Requirements and challenges for SDR implementation

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Outline

The software defined radio
Critical requirements
Receiver solutions?
Transmitter solutions?
Conclusions

Software defined radio

Software defined radio liberates radio-based services from chronic dependency on hard-wired characteristics including frequency band, channel bandwidth and channel coding.

(Joe Mitola, IEEE Communications Magazine, 2005)

Main motivation is that the number of wireless standards and utilized bands increase continuously.
And, future Cognitive radio etc.

Software defined radio

Typical needs:

Consumer terminal (radio, TV, cell phone, WiFi, GPS)

carrier 100MHz-6GHz, bandwidth 200kHz-20MHz

Consumer terminal (cell phone, WiFi, GPS)

carrier 700MHz-6GHz, bandwidth 200kHz-20MHz

(LTE only 698-2690 MHz)

Military, Security (blue light authorities)

carrier 2MHz-2GHz, 70MHz-400MHz

Software defined radio

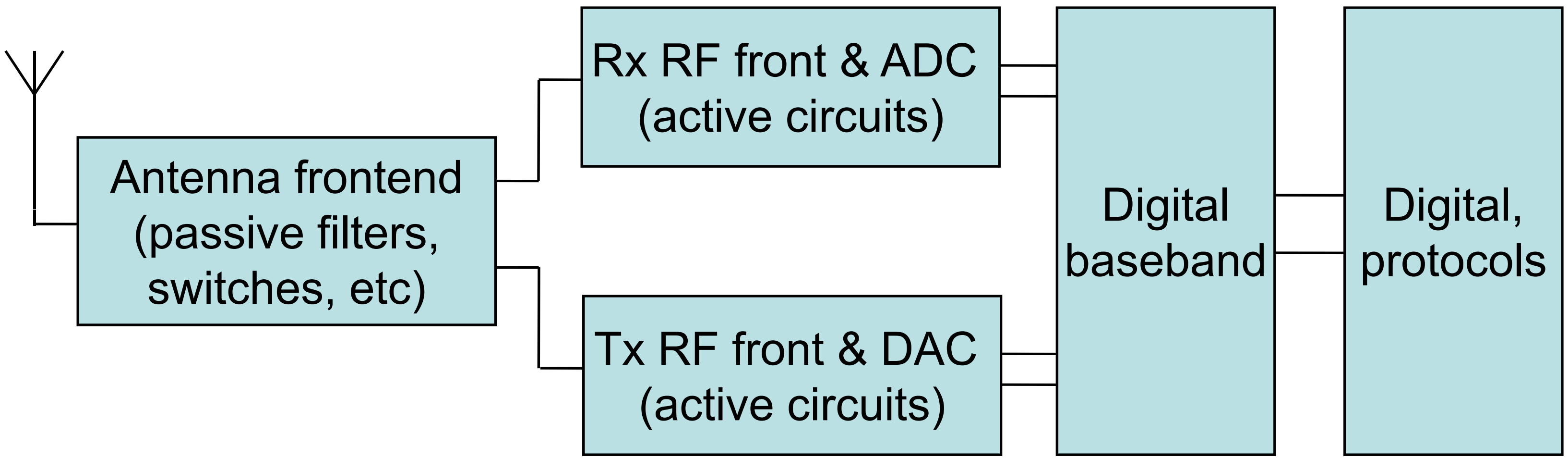
Key Issue

Can this be done?

If so, what technologies are available and which are lacking?

Software defined radio

Generic hardware architecture



Software defined radio

What have we?

Digital, protocols– a lot! Runs on GPP

Digital baseband - OK. Runs on DSP/FPGA or appl. Spec. DSPs

DSP/FPGA high power, application specific DSP low power (Nilsson)

Receiver analog frontend – multiband technology exists
Insufficient

Receiver antenna frontend – multiband solutions lacking
(Except very high cost military)

Transmitter PA and antenna frontend – multiband solutions lacking

Software defined radio

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Possibly a showstoppers

Why so little efforts here?

Critical requirements

Unfortunately, we must adapt to reality.

