

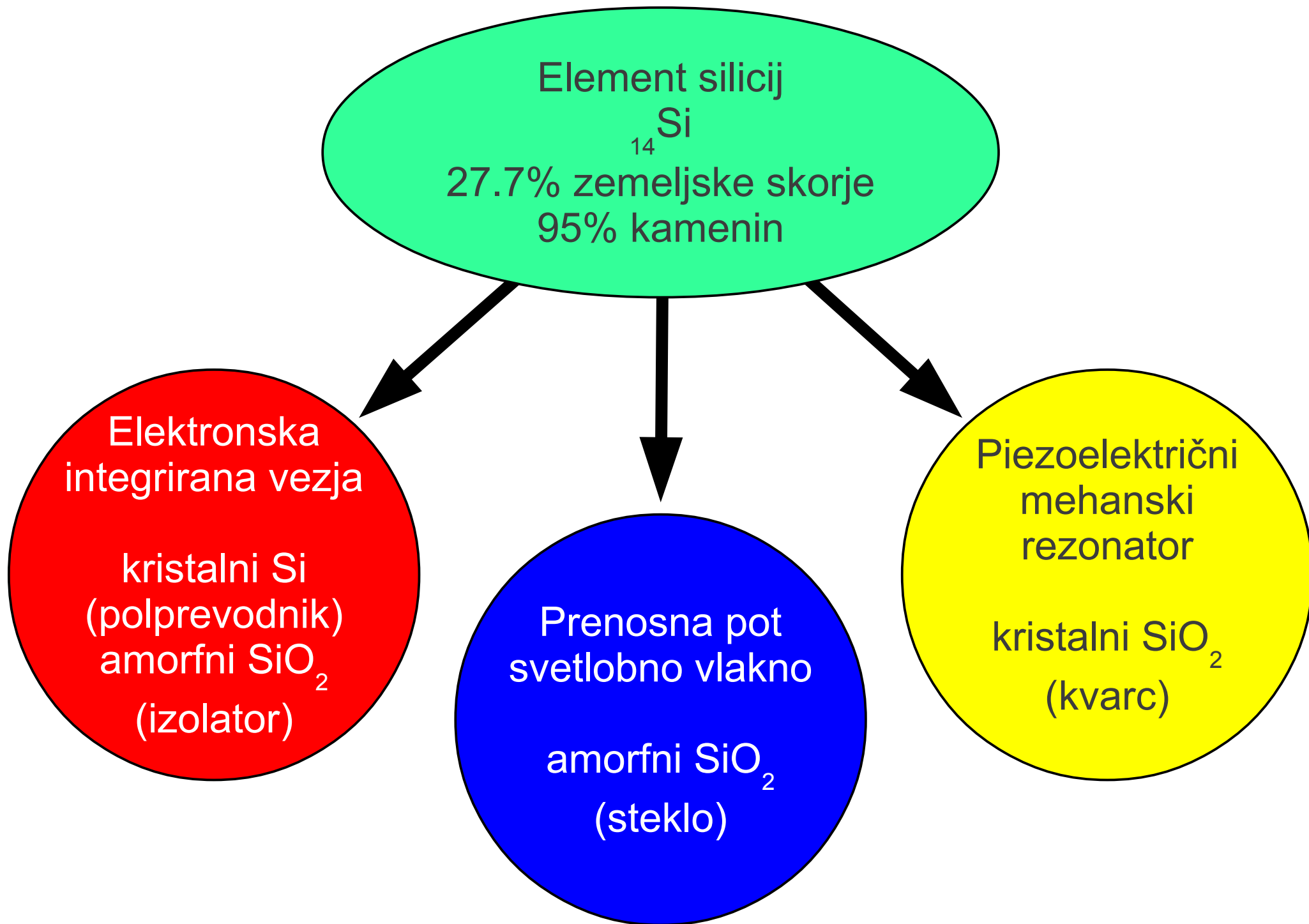
Piezoelektrični rezonatorji v radijski tehniki

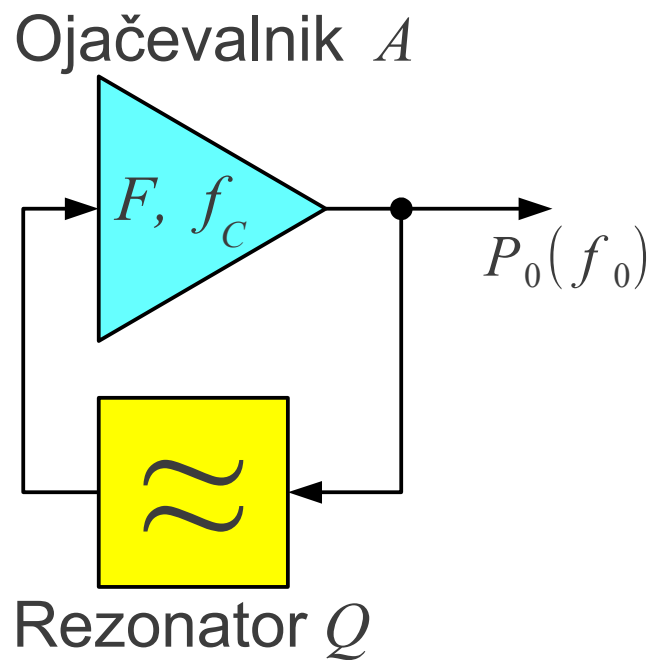
Matjaž Vidmar

LSO, FE, Ljubljana, 31.1.-2.2.2018

Seznam prosojnic predavanja: Piezoelektrični rezonatorji v radijski tehniki

- 1 - Vloge silicija v telekomunikacijah
- 2 - Fazni šum oscilatorja
- 3 - Omejitve faznega šuma
- 4 - Mehanska valovanja
- 5 - Zgodovina kvarca v elektroniki
- 6 - Naravni kremenov kristal
- 7 - Umetni kremenov kristal
- 8 - Režine kremenovega kristala
- 9 - Določanje kristalnih osi z žarki X
- 10 - Rodovi nihanja rezin kremena
- 11 - Režine AT
- 12 - Strižni rodovi nihanja rezine AT
- 13 - Električno nadomestno vezje rezine AT
- 14 - Admitanca rezine AT
- 15 - Röntgenska slika prečnih rodov rezine AT
- 16 - Neharmonski prečni rodovi rezine AT
- 17 - Temperaturna odvisnost frekvence od kota reza AT
- 18 -
- 19 -
- 20 -
- 21 -
- 22 -
- 23 -
- 24 -
- 25 -
- 26 -
- 27 -
- 28 -
- 29 -
- 30 -
- 31 -
- 32 -
- 33 -
- 34 -
- 35 -
- 36 -
- 37 -





Leesonova enačba: spektralna gostota faznega šuma

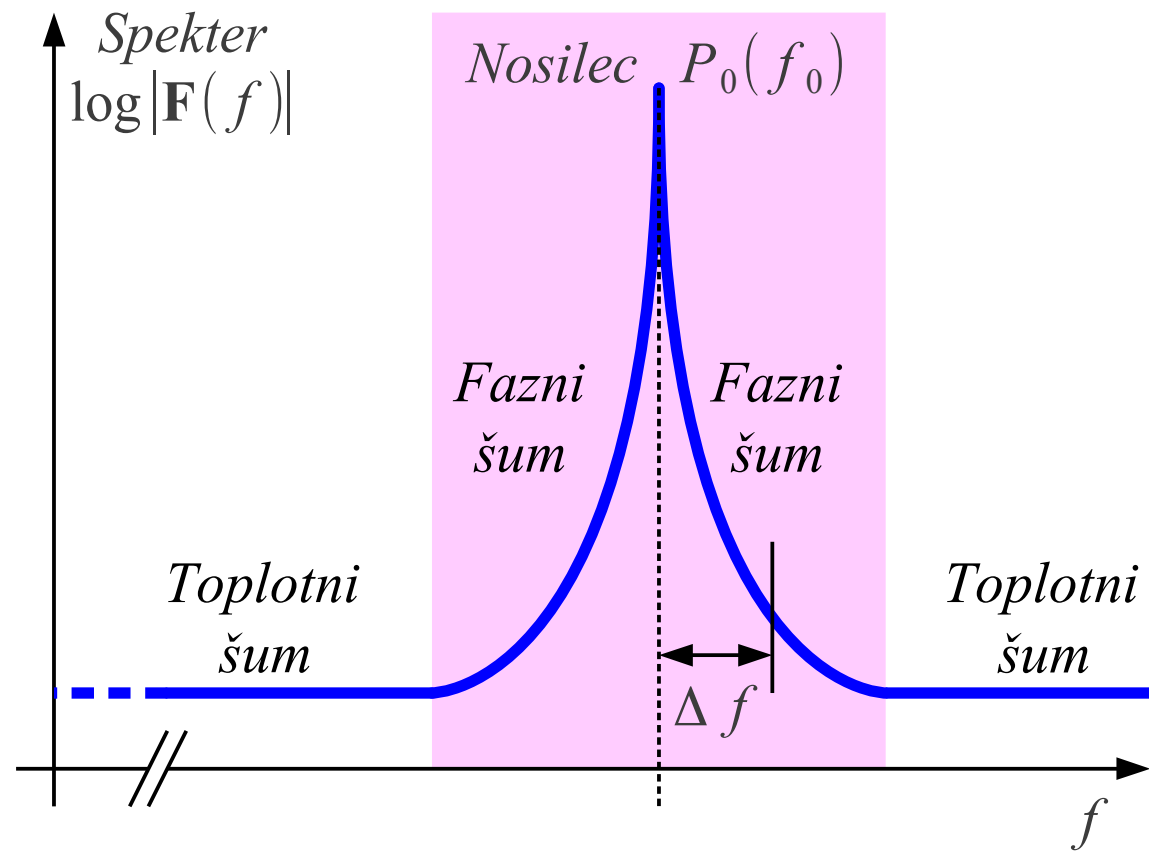
$$L(\Delta f) = \frac{1}{2} \cdot \left[1 + \left(\frac{f_0}{2Q_L \Delta f} \right)^2 \right] \cdot \frac{k_B T_0 F}{P_0} \cdot \left(1 + \frac{f_c}{|\Delta f|} \right)$$

