Information Technology Centre Europe
Telecommunications Laboratory

UWB Non-Coherent High Data Rates Transceiver

Architecture and Implementation

RF studies:

J. B. Doré, **S. Mallégol**

Signal processing:

S. Paquelet, L. M. Aubert, B. Uguen

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General Purpose

"How to transmit hundreds of megabit with impulse radio?"

- **Principles**
  - Impulse radio based solution duplicated on multiple sub-bands
  - Asynchronous treatments → energetic detector instead of correlations
- **Performance study**
  - 600 Mbit/s @ 3 meters, 150 Mbit/s @ 10 meters
  - matches IEEE 802.15.3a requirements
- **Implementation sketches**
  - Use existing analog devices

Presentation progress

Outline

- Principles and performances
- Transceiver architecture
- Transceiver implementation
- Conclusion and prospects

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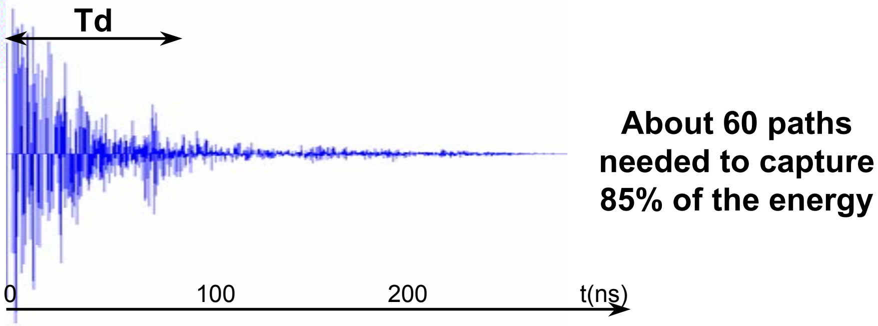
Principles (I)

S. Paquelet et al., UWBST&IWUWBS 2004

- **A traditional approach**
  - **Coherent - RAKE receiver, BUT:**
    - Antenna and channel distortion → unpredictable received waveform.
      - For example:

      - Which matched signal has to be used in the correlators?
    - Multi-paths channel → received signal spreads on tens of nanoseconds.
      - For example:



About 60 paths needed to capture 85% of the energy

      - How can a RAKE receiver, built on a limited number of fingers, benefit from the available energy?

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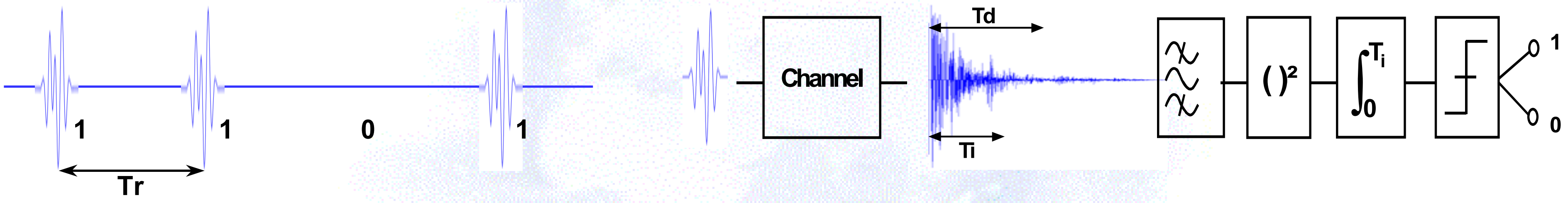
Principles (II)

S. Paquelet et al., UWBST&IWUWBS 2004

- **Adopted approach:**
  - Asynchronous receiver: energy detection → available energy captured
  - On-Off Keying modulation



$T_r > T_d$ → to avoid inter symbol interference
T_i evaluated from channel estimation (synchronization procedure)

  - Extension to multiple bands → achieve channel capacity

- **Decision problem:**

$$\begin{cases} H_0 : x = \int_0^{T_i} [n(t)]^2\, dt \\ H_1 : x = \int_0^{T_i} [s(t)+n(t)]^2\, dt \end{cases}$$

Minimize error probability with known B and estimated T_i, $E = \int_0^{T_i} s^2(t)dt$, $N/2$

Optimal threshold setting

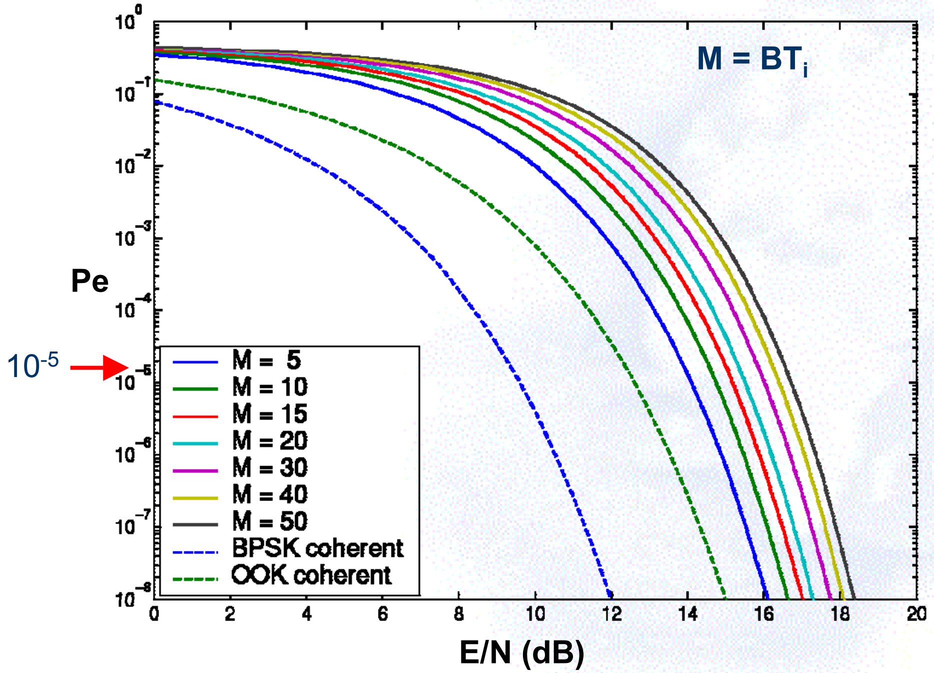
$$x \underset{H_0}{\overset{H_1}{\gtrless}} \rho_{opt}$$

