Your Home as Doctor:
Smart Homes Enable Medical Diagnosis

D. Schreurs

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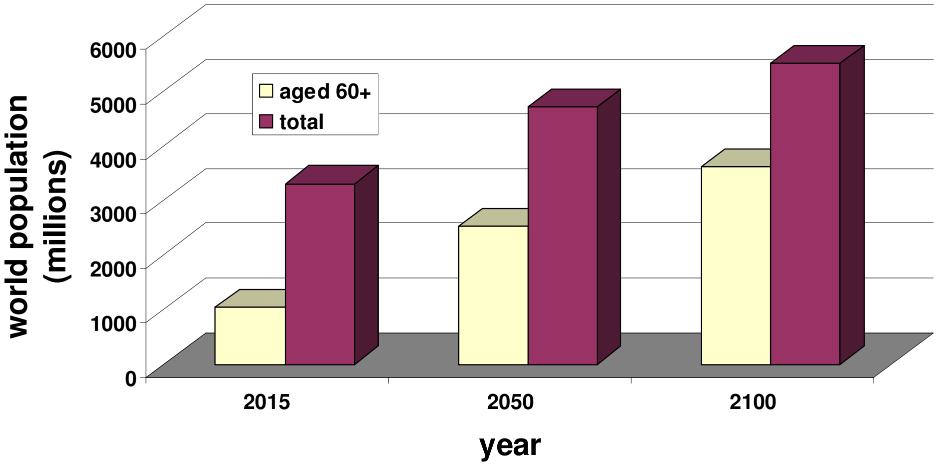
Outline

- **Motivation**
- **System Architecture**
- **Blocks’ Design & Experimental Results**
- **System Design & Experimental Results**
- **Durability**
- **Conclusions**

Motivation

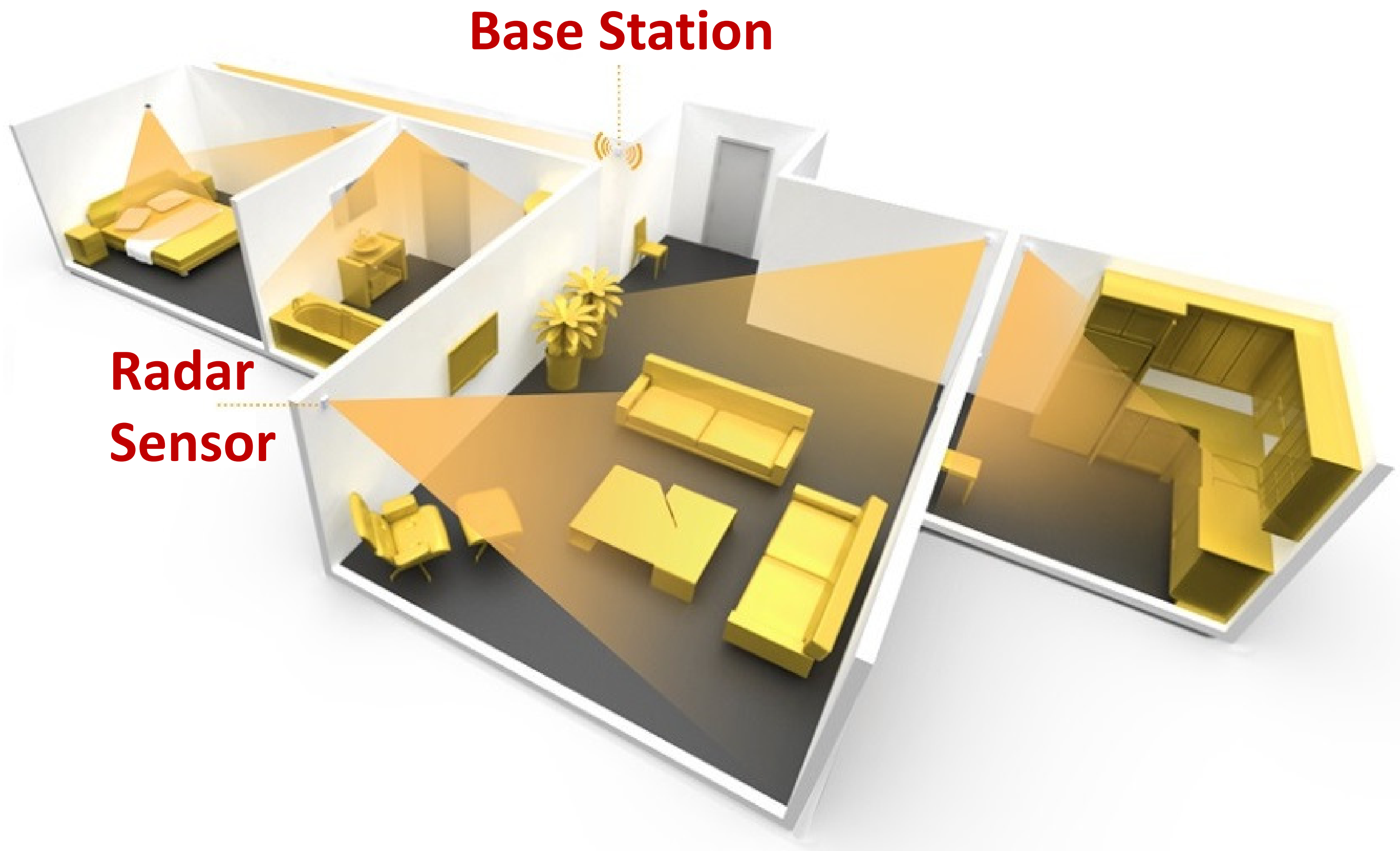
- **Observation: ageing population**



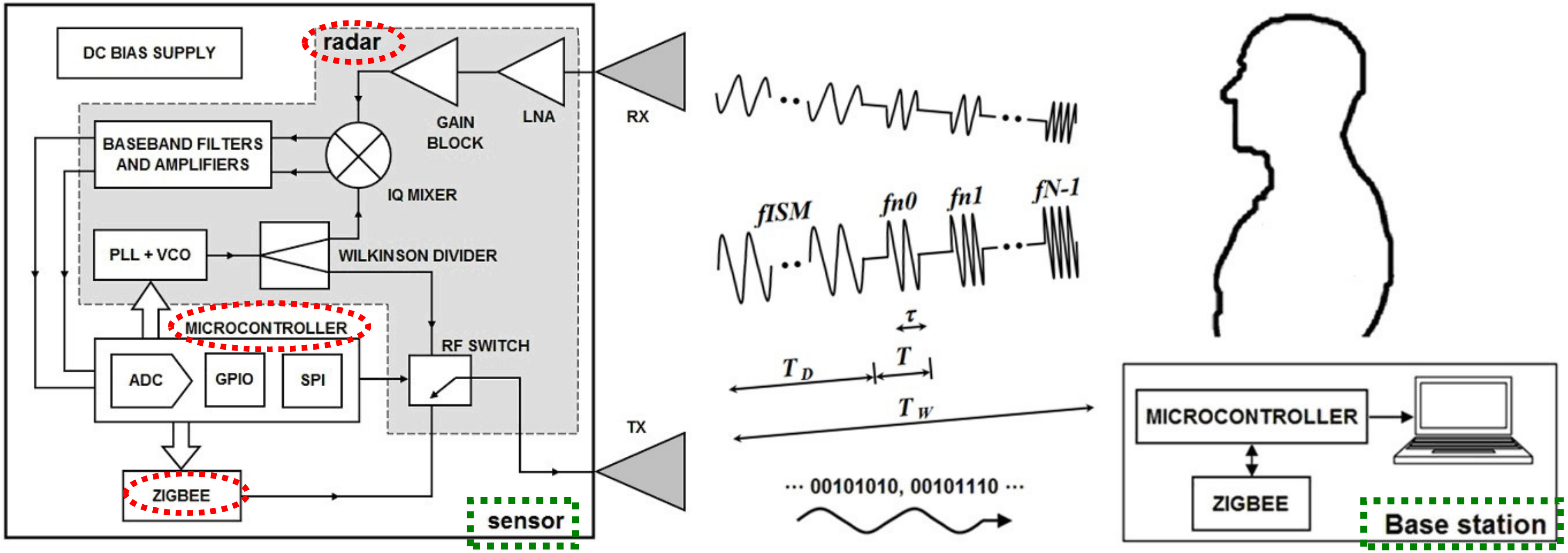
Source: bbc.com

➔ **Importance of Ambient Assisted Living**
= long-term health monitoring
- **Fall detection**
- **Localization**
- **Vital signs monitoring**

Approach: Radar WSN



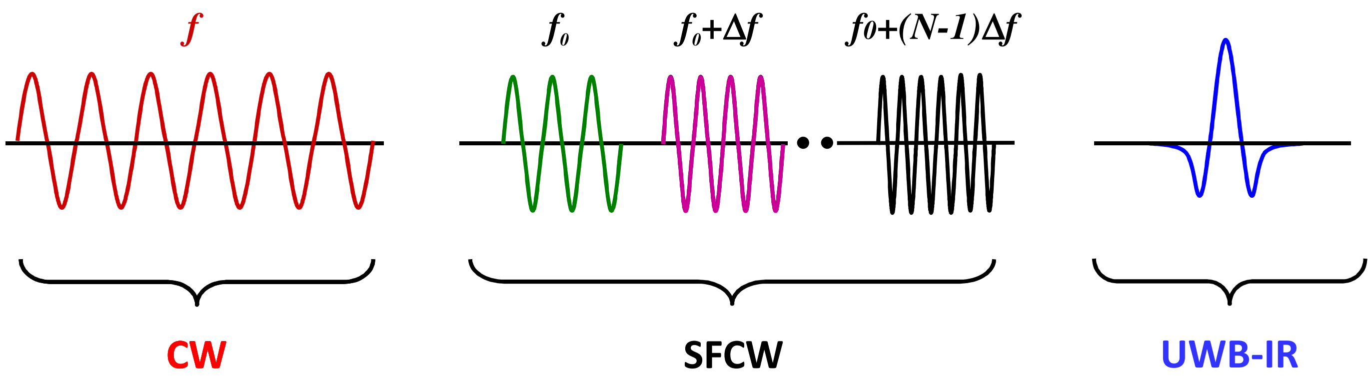
WRSN System Architecture



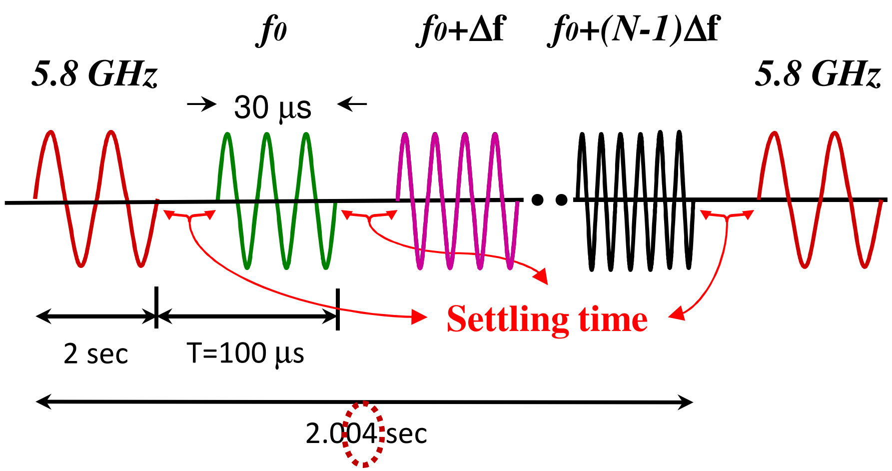
M. Mercuri, *et al.*, "Analysis of an indoor biomedical radar-based system for health monitoring," *IEEE Trans. Microw. Theory Techn.*, vol. 61, no. 5, pp. 2061-2068, May 2013.

Radar Technologies

type	frequency bandwidth	ranging meas.	Doppler	complexity (& costs)
CW	narrowband	NO	YES	low
UWB IR	UWB	YES	NO	high
SFCW/ FMCW	UWB (& narrow band)	YES	YES	low-medium



Radar Waveform



- f_{ISM} → fall detection
  → vital signs monitoring
- SFCW waveform → localization

$$\begin{cases} f_0 = 6 \text{ GHz} \\ N = 40 \\ \Delta f = 25 \text{ MHz} \\ R_{MAX} = 6 \text{ m} \\ \Delta R = 15 \text{ cm} \end{cases}$$

M. Mercuri, *et al.*, "Optimised waveform design for radar sensor aimed at contactless health monitoring," *Electron. Lett.*, vol. 48, no. 20, pp. 1255-1257, 27 Sep. 2012.

