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Coupled Interference in Mixed Signal Wireless ICs and Implications for Package Design

Robert C. Frye

Agere Systems
700 Mountain Avenue, Murray Hill, NJ

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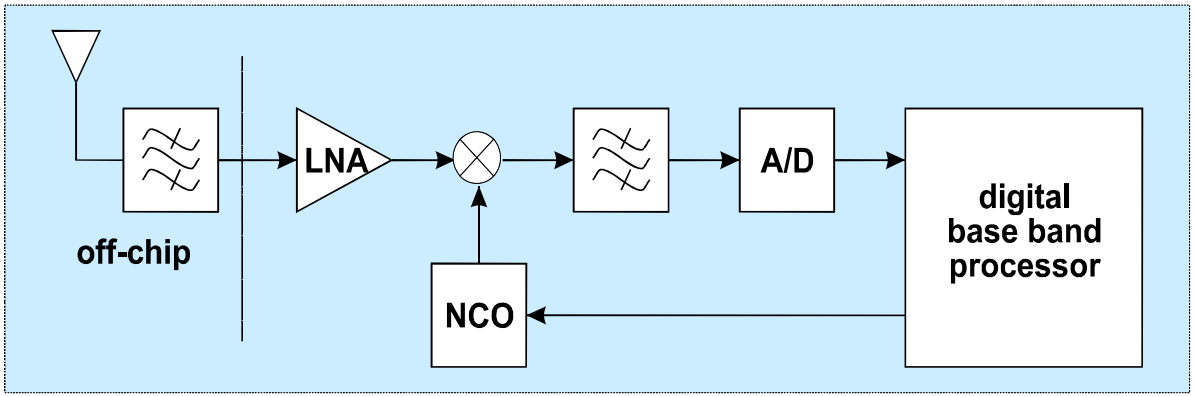
“Mainly digital” receivers



- Direct conversion or low-IF architecture eliminates analog IF stages.
- Digital implementation exploits Moore’s Law.
- Mixed-signal IC design leads to crosstalk noise problems.

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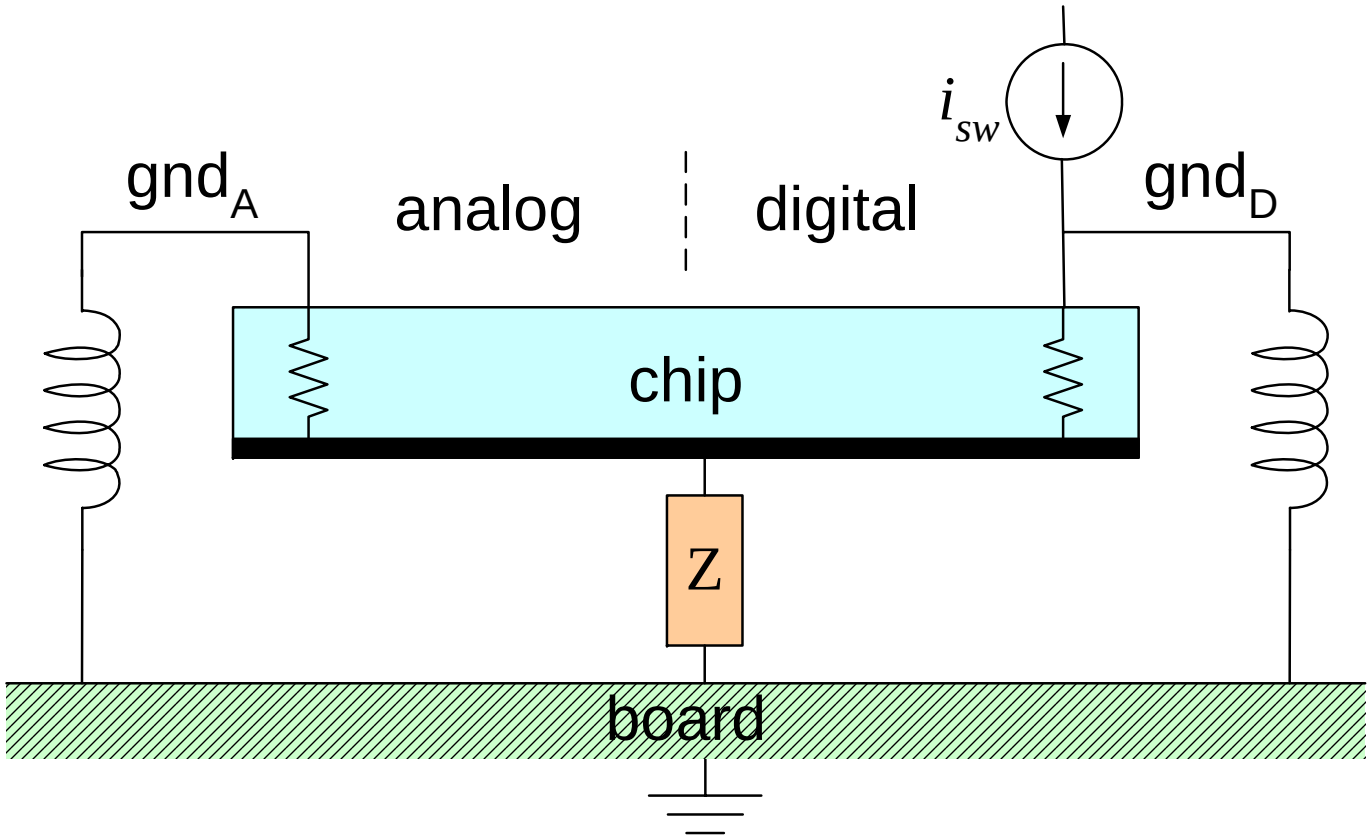
Switching transient coupling