Receiver:

We need to receive a ***weak signal*** in presence of a ***strong one***

Best sensitivity – adapt to thermal noise background

Unintentional disturber (broadcast, nearby client, …)
Our own transmitter
Intentional disturber (jammer)

Critical requirements

A disturber transmitting power P_D at distance R with antenna gain G_D give a received (blocker) power in receiver with antenna gain G_r:

$$P_B = \frac{\lambda^2}{16\pi R^2} G_D G_r P_D$$

Where λ is the wavelength ($\lambda = c/f_c$).

A blocker of power P_B gives a peak-to-peak voltage over $R_0 = 50\Omega$ of

$$V_{p-p} = \sqrt{8 P_B R_0}$$

Critical requirements

Best sensitivity – environmental noise at ambient temperature:

Noise spectral density: $S_N = kT$

With a channel bandwidth of B, we require a dynamic range of:

$$DR = \frac{P_B}{S_N B}$$

Critical requirements

This can be expressed as a ADC requirement of (quantization noise = thermal noise; f_s sampling rate, n bits):

$$f_s 2^{2n} = \frac{4}{3}\frac{P_B}{kT}$$

Theory of ADC power consumption estimates ADC power to about $30P_S$, where P_S is the power needed to sample the signal (Sundström):

$$P_S = 24kTf_s 2^{2n} = 32P_B$$

Critical requirements

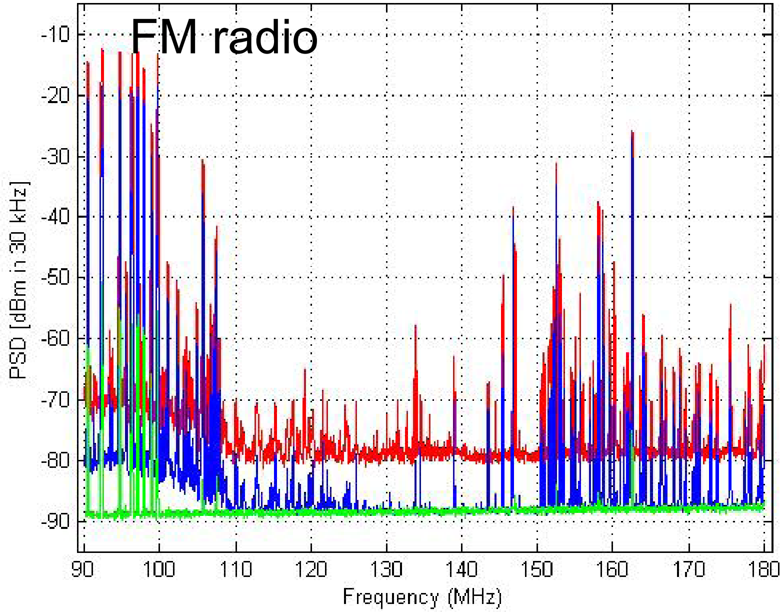
We need to understand blocker power levels in practice

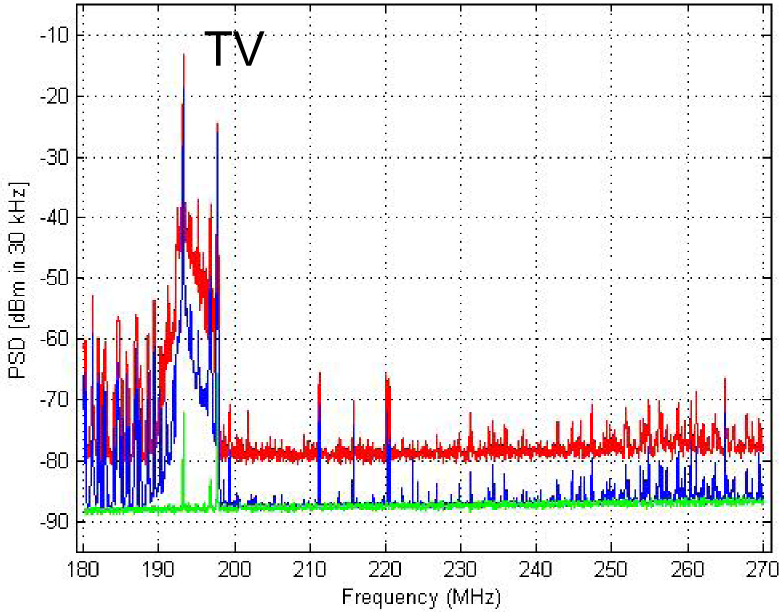
Direct measurements

Estimations for specific transmitters

Own transmitter

Critical requirements





Measured background

Examples of Spectrum Occupancy measurements (Ellingson 2005)