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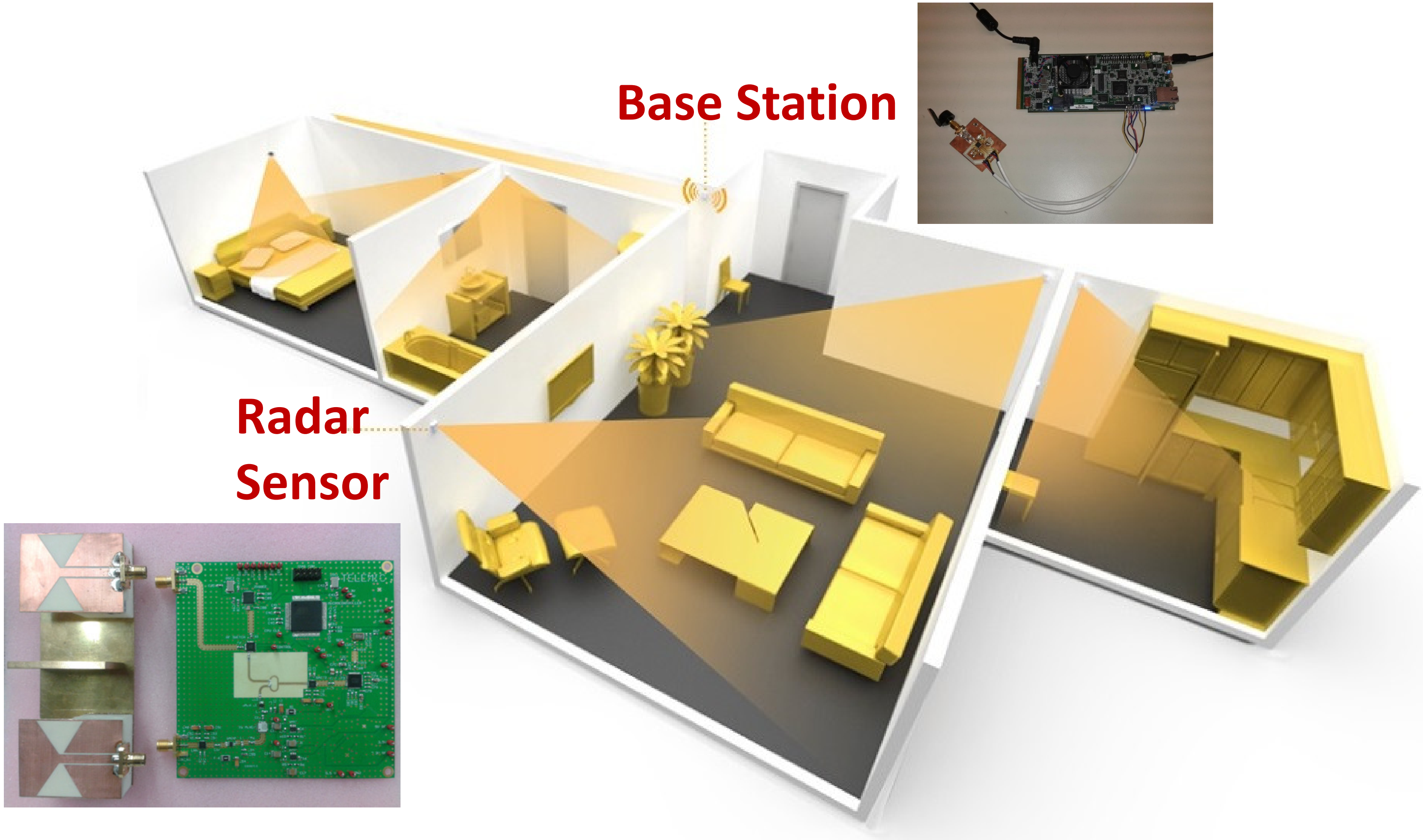
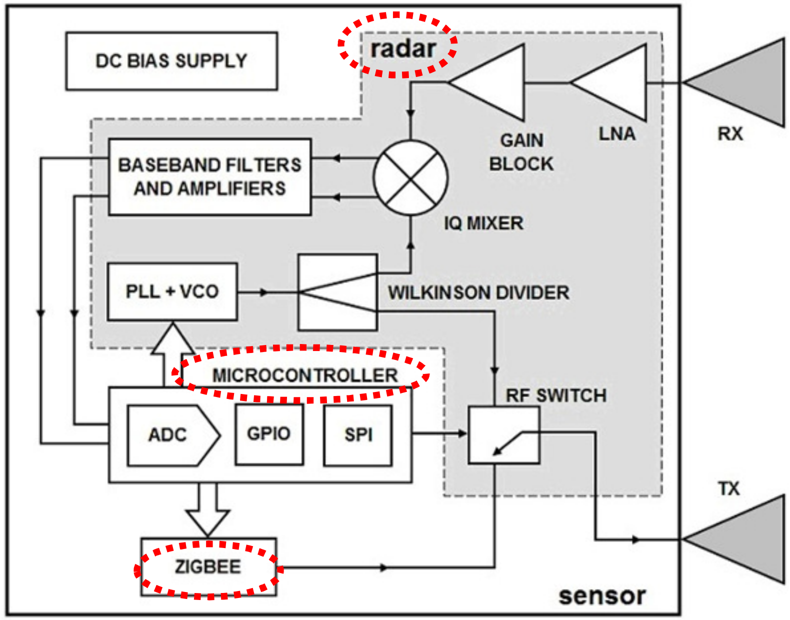
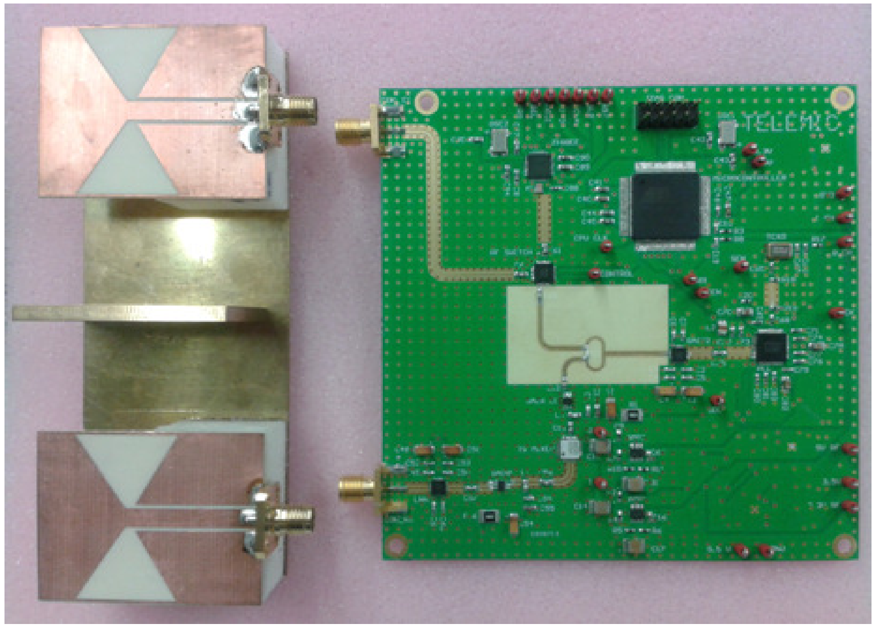
Radar WSN



Radar Sensor

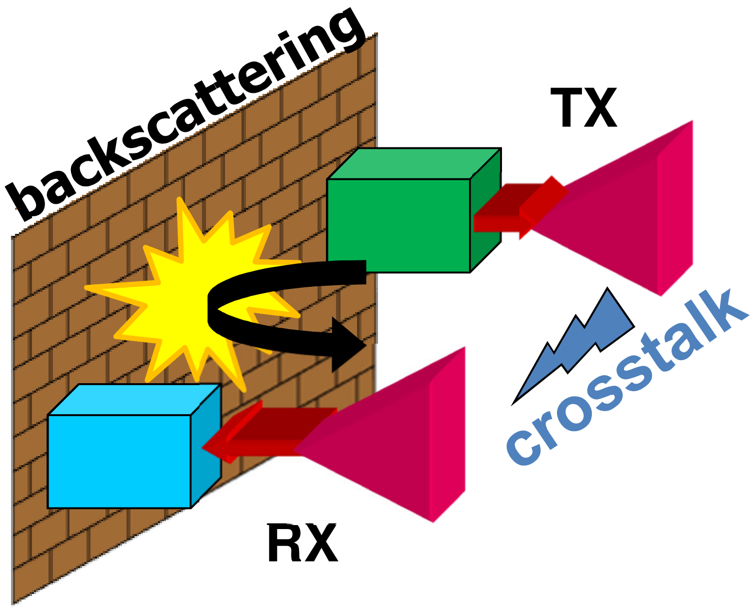


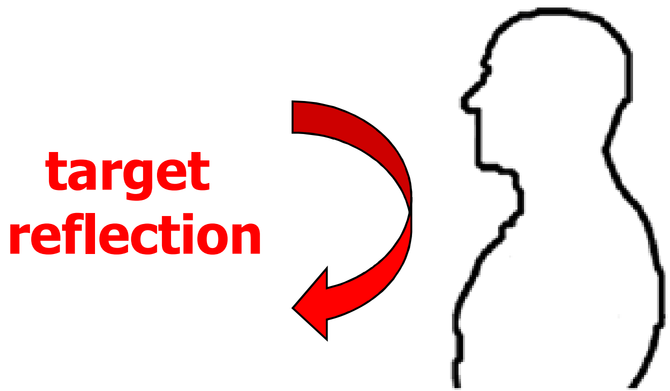


M. Mercuri, *et al.*, "Analysis of an indoor biomedical radar-based system for health monitoring,"
IEEE Trans. Microw. Theory Techn., vol. 61, no. 5, pp. 2061-2068, May 2013.

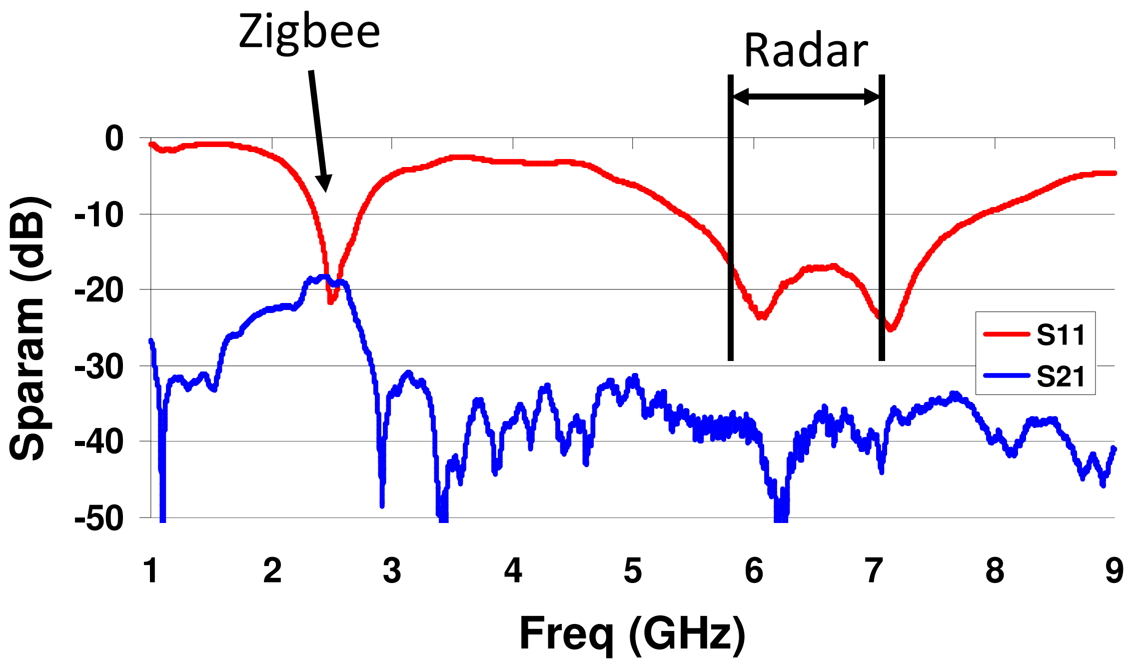
Antenna Design

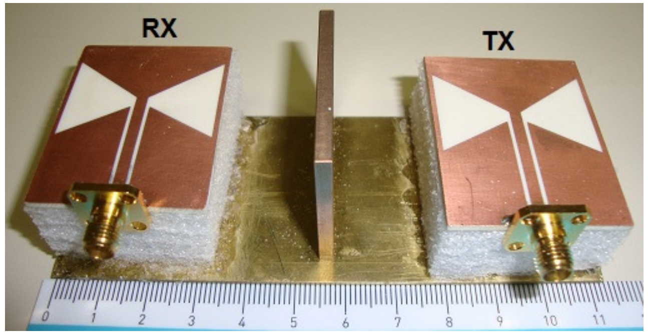
- In-door setting = sensor mounted to wall or ceiling
- Antenna design challenges
  – avoid backscattering & crosstalk
  – semi-spherical radiation pattern
  – wideband requirement





Antenna Design





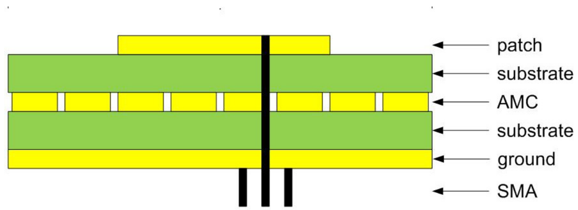
- **Ground Plane:** ***backscattering***
- **Metal Wall:** ***crosstalk*** **(S_{21})**

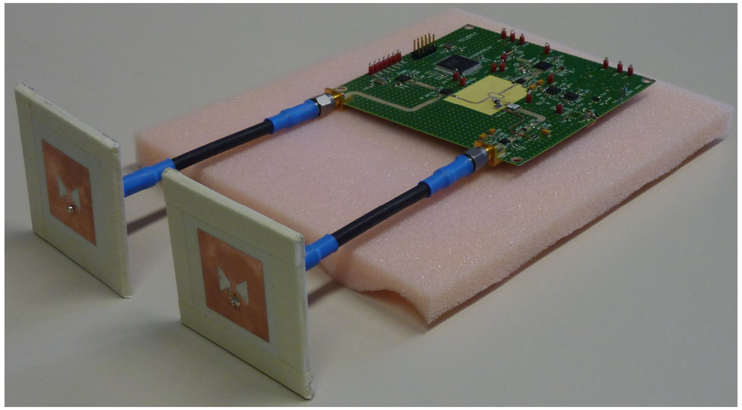
P. J. Soh, *et al.*, "Dual-band Planar Bowtie Monopole for a Fall-Detection Radar and Telemetry System," *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 1698-1701, Dec. 2012.

