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Design Challenges for Ultra-Wide Band Radio

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Contents

- Introduction to UWB
- Why we need UWB?
- UWB Signals
- MBOA Proposal
- Design Challenges
- Receiver Implementation
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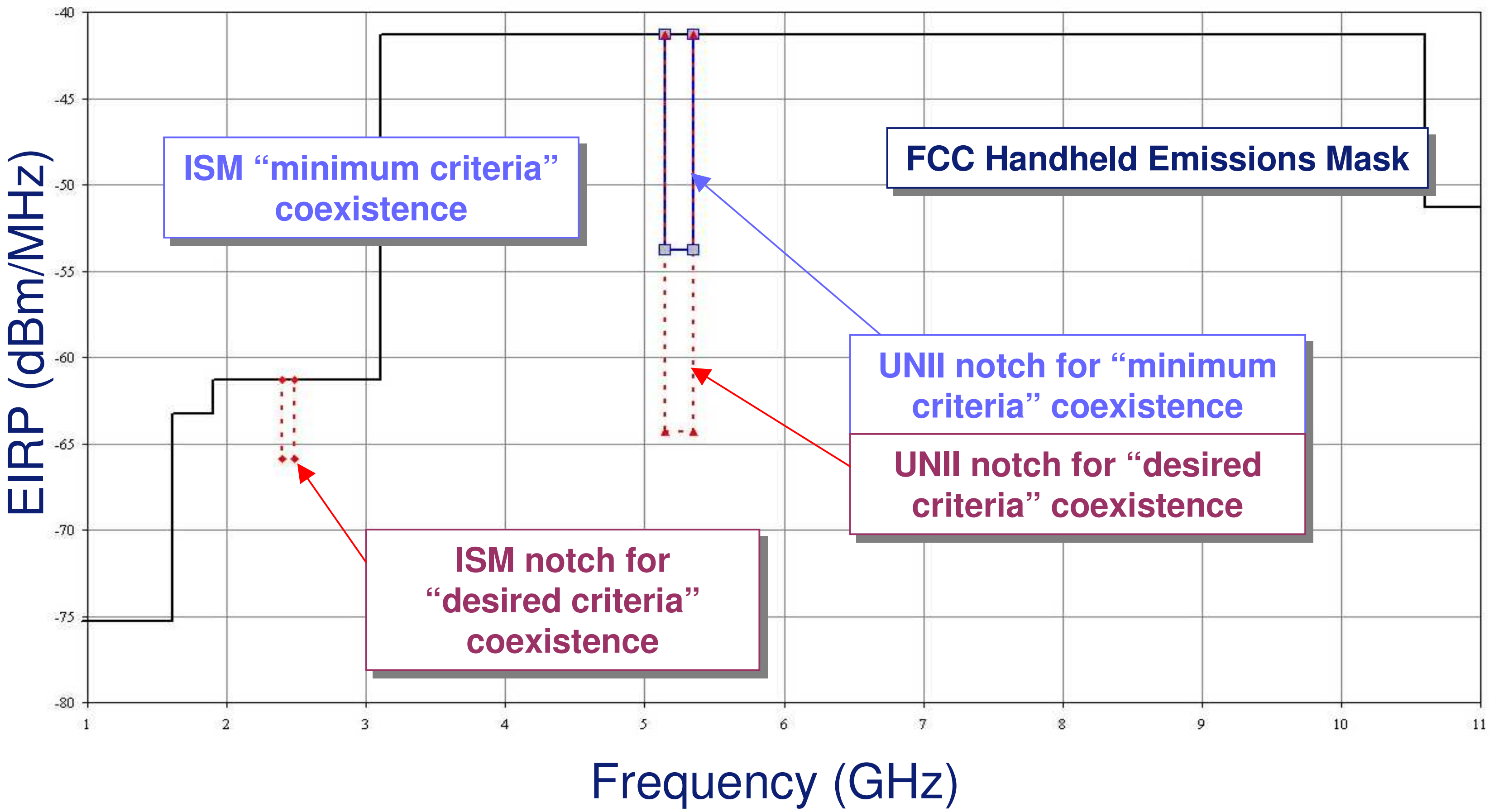
What is Ultra Wideband?

- FCC Definition
  - Signals must occupy a bandwidth > 500MHz
  - Or signal bandwidth 20% of the carrier frequency
- FCC recently opened up new spectrum for ultra-wideband transmissions
  - One of the bands is from 3.1GHz to 10.6GHz
  - Maximum power emission limit is –41.3dBm/MHz

FCC Handheld Emissions Mask for UWB



Generic channel capacity

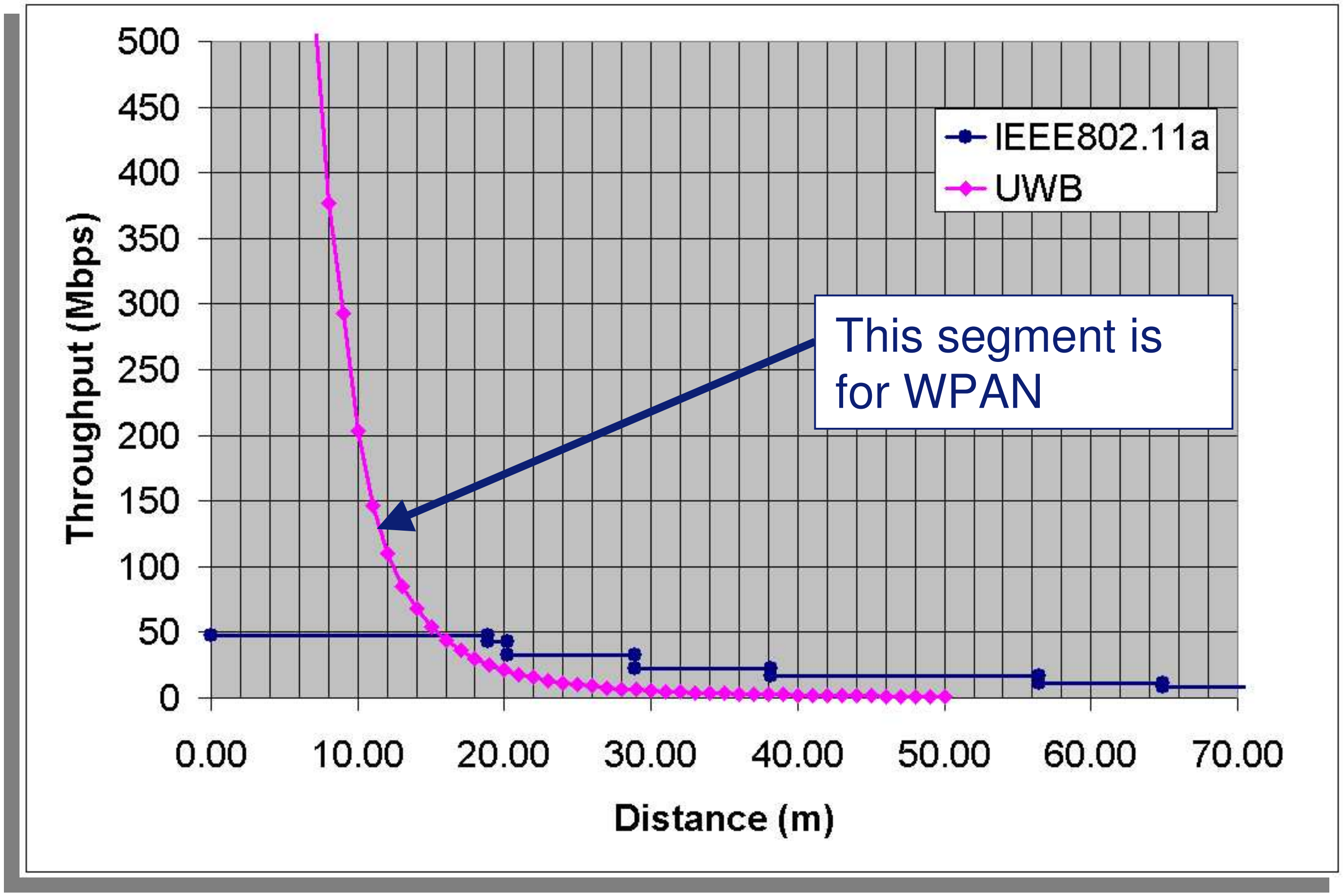
- $C=B.\log_2(1+SNR)$

Capacity per channel (bps) $\propto$ Bandwidth

Capacity per channel (bps) $\propto$ log(1+SNR)

1. Can increase bandwidth
2. Can increase SNR, use higher order modulations
3. Can increase number of channels using spatial separation (e.g., MIMO)

Capacity vs. range for UWB & WLAN



(Assumes 20MHz WLAN, 1GHz UWB bandwidth)

Courtesy: Intel

Expected data rates and ranges for UWB wireless PANs

MB-OFDM rates and ranges:

Rate	AWGN	CM2
110Mbps	20.5 m	10.7 m
200Mbps	14.1 m	6.3 m
480Mbps	7.8 m	2.6 m

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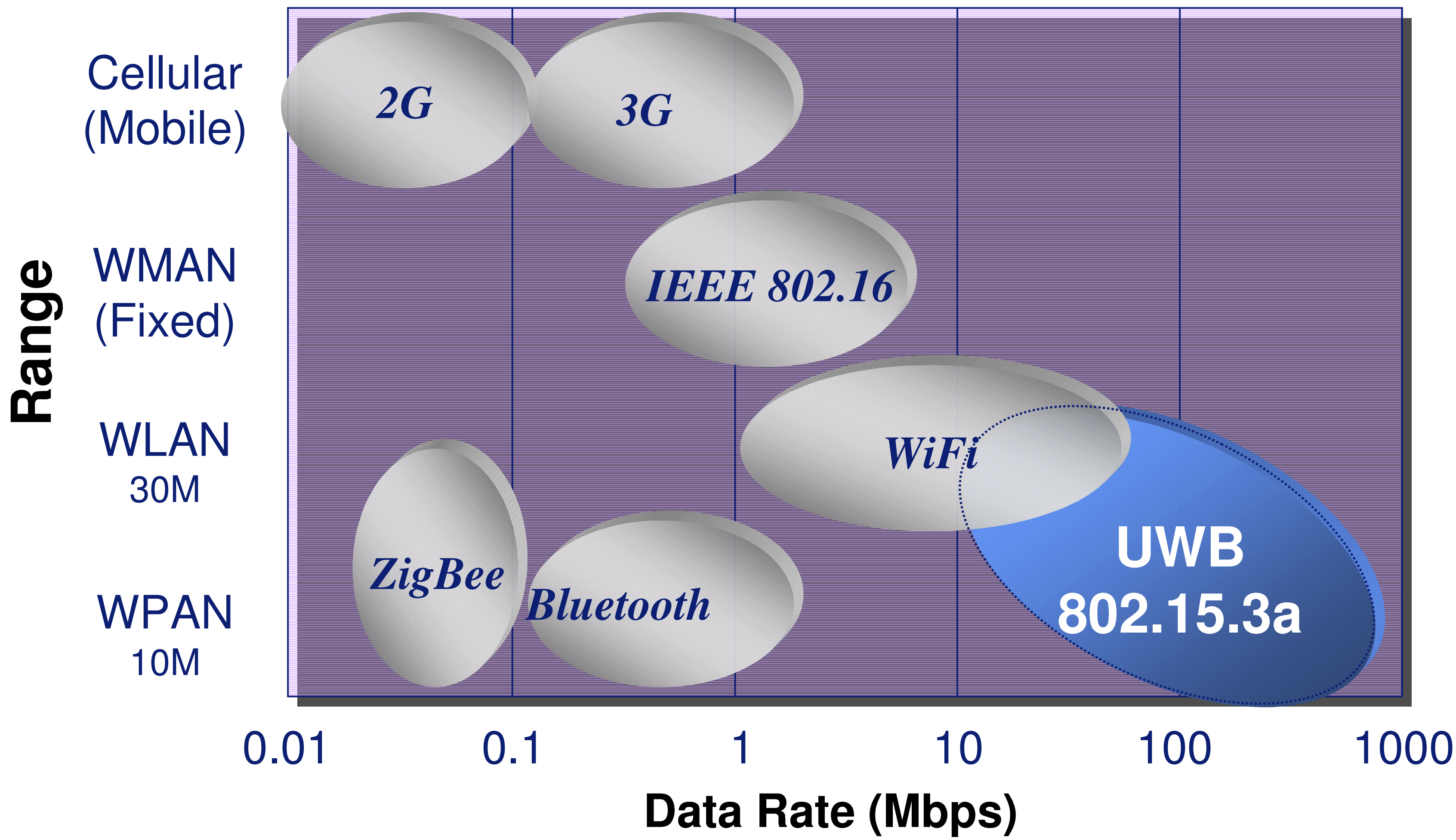
Standards : Range and Data Rate