$$\boxed{\frac{\rho_{opt}}{N} \simeq \frac{L}{4} + M + \sqrt{M-1}.\phi(L)}$$ with $\begin{cases} L = E/N \\ M = BT_i \end{cases}$

Performances

S. Paquelet et al., UWBST&IWUWBS 2004

- **Error probability:**



Coherent - RAKE receiver:

→ Energy recovered on few paths

Quadratic integration:

→ Whole available energy recovered

Ideal rake receiver achieves comparable P_e if it collects 33% to 40% of the whole available energy.

Now, according to: - Power emission limits,
- Channel propagation,
- Demodulation schemes,

→ **Where is the working point?**

- **Link budget example:**

CM: IEEE Channel Model
- 2: NLos 0-4 meters
- 3: NLos 4-10 meters
- 4: extreme NLos multipath

R *	**150**	**240**	**600**	*Mbit/s*
d	**10**	**5**	**3**	*m*
B	500	500	250	*MHz*
N_{band}	12	12	24	
T_r	80	50	40	*ns*

* without FEC code

CM	4	3	2	
T_i	50	40	30	*ns*

P_e *	10^{-5}	10^{-5}	10^{-5}	

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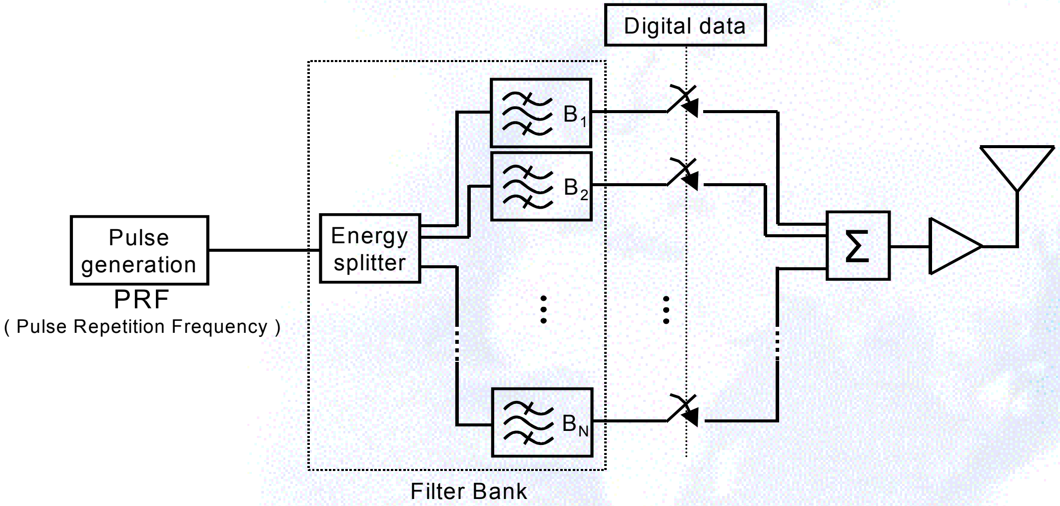
Proposed architectures

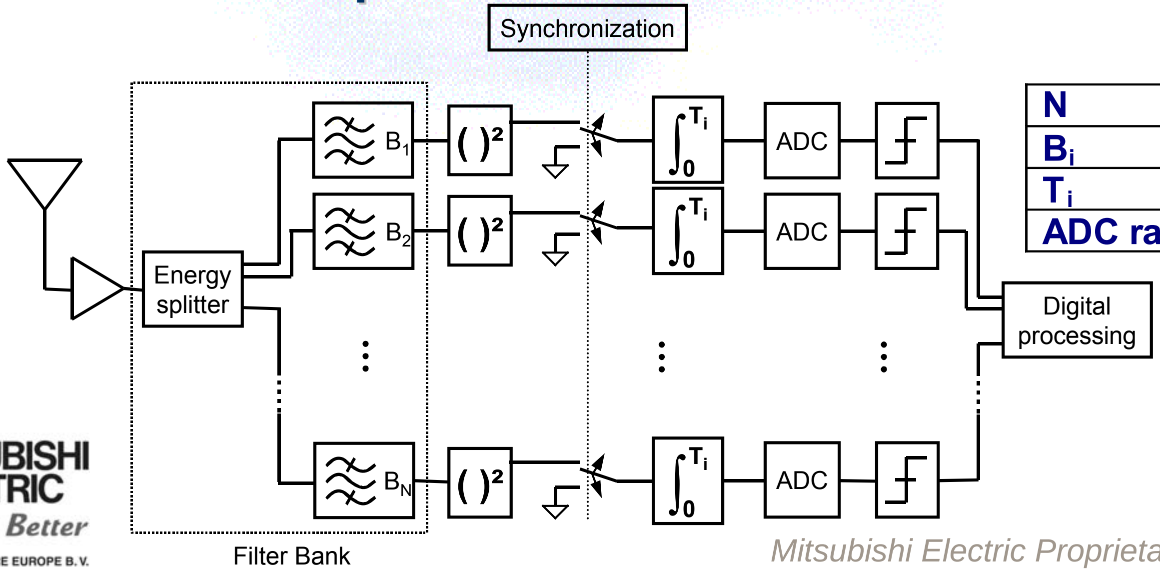
- **Tx architecture: implementation using filter bank**



