Wireless Biomedical Sensors

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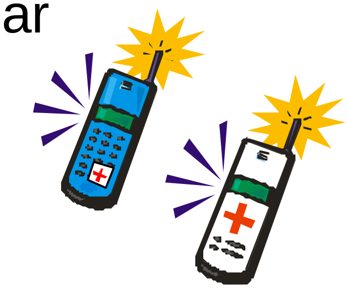
[redacted]

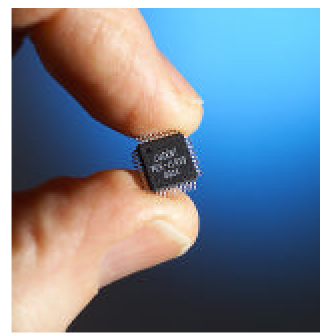
Olga Boric-Lubecke and Victor M. Lubecke - Bell Labs, Lucent Technologies, Murray Hill, NJ

Outline

- Remote Monitoring using Doppler Radar



- Modified Wireless Terminals
- Doppler Radar IC's



- Summary and Future Directions

Remote Health Monitoring

- An estimated 100 million Americans suffer from chronic medical conditions such as heart disease, diabetes, and lung disorders
- Chronic illnesses account for about 75% of total US healthcare costs ($650B/yr)
- There is a growing market for appliances which allow patients to remotely monitor health parameters and transfer data to a physician

PC and Internet Linked Blood Glucose Monitors

(Roche - Camit)

Implantable Cardiac Loop Recorders

(Medtronic - Reveal)

Internet Linked Healthcare Q&A

(Health Hero Network - Health Buddy)

Phone/Pager Linked Vital Signs Monitoring Station

(HomMed - Sentry/Observer)

Human Radio Doppler Applications

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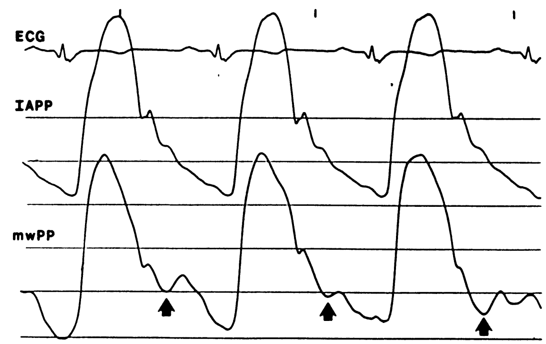
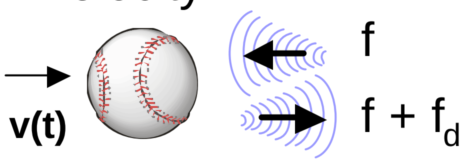
- Medical Diagnostics
  - Respiratory, cardiac, and arterial wall movements, proposed in 1970's ; *University of Illinois, Chicago*
- Post-Earthquake Rescue Operations
  - Proposed life-detection systems, operating at distances up to 30m, or through thick (>1m) barrier walls ; *Michigan State University*
- Motion Detection
  - Automatic door openers, security sensors ; *e.g.. Microwave Solutions, Ltd.*



Arterial Pressure Pulse Sensing
J. Lee and J. Lin, 1985

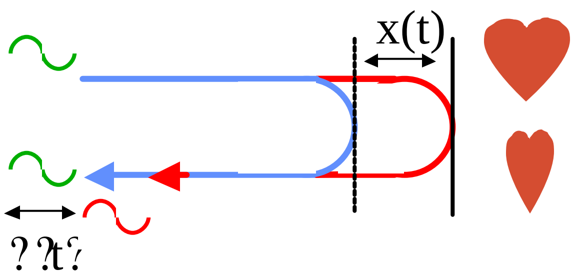
Motion Sensor Principle

- Constant velocity : shift in f
  - frequency proportional to velocity



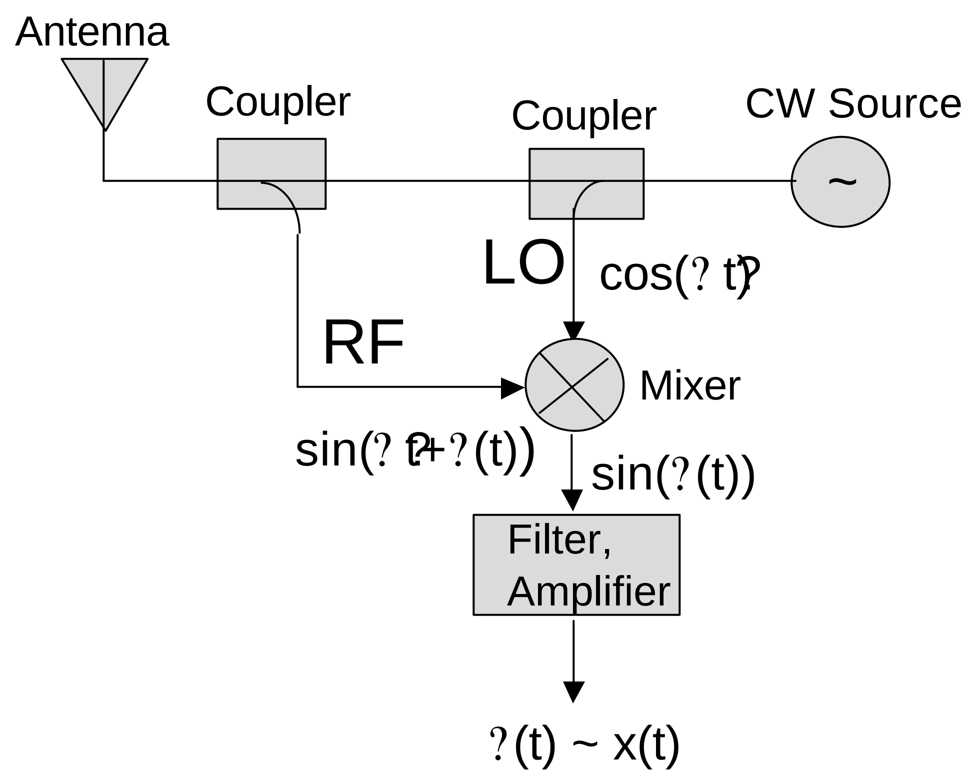
$f_d = 2f\ v(t)/c$

- Periodic motion : FM, AM, & PM
  - phase proportional to displacement

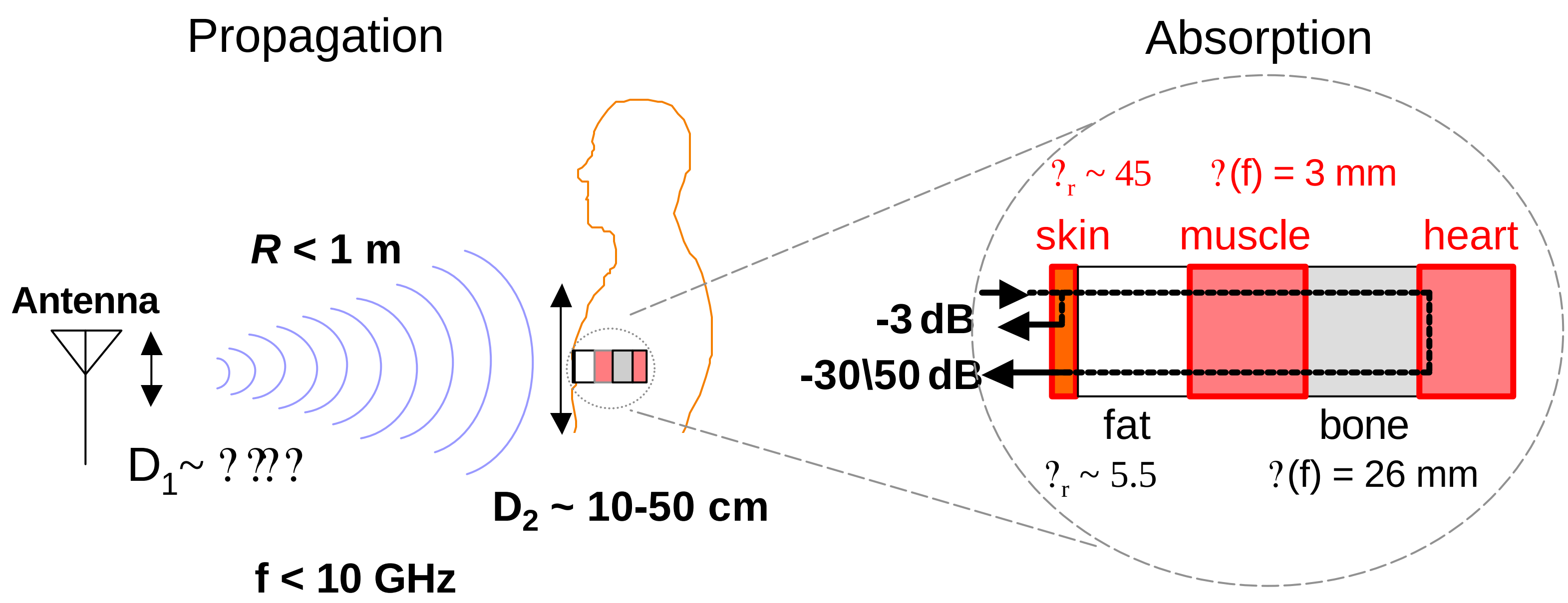


?(t) = (4? ?? ??x(t)