Courtesy: WiMedia

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Why UWB? - High Data Rate

Need for fast video streaming

- **Wireless USB - 480 Mbps *wirelessly***
- **USB Mass Storage Application**

Advantages

- **Reduced installation costs**
  - **Build on current drivers**
- **Portability**
- **Simplicity of use**
- **Easy connections between several sources**
- **No “non-standard” card interface concerns**

Why UWB? Audio Files

- **Need for Speed: Audio**

MP3 Music Download/Check-out:

For "Checking-out" (5MB/music*x*15)

- **10 Mbps (net) takes 1 minute → Boring**
- **300 Mbps (net) takes 2 seconds → Exhilarating !**

CD Download/Check-out:

- **74 Minute audio takes ~700 MB**
- **For "Checking-out"**
  - **10 Mbps (net) takes 10 minutes → Boring**
  - **300 Mbps (net) takes 19 seconds → Exhilarating!**

Why UWB? Image Files

- **Need for Speed: Still Image**

Digital Still Image Download/Upload:

– 128 MB Memory Stick Accommodates 80 Pictures
  - 15 Mbps (net) takes 60 seconds → Not Acceptable
  - 300 Mbps (net) takes 3 seconds → Instant

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- Receiver Implementation
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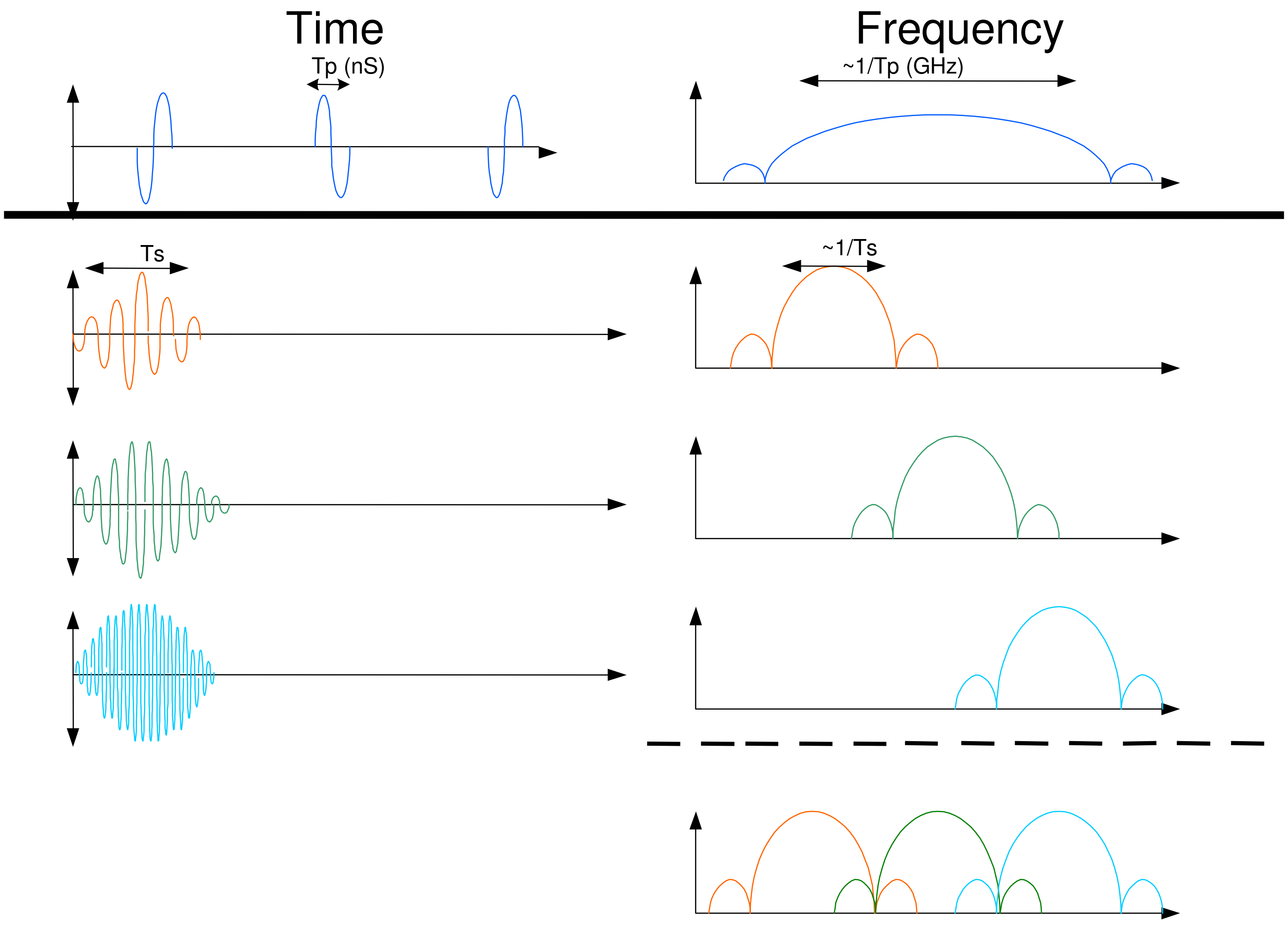
- Conclusions

Signal bandwidth

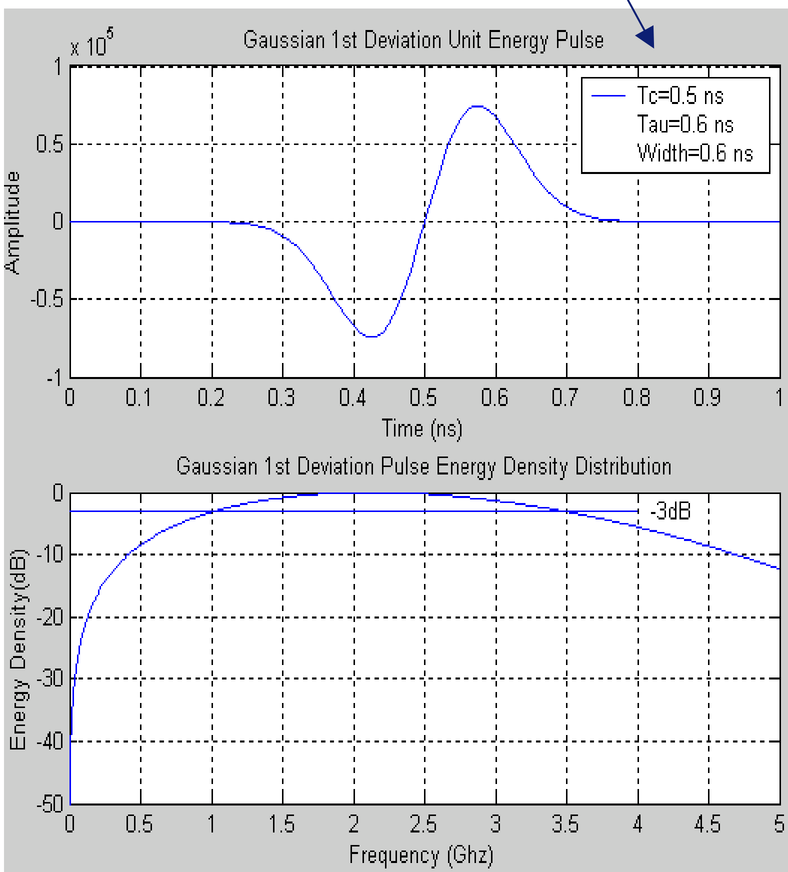


Ultra-Wide Bandwidth Signals

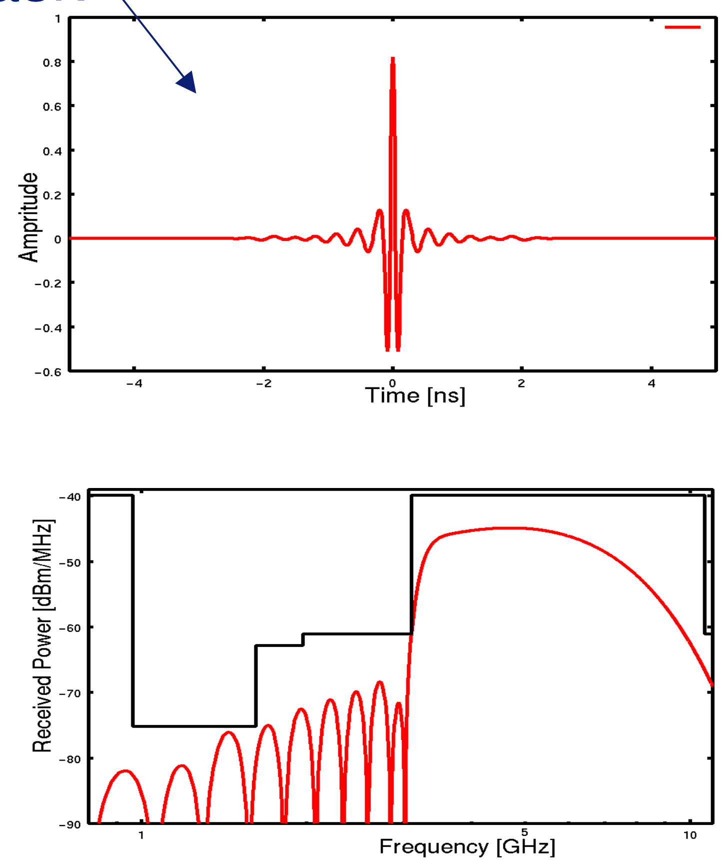
1. Use ultra-narrow pulses
2. Use very fast direct sequence spread spectrum
3. OFDM
4. Multi-band sequencing/hoping

1.1 Ultra-narrow pulses (impulse radio)

Basic Gaussian monopulse



Pulse shape to meet FCC mask



1.2 Practical Issues with Impulse Radio

- Due to very narrow pulse width (0.1-1ns):
  - Very accurate timing generator needed
  - Very high DAC and ADC sampling rates needed
    - E.g., 20,000,000,000 samples per second!
  - Channel matched filter needs to be very long to capture all the significant channel energy
  - Channel estimation algorithm is complex
  - Impulse response of antenna plays a significant role in shaping the transmitted pulse (regulatory and practical issues)