Max power about -12dBm. Above 1GHz frequencies -30dBm

Critical requirements

Specific transmitters

Estimated power levels from specific transmitters

$$P_B = \frac{\lambda^2}{16\pi R^2} G_D G_r P_D$$

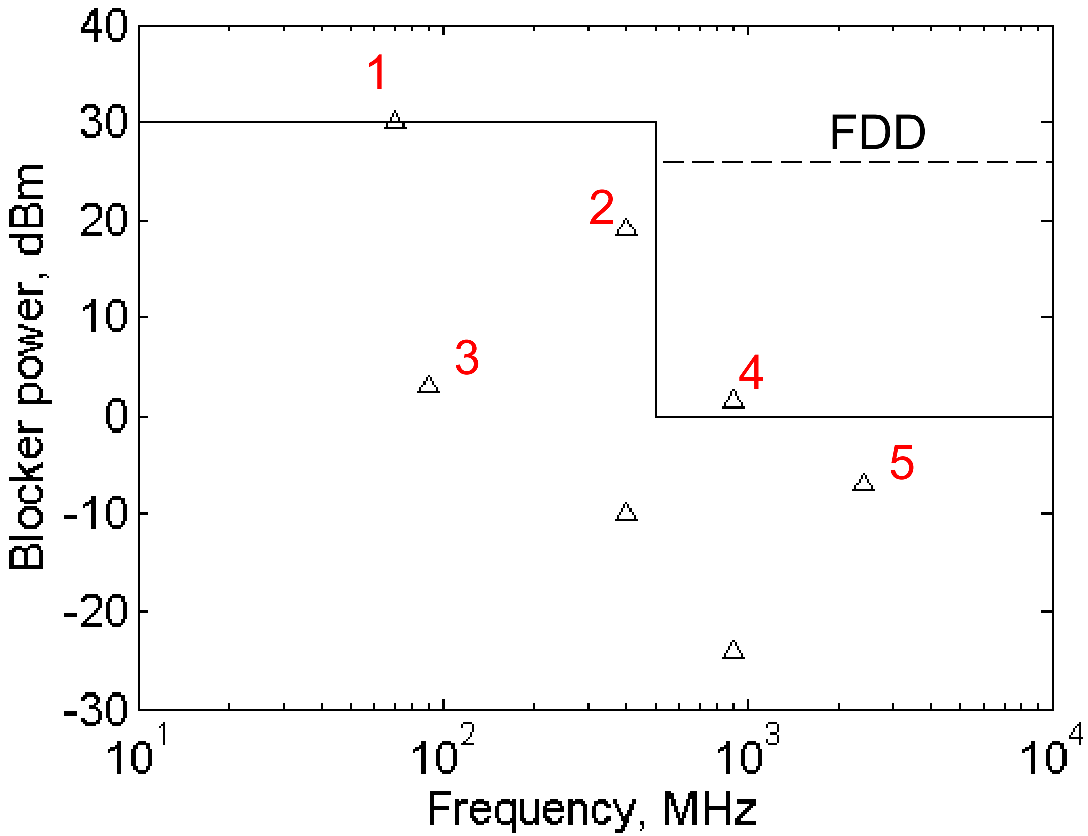
	f_c, MHz	R, m	P_T, W	G_T, dBi	P_B, dBm
VHF	70	3	10	2	30
Tetra	400	3	25	2	19
FM broadcast	90	300	50,000	-20	3
TV broadcast	400	300	50,000	-20	-10
GSM basest.	900	30	100	-20	-24
GSM terminal	900	2	1	2	1.5
WLAN	2400	2	1	2	-7

Critical requirements

Own transmitter (FDD)