Doppler Detection with Baseband Radio



Power Budget



- Radiating near field (vs Far Field: $R > R_{ff} = 2D^2/?$) : radar equation not valid
- 50% of incident power reflected at body surface
- Less than 1% of power from internal reflections

Communications Radios

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Wireless Phones, PDA's, 2-Way Pagers

- 800/900 MHz, 1.8/1.9 GHz
- < 1 W
- Omni-Directional
- Wireless Network

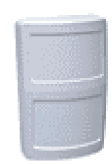
Wireless LAN

- 2.4, 5 GHz
- < 100 mW
- Omni- / Semi-Directional
- Phone Line/ Internet

Cordless Telephones

- 49, 900 MHz, 2.4 GHz
- < 500 mW
- Omni-Directional
- Phone Line

Security Sensors



- 2.4, 10 GHz
- < 20 mW
- Semi-Directional
- Phone Line

Doppler Sensing with Comm. Signals

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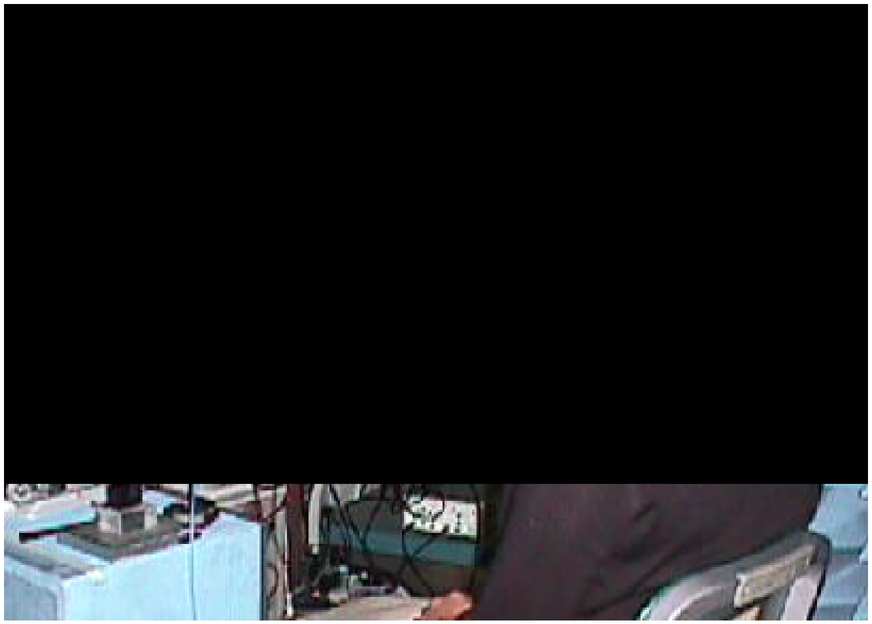
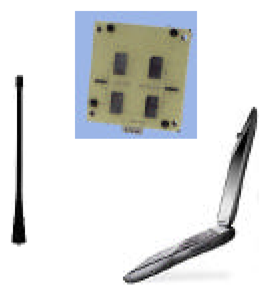
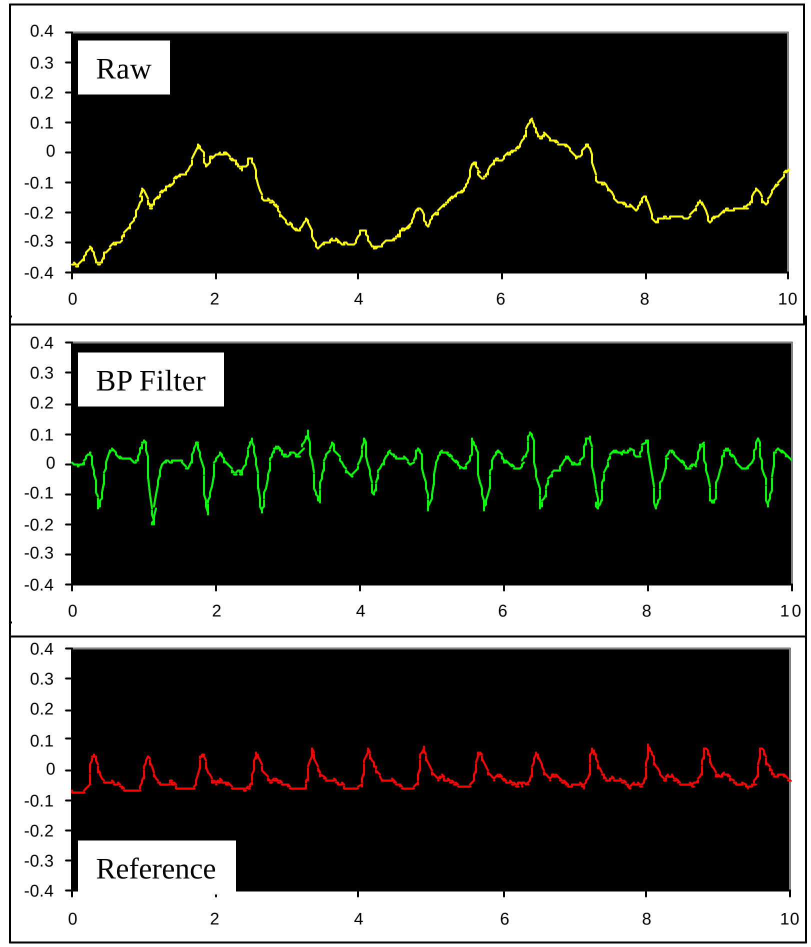
Lab tests simulating various terminals



- 800, 1900, 2,400, and 10,000 MHz
- Omni and directional antennas
- From contact to 2 meters



f = 2.4 GHz, *P* = 0 dBm, 1m



Time [s]

Communications Technology Leveraging

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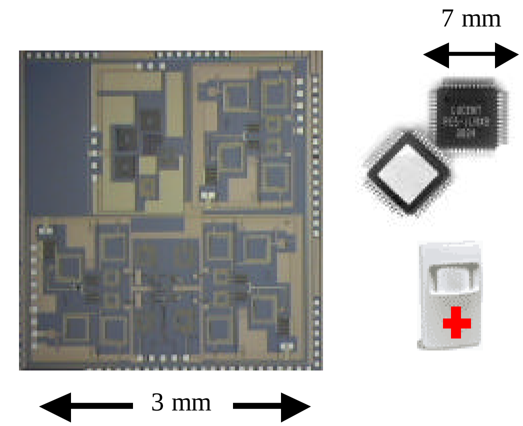
Orinoco

Cordless Phone

Integrated Radio Chip



- Two LO-linked Orinoco cards
- Respiration & heart rates observed

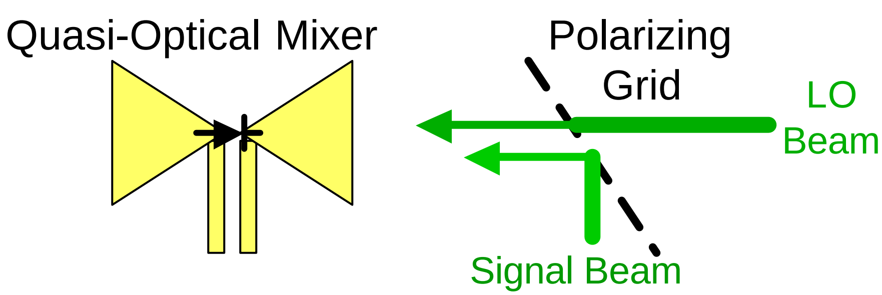
- Low-cost “headset” module
- Respiration & heart rates observed

