5. PŘEDNÁŠKA – SIGNÁLY SRDCE 2

- **Další typy EKG**
  - náhradní umístění svodů
  - zátěžové, Holter, monitorování
  - dětské EKG, veterinární medicína
  - jícnové EKG, intrakardiální
  - mapování
- **Základní EKG křivky**
  - poruchy rytmu
  - ektopické aktivity
  - blokády šíření
  - hypertrofie
- **Zpracování EKG signálů**
  - předzpracování
  - detekce grafoelementů
  - speciální analýzy

Náhradní umístění elektrod

- co nejmenší vliv pohybu vyšetřovaného na kvalitu signálu – pohybové artefakty, myopotenciály;
- co nejmenší vliv vodičů na mobilitu vyšetřovaného

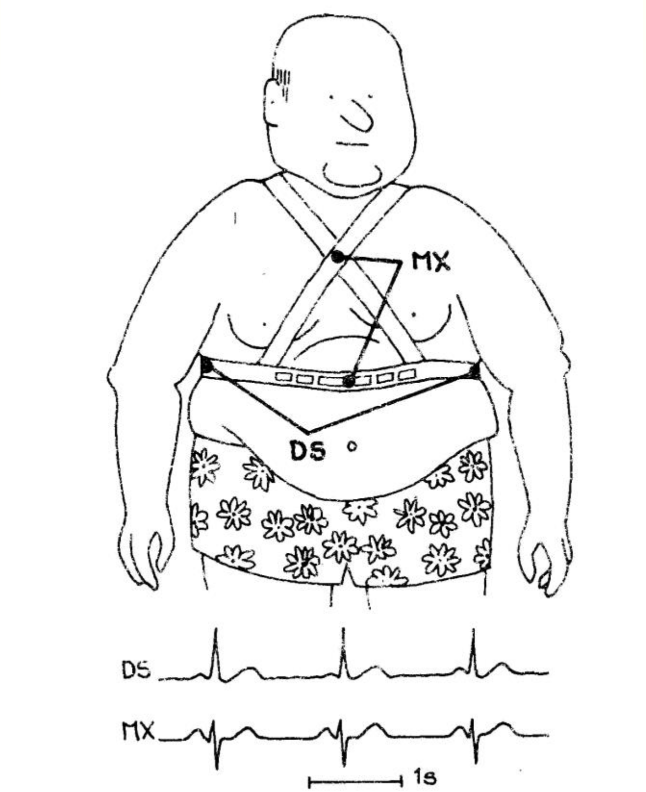
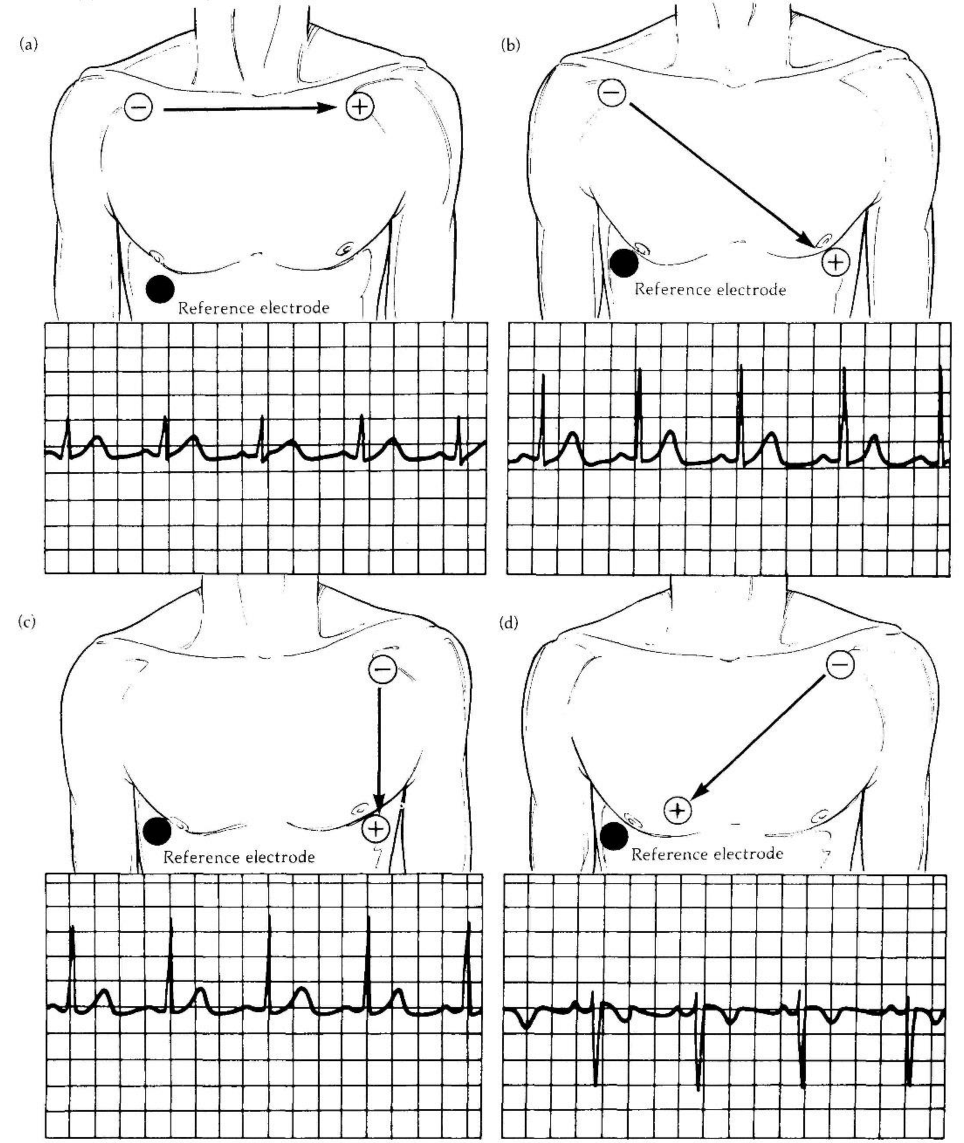


Figure 5.4— Placements of chest electrodes.
(a) For signal similar to lead I.
(b) For signal similar to lead II.
(c) For signal similar to lead III.
(d) For lead MCL_1.



Náhradní umístění elektrod

- končetinové definoval Einthoven (historický aspekt)
- končetinové dávají obecně větší biosignály
- končetinové svody jsou obecně více rušeny
- snadnost připojení

Present state-of-the-art is often based on historical quirks rather than on a profound scientific basis.

Encyclopedia of Medical Devices and Instrumentation, Second Edition, edited by John G. Webster
2006 John Wiley & Sons, Inc

Hrudní svody

- jsou považovány za nejspolehlivější
- dávají nejčistší signál

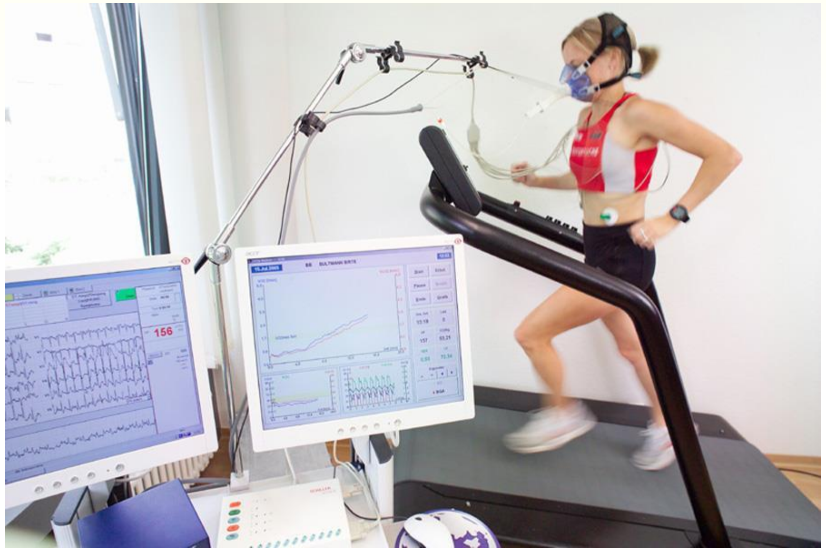
Končetinové svody

- pro redukci rušení doporučeno dávat elektrody výše na rukou
- více citlivé na pohybové artefakty

EKG zátěžové

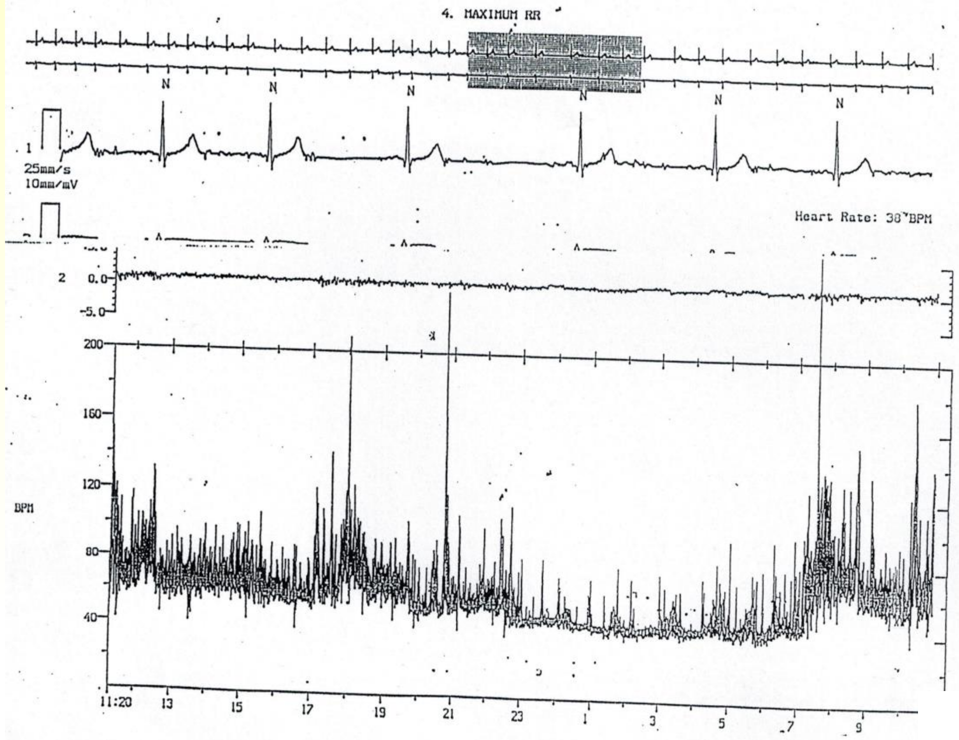
bicyklová ergometrie, ergometrie

Sportovní, pracovní lékařství
- fyzická zátěž
- standardní protokoly
- zastaví se při vysoké tepové frekvenci



Stanovení maximální možné hodnoty srdeční frekvence při zátěžovém testu
MHR = 220 - věk

Holterovská monitorace



SUMMARY

A total of 83122 beats were observed for the entire recording period of 23 hours. 39 minutes.
The maximum heart rate during this period was ~~270~~ 135 BPM. during minute 7:33.
The minimum heart rate was 35 BPM. during minute 1:59.
Atrial Fibrillation was present for 0% of the recording. Atrial Flutter for 0%. Junctional Rhythm for 0%.

SUPRAVENTRICULAR REPORT

A total of 0 supraventricular ectopic beats were observed; with 0 isolated single events. 0 couplets. and 0 runs.

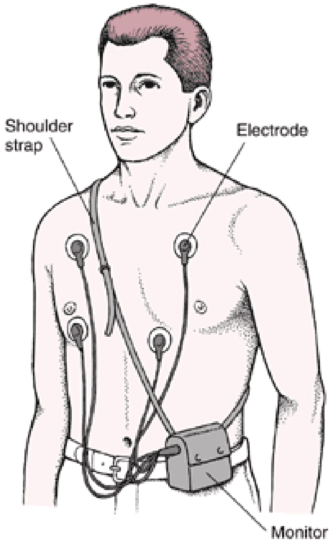
VENTRICULAR REPORT

A total of 0 ventricular ectopic beats were observed; with 0 isolated single events. 0 couplets. and 0 runs.

ST SEGMENT REPORT

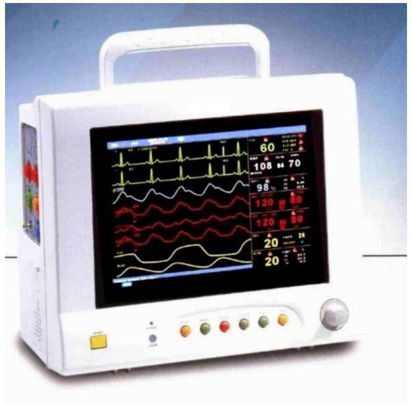
For channel 1. the maximum ST segment elevation/depression observed was + 2.0 mm during minute 8:12.
For channel 2. the maximum ST segment elevation/depression observed was + 1.4 mm during minute 10:56.

Závěr : T^{K}vale sin.r. s přiměřenými tep.fr. při klidném bdění s akelerací na max. 135/min.
Ve spánku nejnižší tep.fr. 35-38 při RR int. 1,6 sec. - sinusová bradykardie.
Jiné formy bradykarcie nezastiženy - nemá AV blok..

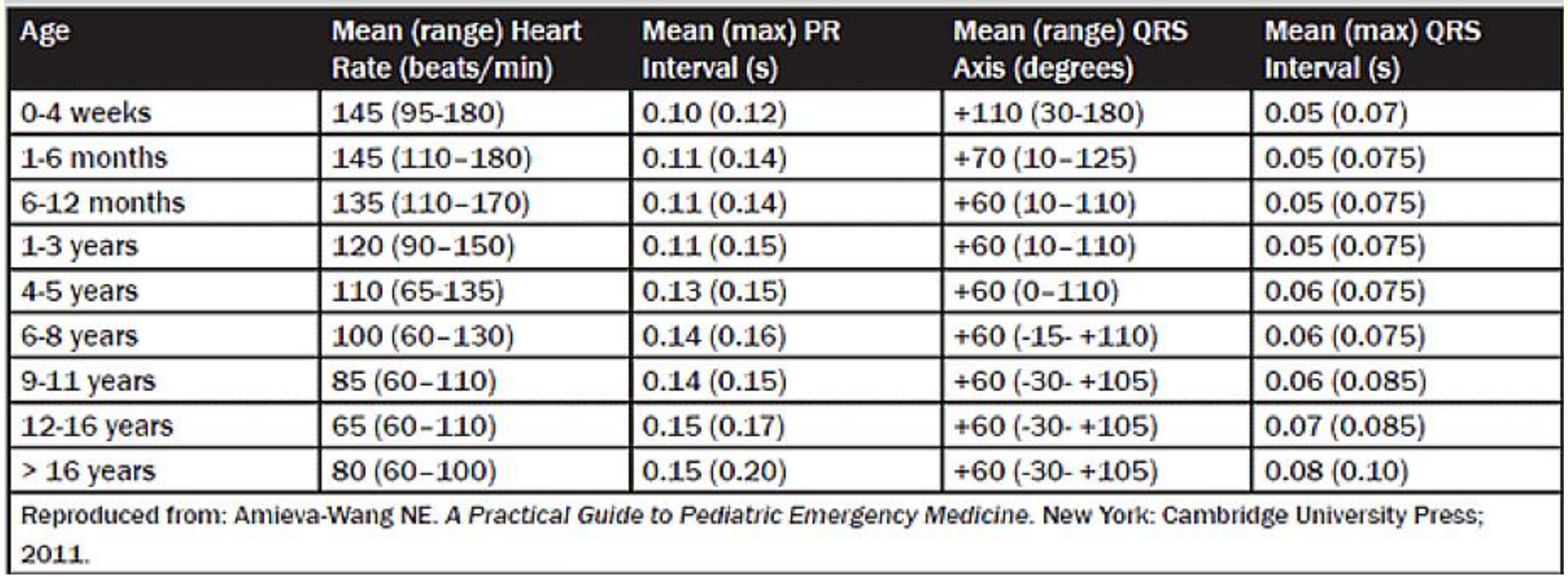


Monitorování EKG v intenzivní péči

- **monitorování** (dlouhodobé)
  - „bedside“ – monitorování jednoho svodu v reálném čase + dechová frekvence
  - změna rytmu
  - výskyt extrasystoly – začne houkat alarm



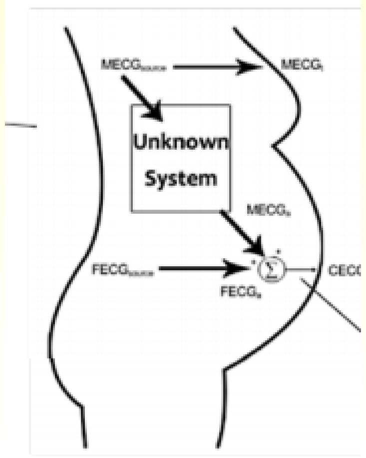
EKG u dětí

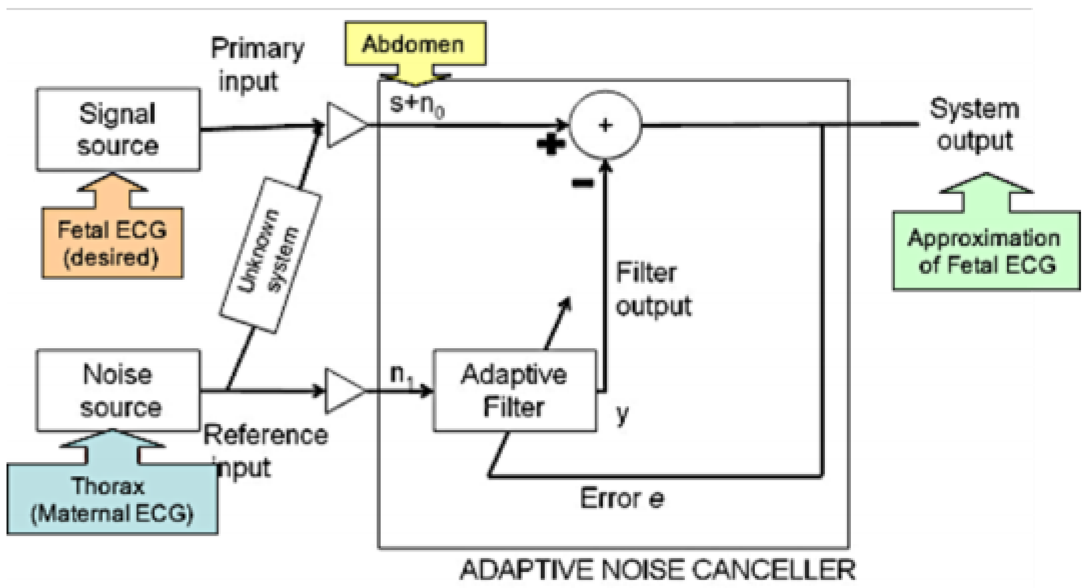


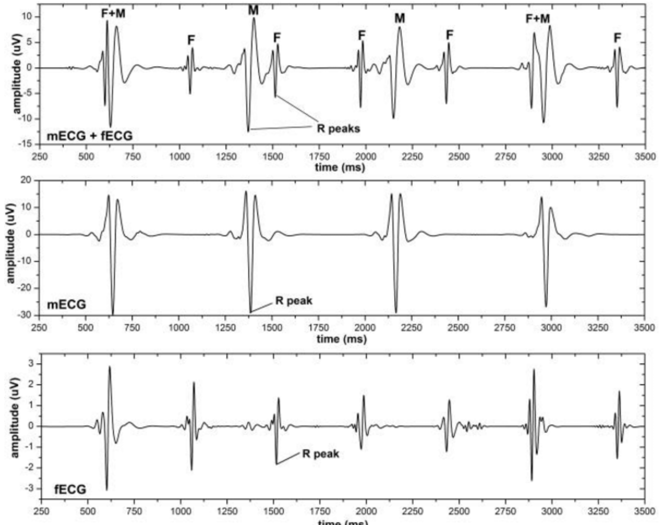
Age	Mean (range) Heart Rate (beats/min)	Mean (max) PR Interval (s)	Mean (range) QRS Axis (degrees)	Mean (max) QRS Interval (s)
0-4 weeks	145 (95-180)	0.10 (0.12)	+110 (30-180)	0.05 (0.07)
1-6 months	145 (110–180)	0.11 (0.14)	+70 (10–125)	0.05 (0.075)
6-12 months	135 (110–170)	0.11 (0.14)	+60 (10–110)	0.05 (0.075)
1-3 years	120 (90–150)	0.11 (0.15)	+60 (10–110)	0.05 (0.075)
4-5 years	110 (65-135)	0.13 (0.15)	+60 (0–110)	0.06 (0.075)
6-8 years	100 (60–130)	0.14 (0.16)	+60 (-15- +110)	0.06 (0.075)
9-11 years	85 (60–110)	0.14 (0.15)	+60 (-30- +105)	0.06 (0.085)
12-16 years	65 (60–110)	0.15 (0.17)	+60 (-30- +105)	0.07 (0.085)
> 16 years	80 (60–100)	0.15 (0.20)	+60 (-30- +105)	0.08 (0.10)

Reproduced from: Amieva-Wang NE. *A Practical Guide to Pediatric Emergency Medicine*. New York: Cambridge University Press; 2011.

Fetální EKG


$MECG_{source}$
$MECG_{t}$
Unknown System
$MECG_{a}$
$FECG_{source}$
$FECG_{a}$
CECG


Abdomen
Primary input
Signal source
Fetal ECG (desired)
s+n_0
+
+
−
System output
Approximation of Fetal ECG
Unknown system
Filter output
Noise source
Thorax (Maternal ECG)
Reference input
n_1
Adaptive Filter
y
Error e
ADAPTIVE NOISE CANCELLER

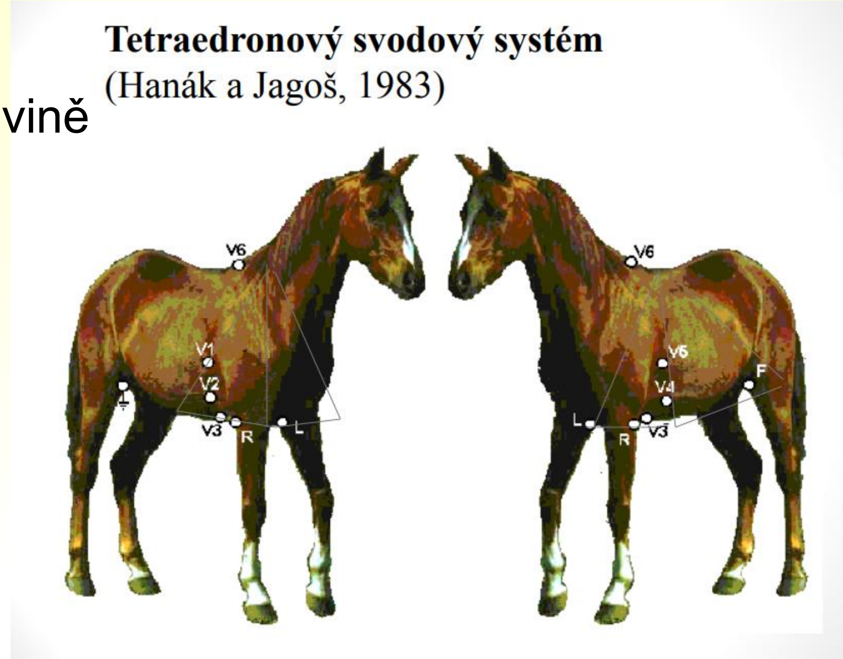

F+M
F
M
F
F
M
F
F+M
F
R peaks
mECG + fECG
amplitude (uV)
time (ms)
10
5
0
-5
-10
-15
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
3250
3500
mECG
R peak
20
10
0
-10
-20
-30
fECG
R peak
3
2
1
0
-1
-2
-3

EKG ve veterinární medicíně

6 končetinových svodů :

snímají srdce ze stran a zezadu v horizontální rovině

I,II,aVL „se dívají“ na levý laterální povrch
III, aVF zezadu
aVR na pravou síň



Tetraedronový svodový systém
(Hanák a Jagoš, 1983)

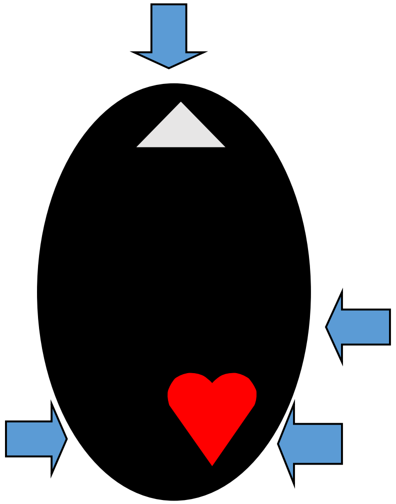
6 hrudních svodů:

snímají srdce v transverzální rovině

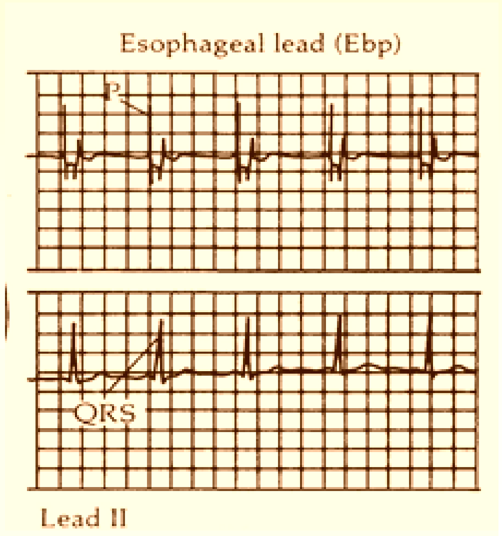
C1 „se dívá“ na pravou síň a komoru
C4 na septum a levou komoru
C5 na levou komoru
C6 levou síň

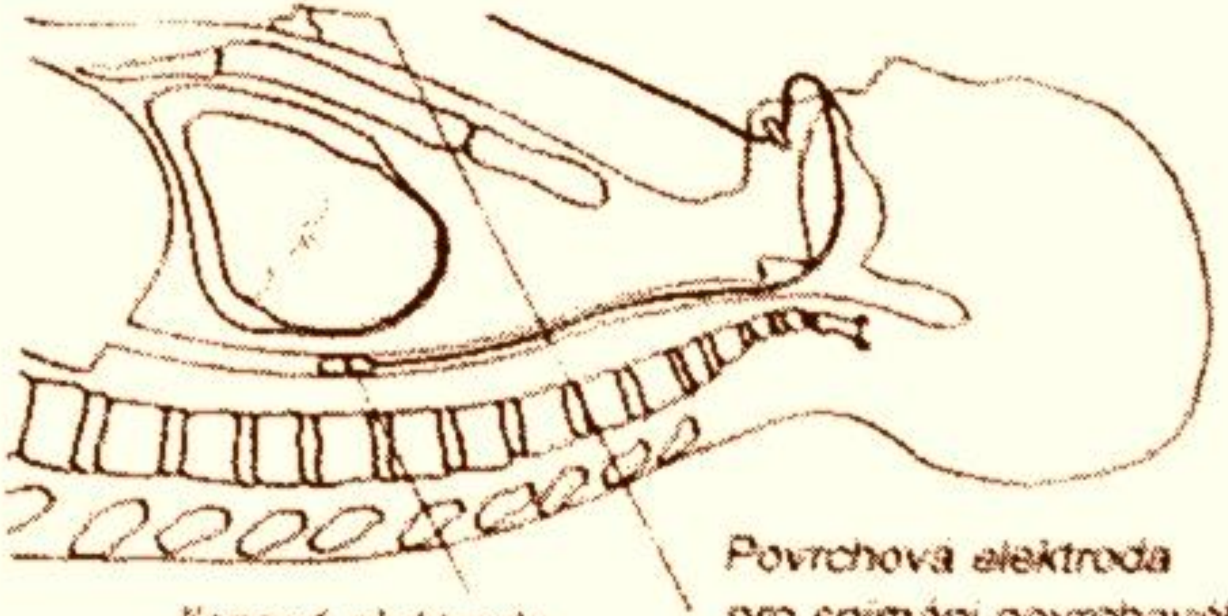
Poloha zvířete

- v sedě
- v náruči majitele
- na pravém boku
  (ve stoje vznikají ARTEFAKTY !)



