

# MKP simulace integrovaného snímače podélných a příčných vln

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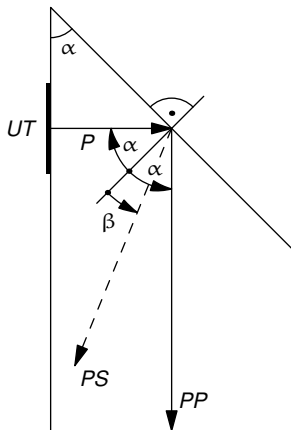


Inženýrská mechanika 2012 - Svratka

# Úvod

- ▶ nedestruktivní testování (NDT) materiálů a konstrukcí,
- ▶ piezoelektrické ultrazvukové snímače,
- ▶ P-vlny  $\times$  S-vlny,
- ▶ měření modulu pružnosti ve smyku a viskoelastických vlastností,
- ▶ schopnost generování a monitorování P-vln i S-vln.

# Snímač typu P-P

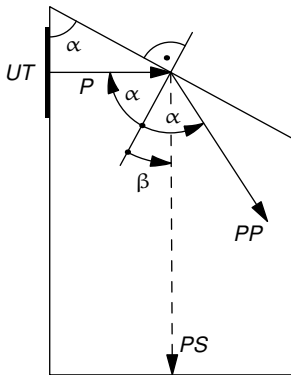


šířka: 16 mm

střed UZ budiče: 20 mm

rozměry UZ budiče: 0,2×6 mm

# Snímač typu P-S



$$\frac{\sin \alpha}{c_1} = \frac{\sin \beta}{c_2}$$

$$\alpha + \beta = 90^\circ$$

⇓

$$\alpha = \arctg(c_1/c_2)$$

⇓

$$\alpha = 61,46^\circ$$

## Energetické koeficienty odrazu

$$R_{PP} = \left( \frac{\cos^2 2\beta - (c_2/c_1)^2 \sin 2\alpha \sin 2\beta}{\cos^2 2\beta + (c_2/c_1)^2 \sin 2\beta \sin 2\alpha} \right)^2$$

$$R_{PS} = \frac{4 (c_2/c_1)^2 \cos^2 2\beta \sin 2\alpha \sin 2\beta}{\left( \cos^2 2\beta + (c_2/c_1)^2 \sin 2\beta \sin 2\alpha \right)^2}$$

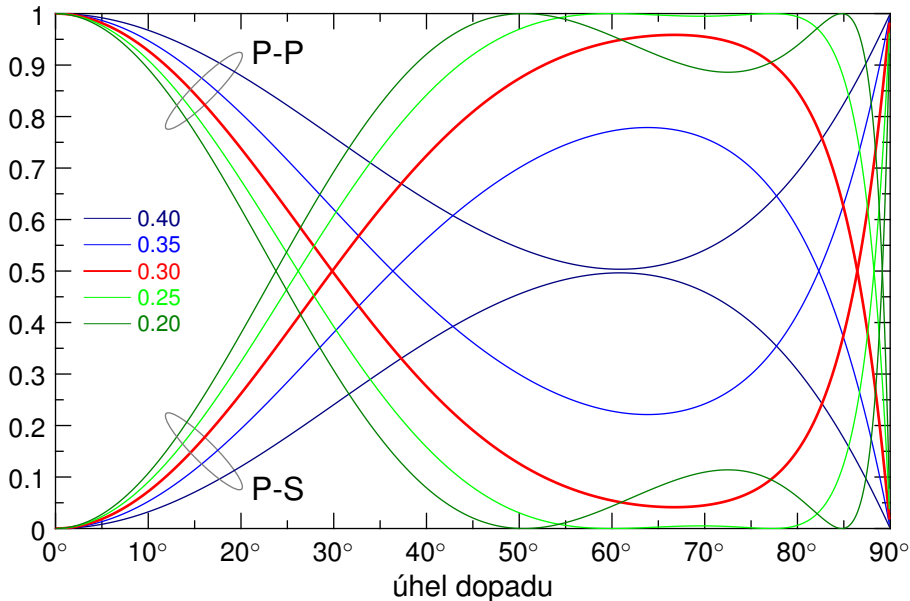
$\alpha$  úhel dopadu a odrazu P-vlny,

$\beta$  úhel odrazu S-vlny,

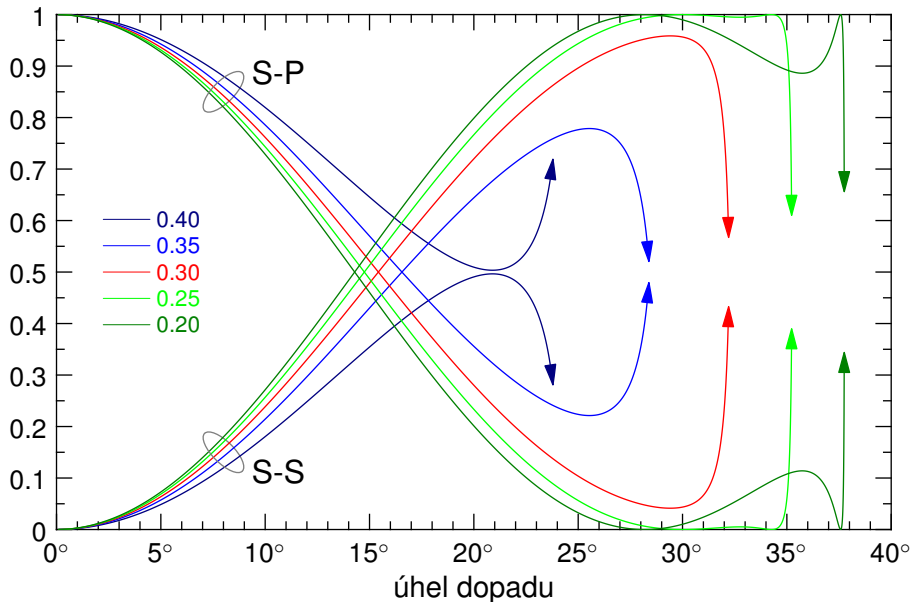
$c_1$  rychlost P-vlny,

$c_2$  rychlost S-vlny.