Typical figures:

N	between 15 and 30
B_i	between 250 and 500 MHz
PRF	lower than 30 MHz

- **Rx architecture: quadratic detector on each sub-band**



Typical figures:

N	between 15 and 30
B_i	between 250 and 500 MHz
T_i	between 20 and 100 ns
ADC rate	lower than 30 MHz

Architecture interests

- **Relaxed hardware constraints:**
  - **Only coarse synchronization needed**
    - ➔ Robust against clock jitter
  - **Energy based processing**
    - ➔ Robust against distortion and phase non-linearity (simplified design: antenna, filter, and amplifier)
  - **Use of passive analog devices**
    - ➔ Low power consumption

- **Flexibility:**
  - **Scalable data rates**
  - **Radio Resource Management / power control**
    - ➔ Possible Frequency Division Multiplexing

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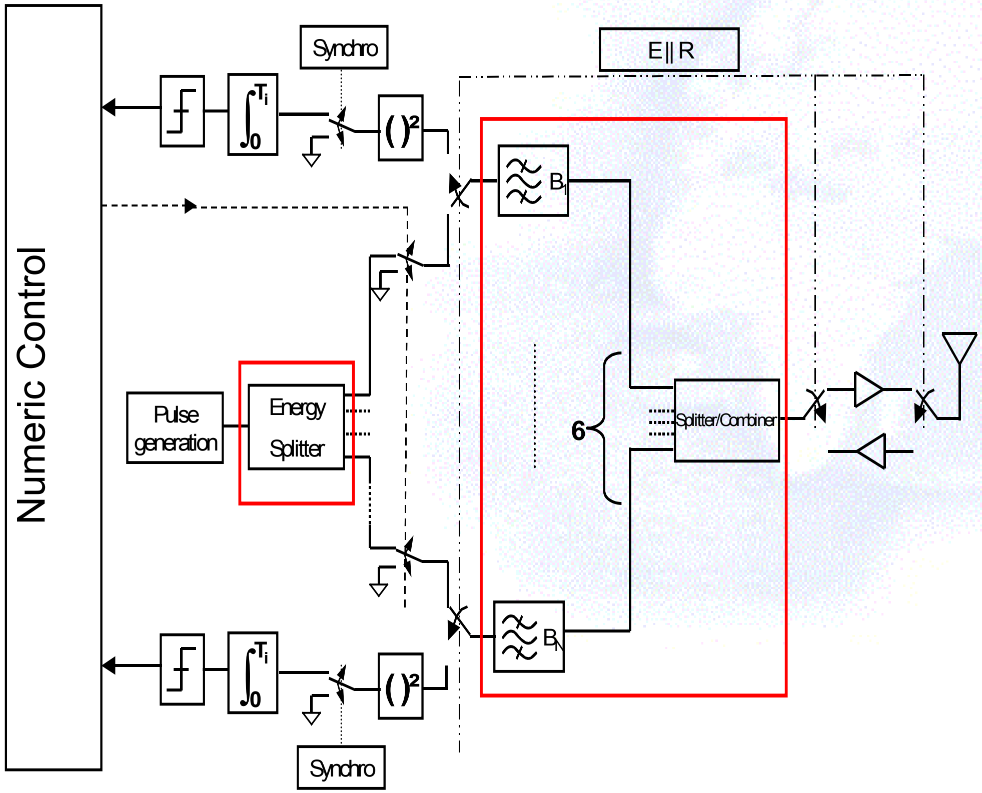
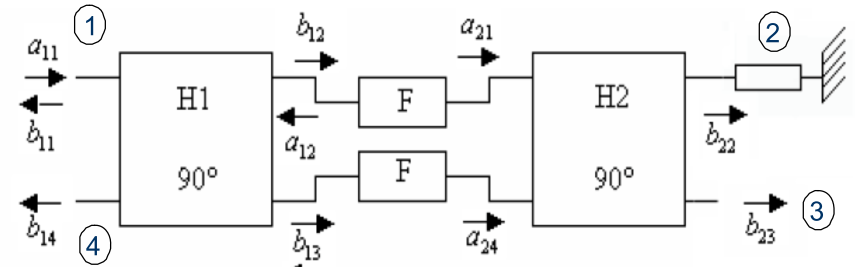
Energy splitter (I)