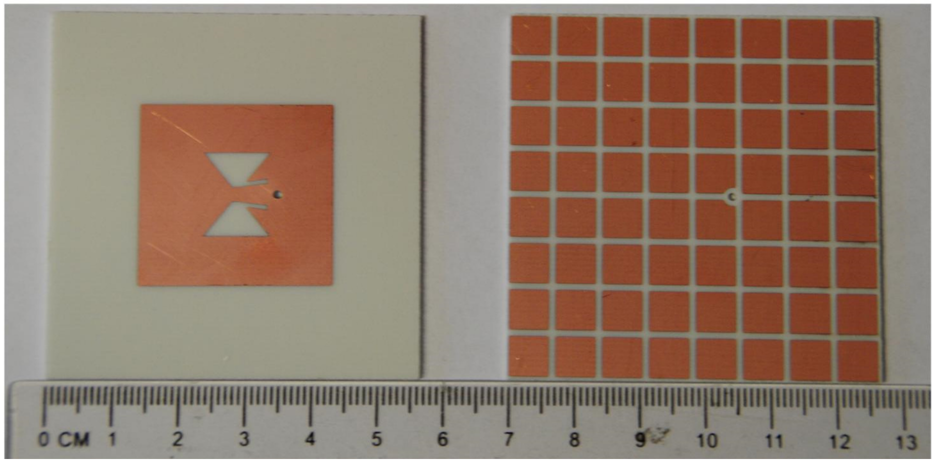
AMC Based Antenna Design

Design based on **Artificial Magnetic Conductor (AMC)** layer

- smaller form factor
- no metal wall!







S. Yan, *et al.*, "A low profile dual-band antenna loaded with artificial magnetic conductor for indoor radar systems," IET Radar, Sonar & Navigation, 7 pp., 2015.

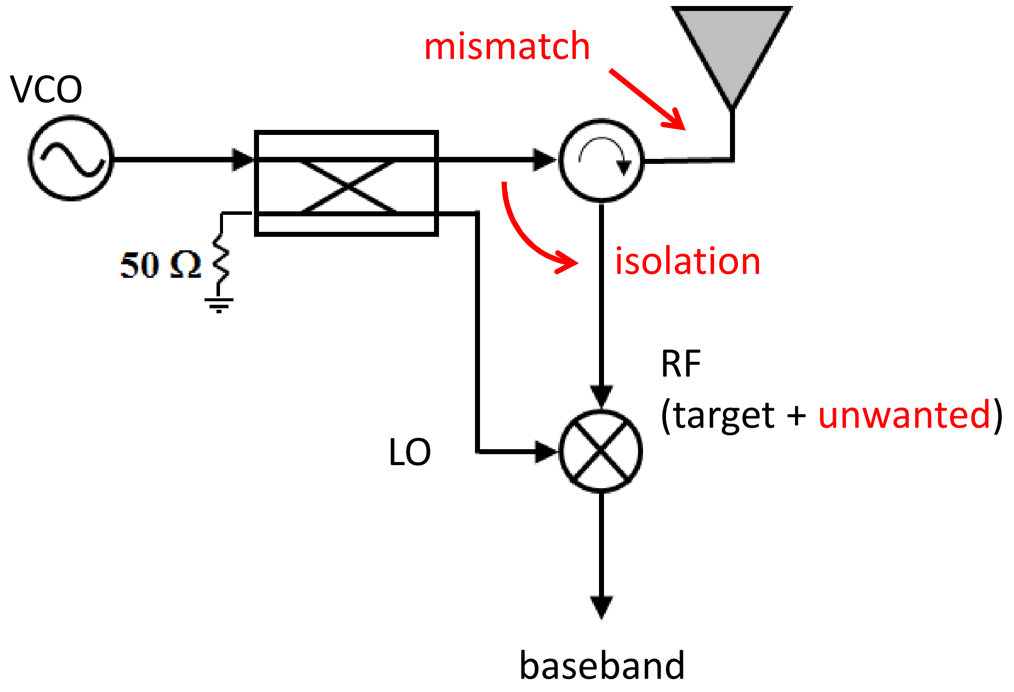
AMC Based Antenna Design

	AMC Antenna	Reference Antenna
Size (mm^3)	56×56×3.12	42×36×32
Low Freq. Band (GHz)	2.395-2.485	2.22-2.48
High Freq. Band (GHz)	5.78-8.89	5.8-6.77
Gain (dB) @ 2.45 GHz	5.05	5.7
Gain (dB) @ 6-7 GHz	>7.0	>7.2
FBR (dB) & 2.45 GHz	15	0
FBR (dB) & 6-7 GHz	>11	>7.5
Cross coupling (dB)	<-25	<-25 ***(with wall)***

FBR = Front-to-Back Ratio

S. Yan, *et al.*, "A low profile dual-band antenna loaded with artificial magnetic conductor for indoor radar systems," IET Radar, Sonar & Navigation, 7 pp., 2015.

Monostatic Radar Architecture



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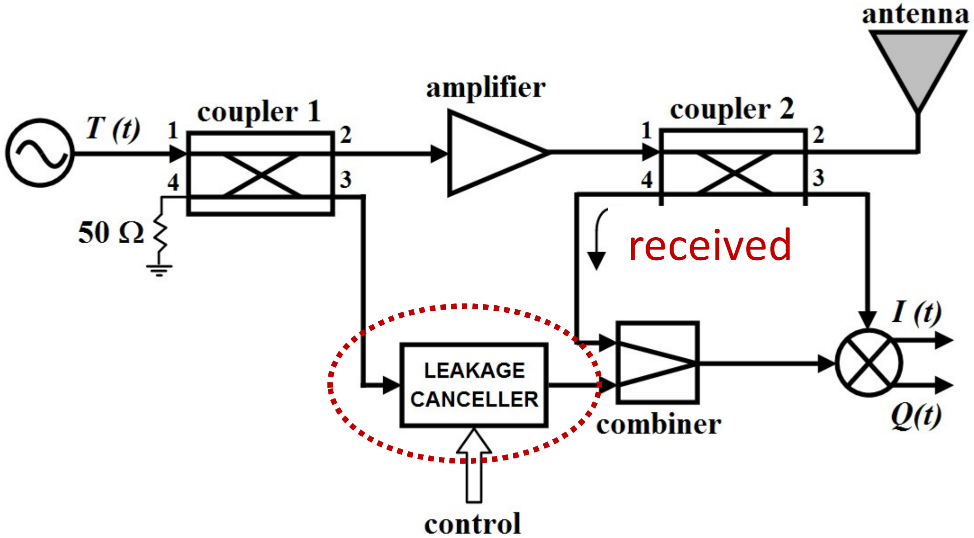
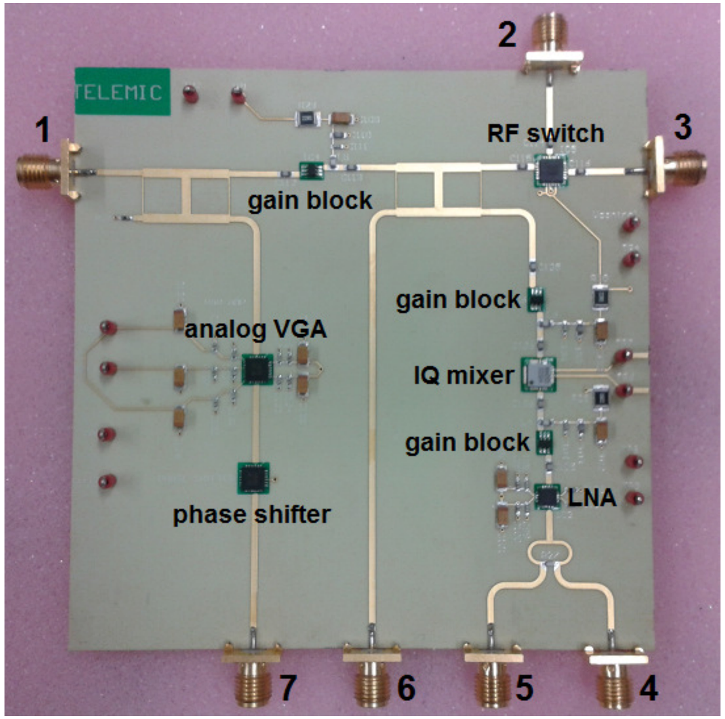
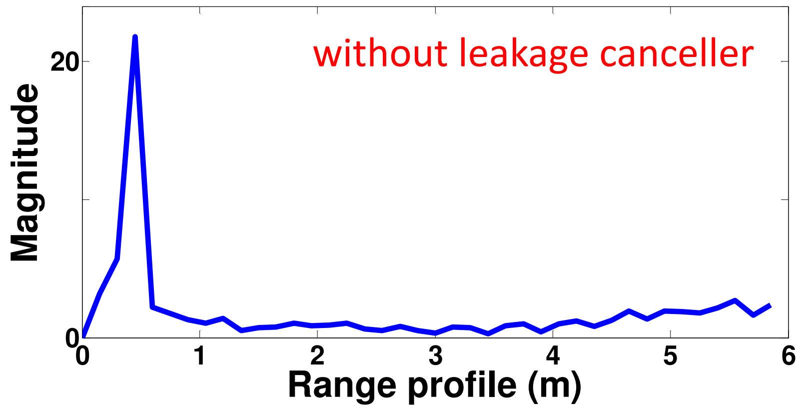
Monostatic Radar Architecture



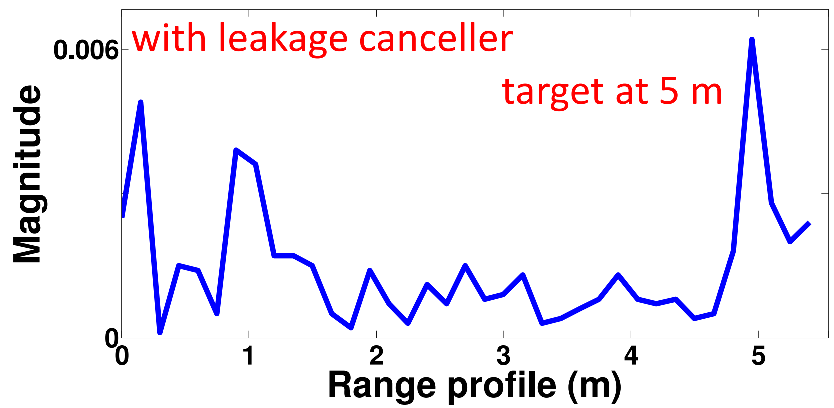


Monostatic Radar Architecture

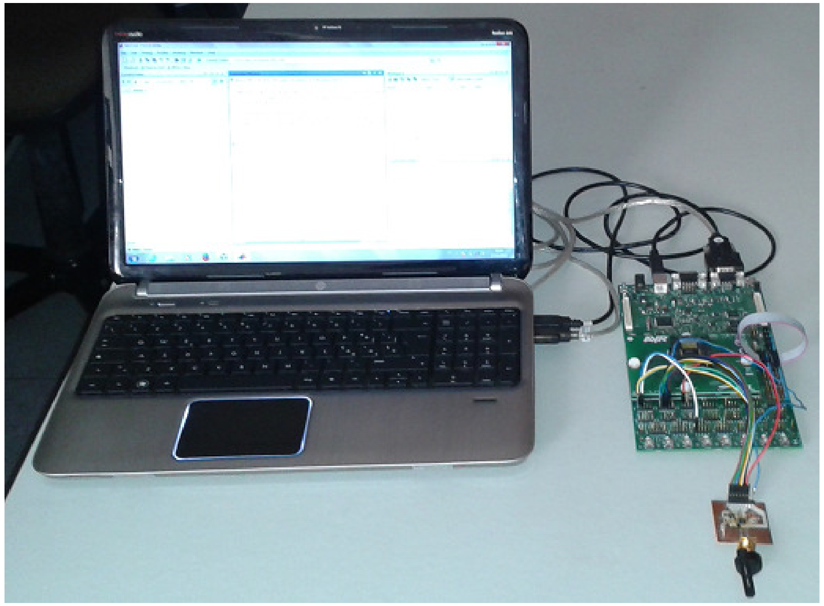
UNWANTED LEAKAGE



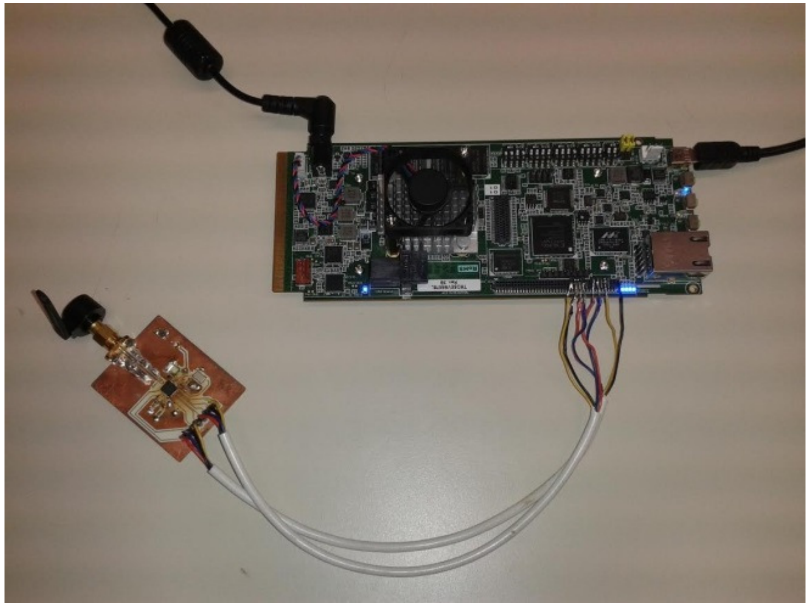
TARGET DETECTED



Base Station



Microcontroller-based



DSP-based

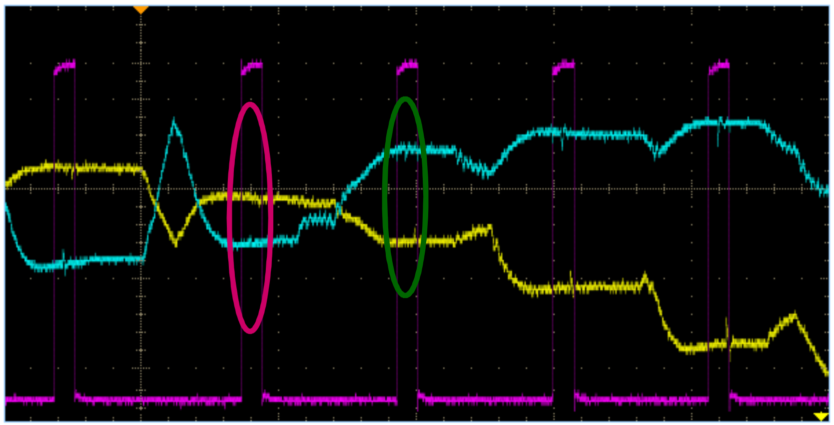
C. Garripoli, *et al.*, "Embedded DSP based Telehealth Radar System for Remote In-door Fall Detection," *IEEE J. Biomed. Health Inform.*, vol. 19, no. 1, pp. 92-101, Jan. 2015.