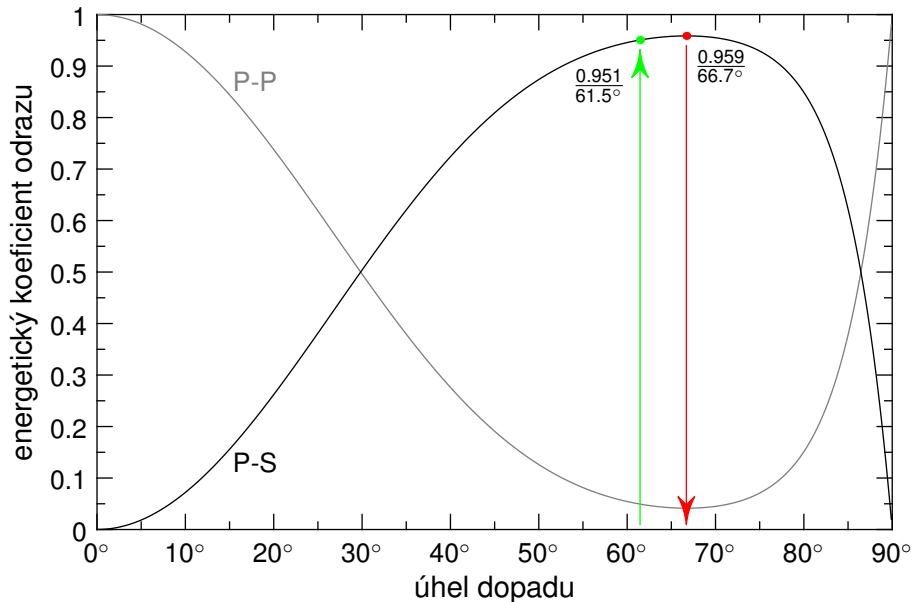
# Energetický koeficient odrazu; dopadající P-vlna



# Energetický koeficient odrazu; dopadající S-vlna

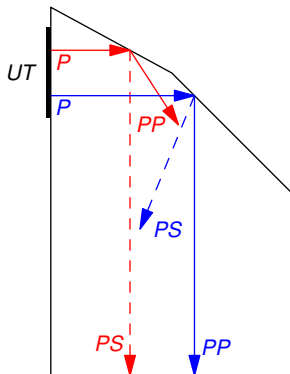


# Geometrická podmínka $\times$ maximum energie





# Integrovaný snímač



Jen, Ch.-K., Kobayashi, M.:

Integrated and Flexible High Temperature Piezoelectric Ultrasonic Transducers.

In: *Ultrasonic and advanced methods for nondestructive testing and material characterization* (C.H. Chen ed.) World Scientific, New York 2007, chap. 2

# Analýza metodou konečných prvků

## COMSOL Multiphysics

- ▶ strukturální mechanika,
- ▶ rovinná deformace,
- ▶ Lagrangeovy – kvadratické prvky.

### Časová analýza

- ▶ Hannův mikrosekundový puls s nosnou frekvencí 5 MHz,
- ▶ 0 až 40  $\mu\text{s}$  s krokem 0,01  $\mu\text{s}$ ,
- ▶ relativní tolerance:  $10^{-4}$ , absolutní tolerance:  $10^{-8}$ ,
- ▶ trojúhelníková síť – maximální velikost prvku 0,2 mm,
- ▶ řešič BDF, s maximálním řádem 2.

# Materiálové vlastnosti

## Ocel

Youngův modul:  $E = 200 \text{ GPa}$ ,

poissonovo číslo:  $\nu = 0,29$ ,

hustota:  $\rho = 7870 \text{ kg/m}^3$



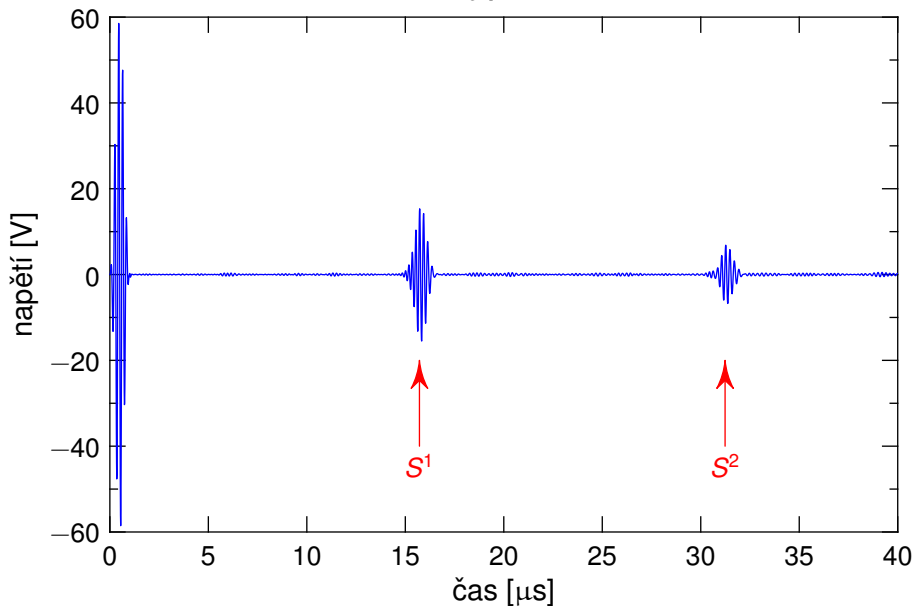
rychlost P-vln:  $c_1 = 5770,8 \text{ m/s}$ ,

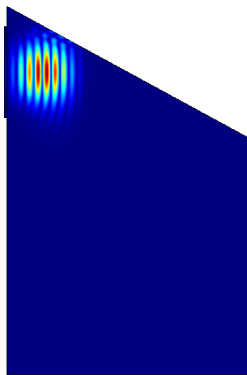
rychlost S-vln:  $c_2 = 3138,5 \text{ m/s}$ .

