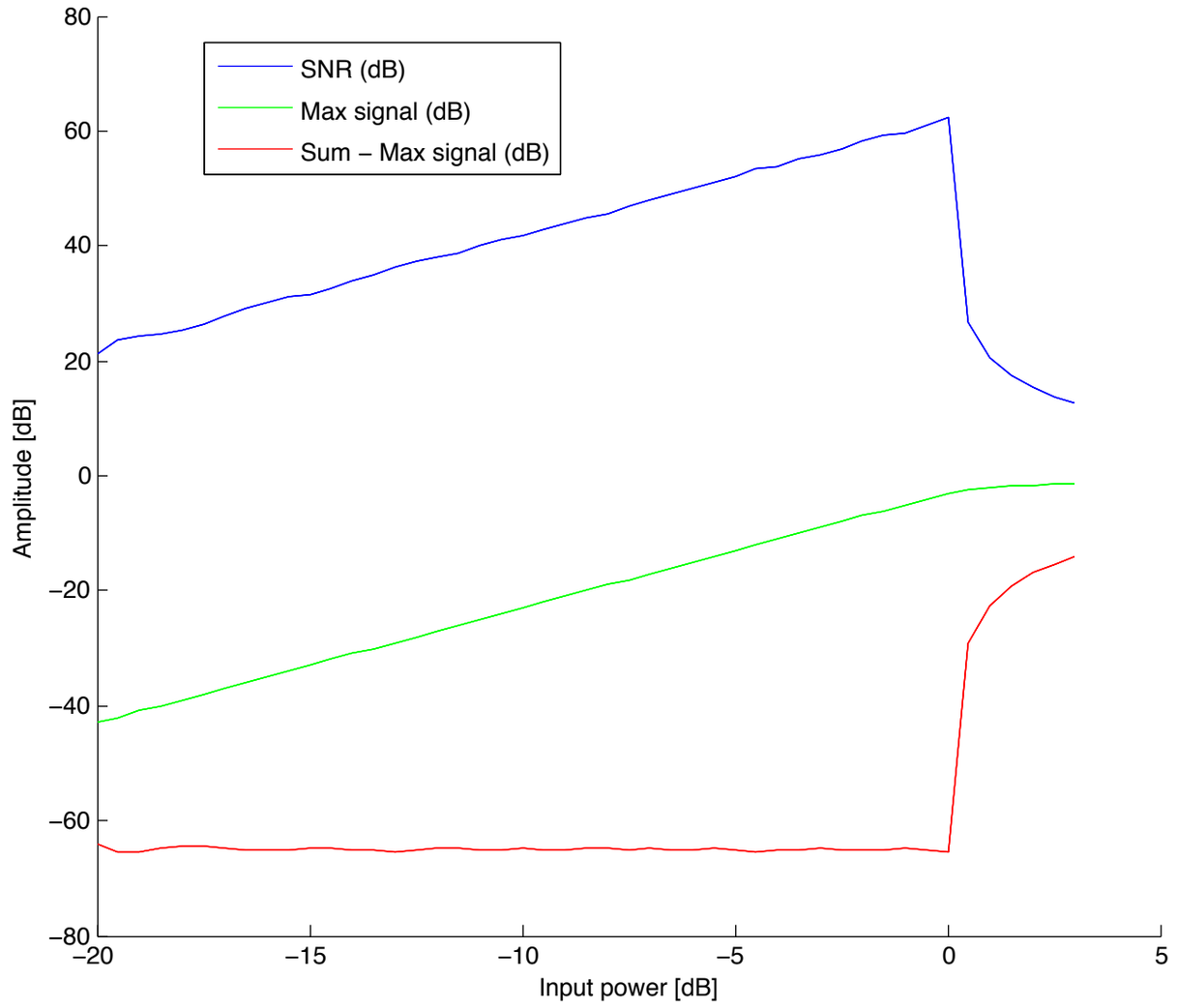
Ex: CP for hard clipping



"Soft" compression also for "hard" nonlinearity

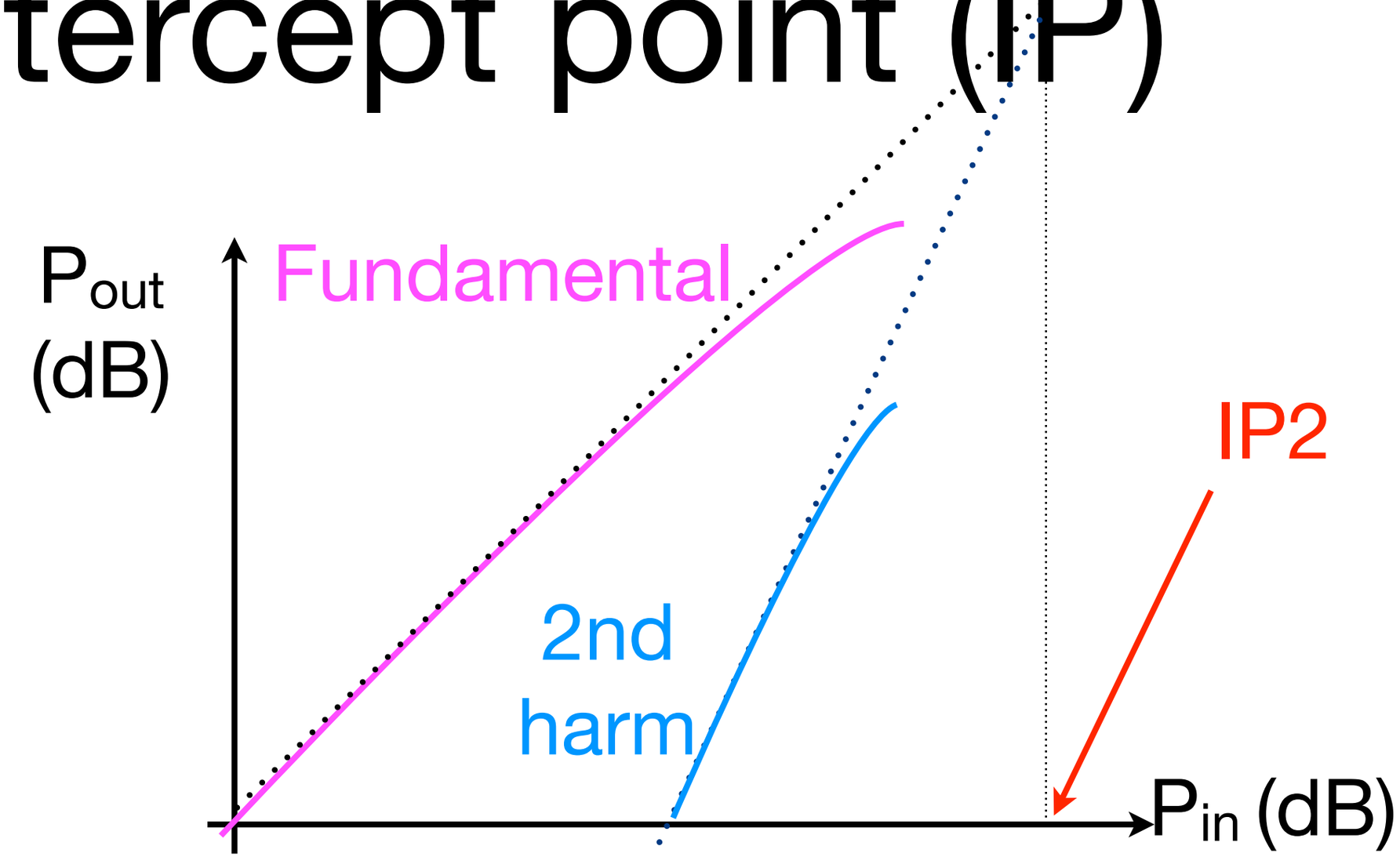