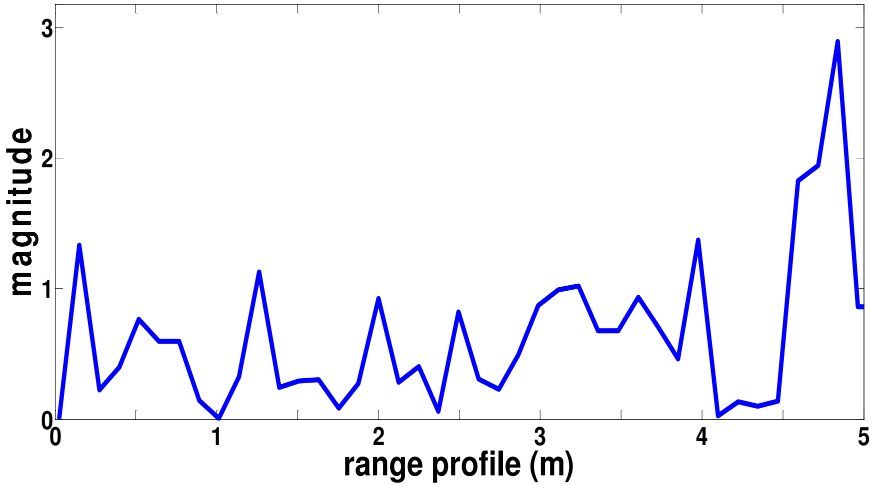
Data Processing: Localisation

- IFFT on SFCW baseband signals → absolute distances

f0	f0+Δ*f*	f0+2Δ*f*	…	f0+(N-1)Δ*f*
C1	C1	C2	…	C1N

IFFT



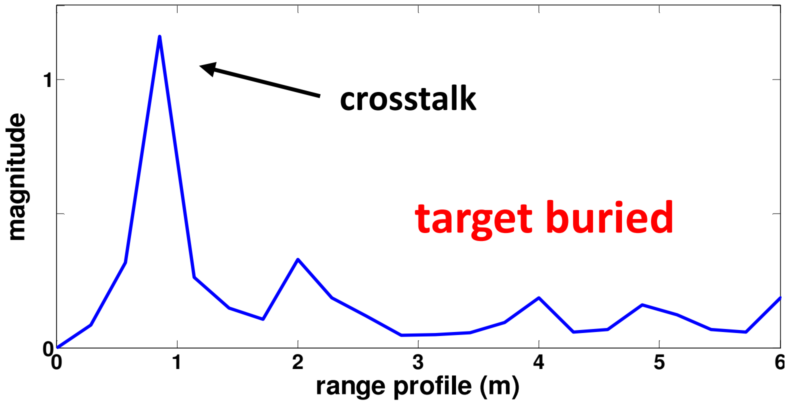


Data Processing: Localisation

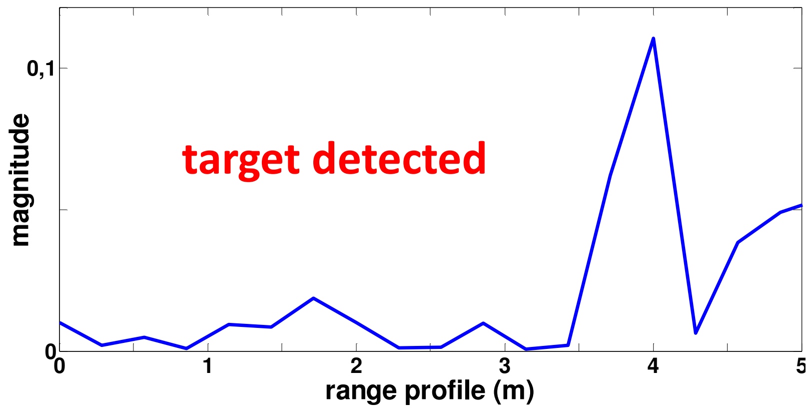
- **Compensation → remove 'static' reflections** (e.g., furniture, crosstalk)
- **Calibration → places the target in the right position**

Example: Target at 4 m

Before compensation and calibration



After compensation and calibration



Reducing backscattering and crosstalk is fundamental!

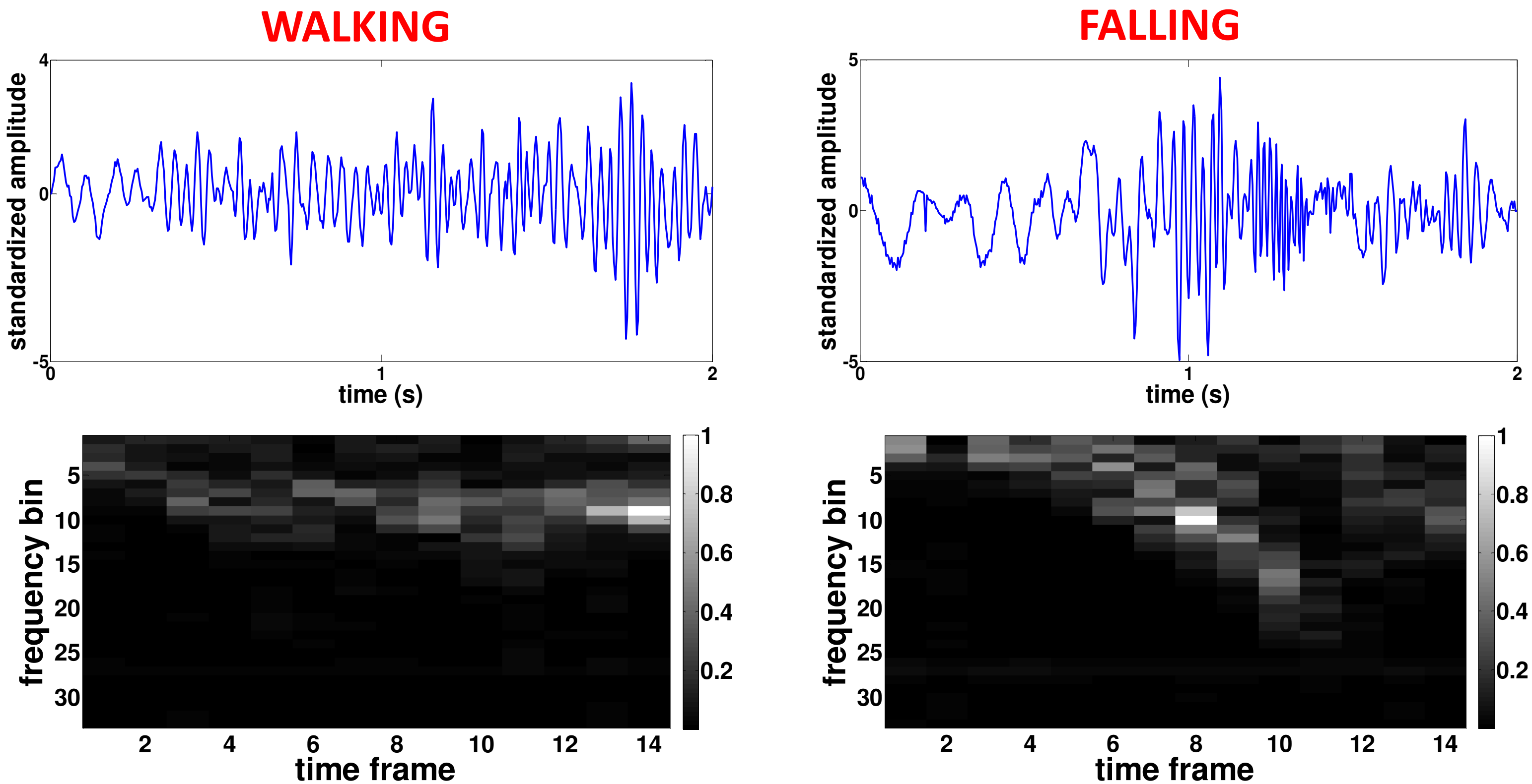
M. Mercuri, *et al.*, "A practical distance measurement improvement technique for a SFCW-based health monitoring radar," *ARFTG Microwave Meas. Conf.*, Jun. 2013.

Data Processing: Localisation

Distance	Anechoic Chamber			Real Room		
	% Person1	% Person2	% Metal	% Person1	% Person2	% Metal
1 m	100	100	100	100	100	100
2 m	100	100	100	100	100	100
3 m	93.3	96.7	100	90	86.7	100
4 m	93.3	93.3	100	90	83.3	100
5 m	86.67	90	100	76.7	73.3	100

➢ **30 range profile measurements for each distance and for each target**

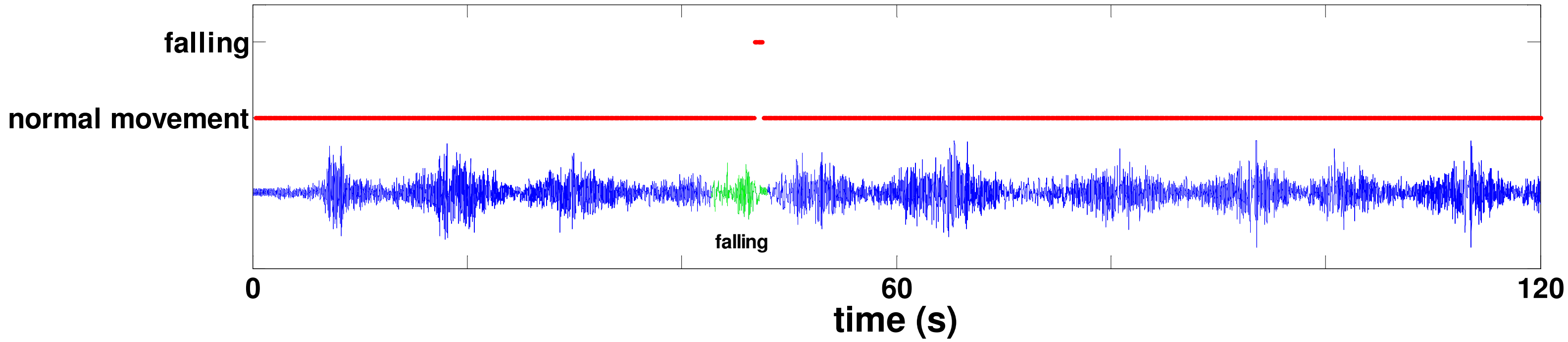
Data Processing: Fall Detection

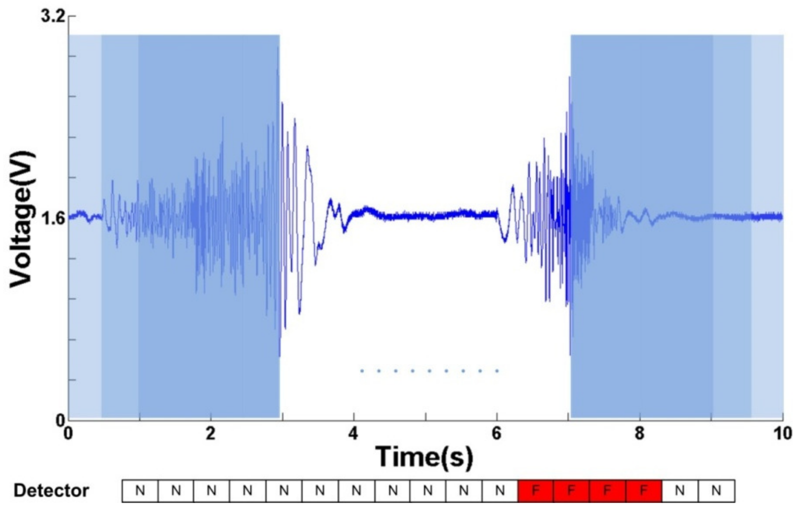


Classification approach: LS-SVM-GA

P. Karsmakers, *et al.*, "Automatic in-door fall detection based on microwave radar measurements," *Eur. Radar Conf.*, 2012.