$k_B \approx 1.38 \cdot 10^{-23} \text{ J/K} \equiv \text{Boltzmannova konstanta}$

$T_0 \approx 290 \text{ K} \equiv \text{temperatura vezja}$

$F \equiv \text{šumno število ojačevalnika}$

$f_c \equiv \text{mejna frekvenca šuma } 1/f$



$Q_L \equiv \text{obremenjeni } Q \text{ rezonatorja}$

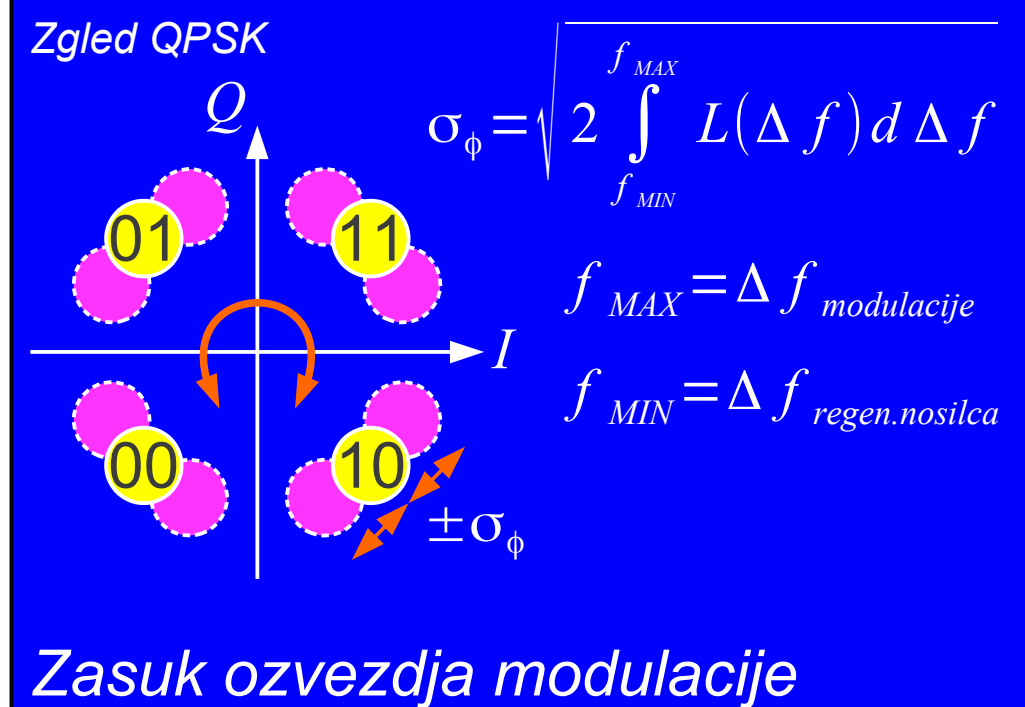
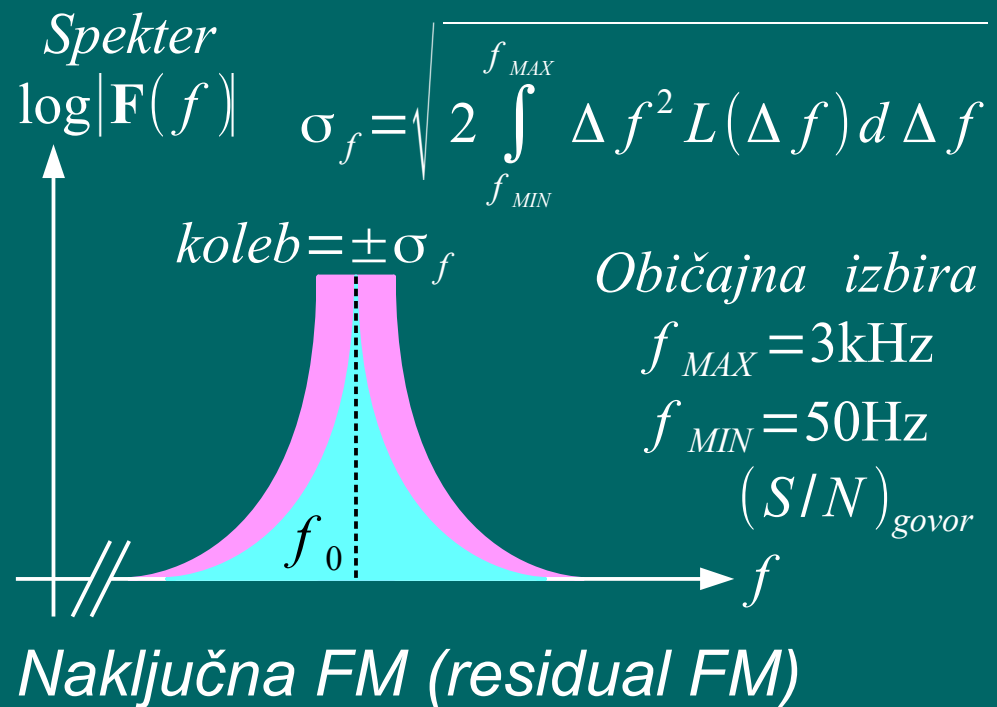
$Q_L \approx 30 \text{ (LC nihajni krog)}$

$Q_L \approx 1000 \text{ (električna votlina)}$

$Q_L \approx 30000 \text{ (kremenov kristal)}$

2 – Fazni šum oscilatorja

$$L(\Delta f)_{\text{dBc/Hz}} = 10 \log_{10} [L(\Delta f) \cdot 1 \text{ Hz}]$$



Analogne radijske zveze:

$$Q_L \approx 30 \dots 1000$$

SSB (A3j brez nosilca) $\rightarrow f_0 < 30\text{MHz}$

FM (govor $B=15\text{kHz}$) $\rightarrow f_0 < 1\text{GHz}$

FM (slika $B=30\text{MHz}$) $\rightarrow f_0 < 30\text{GHz}$

Številске radijske zveze:

$$Q_L \approx 1000 \dots 30000$$

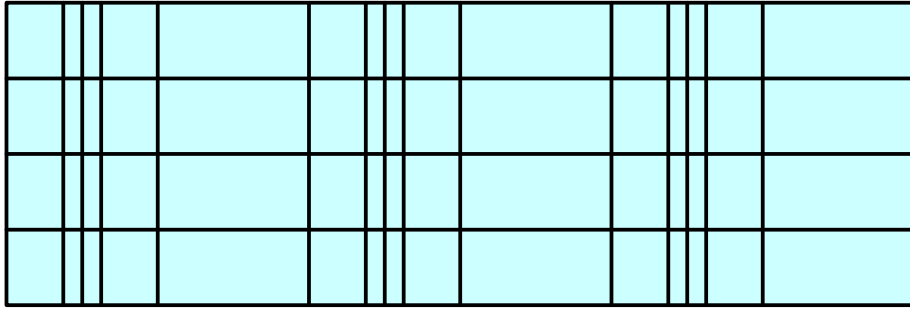
Gost OFDM ($N > 1000$) $\rightarrow f_0 < 1\text{GHz}$

Redek OFDM ($N < 100$) $\rightarrow f_0 < 10\text{GHz}$

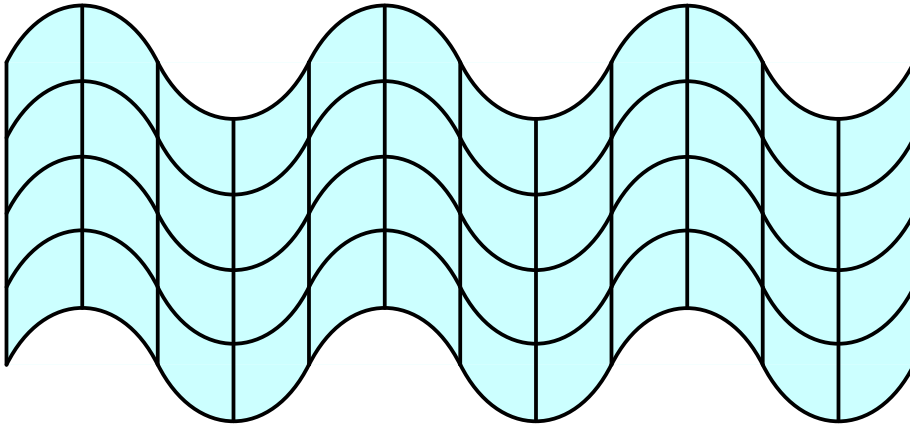
Preprost QPSK $\rightarrow f_0 < 100\text{GHz}$