Transceiver



Frequency sub-bands division based on passive diplexers

Hybrids & filters



$b_{11} = 0$

$b_{14} = \Gamma_1 j a_{11}$

$$[S]_F = \begin{bmatrix} \Gamma_1 & T \\ T & \Gamma_2 \end{bmatrix}$$

$b_{22} = 0$

$b_{23} = Tja_{11}$

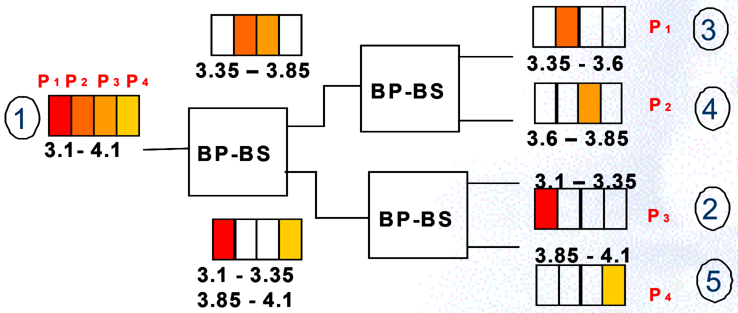
A priori, no external bias field required

BUT

2 couplers & 2 filters for the diplexing operation

Energy splitter (II)

3.1 - 4.1 GHz frequency sub-bands division based on Lange couplers and band-pass filters


P1 P2 P3 P4

①

3.1- 4.1

BP-BS

3.35 – 3.85

BP-BS

3.1 - 3.35
3.85 - 4.1

BP-BS

3.35 - 3.6

P1 ③

3.6 – 3.85

P2 ④

3.1 – 3.35

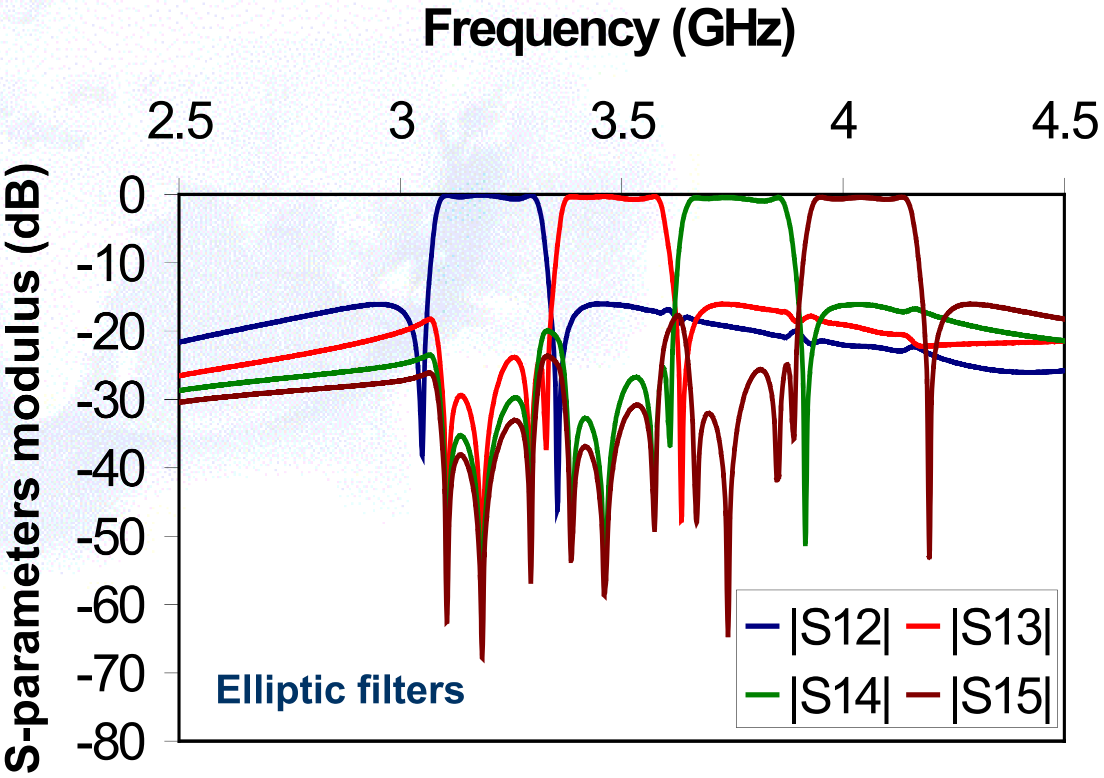
P3 ②

3.85 - 4.1

P4 ⑤

6 couplers & 6 filters (6 BP)

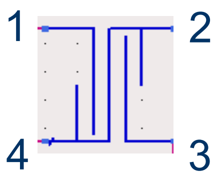
Filter	Response type	Order
Band-Pass: 3.35 – 3.85 GHz	Chebyshev Elliptic	8 5
Band-Pass: 3.1 – 3.35 GHz, 3.35 – 3.6 GHz	Chebyshev Elliptic	5 3



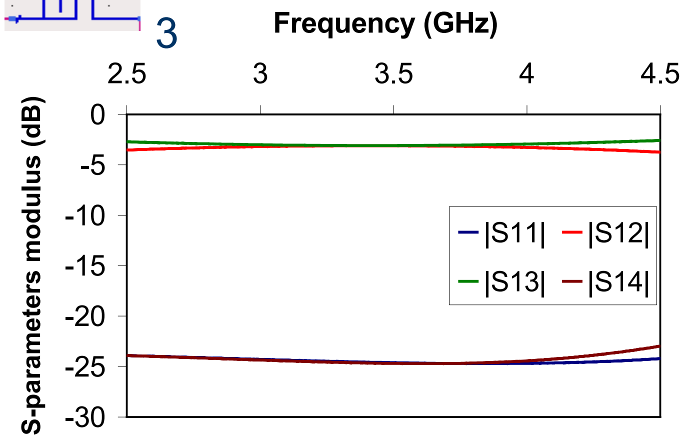
- 3 dB bandwidth = 0.23 GHz
- Passband ripples < 0.2 dB
- Insertion losses < 0.74 dB
- Out-of-band rejection > 15 dB