Real-Time Fall Detection

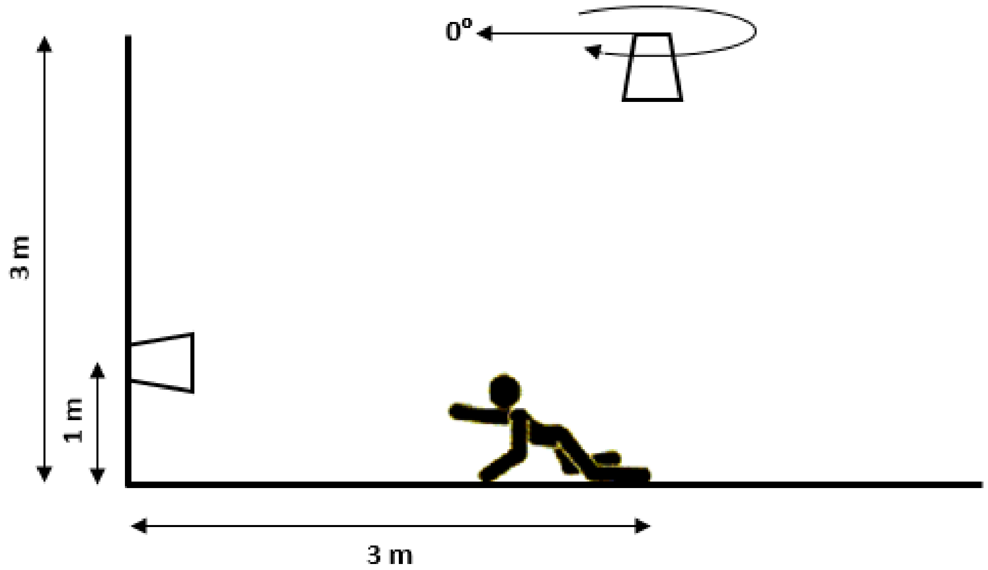




- **Sliding window approach = Segmentation**
- **Real-time operation**
  - **~316 ms maximum delay**

C. Garripoli, *et al.*, "Embedded DSP based Telehealth Radar System for Remote In-door Fall Detection," *IEEE J. Biomed. Health Inform., 2014.*

Fall Detection: Sensor Positioning

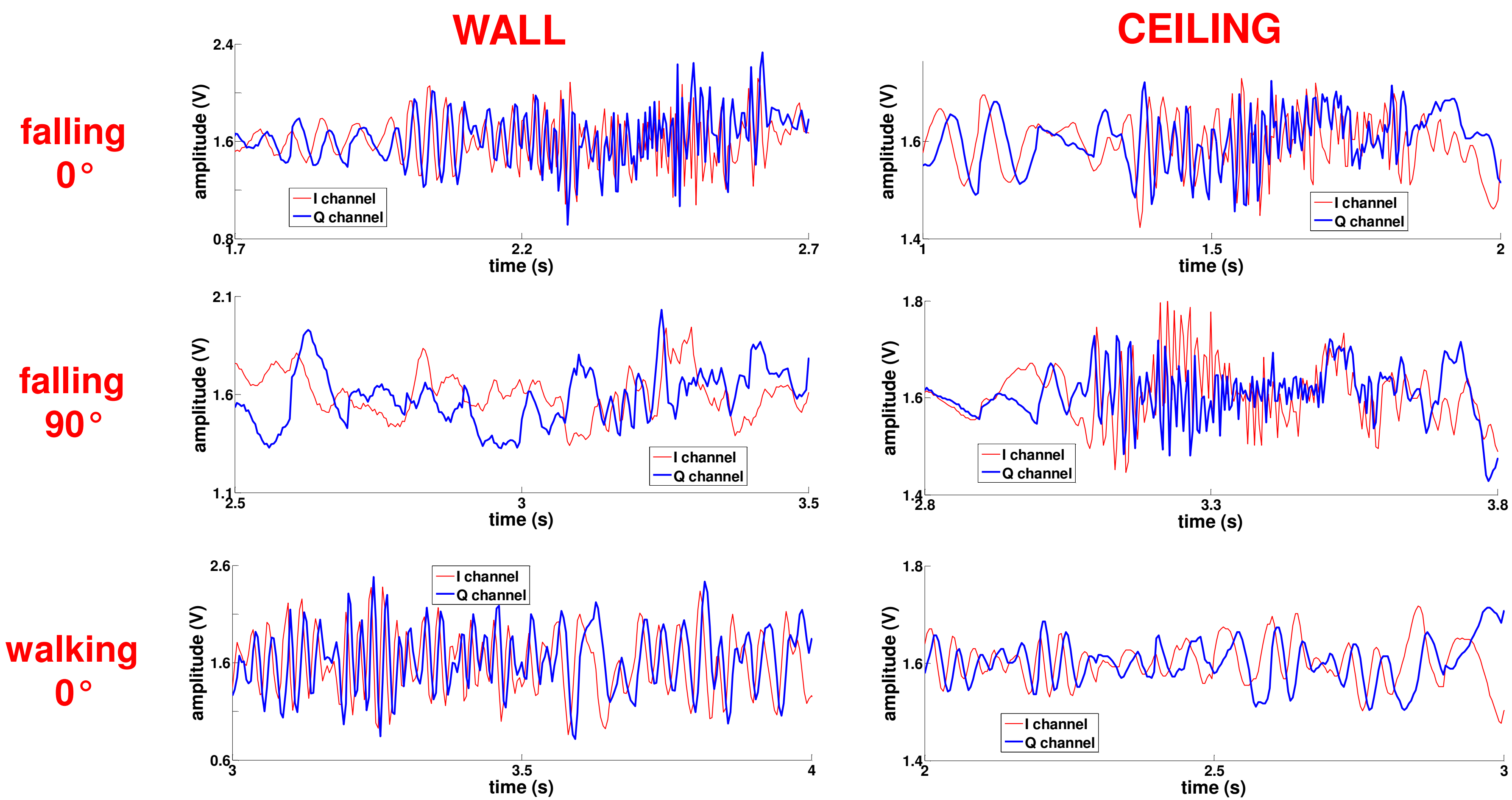


SPEED MEASUREMENTS:

- **Sensor fixed to the wall or ceiling**
- **Falls over different orientations**
- **3 subjects**

M. Mercuri, *et al.*, "Analysis of a Fall Detection Radar placed on the Ceiling and Wall," APMC, Nov. 2014.

Fall Detection: Sensor Positioning



- ➢ **Falls have an important vertical motion component**
- ➢ **Doppler effect limitation**

Fall Detection: Sensor Positioning

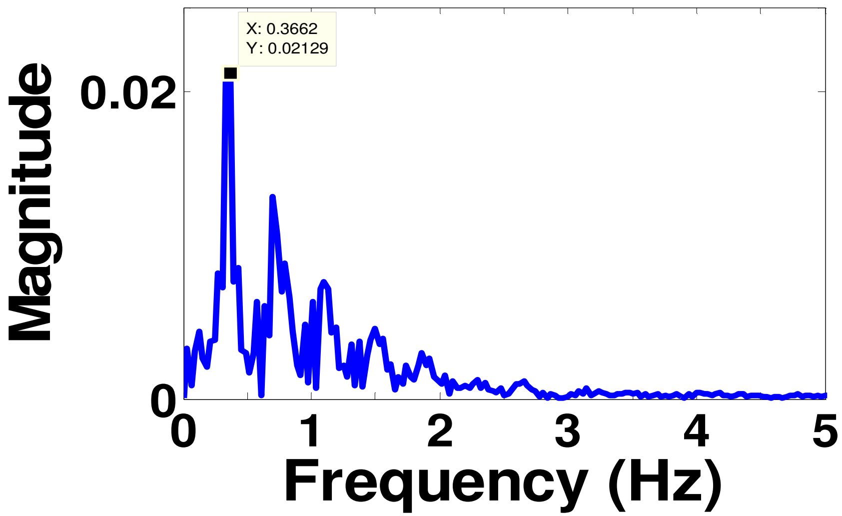
Angle (°)	CEILING			WALL		
	Subject 1	Subject 2	Subject 3	Subject 1	Subject 2	Subject 3
0	3	3	3	3	3	3
30	3	3	3	3	3	3
60	3	3	3	0	0	0
90	3	3	3	0	0	0
120	3	3	3	0	0	0
150	3	3	3	3	3	3
180	3	3	3	3	3	3
210	3	3	3	3	3	3
240	3	3	3	0	0	0
270	3	3	3	0	0	0
300	3	3	3	0	0	0
330	3	3	3	3	3	3

– 3 mimicked frontal falls per target/position

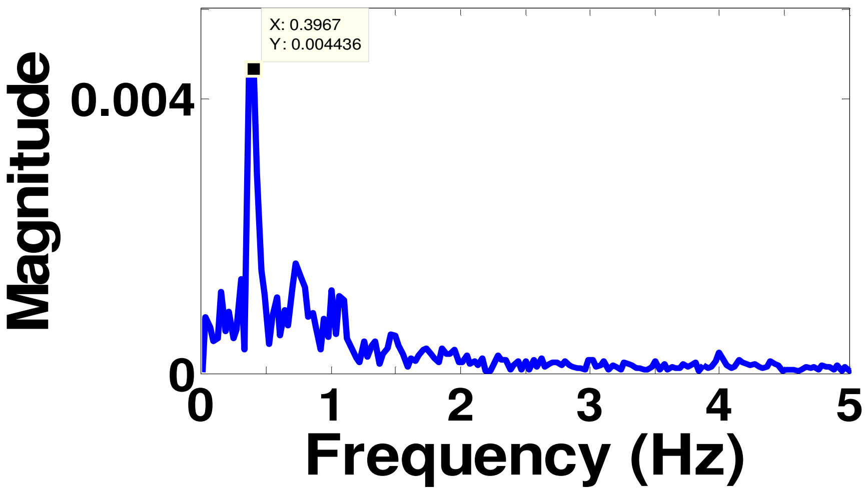
➢ **Radar to the ceiling ➔ to overcome Doppler effect limitation**

Sensor Positioning: Breathing

Wall (Sensor 4 - frontal)

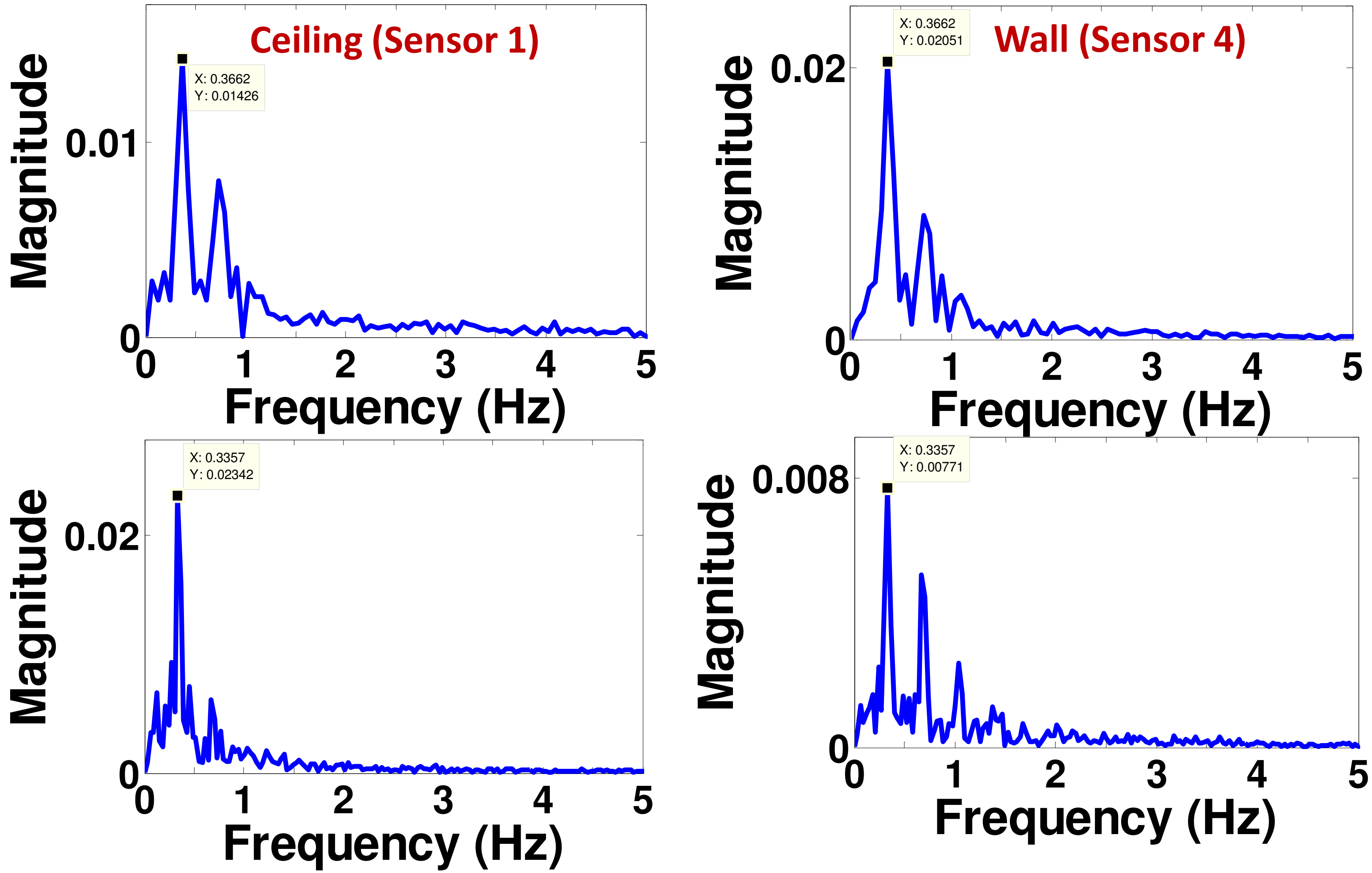


Wall (Sensor 3 - lateral)