2. Ultra-Fast Direct Sequence

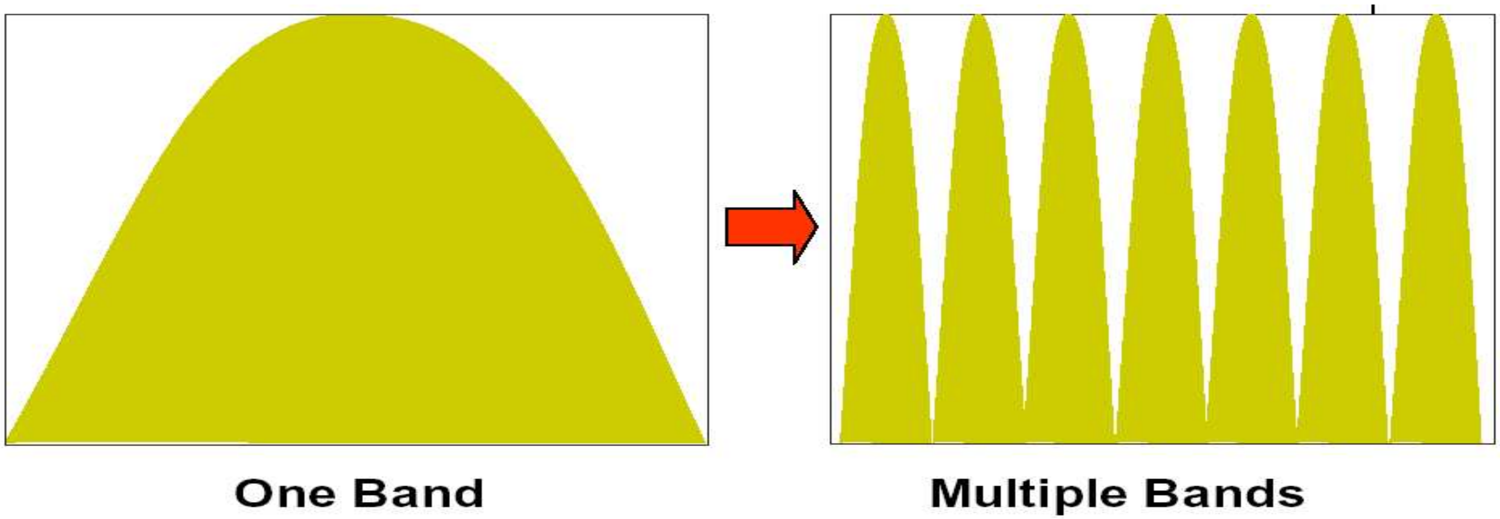
- Approach uses direct-sequence spread spectrum techniques
- Pulse filtering/shaping used with BPSK/QPSK modulation
  - 50% excess bandwidth, root-raised-cosine impulse response
- Overall approach is similar to UMTS/3GPP cellular, except that Walsh codes are replaced by a ternary codes of length 24 or 32

	RRC BW	Chip Rate	Code Length	Symbol Rate
Low Band	1.368 GHz	1.368 GHz (±1 MHz, ± 3 MHz)	24 or 32 chips/symbol	57 or 42.75 MS/s
High Band	2.736 GHz	2.736 GHz (±1 MHz, ± 3 MHz)	24 or 32 chips/symbol	114 or 85.5 MS/s

3. Ultra wideband signals using OFDM

- Orthogonal Frequency Division Multiplexing
  - Can efficiently multiplex many sub-carriers to occupy ~500MHz of spectrum
  - OFDM intrinsically deals with multipath issues by keeping the symbol rate low (e.g., 3.2MHz)
  - Technology derived from 802.11a
    - But only supports QPSK, not 16-QAM nor 64-QAM
    - Uses less ADC precision and lower arithmetic precision than 802.11a/g signal processing

4. Multi-band Sequencing / Hopping



- Apply divide-and-conquer approach
- Each sub-band requires lower rate ADC to digitize
- Length of digital filters needed for channel equalization is divided by *N*.
- Complexity reduction requires sequential use of bands

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Contents

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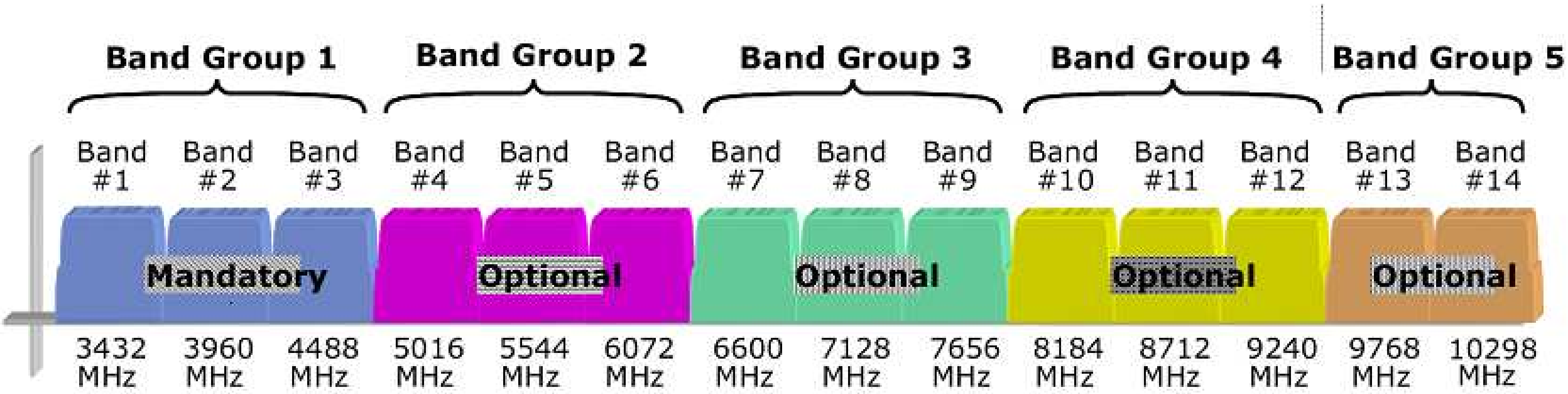
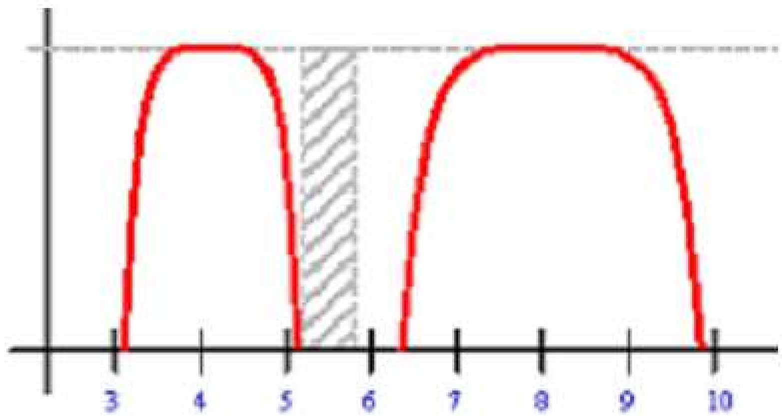
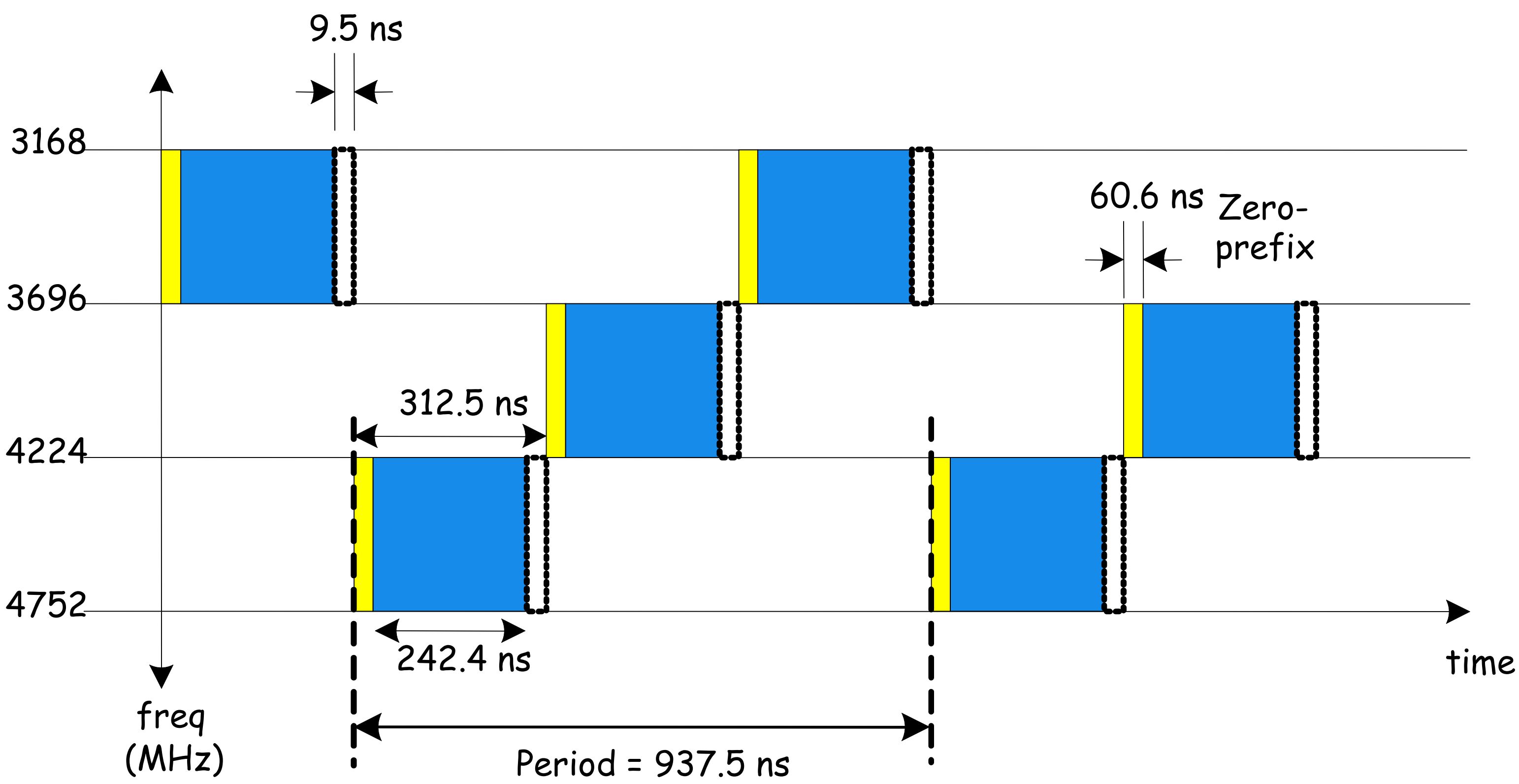
UWB frequency bands- MBOA



