LINC transmitters: concepts, design and performance

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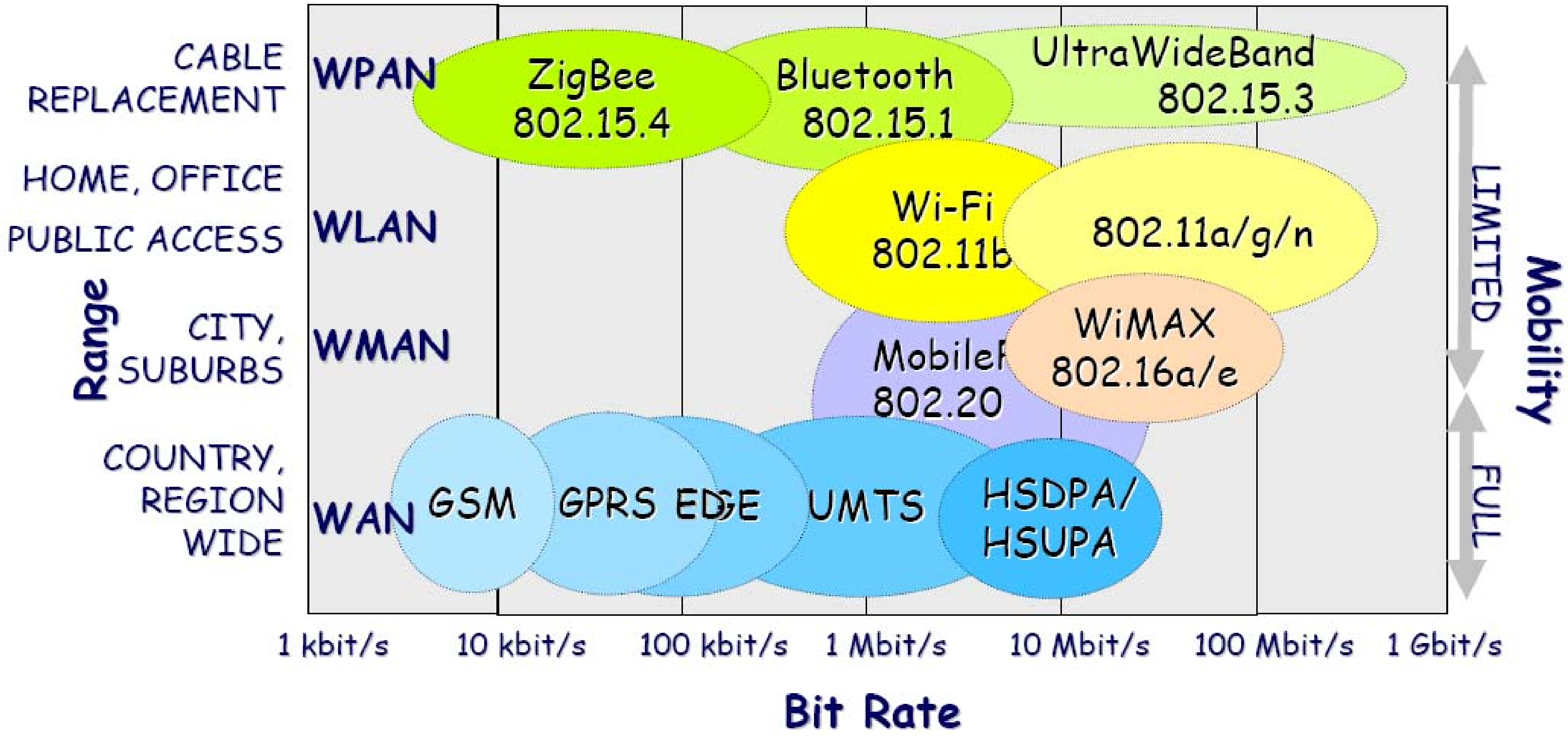
Outline

- Motivation
- LINC Transmitter

- Impact of path imbalances
- Efficiency of Power combination
- Low-power Signal Separation

- Conclusions

Wireless networks



TX Linearization techniques

Technique	Issues	Acceptance
Cartesian feedback	Symmetric feedback paths, feedback BW ~ signal BW, linear PA's, feedback demodulator	Popular
Polar-loop feedback	Asymmetric feedback paths, larger bandwidth, non-linear PA's	Medium
Envelope Elimination and Restoration	Asymmetric paths, BW wider than signal BW, AM/PM conversion	Low
LINC	2PA's, symmetric paths, BW wider than signal BW, recombination/separation efficiency	Under investigation

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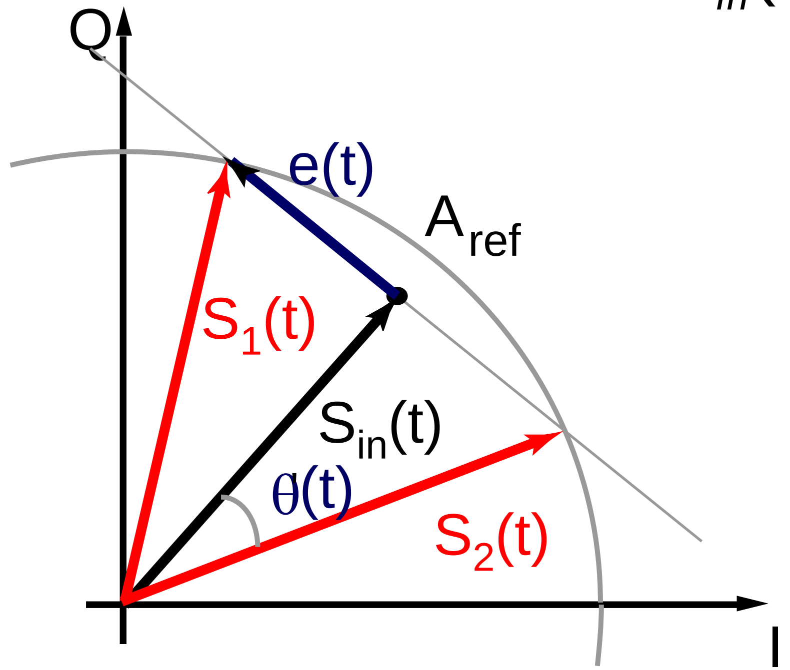
Basic Principle



$$S_{in}(t) = A(t)e^{i\varphi(t)}$$

Separation

$$\begin{cases} S_1(t) = S_{in}(t) + e(t) \\ S_2(t) = S_{in}(t) - e(t) \end{cases}$$