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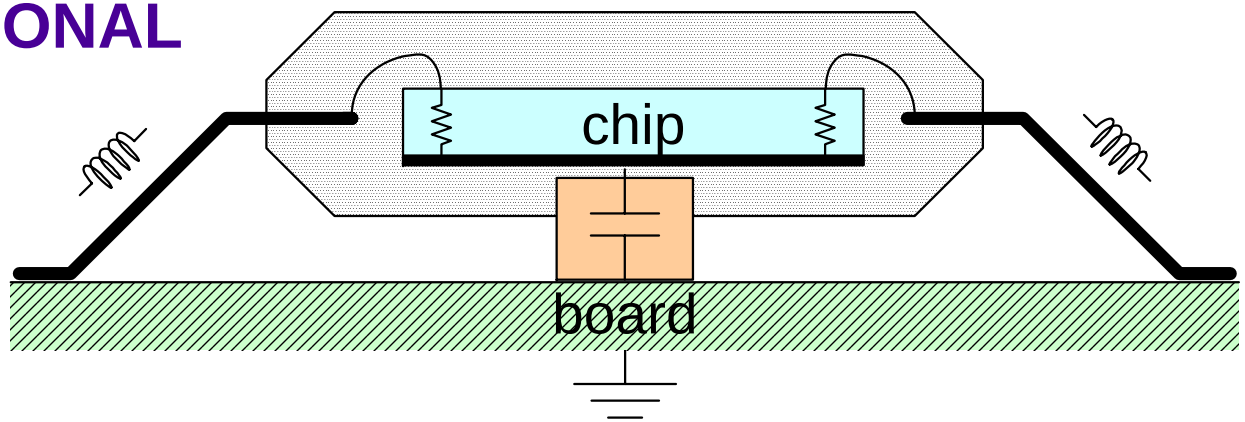
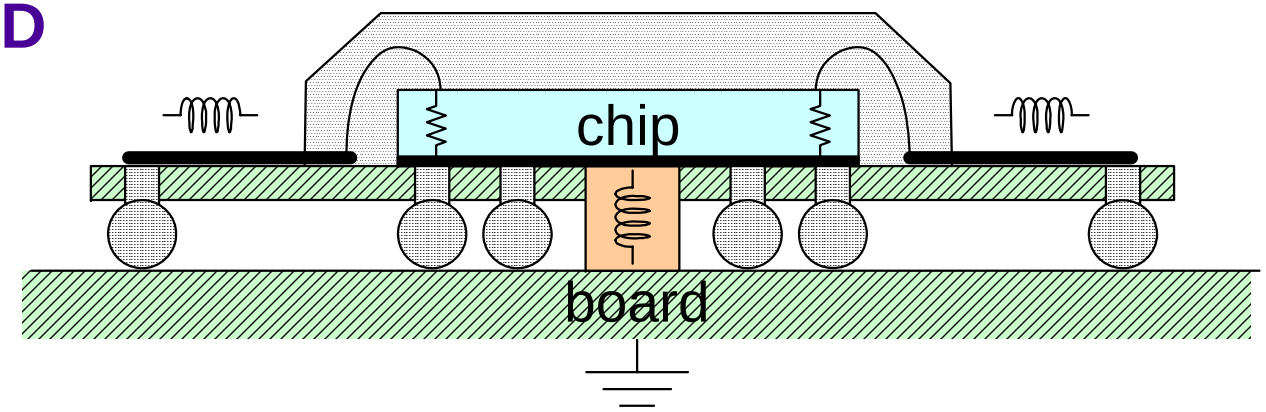
Example package type comparisons