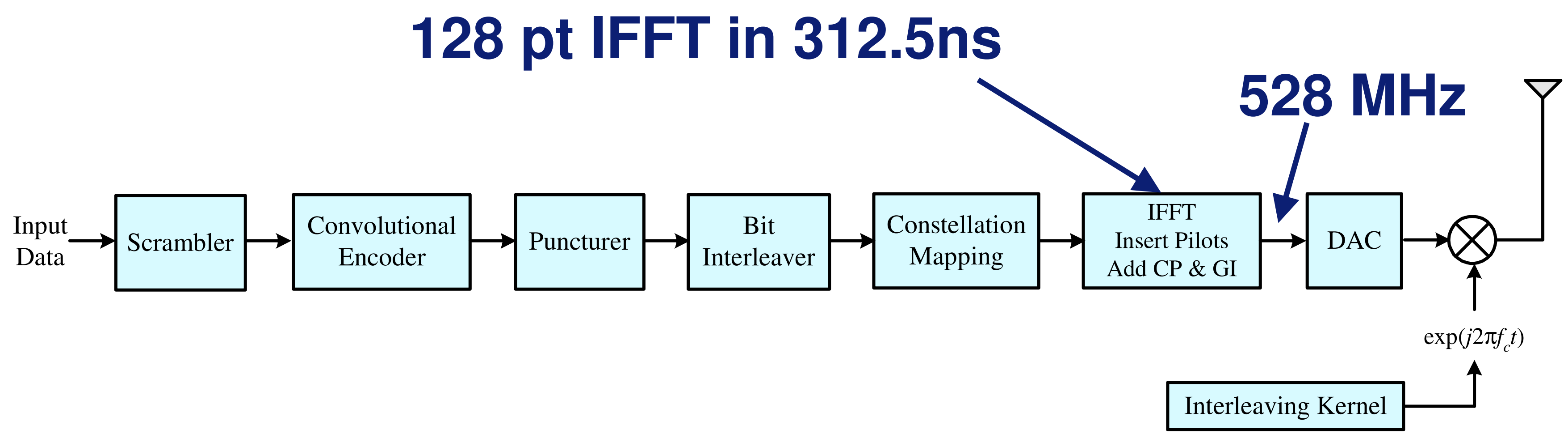
DS UWB

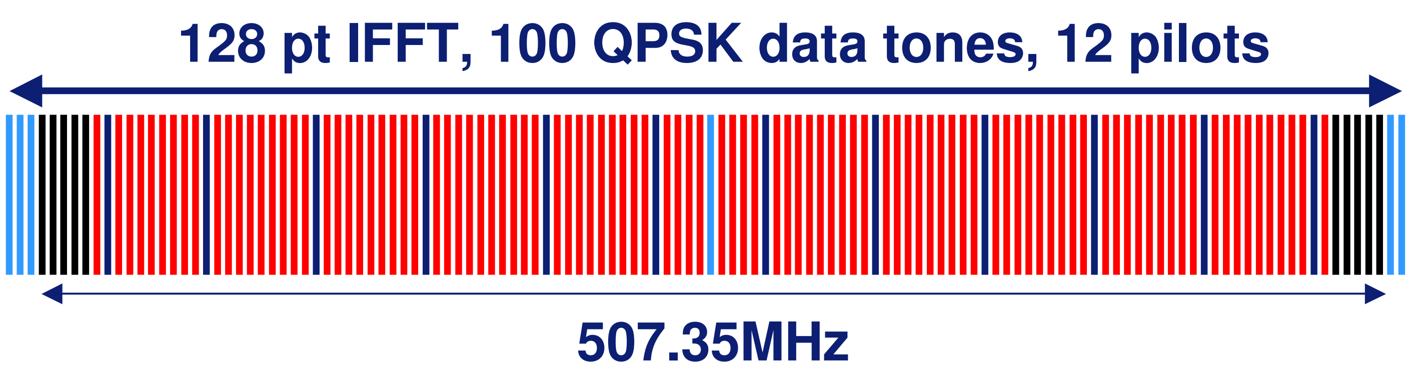


MBOA uses sequenced multiband approach to enhance OFDM



Example OFDM UWB Tx chain





OFDM Advantages

MBOA implementation requires 128-pt complex FFT every 312.5ns

- At 102.4MHz clock, this FFT requires
  - 40 real multipliers, 48 real adders per clock cycle
- 40 real multipliers, compared to 400 required in Rake receiver for DS UWB
- The proposed OFDM symbol deals with up to 60.6ns of delay spread while DS UWB covers only 40ns delay spread

Contents

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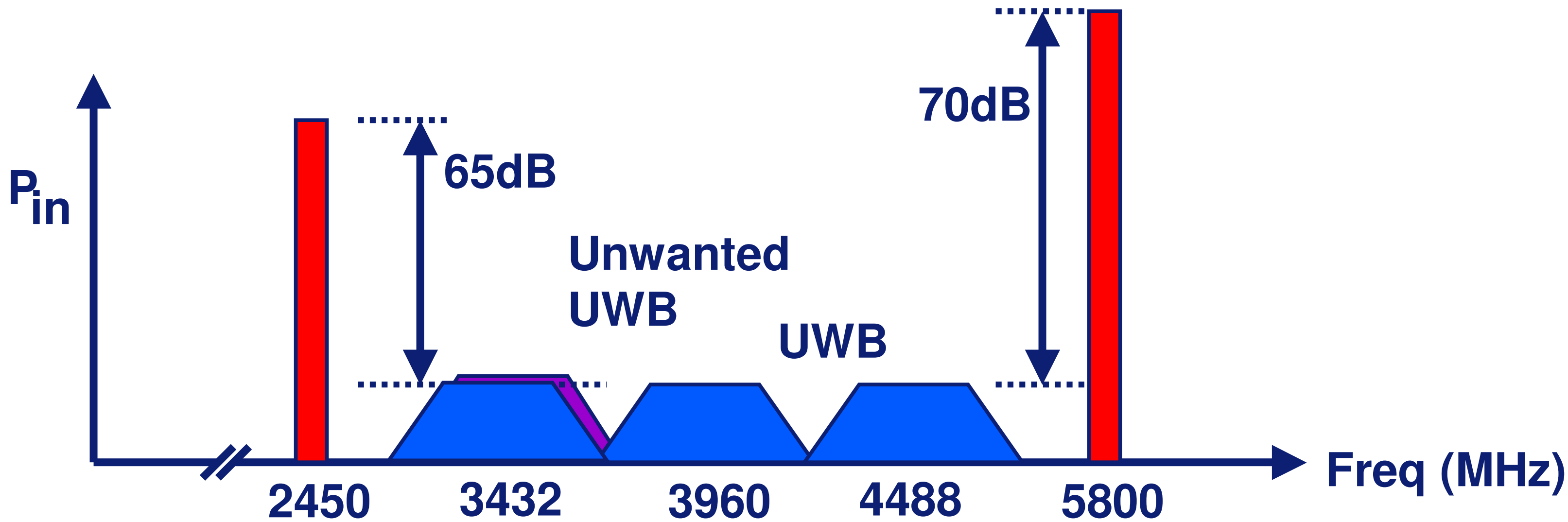
Design Challenges – implementation choice

- SiGe radio vs. All CMOS RF/BB?
  - Several startups, plus TI and Intel focus on CMOS solutions
  - MB-OFDM is designed to be "CMOS friendly"
- Use of 2x oversampling in DACs and ADCs may be too power hungry (e.g., 150mW)
  - Several implementations known to be using 1x oversampling
- Power consumption needs to be balanced with robust handling of large signal interferers

Design Challenges - system



Interferer scenario: (MBOA recommendation)

- Distance wanted UWB: 10.0m (-73dBm)
- Distance 802.11a interferer: 0.2m (-3dBm)
- Distance 2.4GHz ISM interferer: 0.2m (-8dBm)
- Distance unwanted UWB interferer: 2.0m (-60dBm)

Interferer attenuation by pre-filter: 20-30dB

Design Challenges - circuits

- Broadband LNA
  - NF=3dB, G=15dB, OIP3=+10dBm, BW=1.6GHz min.,
  - Notch@ 5GHz, antenna interface
- Filter/VGA
  - BW: >250MHz
  - 3rd order or higher
- ADC
  - 1GS/s
- Multi-tone LO
  - LO must be able to hop in less than 9nS.

Contents

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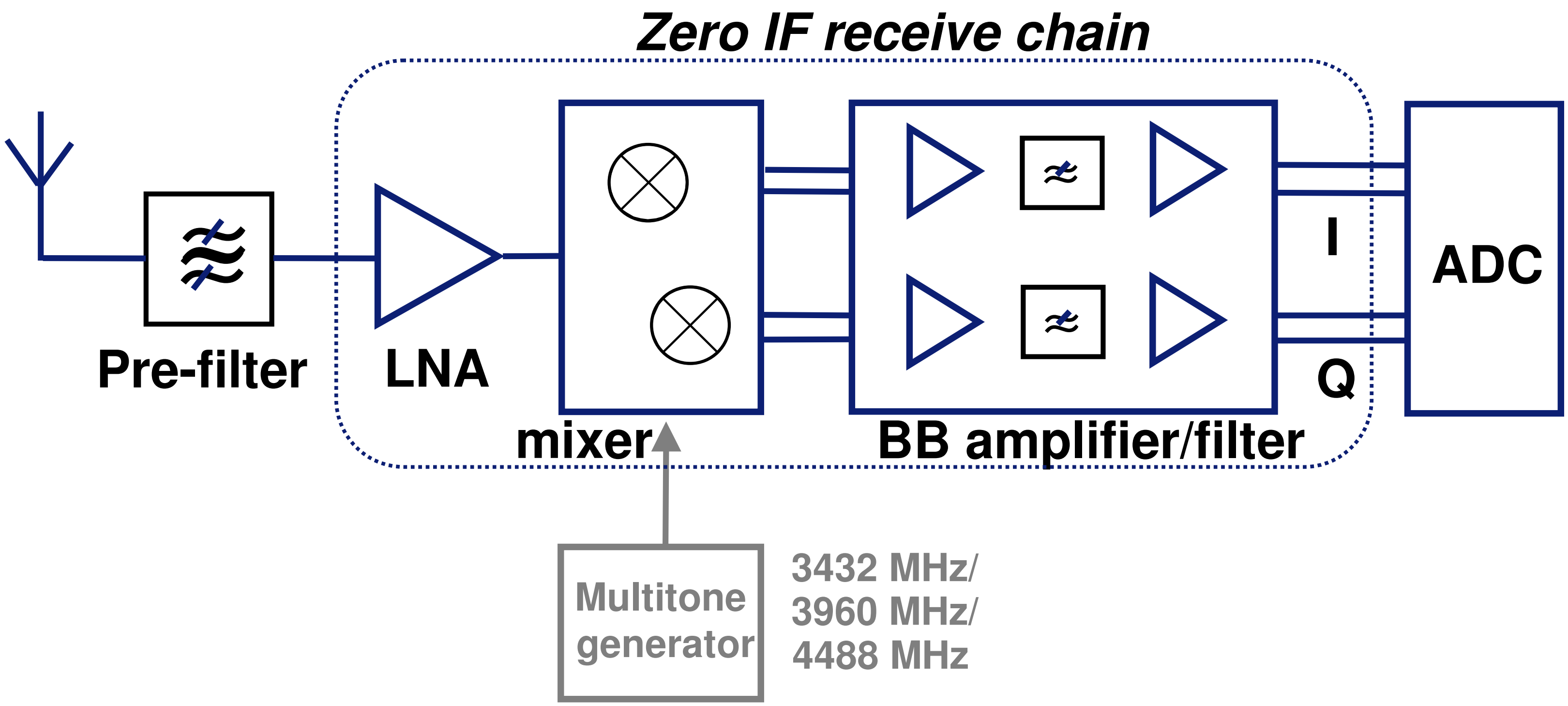
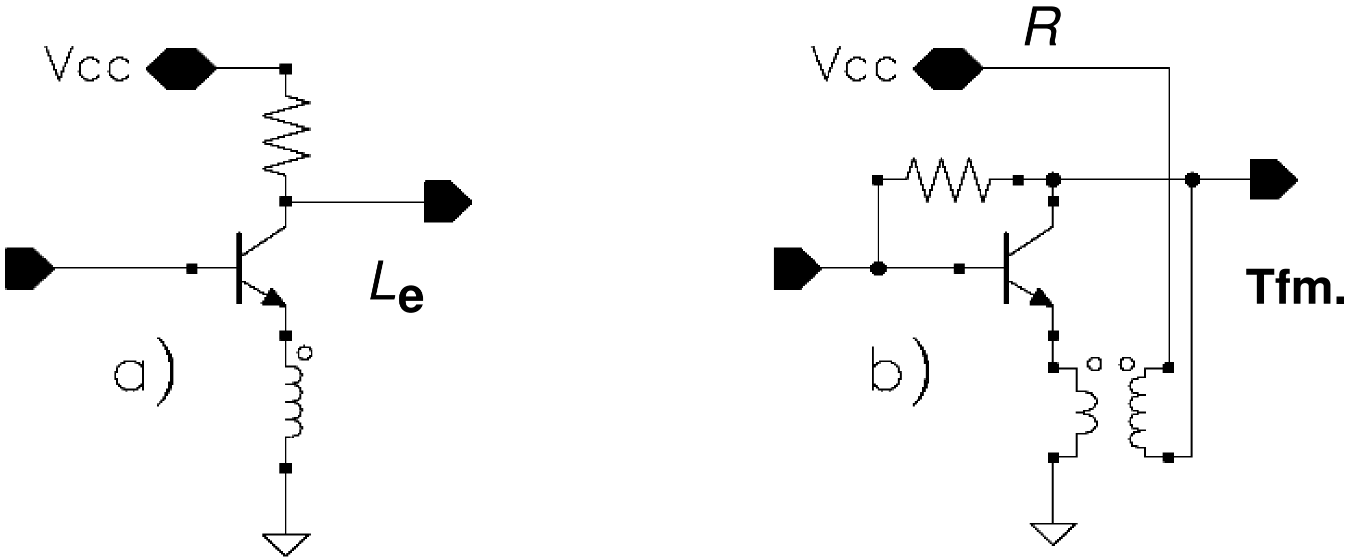
Receive chain: requirements and implementation