3 – Omejitve faznega šuma

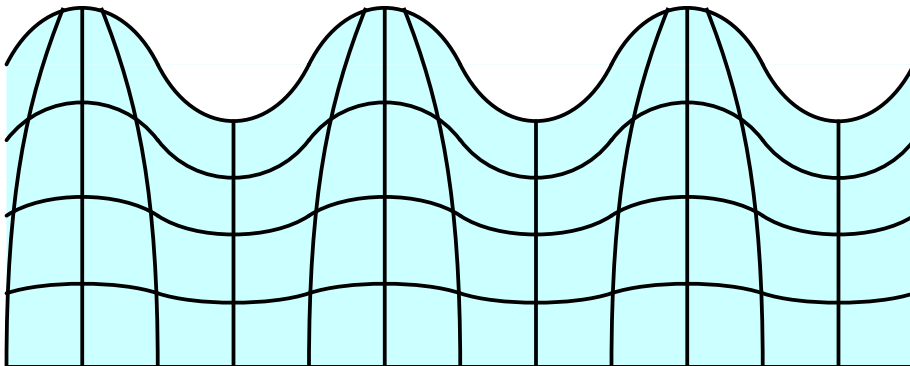
4 – Mehanska valovanja



Tlačni val "P" (pressure wave)
plini, tekočine, trdne snovi
("BAW" bulk acoustic wave)



Strižni val "S" (shear wave)
samo trdne snovi
("BAW" bulk acoustic wave)



Površinski val "SAW"
(surface acoustic wave)
površina trdne snovi

- 1880 – Jacques in Pierre Curie odkrijeta piezoelektrični pojav
- 1905 – G. Spezia hidrotermalna rast kremenovih kristalov v laboratoriju
- 1917 – Prva uporaba piezoelektričnega pojava v sonarju
- 1918 – Prva uporaba piezoelektričnega kristala v oscilatorju
- 1926 – Prvi radiodifuzni oddajnik s kremenovim kristalom
- 1927 – Odkrit prvi temperaturno-kompenzirani rez kristala kremenena
- 1927 – Prva ura s kremenovim kristalom
- 1934 – Razvit prvi praktični temperaturno-kompenzirani AT rez
- 1949 – Razvit obrobljeni visoko stabilni AT rez z visokim Q
- 1956 – Dosegljivi prvi umetno izdelani kremenovi kristali
- 1956 – Opisan prvi TCXO
- 1972 – Kremenov kristal v obliki glasbenih vilic za ročne ure
- 1974 – Napovedan SC rez in preverjen 1976

5 – Zgodovina kvarca v elektroniki

Tališče
1670°C

$T < 573^\circ\text{C}$
 α -kvarc
desnosučni
in levosučni

$T > 573^\circ\text{C}$
 β -kvarc

Mehanski
 $Q > 10^6$

Piezoelektrik



Hidrotermalna rast v $\text{H}_2\text{O} + \text{NaCl}$ (tisoči let) $p \approx 1000\text{bar}$

Nečistoče? Vključki? Prisotnost obeh kristalnih oblik? Nahajališča?

6 – Naravni kremenov kristal

Hidrotermalna rast

$$v_{\text{rast}}(z) \approx 3 \cdot v_{\text{rast}}(x)$$

desnosučni α -kvarc



$p \approx 700\text{--}1000\text{bar}$

$T \approx 345^\circ\text{C}$ $\Delta T \approx 10^\circ\text{C}$

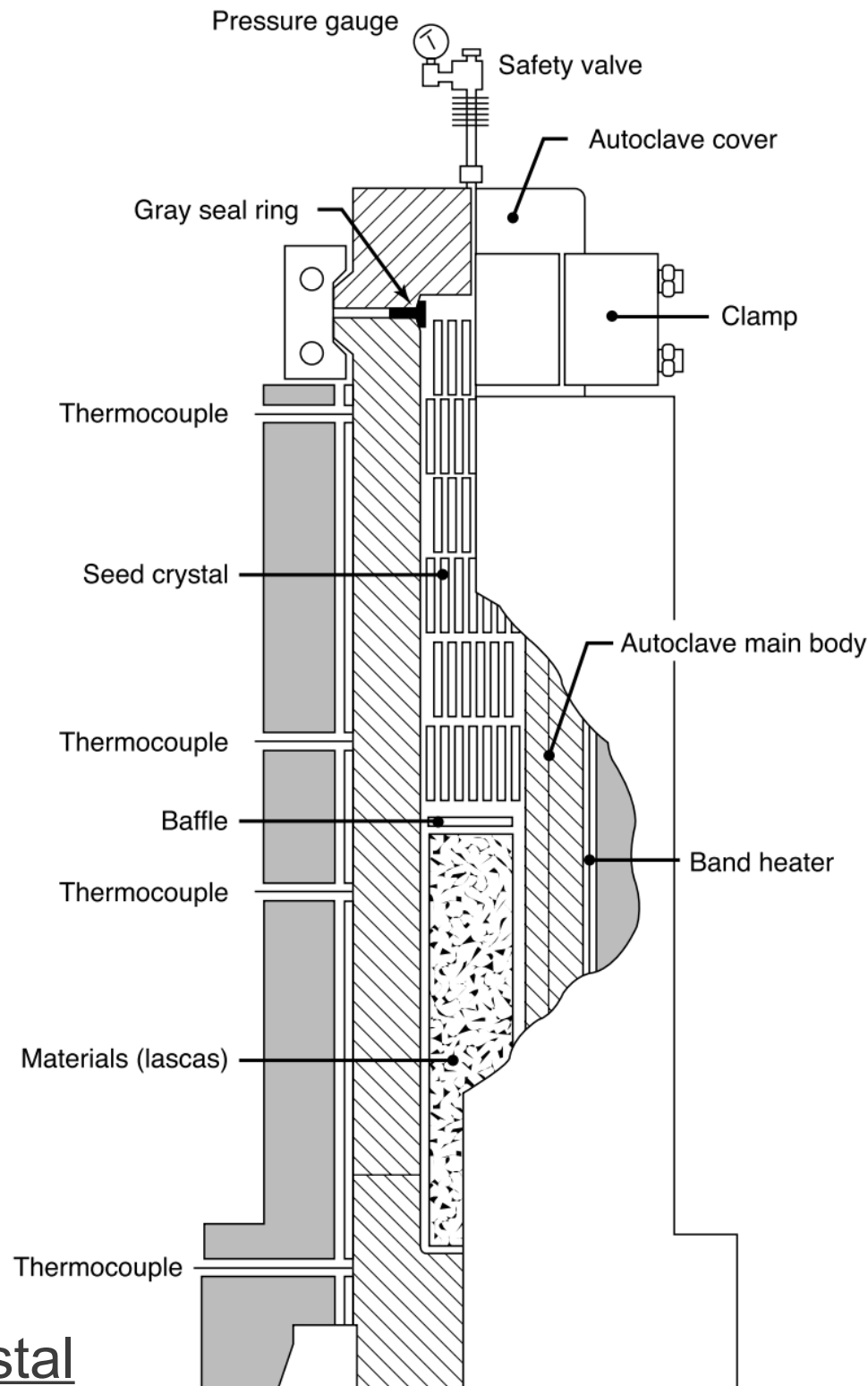
$$v_{\text{rast}}(z) \approx 0.4\text{mm/dan}$$