- Single sinewave clipped at 0dB

Image from a Lab3 report…



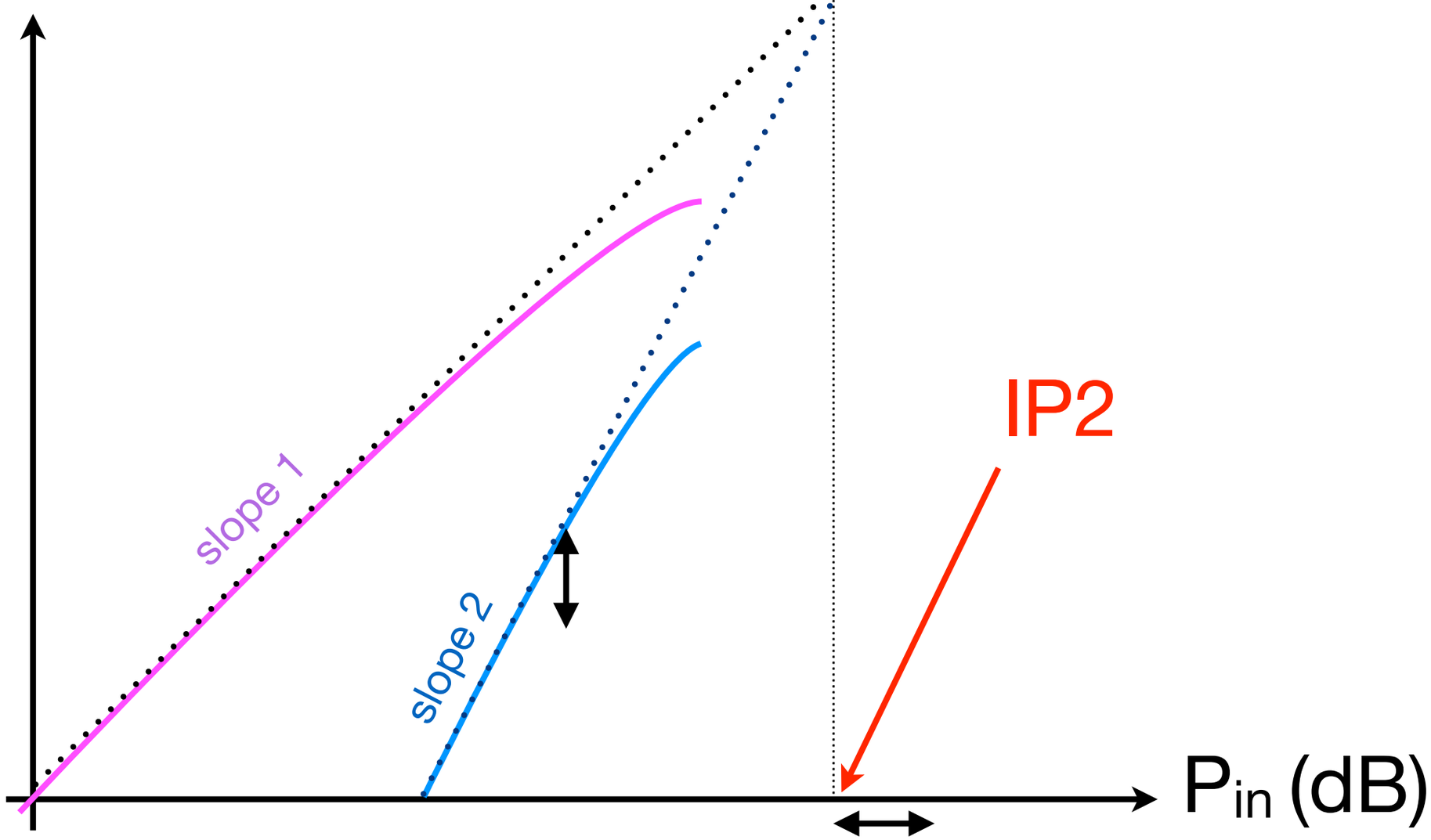
- SNR reduction mostly due to distortion rise