CONVENTIONAL



ENHANCED



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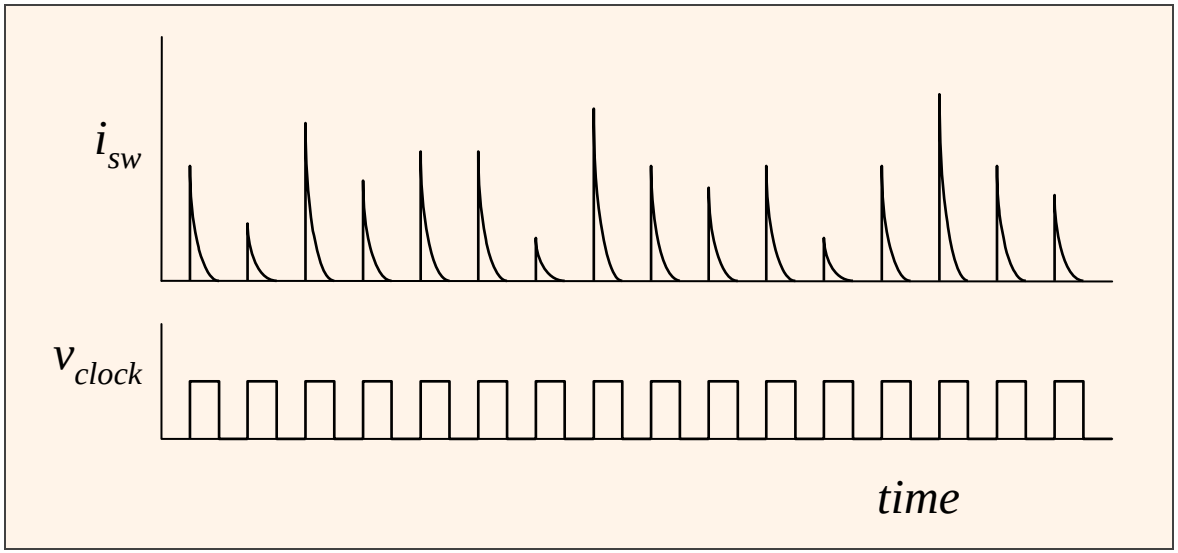
Switching transients



- Digital switching current transients appear stochastic in nature, but are correlated with the digital clock.
- This is a property of a cyclostationary process.

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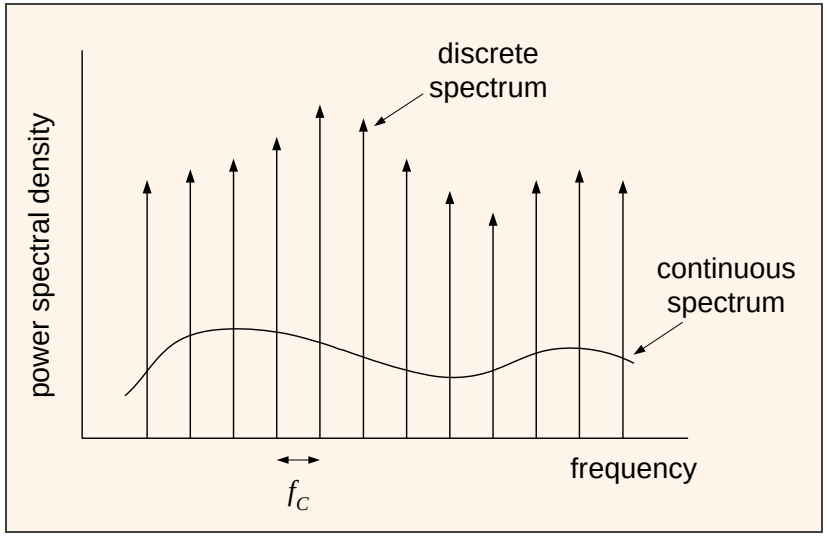
Spectral properties of cyclostationary waveforms

- Spectrum has both discrete and continuous components.
- Continuous spectrum depends on cycle-to-cycle correlation.
- Discrete spectrum, at multiples of clock frequency, depends on time-averaged waveform.