Example 3G mobile, 26dBm, if same antenna P_B=26dBm

Critical requirements



Worst case blockers

1. 10W VHF Tx, 3m distance
2. Tetra system, 3m
3. FM broadcast
4. GSM terminal, 2m
5. WLAN, 2m

Conclusion

<500MHz, 30dBm
>500MHz 0dBm

Critical requirements

Consequences

Blocker	Voltage p-p	ADC power
1mW (0dBm)	0.63V	0.96W
1W (30dBm)	20V	960W

We can hardly accept more than ~1mW at ADC (ADC power)
We can hardly accept more than ~1mW by receiver electronics (voltage)

This may be a show-stopper

Is any other contribution at this conference addressing this issue?

Critical requirements

Transmitter:

High power, 300mW – 30W, requires voltages of 11-110V @50Ω
May require special technology (except possibly 300mW)

Low spurious content

High efficiency
Particularly tough at advanced modulation
(including non-constant envelope)

Not availible for wide frequency ranges

Receiver solutions?

Very wide frequency range

Passive tunable filters not availible

} No passive filters in frontend preferred

If not possible – we need tunable passive filters or filter banks

So, what is possible?

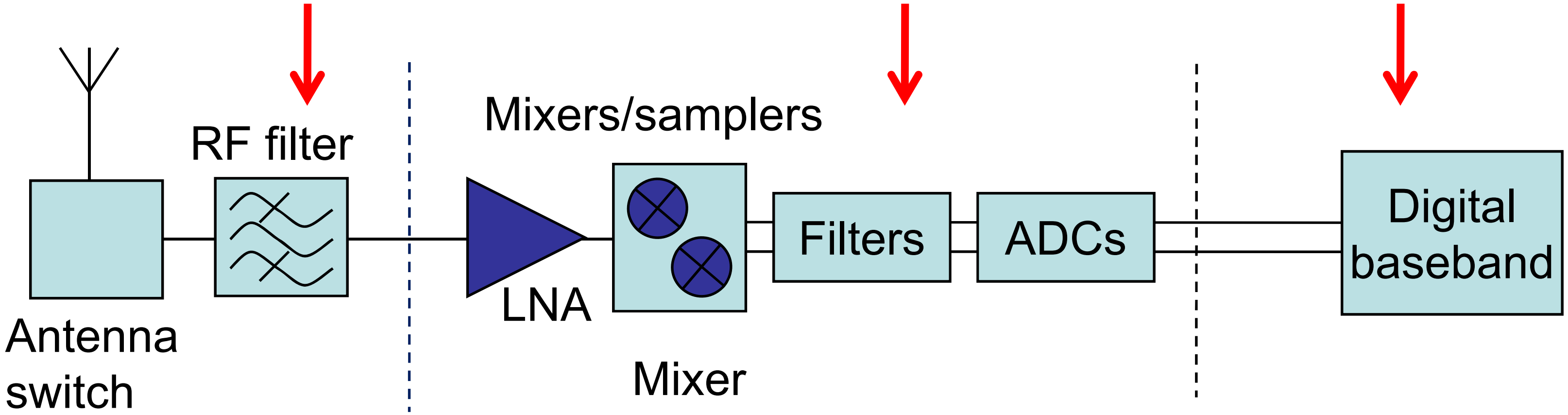
For blocker < 1mW maybe no passive filters possible

For blocker > 1mW passive filters mandatory

Receiver solutions?

Blockers > 1mW
MUST be stopped here
NEED passive RF filters *unflexible*
<500MHz; FDD systems
Tunable RF filter