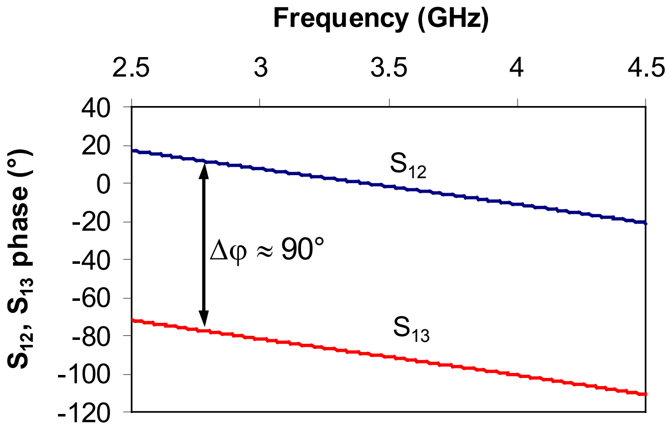
Energy splitter (III): -3dB, 90° hybrid

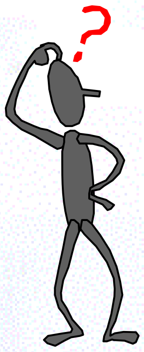
Lange coupler ($\varepsilon_r = 10.5$, $\tan\delta = 10^{-3}$)



w = 39.5 µm, s = 52.9 µm,L = 8.52 mm



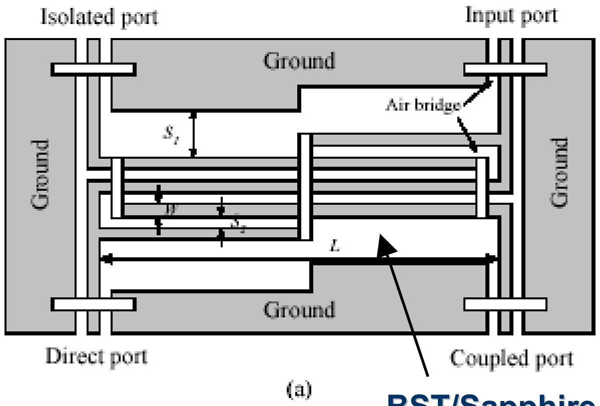




Integration capability?

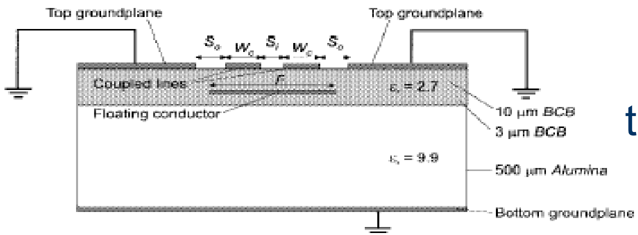
Dielectric films & high ε_{eff} → size reduction

D. Kim et al., IEEE MTT S, 2002



L = 9.4 mm
W = 0.04 mm
S_1 = 0.3 mm
S_2 = 0.06 mm
F < 4 GHz

BST/Sapphire



MCM-D technology

P. Pieters et al., IEEE MTT, 1999

Energy splitter (IV): passive band-pass filters

- **3.35 - 3.85 GHz (order: 5)**
- **3.1 - 3.35 GHz (order: 3)**
- **3.35 - 3.6 GHz (order: 3)**