$$S_{out}(t) = G_{PA} \cdot [S_1(t) + S_2(t)]$$
$$= 2G_{PA} \cdot S_{in}(t)$$

Amplification + Recombination

LINC TX

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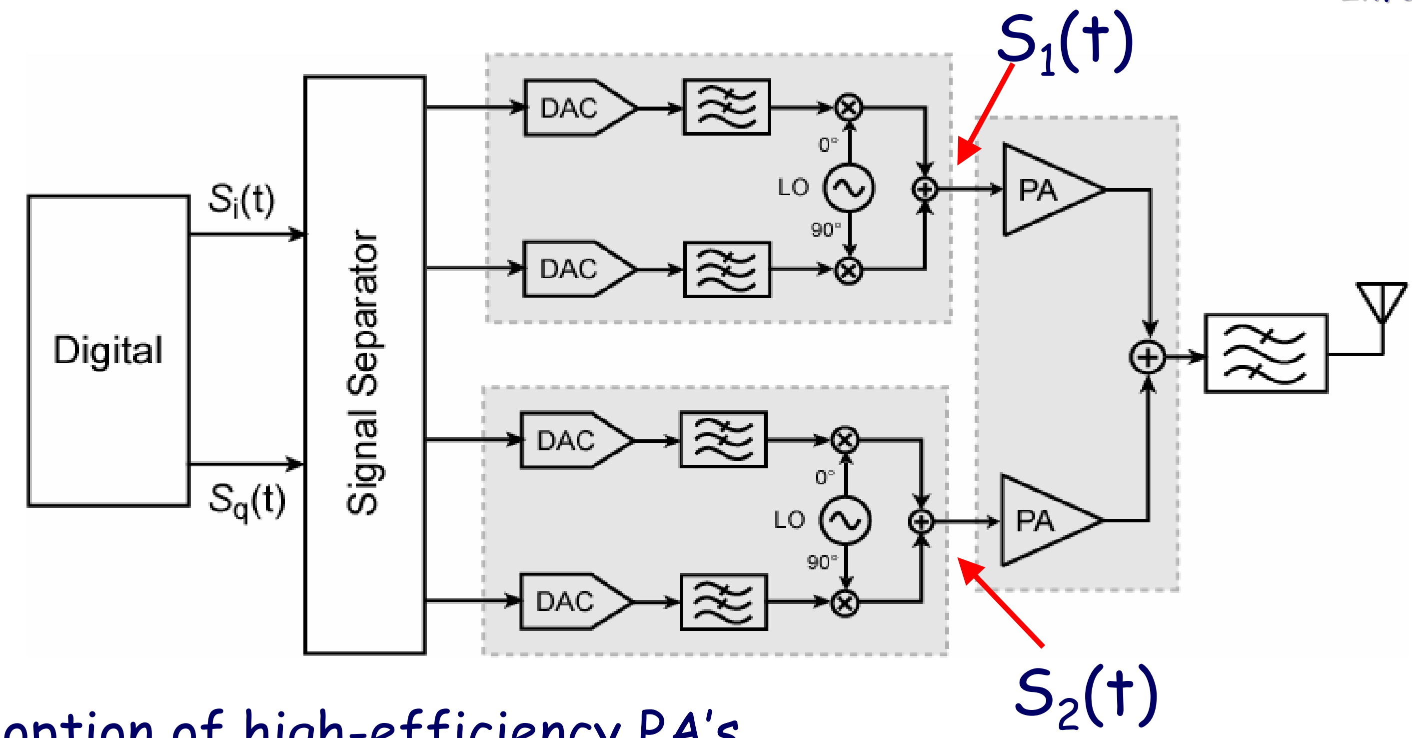

- Adoption of high-efficiency PA's
- Doubling the transceiver circuitry
- Major challenges:
  - accurate matching of the two amplification paths
  - efficient power recombination after PA's
  - low-power processing

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Signal clipping of the separator

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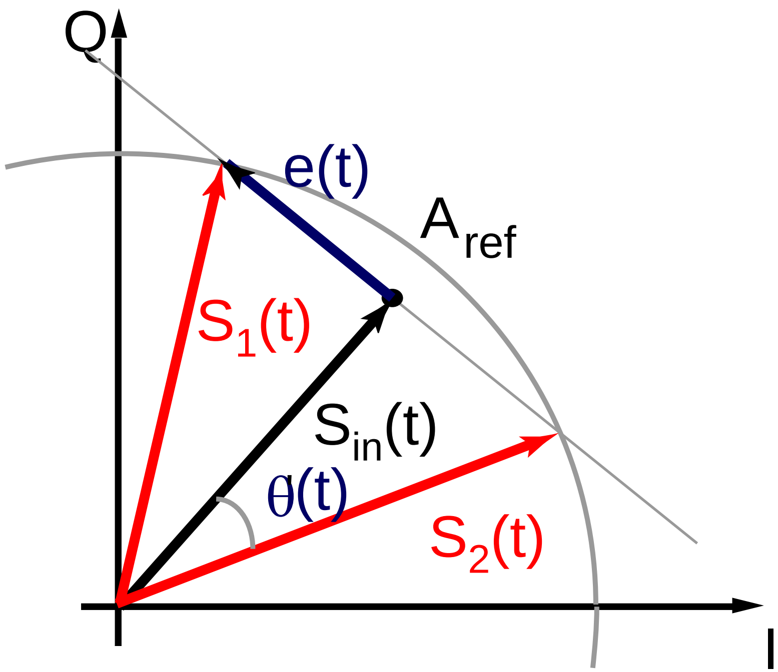