Intercept point (IP)



- IP2, IP3 etc (per harmonic)
  - IP3 typically the most critical one
- With CP, relates H*n* to fundamental

High IP is good!



- Suppress harmonic *n* by *x* dB
  - IP*n* increases by *x* / (*n* – 1) dB

High-f distortion?

- Pure harmonic falls outside band of interest!
- More important: 3rd-order <u>intermodulation</u> (IM)

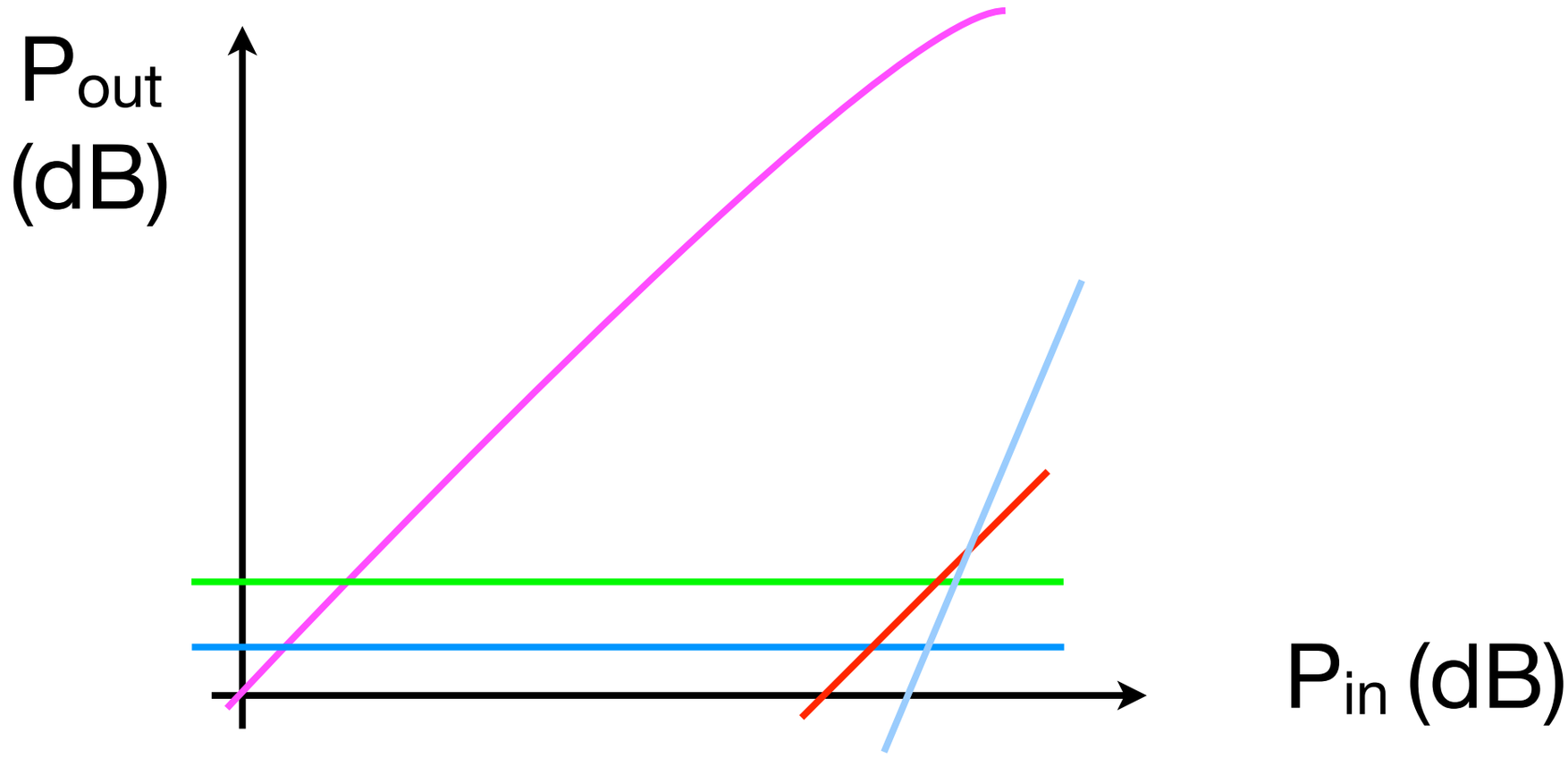
$$(\sin(2\pi f_1 t) + \sin(2\pi f_2 t))^3 =$$