- 1.6 GHz GSM BTS circuits (Agere 0.25?m BiCMOS)
- Respiration & heart rates observed

Separate Doppler Receiver

RF and LO through same antenna

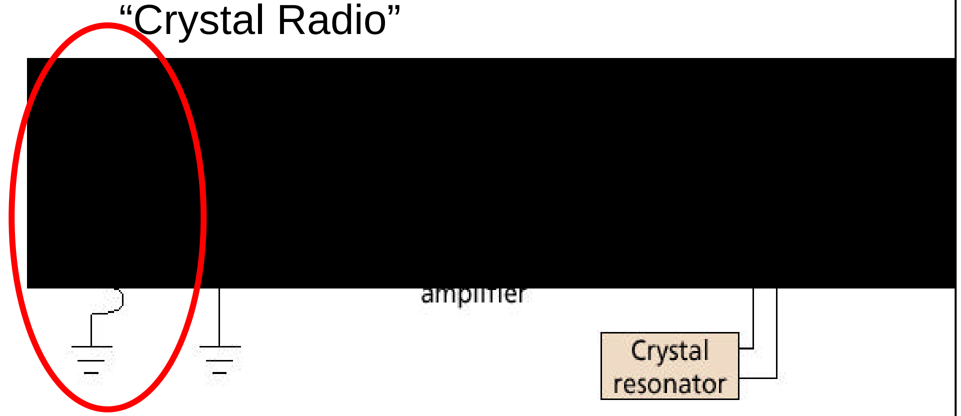
TeraHertz Radiometer



Low-cost radio approach

RF Backscatter-Type “Electronic Price Label”

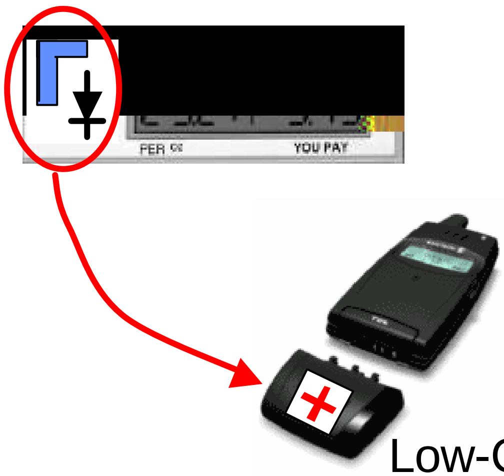
“Crystal Radio”



Tag Communications Costs under $1

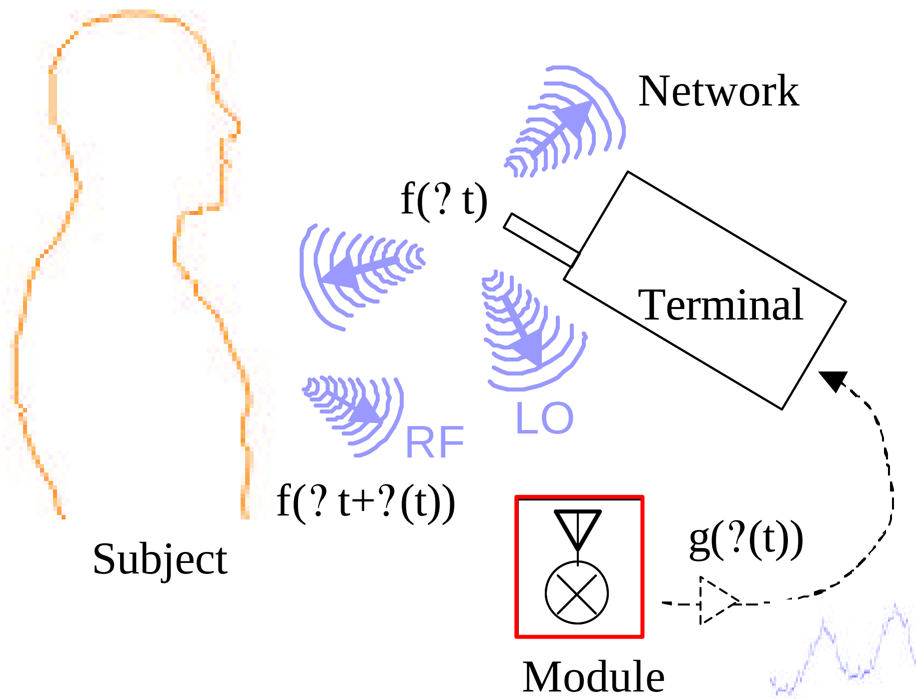
Low-Cost Add-On Sensor Concept

“Electronic Price Label” Front-End
(Inverted-F Antenna, Schottky Diode)



Phone
with
Headset
Jack

Low-Cost
Attachment
Module



Low-Cost Ad-On Sensor Demo

f = 2.4 GHz, d = 1/2 m

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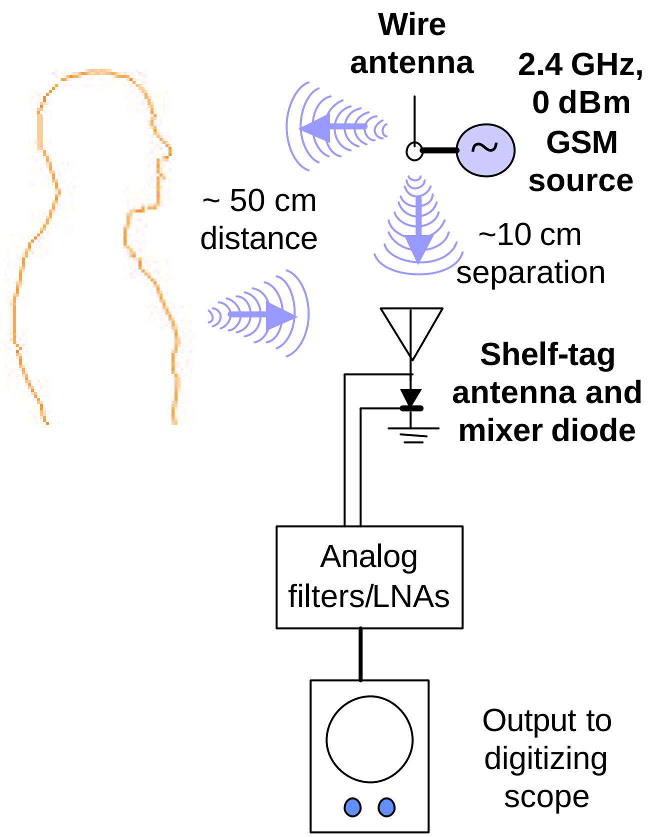
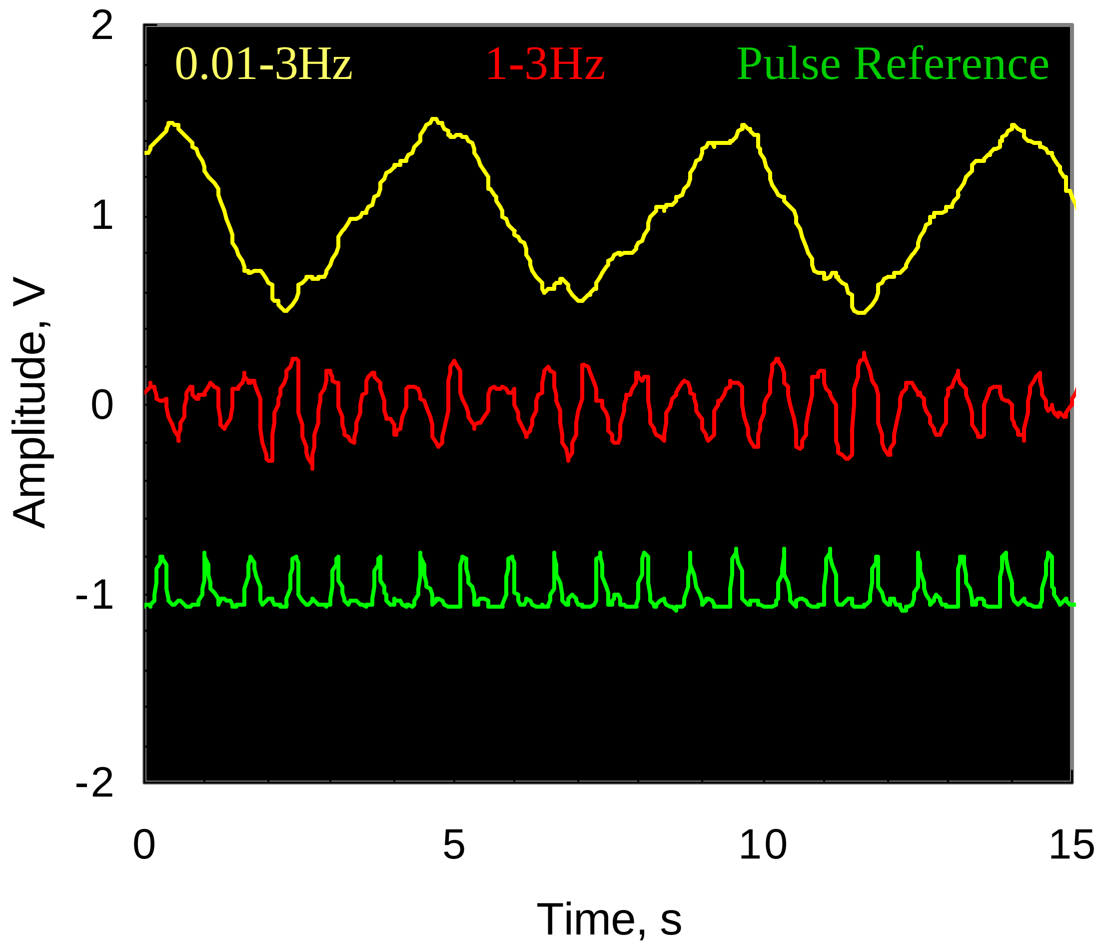