## Piezokeramika

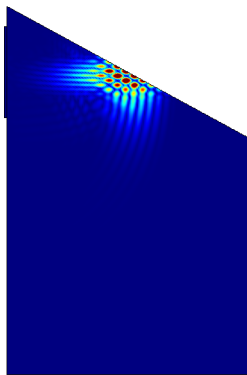
PZT-4

# Snímač typu P-S

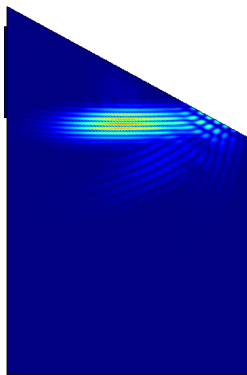




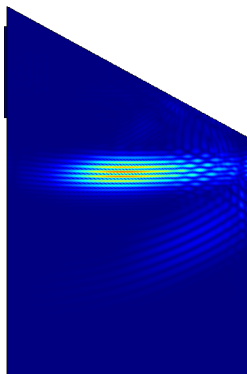
1  $\mu$ s



2  $\mu\text{s}$

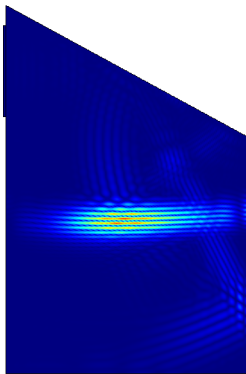


3  $\mu\text{s}$

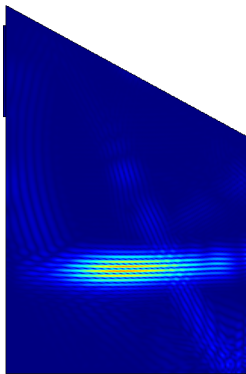


4  $\mu\text{s}$

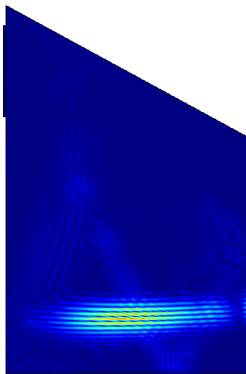




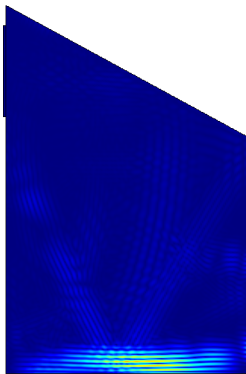
5  $\mu\text{s}$



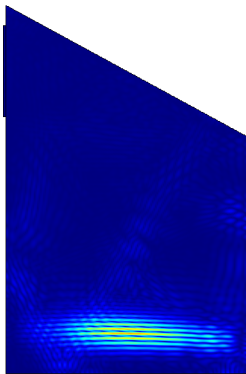
6  $\mu$ s



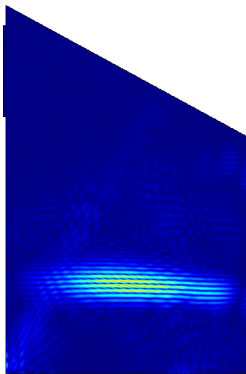
7  $\mu\text{s}$



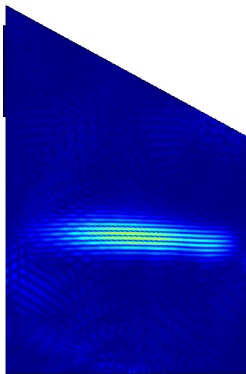
8  $\mu$ s



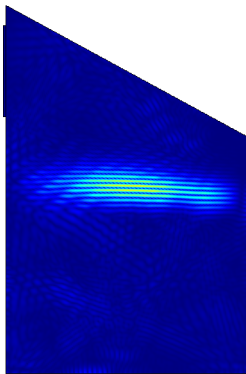
9  $\mu\text{s}$



10  $\mu\text{s}$

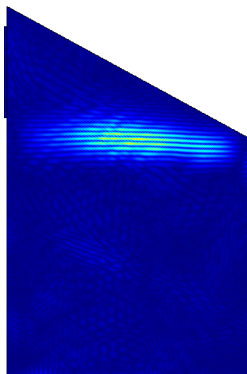


