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Pulse Shaping for Time-Domain Microwave Breast Cancer Detection: Experiments with Realistic Tissue Phantoms

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Introduction

- Early detection pivotal for successful treatment [1]
- X-ray mammography:
  - Uncomfortable / Painful
  - Ionizing Radiation
  - Unreliable for dense breast tissues (young women)
- Microwave Imaging:
  - Complementary technique
  - Promises early-stage cancer detection [2]
  - Most systems reported to date employ frequency-domain analysis [3],[4]
- Time-Domain System:
  - Initially developed in [5]
  - Cost-effective
  - Reduction in scanning time
- Including custom-shaped pulses:
  - Reshape generic impulse with a passive microwave device [6]
  - Strategically tailored pulses improve signal transmission
  - Our solution is cost-effective and easily integrable
  - Hypothesis: The improved signal transmission will improve tumour detection abilities of the system

Background

- A signal launched into the breast tissues is scattered and reflected:
  - Breast tissue is dielectrically inhomogeneous (contrast between different tissues)
  - On average, healthy breast tissue is fatty and relatively low-loss in the microwave range
- Reshaping of the generic impulse:
  - Create pulse with spectral content to improve signal transmission
  - *A priori* knowledge of pulse and system characteristics required
  - Synthesized Broadband Reflector (SBR)

Fig.1: Photograph of SBR device

Phantom Construction

- Created from household chemicals [10]
- The phantom materials mimic skin, fat, gland and tumour at microwave frequencies.
- Discrete number of cones used to model glands as conical structures

Fig.2: Photograph of Breast Phantom with conical glandular structures (70% by volume)

System Design

1. Pulse Shaping:

- Mould frequency content of signal to 2 – 4 GHz
  - Optimize antenna performance
  - Limit signal attenuation at higher frequencies
- Outside frequencies attenuated
- SBR operating in reflection mode
- Reflected signal contains new pulse
- Directional coupler used to reroute signal toward antenna

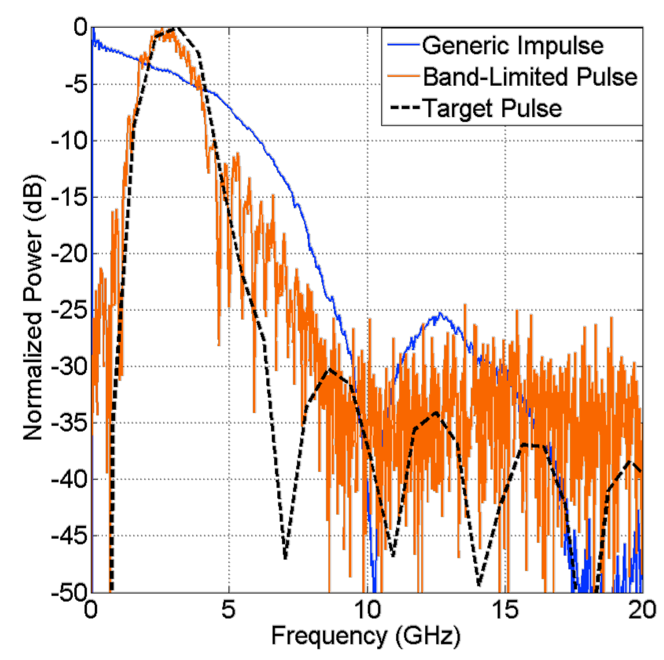


Fig. 3: Spectral content of the original and reshaped pulse with the target pulse shape

2. System Components:

- Clock (25 MHz)
- Impulse Generator
- Directional Coupler (2 – 8 GHz, - 6 dB)
- SBR
- Broadband Amplifier (+35 dB)
- Radome
- Antenna
- Breast Phantom
- Oscilloscope (80 GSa/s)