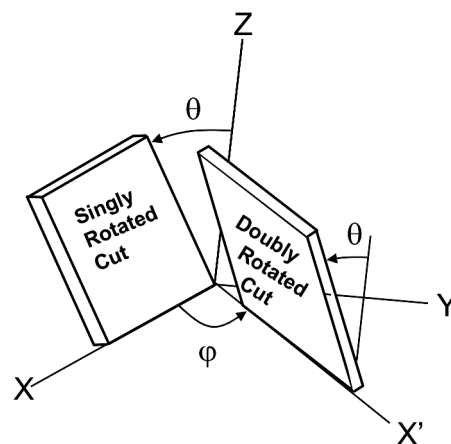
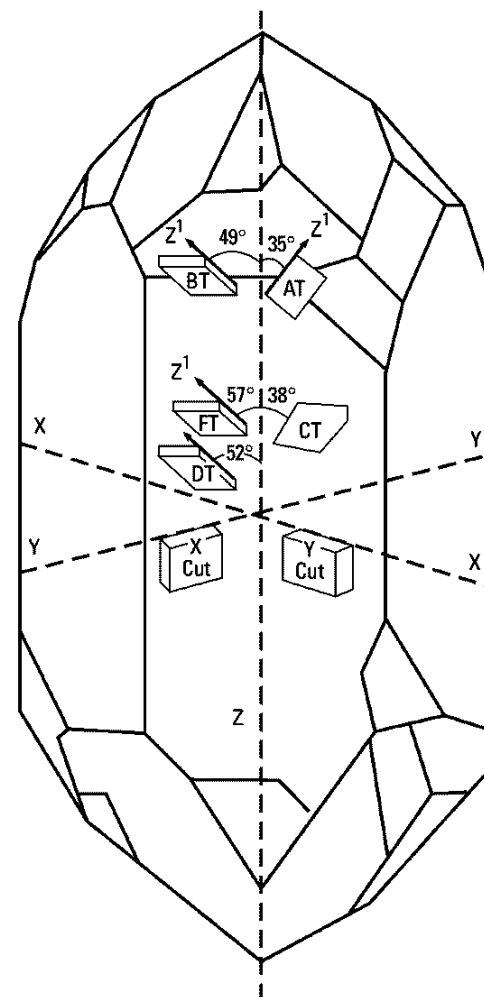
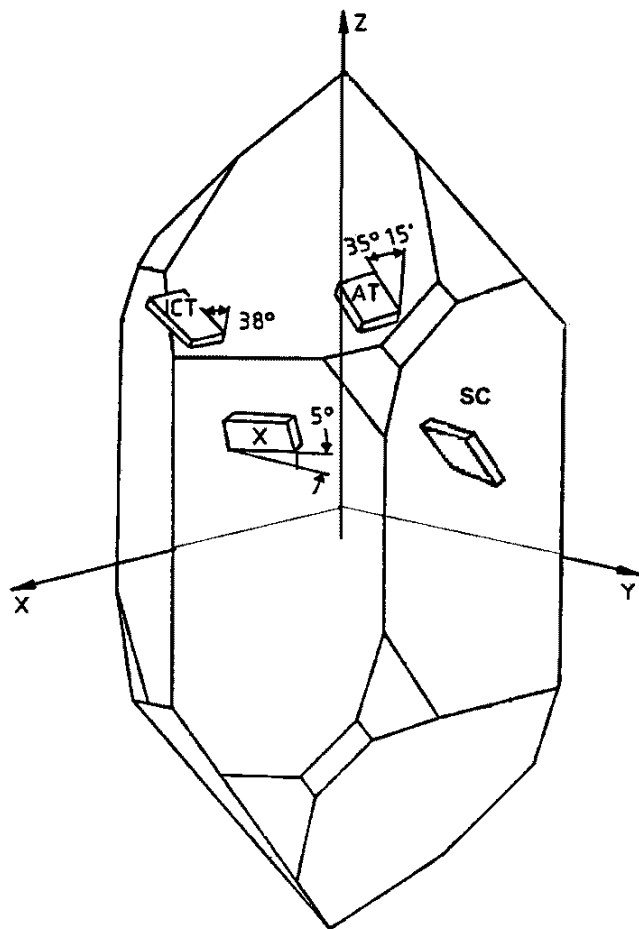
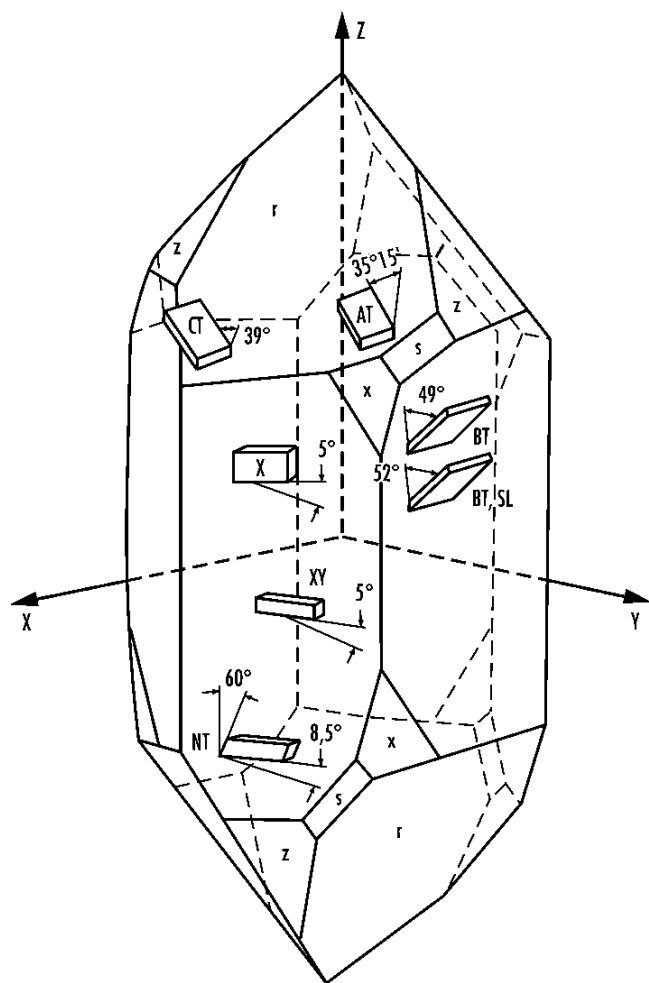