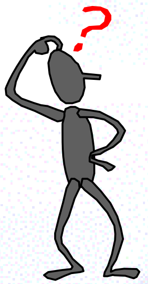
Response type: elliptic

L: 0.12-28.3 nH, C: 0.06-14.4 pF

Insertion losses < 0.2 dB

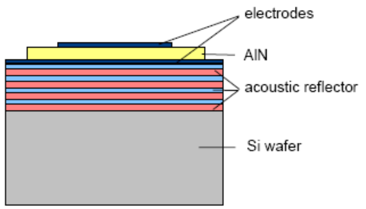
Out-of-band rejection > 15 dB

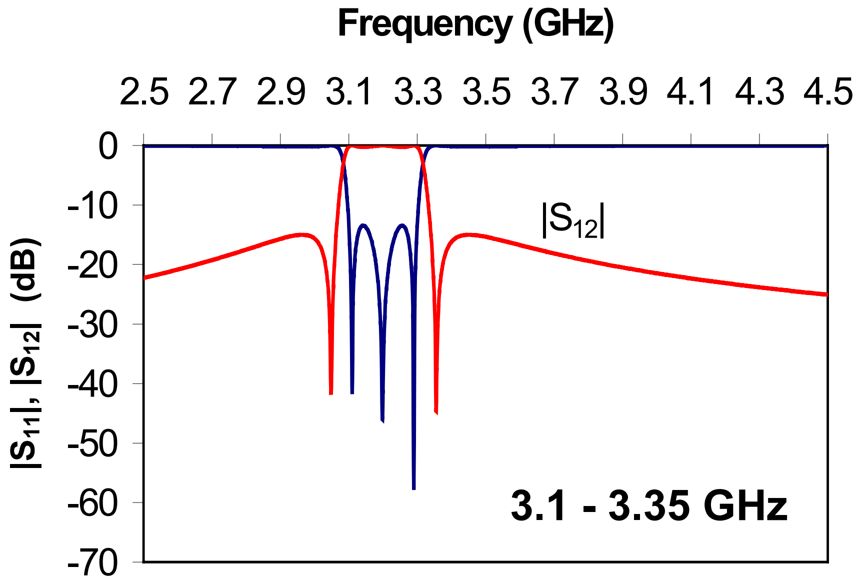
In-band reflection > 13.5 dB



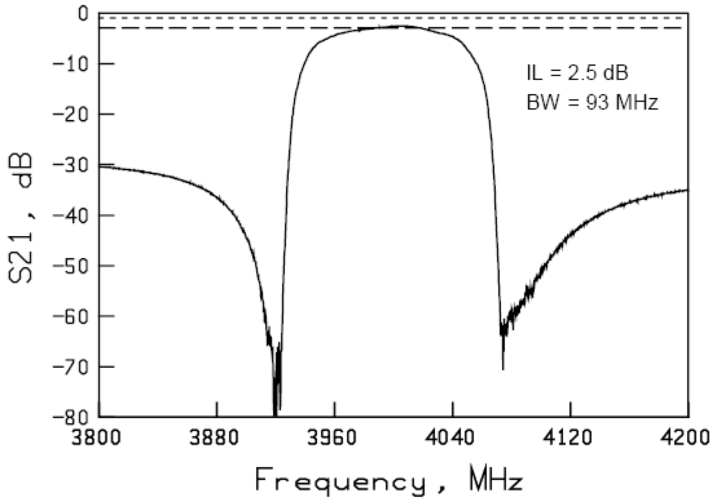
Integration capability?

Ladder or lattice filter based on BAW resonators



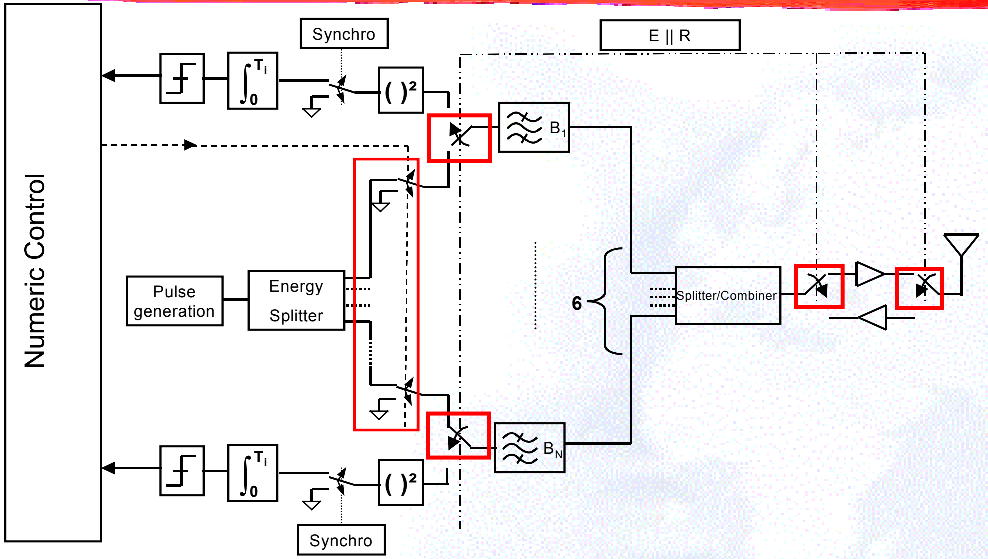


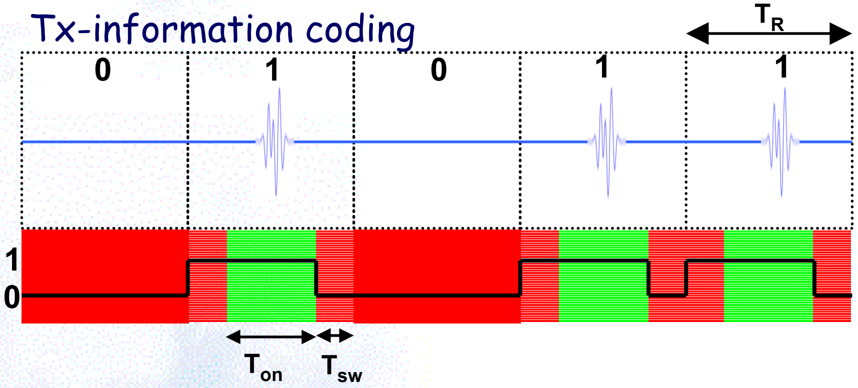
K. M. Lakin et al., IEEE MTTS, 2002



Ladder filter: 5 series & 4 shunt resonators (90*90 μm^2, piezoelectric: $t = 0.9\ \mu m$)

RF Switch





- T_R = 40 ns
- T_{on} = 2 - 10 ns (250 MHz ➤ 4 ns)

MEMS switch

☺
- Near-zero power (10-100 nJ/switching cycle)
- High isolation < 40 GHz
- Low insertion loss (typ. < 0.1 dB)
- Low intermodulation product (FET + 30 dB)

