VM Pager Methodology: RF

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cadence

Goals

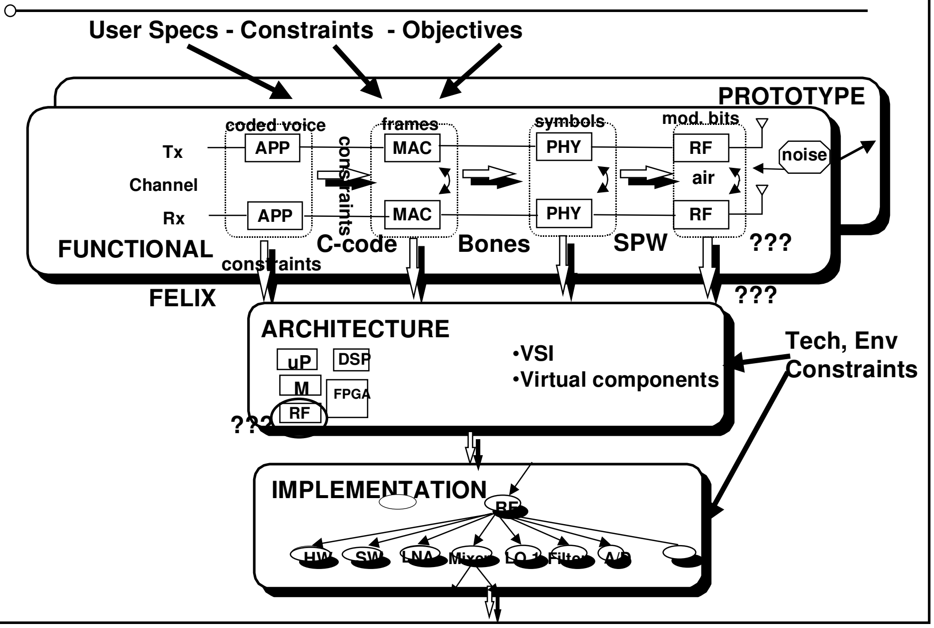
- consider RF implementation from top-level
- define tool flows considering RF/mixed signal
- complete RF system design and implementation

Pager Specifications

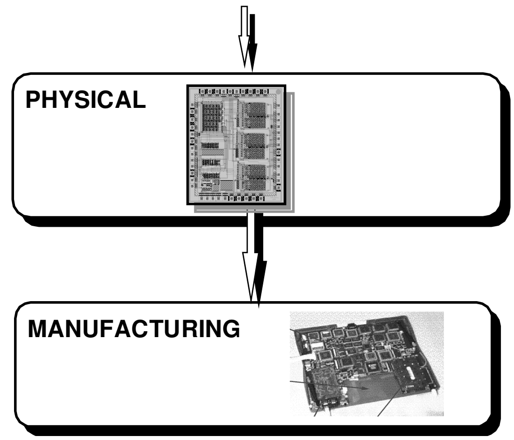
- One-way voice pager system
- 1 cell only, ~1km radius, industrial site environment
- BW requirements: 250Kbps
- ISM band 902-928 MHz
- FCC requirements
  - > 50 hop channels,
  - < 1W max power
  - < 500 kHz BW/channel (20 dB)
  - < 0.4 sec hop time
  - radiation
- System - level solution so far:
  - Slow FH system, 50 channels, 50ms hop time
  - Each hop channel: 8 channels FDMA, each channel 8 TDMA slots
  - 60KHz/FDMA channel -> 30kB/sec , 1/8 sec speech /slot
- Modulation scheme
  - technology (CMOS, BiCMOS)

- Other Constraints
  - CMOS process
    - potential full integration
    - more power than bipolar/BiCMOS
  - 1.5V battery Minimize power