Sensor output with signal generator source



Low-Cost Ad-On Sensor

f = 2.4 GHz, d = 1/2 m

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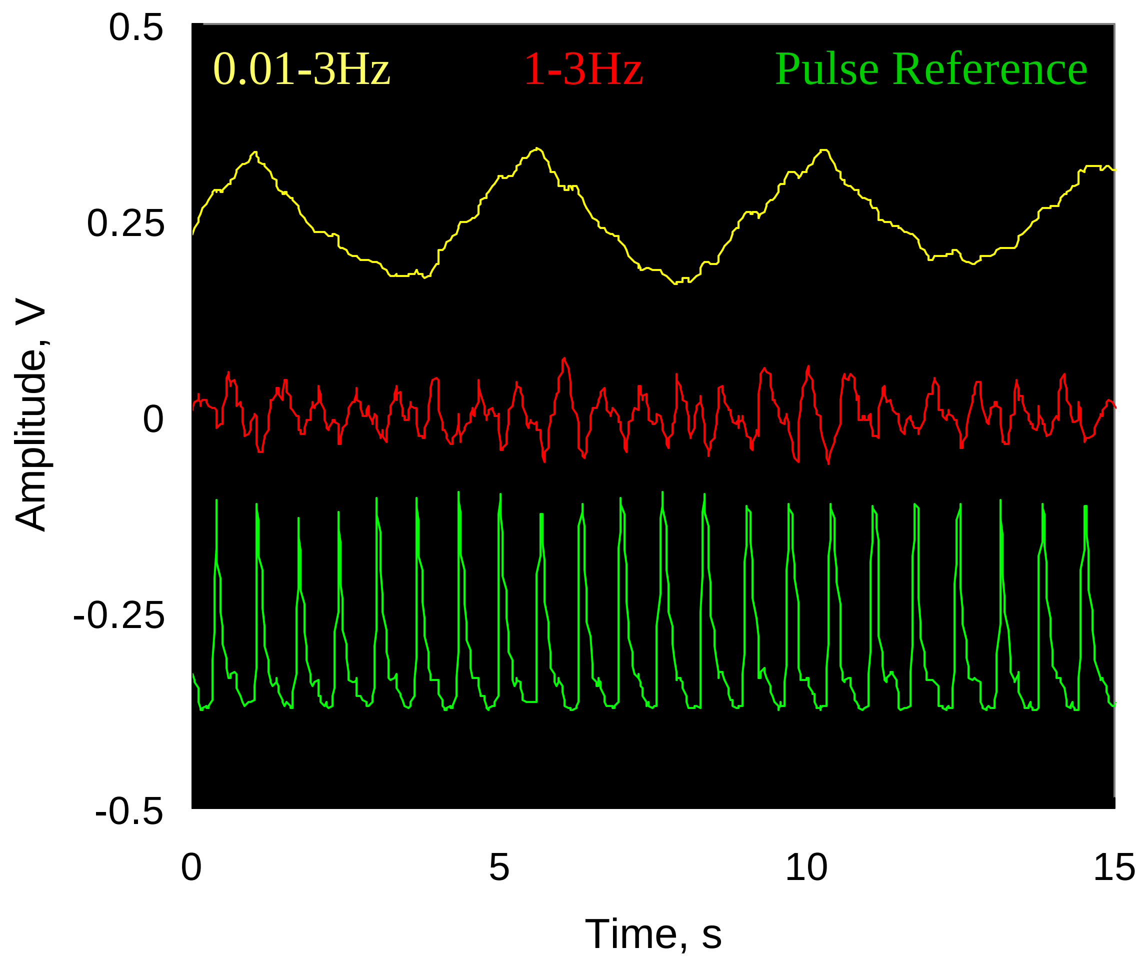
Sensor output with unmodified cordless phone