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Coupled digital noise in wireless systems

- The discrete spectral component of a cyclostationary noise source is particularly important because its power is concentrated at specific frequencies.
- For common digital clock frequencies, many spectral lines will fall inside a communication band, so interference is unavoidable.
- The severity of the interference depends not only on the degree of coupling, but also on the receiver's resolution bandwidth.

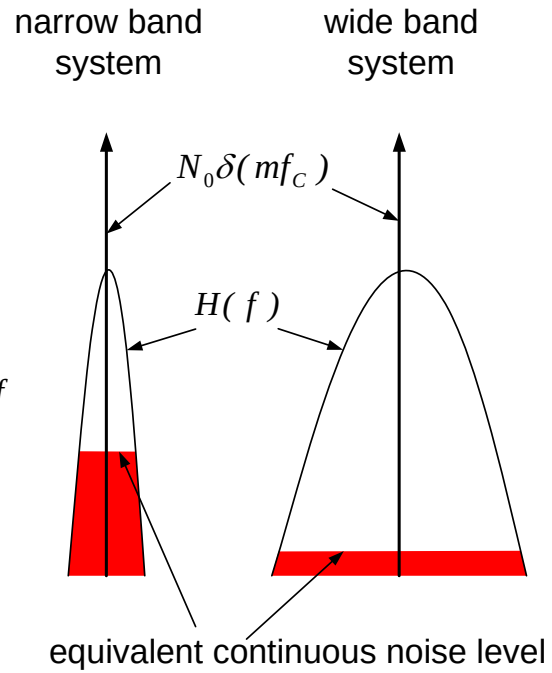
Discrete spectral noise and system bandwidth

- Discrete spectral noise is a delta function with infinite density at a single frequency.
- We can define an equivalent continuous spectrum of noise such that total noise power is the same.
- Discrete noise has greater impact on narrow band systems.

total noise power:

$$P_{tot} = \int H(f) S_N(f) df$$

$$S_{EQUIV} \approx N_0 / BW$$



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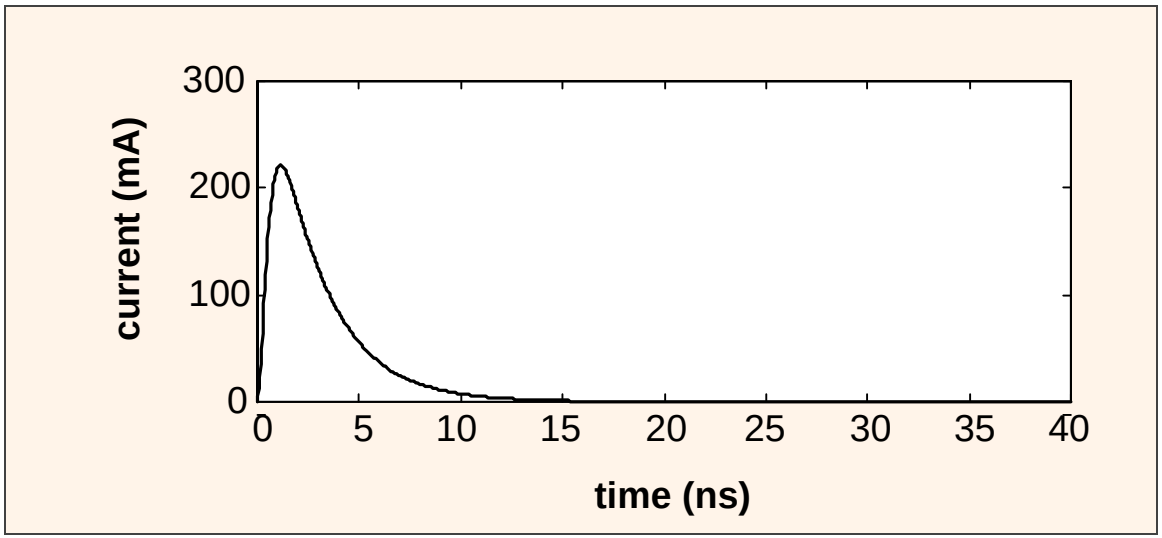
Average switching current macromodel for discrete spectrum



Example assumptions:

$$\text{dc power}: \; I_{DC} = \langle I(t) \rangle = 20mA$$

$$\text{rise time}: \; t_{rise} = 1ns$$

$$\text{pulse width}: \delta t = \langle t \cdot I(t) \rangle / \langle I(t) \rangle = 5ns$$