Jícnová elektrokardiografie

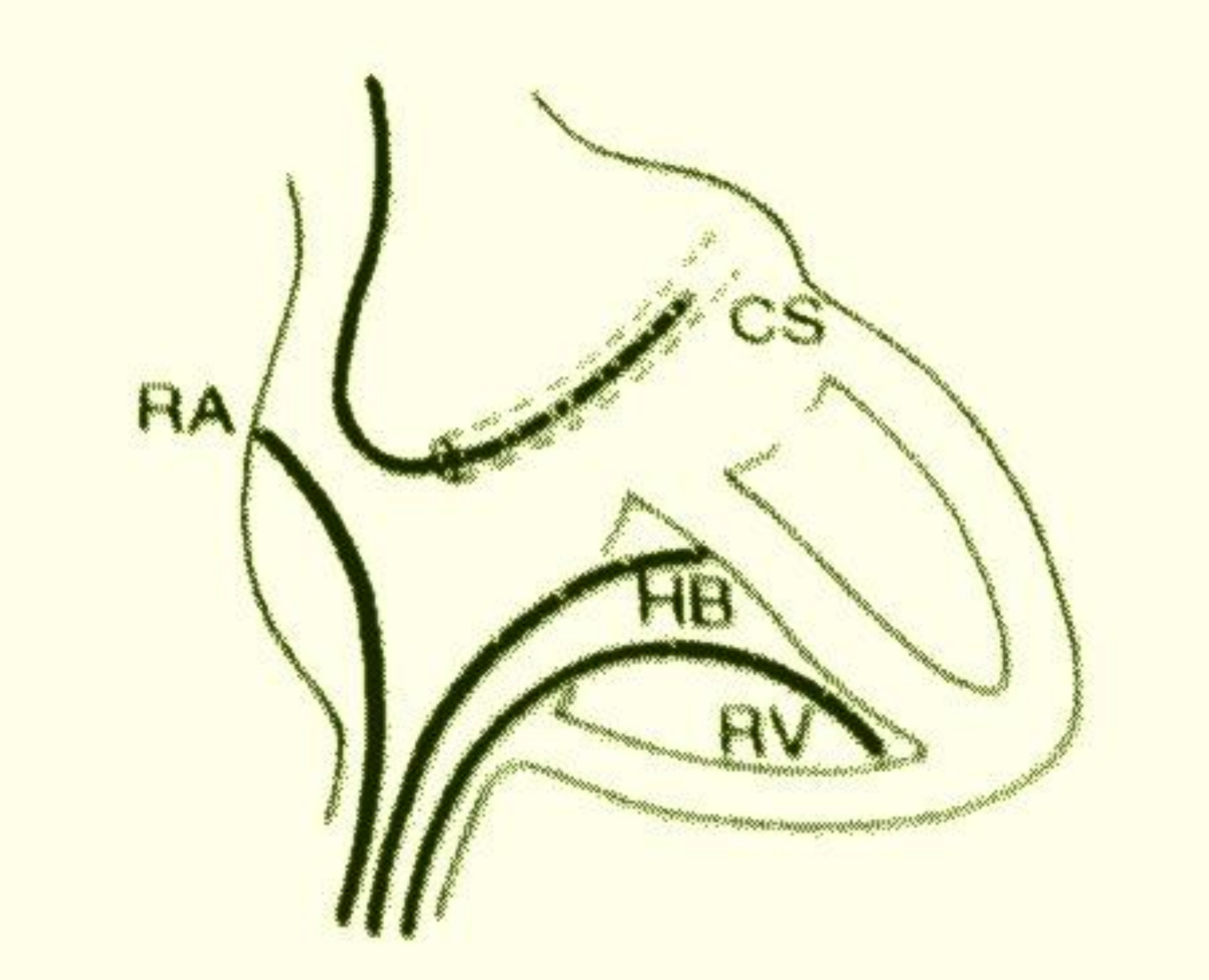




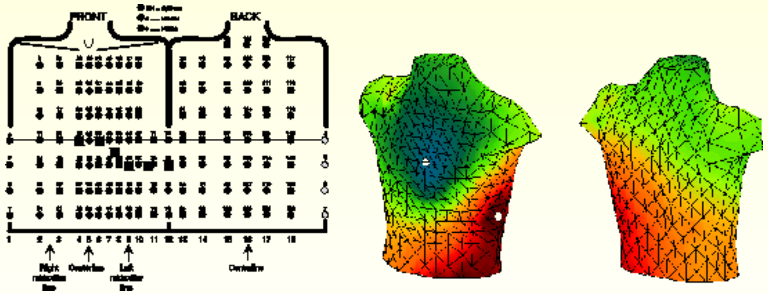
Povrchová elektroda
pro snímání povrchového EKG

Jícnová elektroda
pro snímání EKG
a srdeční stimulaci

Intrakardiální EKG



Izopotenciálové mapování

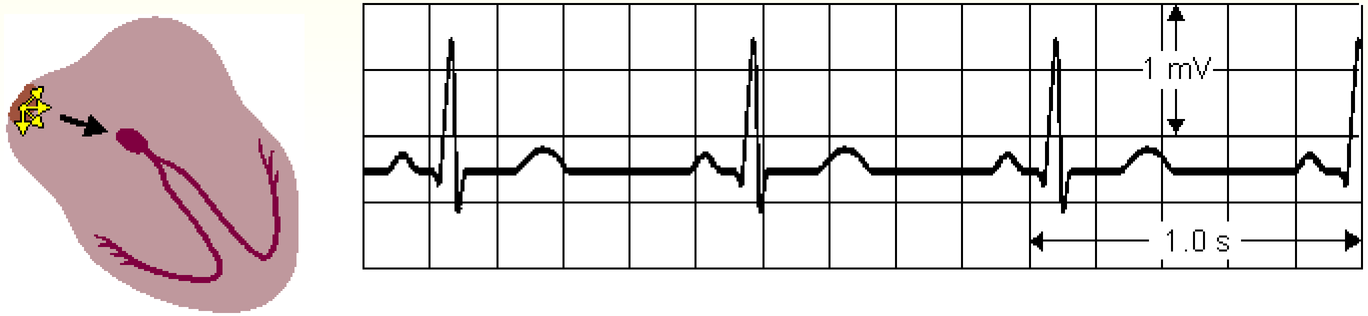


Základní EKG křivky

Normální sinusový rytmus

NORMAL SINUS RHYTHM

Impuses originate at S-A node at normal rate

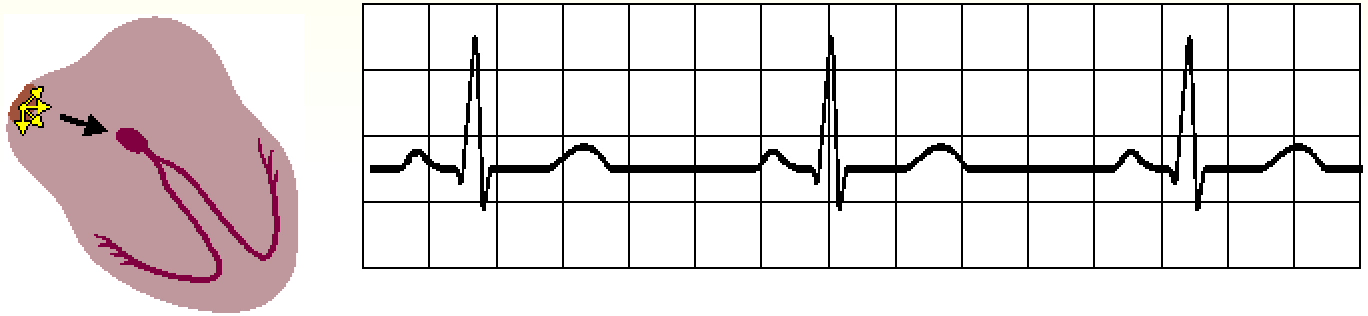


All complexes normal, evenly spaced
Rate 60 - 100/min

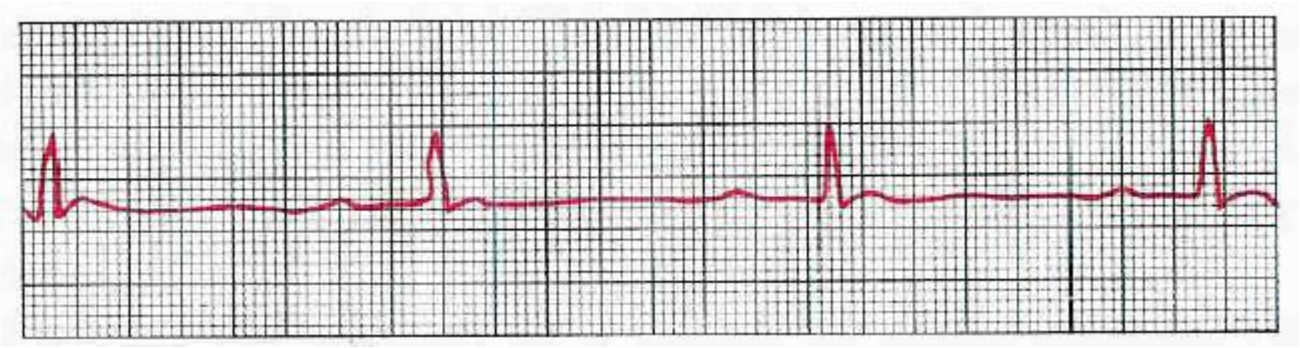
Sinusová bradykardie

SINUS BRADYCARDIA

Impuses originate at S-A node at slow rate



All complexes normal, evenly spaced
Rate < 60 - 100/min

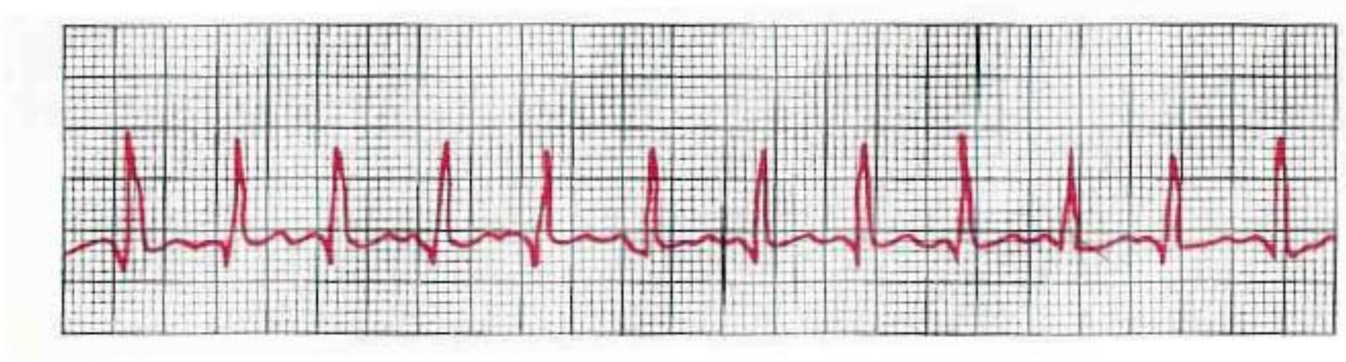


Sinusová tachykardie

SINUS TACHYCARDIA

Impuses originate at S-A node at rapid rate

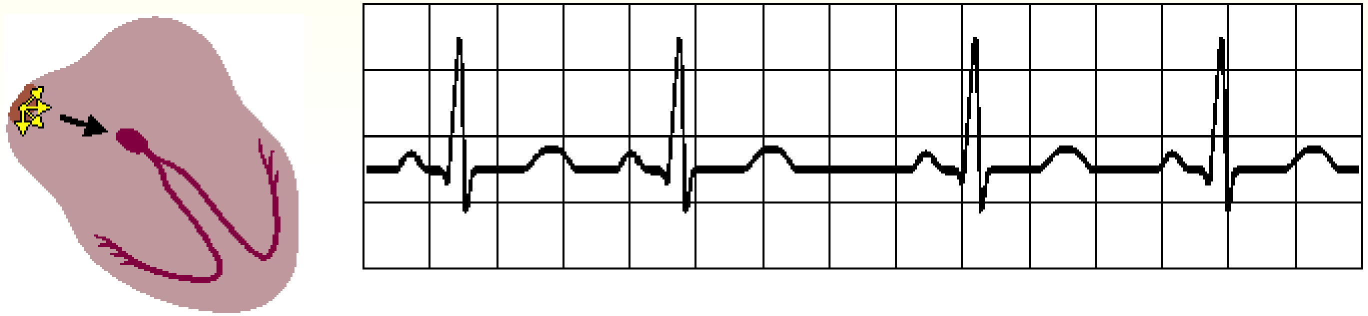
All complexes normal, evenly spaced
Rate > 100/min



Respirační arytmie

SINUS TACHYCARDIA

Impuses originate at S-A node at rapid rate

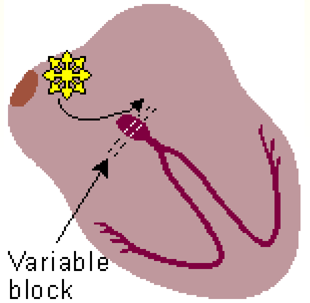


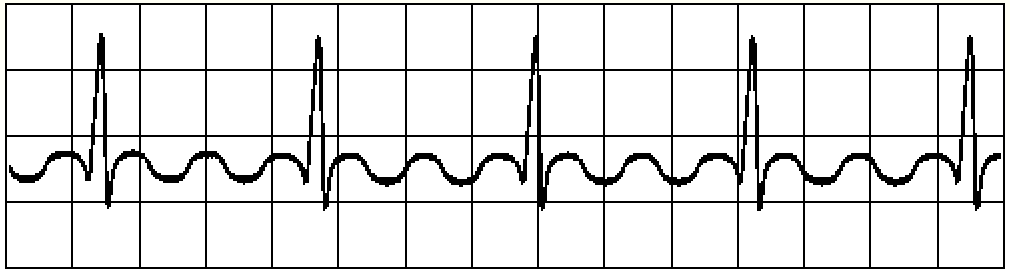
All complexes normal, rhythm is irregular
Longest R-R interval exceeds shirtest > 0.16 s

Flutter síní

ATRIAL FLUTTER

Impulses travel in circular course in atria



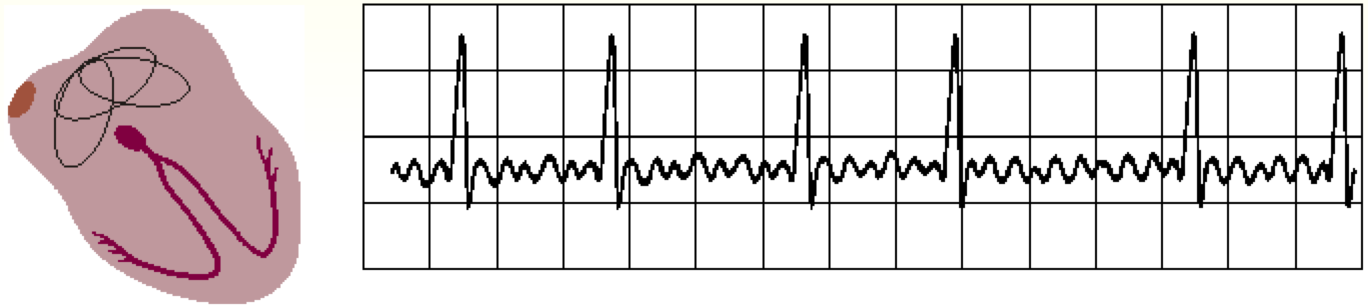


Rapid flutter waves, ventricular response irregular

Fibrilace síní

ATRIAL FIBRILLATION

Impuses have chaotic, random pathways in atria



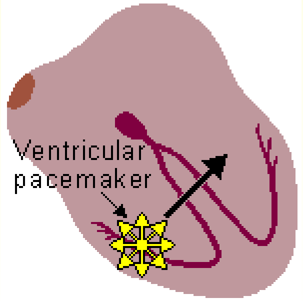
Baseline irregular, ventricular response irregular

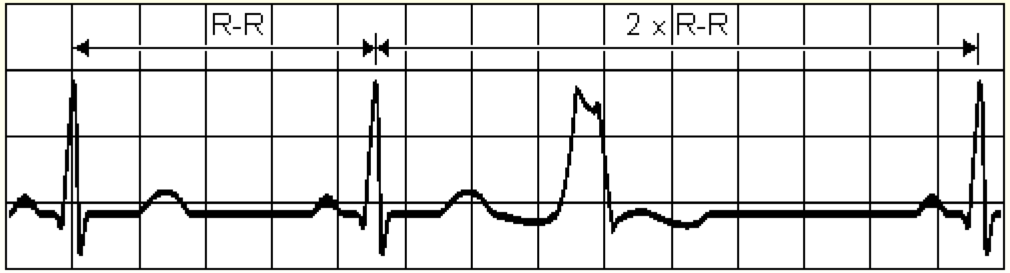
Komorová extrasystola

(premature ventricular contraction, PVC)

PREMATURE VENTRICULAR CONTRACTION

A single impulse originates at right ventricle



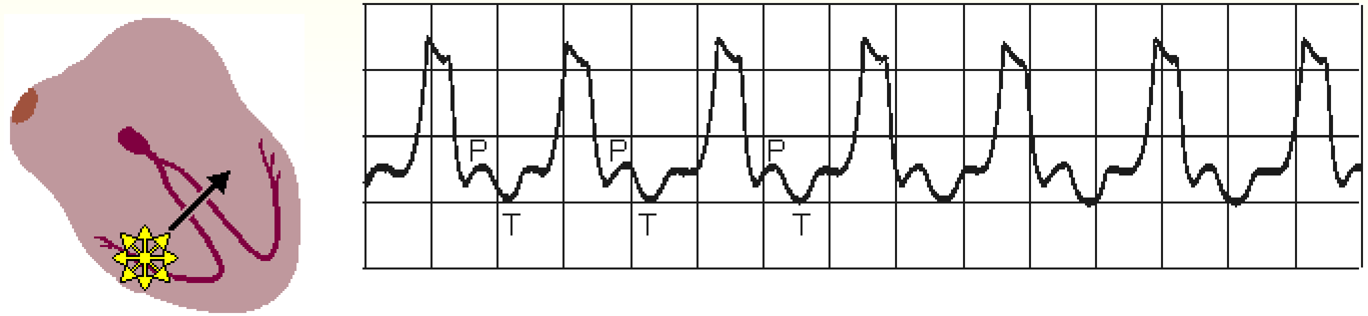


Time interval between normal R peaks
is a multiple of R-R intervals

Komorová tachykardie

VENTRICULAR TACHYCARDIA

Impulse originate at ventricular pacemaker

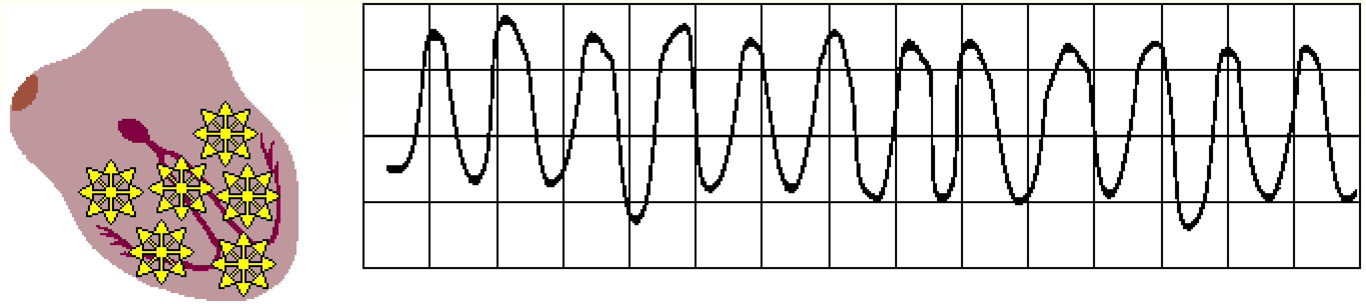


Wide ventricular complexes
Rate> 120/min

Fibrilace komor

VENTRICULAR FIBRILLATION

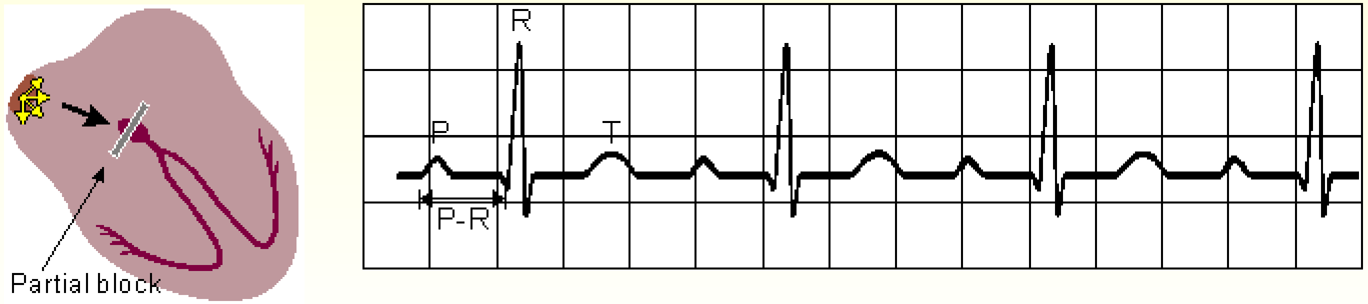
Chaotic ventricular depolarization



Rapid, wide, irregular ventricular complexes

A-V blokáda, 1. stupeň

A-V BLOCK, FIRST DEGREE
Atrio-ventricular conduction lengthened



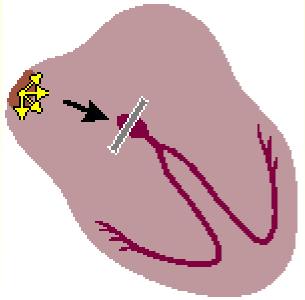
P-wave precedes each QRS-complex but PR-interval is > 0.2 s

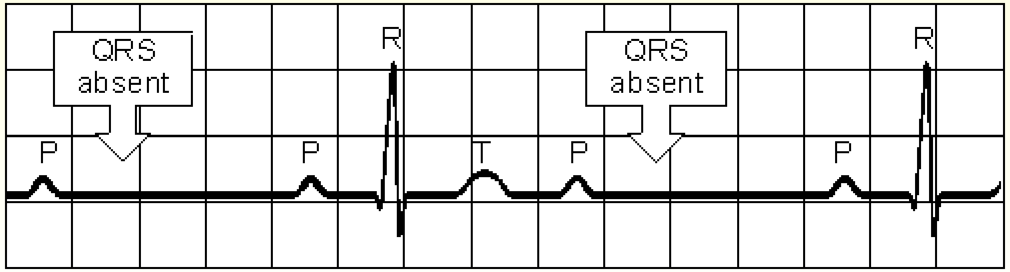
Prodloužení srdečního cyklu při 1.-stupňové blokádě AV uzlu