- Noise figure: < 6 dB
- Input IP2: > +15 dBm
- Input IP3: > -9 dBm

Single-ended LNA with high linearity



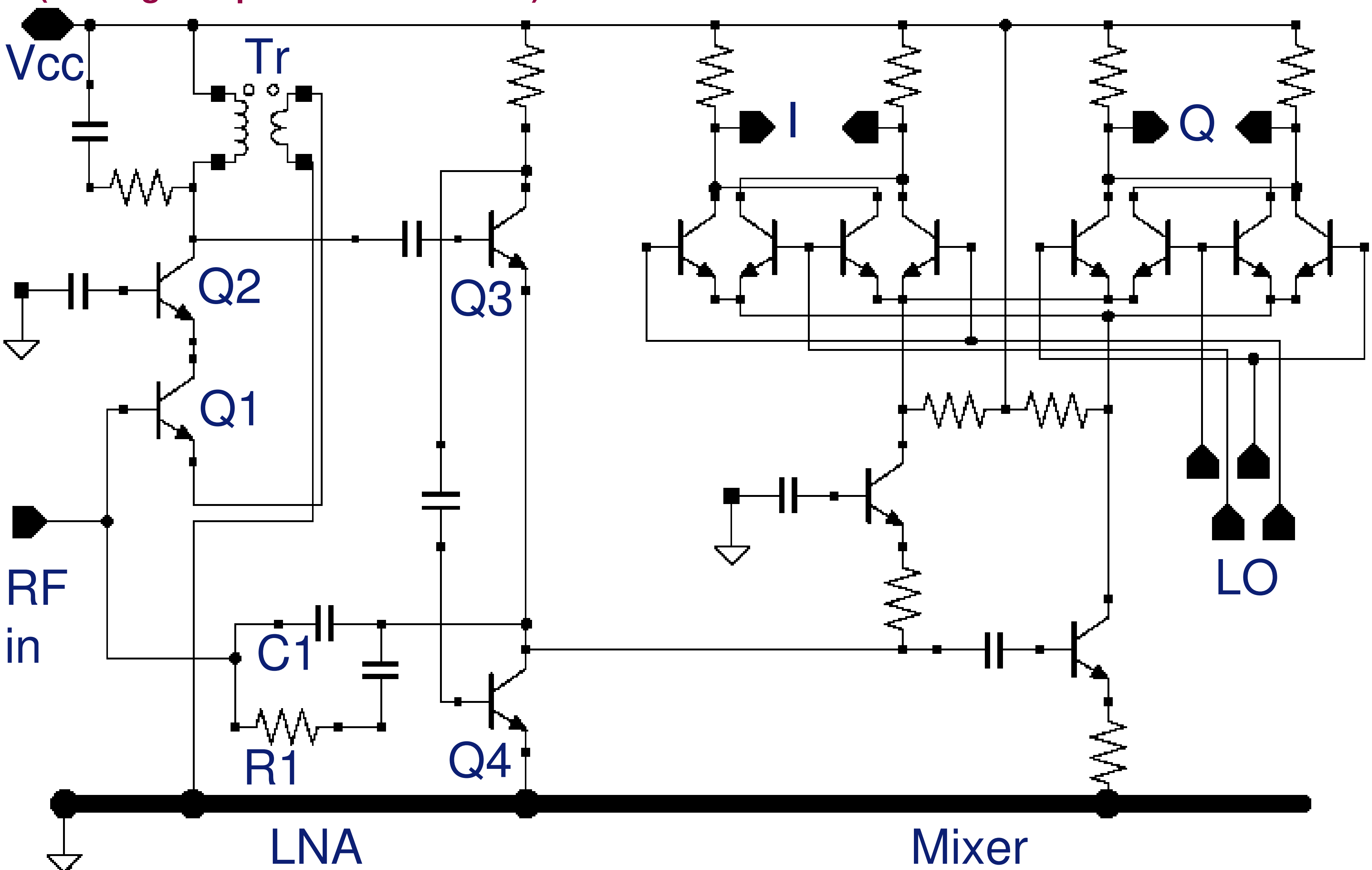
- Emitter degeneration coil (option a) would have to be very large.
- Circuit b) gives simultaneous noise and power matching using current feedback (R) and voltage feedback (transformer).
- Transformer is in fact area-friendly compared with coil alone:

$$V_{\mathrm{FB}}^{(\mathrm{Tfm.})} = I_{\mathrm{e}} j\omega L_{\mathrm{e}} + I_{\mathrm{c}} j\omega M = I_{\mathrm{e}} j\omega L_{\mathrm{e}} (1 + K\sqrt{L_{\mathrm{c}}/L_{\mathrm{e}}})$$

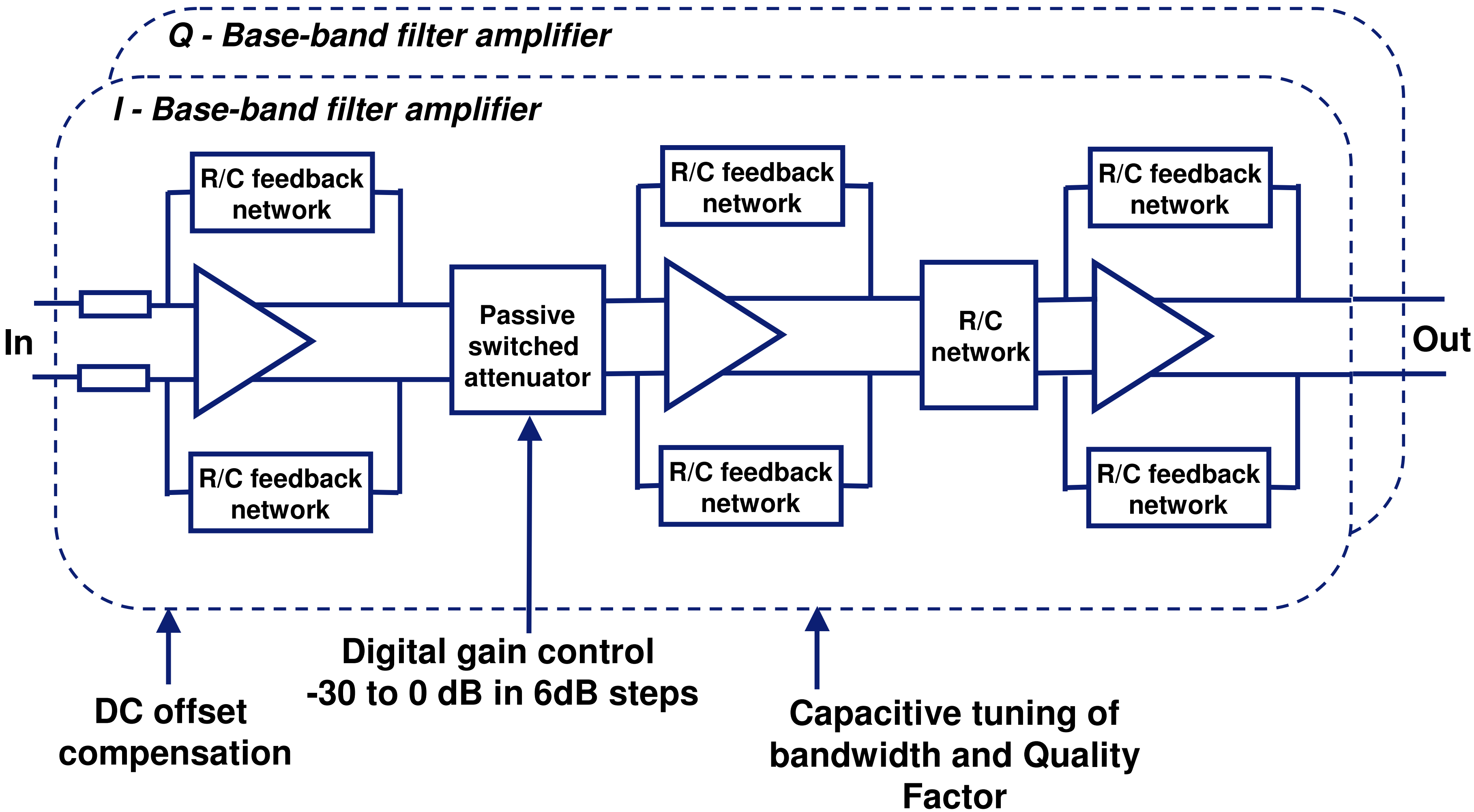
$$V_{\mathrm{FB}}^{(\mathrm{coil})} = I_{\mathrm{e}} j\omega L_{\mathrm{e}}$$

Implementation of LNA plus mixer

(biasing components not shown)