11  $\mu\text{s}$

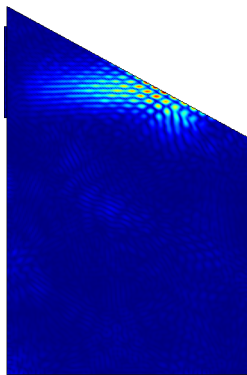


12  $\mu\text{s}$

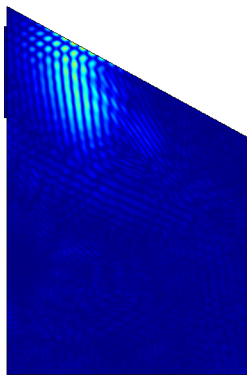




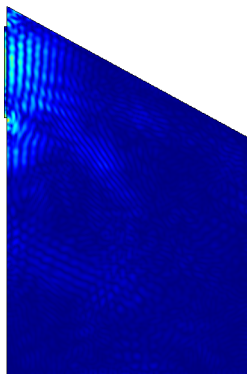
13  $\mu$ s



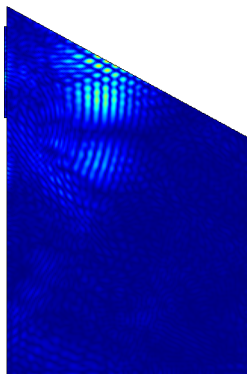
14  $\mu\text{s}$



15  $\mu\text{s}$

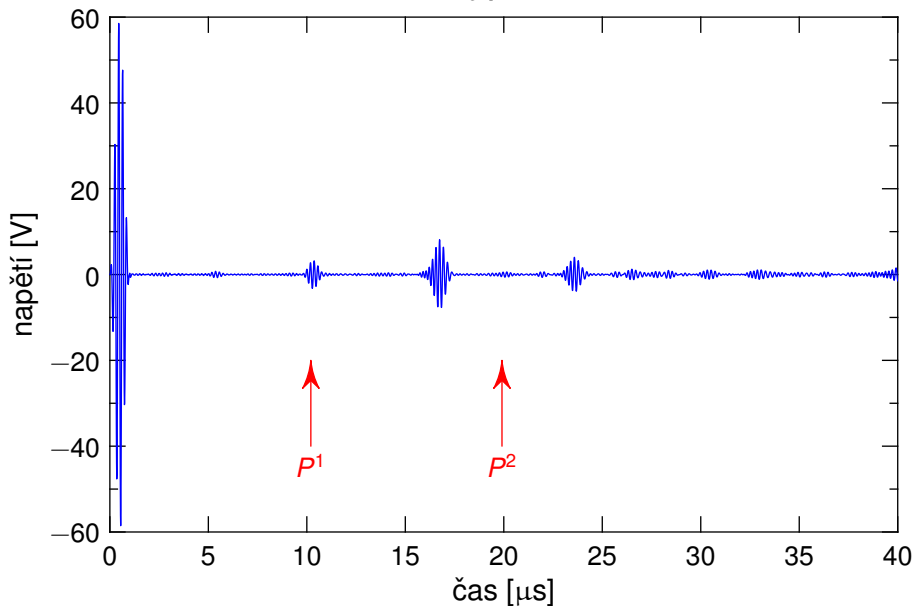


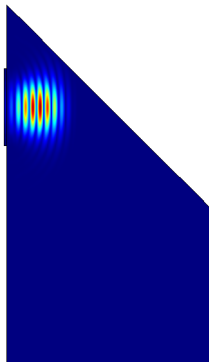
16  $\mu\text{s}$



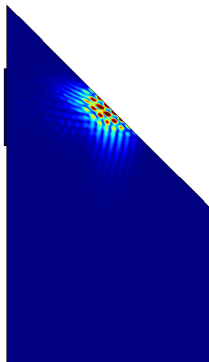
17  $\mu$ s

# Snímač typu P-P



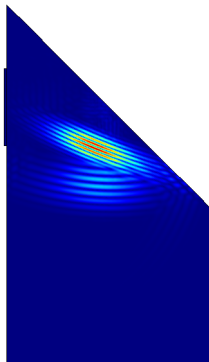


1  $\mu\text{s}$

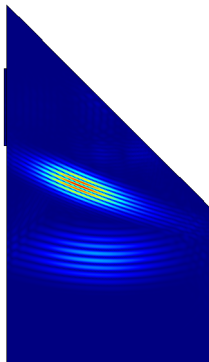


2  $\mu\text{s}$

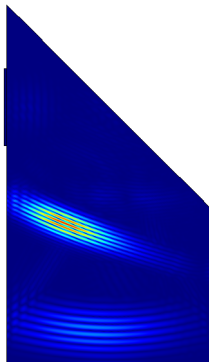




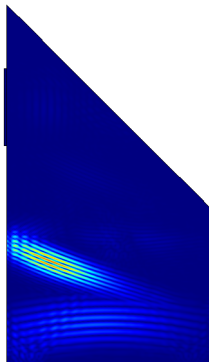
3  $\mu\text{s}$



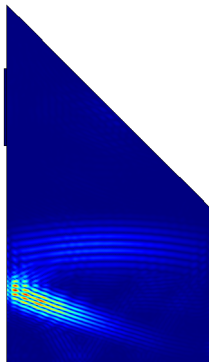
4  $\mu\text{s}$