Digital Signal Processing

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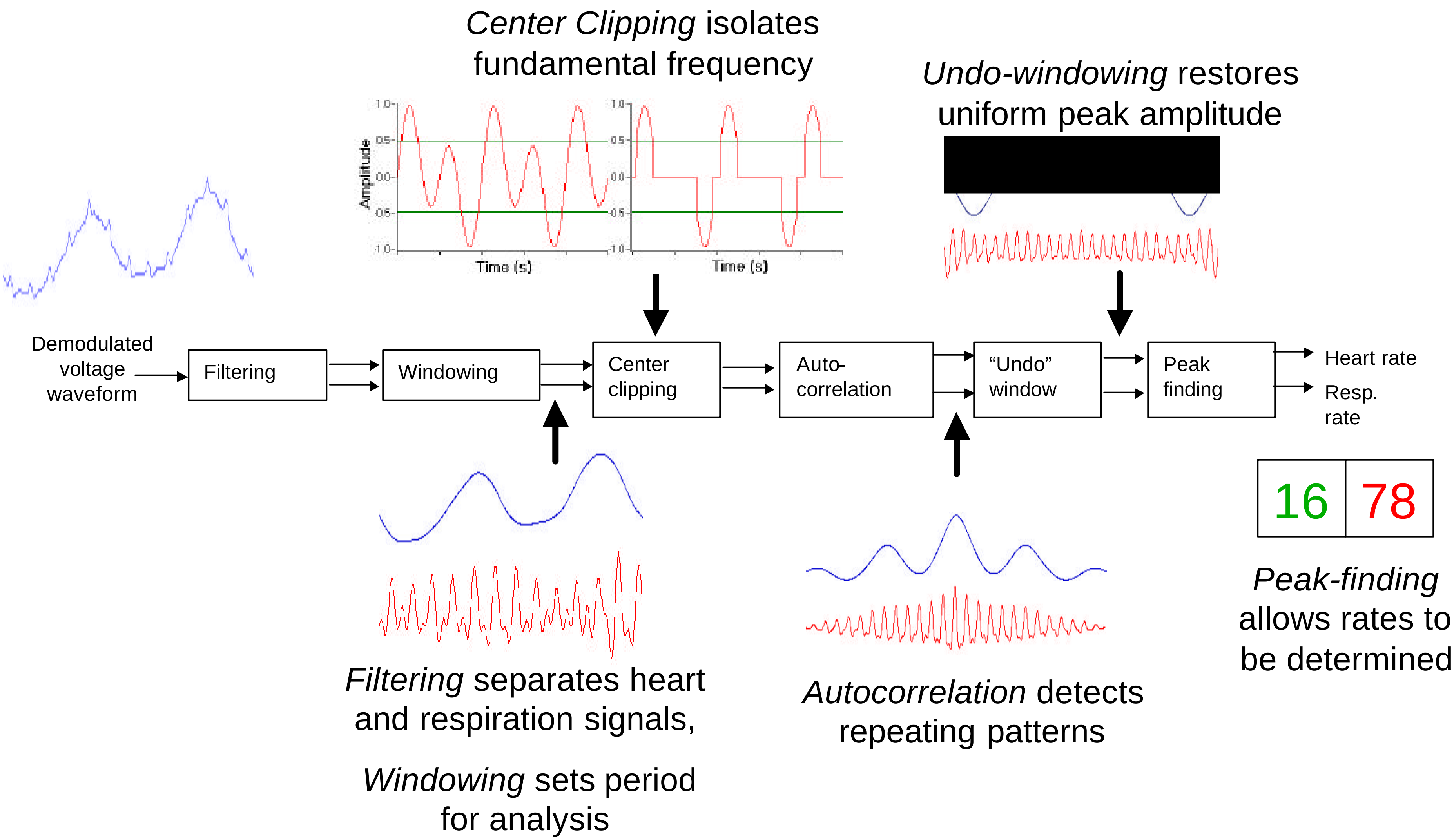
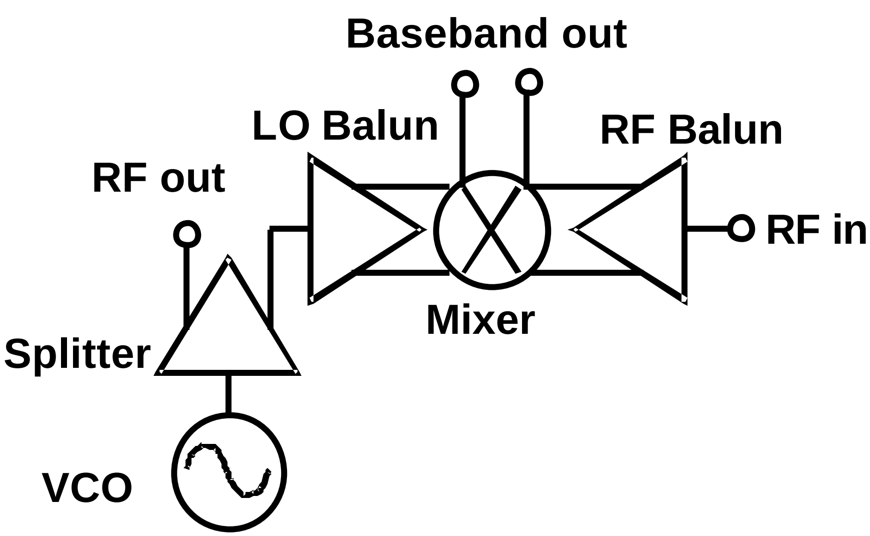
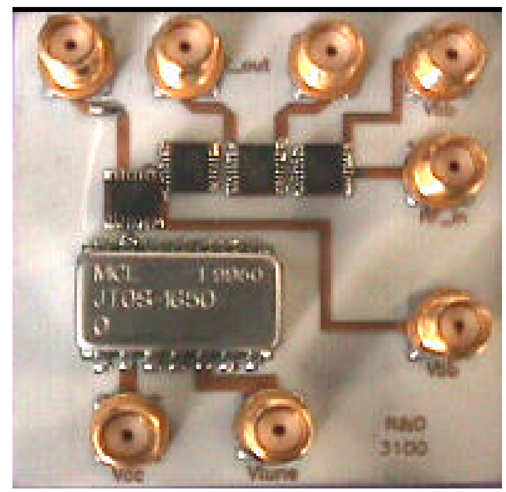


BiCMOS/CMOS Doppler Radar



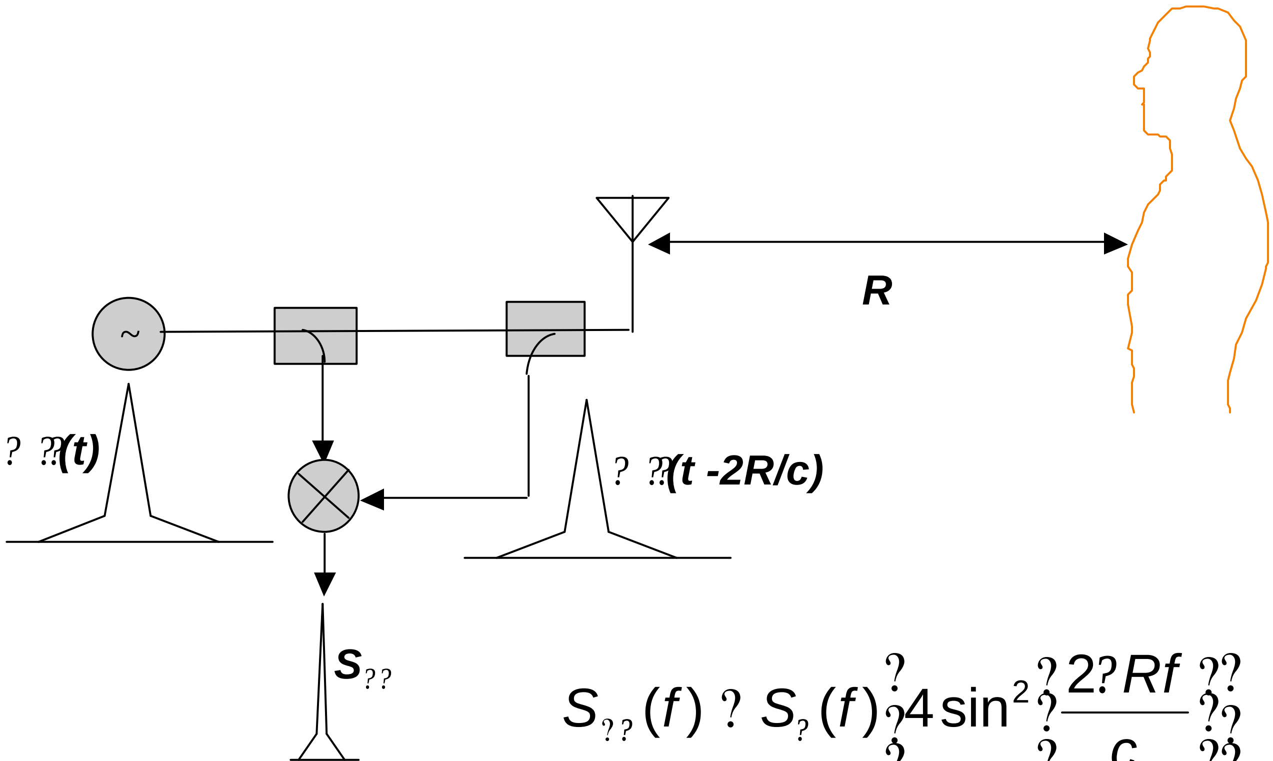
Hybrid radio with BTS components



50 x 50 mm^2

- **RFIC's developed for GSM BTS applications**
- **1.6 GHz, 6.5 mW output power**
- **Mixer: < 6.5 dB conversion loss**
- **Balun: 40 mW, -125 dBc/Hz residual phase noise at 10 Hz**
- **On-chip VCO: 40 mW, -80 dBc/Hz phase noise at 10 kHz**

Range Correlation



$$S_{??}(f) ? S_{?}(f) ? 4\sin^2 ? \frac{2?Rf}{c} ??$$

- **For R = 0.5 m, f = 10 Hz, phase noise decreases by 134 dB!**
- **Budge and Burt, 1993 IEEE Radar Conference**