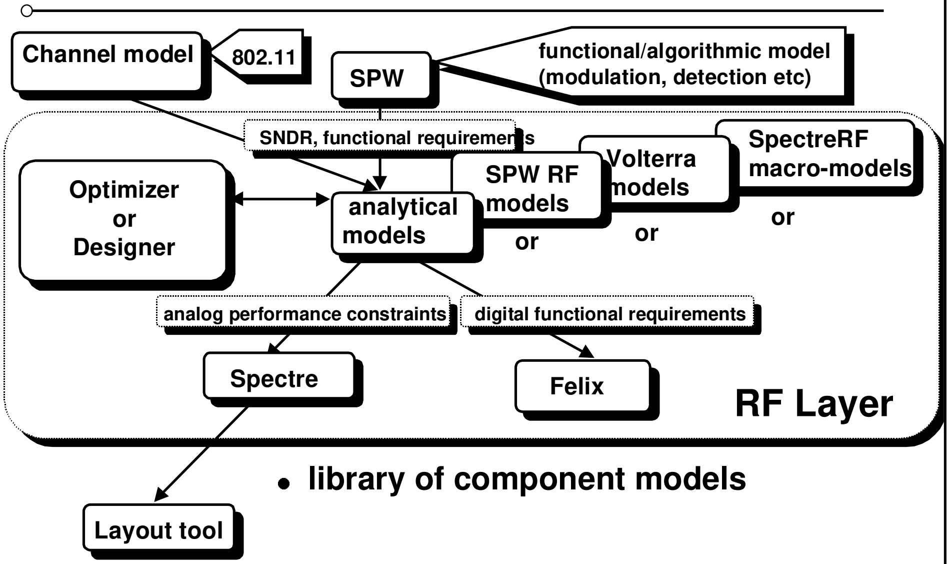
Hierarchy of VM Pager



Hierarchy of VM Pager (cont.)