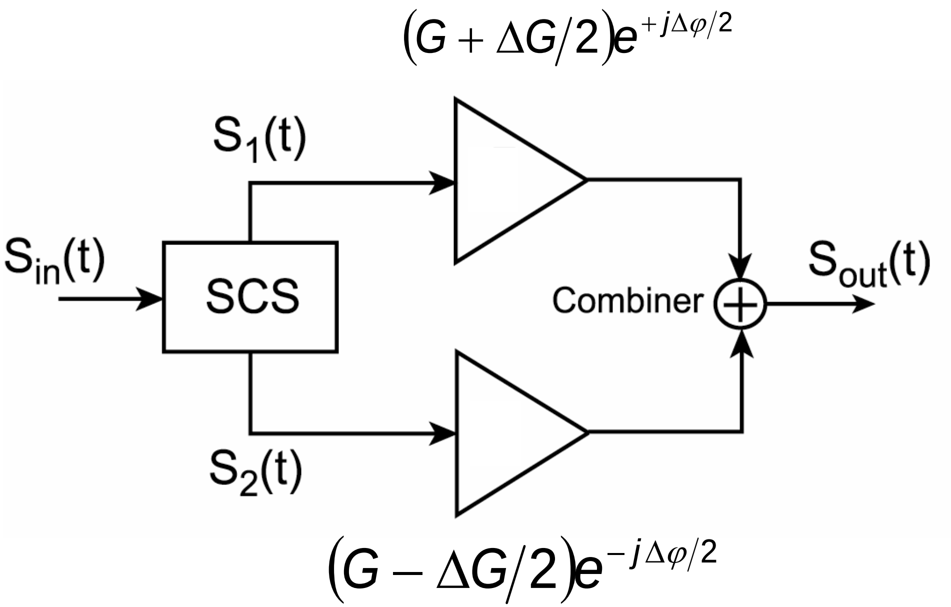
θ (t) is the outphasing angle

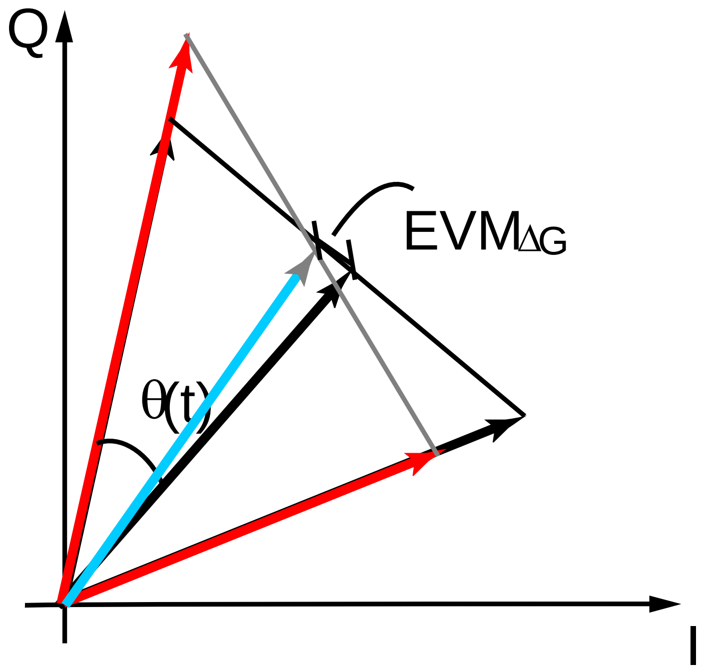
- If |Sin| > Aref, the signal clips
- Margin from signal clipping

$$B = \sqrt{\frac{A_{ref}^2}{< S_{in}(t)^2 >}}$$

- The larger the back-off, the larger |e(t)|

Gain and phase mismatches





$$EVM = (B-1)\cdot\left[\left(\frac{\Delta\varphi}{2}\right)^2 + \left(\frac{\Delta G}{2G}\right)^2\right]$$

Adjacent Channel Power Ratio

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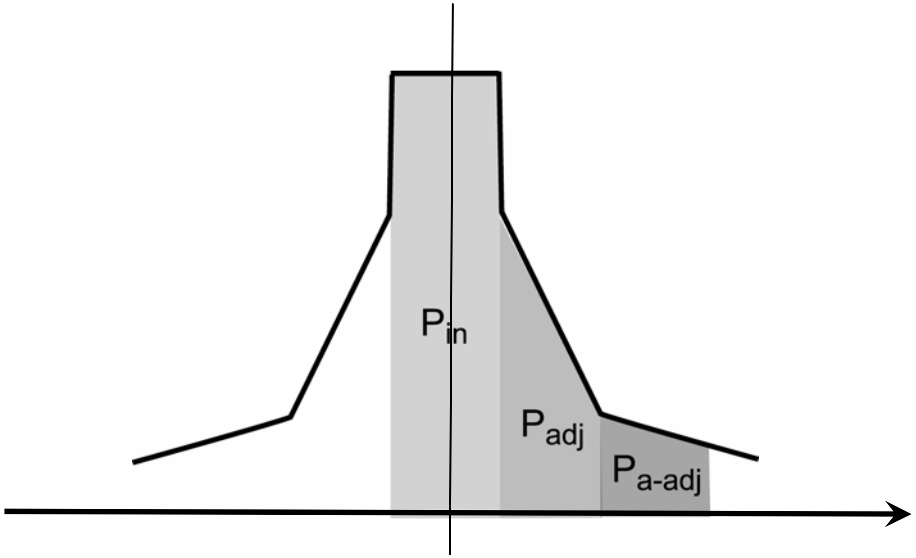

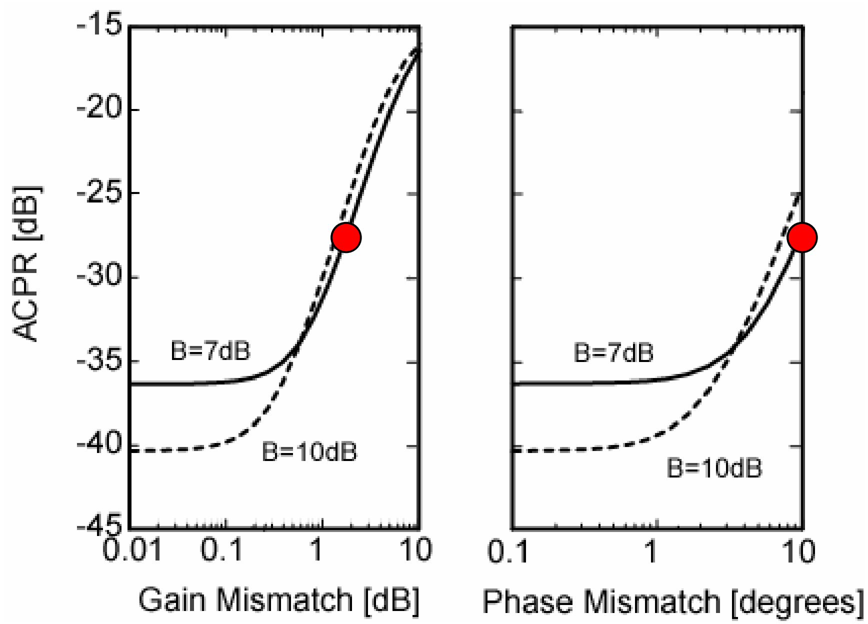

$$ACPR \propto (B-1)\cdot\left[\left(\frac{\Delta\varphi}{2}\right)^2+\left(\frac{\Delta G}{2G}\right)^2\right]$$