Radar Chip Photographs

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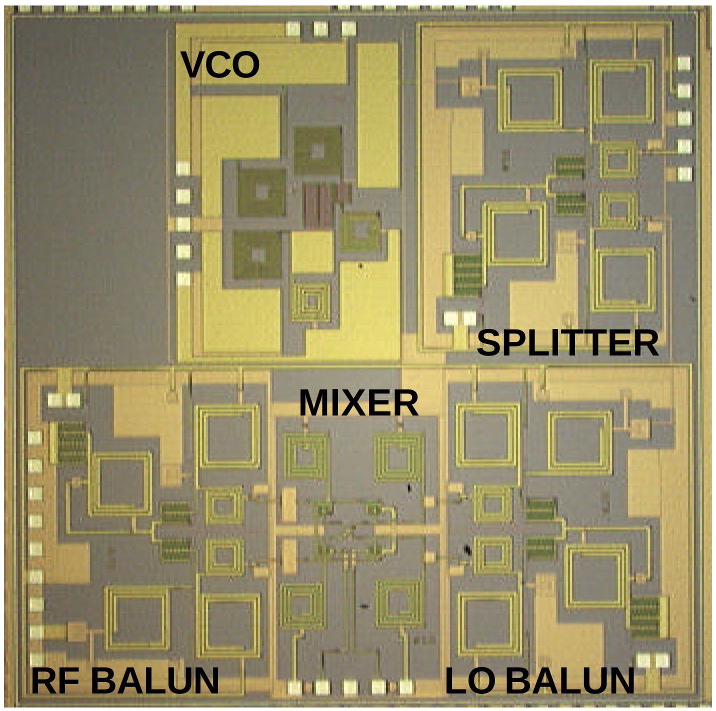
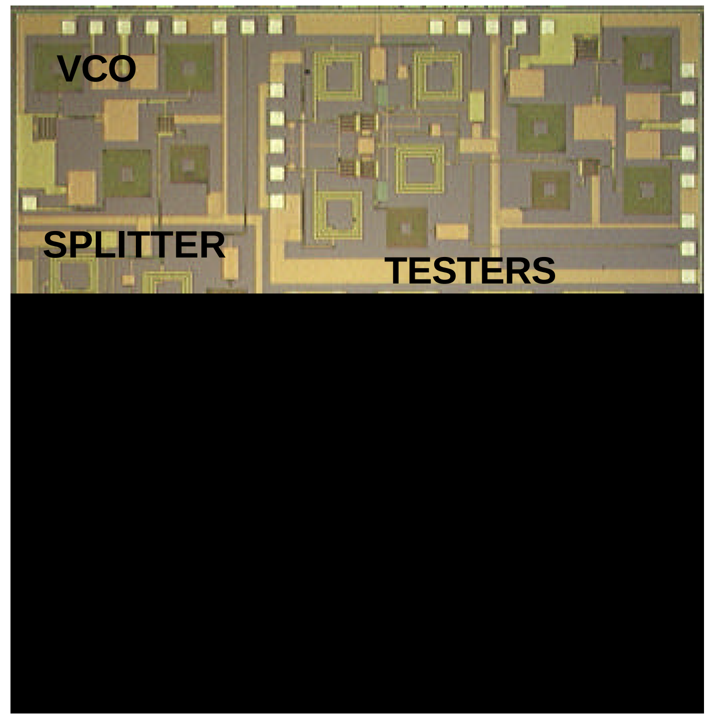
BiCMOS



4 x 4 mm^2

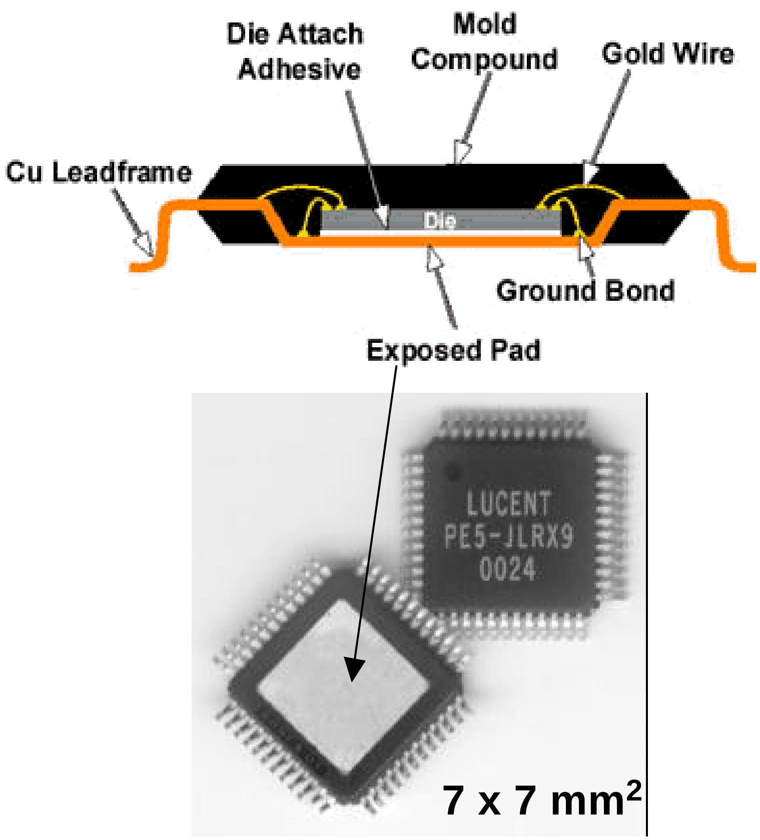
CMOS



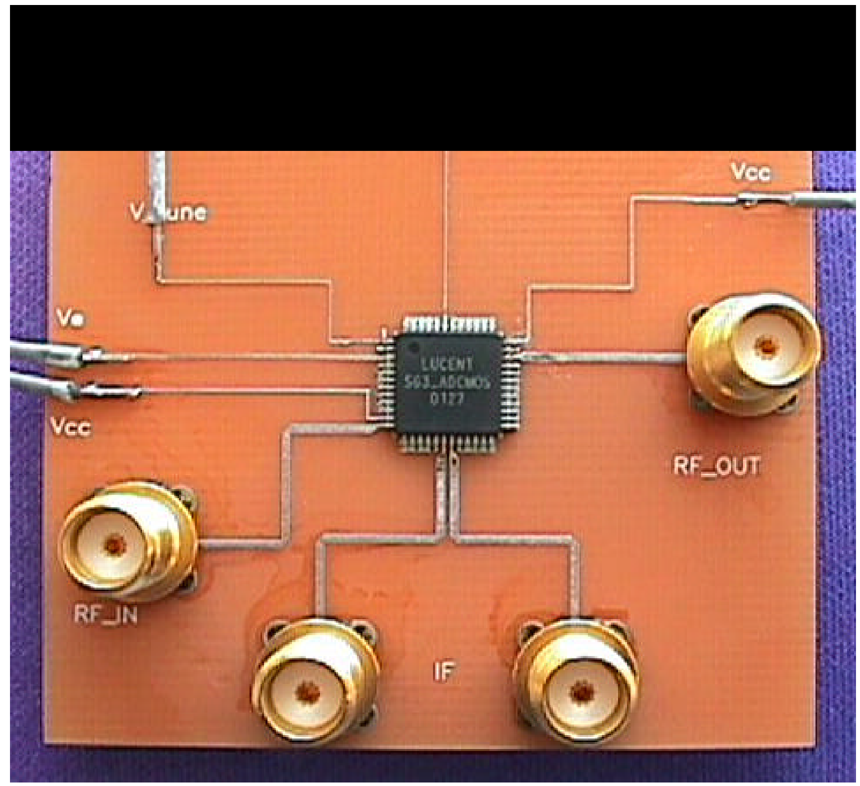
4 x 4 mm^2

- **External source option**

Package and Test Board



7 x 7 mm^2



50 x 50 mm^2

- Exposed pad TQFP-48 package: Lg < 0.5 nH
- Test board built on Rogers RO-4003 (Er = 3.38, h = 0.5 mm)