Person Sitting on a Chair

Sensor Positioning: Breathing



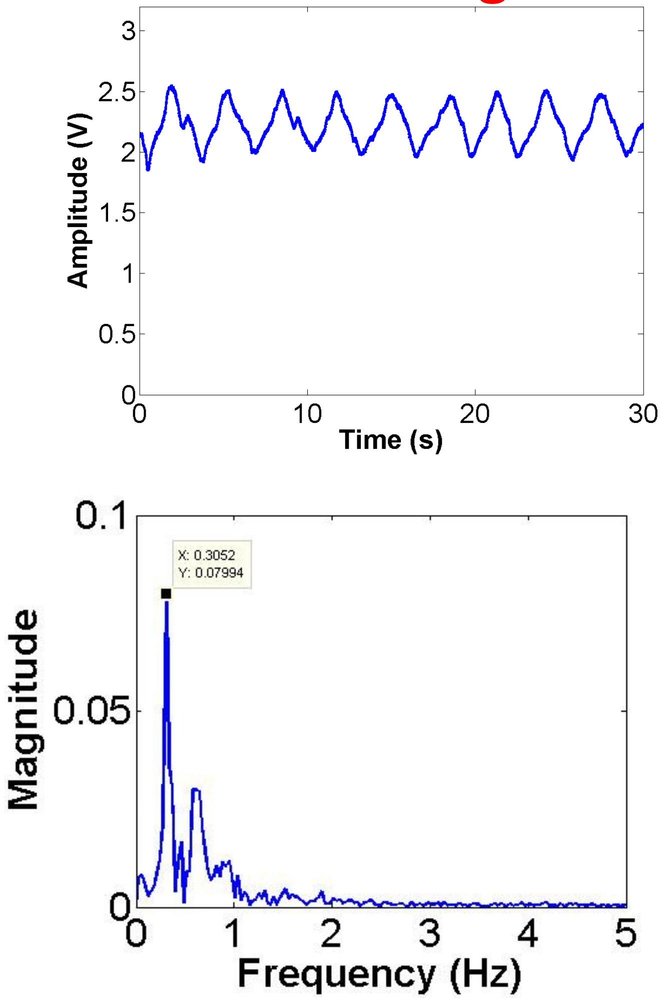
Prone

Supine

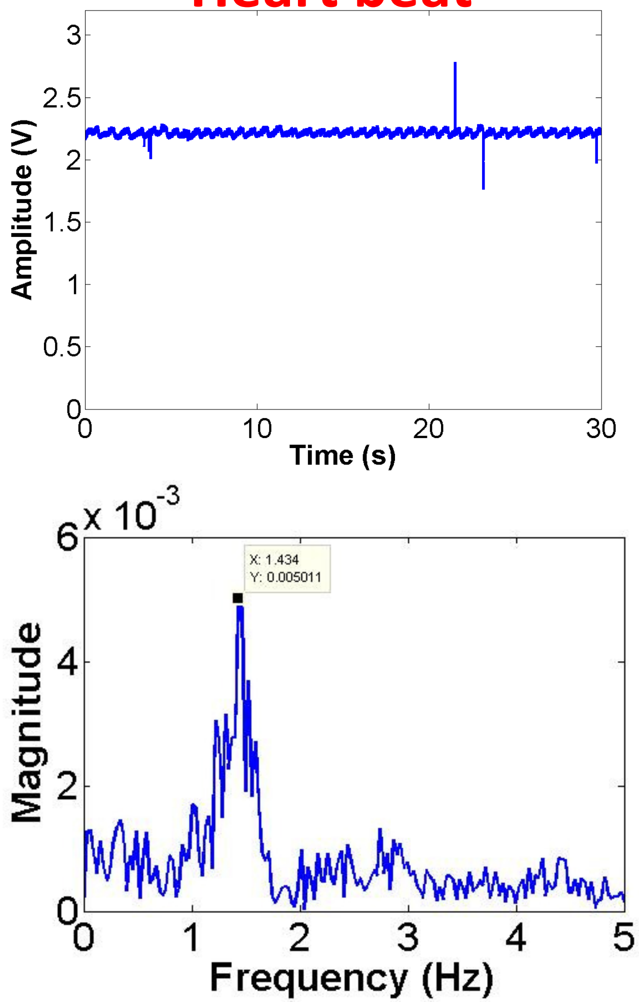
→ Clear benefit of having radar sensor ***network***!

Vital Signs Monitoring

Breathing



Heart beat



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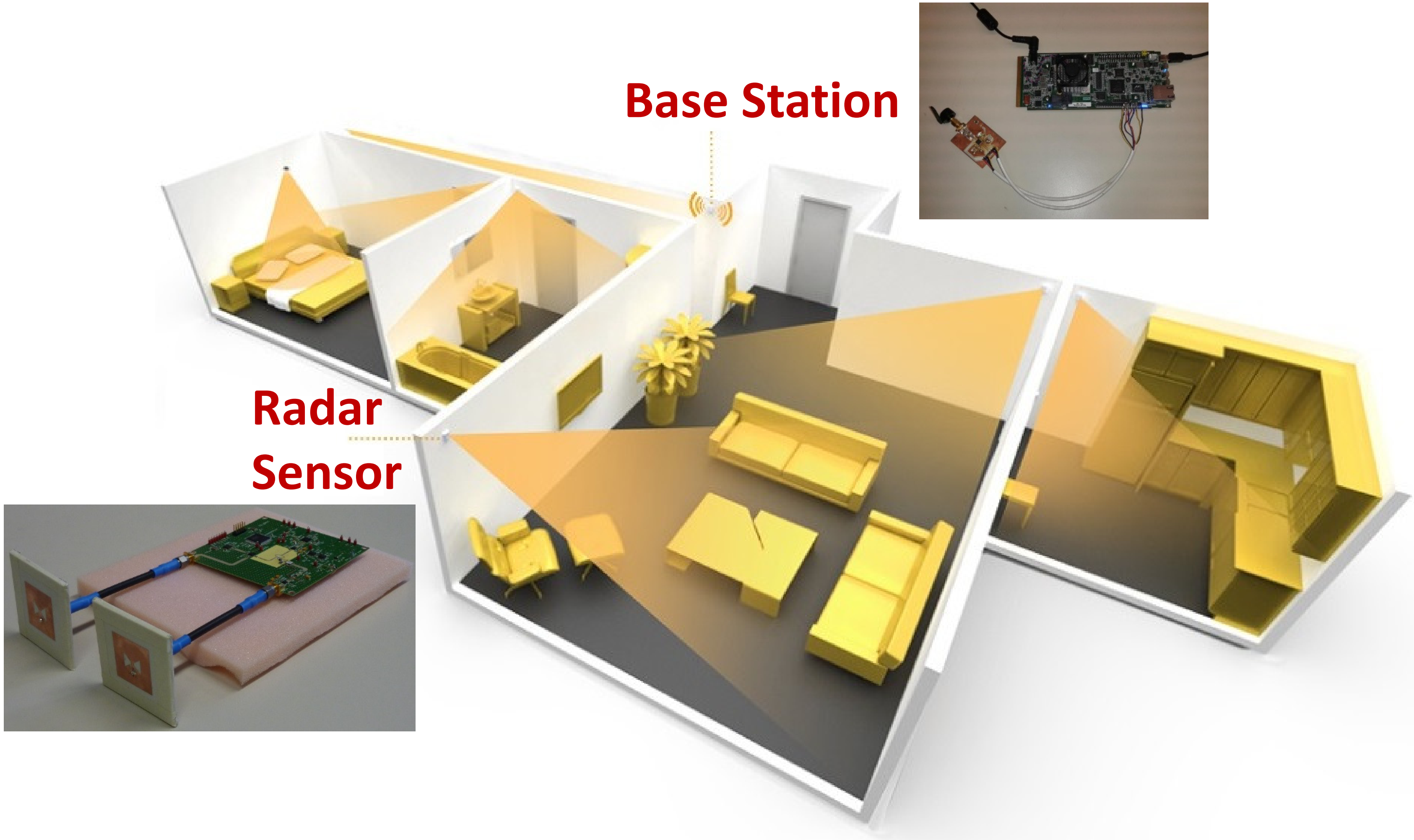
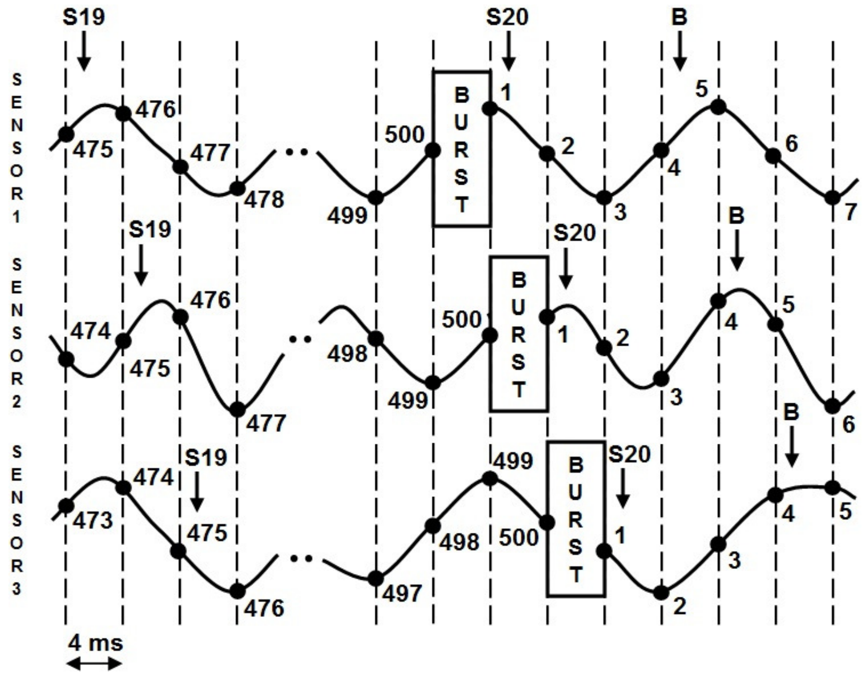
Radar WSN



Wireless Radar Sensor Network

- Challenges: synchronization & avoiding interference
  - Radar operation
    - ➢ Speed: FDM among radar sensors
    - ➢ Localisation: TDM
      - → one sensor at a time
  - Wireless communications
    - ➢ TDM: Zigbee and radar sensing
    - ➢ TDM: 4 ms delay among sensors

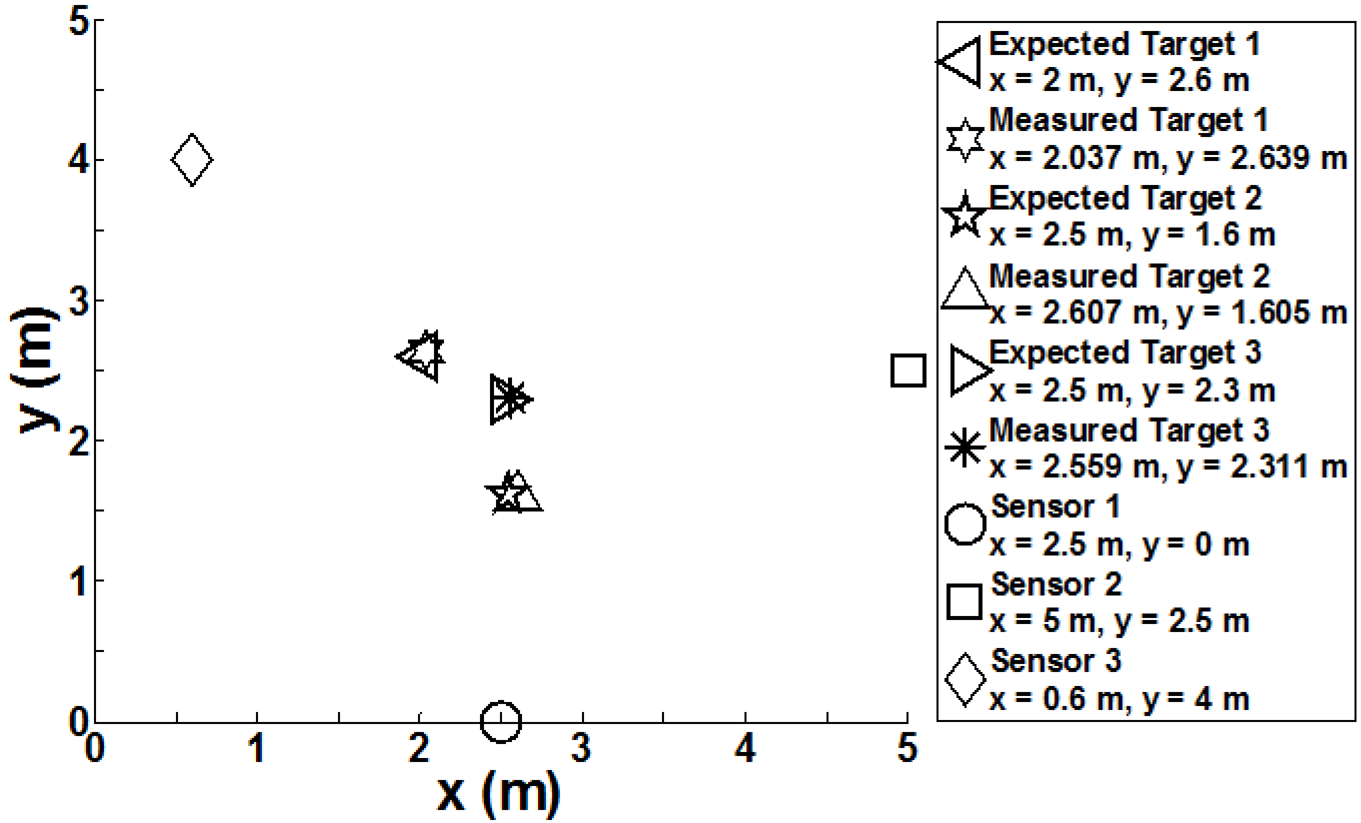


➔ THE SENSORS VIRTUALLY OPERATE AT THE SAME TIME!!!