Back-off	Gain mismatch	Phase mismatch
7 dB	0.4 dB	2°

L. Romanò et al, IEEE Trans. on Circuit and Systems-I, (2006)

Summary

- To avoid signal clipping a proper back-off of the signal separator should be set
- The larger the back-off the higher the sensitivity to path imbalances
- Mismatches of monolithic implementations can meet the requirements of high-bit rate wireless standards

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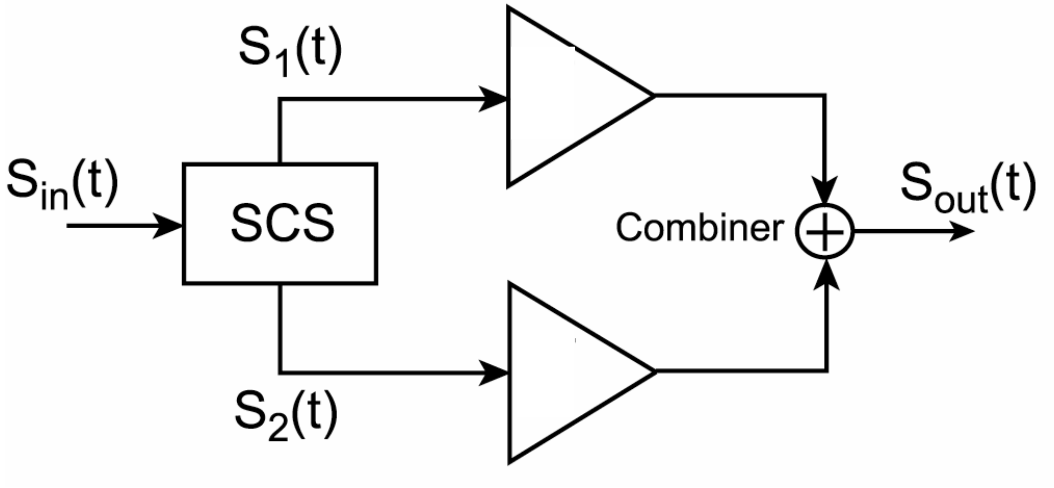
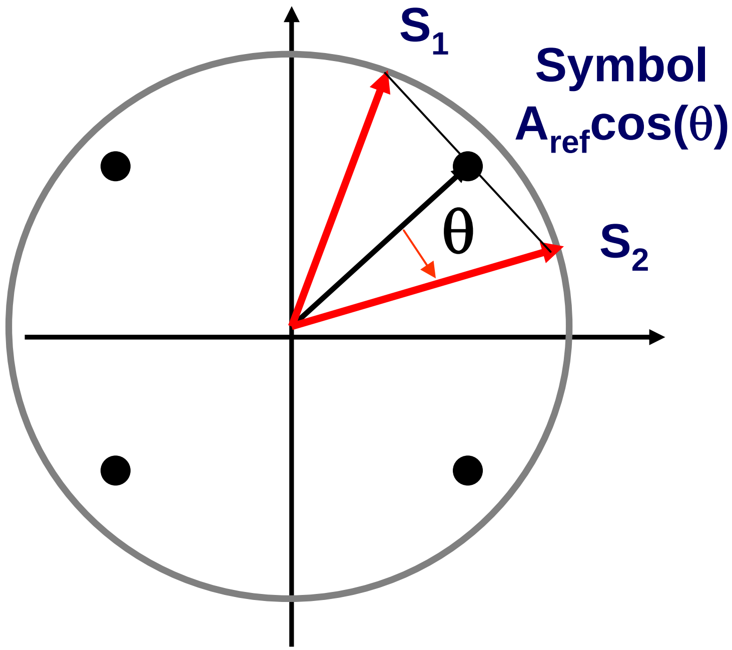
Combiner efficiency





$$PAE \approx PAE^{*} \cdot < \cos^2(\theta) >$$

θ - outphasing angle

- The higher θ, the lower the PAE
- 20% max for IEEE 802.11 @7dB back-off

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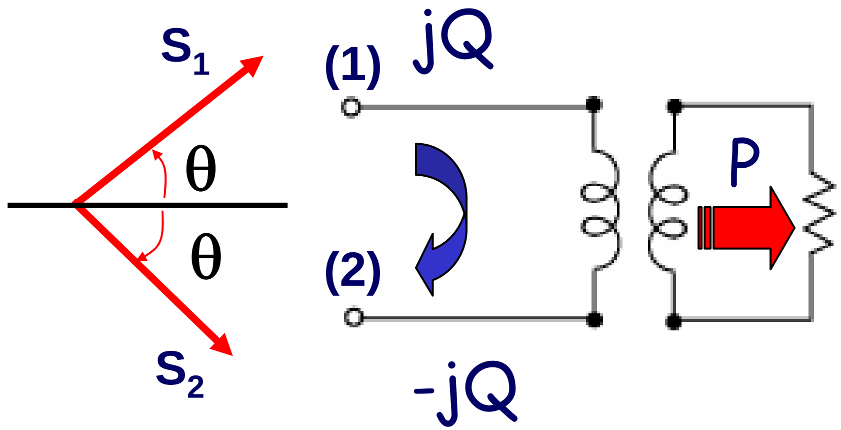
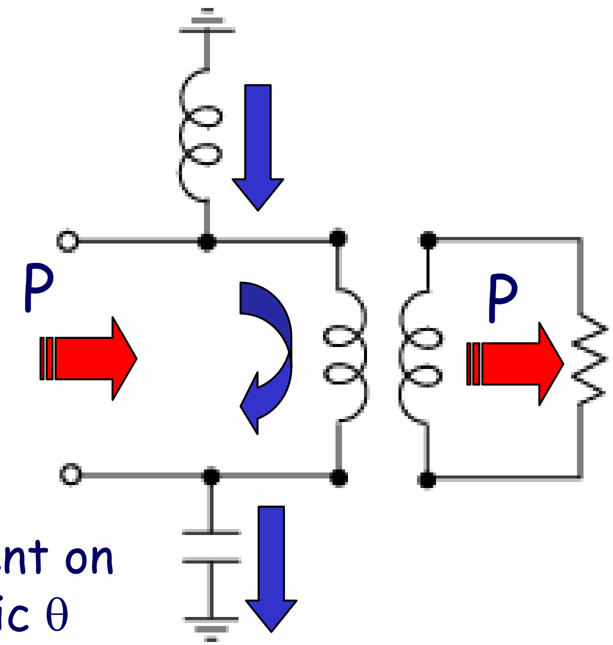
Improving combiner efficency