A-V blokáda, 2. stupeň

A-V BLOCK, SECOND DEGREE

Sudden dropped QRS-complex





Intermittently skipped ventricular beat

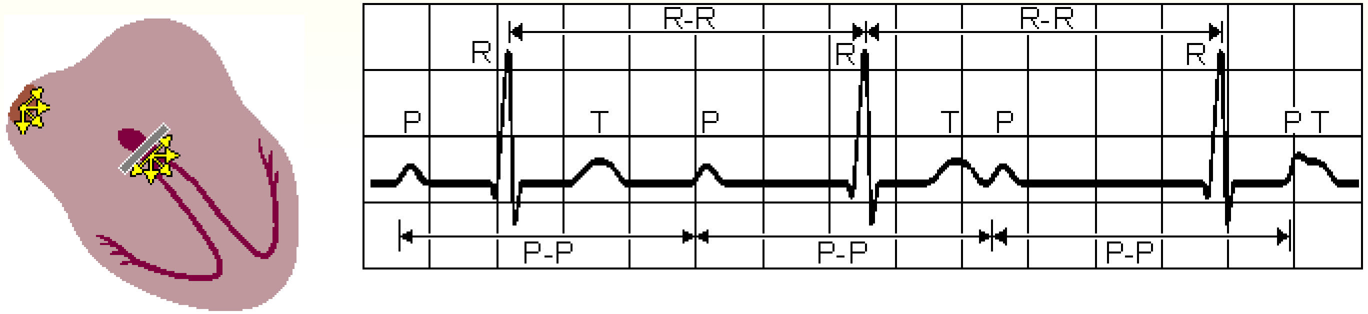
Blokáda AV uzlu 2. řádu, III. svod

A-V blokáda, 3. stupeň

A-V BLOCK, THIRD DEGREE

Impulses originate at AV node and proceed to ventricles

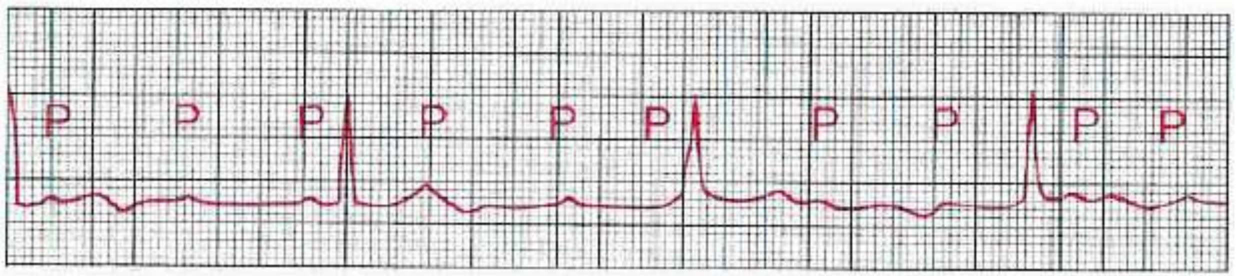
Atrial and ventricular activities are not synchronous



P-P interval normal and constant,

QRS complexes normal, rate constant, 20 - 55 /min

Úplná AV blokáda

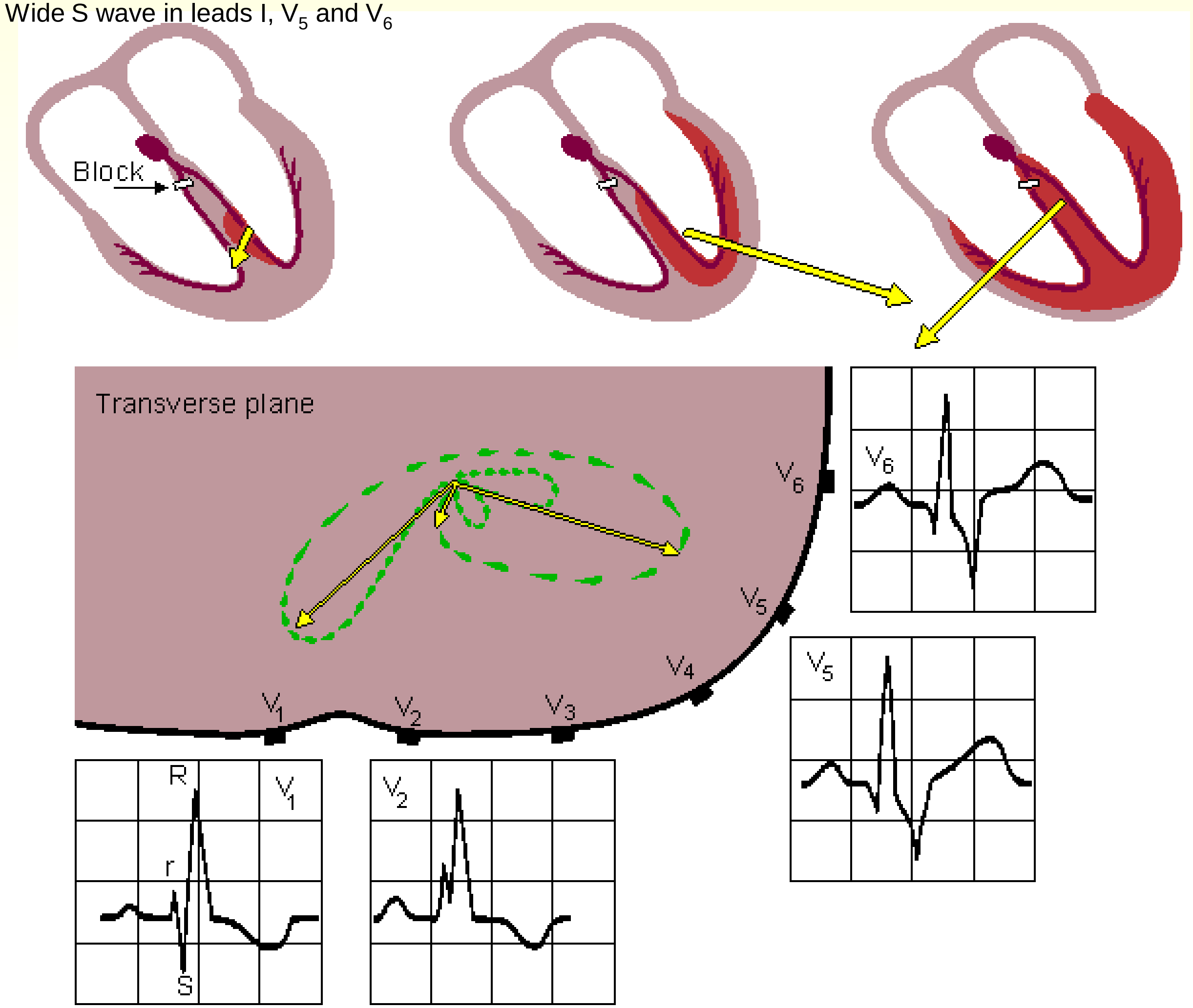


Blokáda pravého Tawarova raménka

RIGHT BUNDLE-BRANCH BLOCK

QRS duration greater than 0.12 s

Wide S wave in leads I, V_5 and V_6

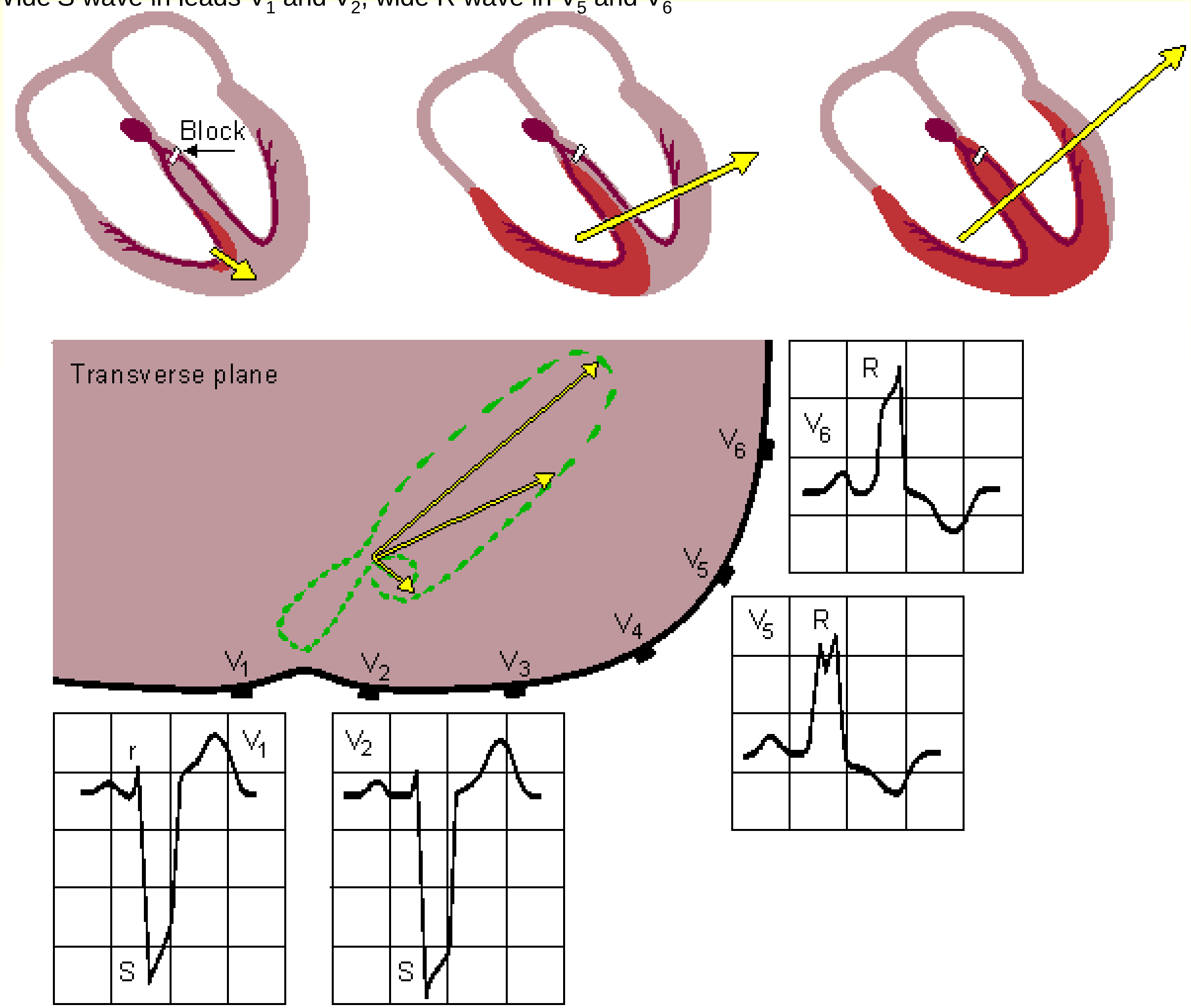


Blokáda levého Tawarova raménka

LEFT BUNDLE-BRANCH BLOCK

QRS duration greater than 0.12 s

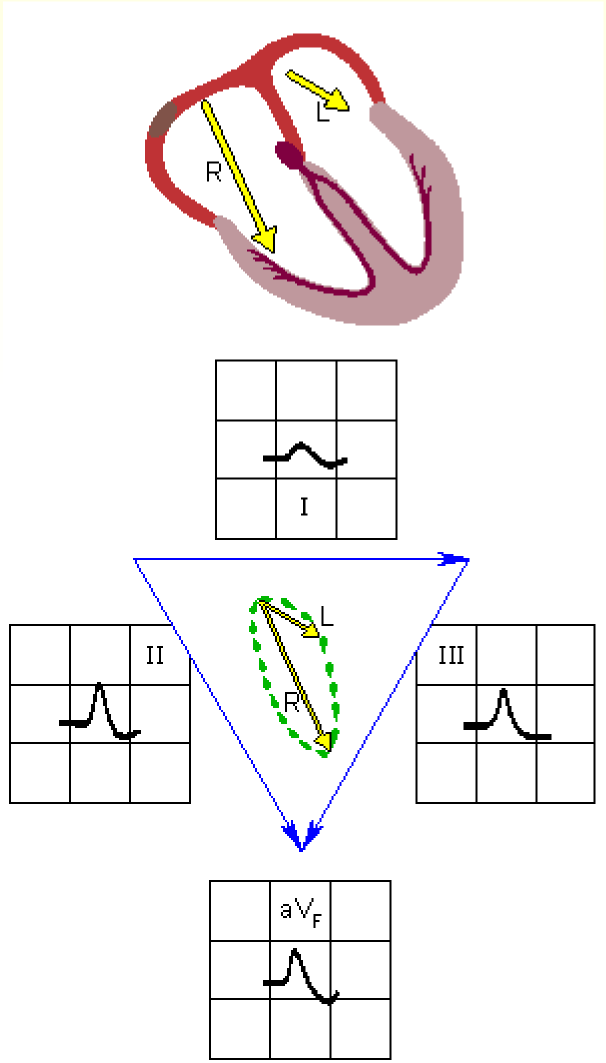
Wide S wave in leads V_1 and V_2, wide R wave in V_5 and V_6



Síňová hypertrofie

RIGHT ATRIAL HYPERTROPHY

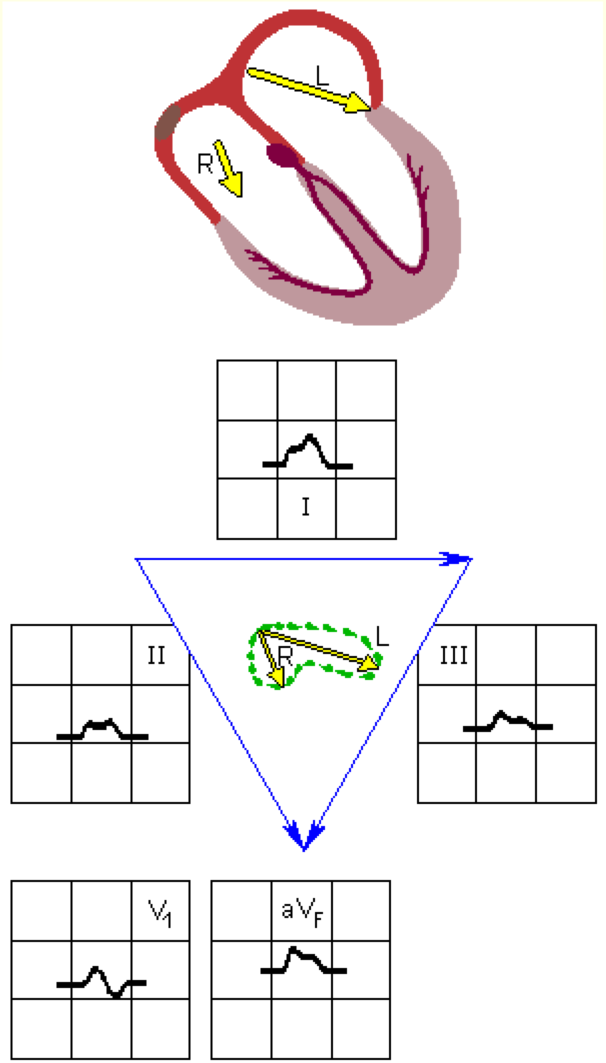
Tall, peaked P wave in leads I and II



LEFT ATRIAL HYPERTROPHY

Wide, notched P wave in lead II

Diphasic P wave in V_1

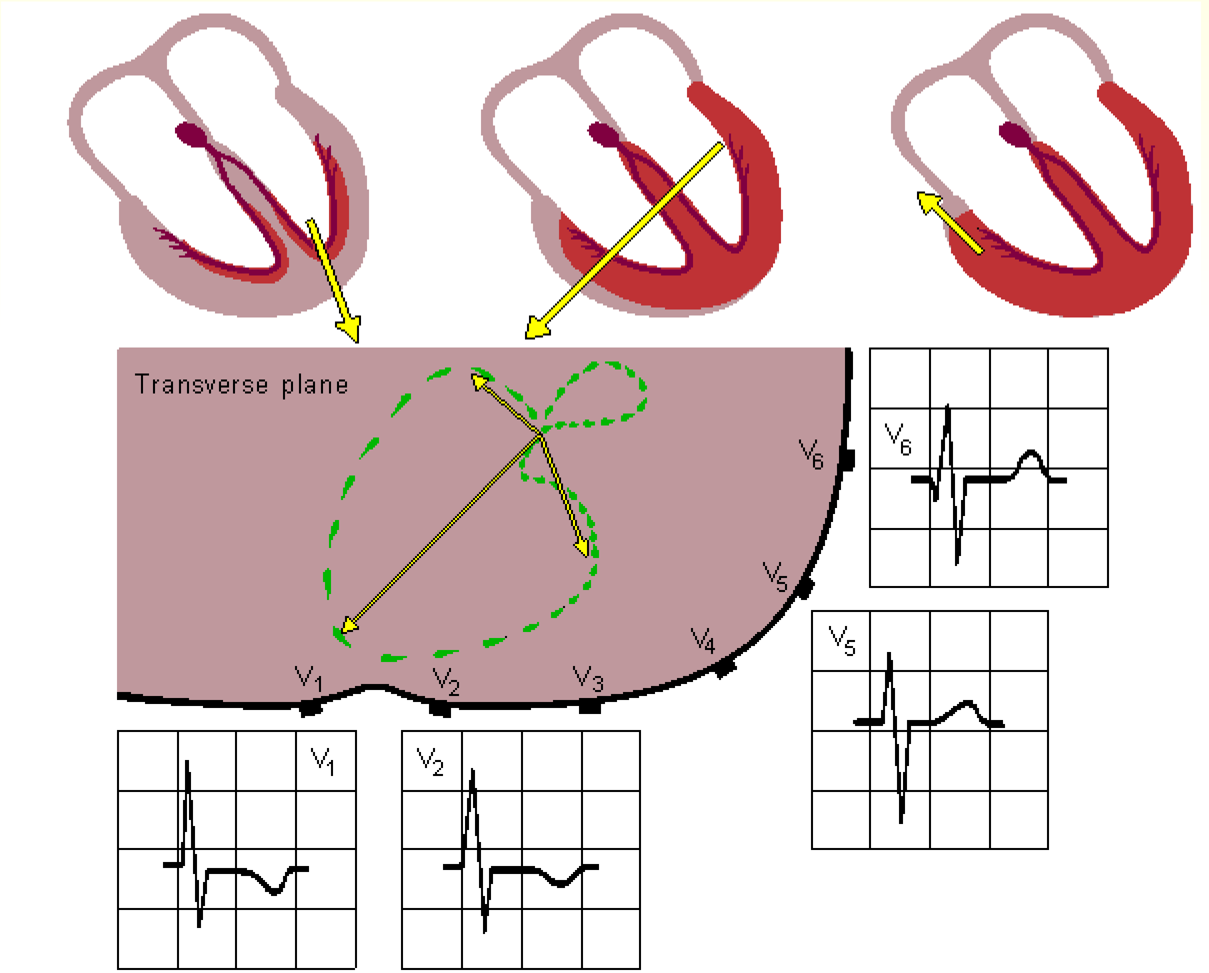


Hypertrofie pravé komory

RIGHT VENTRICULAR HYPERTROPHY

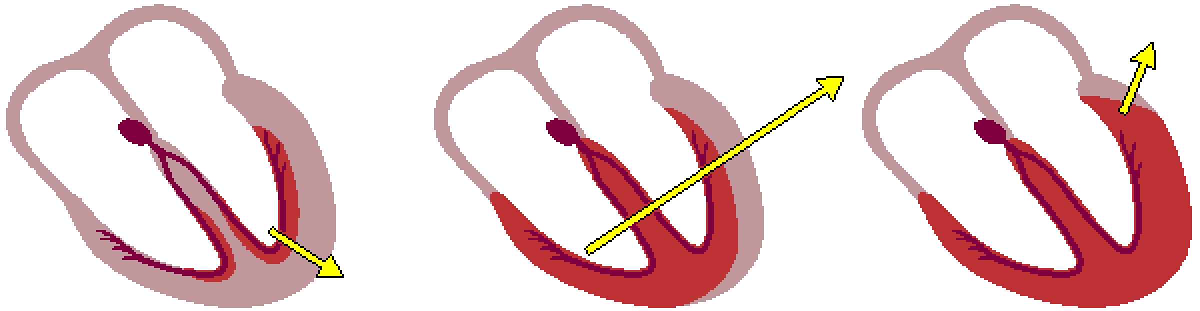
Large R wave in leads V_1 and V_3

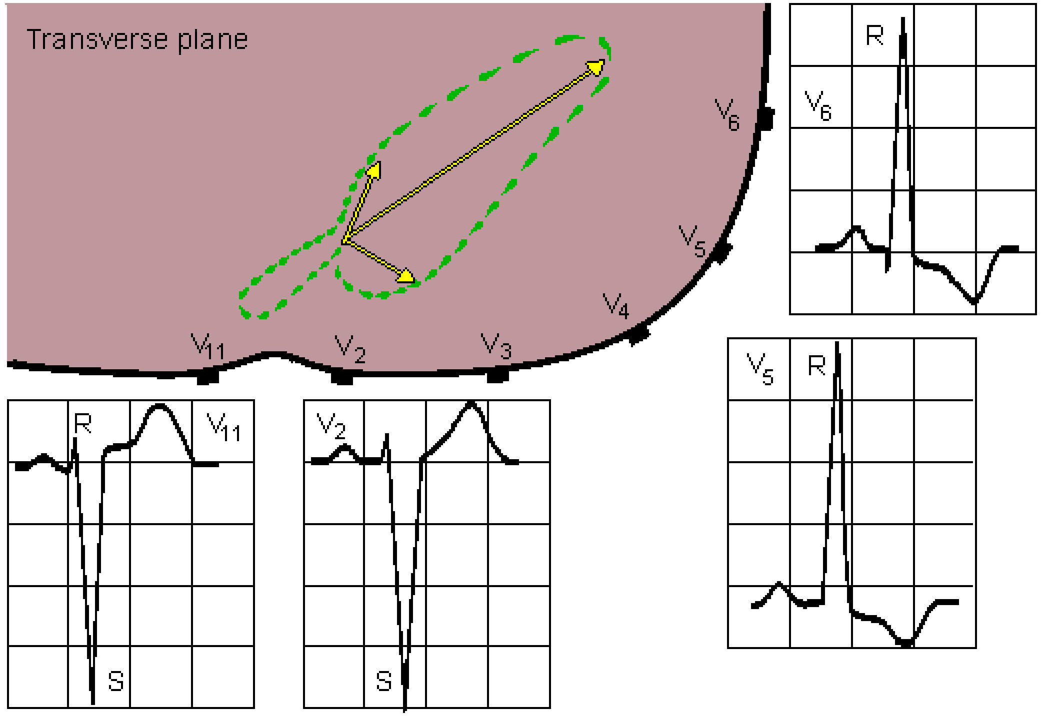
Large S wave in leads V_6 and V_6



Hypertrofie levé komory

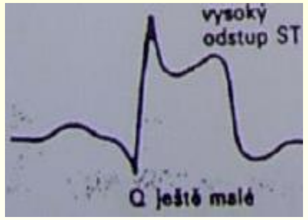
LEFT VENTRICULAR HYPERTROPHY
Large S wave in leads V_1 and V_2
Large R wave in leads V_6 and V_6



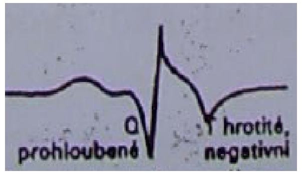


Infarkt myokardu

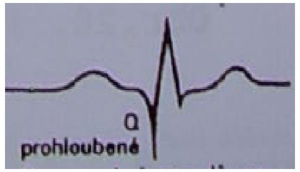
1. **Akutní stadium**
   (po hodinách)

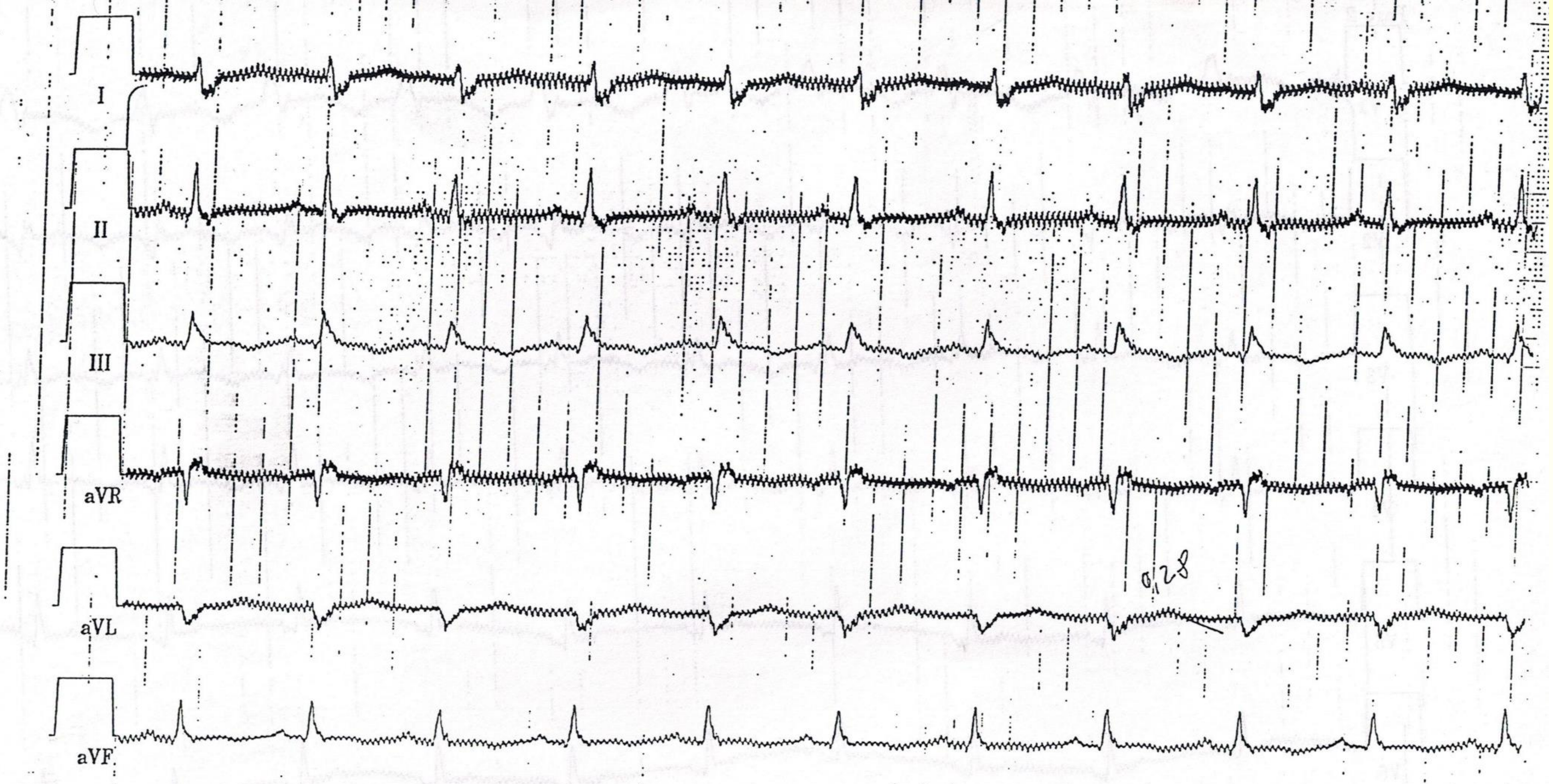


2. **Následné stadium**
   (po dnech až týdnech)