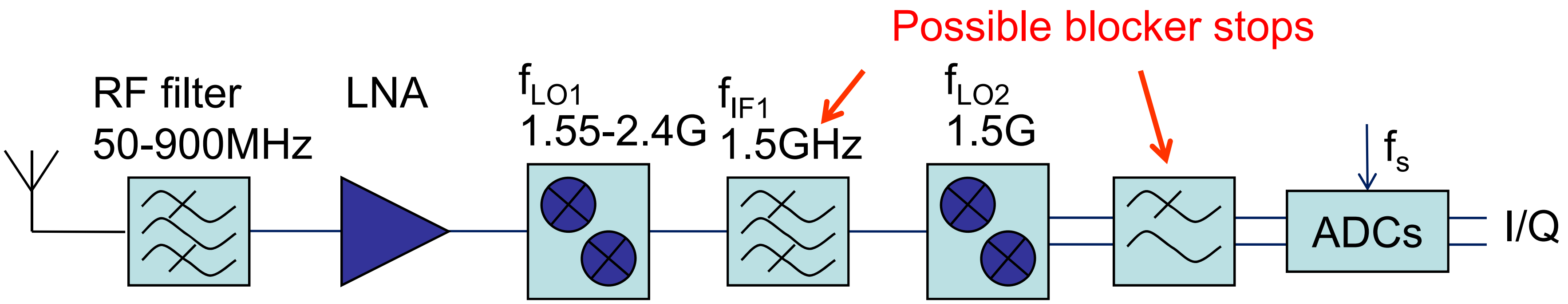
Blockers ~1mW
Stopped in digital baseband
OR in analog baseband
>500MHz, no FDD
Fixed (all bands) RF filter



Receiver solutions?

Example 1

Fixed RF filter, upconverting superheterodyne ($f_{IF1}>f_{cmax}$)



1dBm blocker at ADC: We can choose f_s=100MHz gives n=16 (commercially available, eg. 160MS/s 16b 1.45W).

Narrow IF and baseband may remove blockers; much relaxed ADC

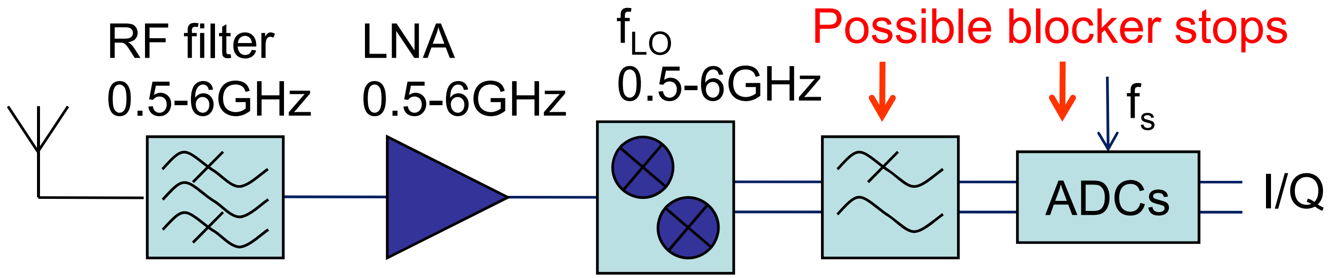
Similar solutions are available as TV receivers

50-900MHz, single chip complete receiver, ~1W (but P_B<-10dBm)

Receiver solutions?