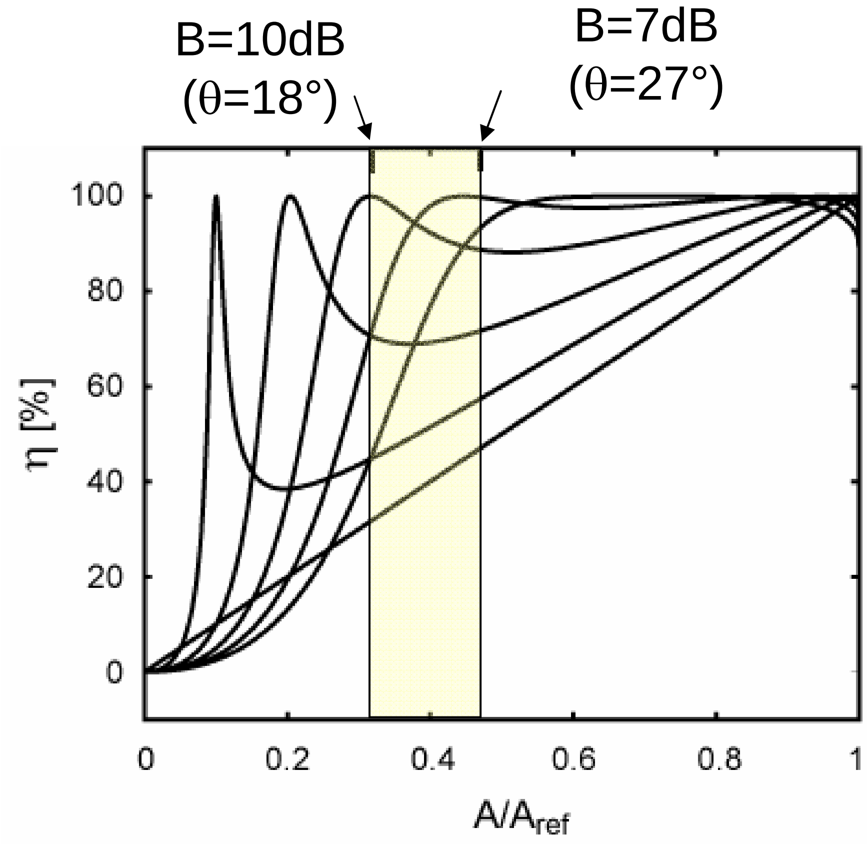


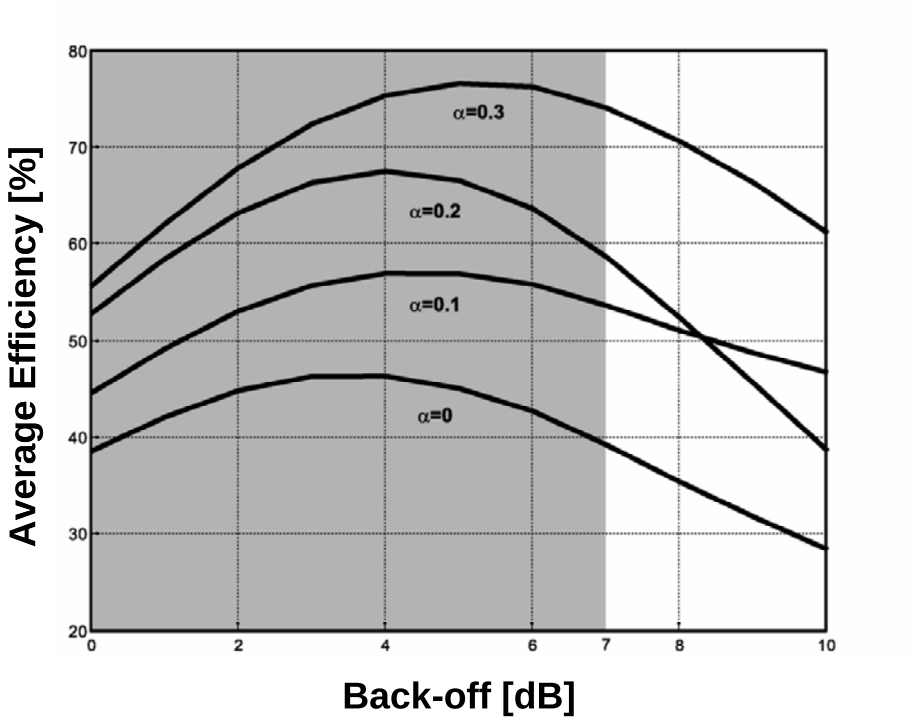
$$Z_{1\text{-}2}=R/2(1\pm \cot g\theta)$$



- Chireix combiner
- Input impedance dependent on θ – Tuning at some specific θ

Performance





- IEEE 802.11g – Average efficiency larger than 70% @ 7dB back-off
- Reactance tuning - S. Moloudi et al. ISSCC'08

Summary

- The efficiency of power combination is key figure for a LINC transmitter
- Loss-less recombination drains reactive power which degrades PA efficiency.
- Chireix recombination tunes out reactive components
- Reactance tuning may improve performance