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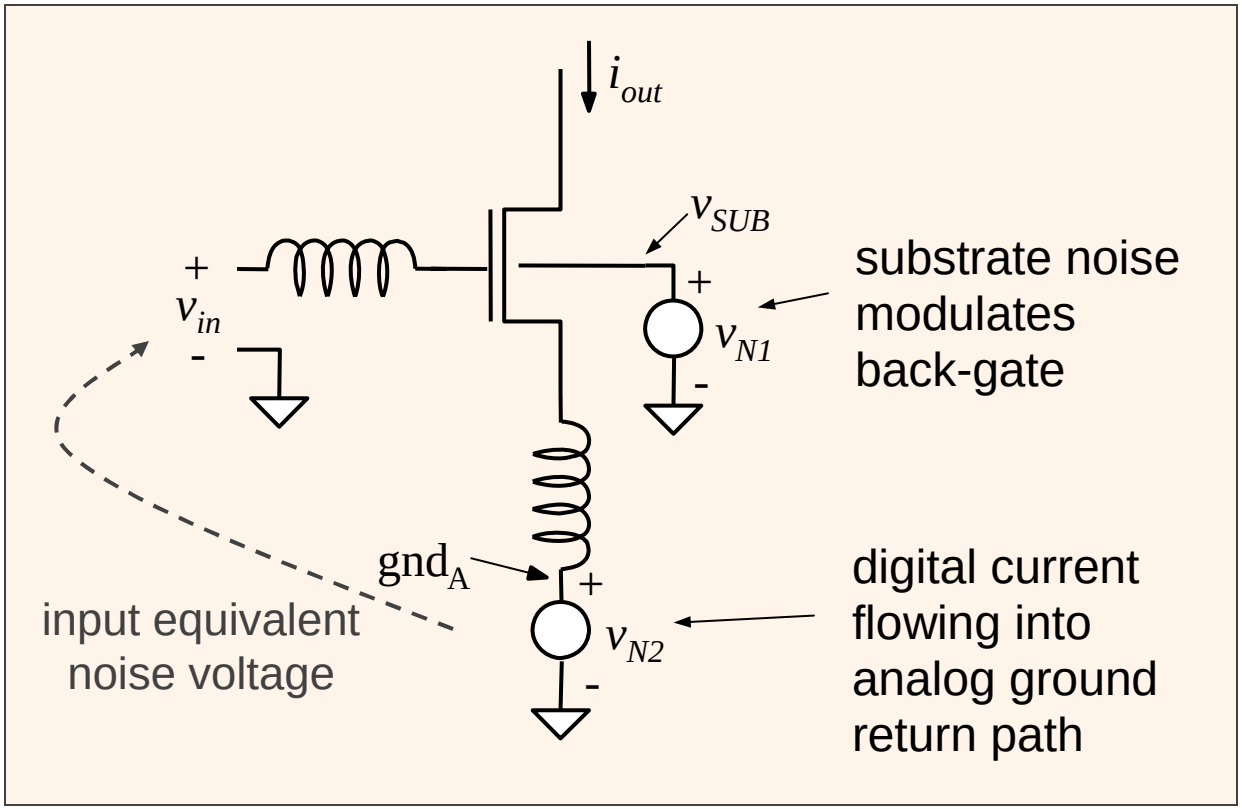
Noise coupling mechanisms