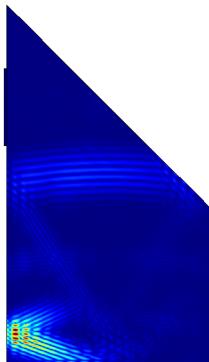
5  $\mu$ s



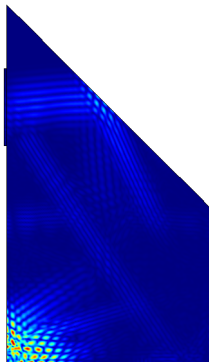
6  $\mu\text{s}$



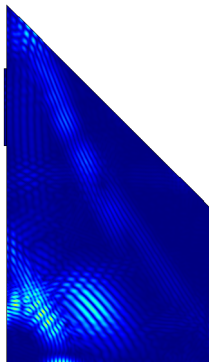
7  $\mu\text{s}$



8  $\mu\text{s}$

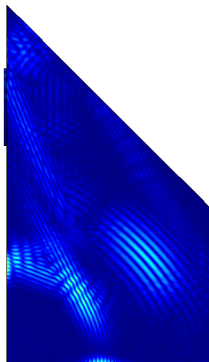


9  $\mu\text{s}$



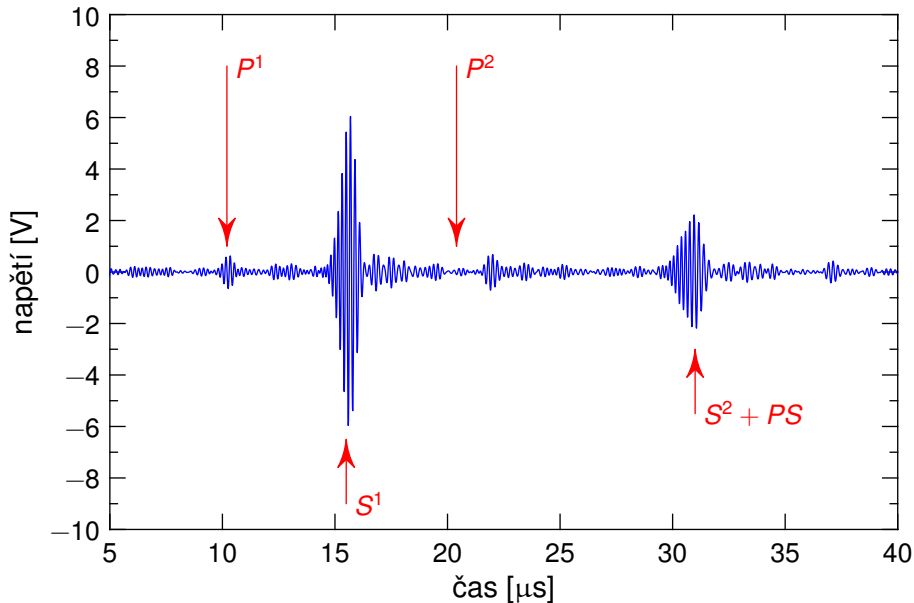
10  $\mu$ s



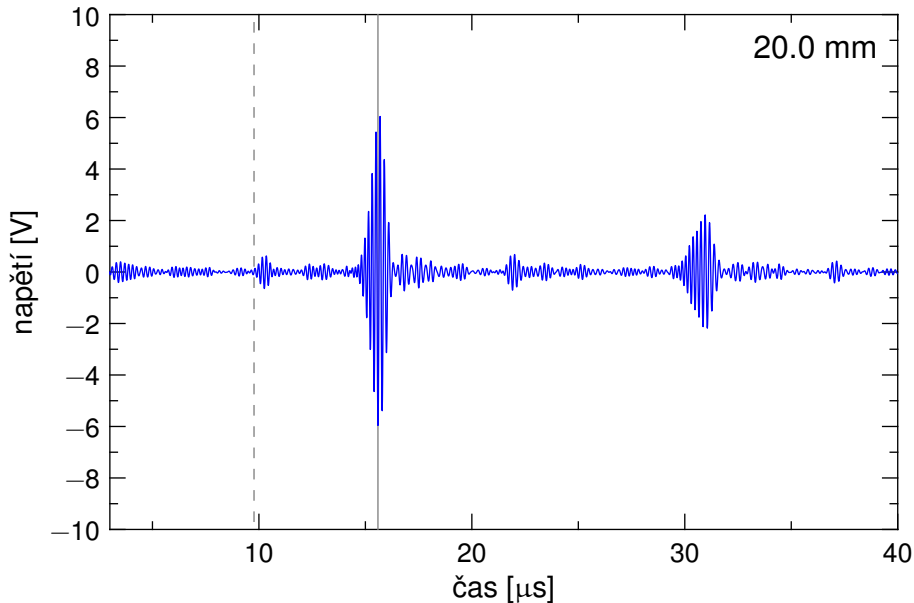


11  $\mu\text{s}$

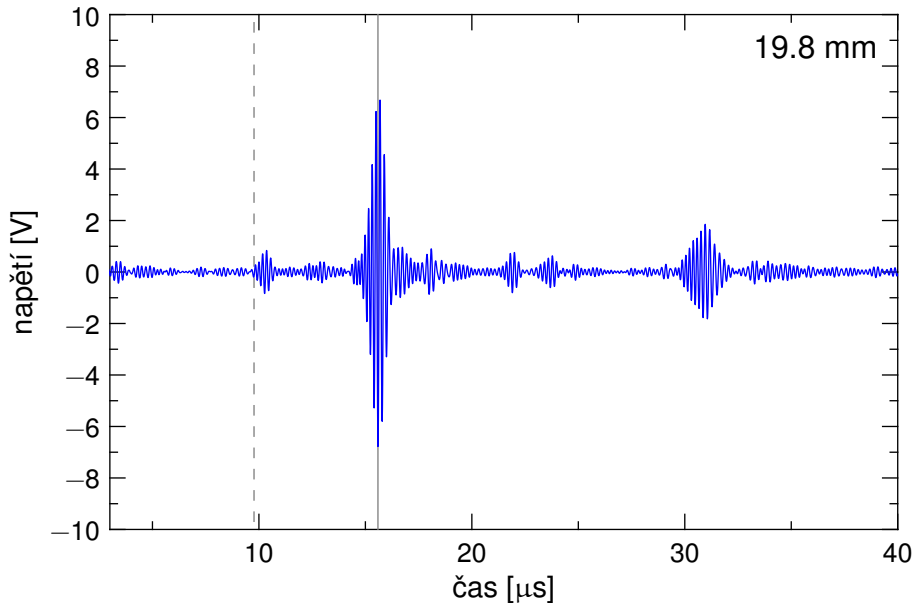
# Integrovaný snímač



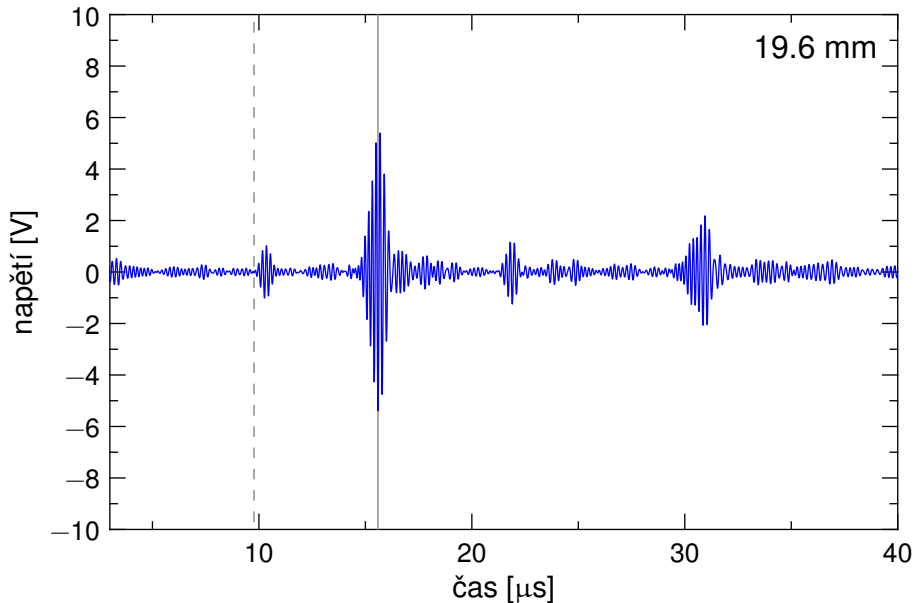
# Vliv posunu UZ-budiče u integrovaného snímače



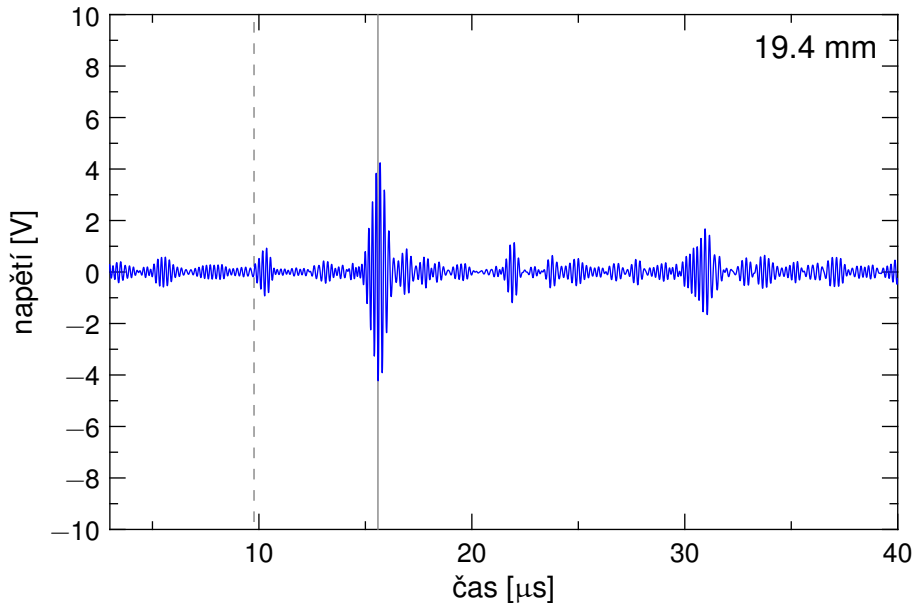
# Vliv posunu UZ-budiče u integrovaného snímače



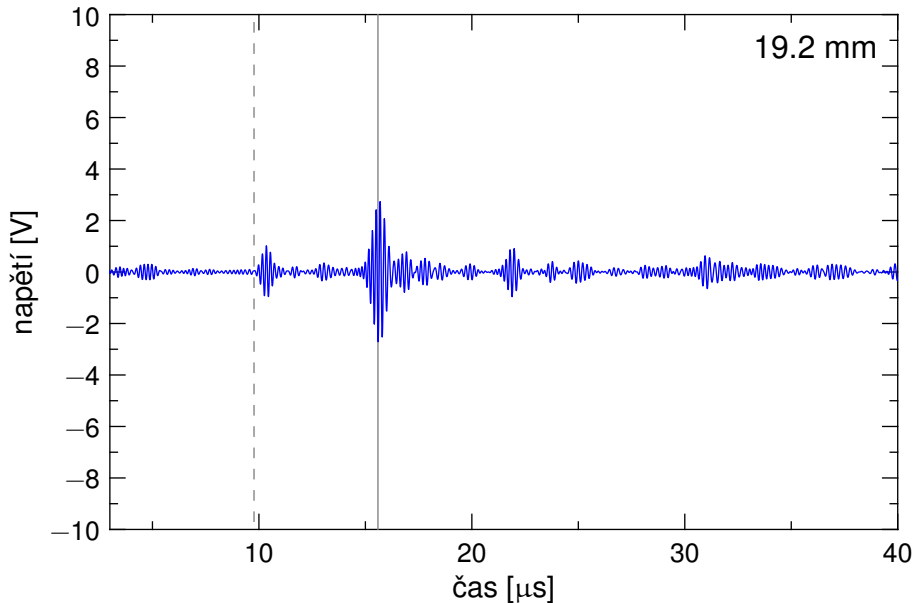
# Vliv posunu UZ-budiče u integrovaného snímače