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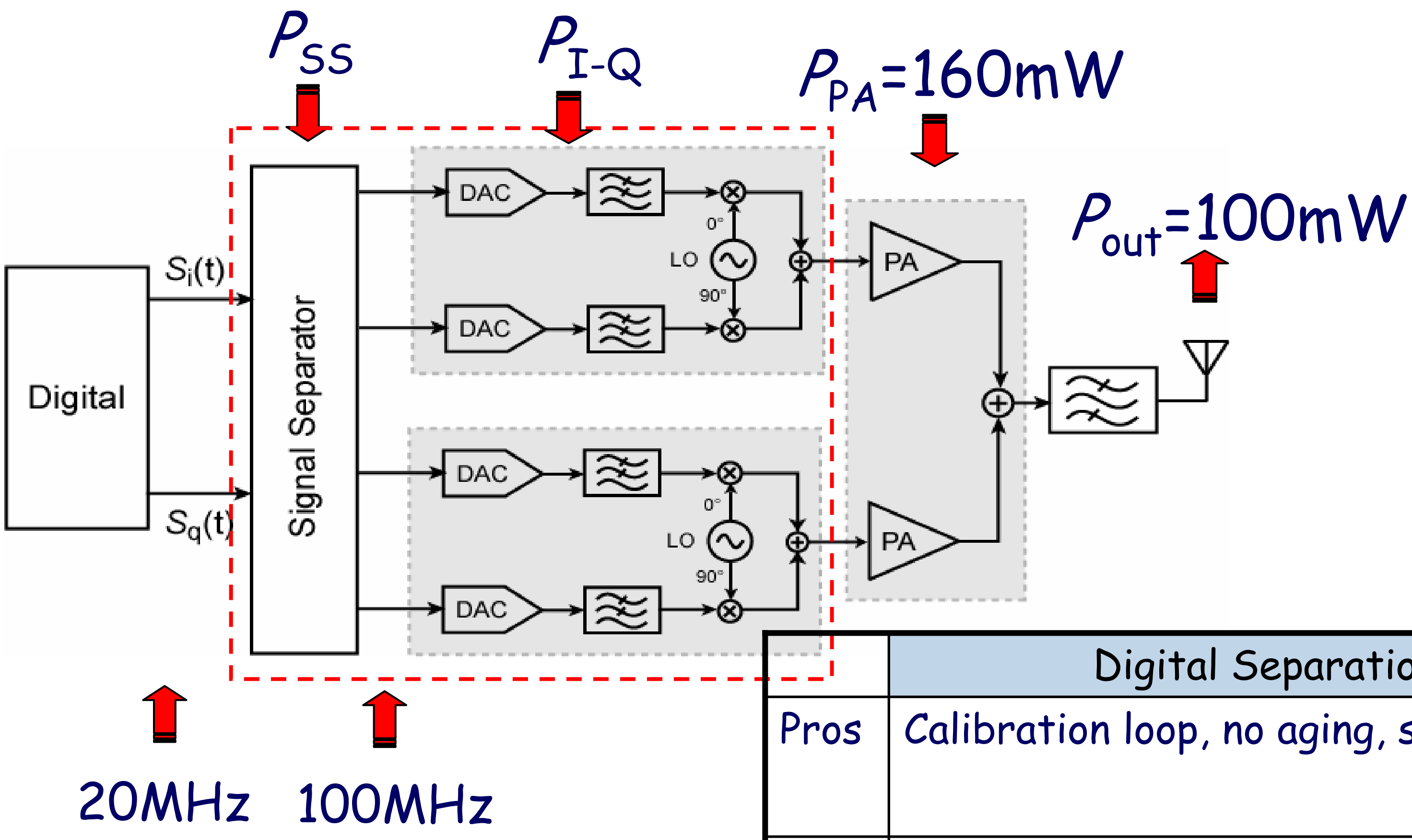
LINC TX – Digital separation



	Digital Separation
Pros	Calibration loop, no aging, scaling
Cons	Baseband BW = 5x Signal BW 4x DACs (10 bit)@400MHz 4x Filters (4th order)

LINC TX: Digital vs. Analog Separation

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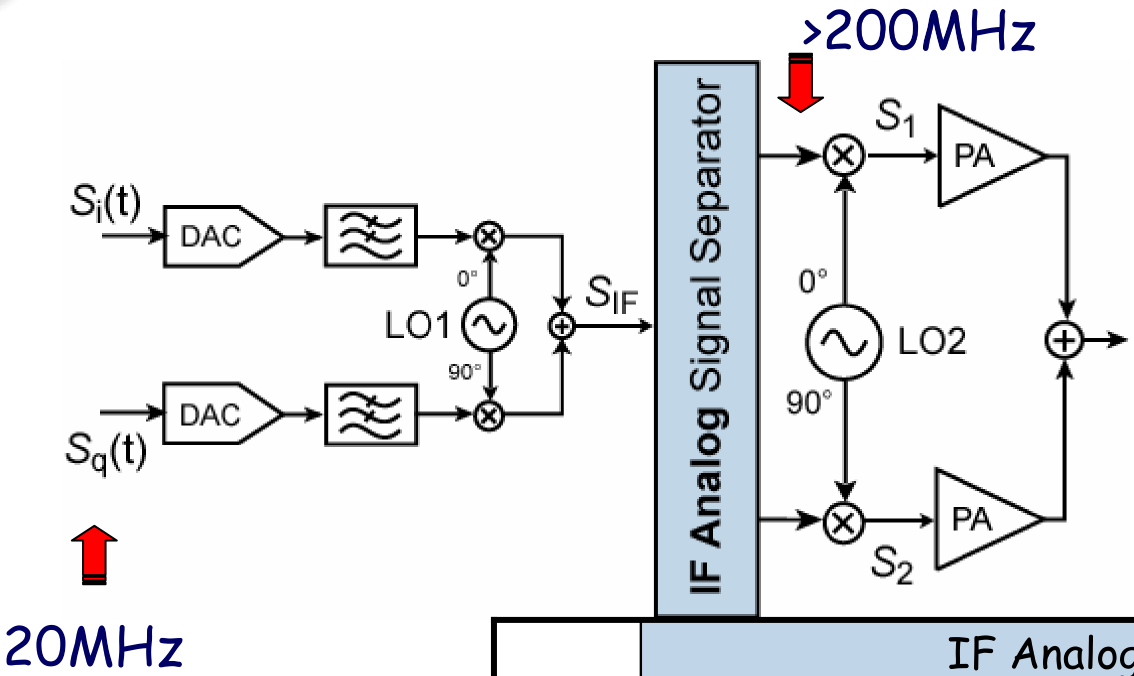

	IF Analog Separation
Pros	Baseband BW = Signal BW 2x DACs (10 bit) @ 40MHz 2x Filters (4th order)
Cons	Analog Separator BW = IF > Signal BW Requires complex filter and matching at IF Non-linear feedback