$$= \sin^3(2\pi f_1 t) + 3\,\sin^2(2\pi f_1 t)\,\sin(2\pi f_2 t) + \ldots$$

$3f_1$ f_1 $2f_1$ dc f_2 $2f_1 \pm f_2$

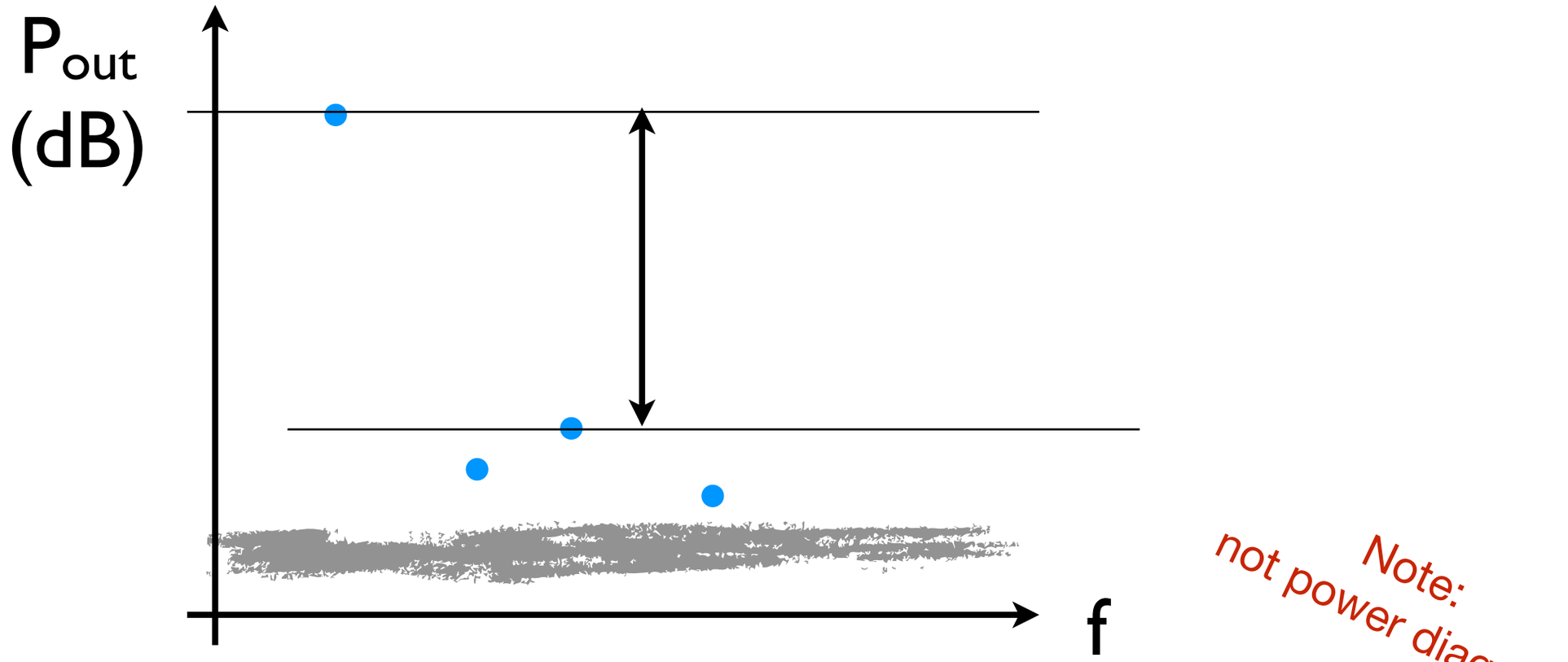
- With $f_2 \approx f_1$, $2f_1 - f_2 \approx f_1$ 😫
- Intermodulation products close to input signals!
- Can't be removed by frequency-selective filter!
- Magnitudes characterized by IP3