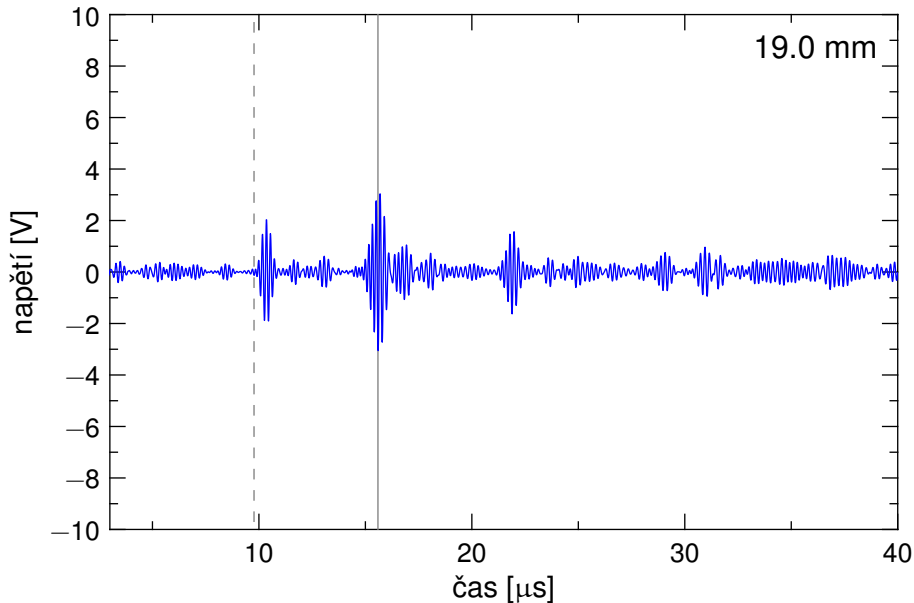
# Vliv posunu UZ-budiče u integrovaného snímače



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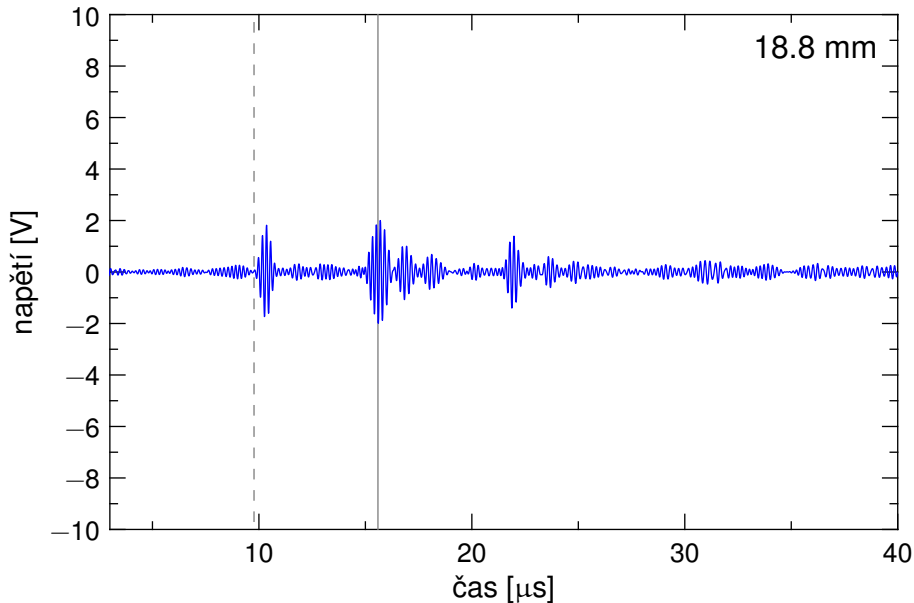


# Vliv posunu UZ-budiče u integrovaného snímače

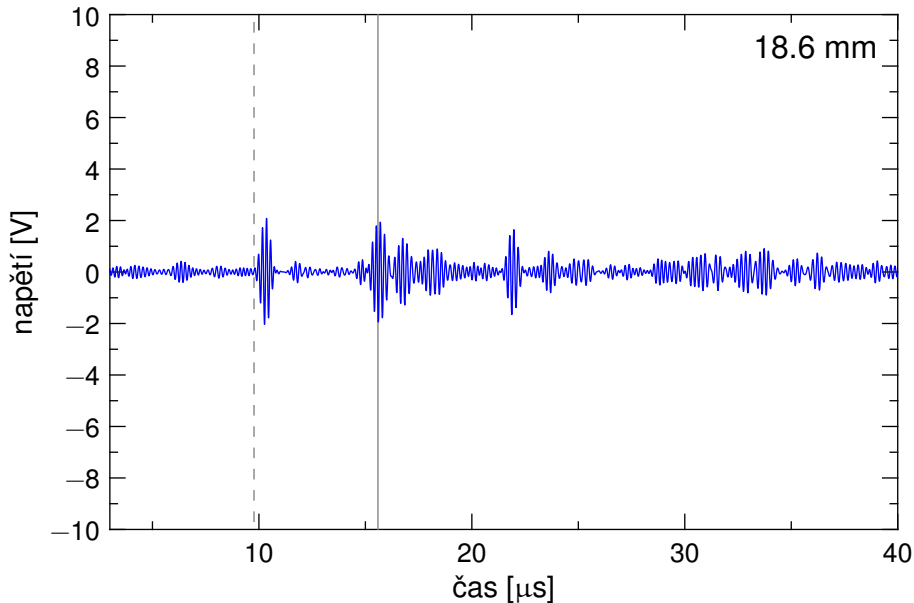




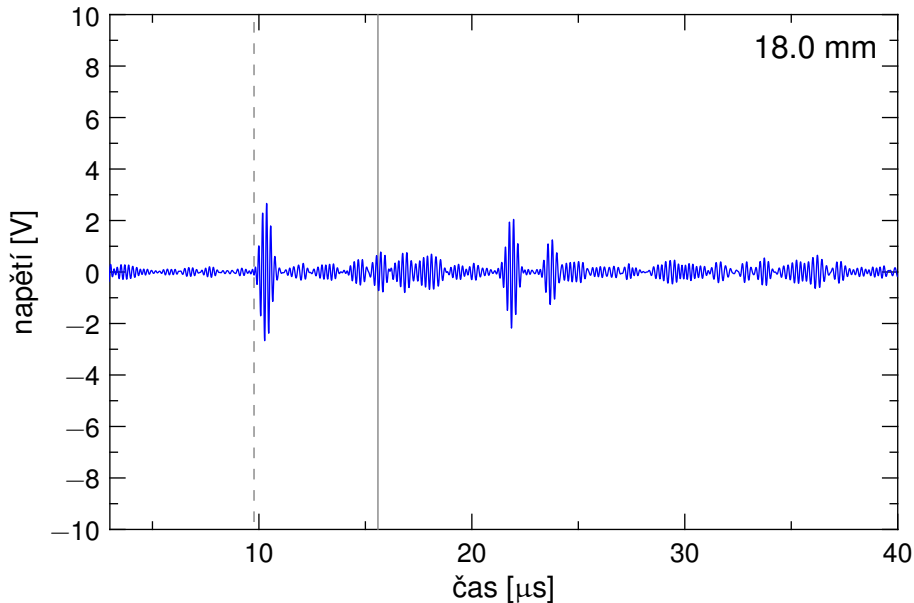
# Vliv posunu UZ-budiče u integrovaného snímače