typical LNA input stage

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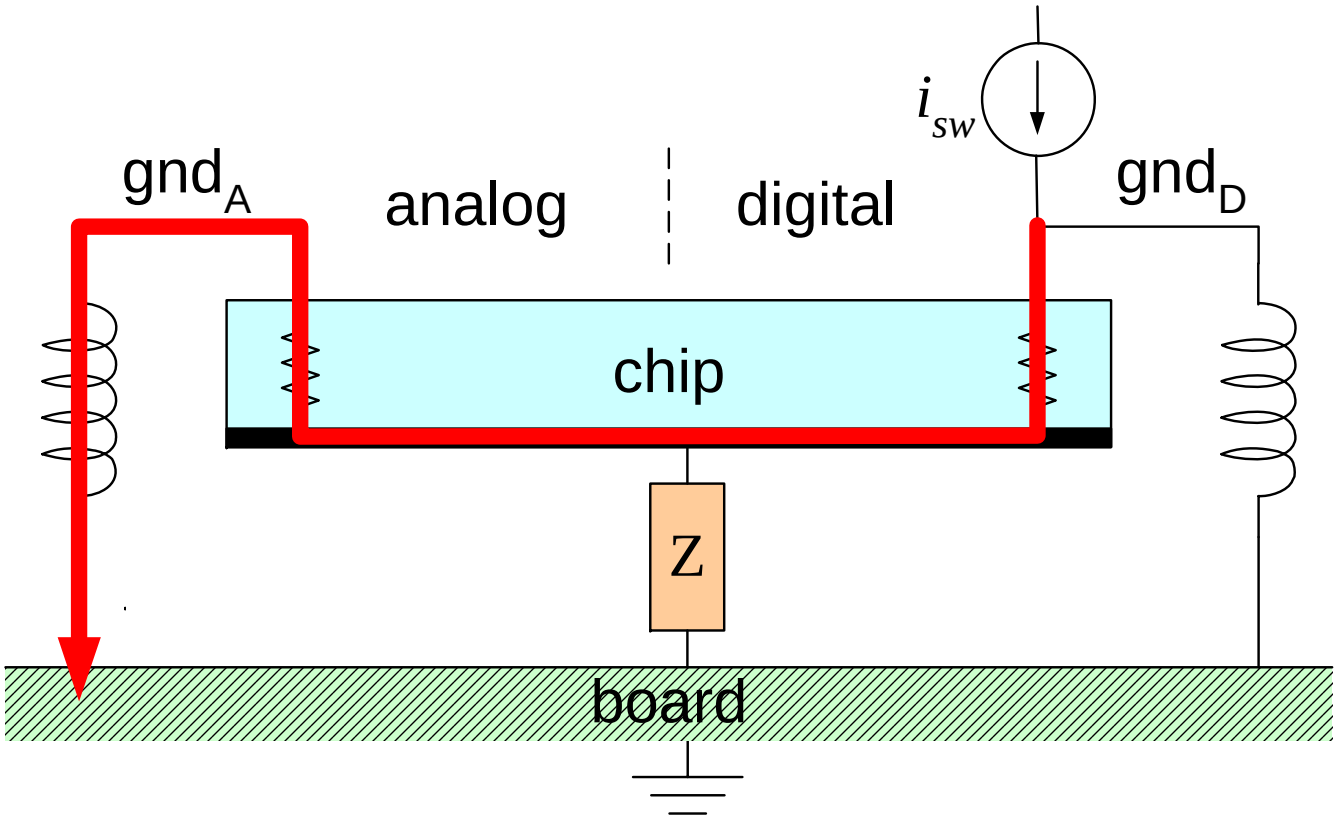
Key noise coupling mechanism



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Package assumptions

parameter	value	description
L_P	3 nH	Package pin inductance
L_{GD}	0.6 nH	Ground inductance (5 pins)
L_{GA}	0.6 nH	Ground inductance (5 pins)
C_{BG}	3.5 pF	Substrate to ground capacitance (conventional package)
L_{BG}	0.05 nH	Substrate to ground inductance (enhanced package)