Balance



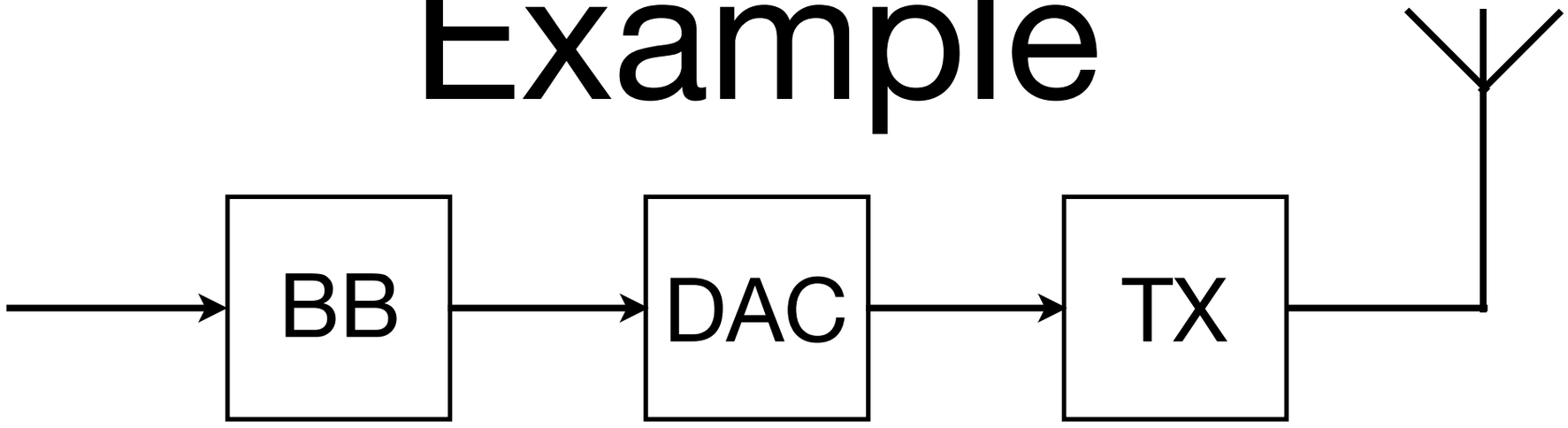
- Useful dynamic range often limited by H3, jitter
  - Strive to make neither error much worse than the other

Spurious-Free Dynamic Range (SFDR)



- Signal vs. worst harmonic
  - Always numerically higher than SNDR
- Important in e.g. telecom systems

Example



- Radio modem (baseband, DAC, transmitter)
- Spectrum mask for transmitted signal
  - Specifies max transmitted power vs frequency
  - High power in intended band/channel, low elsewhere
- DAC SFDR may limit power outside intended band
  - Often given in dBc (relative to carrier, i.e. the intended signal)

Additional specs

- Power
- Electrical levels
- Temperature stability
- Drift
- Latency
- Timing
- …

Converter data sheets

The internet is full of them

Converter vs. system

- Same specification terminology useful for full interface system!
  - Converter, filters, amplifiers, etc
    - Useful for DACs as well as for ADCs
    - From full specs, derive specs for blocks
      - Assign “noise/distortion budgets”

Larger example

- Gigabit Ethernet signalling (twisted-pair copper wire)
- Issues:
  - Compatibility w/ 100Mb/s signaling
  - Cable properties
  - Error probabilities

Twisted-pair cable

- Four pairs, twisted at different #turns / m
- Cabling standard states length ≤100m

100Mb/s signalling

- Use one pair per direction
  - Two pairs unused!
- Three voltage levels (+1, 0, –1)
- Apply channel coding to avoid DC transmission
  - Essentially a filter with 0 at DC

1GB/s signalling

- As 100MB/s, but…
  - … use all 4 pairs…
  - … and each in both directions…
    - … and 5 levels (±2, ±1, 0)
    - … and better coding

- Figures from Roo et al (uploaded)

Bidirectional signalling?