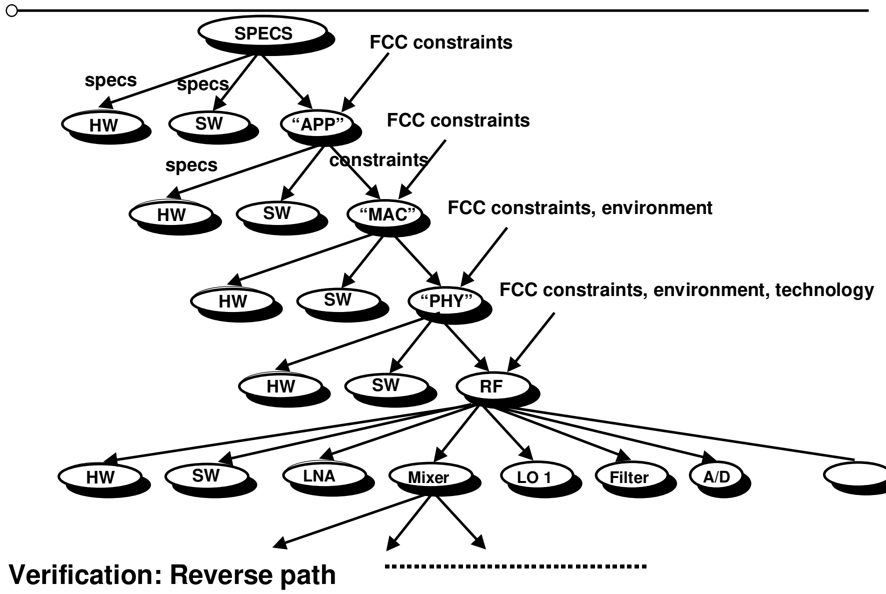


Tool Flow

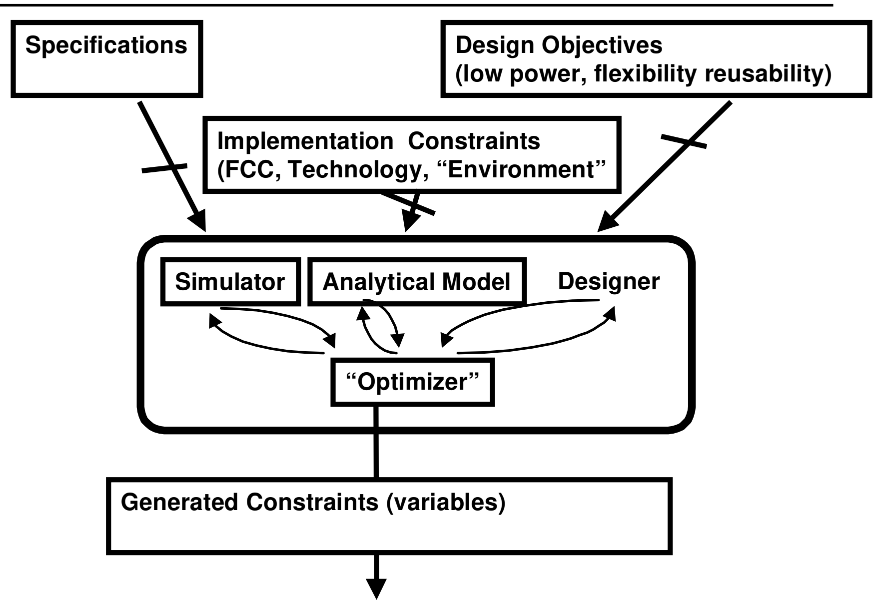


- library of component models

Hierarchy of VM Pager



Constraint Translation



“RF” Level

- **Constraints**
  - From “APP”
    - BER
  - From “MAC”
    - BW, FH hop rate
  - From “PHY”, FCC, Environment
    - modulation scheme
    - desired SNDR (?)
    - interference model

- **Objectives**
  - re-usability
  - low power
  - fast design

- **Generated “constraints”**
  - RF block behavioral description
  - digital HW functional requirements
  - DSP SW (?)

Tool Flow?

System Choices Affecting RF

- TDMA 500kHz vs 8 FDMA 60kHz
  - TDMA
    - A/D more bits
    - same power
    - more DSP
  - FDMA
    - More filtering
    - Adjacent channel interference (one cell - no problem)
- 2/4 FSK vs GMSK
  - FSK:
    - \+ direct conversion
    - \+ simplicity
    - \+ incoherent detection
    - \- better SNR requirements
  - GMSK:
    - \+ used in GSM, build library,
    - \+ more BW efficient
    - \- more power @ processing,
    - \- harder direct conversion

Channel Models

- Determine sensitivity requirement
- Define available SNR degradation
  - high- available SNR @ receiver input
    - subsampling possible (lowest power, bad NF)
    - FSK - incoherent detection possible
  - low SNR:
    - need good NF (more power)
    - more efficient detection and modulation scheme than incoherent FSK
- Interference ? (cordless phones, other LANS etc)
  - IM requirement
  - blocking requirements
  - dynamic range requirements
- Model: Indoor propagation w/ Rayleigh fading?

	TDMA	*FDMA*
band	**500kHz**	**60 KHz**
Noise Floor	**-117dBm**	**-126 dBm**
Transmitted power	**30 dBm**	**20.8 dBm**

Specifications

- Channel model (from 802.11)
  - sensitivity: -90dBm
  - blocking: wanted -87dBm blocker @2 channels -47dBm
  - blocking: wanted -87dBm blocker @3channels -37dBm
  - Image rejection: blocker @image (3 channels -47dBm)
  - IP3: wanted -87dBm blocker @2,4 channels -47dBm, -47dBm
  - compression: wanted: -20dBm
- Alternative (more conservative) channel
  - sensitivity: -90dBm
  - blocking: wanted -87dBm blocker @2 channels -30dBm
  - blocking: wanted -87dBm blocker @3channels -20dBm
  - Image rejection: blocker @image (3 channels -20 dBm) ????
  - IP3: wanted -87dBm blocker @2,4 channels -37dBm, -37dBm
  - compression: wanted: -20dBm
- Channel unknown, probably try the best ?

Specifications (cont.)

- From 802.11
  - NF < 26 (try 10?)
  - IP3 > -22dBm
  - Phase noise < -83dBc/Hz @ 100Khz
  - Filtering > 70dB @ 3 channels
  - A/D dynamic range
    - DR = 174-10logBW-NF+Margin+Sblock-Anti/Alias+2DG = 60dB = 10 bits
    - Gain control:
      - max gain (-87dBm + blocker) : 80dB
      - min gain: 30 dB
      - LNA, mixer: +30, 0 dB gain
      - baseband: 50dB - 30 dB gain control
      - GAIN CONTROL LOOP ?

To Define RF We Need

- BER (assume 10^{-3})
- Channel model
- Other interference at 902-928 band (part 15 devices)
- Baseband detection scheme

- Sensitivity (-102dBm for PCS1900)
- Blocking
  - in-band (of 500KHz band)
  - out-of-band
- Intermodulation
- Dynamic range

Typically given by standards such as GSM - need to define them

RF NF, IP3, blocking, phase noise etc ..