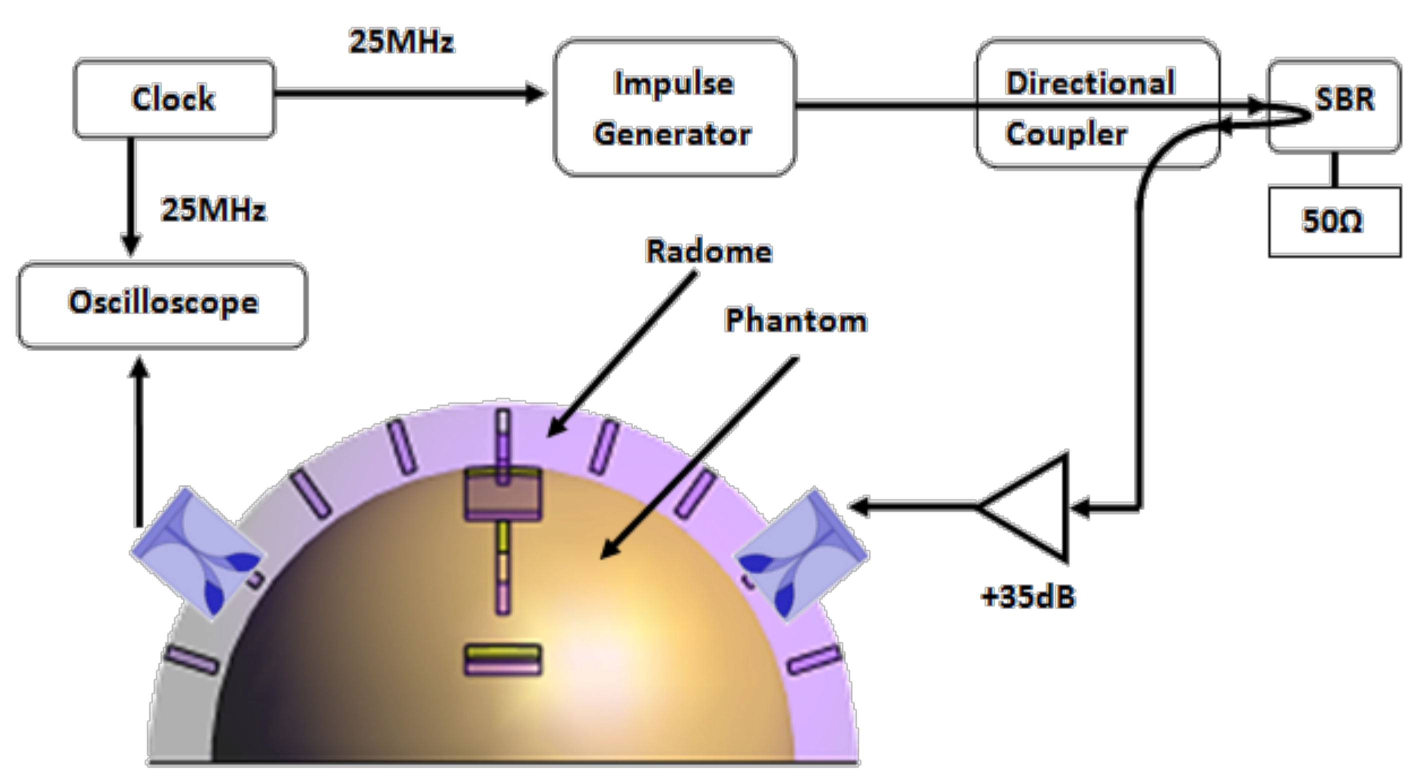
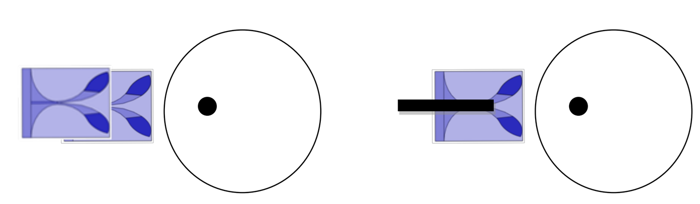


Fig. 4: A high-level depiction of the experimental setup. Antennas are placed within the slots of the radome.

Results

- Four breast phantoms tested:
  - Homogeneous: 100% adipose tissue
  - Homogeneous + 2 mm skin layer
  - Heterogeneous; skin + 50% glandular tissue
  - Heterogeneous; skin + 70% glandular tissue
- Four antenna arrangements:
  - Specifically oriented pair of antenna
  - Reflective arrangement [5],[11], [12]
- Case 1 through Case 4
  - Antennas in 2nd and 3rd slot from chest wall
  - Case 1/Case 3: co-polarized (LEFT)
  - Case 2/Case 4: cross-polarized (RIGHT)



- Measurement procedure:
  - Two signals recorded for each Case
  - Baseline: healthy breast
  - Insert a tumour (cylinder, 3 cm x 1 cm)
- Tumour Response Signal
  - Difference signal between the healthy baseline and when the tumour is inserted
- Tumour Response Parameter, *T*:

$$T = 20\log\left(\frac{\max|\text{Tumour Response Signal}|}{\max|\text{Input Signal}|}\right)$$