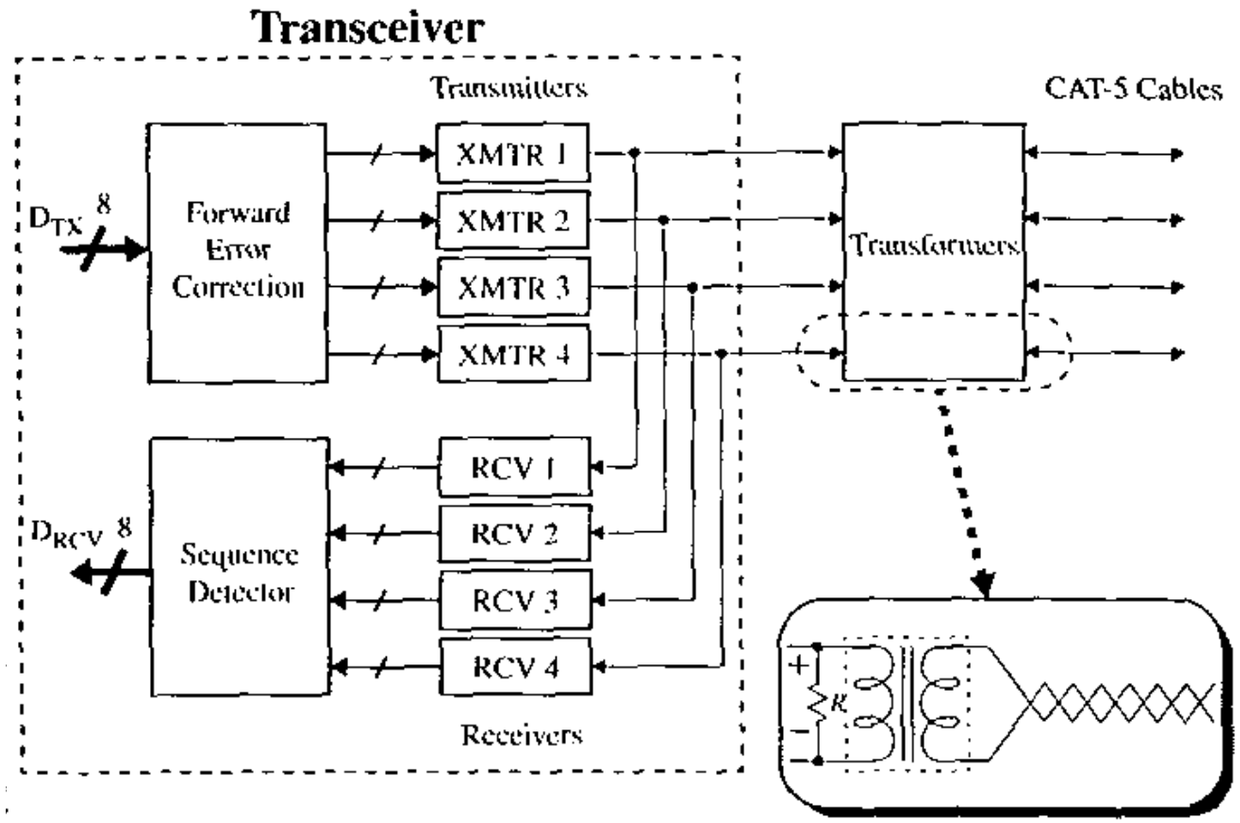
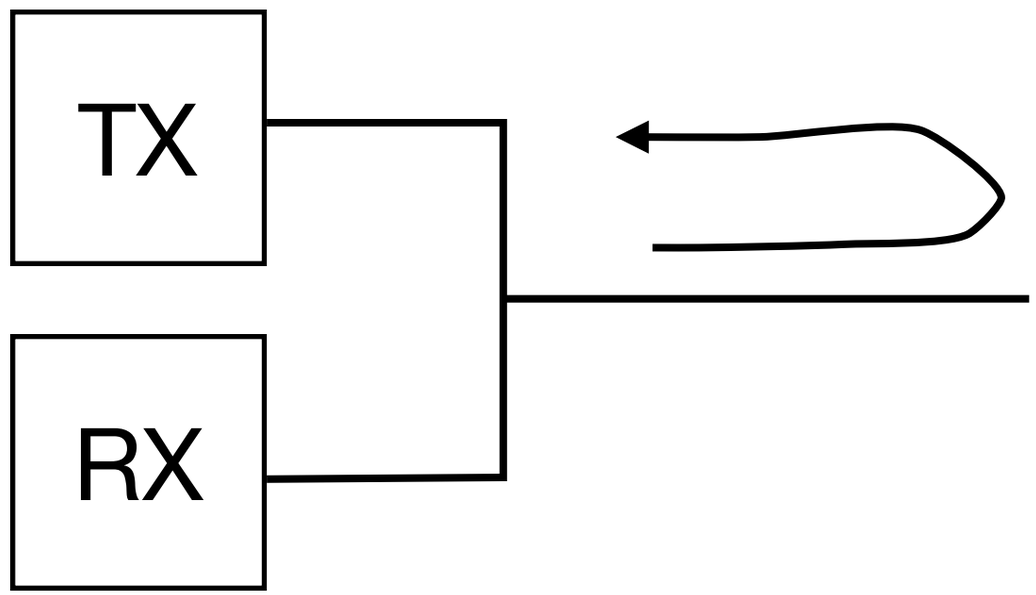


Figure 19.7.1: Gigabit transceiver system block diagram.

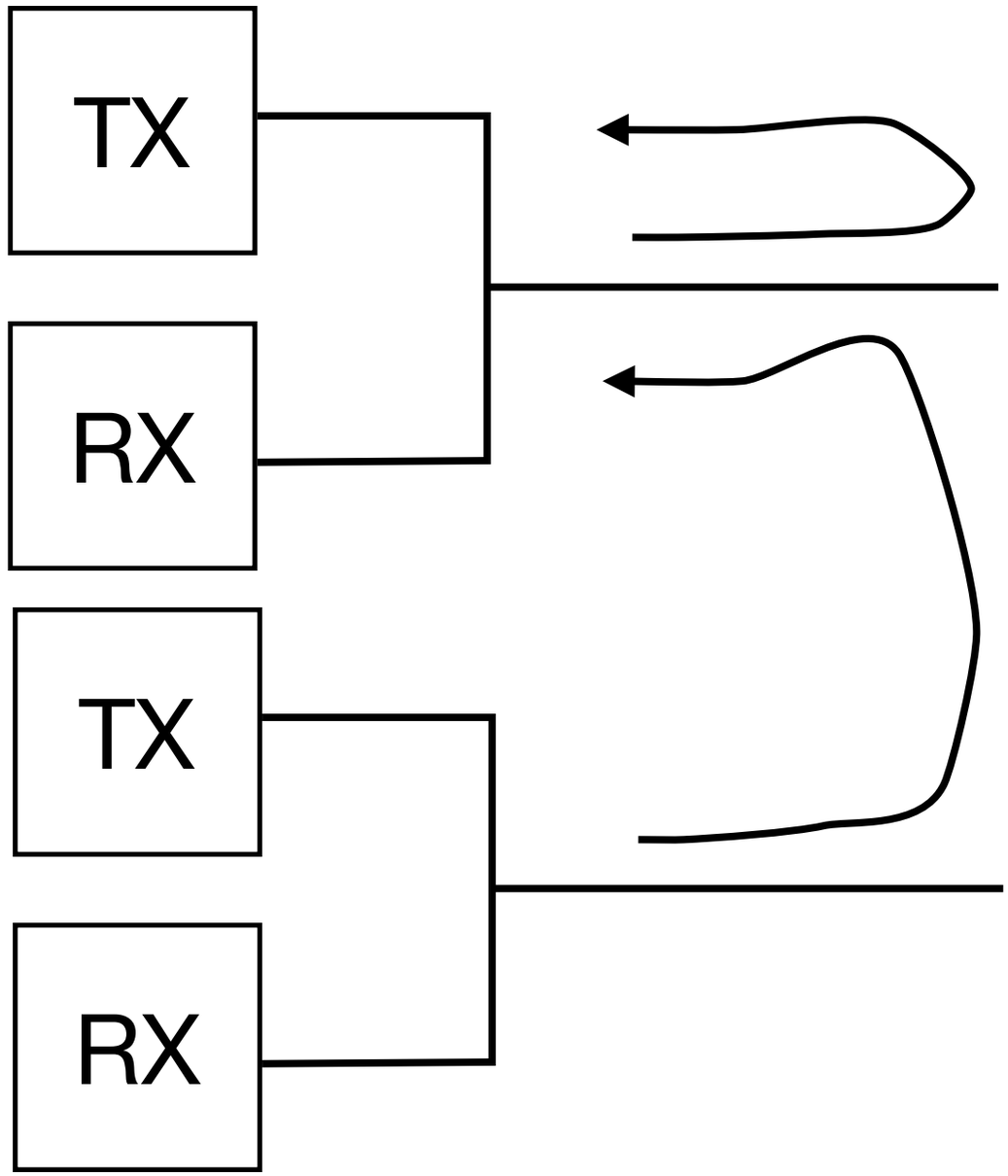
- Transmitter drives each line
- A receiver listens to <u>the same</u> line
- Must subtract transmitted signal from received signal