$p \approx 1000\text{--}1500\text{bar}$

$T \approx 380^\circ\text{C}$ $\Delta T \approx 25^\circ\text{C}$

$$v_{\text{rast}}(z) \approx 1\text{mm/dan}$$





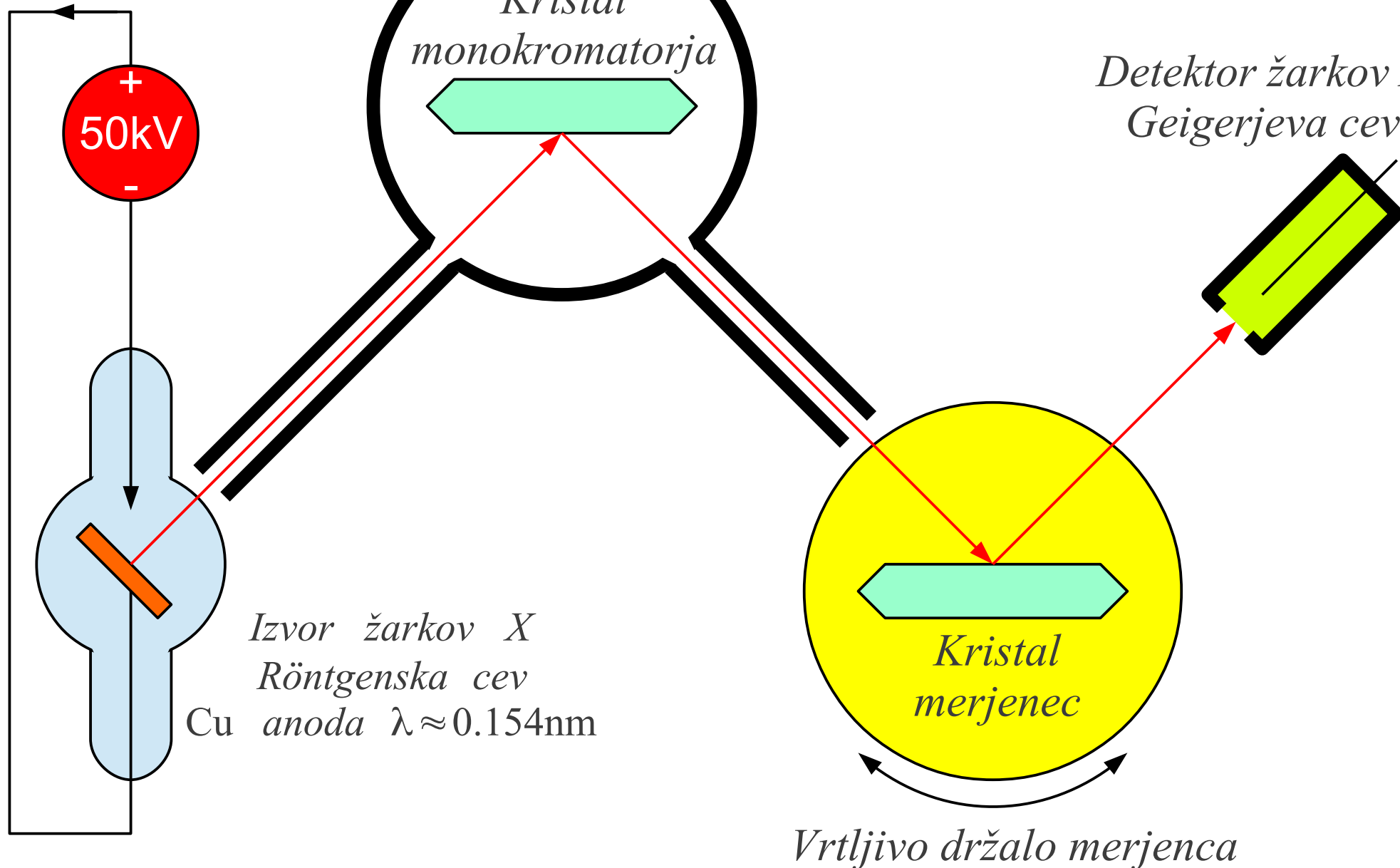
8 – Rezi kremenovega kristala

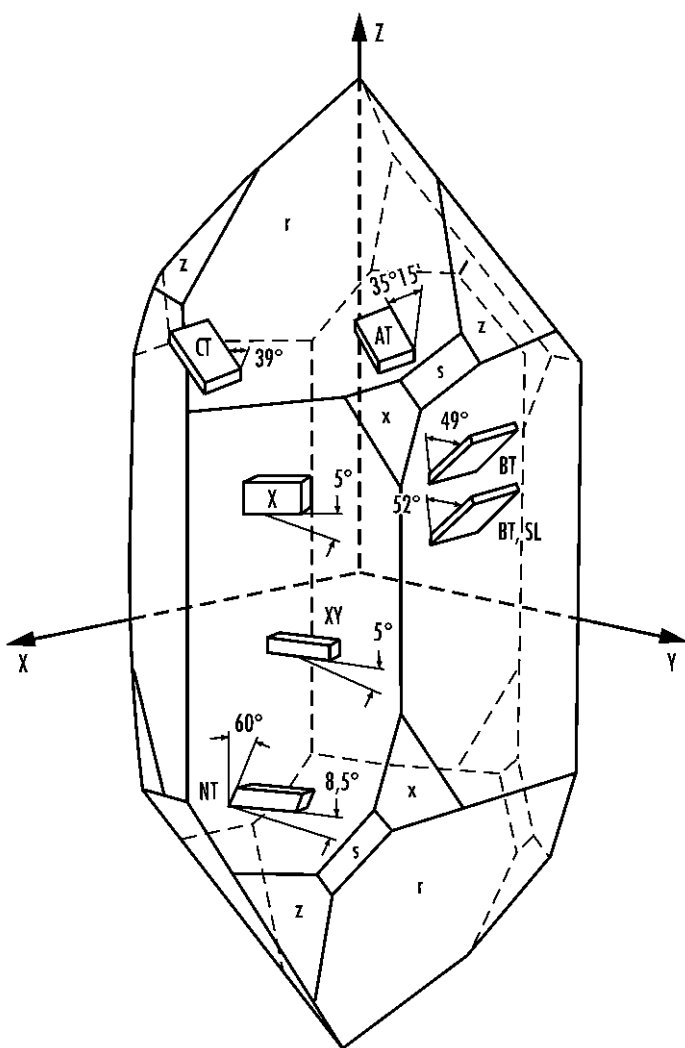
Pb oklop za žarke X

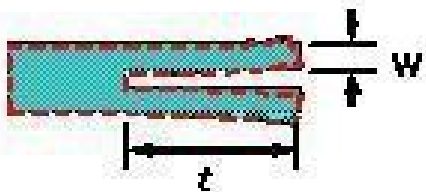
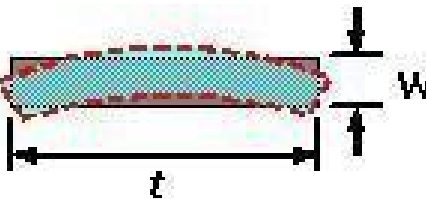
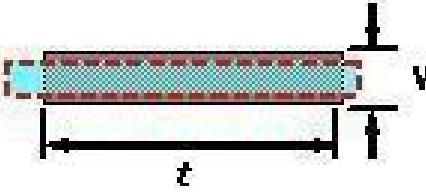
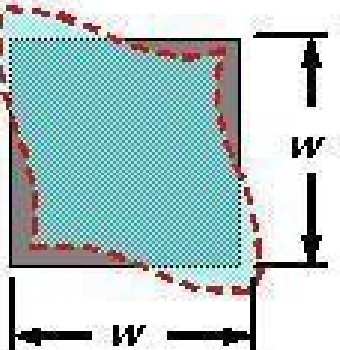
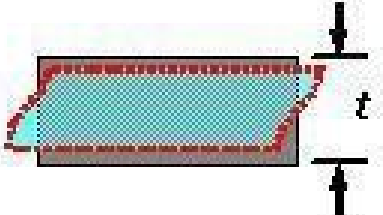
$I \approx 10\text{mA}$

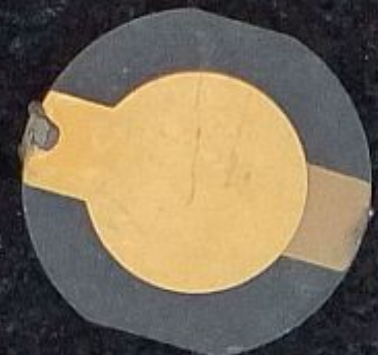
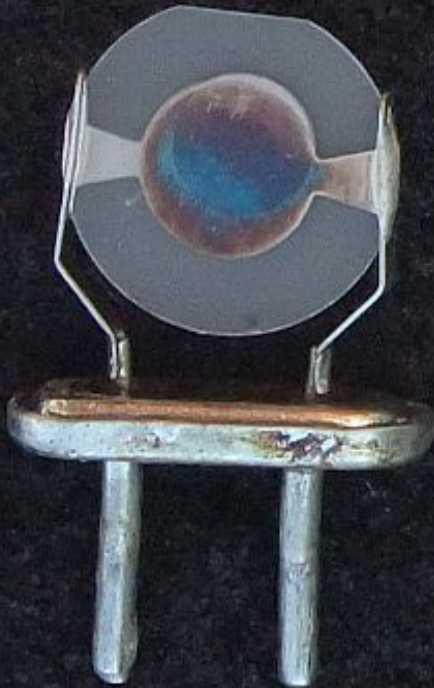
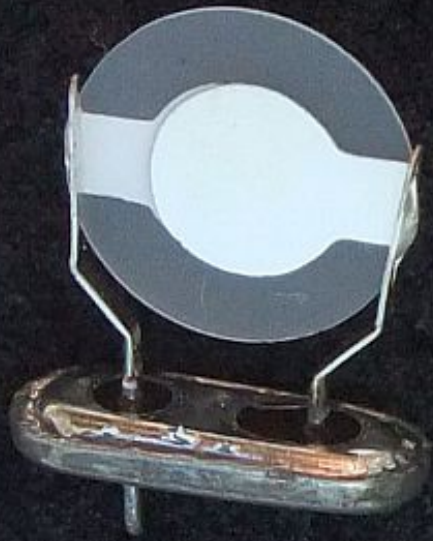
*Kristal
monokromatorja*

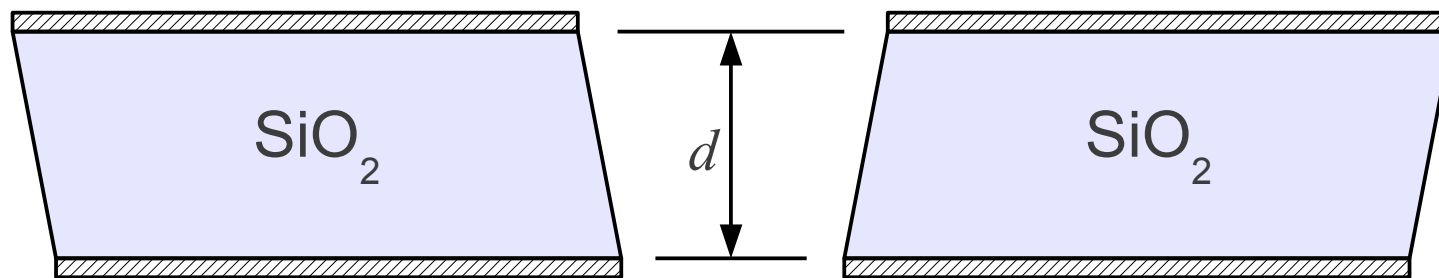
*Detektor žarkov X
Geigerjeva cev*



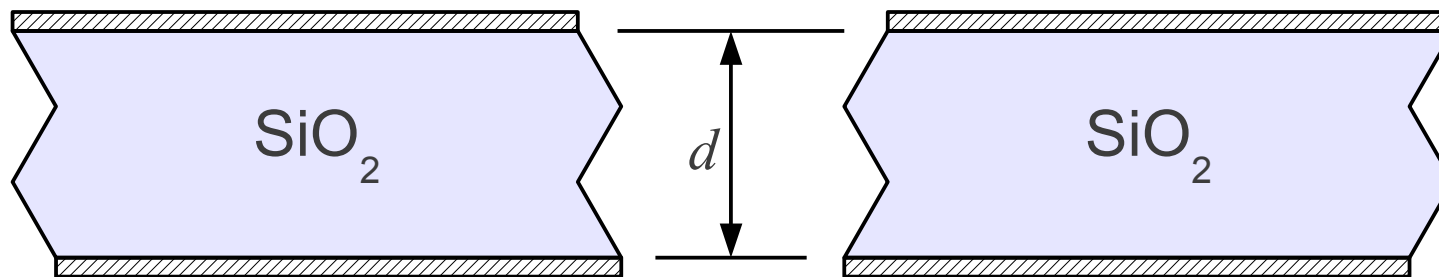


Vibration Mode	Orientation Angle
Tuning Fork 	$+ 2^{\circ} X$
Flexure 	XY NT
Extension 	$+ 5^{\circ} X$ $- 18.5^{\circ} X$
Face Shear  Thickness Shear 	DT CT SL AT Fundamental AT 3 rd Overtone AT 5 th Overtone BT Fundamental