B. Shi and L. Sundstrom, 2000 VLSI Symp. and 2001 CICC

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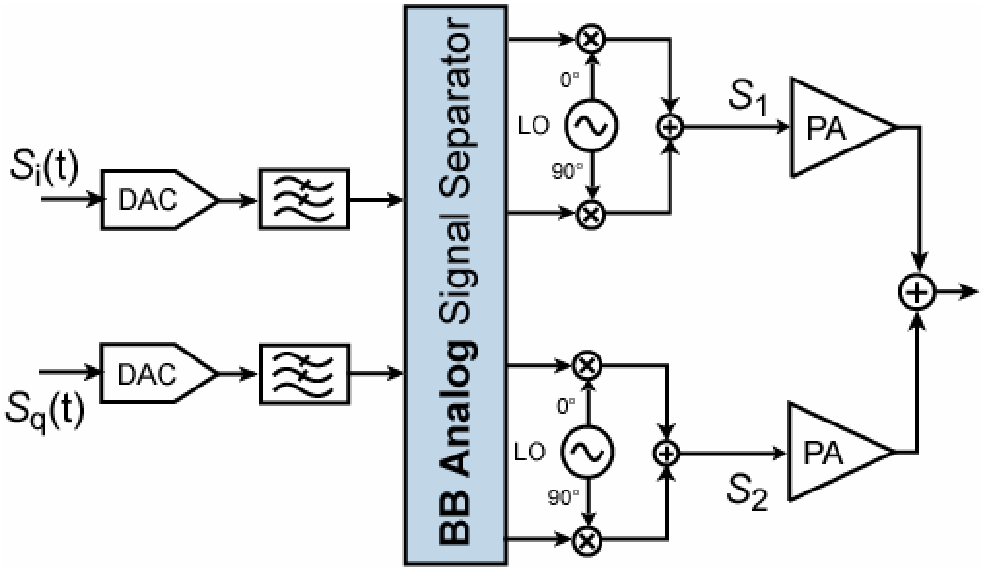
LINC TX: Analog-BB SCS



	Baseband Analog Separation
Pros	Baseband BW = Signal BW Analog Separator BW = Signal BW 2x DACs (10 bit) @ 40MHz 2x Filters (4th order)
Cons	Non-linear feedback

L. Panseri et al., CICC 2006
L. Romanò, C. Samori, A. Lacaita, Italian Patent

Analog-BB SCS: Implementation

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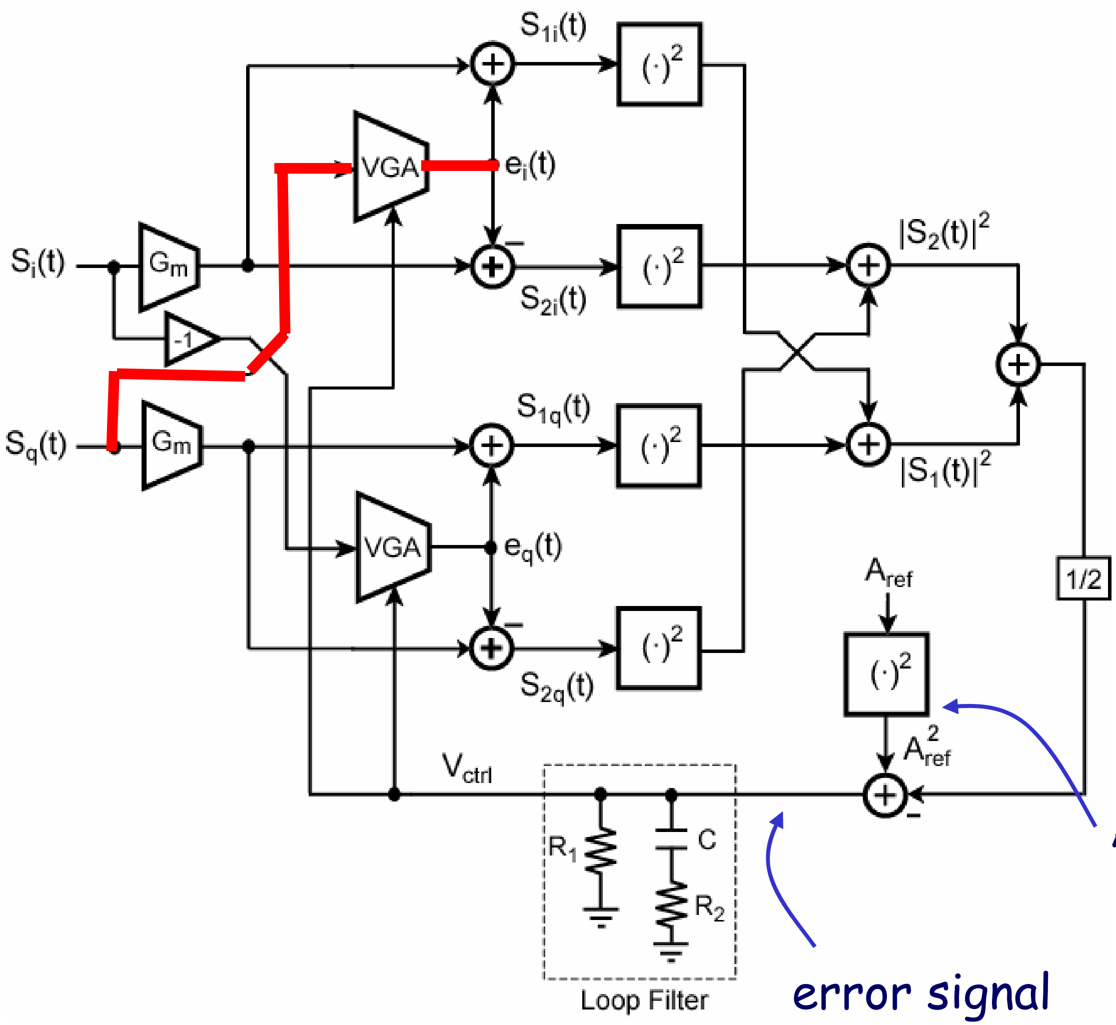
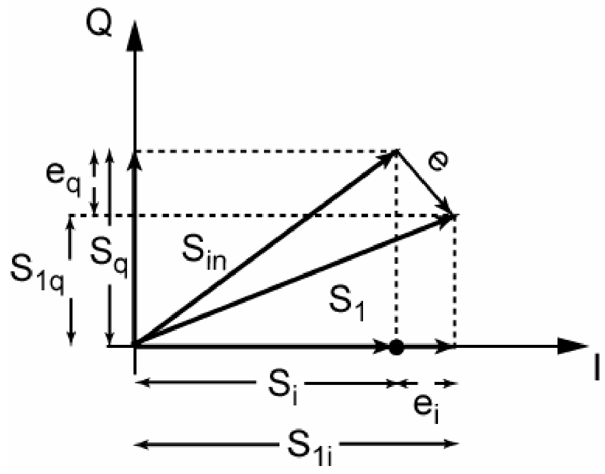