Example 2

Fixed RF filter, high compression point LNA+mixer

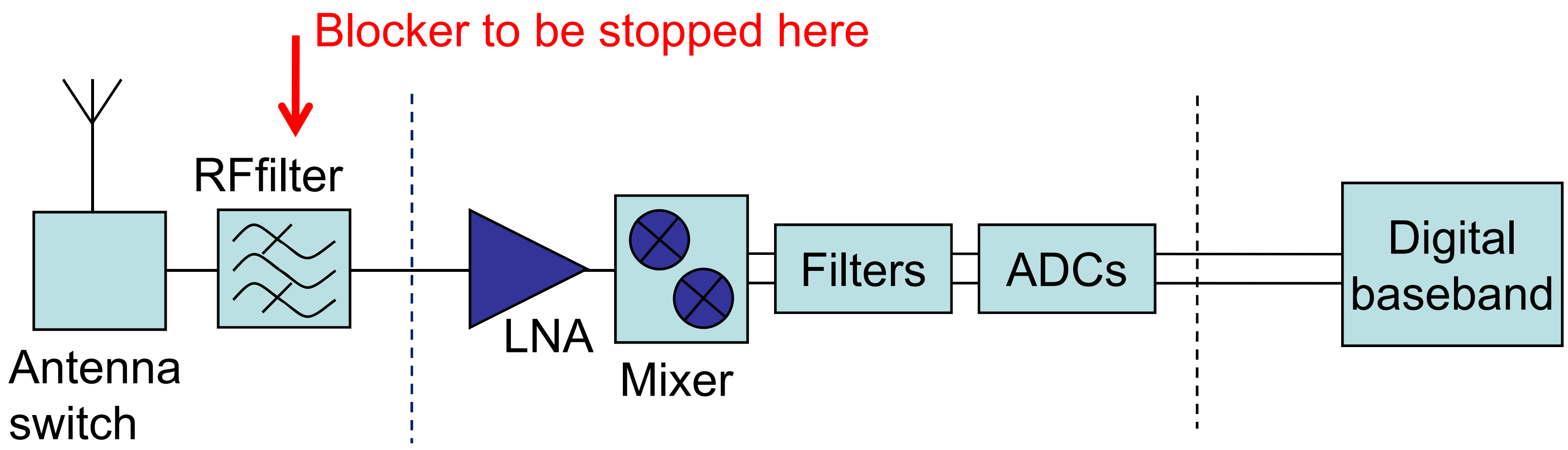


Gain to be supplied by low-pass filter or ADC

Note, LNA *and* mixer *and* ADC must have low noise figure!

No solution at hand, but promising research (Rodriguez, Ahsan)

Receiver solutions?



Need narrow band passive RF filters at input.
Requirements: 1W blocker power
Blocker offset frequency ~6% (military spec., CDMA FDD spec.)

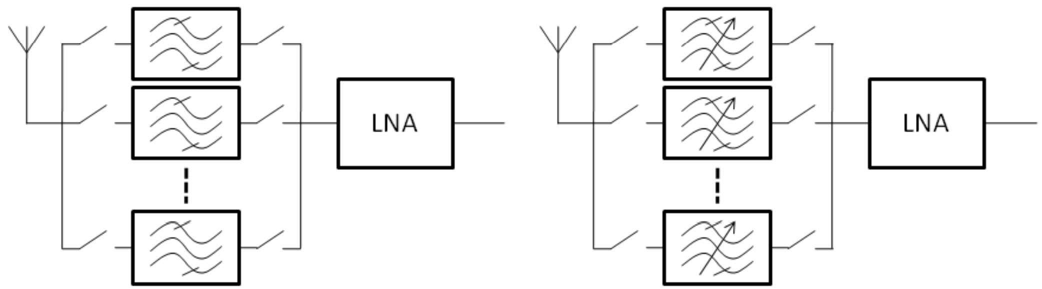
Need >30dB attenuation at 6% frequency offset

Receiver solutions?

Filter solutions

Filter bank

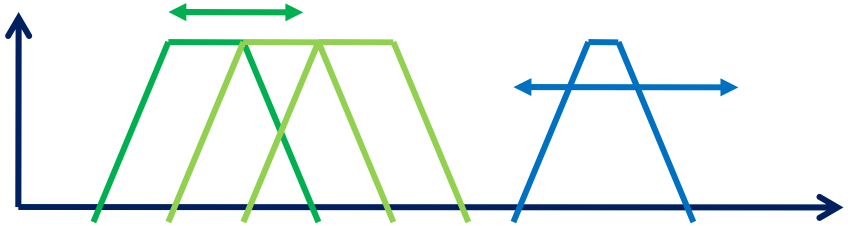
Each filter 3% bandwidth and 3% allocated for slope.
Requires 24 filters/octave.
100MHz-6GHz requires144 filters.



a) Fixed filter bank, 24 filters/octave b) Tunable filter bank, 1 filter/octave

Tunable filters

1% bandwidth and 30dB attenuation at 6% requires second order.
1 octave tuning range
100MHz-6GHz requires 6 filters.

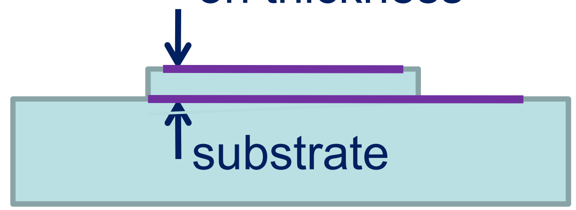


Receiver solutions?