Echo



- Received signal also contains delayed version of transmitted signal
- Echo depends on cable, contacts, etc
  - Transceiver must adapt to whatever is plugged in

More echos

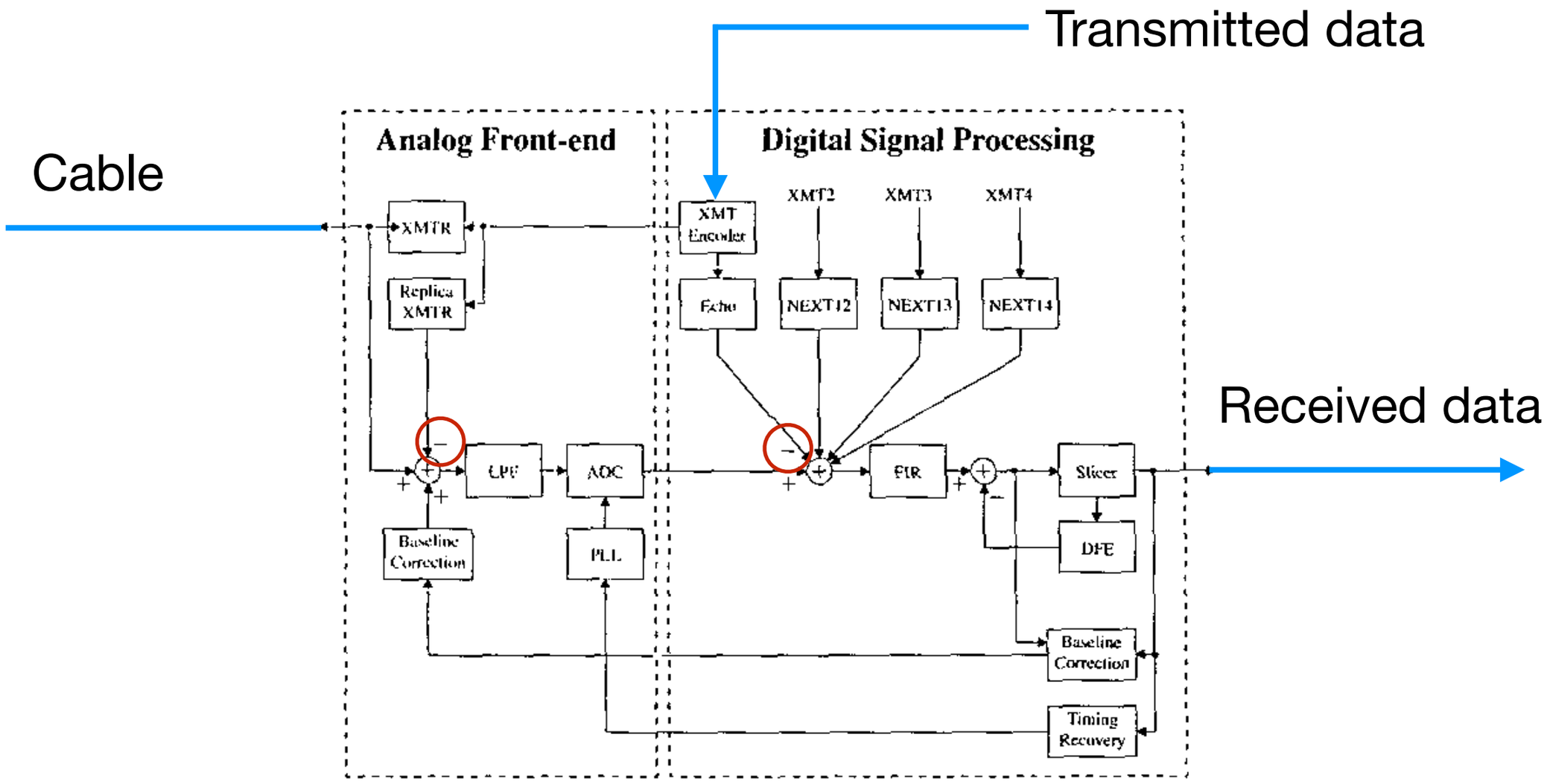


"Crosstalk" echoes have lower power

Not low enough to be ignored :-(

- All 4 near-end transmitters cause echo!