- Input signals of unmatched power
- Unbiased account of system's tumour detection ability

Phantom Type	Tumour Response Signal [mV]			Tumour Response Parameter, T [dB]		
	Original System	SBR System	Gain from SBR-System [mV]	Original System	SBR System	Gain from SBR-System [dB]
Fat	19.6 (Case 1)	28.2 (Case 1)	+ 8.6	-50.16	-48.82	+ 1.3
Fat +Skin	36.7 (Case 4)	63.8 (Case 1)	+ 27.1	-44.69	-41.72	+ 3.0
50% Gland	12.3 (Case 4)	55.6 (Case 1)	+ 43.3	-56.02	-42.92	+ 13.1
70% Gland	15.7 (Case 4)	46.8 (Case 3)	+ 31.1	-52.08	-44.42	+ 7.7

Measurement Summary

- Incorporation of SBR:
  - Retains input pulse shape
  - Gain in tumour response signal
  - Increase in tumour response signal relative to input power
  - Tumour detection most improved in complex heterogeneous scenario
- Original System:
  - Significant signal distortion
  - Difficulties detecting tumour in life-like heterogeneous cases

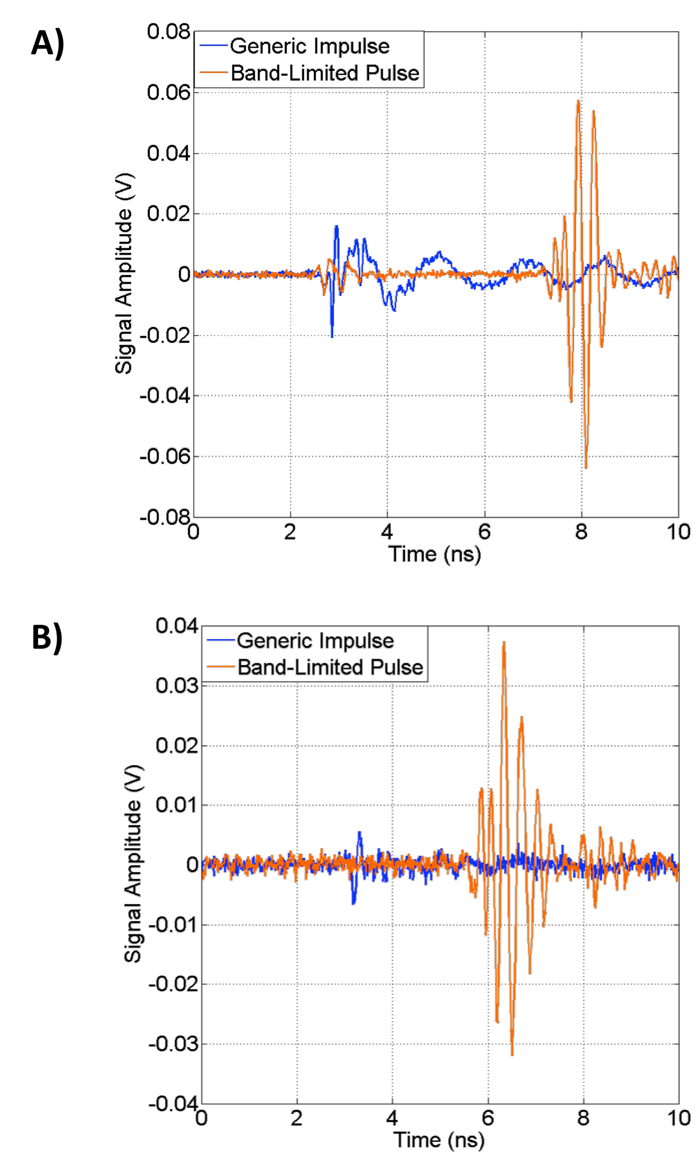


Fig. 5: Comparison of tumour response signal for Case 3 in A) 2 mm skin + fat phantom B) 70% gland phantom

Conclusion

- SBR is easily integrated into pre-existing experimental system
- Pre-shaping input improves signal transmission and system's tumour detection abilities
- Increase in tumour response signal regardless of breast phantom investigated
- Improvements in tumour detection from SBR-implementation are most significant in the complex heterogeneous breast phantoms the (most difficult imaging scenario)
- Co-polarized antenna arrangement improves signal transmission and tumour detection

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