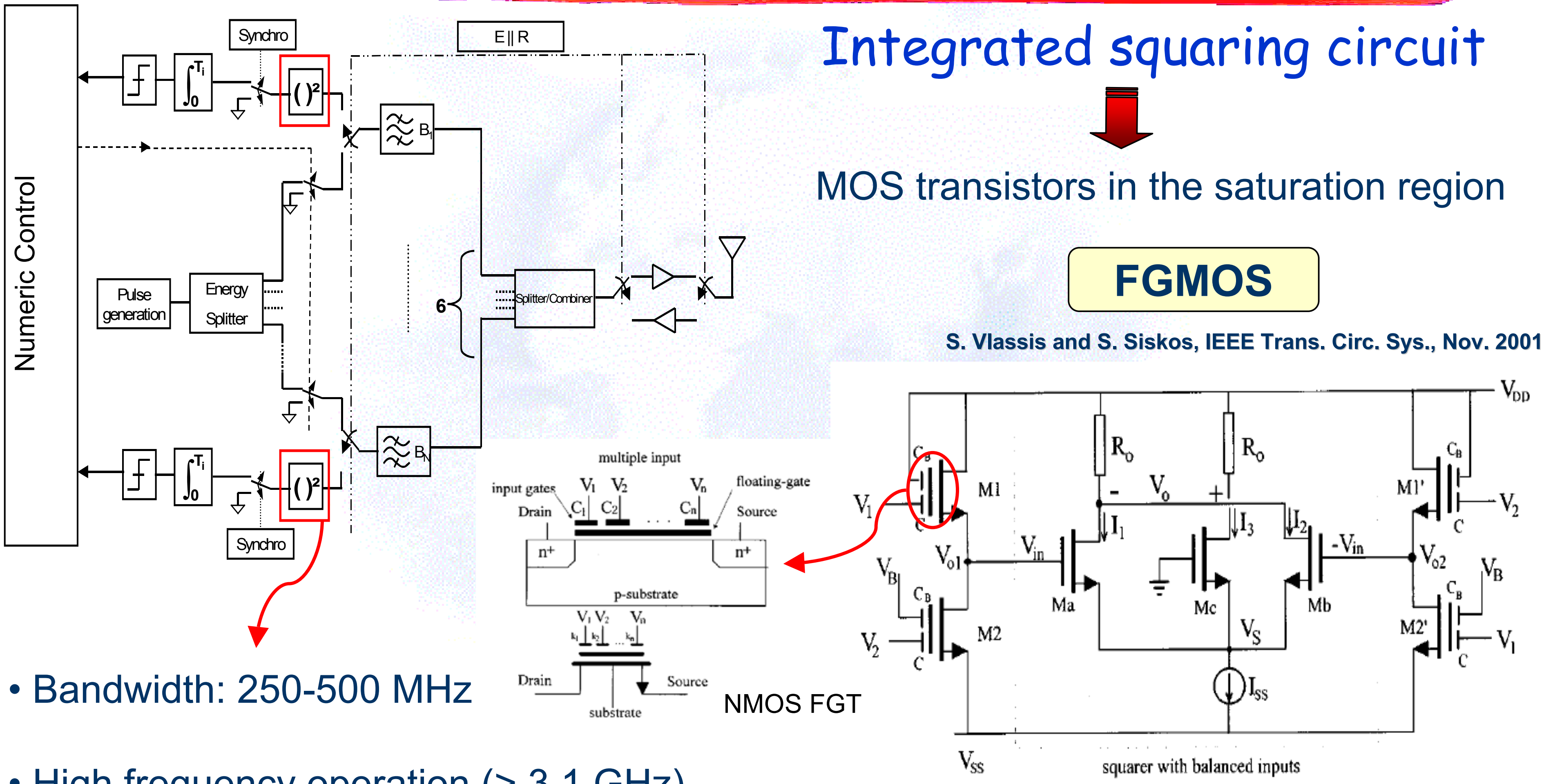
☹
- High voltage drive (typ. 20-80 V)
- Low switching speed (**1-40 µs**)

FET switch

☺
- Broadband (typ. < 6 GHz)
- Good isolation (typ. > 40 dB)
- Low power (typ. < 0.1 mW)
- High switching speed (**1-100 ns**)

☹
- High insertion loss (typ. 0.4-2.5 dB)
- Max. control voltage: 6 V typ.

Squarer



Integrated squaring circuit

MOS transistors in the saturation region

FGMOS

S. Vlassis and S. Siskos, IEEE Trans. Circ. Sys., Nov. 2001

NMOS FGT

squarer with balanced inputs

- Bandwidth: 250-500 MHz
- High frequency operation (> 3.1 GHz)