3. **Pozdní stadium**
   (po měsících až letech)





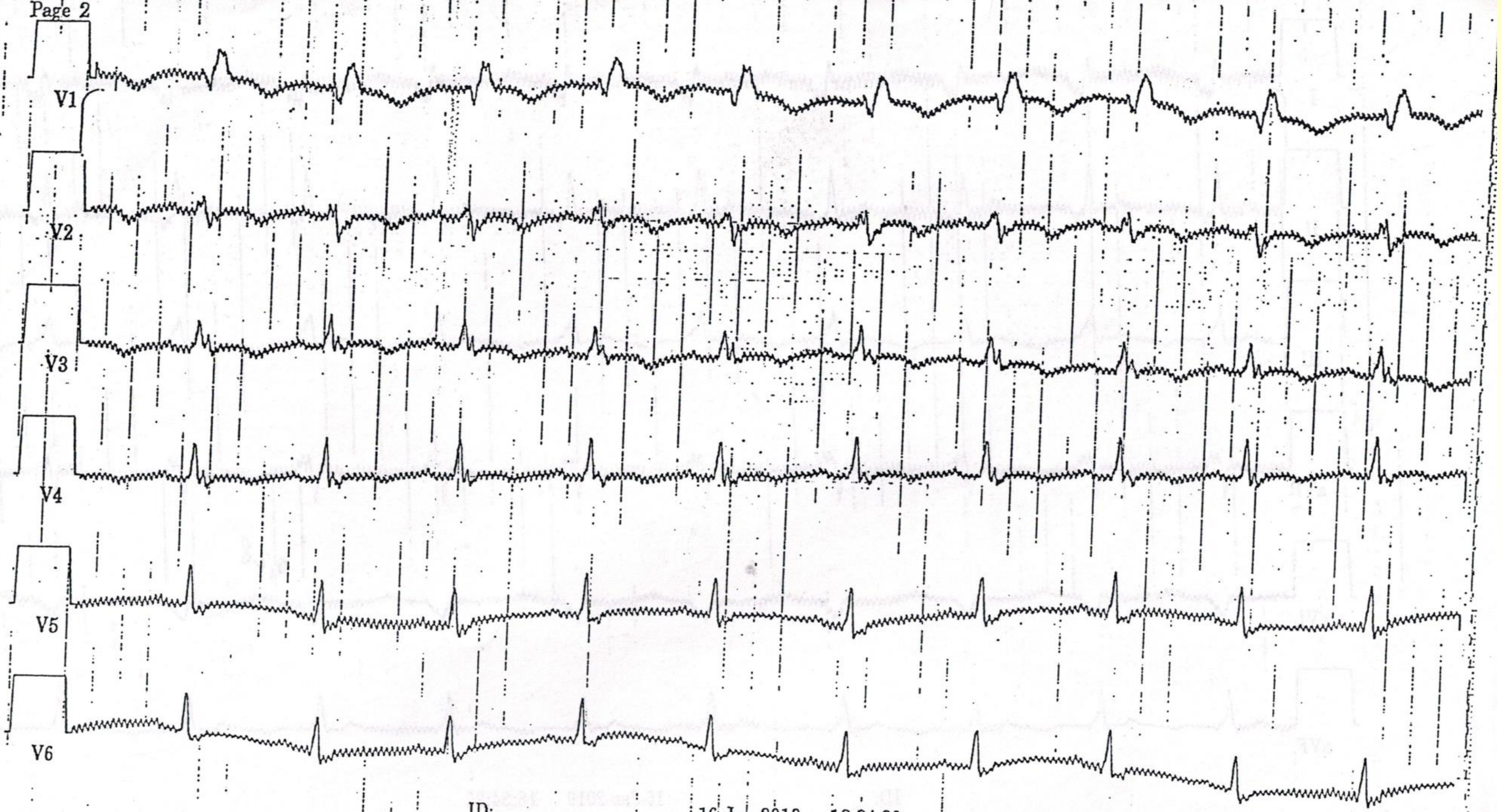
ID: 16-Jan-2010 18:34:26

Vent. rate	126	bpm
PR interval	124	ms
QRS duration	96	ms
QT/QTc	320/463	ms
P-R-T axes	56 88 -6	

Sinus tachycardia
Low voltage QRS
Incomplete right bundle branch block
T wave abnormality, consider anterior ischemia
Abnormal ECG

Unconfirmed

150 Hz 50.0 mm/s 10.0 mm/mV 2 by 5s @50mm/s MAC5K 007A.2 12SL™ v235



ID: 16-Jan-2010 18:34:26

Vent. rate	126 bpm
PR interval	124 ms
QRS duration	96 ms
QT/QTc	320/463 ms
P-R-T axes	56 88 -6

150 Hz 50.0 mm/s 10.0 mm/mV

2 by 5s @50mm/s

MAC5K 007A.2 12SL™

Základní EKG křivky

Sinus Rhythm
Sinus Bradycardia
Sinus Tachycardia
Sinus Arrhythmia
Sinus Exit Block
Sinus Arrest

NSR with PAC
SVT
Atrial Fibrillation
Atrial Flutter
Paced Atrial

NSR with 1° AVB
2° AVB Type I
2° AVB Type II
2° AVB 2:1
3° AV Block

NSR with PJC
Junctional Rhythm
Accel Junctional
Junctional Tachy
Wandering Pacemaker

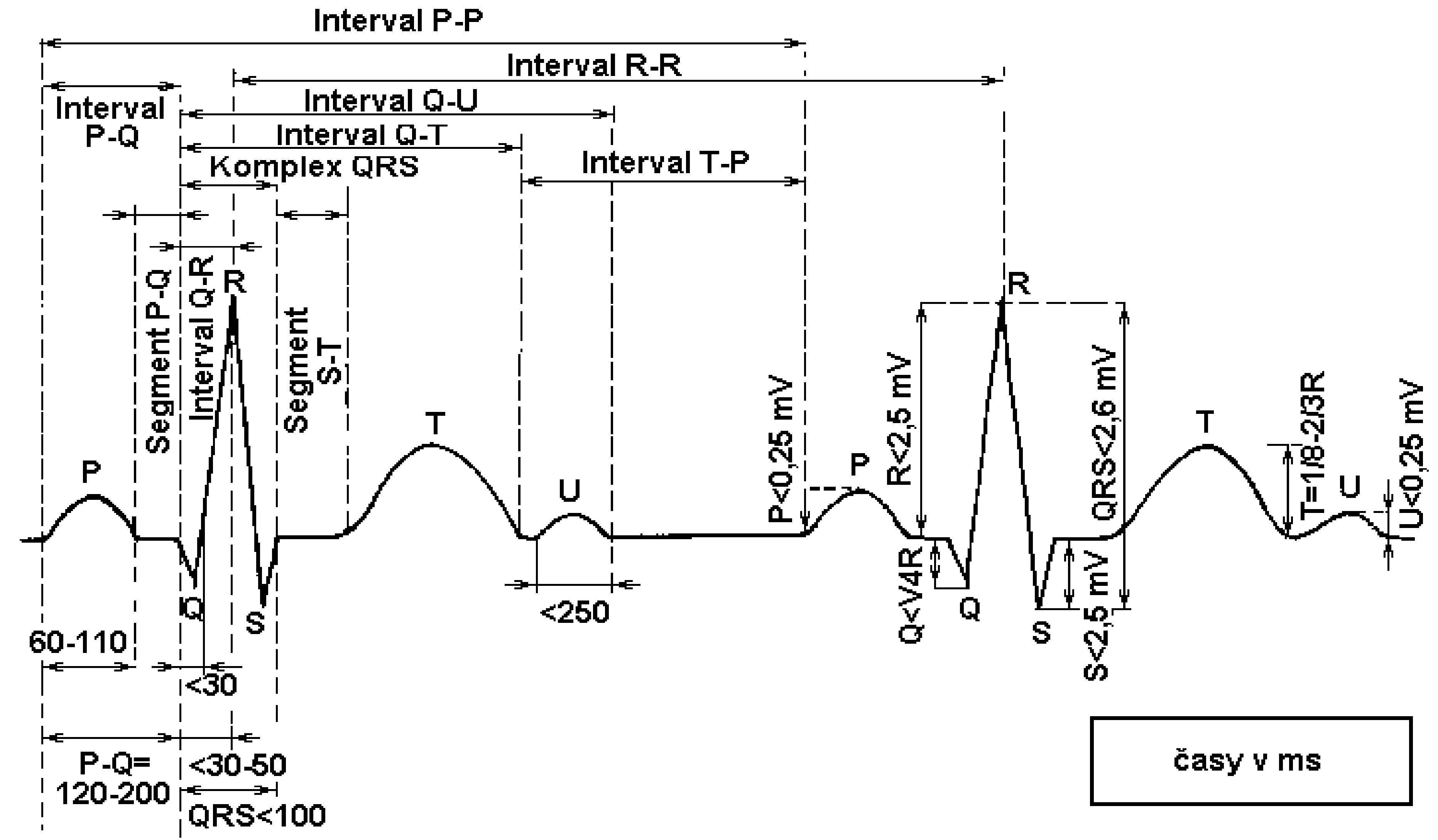
NSR with PVC
Idioventricular
Accelerated IVR
VTach
VFib
Paced Ventricular

https://www.skillstat.com/tools/ecg-simulator

Zpracování a analýza signálu EKG

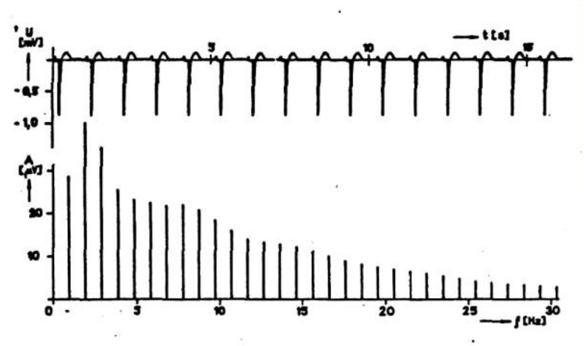
- **potlačení rušení**
- **výběr charakteristik** (detekce hrotů a vln)
- klasifikace
- interpretace

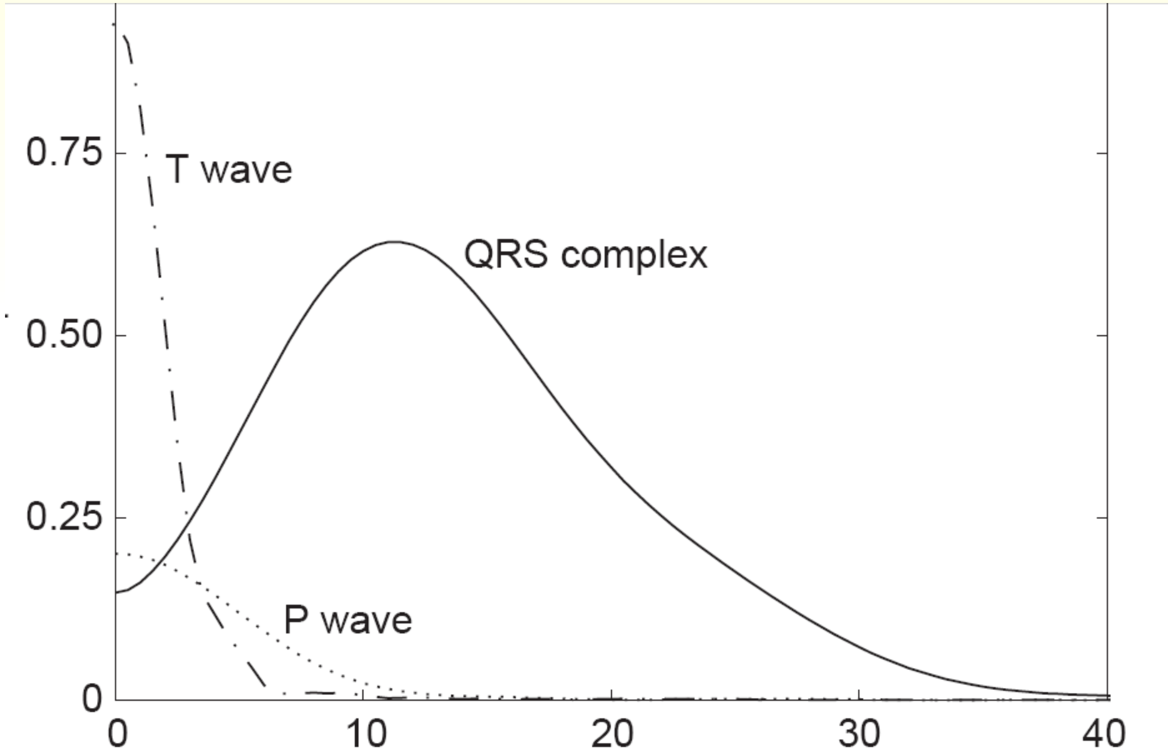
Vlastnosti signálu EKG v časové oblasti

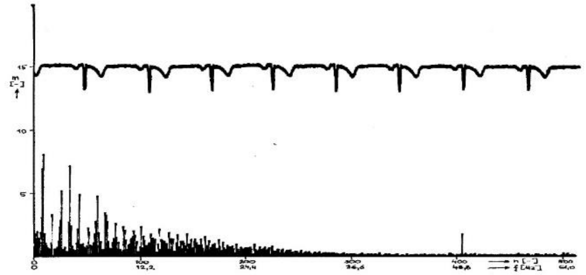


časy v ms

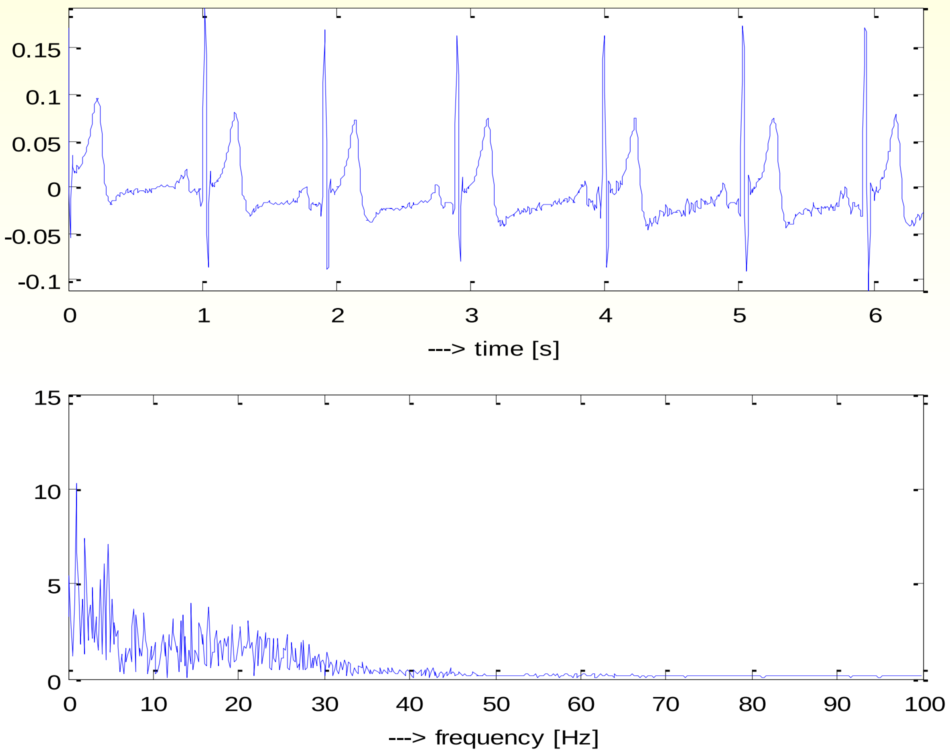
Vlastnosti signálu EKG ve frekvenční oblasti



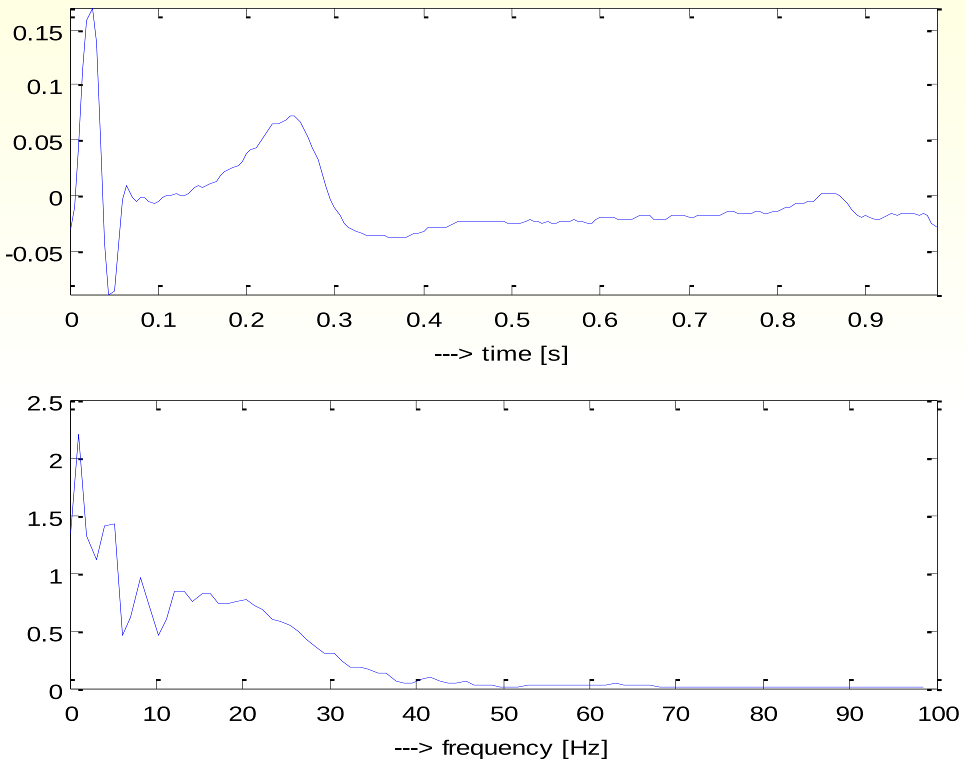




Analýza EKG ve frekvenční oblasti

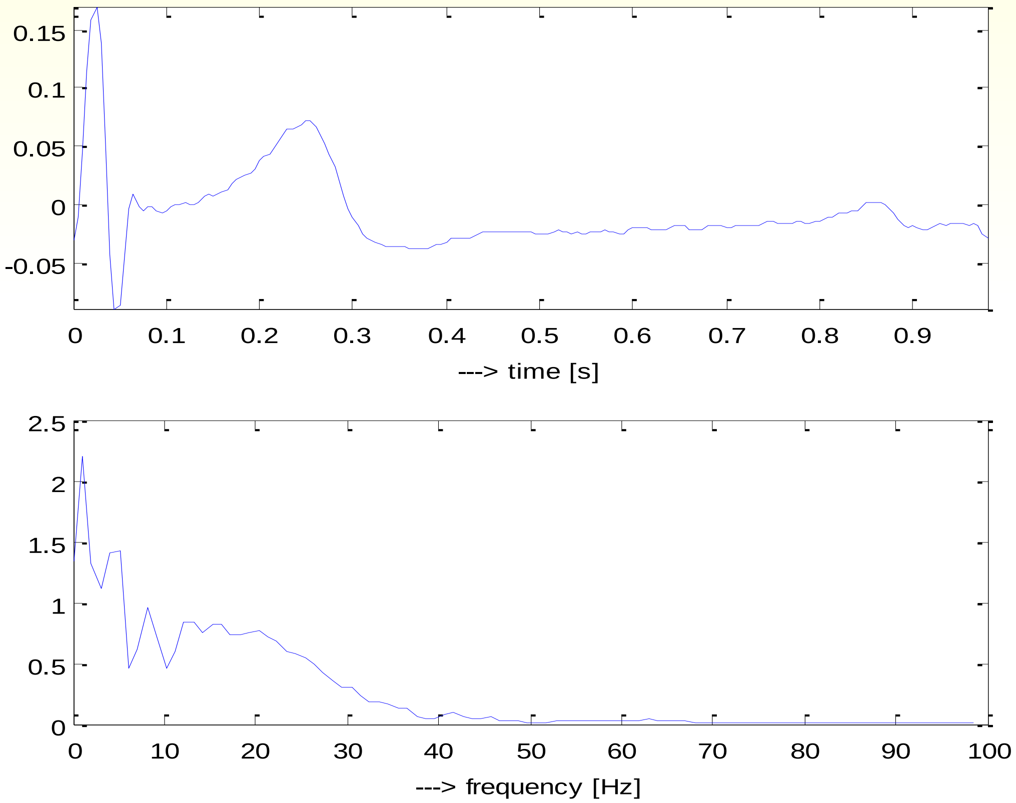


několik period signalu a odpovidajici rozmazane spektrum



jedna perioda (jeden cyklus)

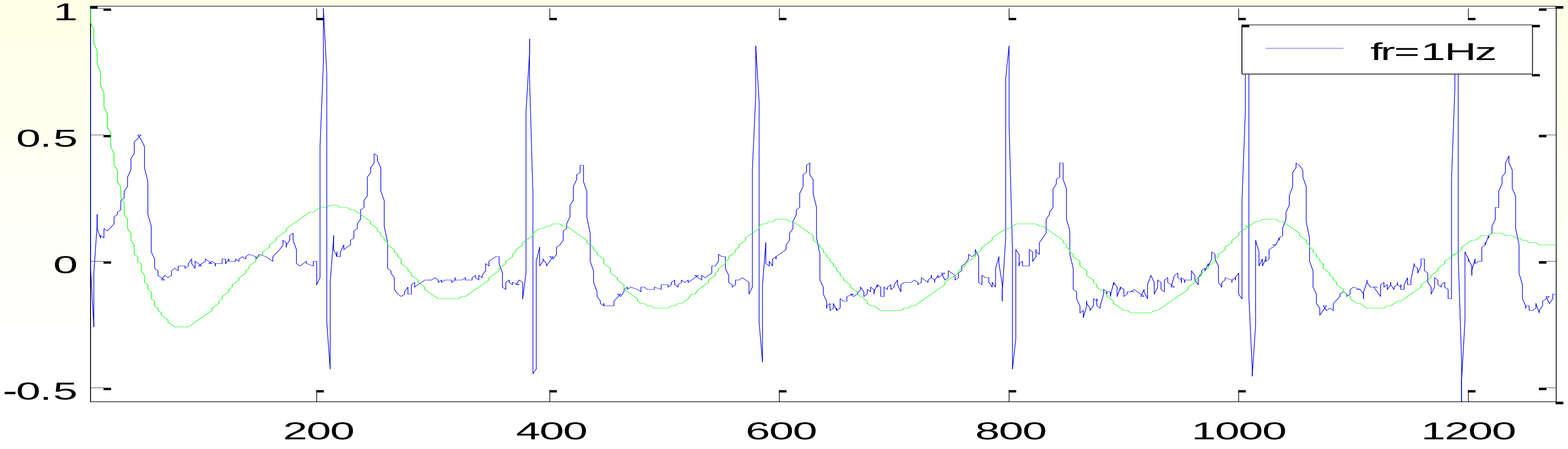
Analýza EKG ve frekvenční oblasti



Ve spektrech lze
sledovat několik vrcholu
1 az 2 Hz
4 az 5 Hz
kolem 8 Hz
od 12 Hz vyse

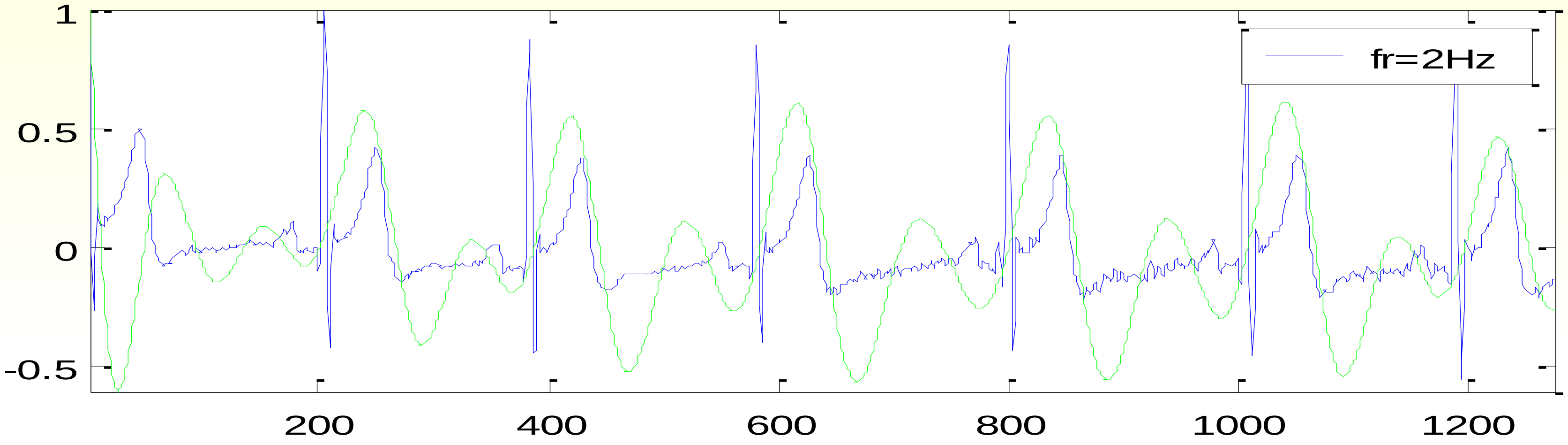
Kterym castem spektra prislusi jednotlive grafoelementy z EKG signalu?