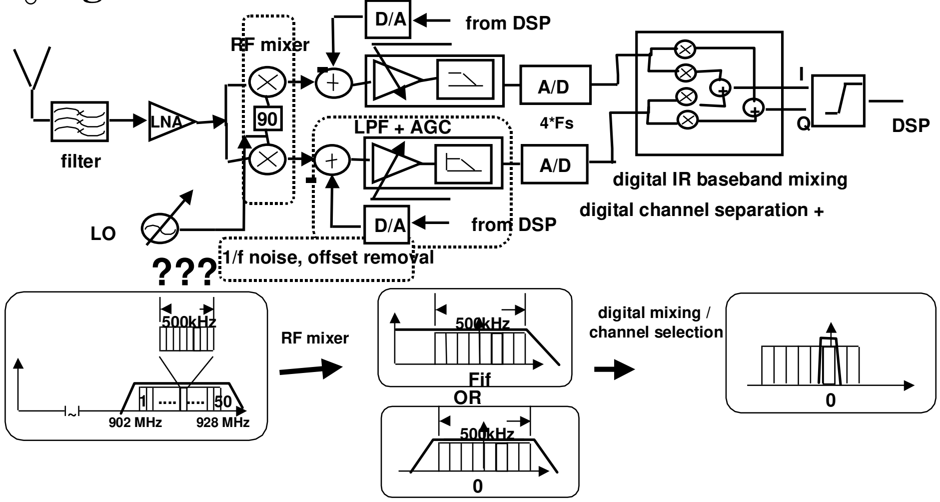
Tool Flow (cont.)

- Analytical models
  - + simple
  - – accuracy
  - – co-simulation, verification
- SPW
  - + co-simulation, verification
  - + accuracy (BER)
  - + accurate K-models (J. Chen)
  - – accuracy (analog effects)
  - – simulation time
- Volterra simulator (New)
  - +accuracy (analog effects)
  - +simulation time
  - –accuracy (BER)
  - –co-simulation, verification
- SpectreRF macro-models
  - +compatibility
  - +extraction
  - –accuracy
  - –simulation time

Architecture Evaluation

- Architectures
  - Low Digital IF
  - Superheterodyne
  - Wide-band double conversion
- Criteria
  - performace
  - power
- Parameters
  - behavioral parameters for each block: NF, $IP_{3...}$

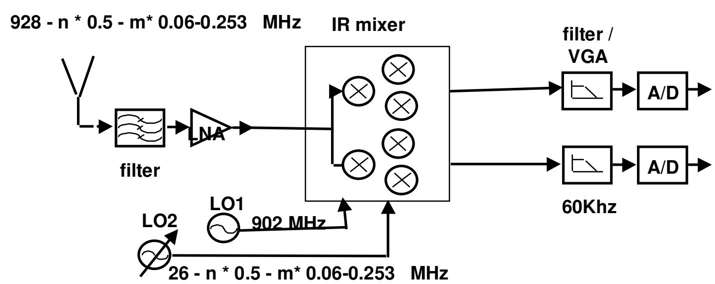
RF Architecture Impementation: Low Digital IF



☺programmability, reusability, integration

☹power (?), dynamic range, selectivity

Wideband Double Conversion to Baseband (Berkeley DECT)



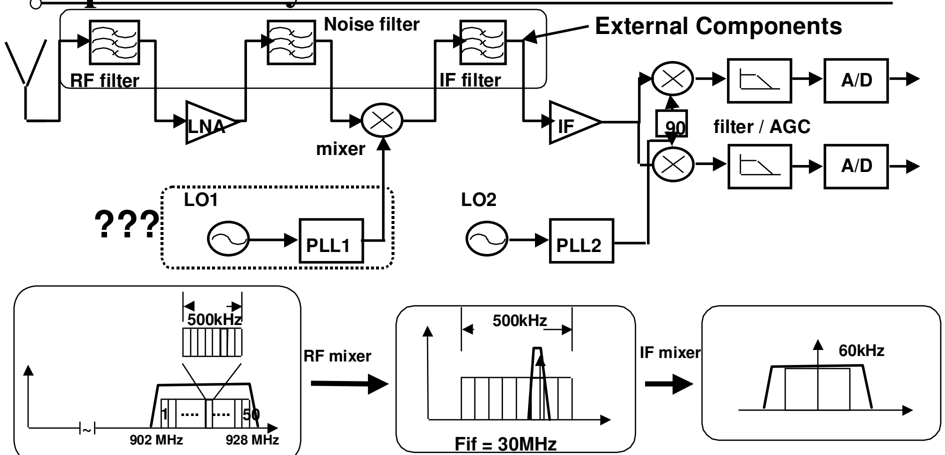
☺easier LOs than 1 (phase noise, channel separation)