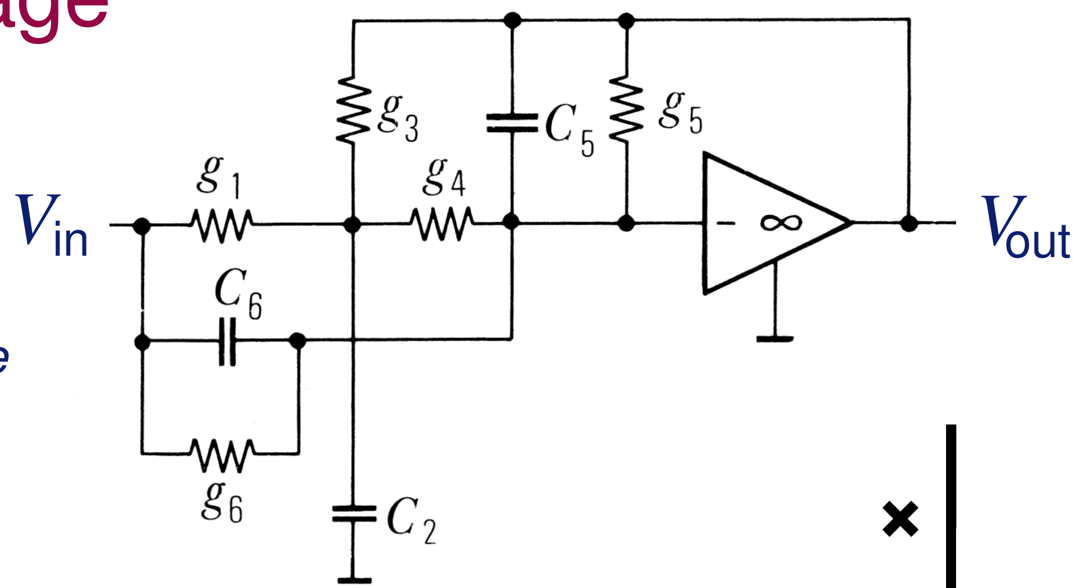
Baseband Filter/Amplifier



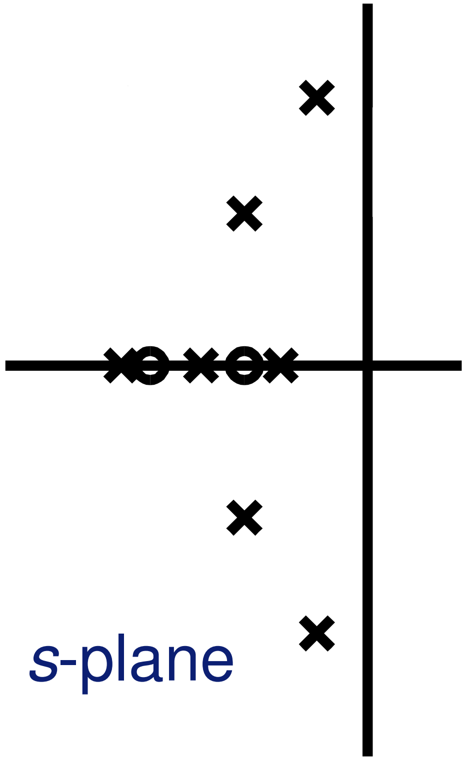
Base-band filter stage

Rauch filter, general:

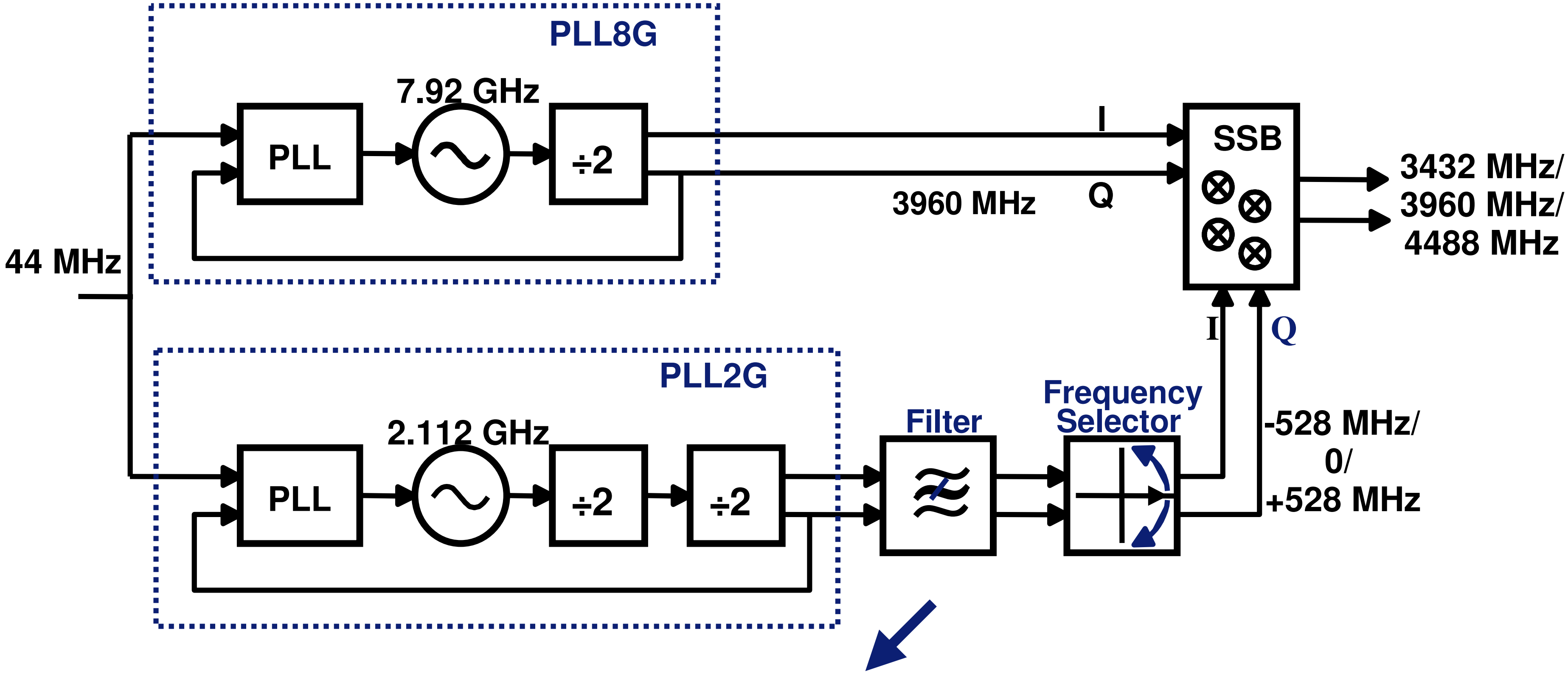
(e.g.:Heinlein and Holmes, “Active Filters for Integrated Circuits.”)



•Not all components required for each stage.
•One stage can give at most two poles and two zeros (bi-quadratic).
•Good channel selection can be obtained.



Proposed LO Implementation



Third order harmonic of 528MHz:

$$3960MHz + 3 \cdot 528MHz = 5544MHz$$

$$3960MHz - 3 \cdot 528MHz = 2376MHz$$

→ **Spur issue**

Contents

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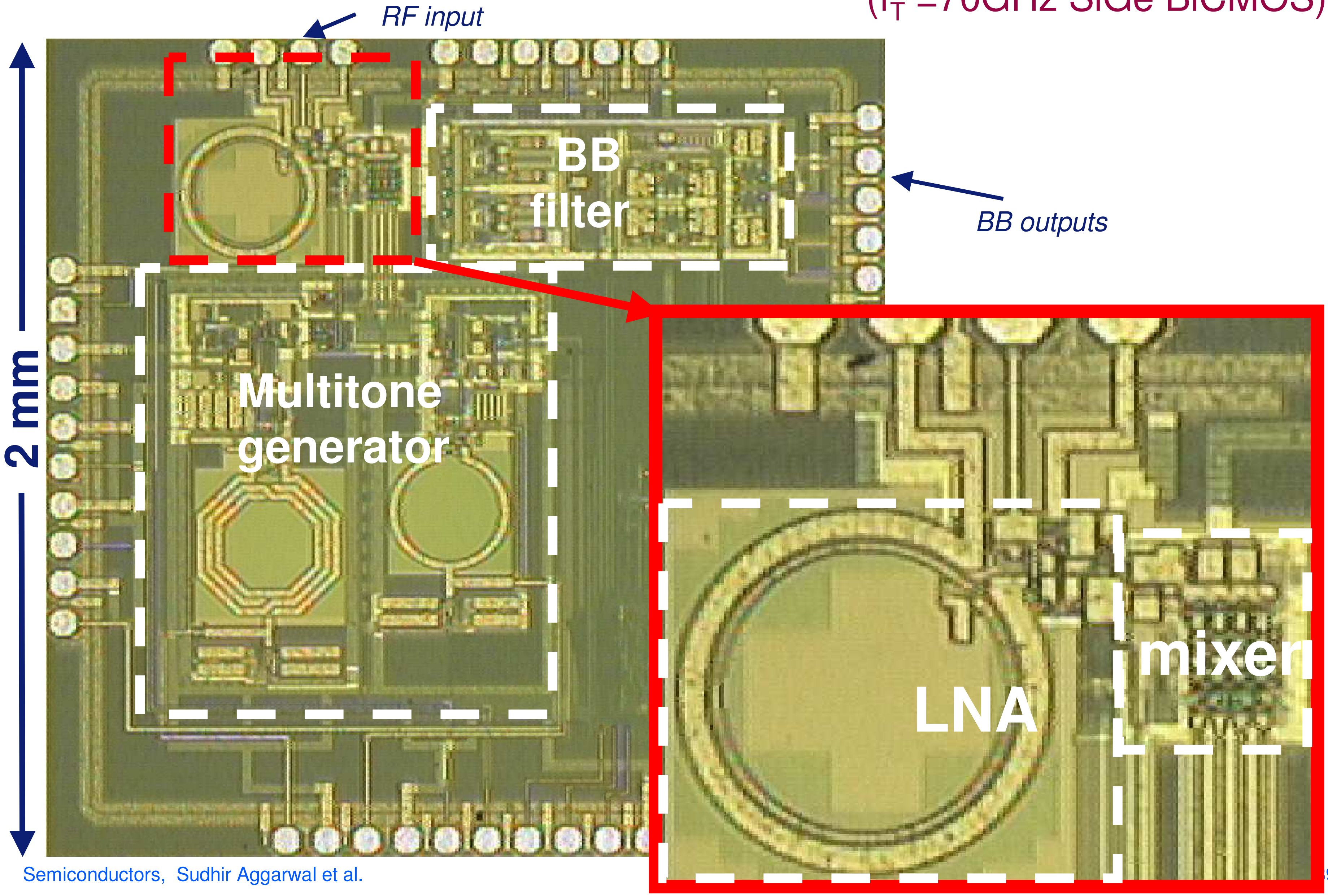
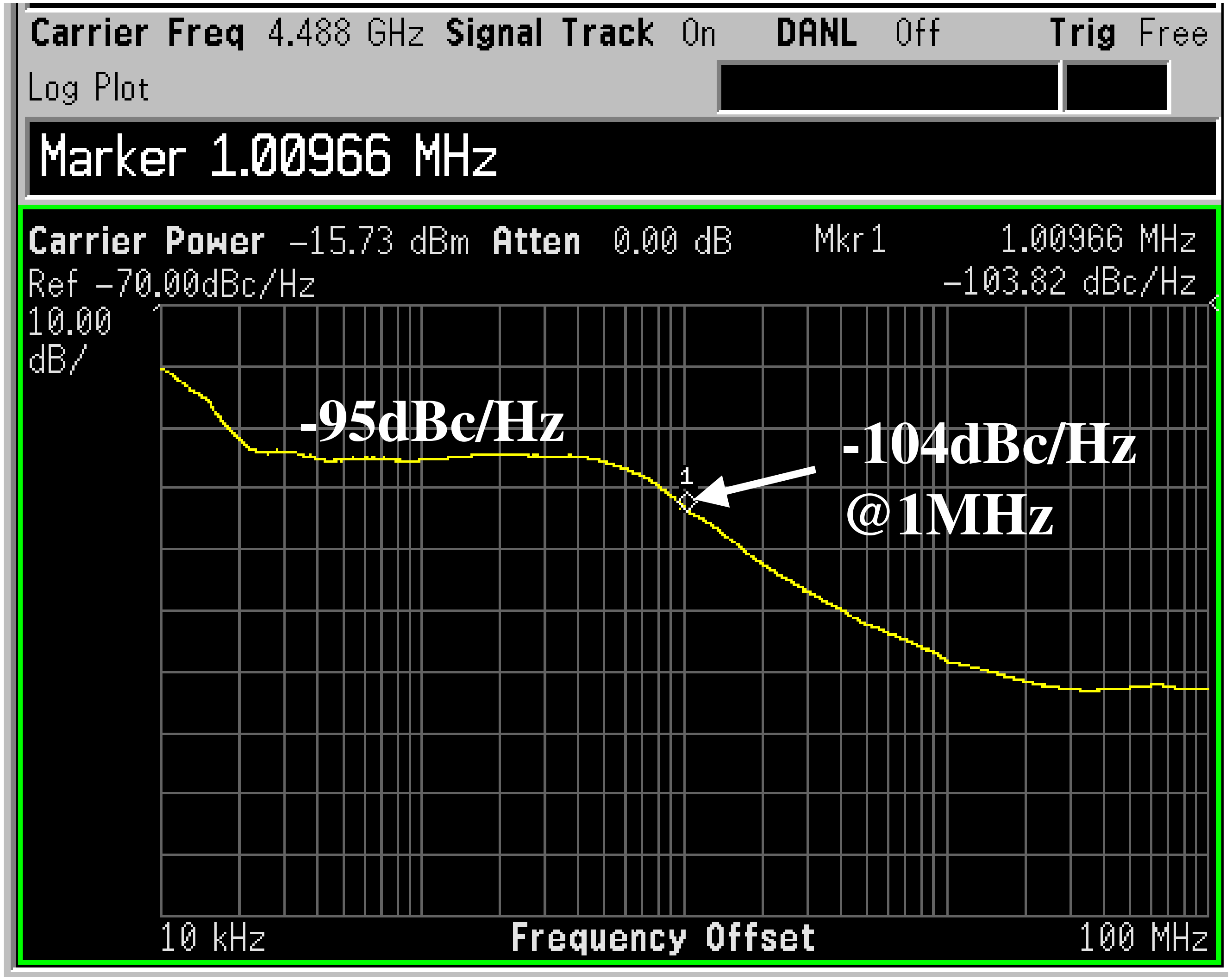
Chip photo