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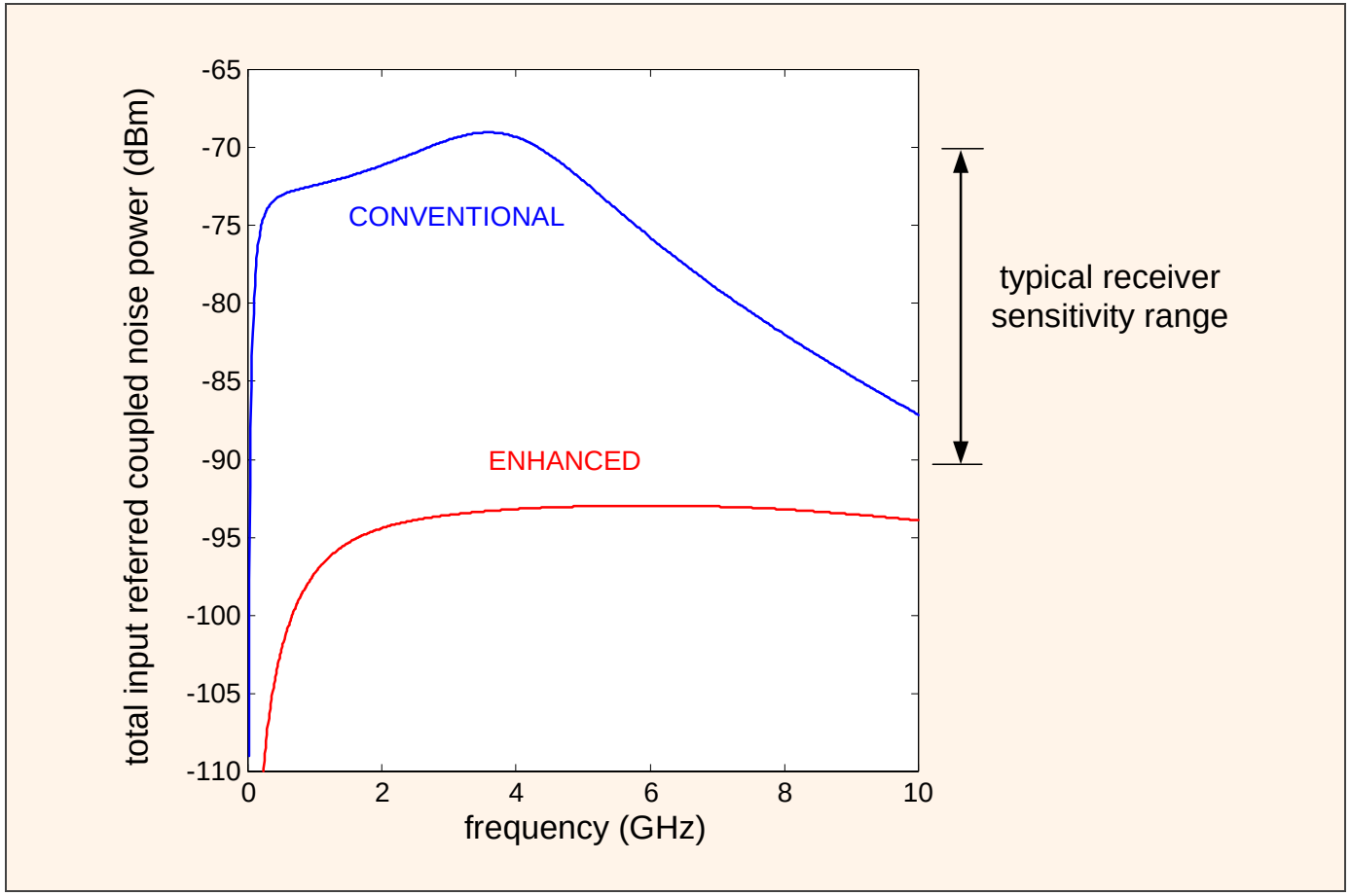
Typical coupled noise power comparison



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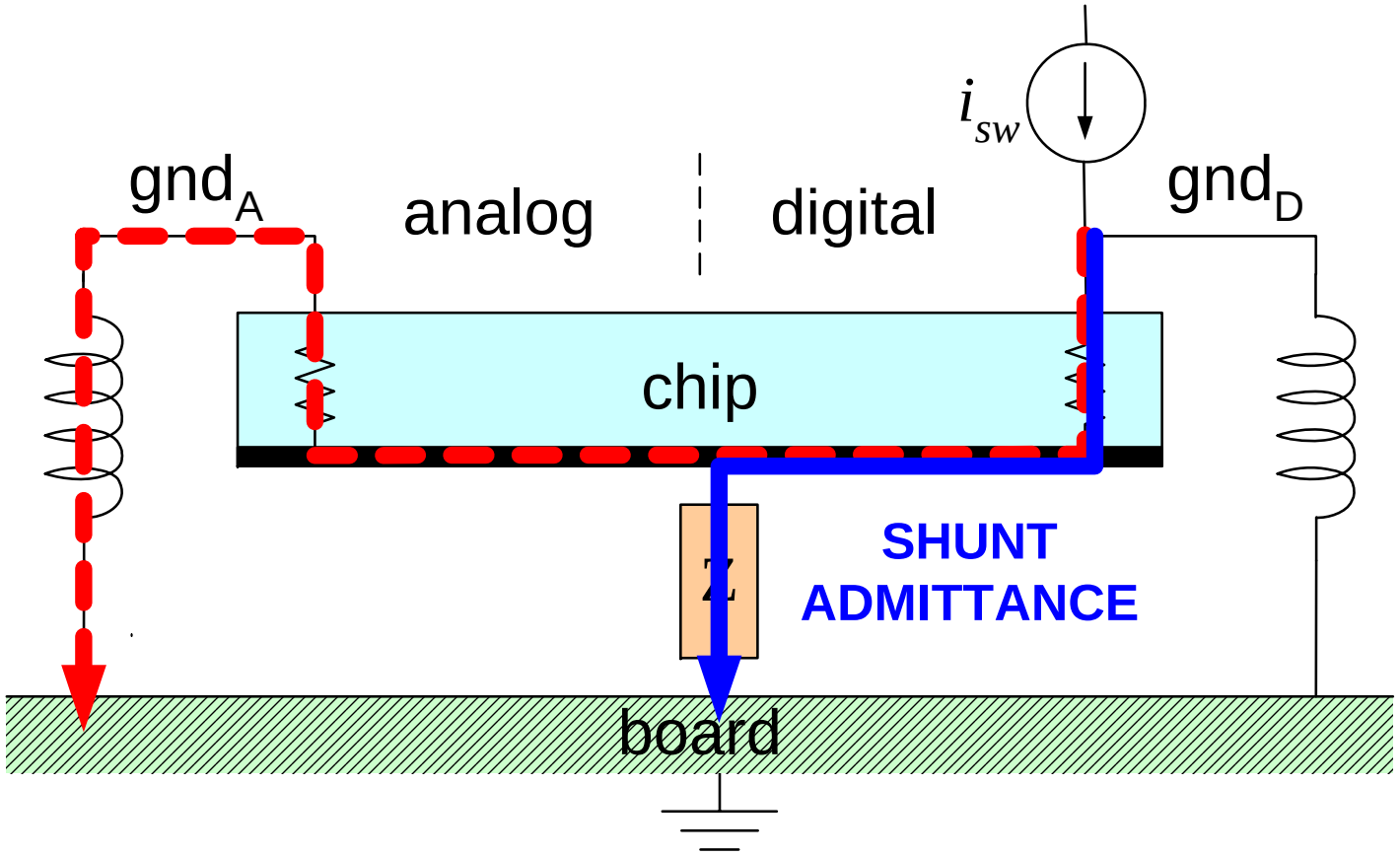
Noise reduction mechanism