☹higher power

☹still DC offset problem

☹worse NF, IM than direct

RF Architecture Impementation: Superheterodyne



☺simpler, easier to design

☹not fully integrated

☹re-usability

☹RF LO accurate to 60kHz

Architecture Evaluation (analytical model)

	Incoming	Antenna	RF Filter	Balun	LNA	Mixer
Block parameters						
Power Gain (dB) (max)		0	-3	-1		
Voltage Gain (dB) (max)					20	6
Voltage Gain (dB) (min)					0	0
Voltage Gain (max) (abs)		1	1	1	10	1.995262315
Input IP3 (dBm)		13	10	10	-6	6
Input IP3 (V)		0.998814876	0.707106781	0.70710678	0.112068872	0.446154217
NF (dB) 50 Ohm		0	2	1	3.5	10
NF 50 Ohm		1	1.584893192	1.25892541	2.238721139	10
Req		0	29.24465962	12.9462706	61.93605693	450
Added noise (dBm)						
Added noise (V rms)						
P-1dB						
Attenuation out of ism		0	30	0	10	0
Attenuation out of hop band	0	0	0	0	0	0
attenuation @ 1MHz						
attenuation @ 1.5MHz						
atenuation@ 60KHz						
phase noise@ 100KHz (dBc/Hz)						
image rejection						30
total SNDR (dB)						
#bits						
max in (dBm)						
max out (dBm)						
Power Estimate		0	0	0	0.016462526	0.011327504
Sensitivity test	Incoming	Antenna	RF Filter	Balun	LNA	Mixer-LO1
wanted signal (dBm)	-90	-90	-93	-94	-74	-68
total gain	0	0	-3	-4	16	22
total input referred noise (dBm)	-126.02	-126.02	-124.02	-122.79	-118.85	-118.66
total signal (V)	0.00001	0.00001	7.07946E-06	6.3096E-06	6.30957E-05	0.000125893
cumulative NF		0	2	3.22532971	7.170914013	7.355281541
total SNDR	36.02	36.02	34.02	32.79	28.85	28.66
out of band blocker	Incoming	Antenna	RF Filter	Balun	LNA	Mixer-LO1
wanted signal (dBm)	-87	-87	-90	-91	-71	-65
total gain	0	0	-3	-4	16	22
unwanted signal	0	0	-33	-34	-24	-18

- created specs for 3 architectures

Architecture Evaluation (analytical model)

- Use analytical formulas to model 2nd order effects
  - NF, IM3, Phase Noise, quantization noise, ...
- apply to architecture for all possible input conditions defined by 802.11
- select parameters to satisfy SNDR (BER)
- Objective?

High-Level Objective

- Implementation details unknown
- Difficult to predict power
  - analyze various implementations
  - power(IP3, NF, phase noise ...)f
- Example:
  - Gilbert Mixer: $P = K\ V_{IP3}\ (1+K_2/CG)/(NF-1)$
  - LNA: $P = K\ V_{IP3}/(NF-1)^{1/2}$
  - LO $P = K\ (F_o/\Delta F\ )^2/PN$
  - A/D : $P = Max(K_1\ Pmin,\ K_2\ B\ Fs,\ K_3\ B2^{2B}\ F_S)$
  - Filter: $P = (K/V_n^2)\ N_{poles}$
- Each analysis a different problem
- “Library”: parameter limits + “flexibilities”
  - derived from existing implementations

Summary

- So far
  - tool flow - methodology
    - fit analog RF/mixed signal in design flow
  - preliminary architecture with performance specs for blocks
  - implementation of architecture evaluation framework in Excel
- To do
  - digital/analog co-simulation (SPW)
  - add volterra simulator in flow
  - final architecture with specs
  - design integrated RF receiver components (N. Weste)