$$V_0 = 2R_0\beta\alpha^2(V_1 - V_2)^2$$

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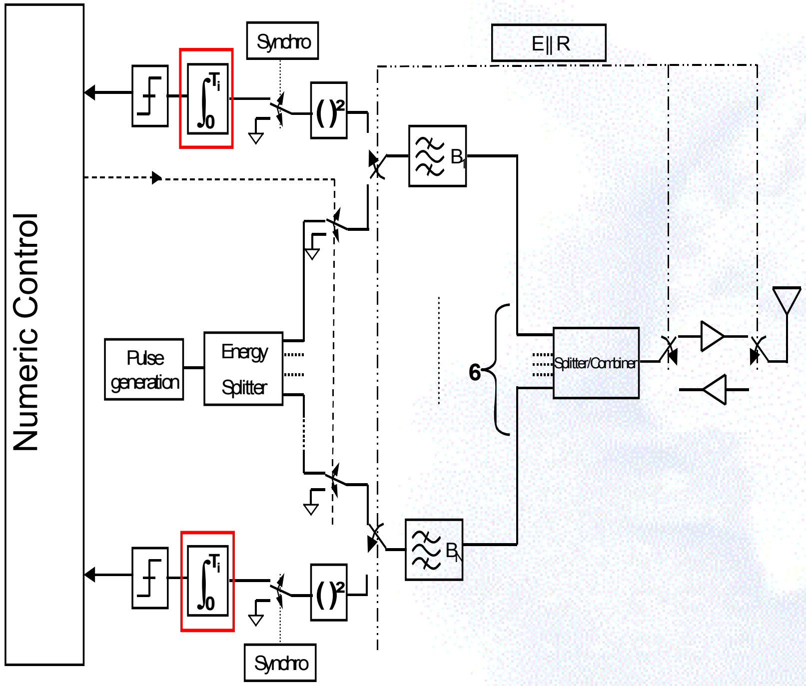
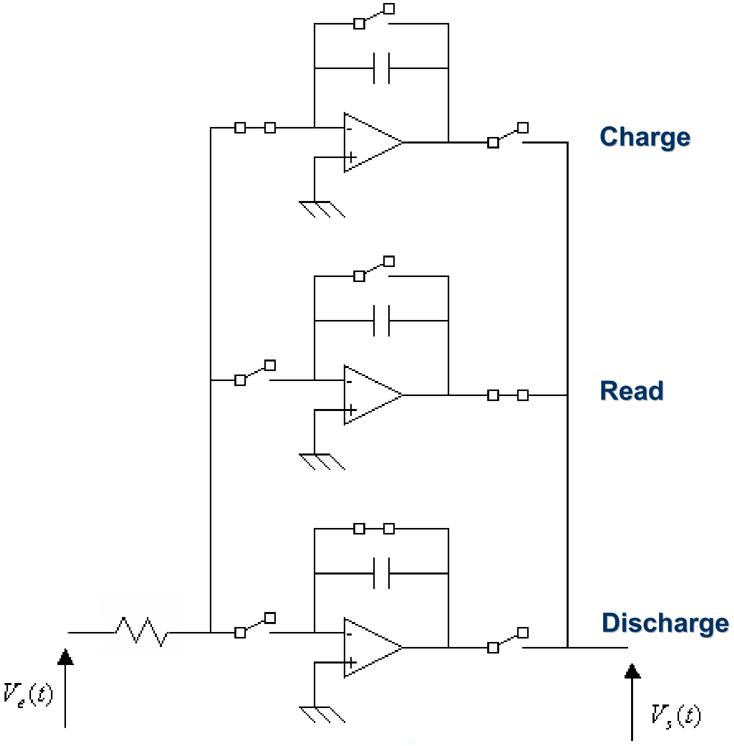
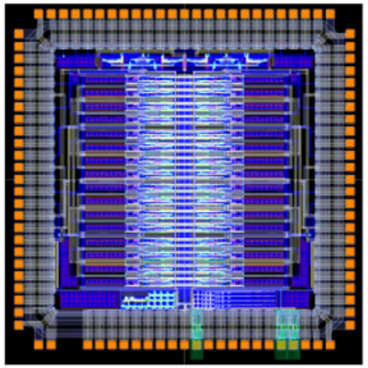
Charge-successive integrator







- 3.9 x 3.9 mm² CSI chip
- 0.6 µm CMOS technology
- Offset voltage < 2 mV
- 5 V power supply

$$v_s(t) = -\frac{1}{RC}\int_{t}^{t+T_i} v_e(\tau)\,d\tau$$

Y. Tanaka et al., IEEE Trans. Nuc. Sci., Aug. 2002

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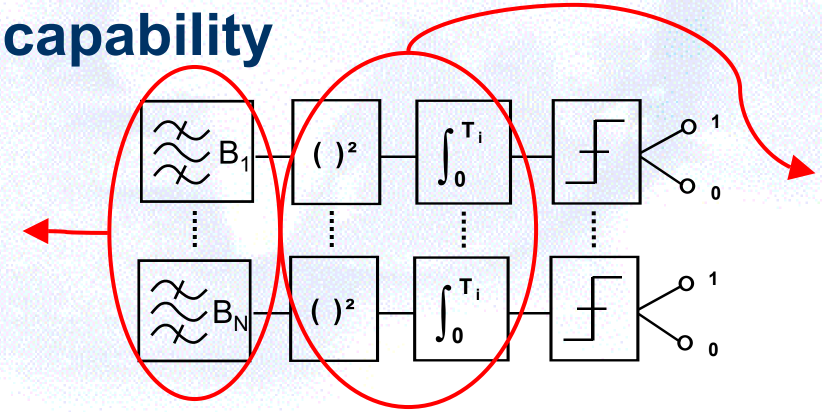
Conclusion and prospects

Conclusion

- **Identification of possible architectures for an UWB HDR transceiver based on Impulse-Radio:**

→ **MBOOK modulation & non-coherent demodulation (receiver = energy detector)**

- **Good integration capability**



Passive analog filter
bank based on
hybrids and FBAR

Active analog devices

Prospects

- **Implementation of the proposed UWB HDR transceiver within *PULSERS PHASE 2* for very short range point-to-point extremely high speed applications**
- **Collaborations for pulse generation are welcome!**