Analýza EKG ve frekvenční oblasti



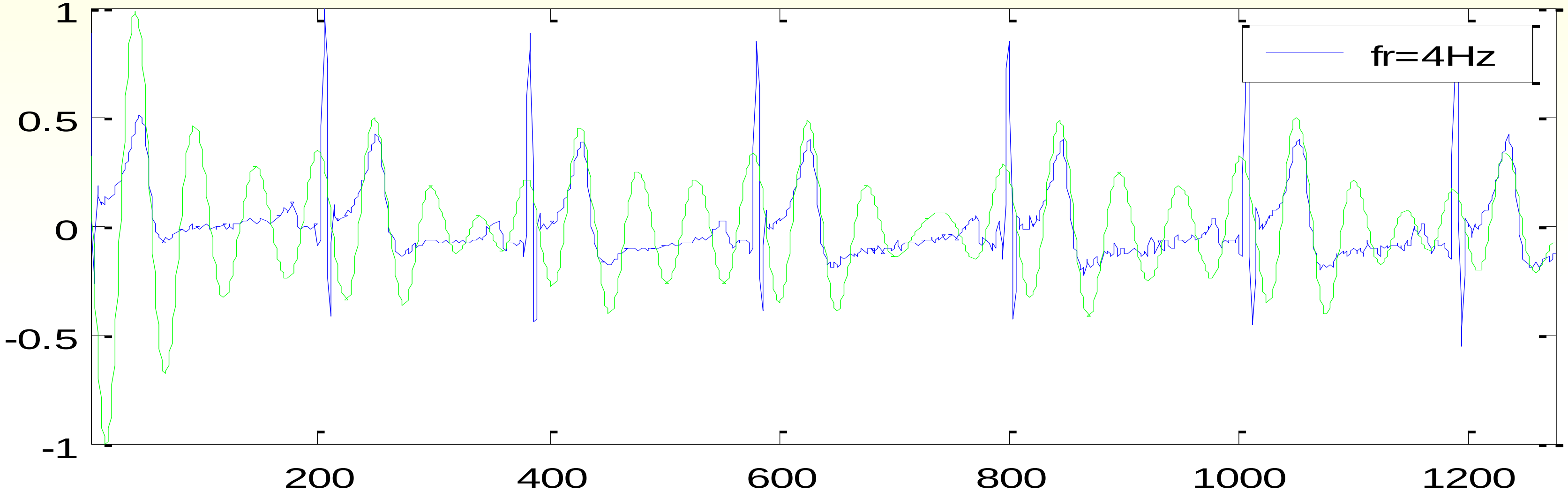
prubeh po pruchodu filtrem vyladěným na 1 Hz je ve fazi s jednotlivými cykly
– 1 Hz odpovídá tepove frekvenci,
je tedy zakladni periodou signalu

Analýza EKG ve frekvenční oblasti



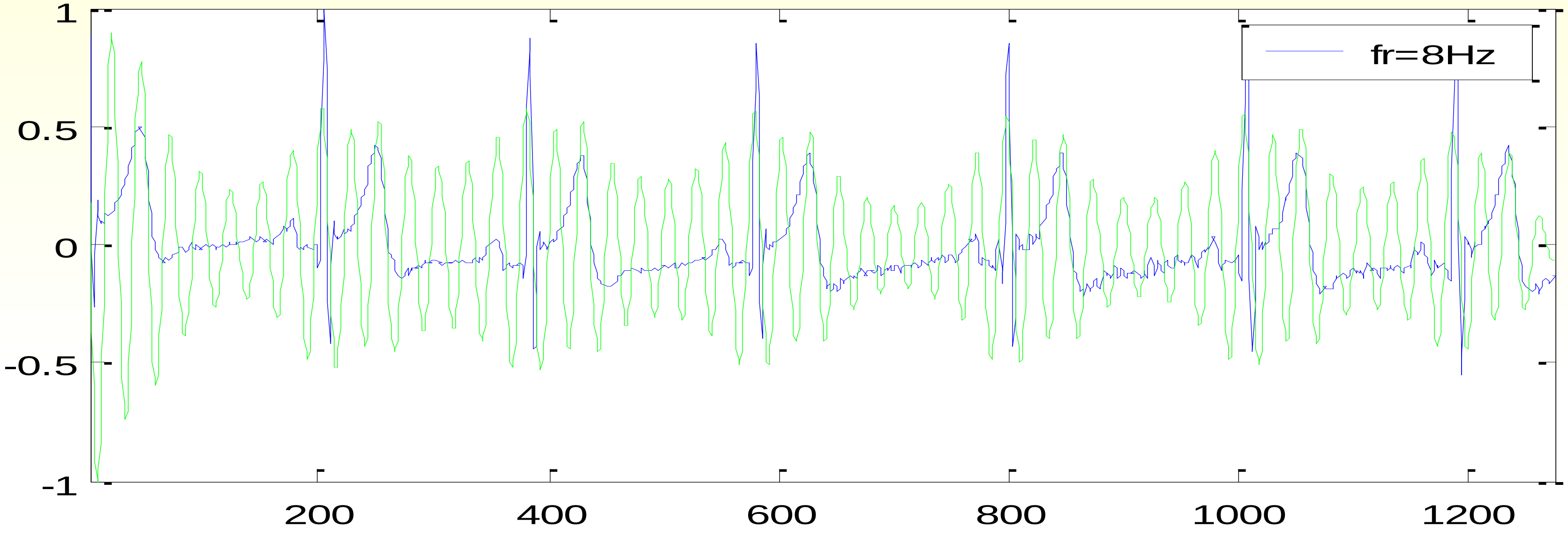
Průchod rezonátorem s fr=2Hz je ve fazi s usekem S-T

Analýza EKG ve frekvenční oblasti



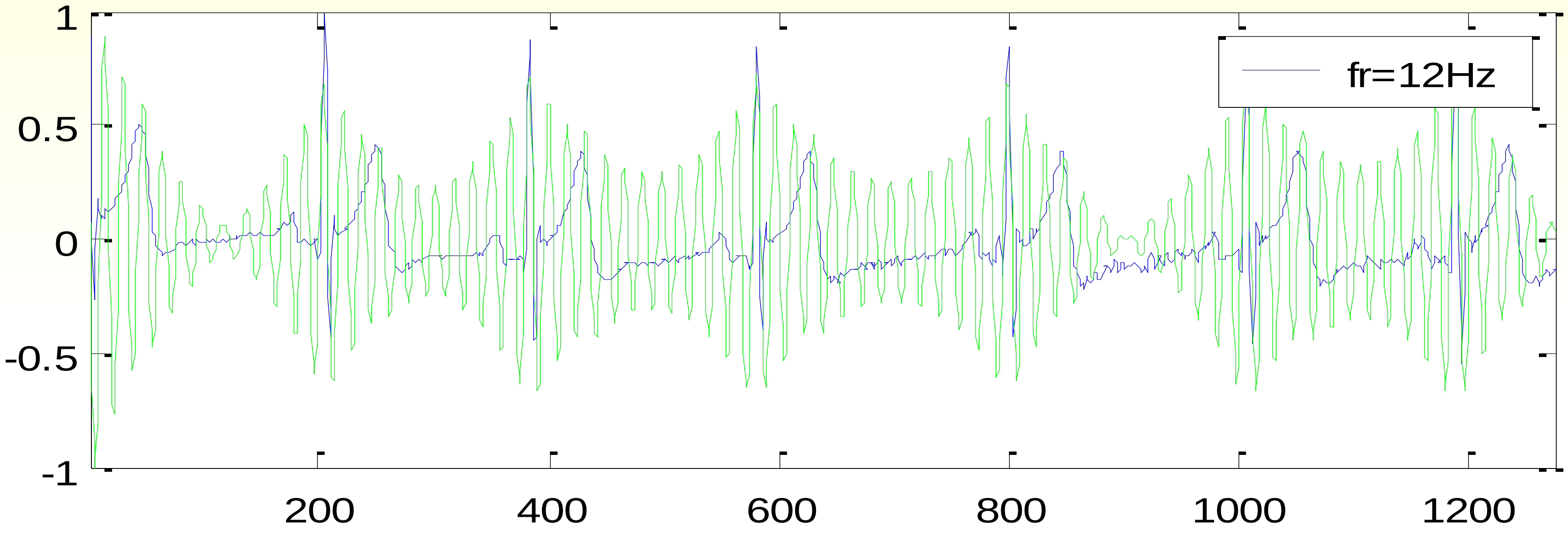
Prubeh pro fr=4Hz je ve fazi s T vlnou

Analýza EKG ve frekvenční oblasti



Prubeh pro fr=8Hz se chyta P vlny (a uz i trochu QRS)

Analýza EKG ve frekvenční oblasti



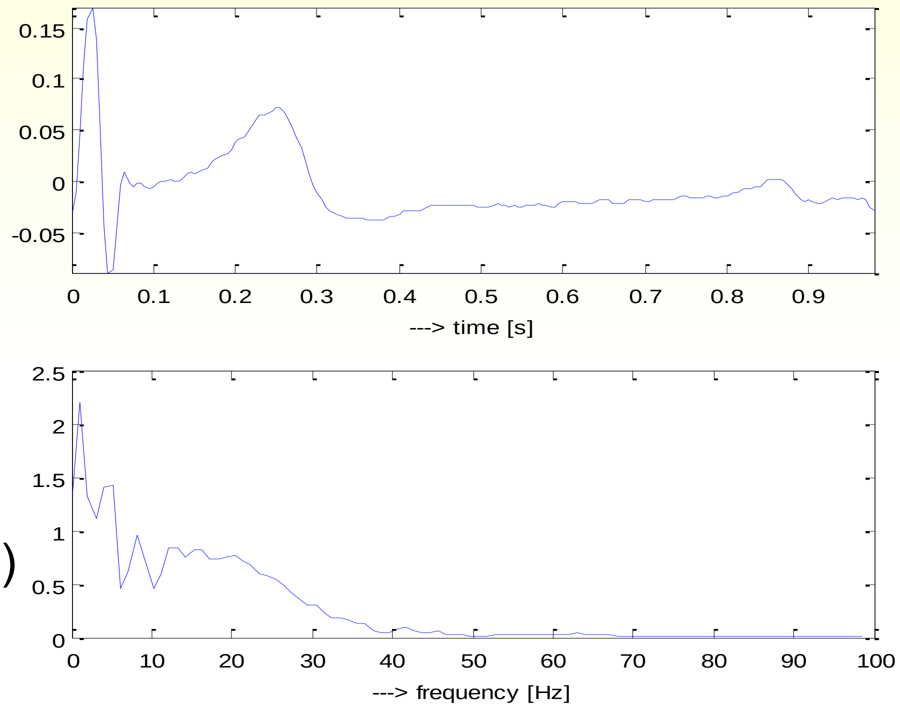
Od 12 Hz vyse průběhy silne „rezonuji“ s QRS komplexem

Analýza EKG ve frekvenční oblasti

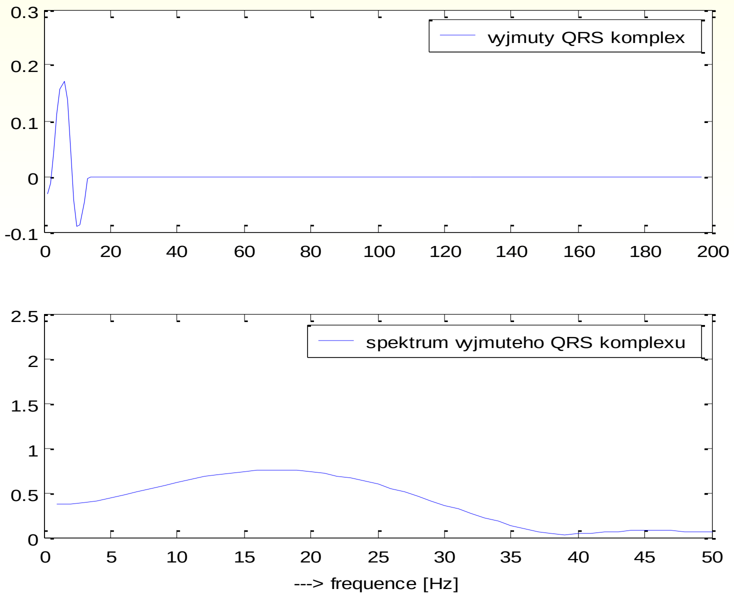
Zaver:

spicky ve spektru jsou „zpusobeny“:

1 Hz	tepovou frekvenci
2 Hz	S-T usekem
4 az 5 Hz	T vlnou
kolem 8 Hz	P vlnou
od 12 Hz vyse	QRS komplexem (úzkým impulsum odpovídají sirsi spektra a naopak)

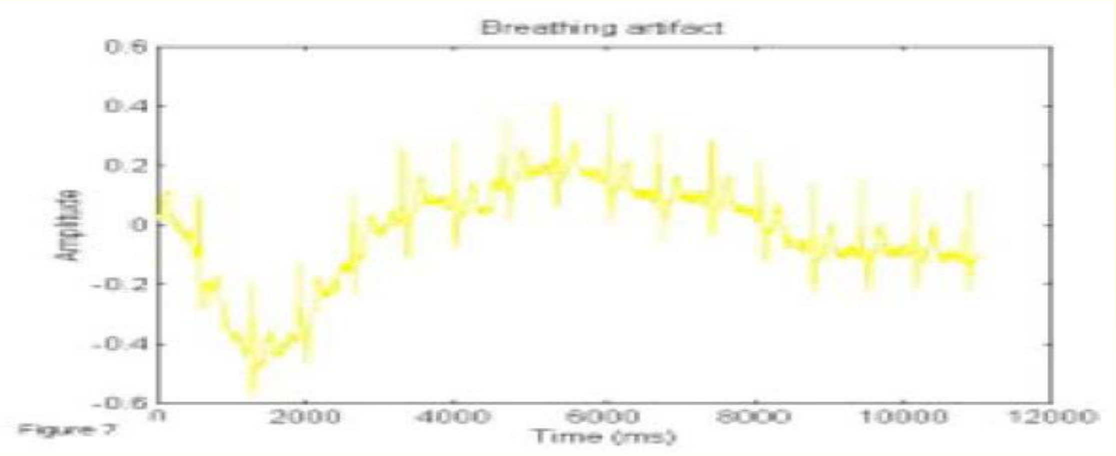


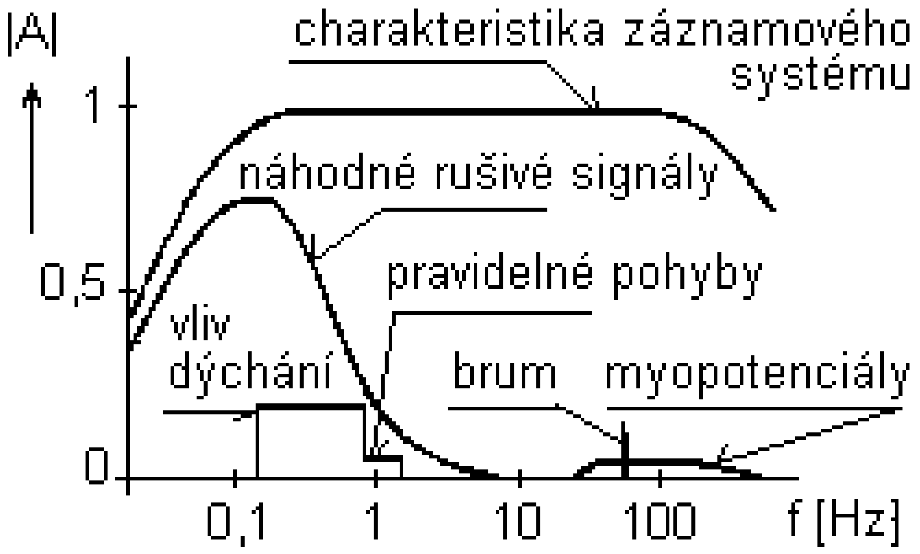
Analýza EKG ve frekvenční oblasti



Rušení signálu EKG

- **ÚZKOPÁSMOVÉ RUŠENÍ**
  - kolísání (drift) základní izoelektrické linie
  - síťové rušení (50 Hz)
- **ŠIROKOPÁSMOVÉ RUŠENÍ**
  - myopotenciály
  - rychlé (skokové) změny izoline
  - impulsní rušení



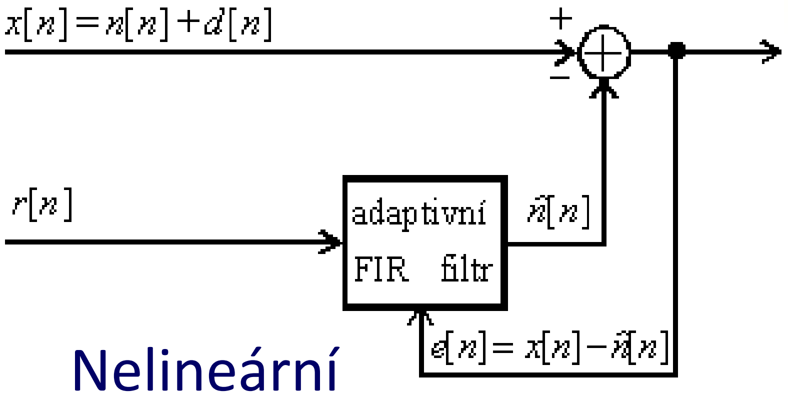


50 Hz

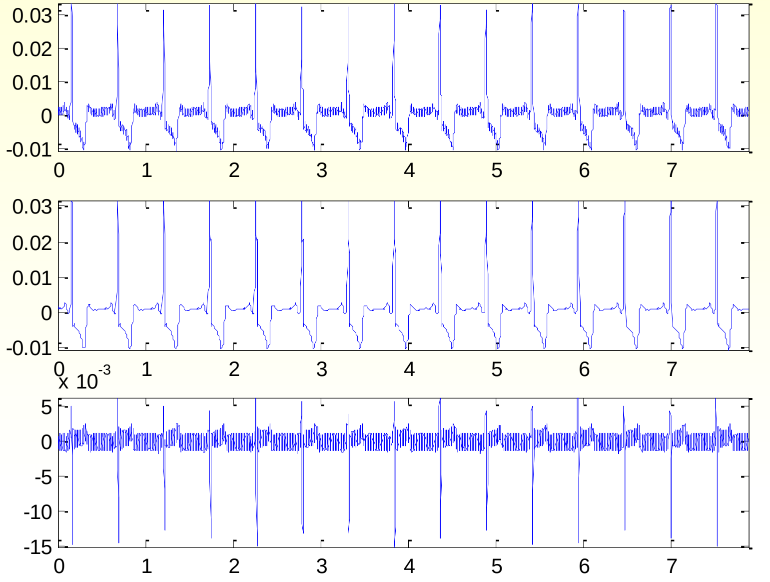
Potlačení rušení

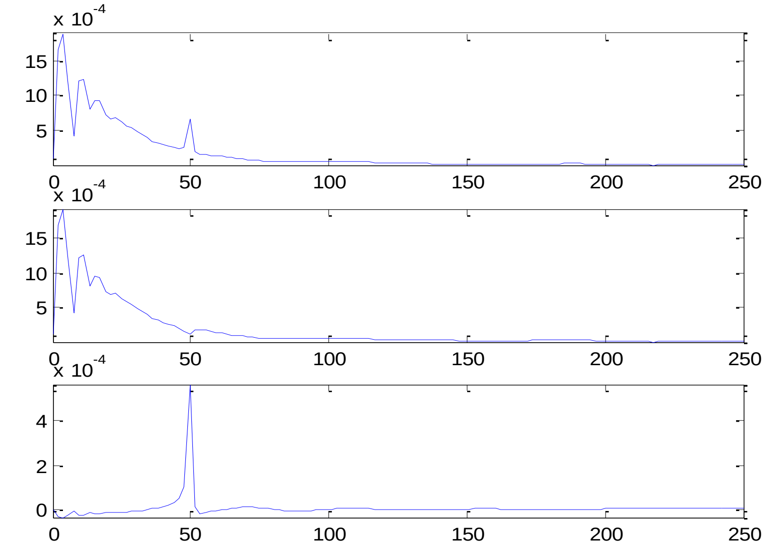
Filtrace síťového brumu 50 Hz

- Lineární filtrace
- Adaptivní filtrace



- Nelineární heuristické algoritmy

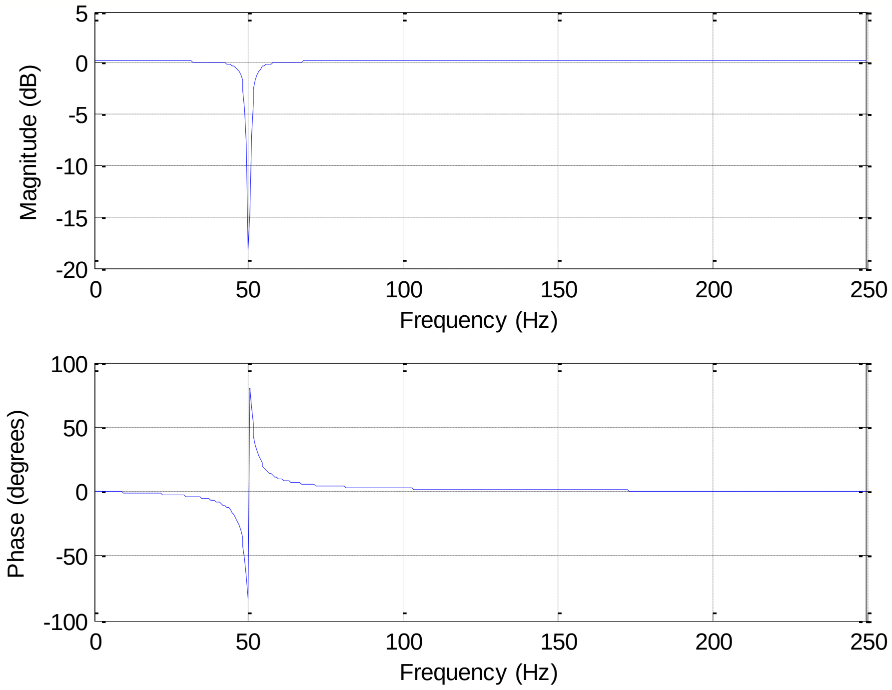


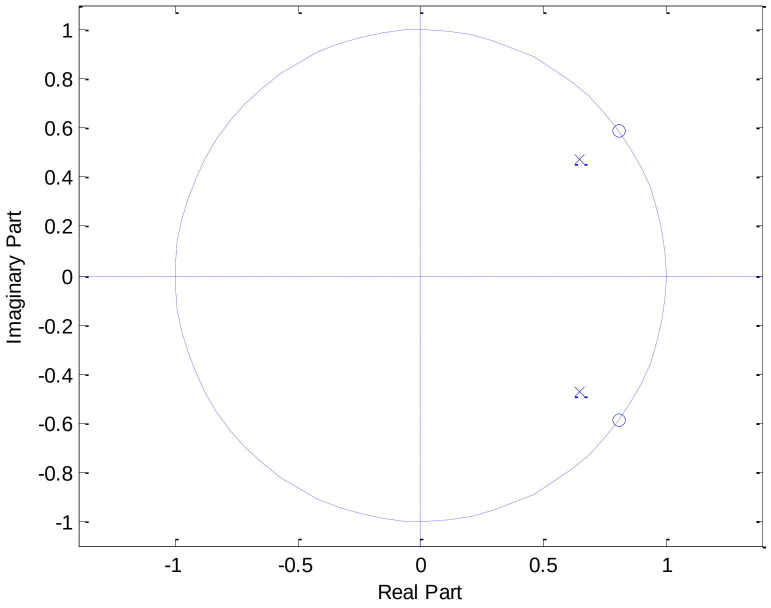


50 Hz

Úzkopásmové filtry – bikvády

$$H(z)=\frac{1-2R\cos\hat{\omega}_0 z^{-1}+R^2z^{-2}}{1-2r\cos\hat{\omega}_0 z^{-1}+r^2z^{-2}}=\frac{z^2-2R\cos\hat{\omega}_0 z+R^2}{z^2-2r\cos\hat{\omega}_0 z+r^2}$$