Phase Noise Reduction

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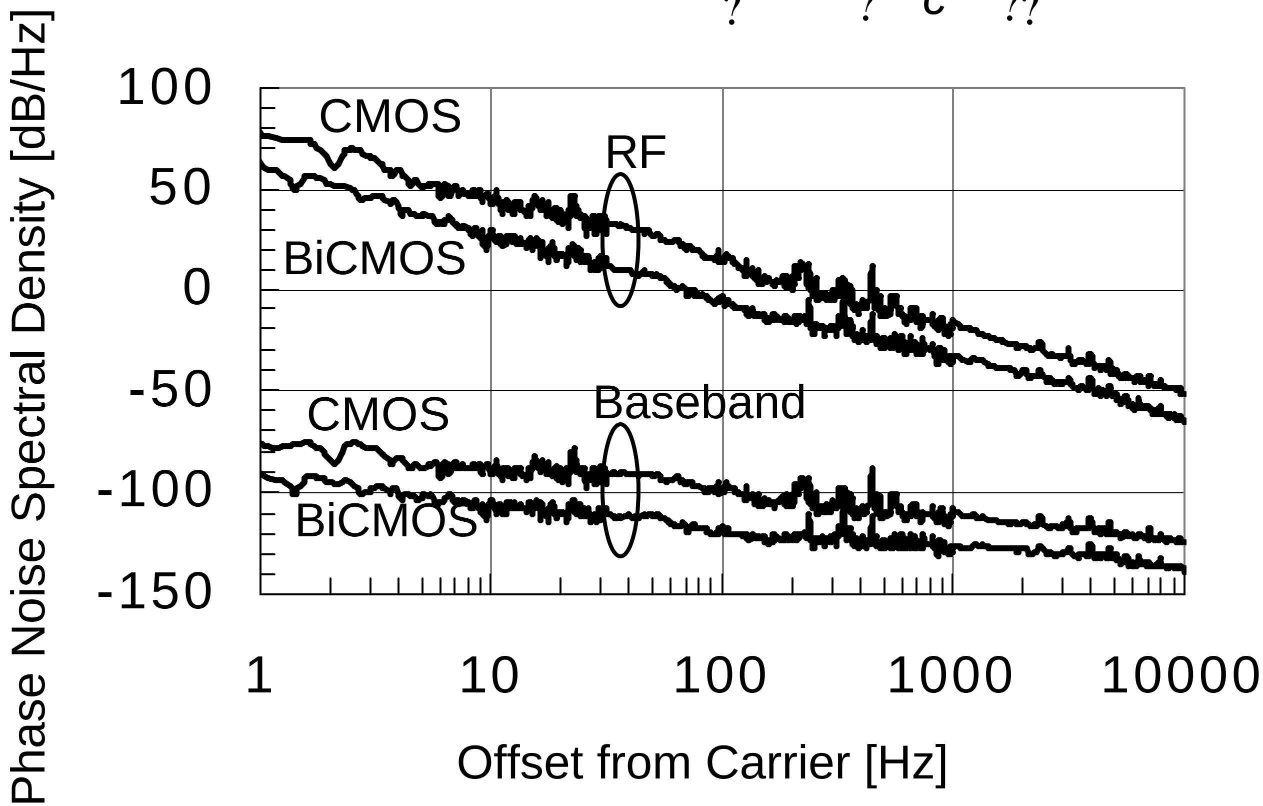
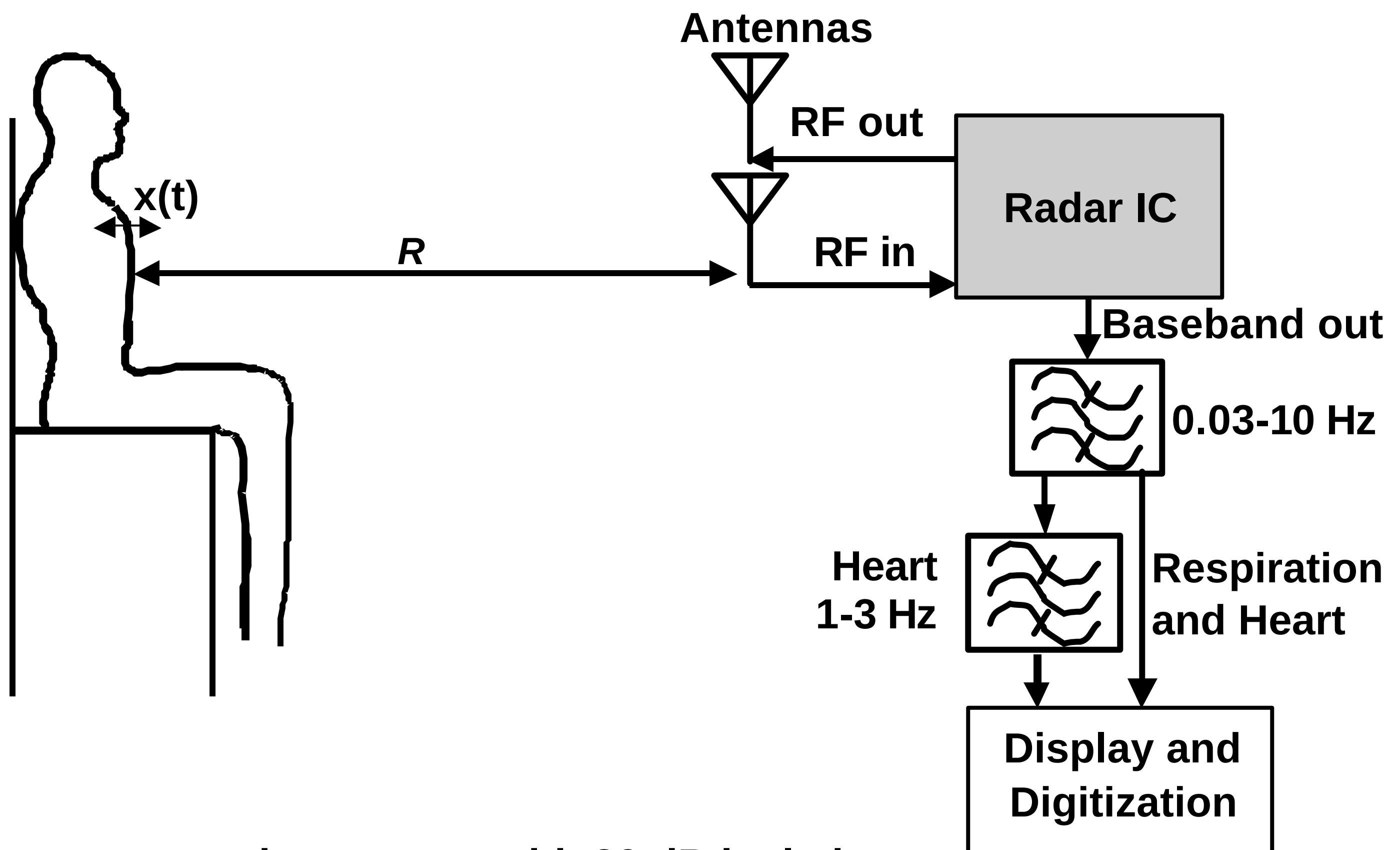
$$S_{??}(f)\ ?\ S_{?}(f)?4\sin^{2}?\frac{2?Rf}{c}??$$