M. Mercuri, *et al.*, "Dual-Mode Wireless Sensor Network for Real-time Contactless In-door Health Monitoring," IMS, 2015.

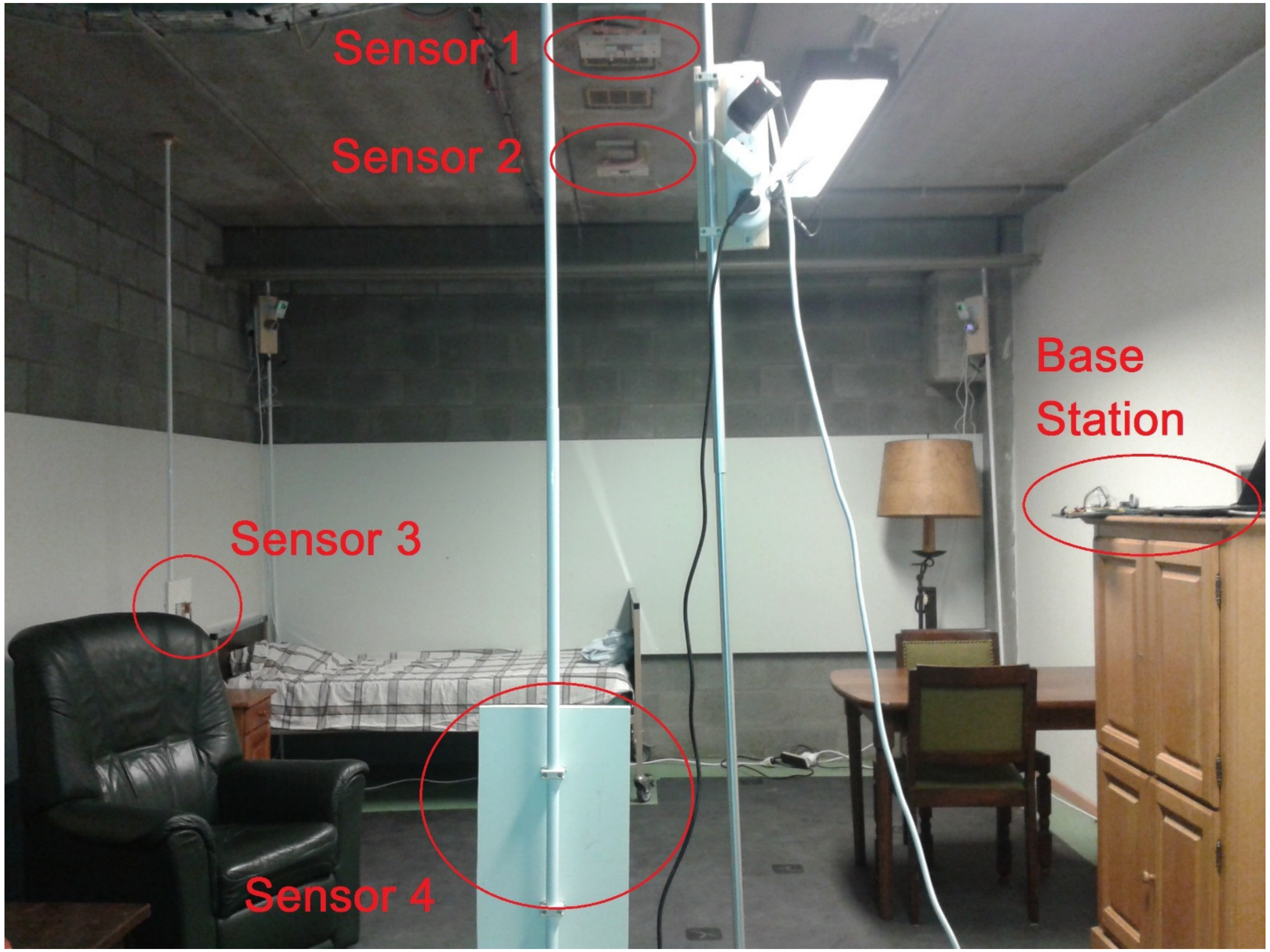
Experimental Setup

Localisation

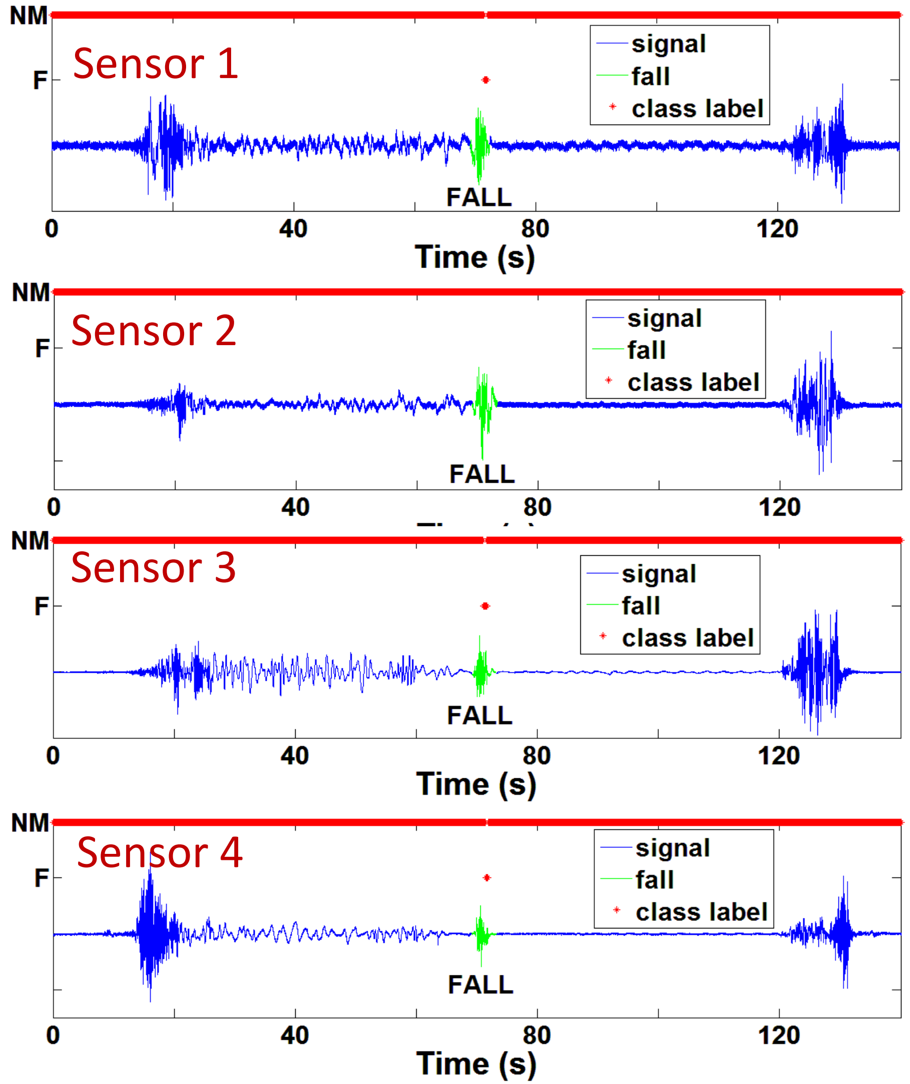


➔ **Errors within the radar resolution of 15 cm!**

Experimental Setup



Experimental Results



Fall Detection

- Fall is not detected by Sensor 2
- Multiple sensors expand coverage range and improve detection reliability!

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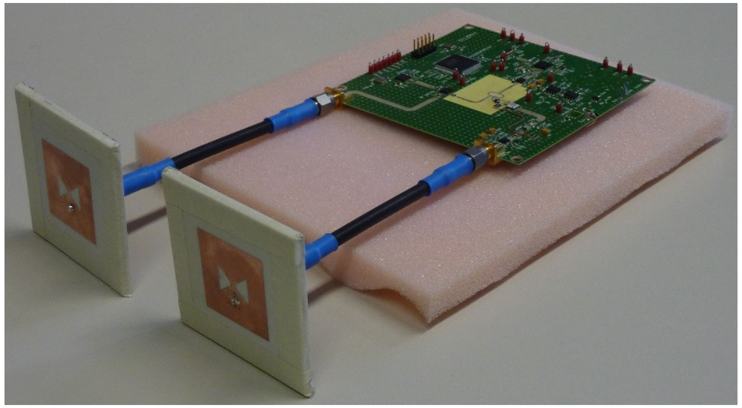
Smart Homes: Durability

Power needs

Sensor	Power consumption (order of magnitude)
Zigbee node	40 mW
Temperature sensor	0.5 mW
IR motion detector	0.3 mW
Biomedical sensor	> 100 mW

Smart Homes: Energy Needs

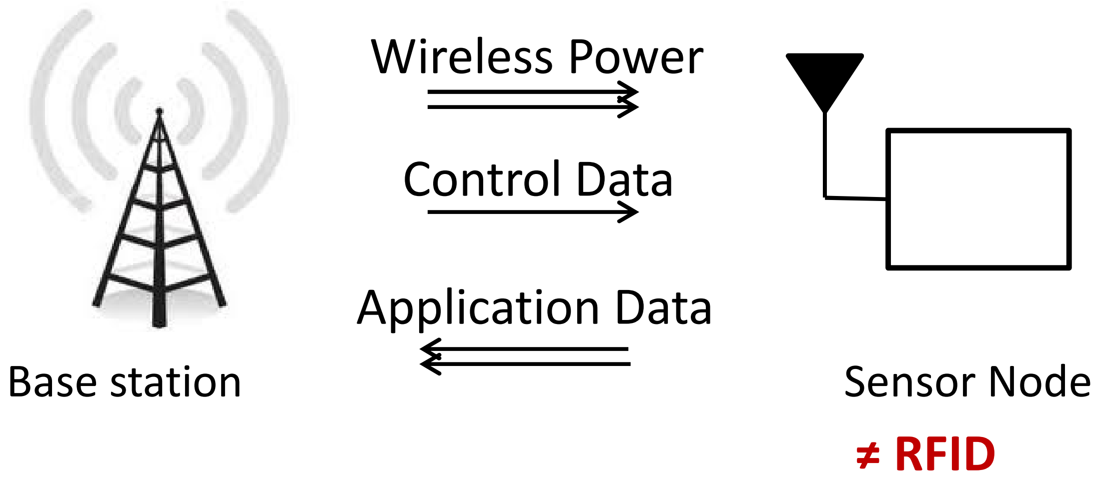


Power consumption radar sensor

- using off-the-shelf components:
  - wireless communications (Zigbee): 40 mW
  - radar sensing: >100 mW
  - microcontroller: 100 mW

- using dedicated chip design: 50 mW - 100 mW expected

Smart Homes: WPT?