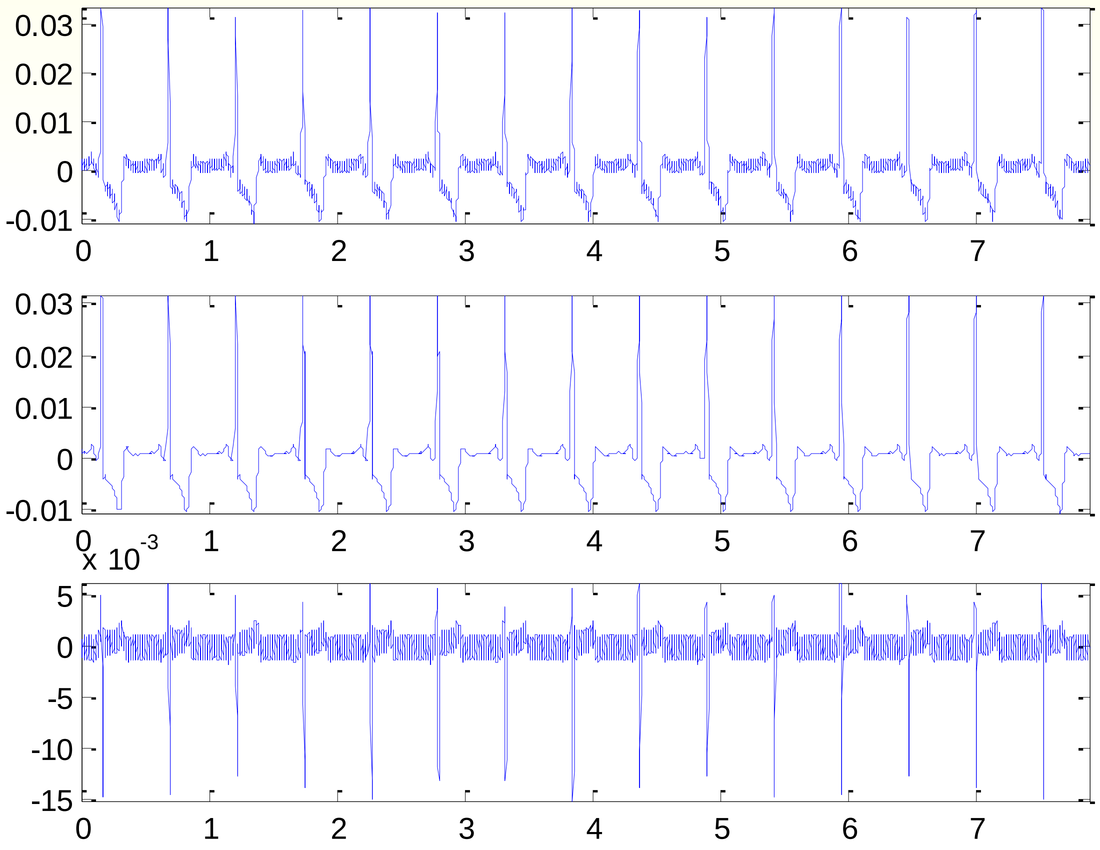


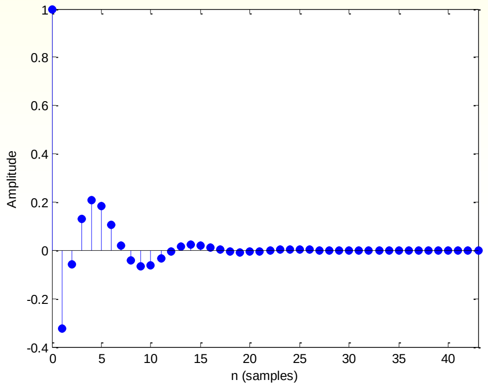


50 Hz

Úzkopásmové filtry – bikvády

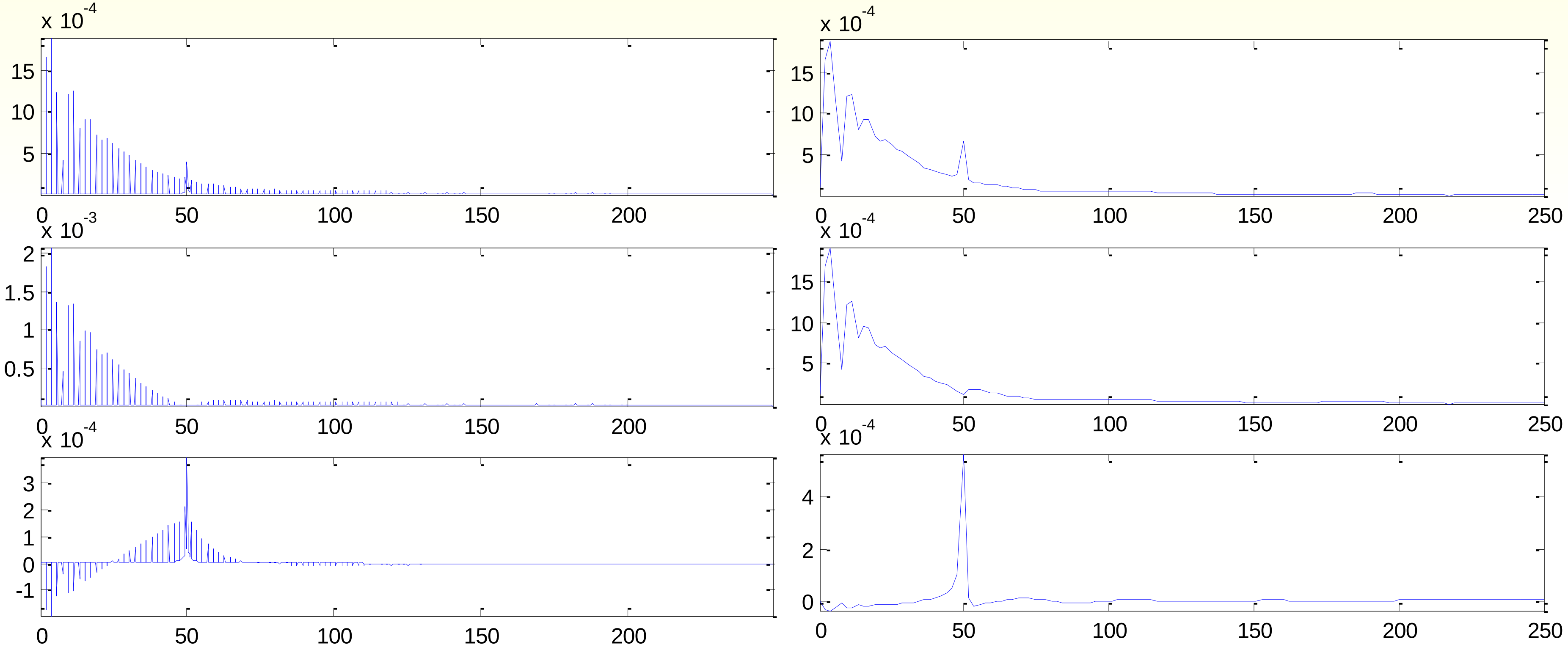
```
R   =  1; r   =  0.98;
b = [1 -2*R*cos(2*pi*f0/fs) R*R];
a = [1 -2*r*cos(2*pi*f0/fs) r*r];
```





50 Hz

Úzkopásmové filtry – bikvády

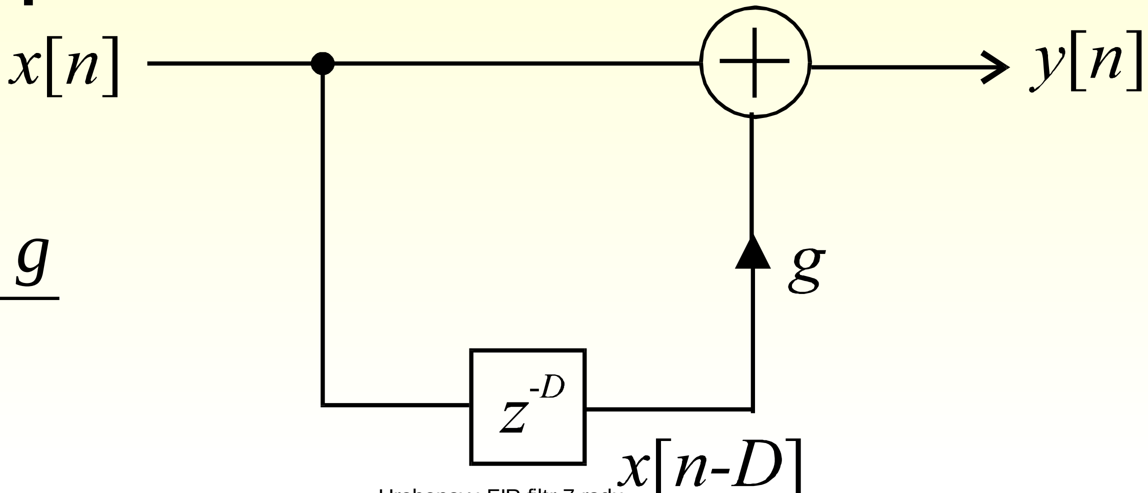


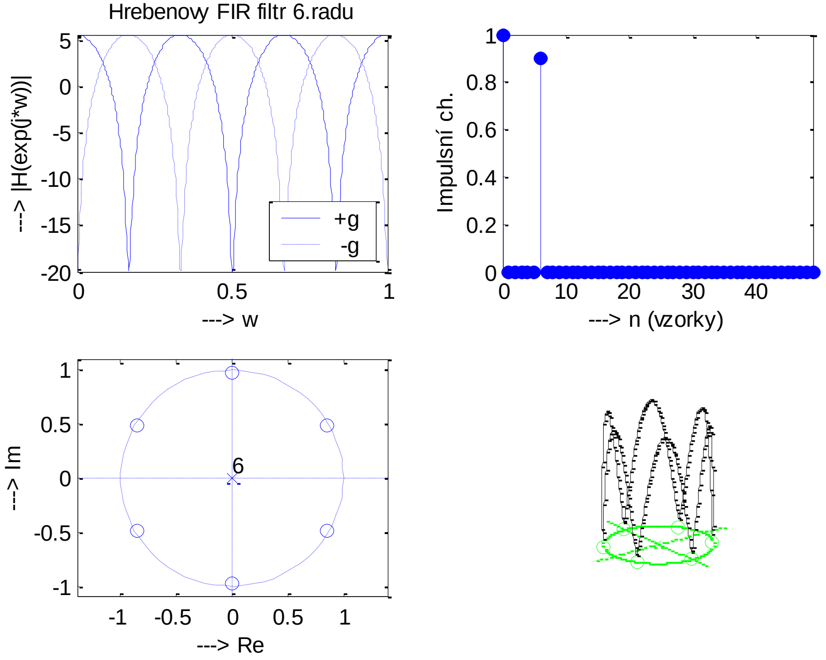
50 Hz

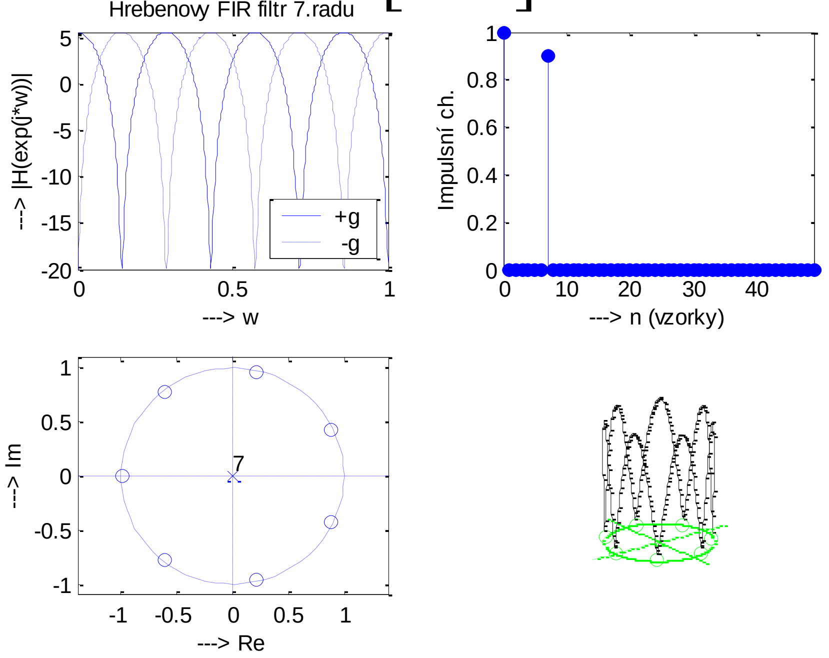
Hřebenový FIR filtr pro potlačení

$$y[n] = x[n] + g \cdot x[n-D]$$

$$H(z) = 1 + g \cdot z^{-D} = \frac{z^{D} + g}{z^{D}}$$

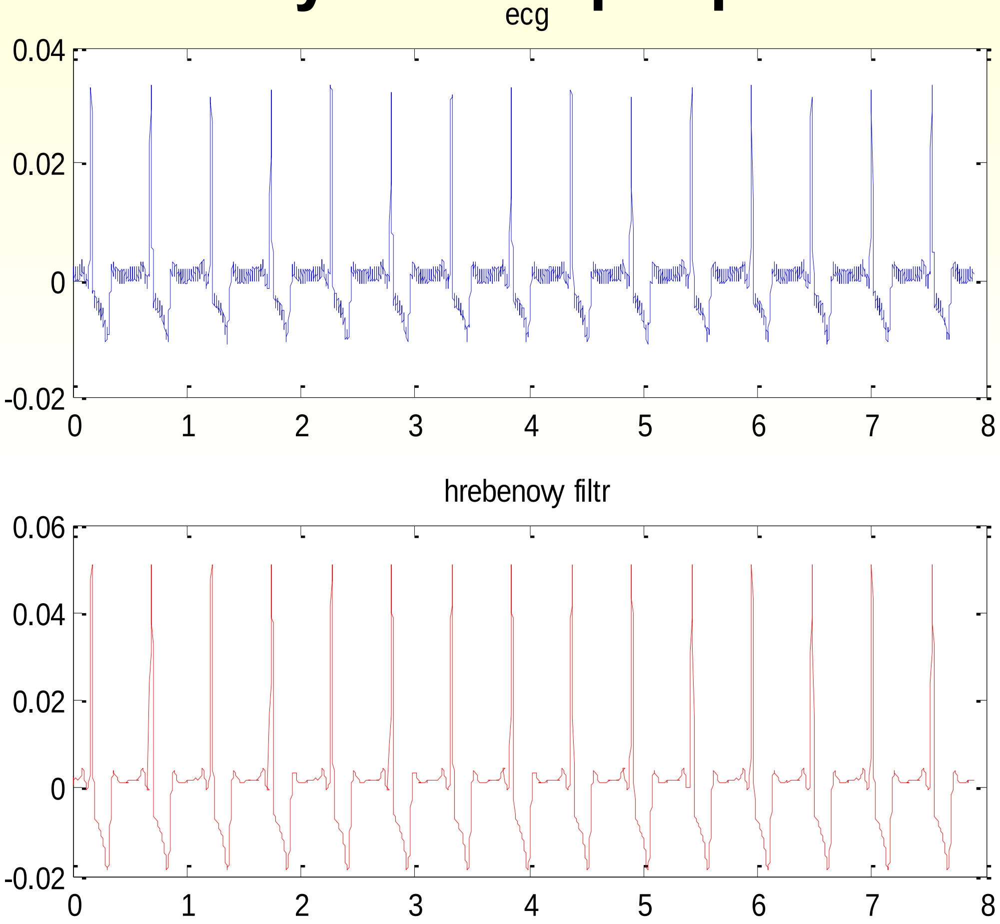




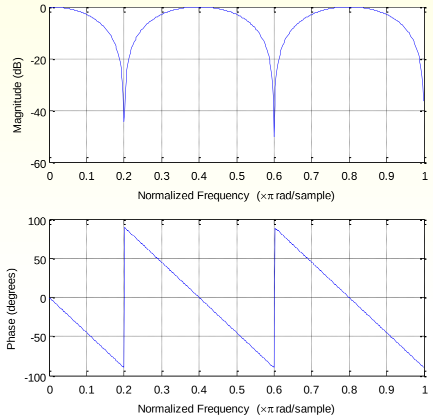


50 Hz

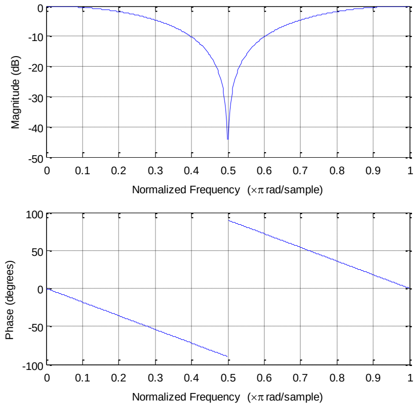
Hřebenový FIR filtr pro potlačení



```
b = 0.5* [1 0 0 0 0 1]
% pro fs = 500 Hz
```



```
b = 0.5*[1 0 1];
% pro fs = 200 Hz
```

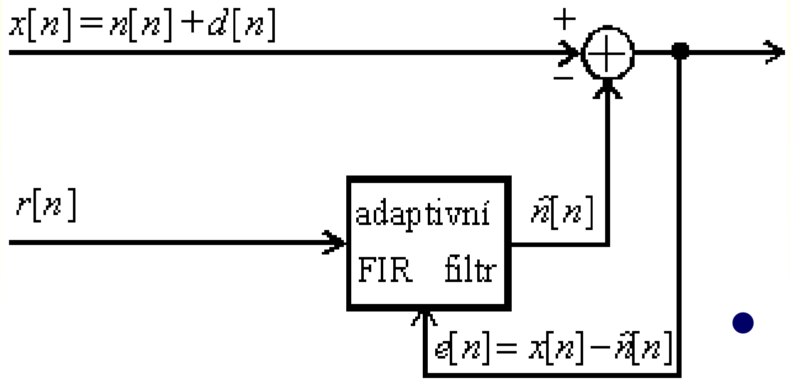


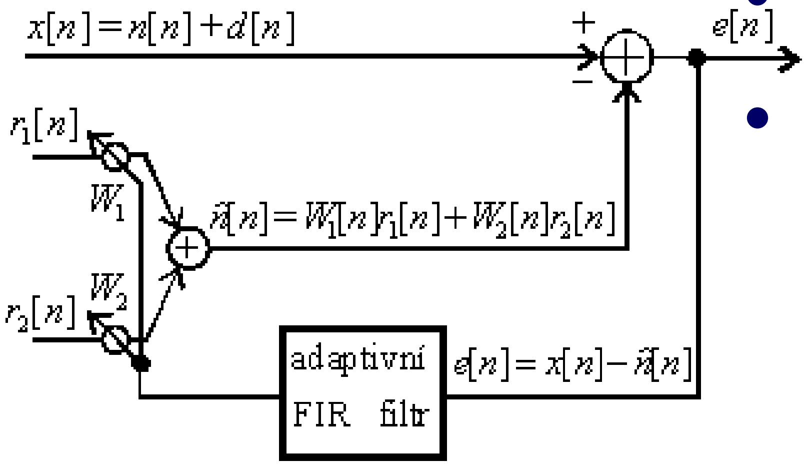
```
>> freqz(0.5* [1 zeros(1,9) 1],1,1000,1000)
>> freqz(0.5* [1 zeros(1,4) 1],1,1000,500)
>> freqz(0.5* [1 zeros(1,1) 1],1,1000,200)
```

50 Hz

% Adaptive Noice Canceling - ANC

ADAPTIVNÍ FILTRY





CO CHCEME ?

- **rychlou konvergenci;**
- **robustnost vůči šumu;**
- **malé výpočetní nároky;**

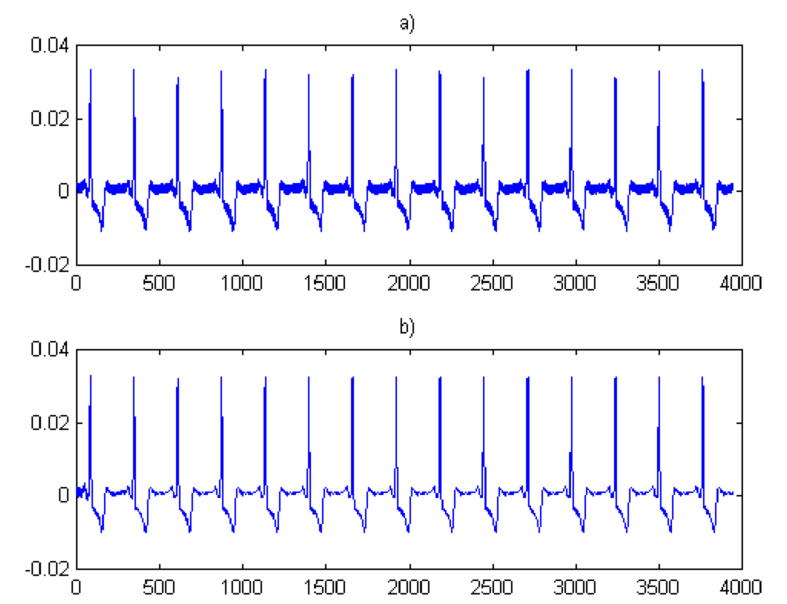
LMS

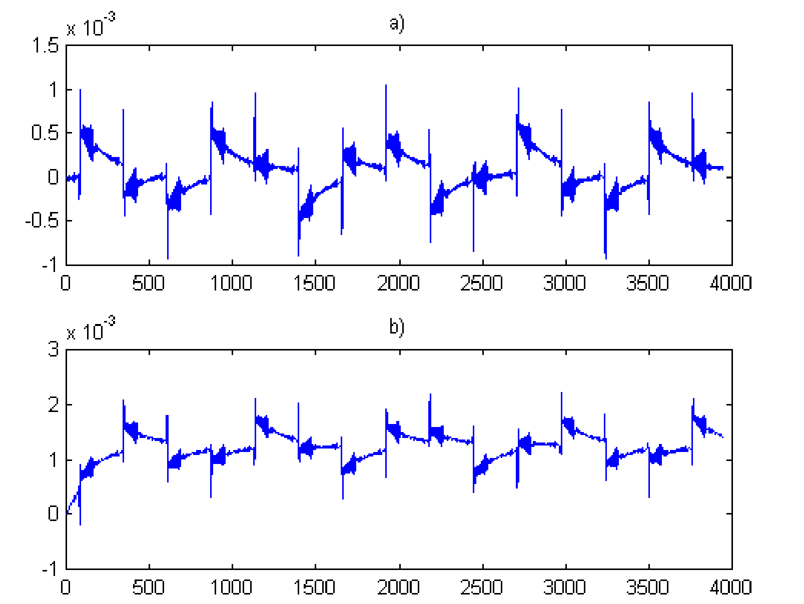
FIR :

$\mathbf{W}(n+1)=\mathbf{W}(n)+2\mu.e(n).\mathbf{x}(n)$

50 Hz

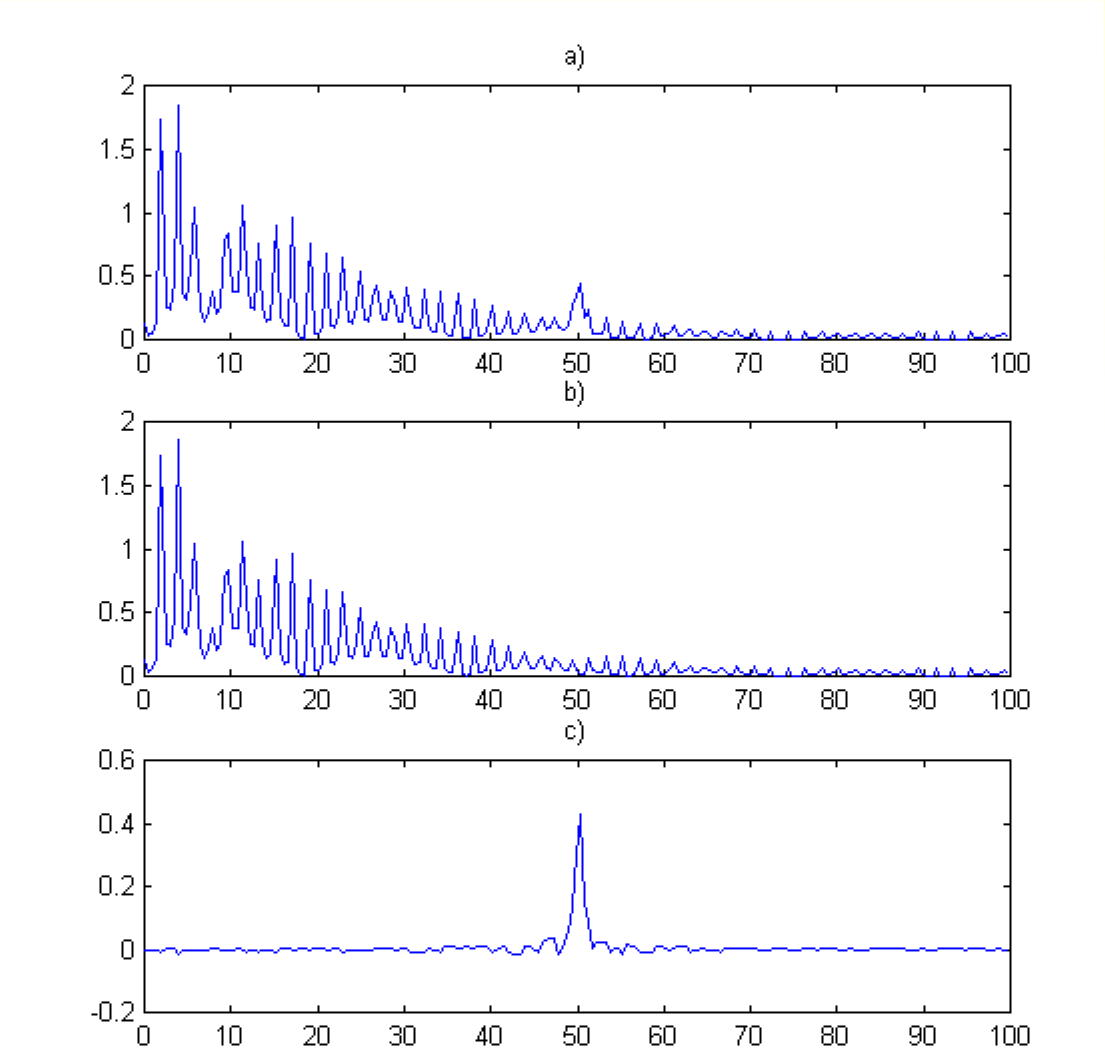
ADAPTIVNÍ FILTRY





50 Hz

ADAPTIVNÍ FILTRY

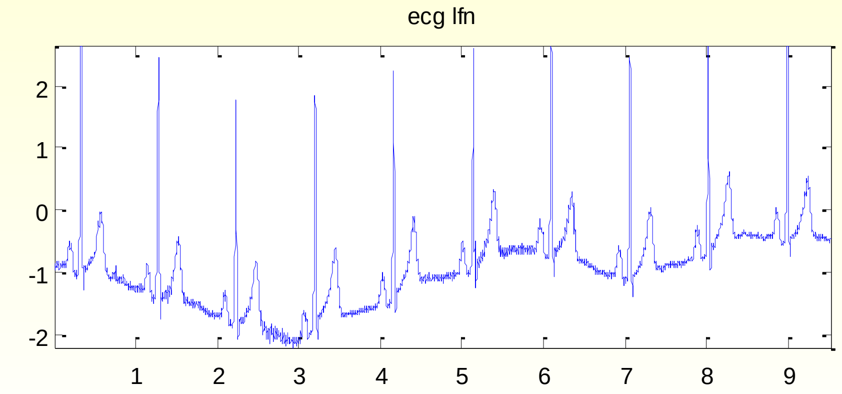


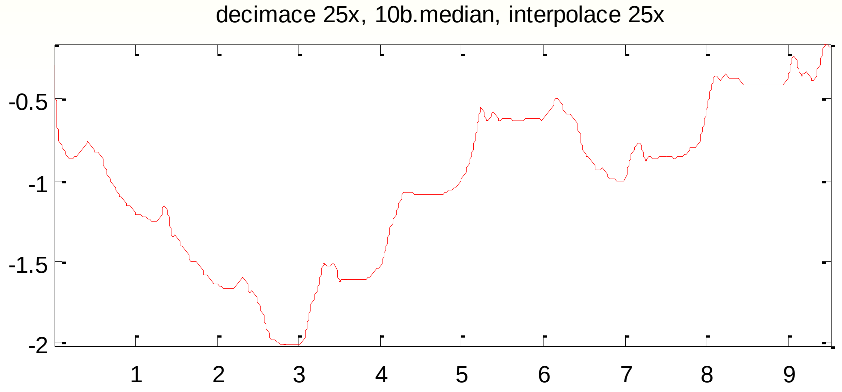
drift

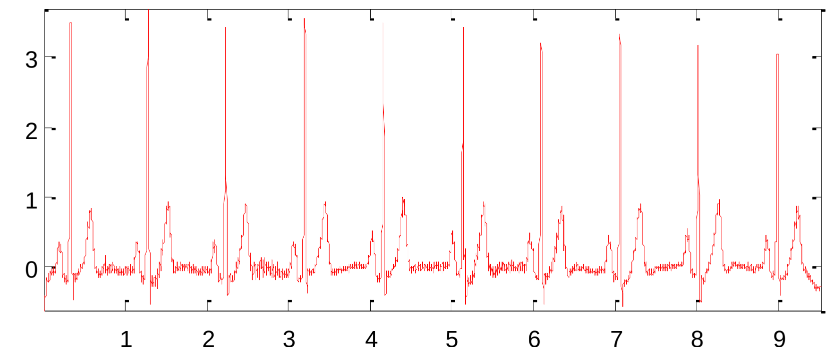
Potlačení rušení

Filtrace driftu izoelektrické linie

- **lineární filtrace horní propustí**
- **odečtení odhadu kolísání driftu**
- heuristické algoritmy