Filter candidates - Filter banks

Bulk acoustic wave filters (BAW, FBAR)

frequency depends on thickness



Presently used in mobile phones
Good performance, small size (100μm)

Unsuitable for frequencies below 500MHz
Unclear how to fabricate 144 different frequencies
High loss in switches

MEMS resonators

Good performance, small size (30-300μm)

High impedances (>kΩ)
Insufficient linearity IIP_3<20dBm

Receiver solutions?

Filter candidates – Tunable filters

Electromagnetic resonators with paraelectric varactor

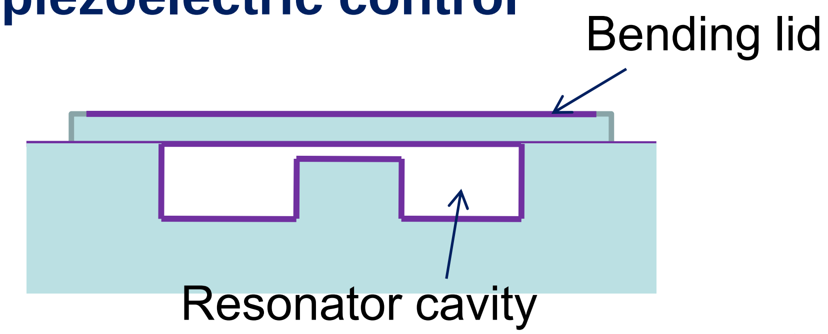
Commercially available (for antenna tuning)
Sufficient performance.

Relatively large (10-20mm)
10-100V tuning voltage

Electromagnetic resonators with piezoelectric control

Good performance.

Relatively large (10-20mm)
100-200V tuning voltage



Receiver solutions?

Conclusions narrow filters

To manage high blocking powers we need passive filters

Filter banks require very many filters

A tentatively possible solution is BAW filters

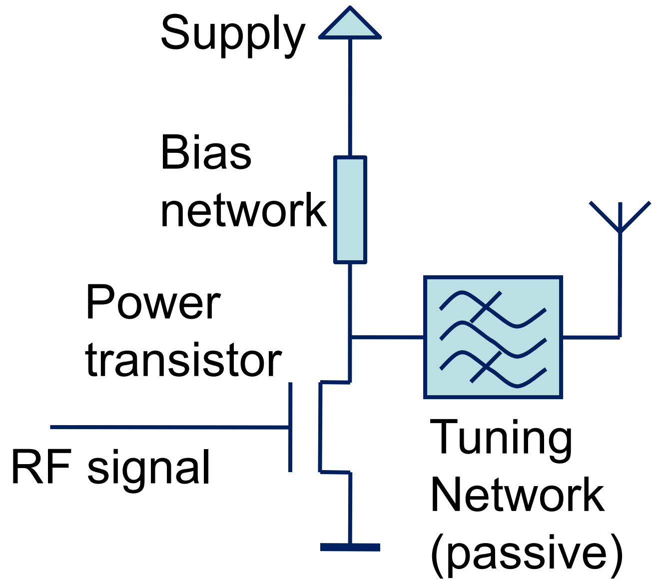
Tunable filters need much fewer filters, but they are larger

Tentative solutions are electromagnetic resonators

based on paraelectric varactors

or piezoelectrically activated mechanical tuning

Transmitter solutions?



Class A, AB, B
May avoid tuning network
Medium efficiency
Low efficiency at lower power

Class C, E, F
Must have tuning network
Fixed output power (from fixed supply)
Good efficiency

Class D
May avoid tuning network
Good efficiency possible

Conclusions

Antenna/RF frontends are the most challenging part for SDR

Problems related to radio basics – not to waveforms or software

No technology available today for the most demanding requirements

>0dBm disturbers

Need tunable passive filters or switched passive filter banks

Some mobile/WiFi may be designed using available technology

≤ 0dBm disturbers, no FFD

Challenges: appropriate receiver architecture (learn from TV tuners)
receiver dynamic range and linearity
low power digital baseband (application specific DSP)
appropriate PA technology

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