Challenge: Single antenna @ Sensor Node

Regulations

Frequency Bands for Non-Specific Short Range Devices in Europe

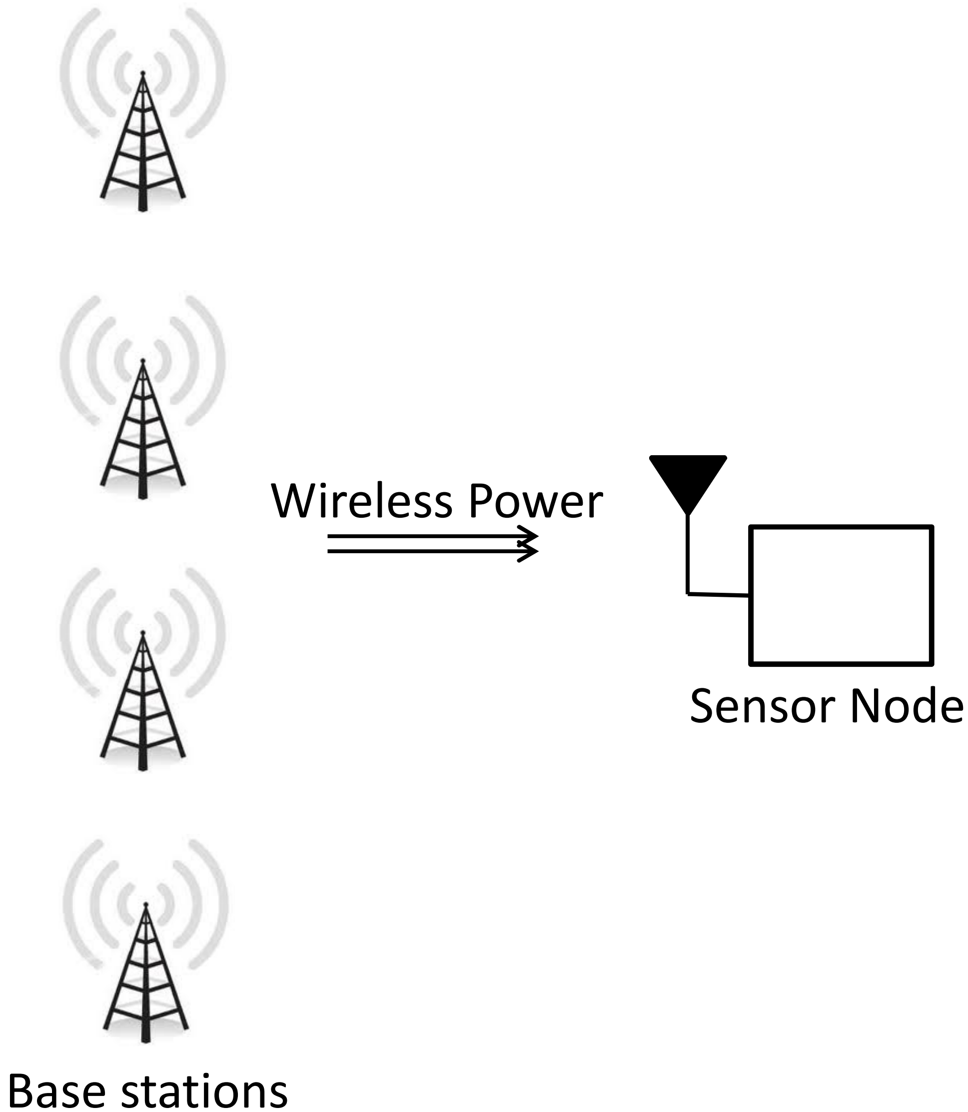
Frequency Band	ERP	Duty Cycle	Channel Bandwidth	Remarks
433.05 – 434.79 MHz	+10 dBm	<10%	No limits	No audio and voice
433.05 – 434.79 MHz	0 dBm	No limits	No limits	≤– 13 dBm/10 kHz, no audio and voice
433.05 – 434.79 MHz	+10 dBm	No limits	<25 kHz	No audio and voice
868 – 868.6 MHz	+14 dBm	< 1%	No limits	
868.7 – 869.2 MHz	+14 dBm	< 0.1%	No limits	
869.3 – 869.4 MHz	+10 dBm	No limits	< 25 kHz	Appropriate access protocol required
869.4 – 869.65 MHz	+27 dBm	< 10%	< 25 kHz	Channels may be combined to one high speed channel
869.7 -870 MHz	+7 dBm	No limits	No limits	
2400 – 2483.5 MHz	+7.85 dBm	No limits	No limits	Transmit power limit is 10-dBm EIRP

Ref: Electronic Communications Committee

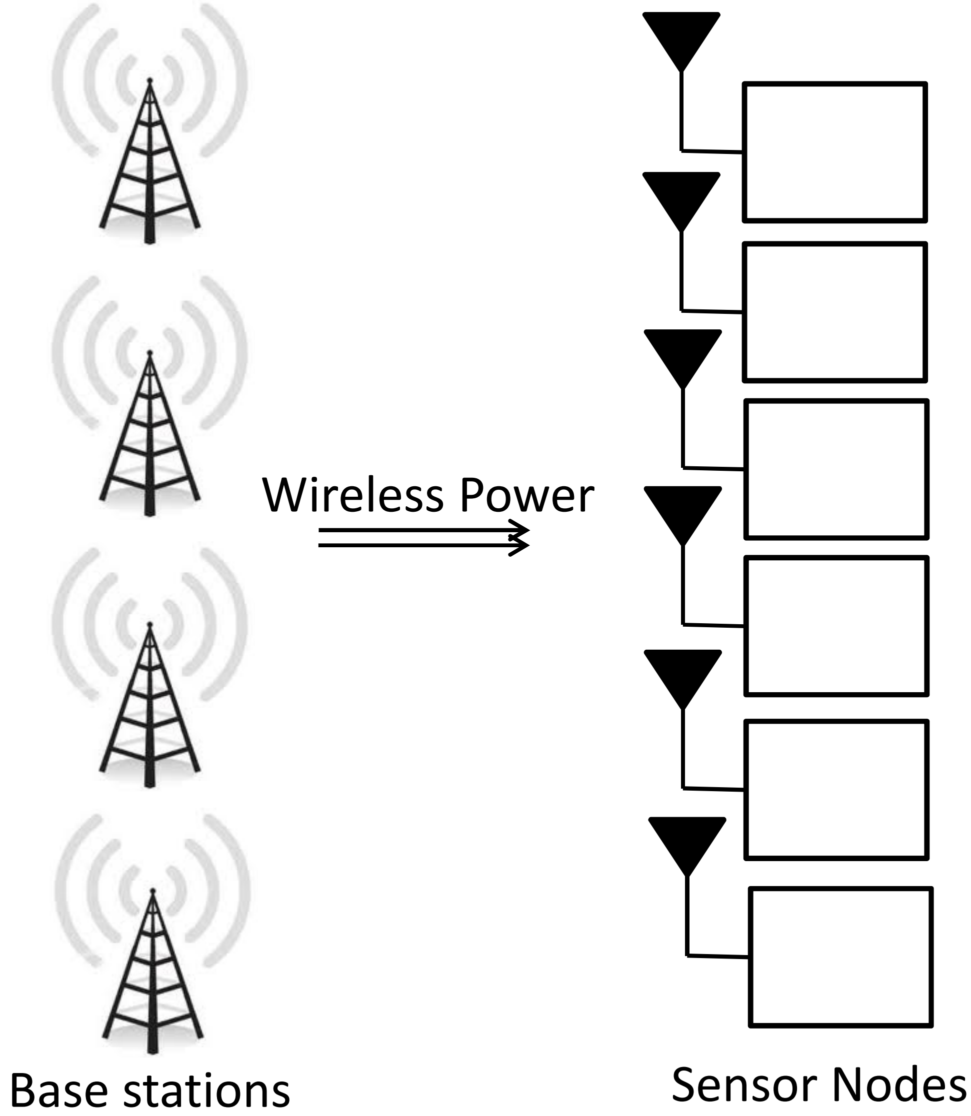
⇩

Single base station is not feasible

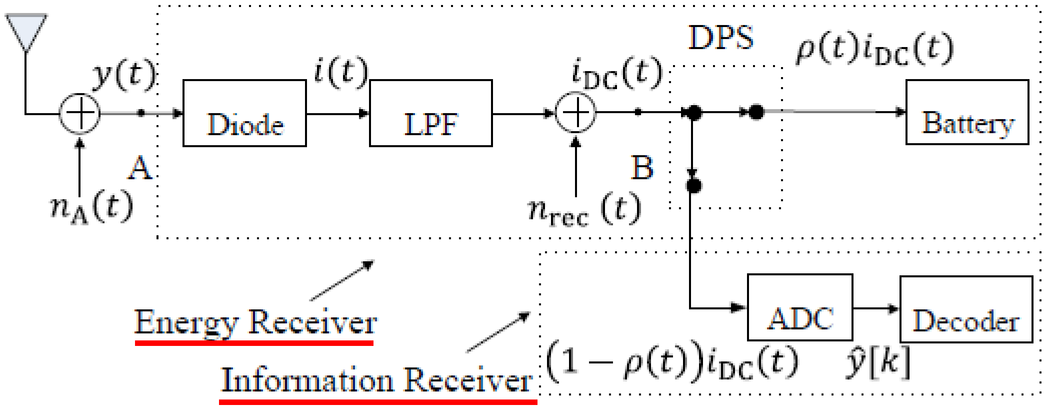
MISO WPT



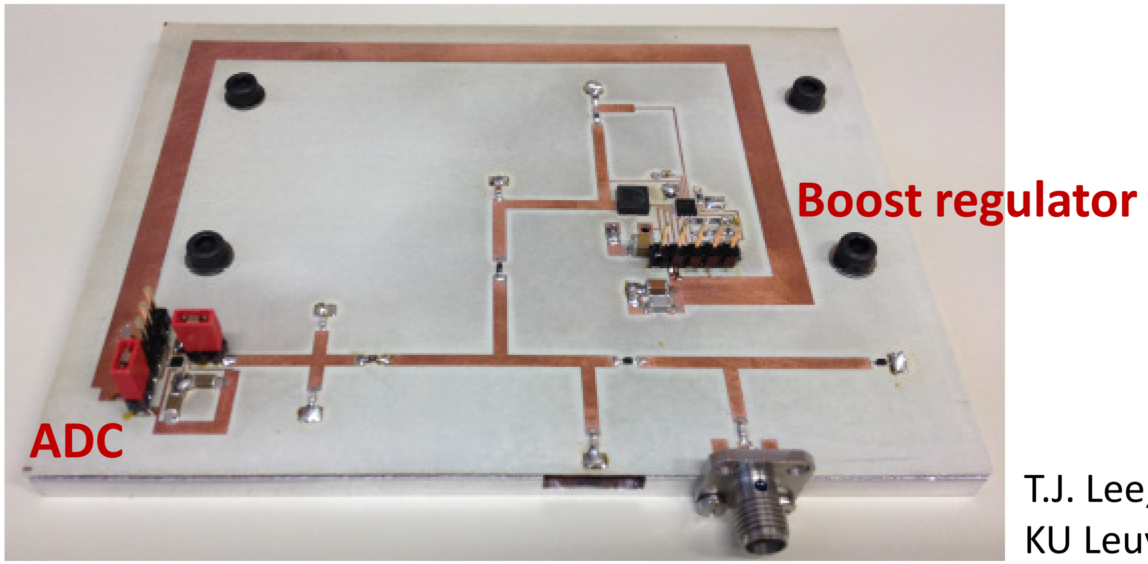
MIMO WPT



WPT & Data Receiver



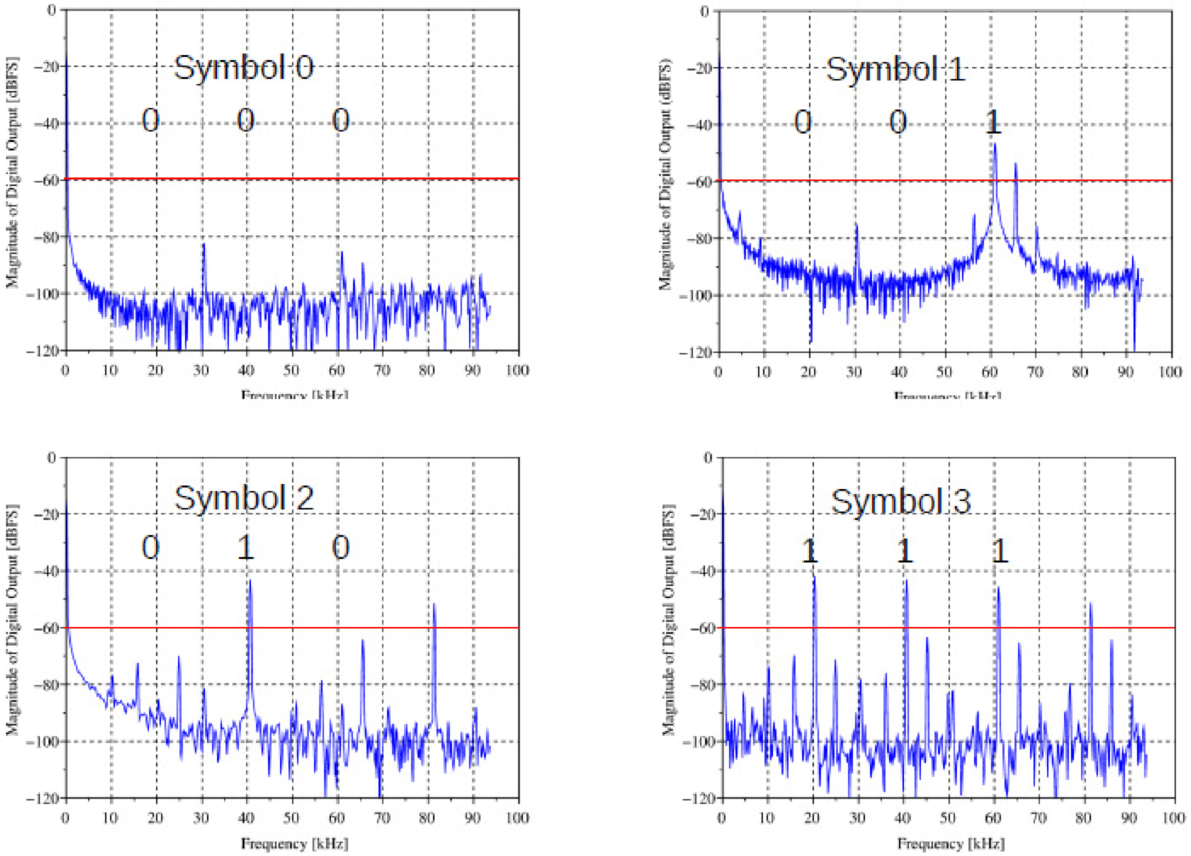
X. Zhou, *et al.*,
IEEE Trans. Comm.,
2013.



T.J. Lee, masterthesis,
KU Leuven, 2016.

Experimental Results

- Modulation scheme such that received symbols are clear
- Received data signal is based on baseband intermodulation products of multisine RF excitation



T.J. Lee, masterthesis, KU Leuven, 2016.

Conclusions

Wireless radar sensor networks:

= viable technology for Smart Homes!