PHY architecture

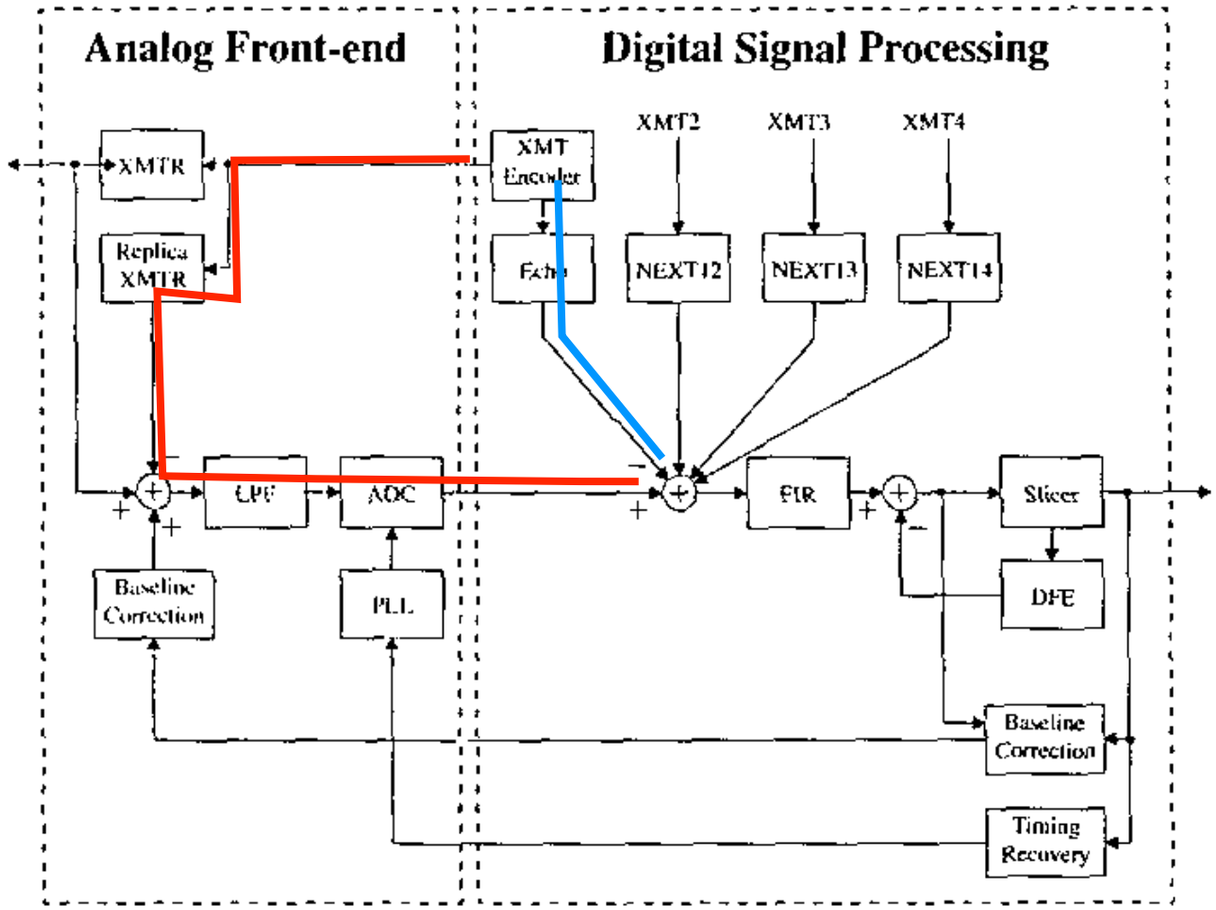


- Transmitted signal subtracted twice
  - Analogly(?) + digitally

How specify ADC, DAC?

- Cable standard specifies frequency response, echo, allowable voltage, external noise
  - Calculate worst-case power loss @ max length
    - Derive worst-case (weakest) signal power at receiver input
- Allowable bit error rate set by Ethernet standard
  - Derive necessary SNR, thence ADC ENOB etc.
- Simulate to verify!

DAC accuracy



- DAC-ADC path must cancel digital path
- High DAC accuracy needed, despite only 5 levels!

Summary

- Many ways to specify data conversion / mixed-signal performance
- Most specification styles are related
  - Often possible to estimate one from the other
  - Questionable accuracy…
- Preferred performance measure application dependent

Summary, cont.

- At system level, digital processing helps reduce requirements for ADC/DAC
- May also help improve ADC/DAC
  - Digital correction
  - Randomization
- Look forward to Theme 7!