(f_T =70GHz SiGe BiCMOS)

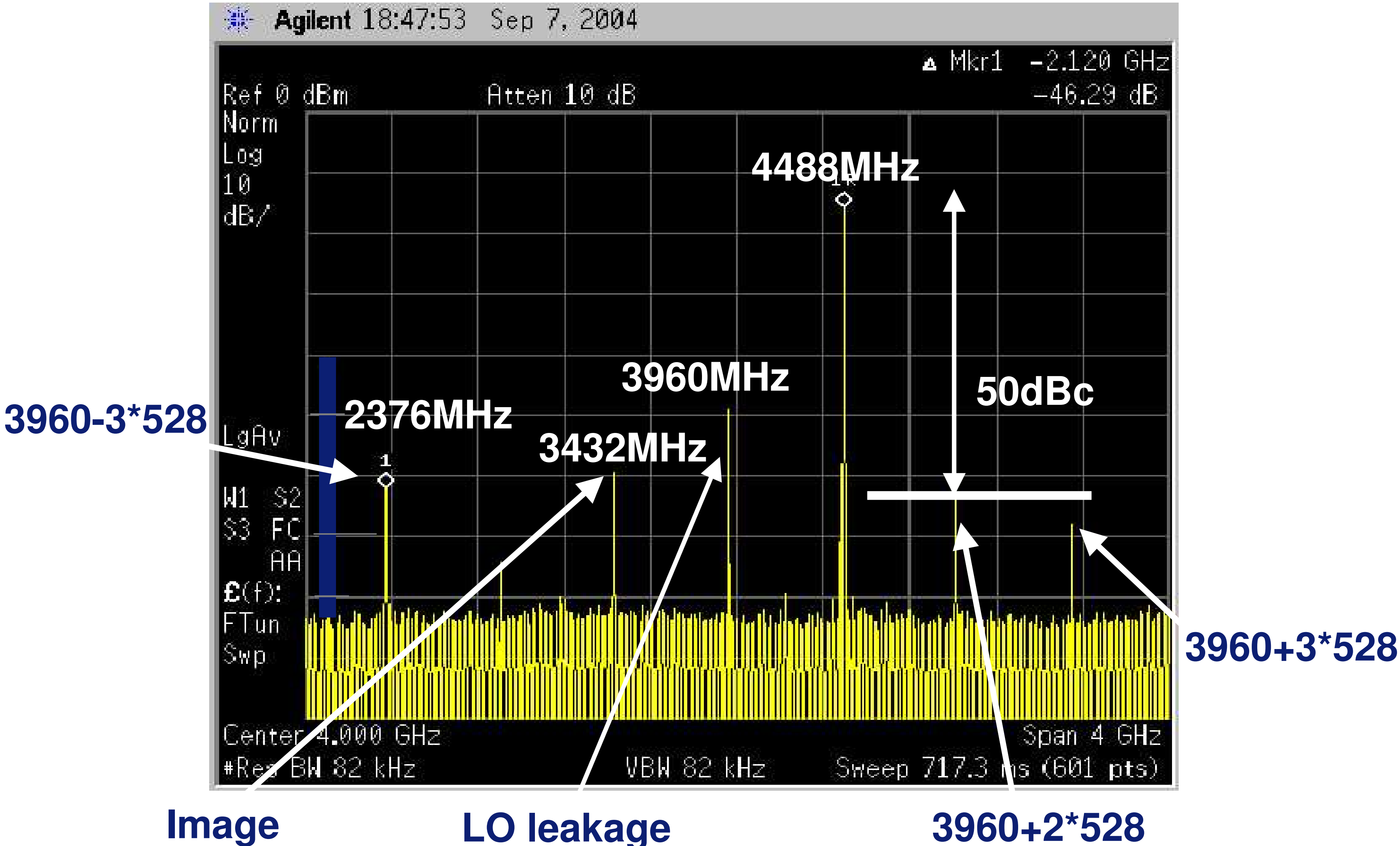


Phase Noise Measurement

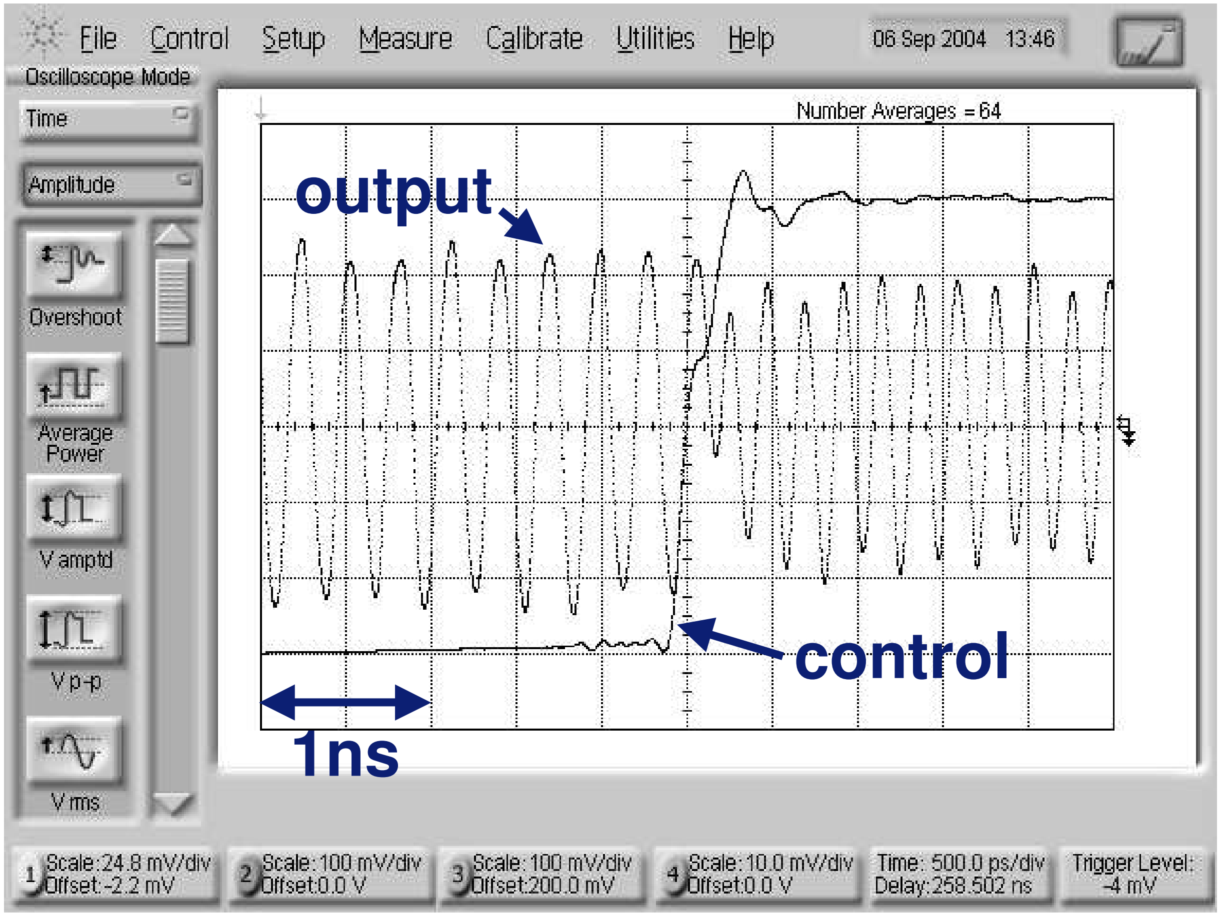


Phase Noise for band #3 < 0.5° rms

Spurs Measurement



Switching Time Measurement

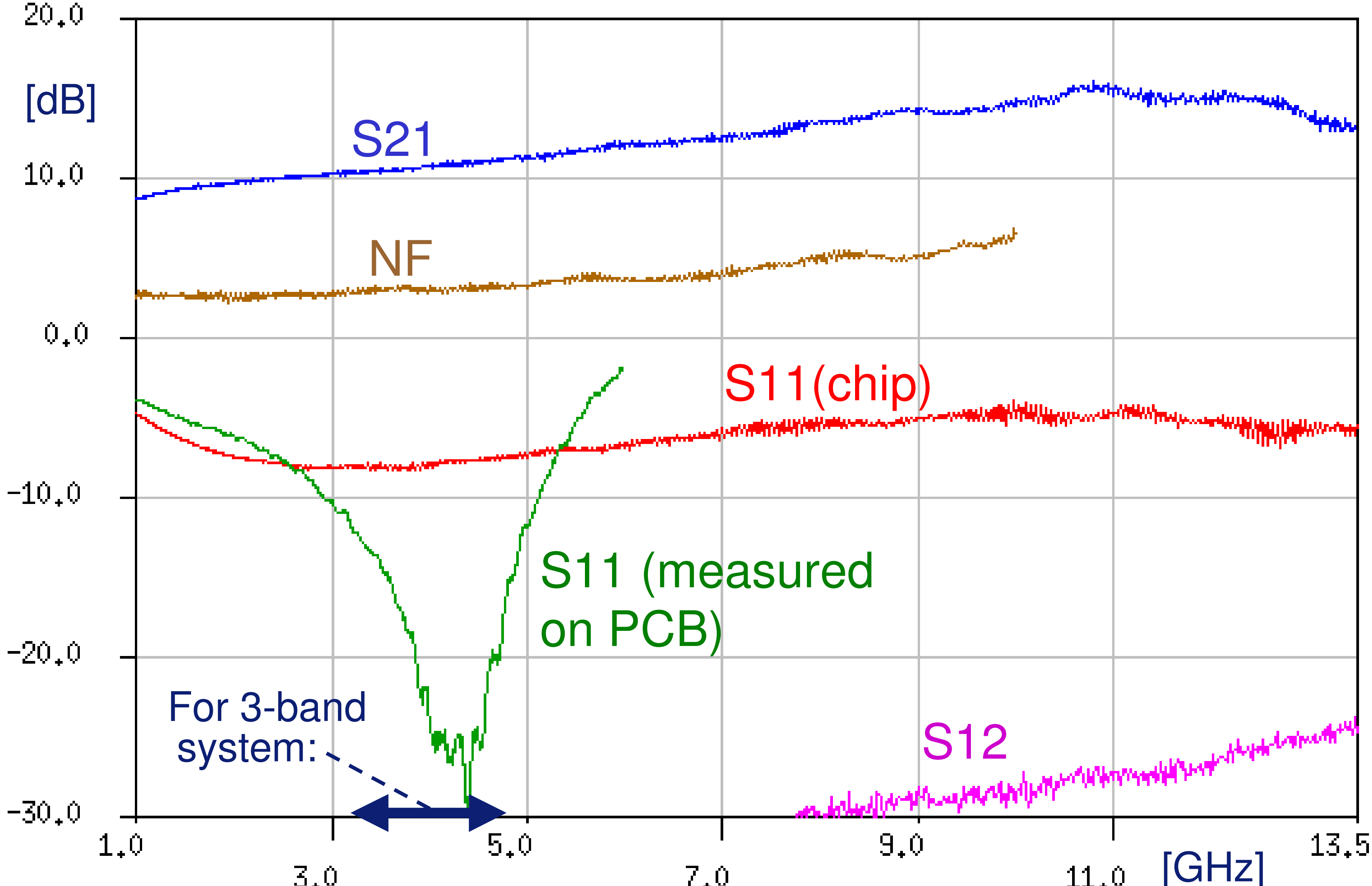


Hopping from band #1 to #3

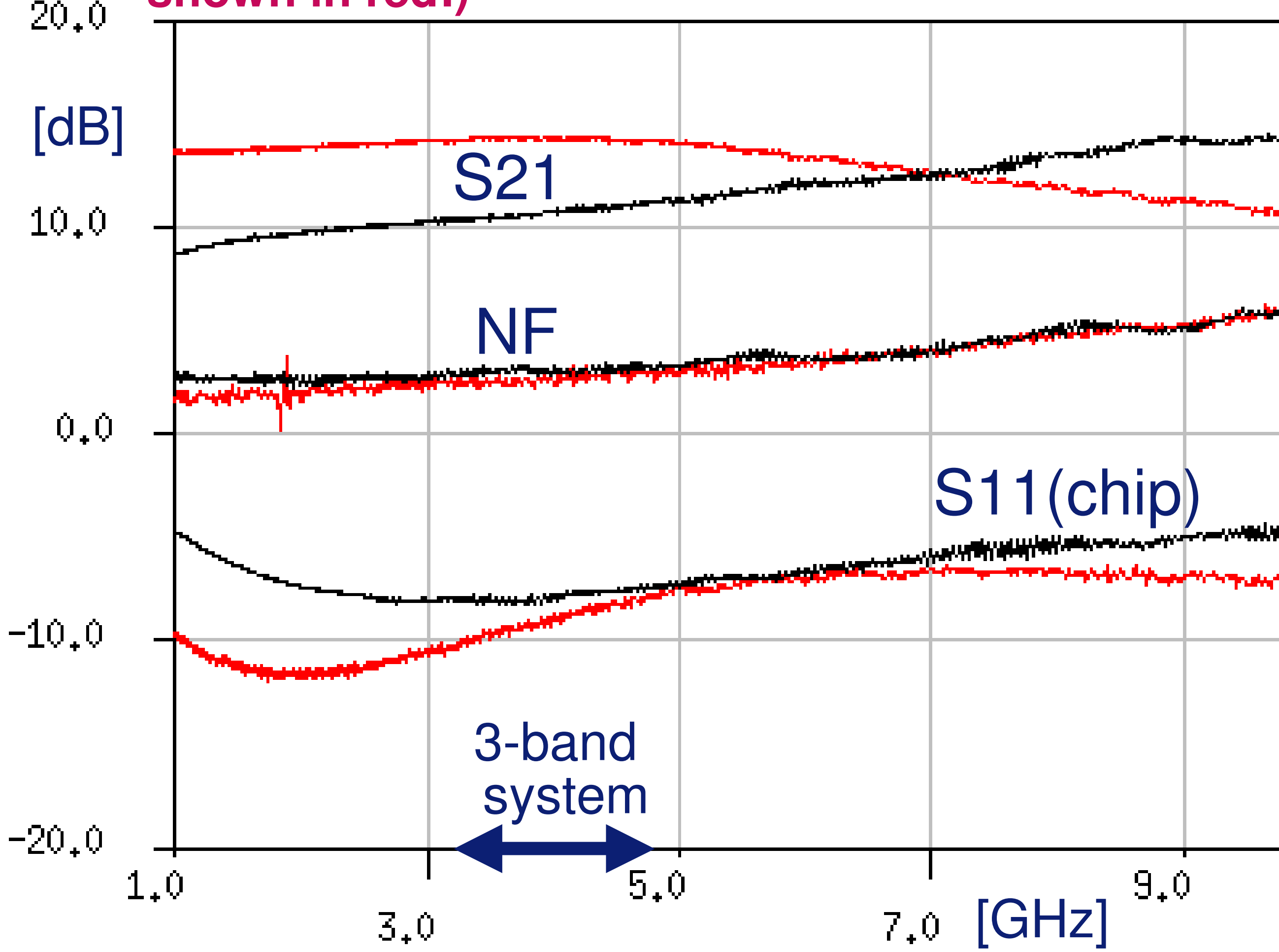
Calculate FFT to measure the switching time

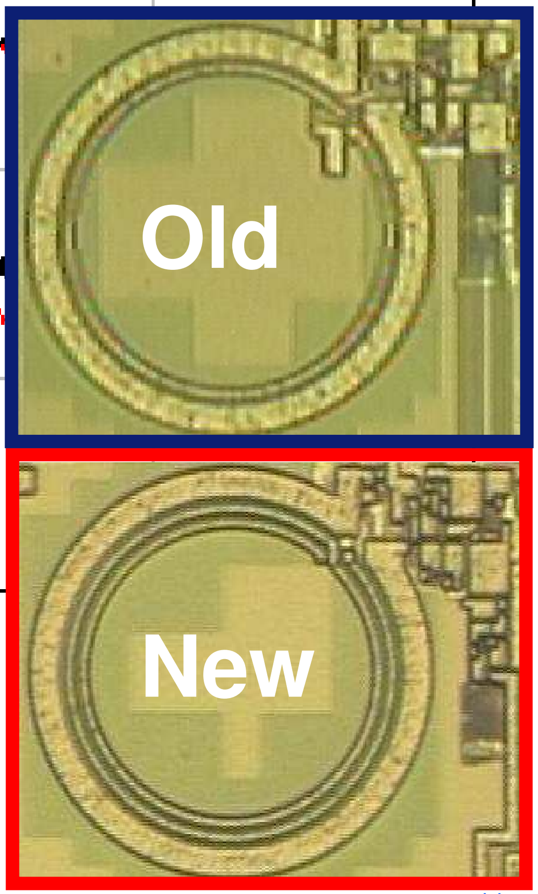
For all hopping scenarios: Settling time below 1ns.

Measured LNA characteristics



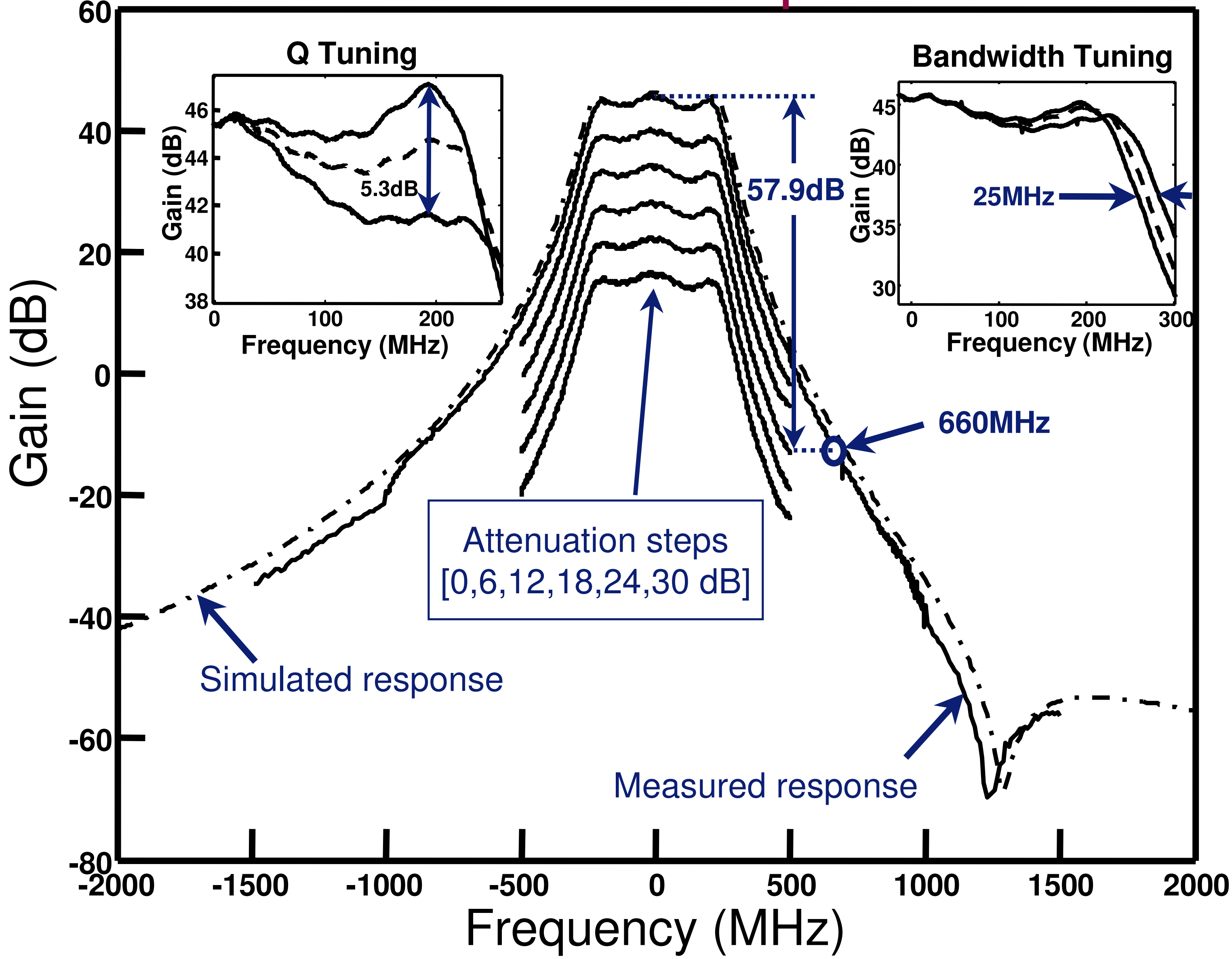
Measured LNA results (recentered design shown in red!)





Increased LNA gain, for better overall system noise figure!

Measured baseband filter response



Summary of RX system measured parameters

Noise figure	5 dB	On PCB, center of band, f_{LO}=4GHz
Gain	62 dB	power gain from RF input to BB output
Input IP2	+16 dBm	f_{in1} : 5 GHz ISM, f_{in2} : 2.4 GHz ISM
Input IP3	-7 dBm	f_{in1} : 5 GHz ISM, f_{in2} : 802.11a
LO Hoping time	1nS	Band#2 to Band#1 or Band#3
Supply	2.5V, 47mA, 27mA	Receiver chain, LO generator

PHILIPS

Contents

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Conclusions

- A low power fast-hopping (<1nS) synthesizer for UWB radio is demonstrated
- A UWB radio can be designed to be robust to the interference of the existing WLAN wireless devices
- A UWB radio using large bandwidth is possible at low power offering opportunity to exploit Shannon’s capacity formula for high data rates
- UWB technology is ripe for exploitation to achieve high data rates for WPAN applications.

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