- **$1/f^3$ ⟶ $1/f$**
- **CMOS Phase Noise about 10 dB higher than for BiCMOS**

Experimental Setup

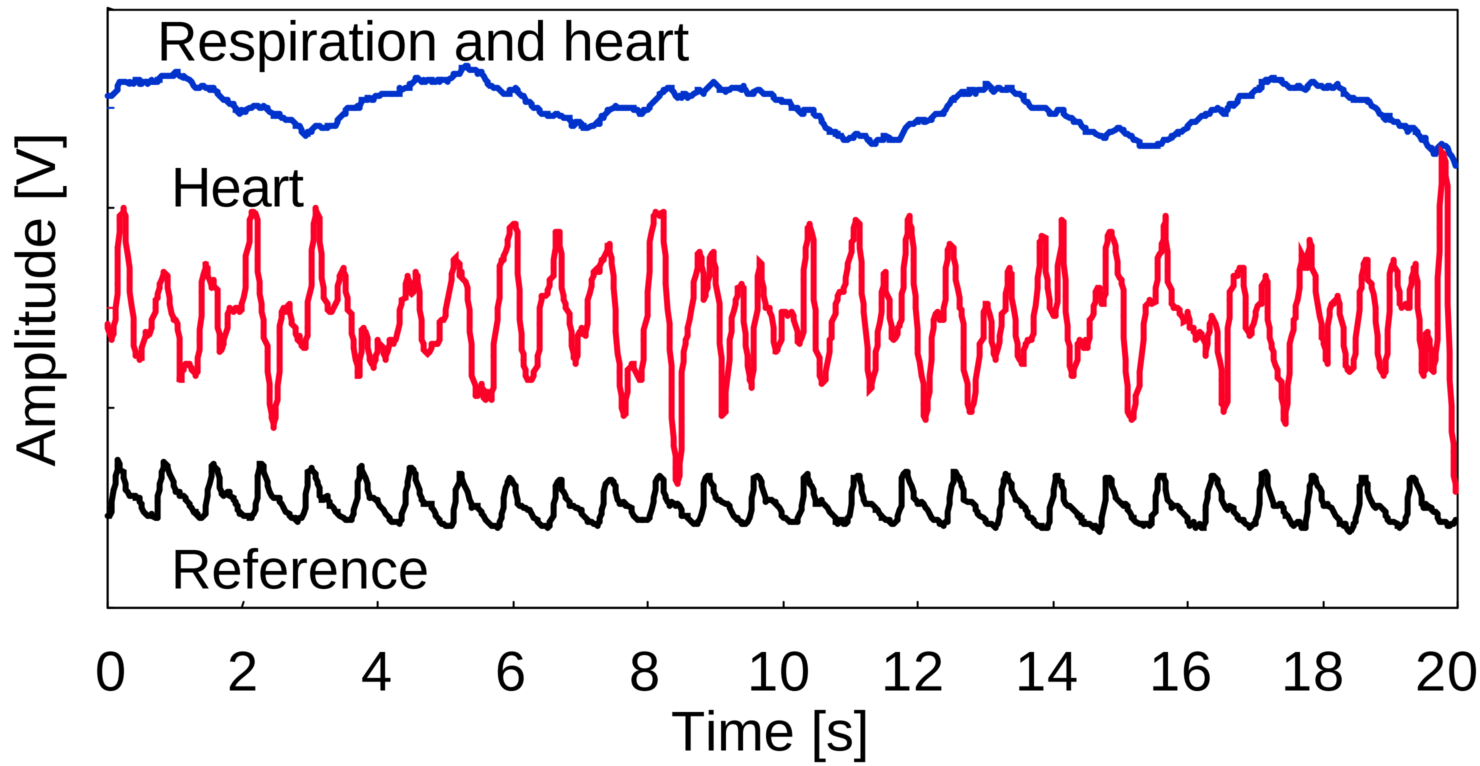


- **Two custom patch antennas with 30 dB isolation**
- **Signal conditioning with analog filters**
- **DSP determines rates using autocorellation**
- **Accuracy - measured rate within 2% of reference rate (pressure pulse)**

BiCMOS Radar Output

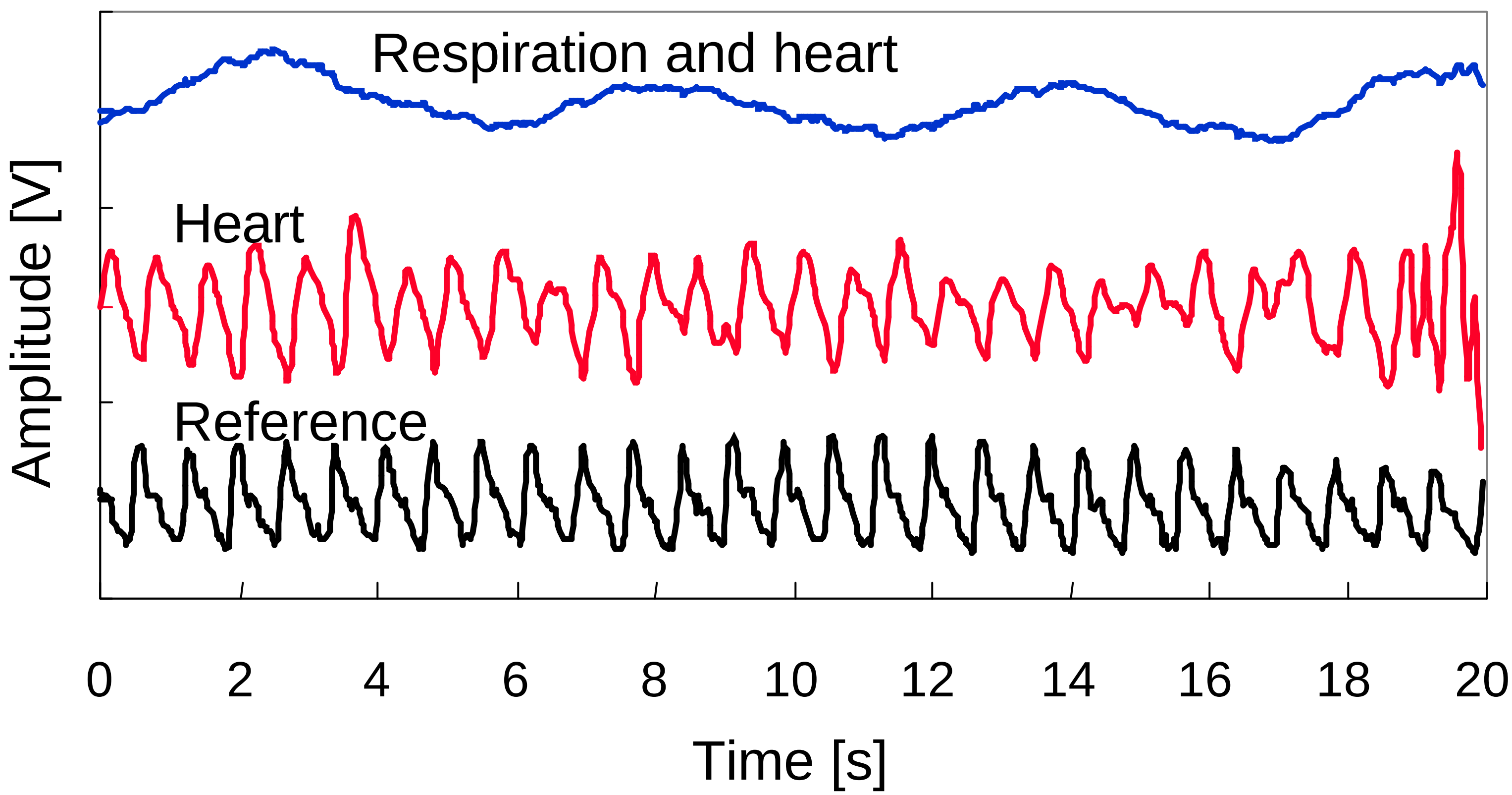
89% accurate

CMOS Radar Output



83% accurate

Radar Output with Signal Generator



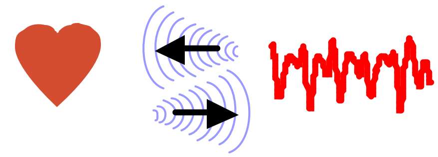
93% accurate

Radar Results Summary

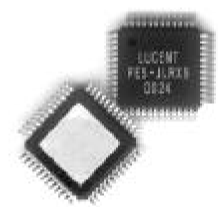
Chip	CMOS	BiCMOS	CMOS with external source
Frequency	1.6 GHz	1.6 GHz	1.6 GHz
Output Power	6.5dBm	6.5dBm	6.5dBm
RF Phase Noise Spectral Density (10Hz offset)	42 dB/Hz	30 dB/Hz	-77 dB/Hz
Baseband Phase Noise Spectral Density (10Hz offset)	-92 dB/Hz	-104 dB/Hz	-211 dB/Hz
% Agreement with Reference	83%	89%	94%

Summary and Future Directions

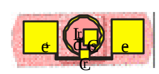
- Demonstrated remote sensing of heart and respiration rates with comm. signals
  - Heart and respiration rates easily detected
  - Possible to observe respiration and heart signatures

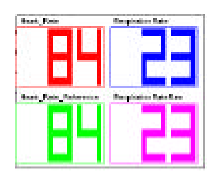


- Demonstrated potential for technology leveraging
  - Added feature for communications terminal
  - Dedicated new *telesensing* instrument using existing wireless technology
  - Expanded application opportunities for wireless networks



- Improvement through DSP and “bandaid” sensor enhancements





Acknowledgements

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- Agere Systems for chip fabrication
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