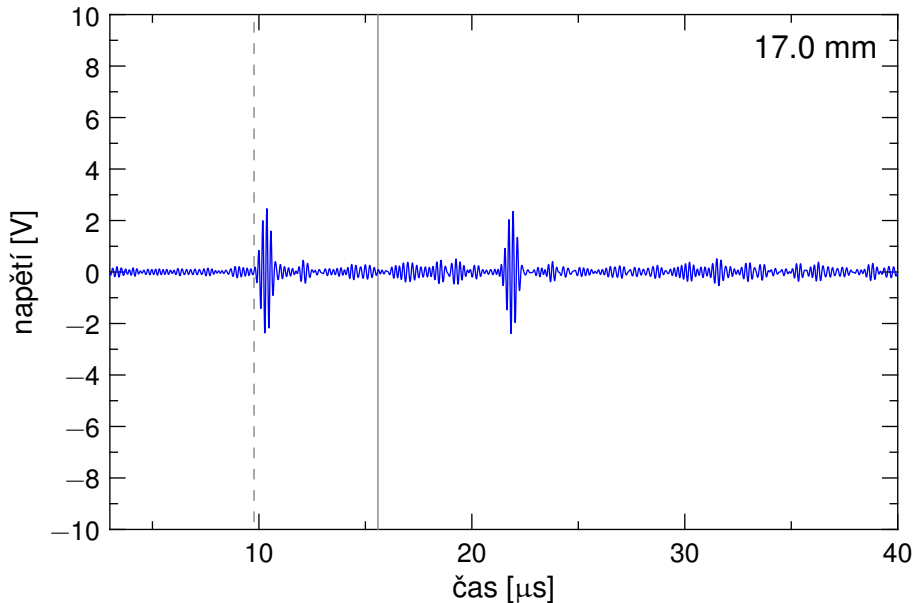
# Vliv posunu UZ-budiče u integrovaného snímače



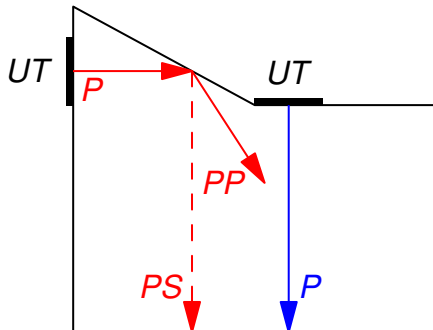
# Vliv posunu UZ-budiče u integrovaného snímače



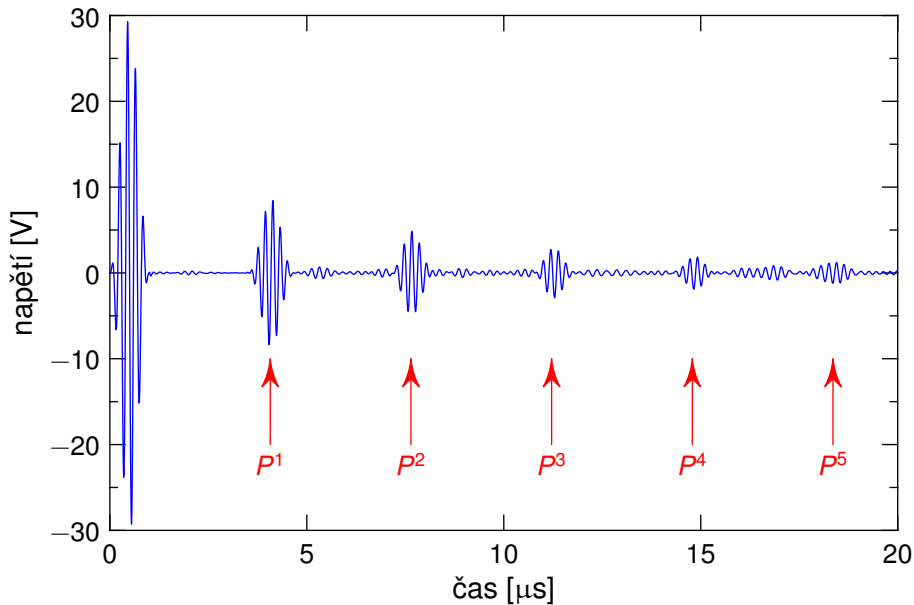
# Vliv posunu UZ-budiče u integrovaného snímače