ecg lfn

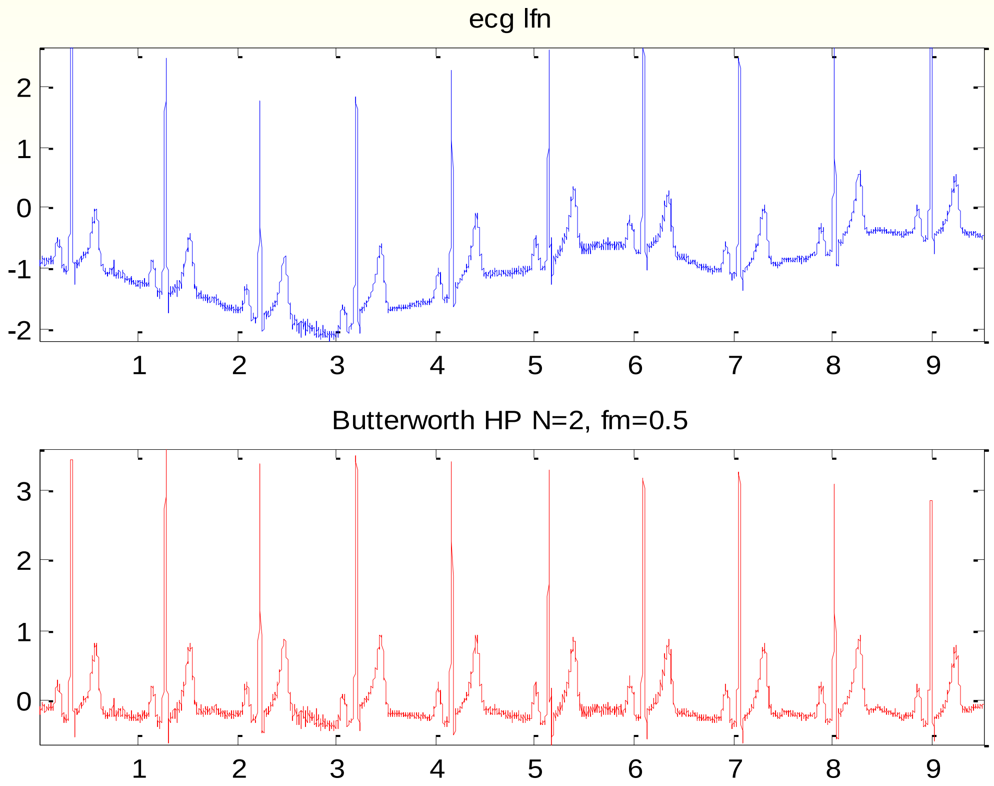

decimace 25x, 10b.median, interpolace 25x



drift

Jednoduchá horní propust 2.řádu

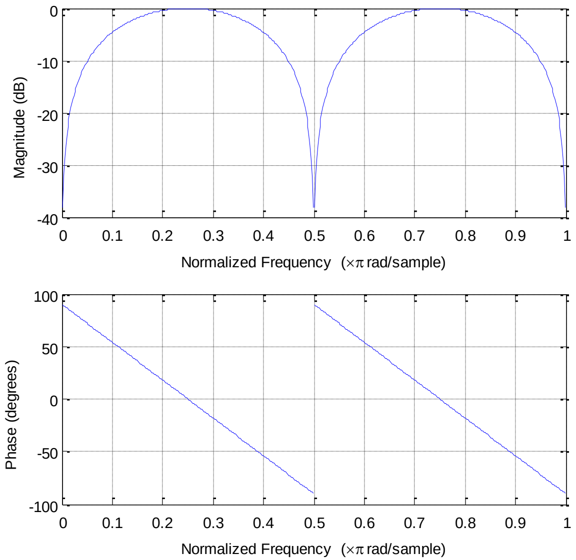
```
[b,a] = butter(2,0.5/(fs/2),'high')
```

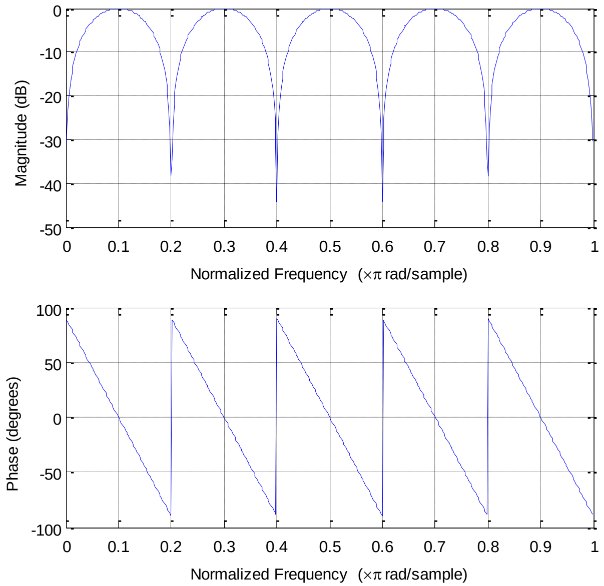


drift

- filtry s FIR
  - **Hřebenové filtry**
    společné odstranění driftu s brumem

```
>> freqz(0.5* [1 zeros(1,19) -1],1,1000,1000)
>> freqz(0.5* [1 zeros(1,9) -1],1,1000,500)
>> freqz(0.5* [1 zeros(1,4) -1],1,1000,250)
>> freqz(0.5* [1 zeros(1,3) -1],1,1000,200)
```

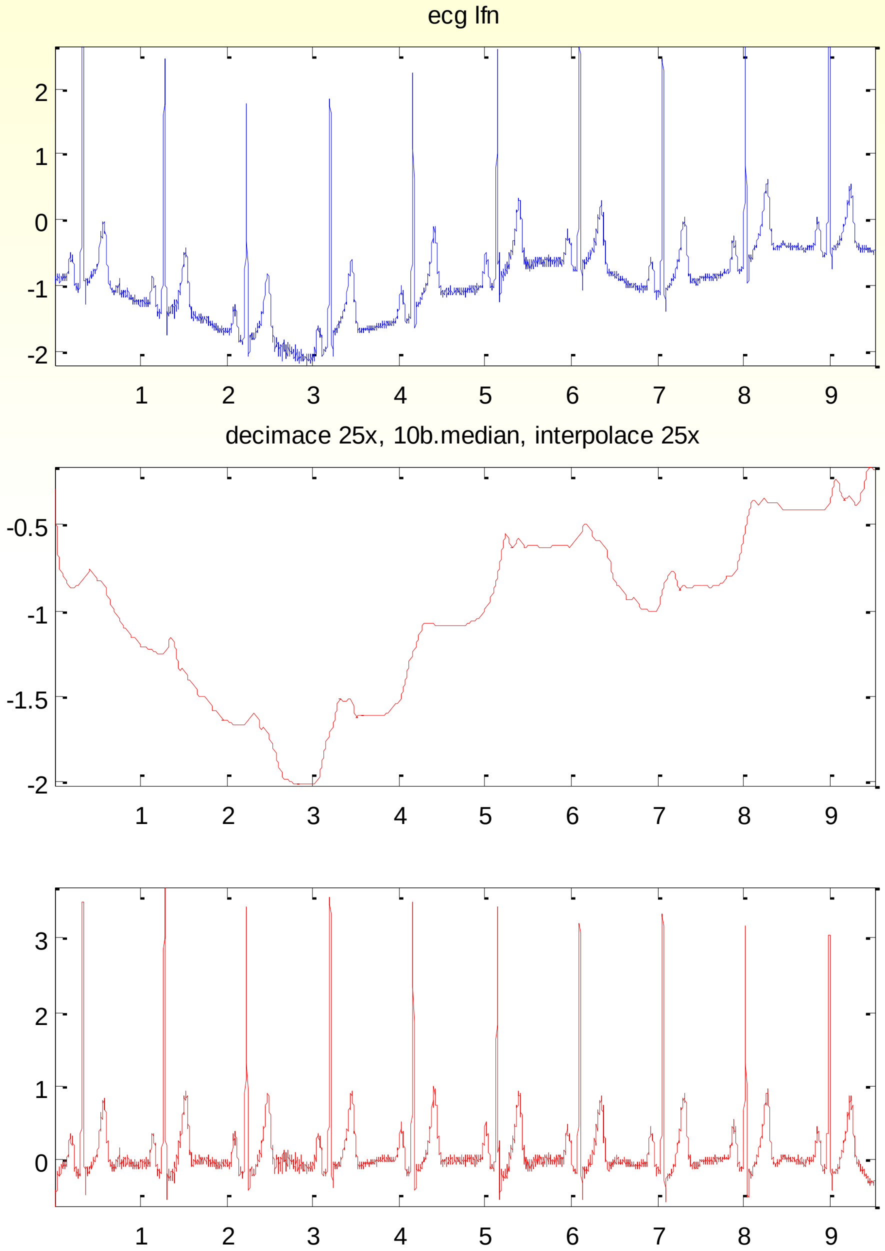




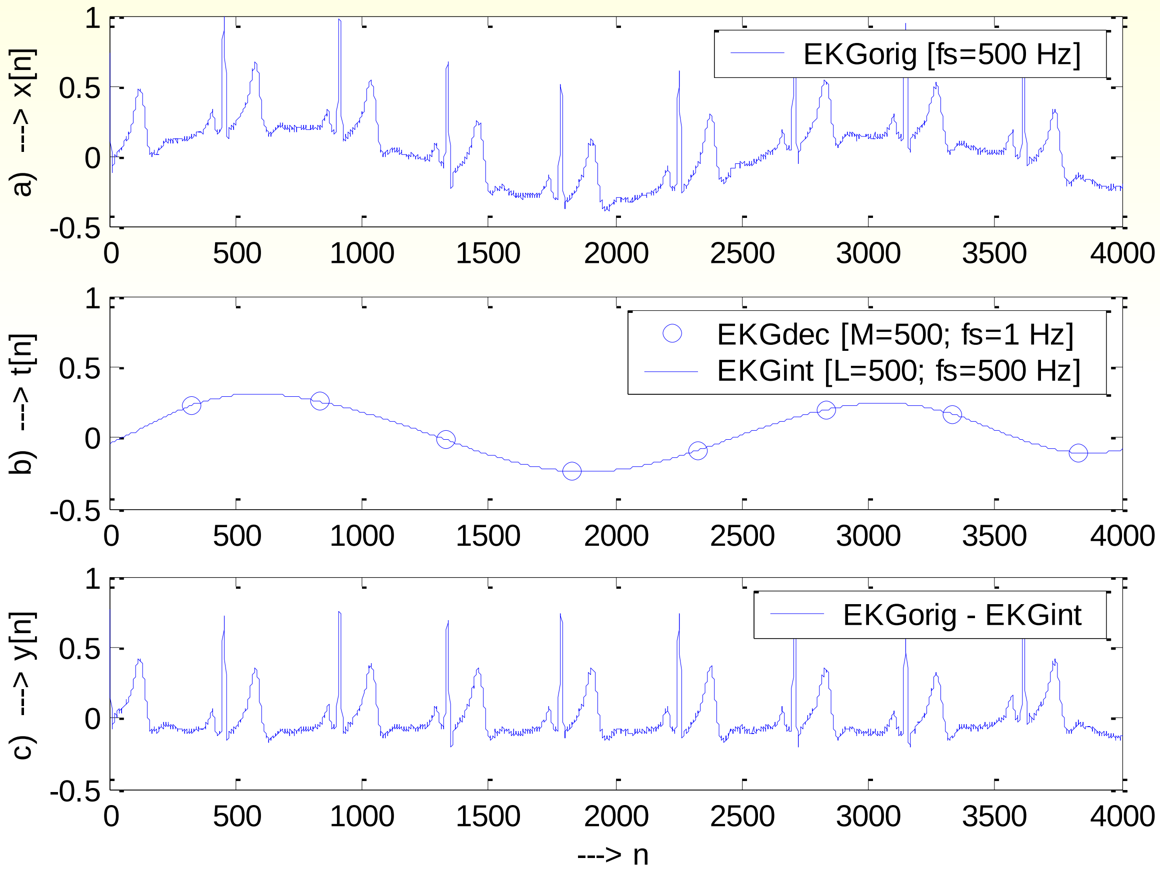
drift

Odhad driftu

```
xd=decimate(ecg,round(fs/20),'fir');

lbx=medfilt1(xd,10);

lb=interp(lbx,round(fs/20));

z=ecg-lb(1:length(ecg));
```



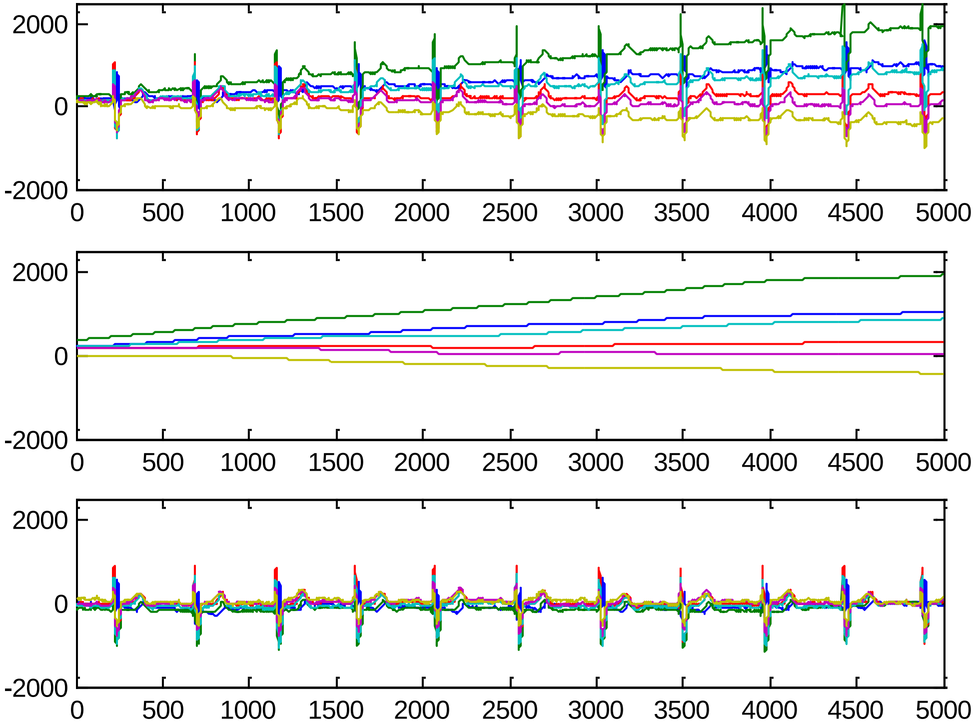
drift



a) ---> x[n]
EKGorig [fs=500 Hz]
b) ---> t[n]
EKGdec [M=500; fs=1 Hz]
EKGint [L=500; fs=500 Hz]
c) ---> y[n]
EKGorig - EKGint
1
0.5
0
-0.5
0
500
1000
1500
2000
2500
3000
3500
4000
---> n

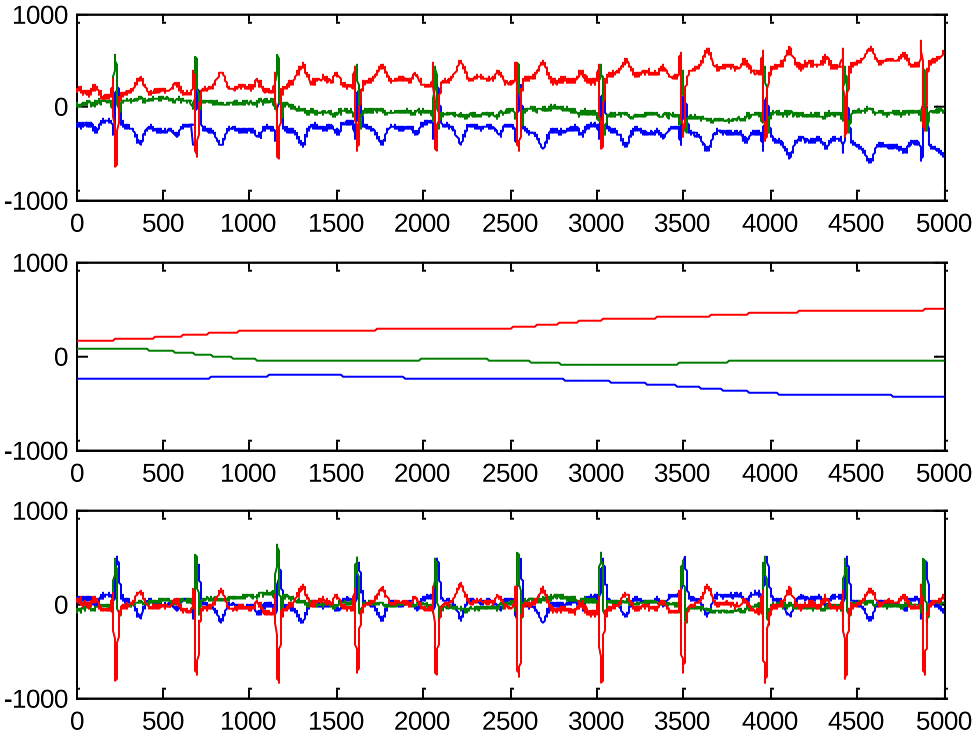
drift

fs=500 Hz, M = 500



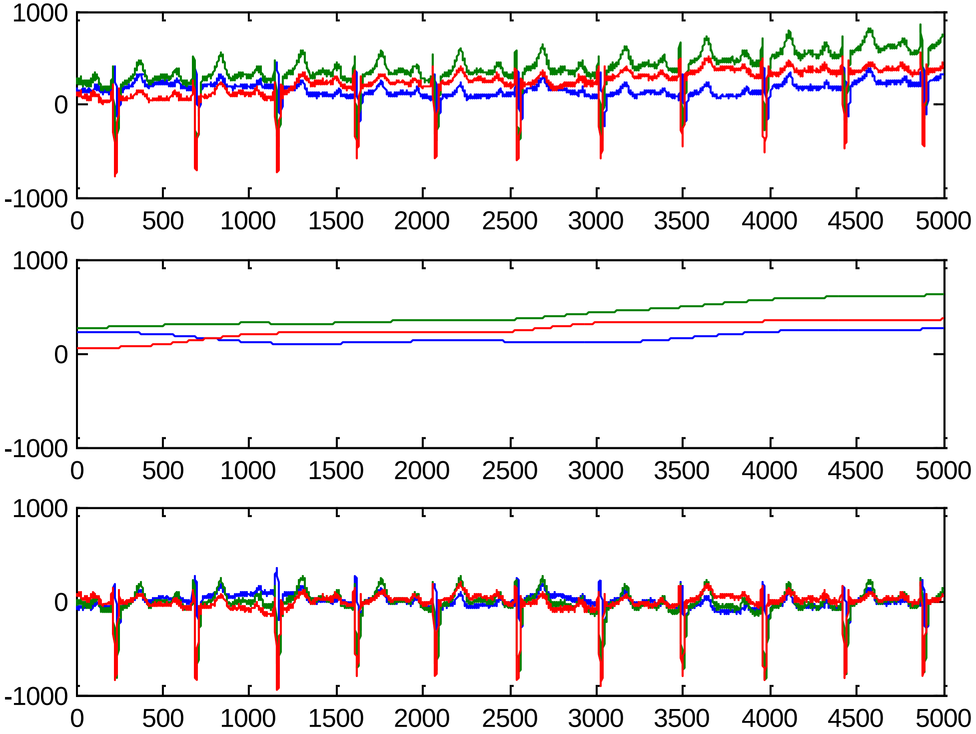
drift

fs=500 Hz, M = 500



drift

fs=500 Hz, M = 500

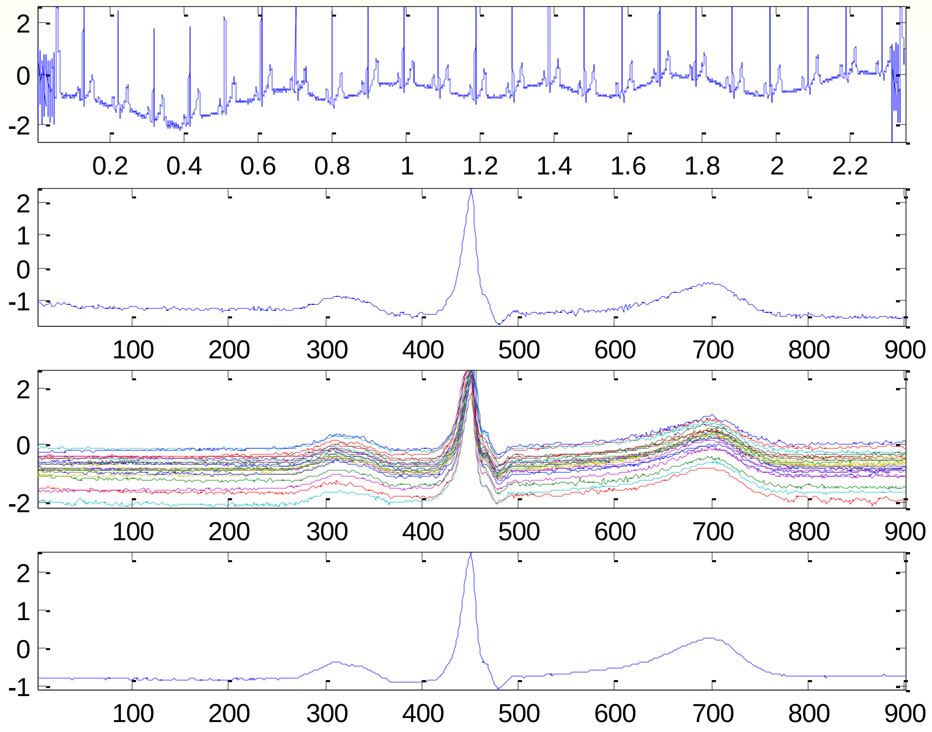


myo

Potlačení rušení

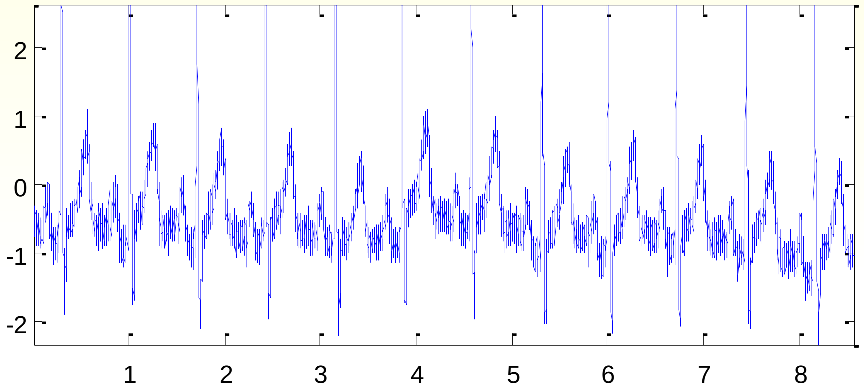
Filtrace myopotenciálu

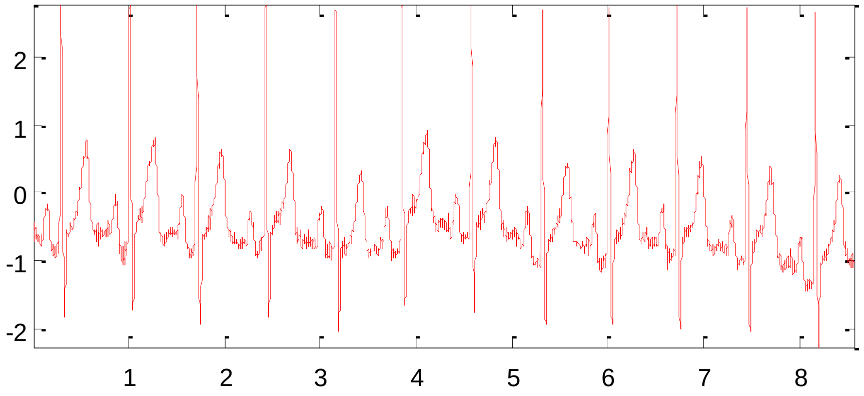
- **synchronní průměrování**
- wavelety
- dekompoziční techniky