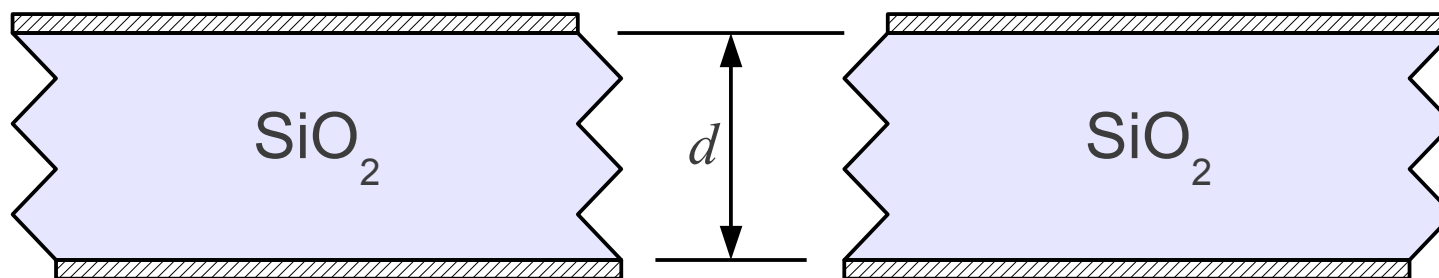




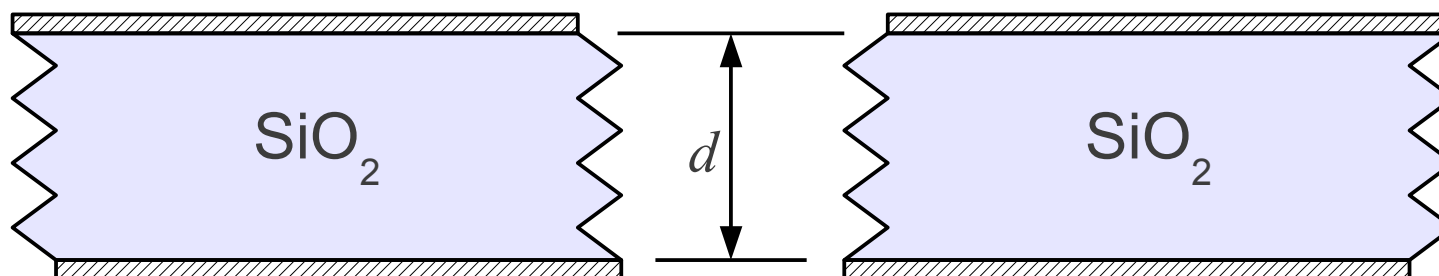
Osnovna
rezonanca
 $f_1 \approx v/2d$



Tretji
overton $\sim 3f_1$

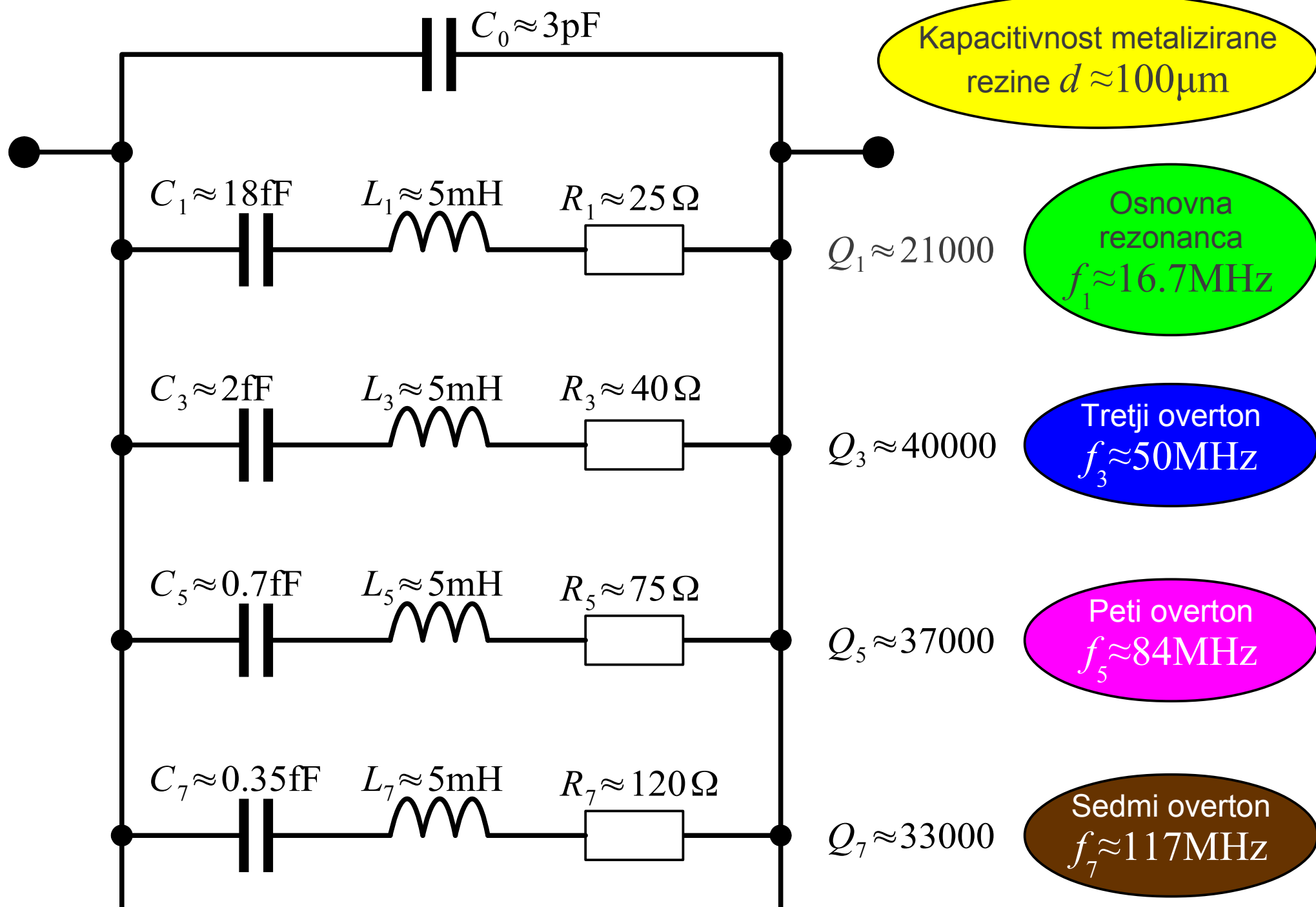


Peti
overton $\sim 5f_1$



Sedmi
overton $\sim 7f_1$

$v \approx 3.32\text{km/s}$



$B = \text{Im}[Y]$

$$Y(f) = G + jB$$