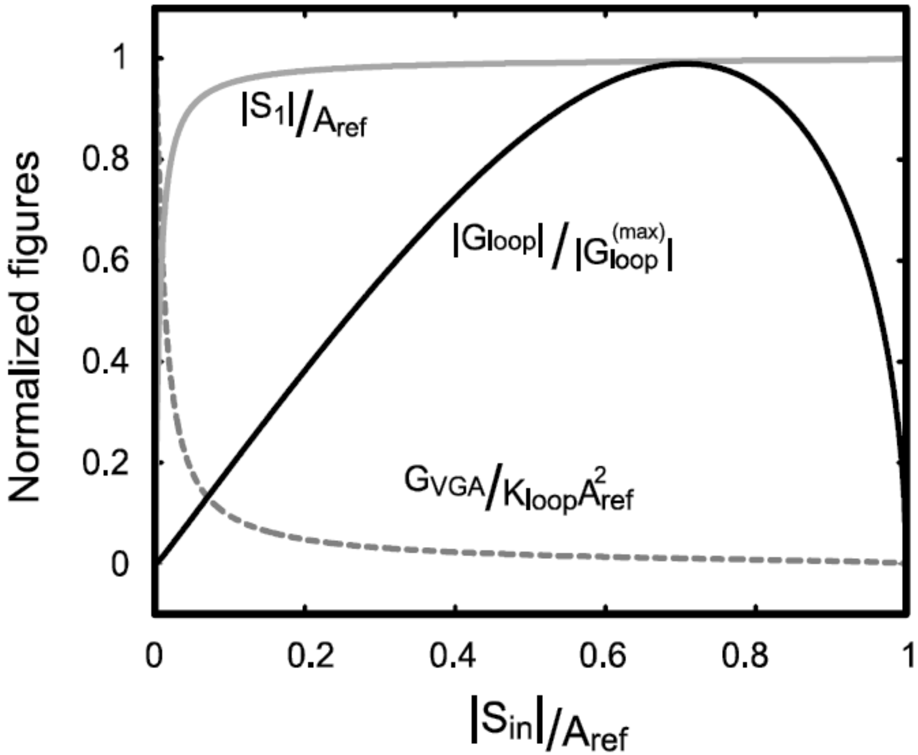


$e(t) \sim -jS_{in} = -j[S_i + jS_q] =$
$= [S_q - jS_i]$

The feedback forces $(|S_1|^2 + |S_2|^2)/2 = A^2_{ref}$

L. Panseri et al., 2006 CICC
L. Romanò, C. Samori, A. Lacaita, Italian Patent

Non linear feedback



	Values
Separator back-off	7dB
Maximum loop gain	40dB
VGA gain	25dB -10dB
Bandwidth	200MHz

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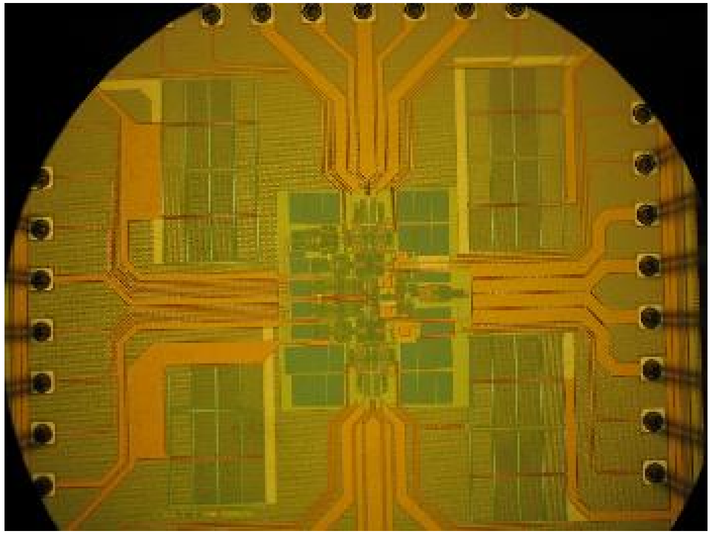
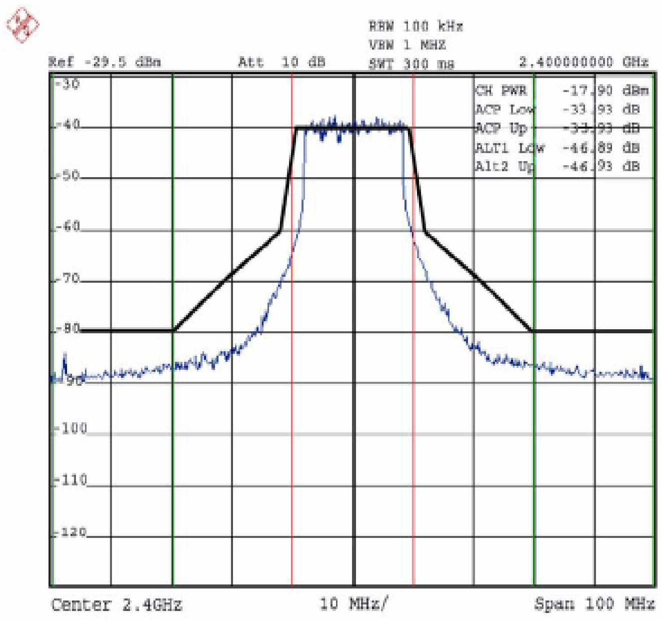
Experimental measurements





- Technology: STM 0.25mm CMOS
- Core Area: 0.09 sq. mm
- Input signal BW: 16 MHz
- Dissipated Power: 45mW

L. Panseri et al. JSSCC (2008)

This work has been supported by MEDEA+ A107 project

Conclusions

- Wireless high-data-rate communications are pushing towards high-efficiency and high-linearity TXs
- Among the linearization techniques, the LINC is a promising option, entailing no feedback and similar signal paths. Efficiency can be boosted up using switching PAs.
- In LINC, the signal separator back-off has to chosen trading between linearity and sensitivity to paths imbalance. The required matching obtainable in monolithic implementations.
- Signal recombination and separation crucial for the TX efficiency:
  - Chireix recombination leads to satisfactory efficiency.
  - Analog signal separation avoids duplication of DACs and filters and leads to better efficiency.