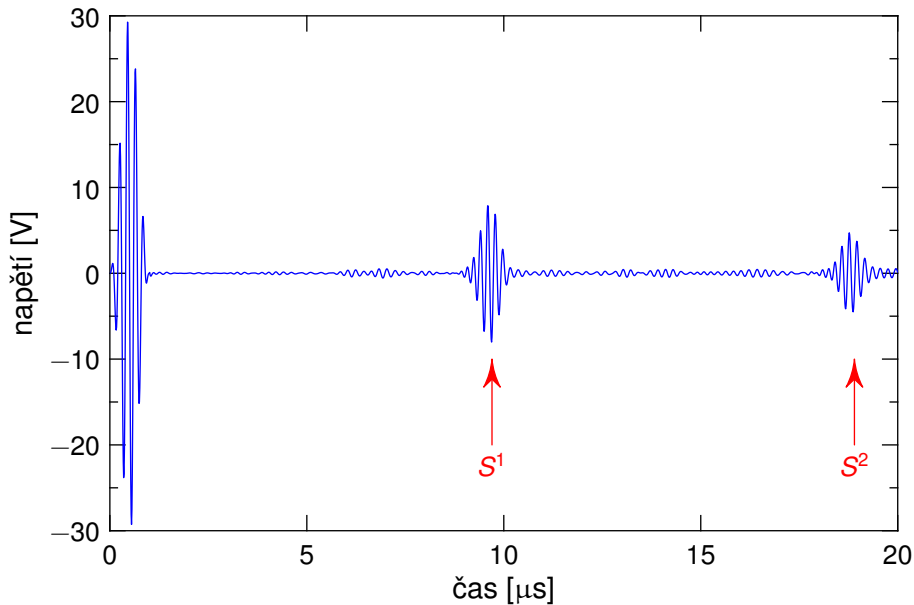
# Duální snímač

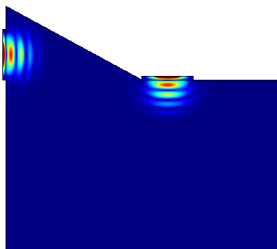


# Duální snímač - část P



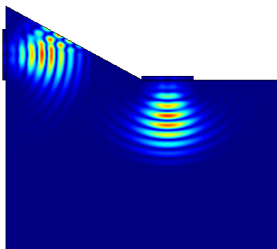
# Duální snímač - část S



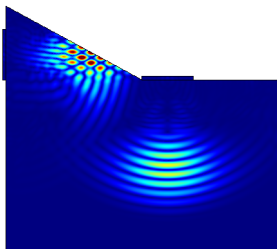


0.5  $\mu\text{s}$

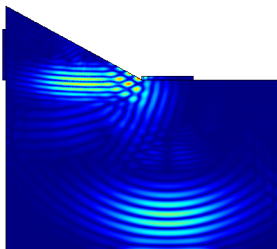




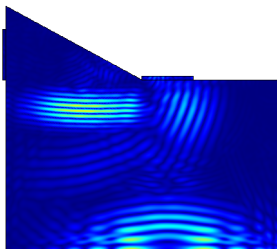
1.0  $\mu\text{s}$



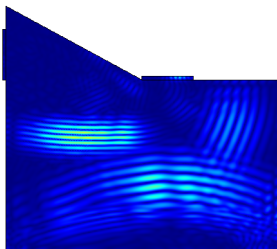
1.5  $\mu\text{s}$



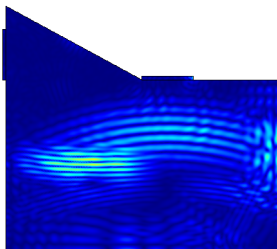
2.0  $\mu\text{s}$



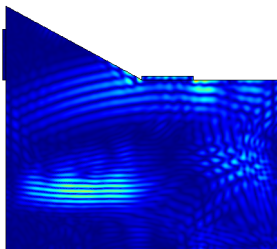
2.5  $\mu\text{s}$



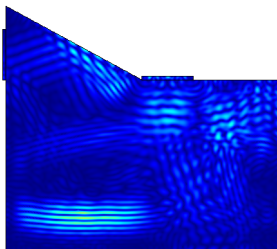
3.0  $\mu\text{s}$



3.5  $\mu\text{s}$

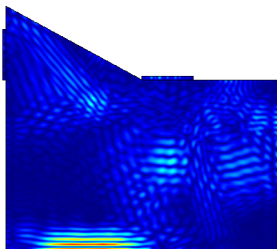


4.0  $\mu\text{s}$

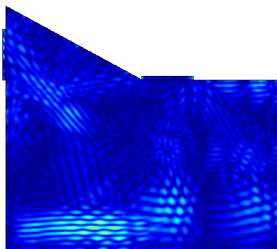


4.5  $\mu\text{s}$

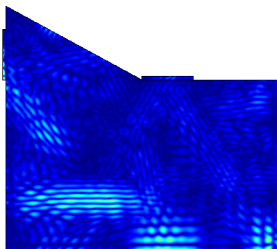




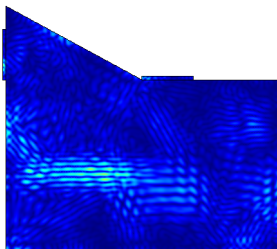
5.0  $\mu\text{s}$



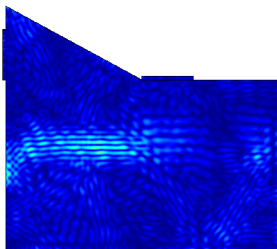
5.5  $\mu\text{s}$



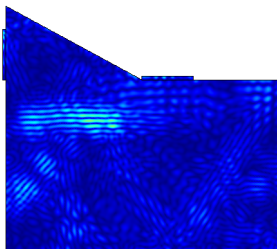
6.0  $\mu\text{s}$



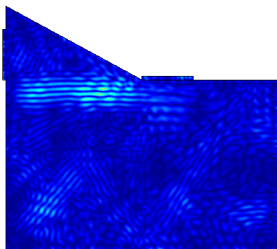
6.5  $\mu\text{s}$



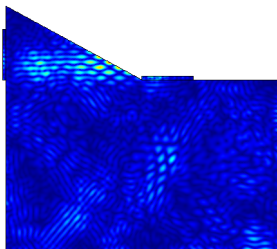
7.0  $\mu\text{s}$



7.5  $\mu\text{s}$

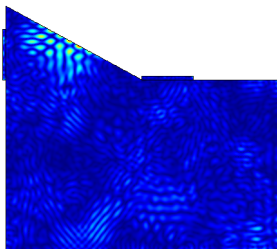


8.0  $\mu\text{s}$

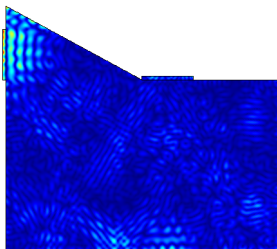


8.5  $\mu\text{s}$

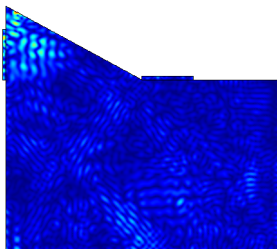




9.0  $\mu\text{s}$



9.5  $\mu\text{s}$



10.0  $\mu\text{s}$

# Závěr

- ▶ Byly provedeny MKP simulace snímače typu P-P, P-S a integrovaného snímače.
- ▶ Byl proveden detailní rozbor vlivu polohy UZ budiče u integrovaného snímače.
- ▶ Získané výsledky jsou v dobré shodě s experimentálními výsledky Jena a Kobayashiho.
- ▶ Byl navržen duální snímač, který poskytuje tyto výhody:
  - ▶ neexistence parazitních módů,
  - ▶ nezávislé ovládání amplitudy a počátku jednotlivých módů.

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- ▶ Byly provedeny MKP simulace snímače typu P-P, P-S a integrovaného snímače.
- ▶ Byl proveden detailní rozbor vlivu polohy UZ budiče u integrovaného snímače.
- ▶ Získané výsledky jsou v dobré shodě s experimentálními výsledky Jena a Kobayashiho.
- ▶ Byl navržen duální snímač, který poskytuje tyto výhody:
  - ▶ neexistence parazitních módů,
  - ▶ nezávislé ovládání amplitudy a počátku jednotlivých módů.

Příspěvek vznikl na základě podpory projektu GA ČR č. 101/09/1630 *Numerické řešení stacionárních a nestacionárních problémů dispersního šíření vln v mechanických systémech na různých úrovních* a záměru ÚT AV ČR, v.v.i., AV0Z20760514.