$j\omega C_0$

$1/R_7$

$1/R_5$

**Sedmi
overton**

$1/R_3$

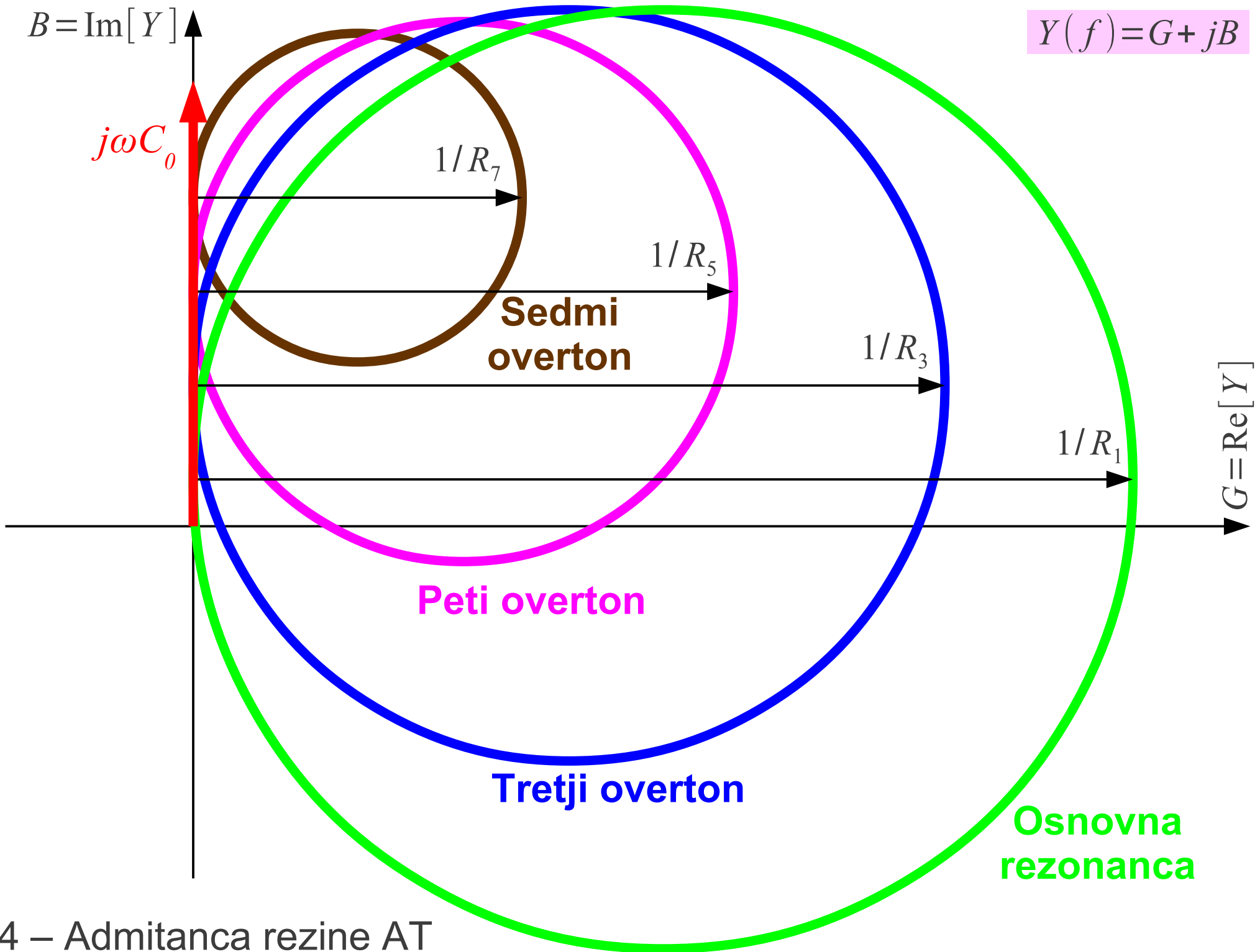
$1/R_1$

$G = \text{Re}[Y]$

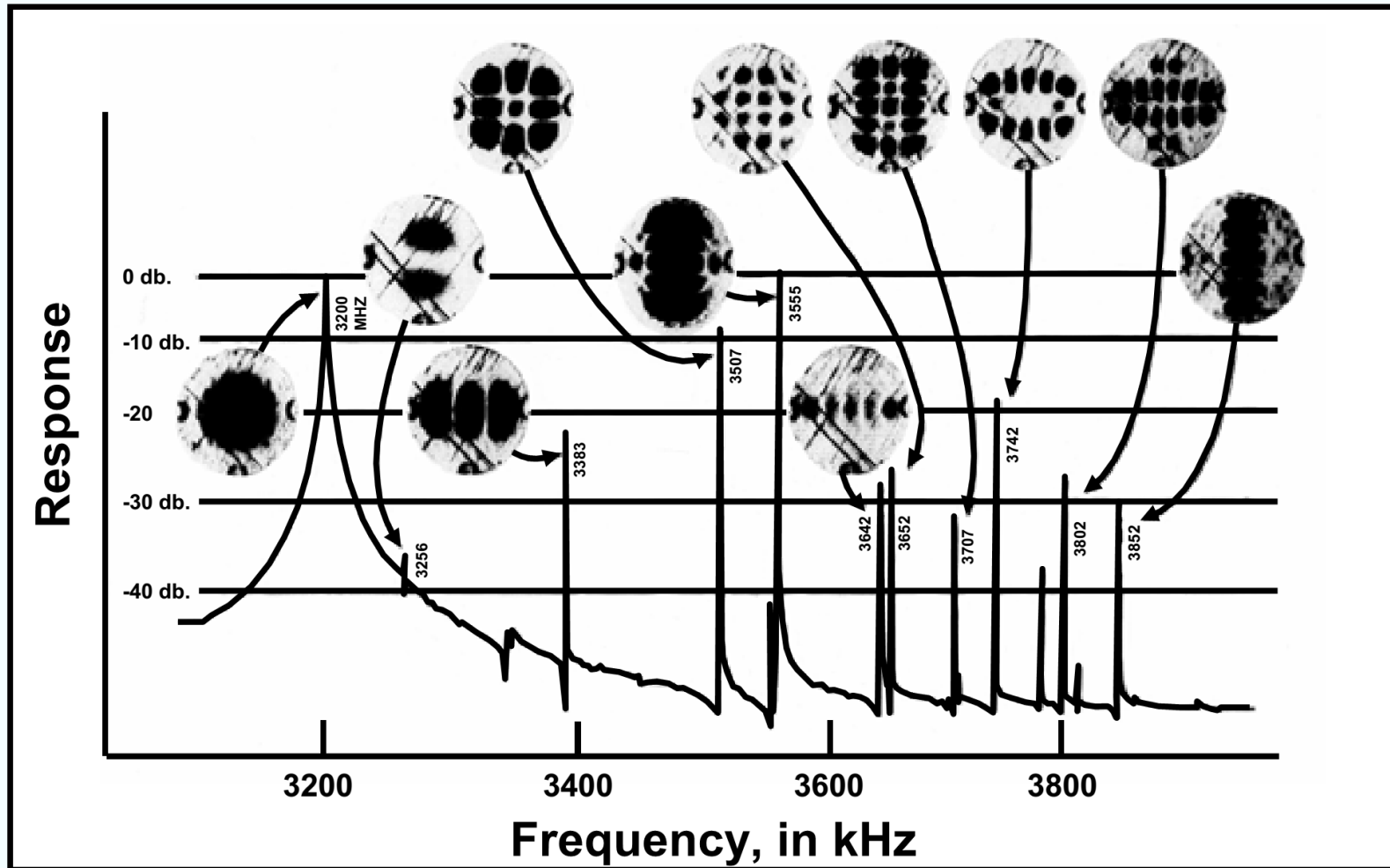
Peti overton

Tretji overton

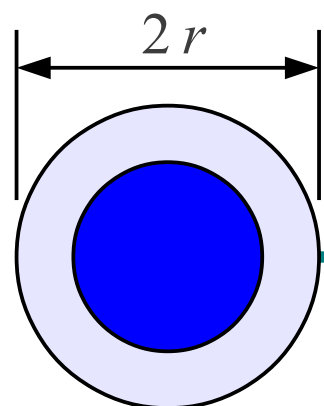
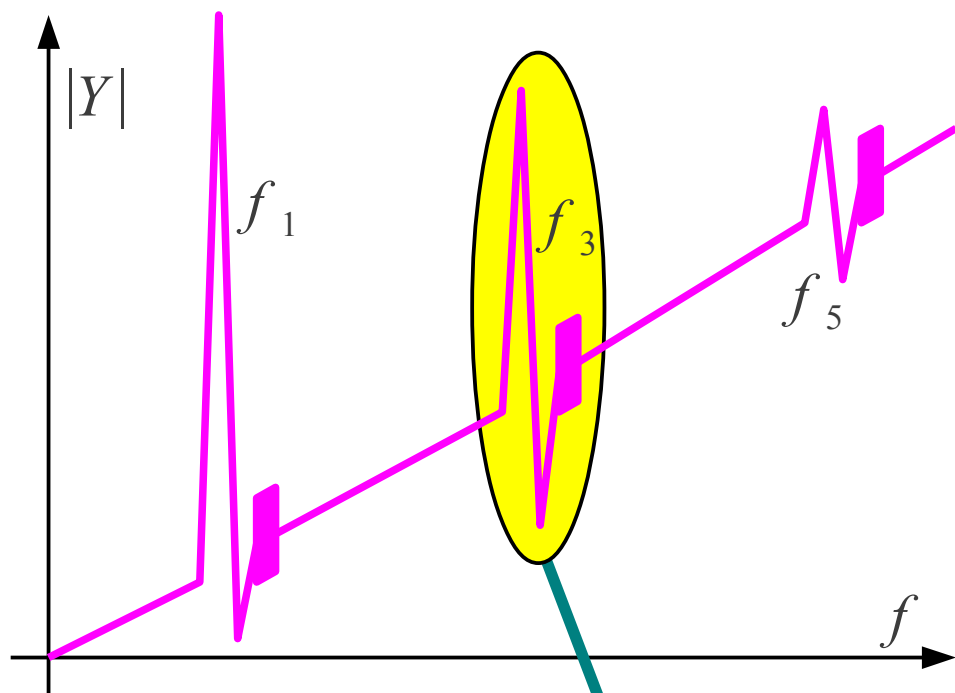
**Osnovna
rezonanca**