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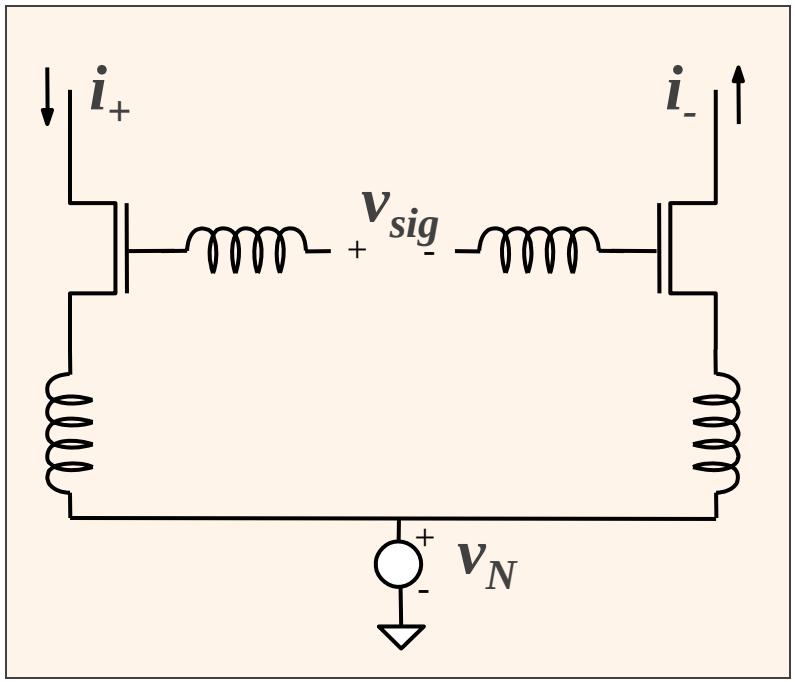
Differential noise cancellation

- Coupled switching noise is not really noise, but crosstalk.
- It can be partially eliminated by the use of differential-mode circuit designs.
- The effectiveness of this is limited by component matching.



Differential LNA

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Circuit and system design issues

- Coupled noise levels need to be substantially below sensitivity to meet SNR requirements.
- Enhanced packages with low substrate ground impedance reduce coupled noise by 20-25 dB.
- This greatly relaxes the component matching requirements for semiconductor technology.

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Package design implications

- The main source of coupled noise at wireless frequencies is by leakage of digital switching current into the analog ground return path.
- The IC substrate is the common impedance path for this coupling.
- Low pin inductance (usually resulting from miniaturization) improves noise performance.
- Enhanced packages that provide low impedance substrate ground can substantially reduce noise compared with conventional leaded packages.