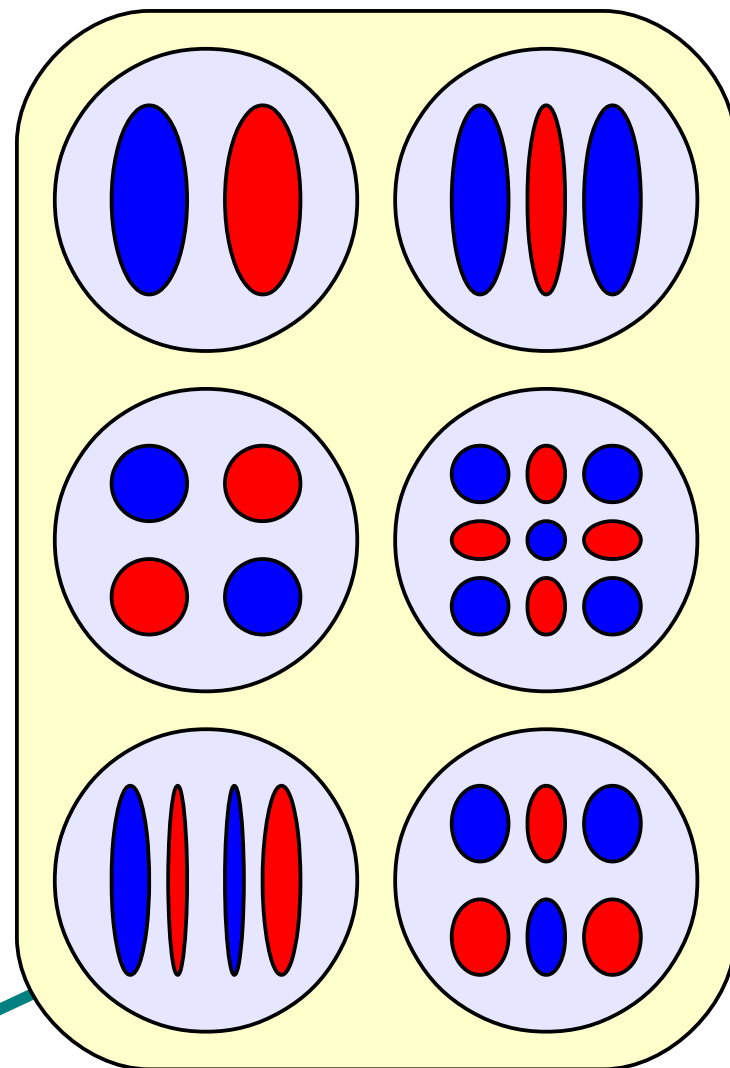
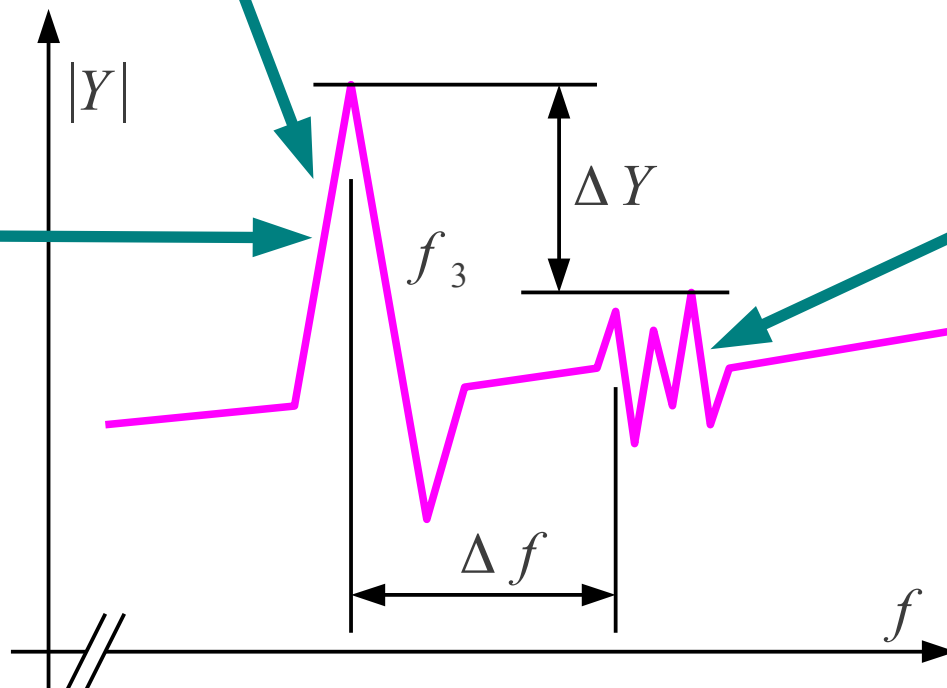
Resonant Vibrations of a Quartz Plate



X-ray topographs ($21\cdot\bar{0}$ plane) of various modes excited during a frequency scan of a fundamental mode, circular, AT-cut resonator. The first peak, at 3.2 MHz, is the main mode; all others are unwanted modes. Dark areas correspond to high amplitudes of displacement.



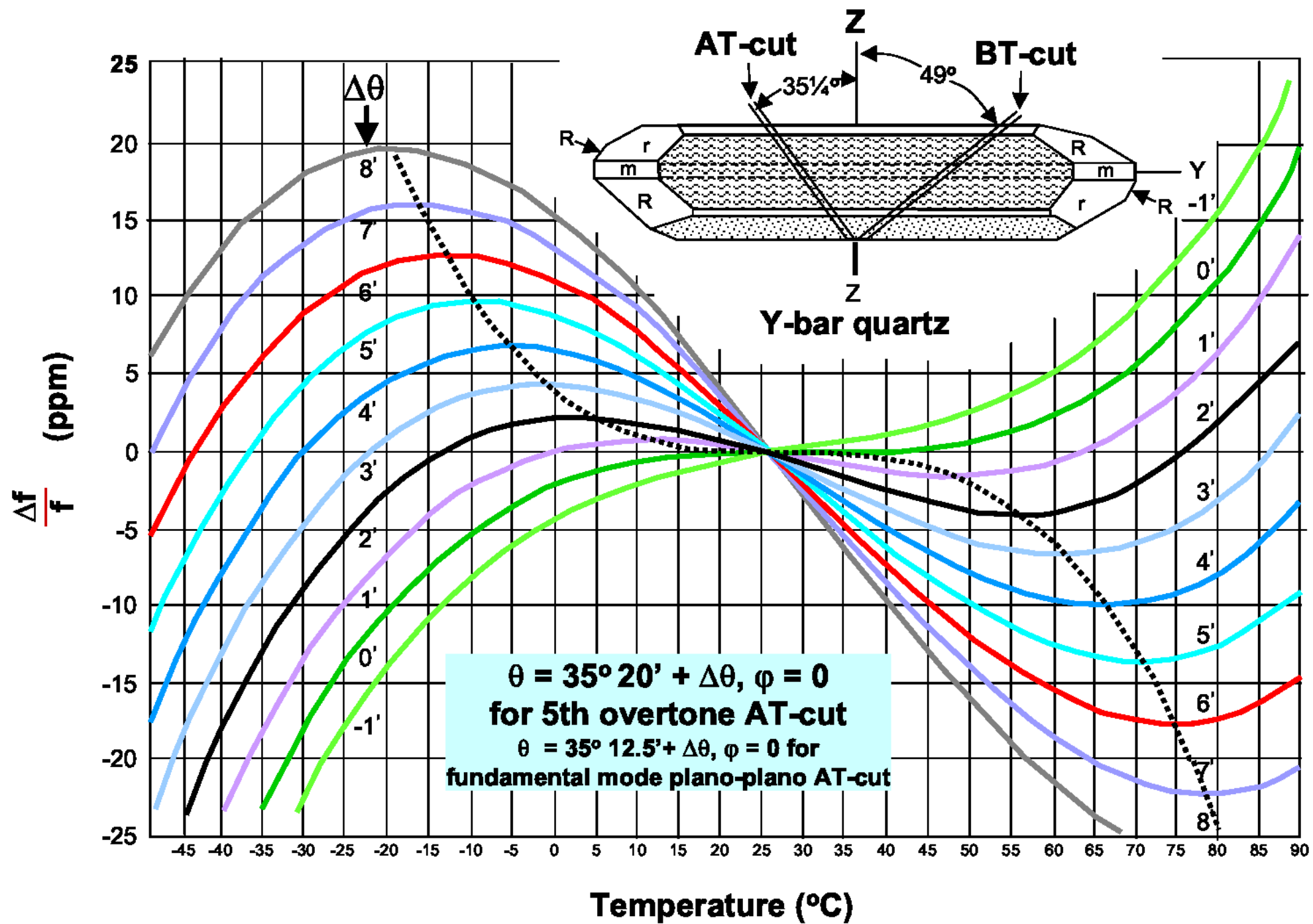
Osnovni prečni rod



Višji prečni rodovi (anharmonics)

$$\frac{\Delta f}{f_1} \approx \frac{d}{2r}$$

$$\Delta f \approx 100\text{kHz} < 1\text{MHz}$$



17 – Temperaturna odvisnost frekvence kota reza AT