myo

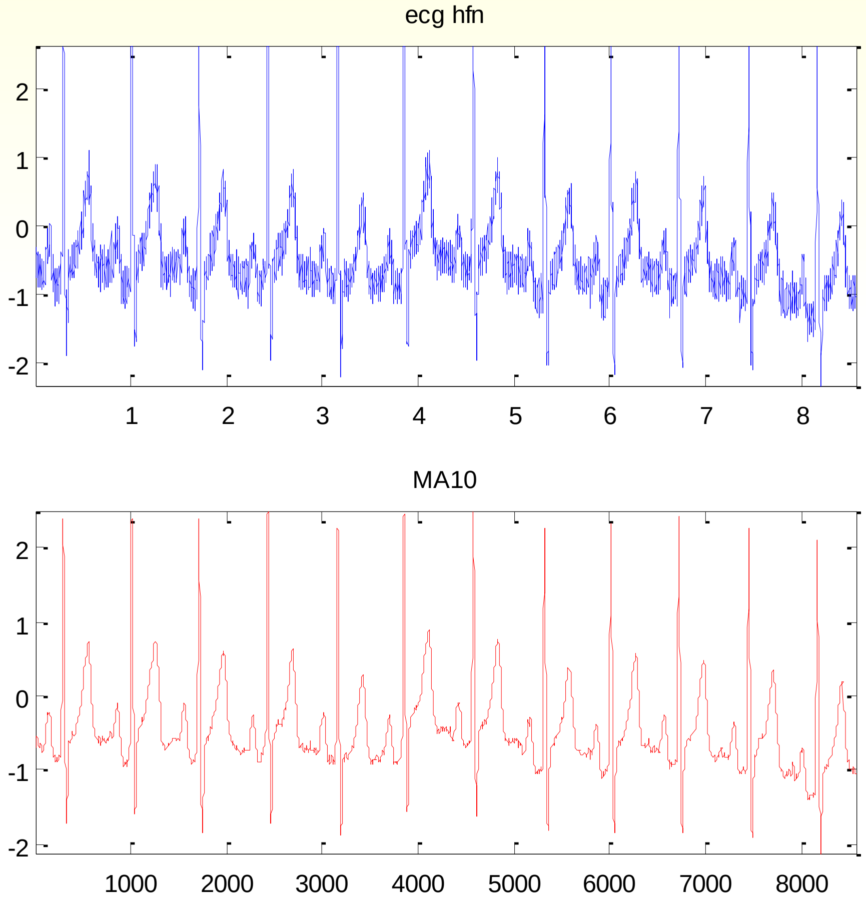
Dolnopropustný filtr


ecg hfn


Butterworth DP N=8, fm=40

myo

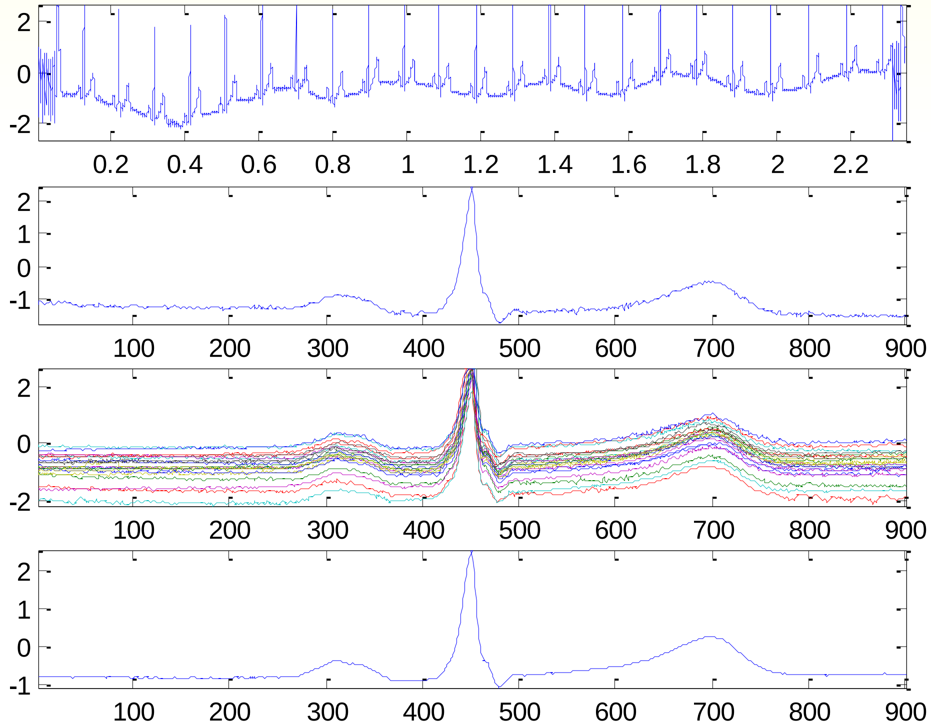
Klouzavé průměry



myo

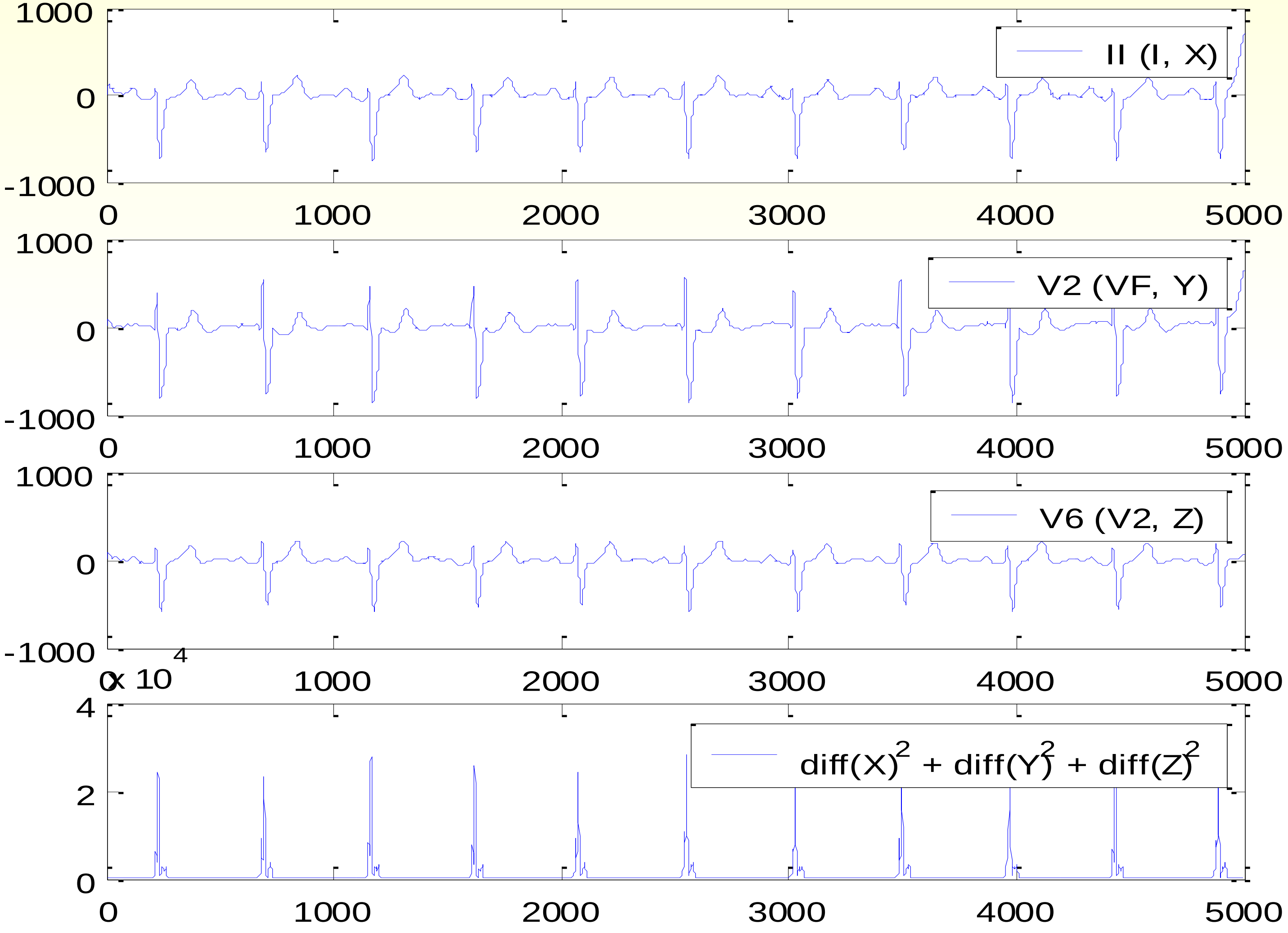
překrývání spekter rušení a užitečného signálu ⇒ průměrování

$$y(t+kT)=x(t+kT)+n(t+kT)$$



- signál x(t) je časově invariantní;
- n(t) je aditivní a nekorelovaný s x(t);
- n(t) je stacionární;
- n(t) má normální rozložení s nulovým průměrem;

Zpracování vícesvodového záznamu



Detekce signálů v EKG

Obecný postup:

- Pan Tompkinsův algoritmus detekce R špičky
- Rozměření QRS komplexu
- Detekce T-vlny
- Určení konce T vlny
- Detekce atriálního signálu
- Analýza S-T segmentu

Detekce komplexu QRS

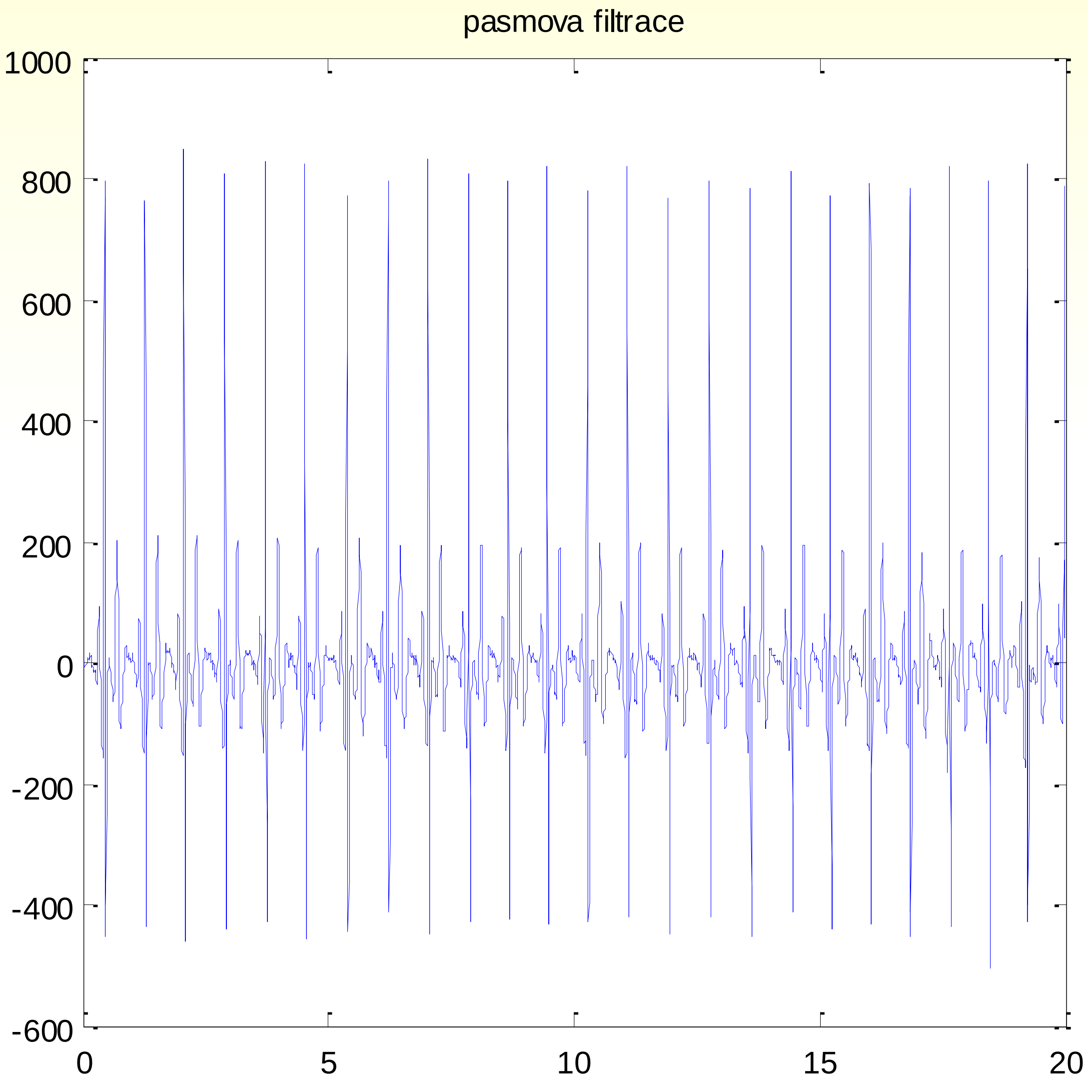
QRS komplex

- nejvýraznější grafoelement v EKG signálu
- základní procedura všech počítačových analýz
- na spolehlivosti, přesnosti a rychlosti QRS detekce závisí celá EKG analýza

Pan-Tompkinsonův algoritmus nalezení QRS

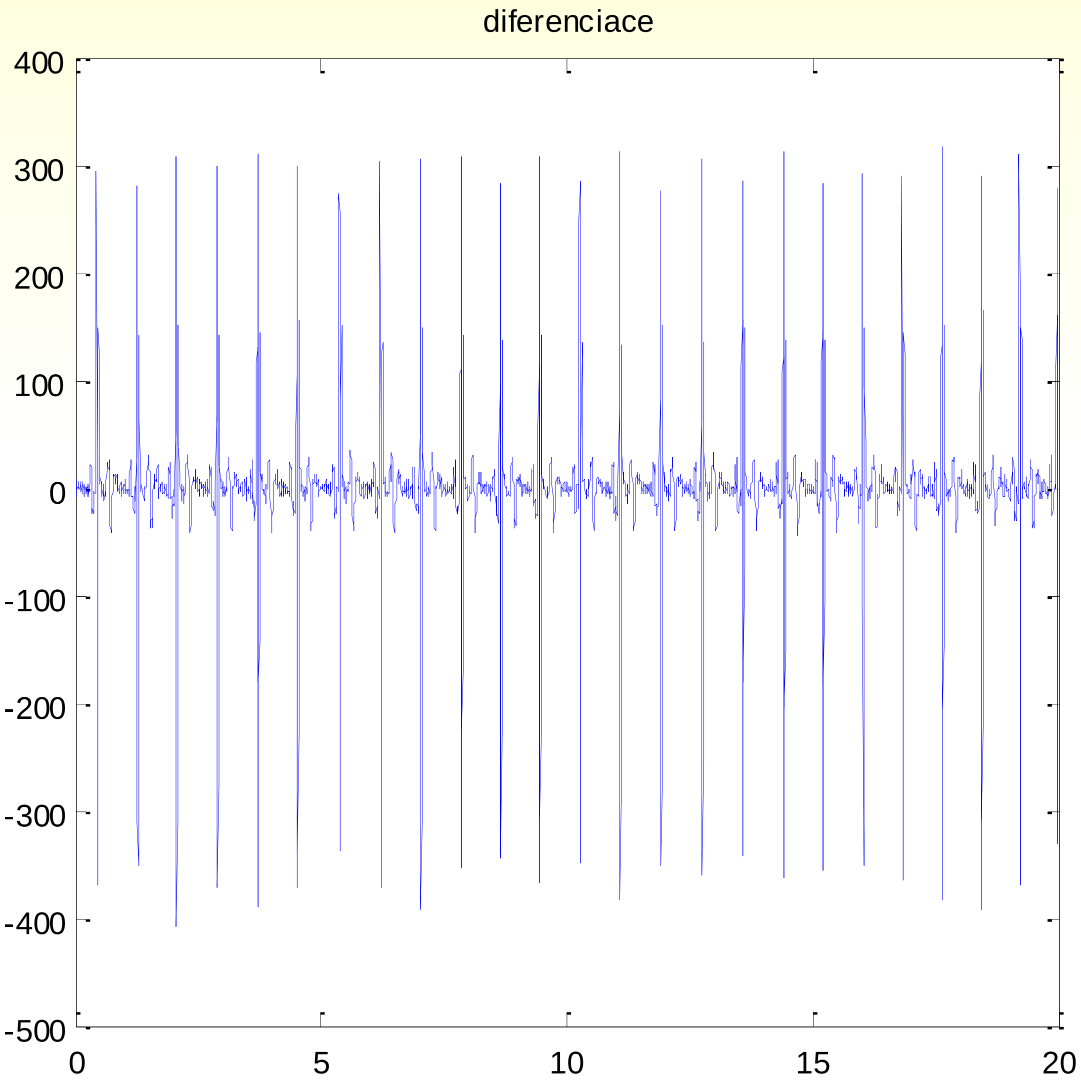
1. PP
2. diff(x)
3. x^2
4. MA
5. práh

1. filtrace



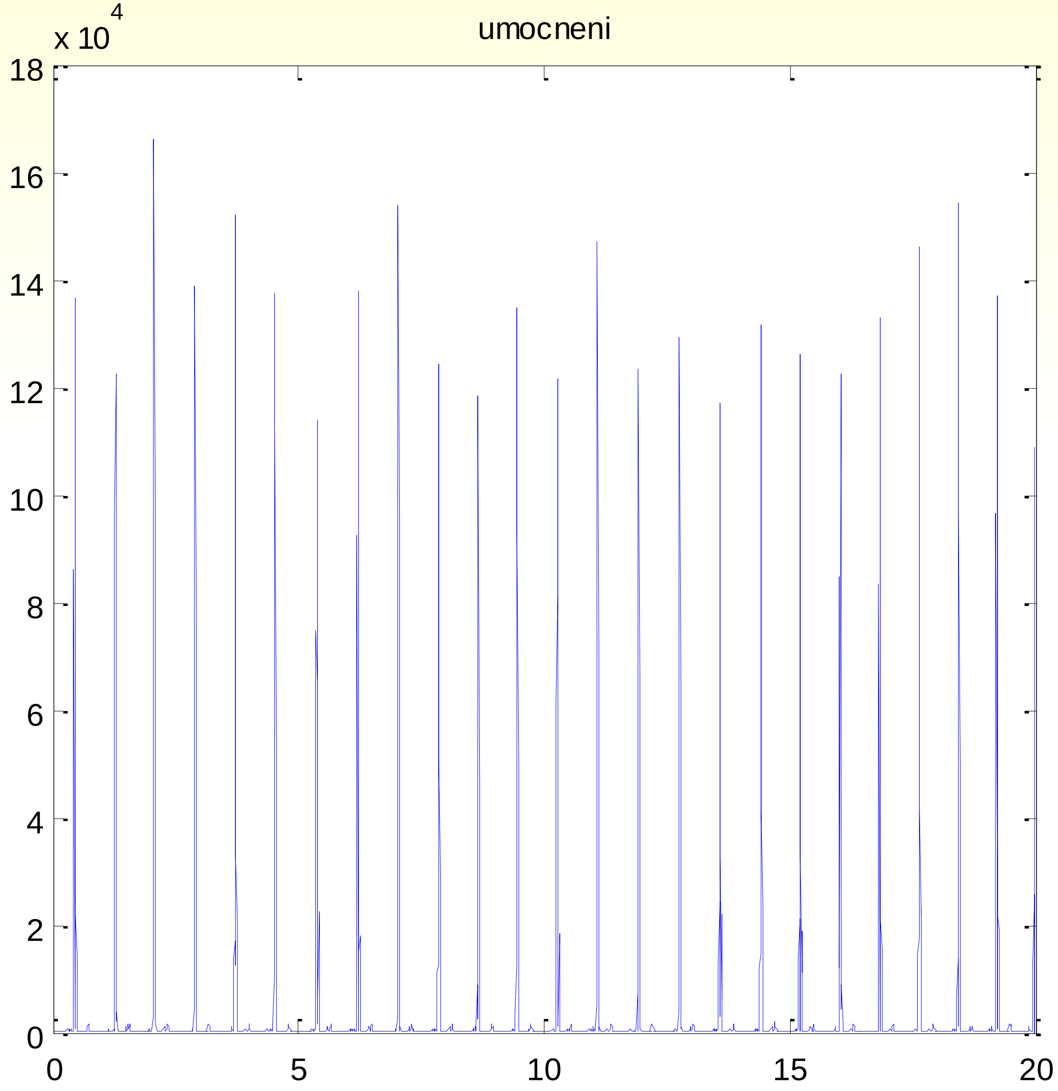
```
[b,a] = butter(2, [4 30]/(fs/2));  % filtrace mezi 4 a 30 Hz
```

2. diferenciace

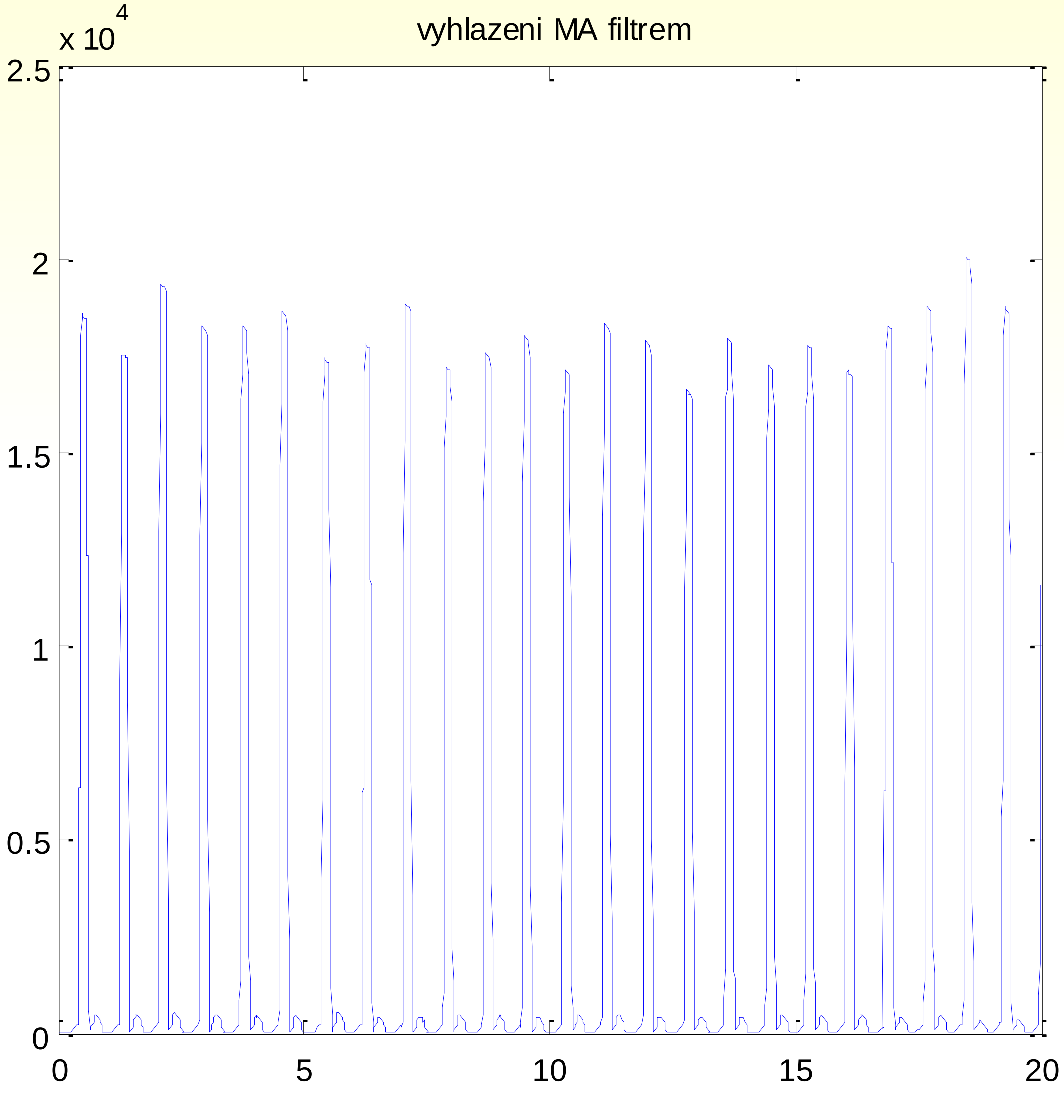


3. umocnění

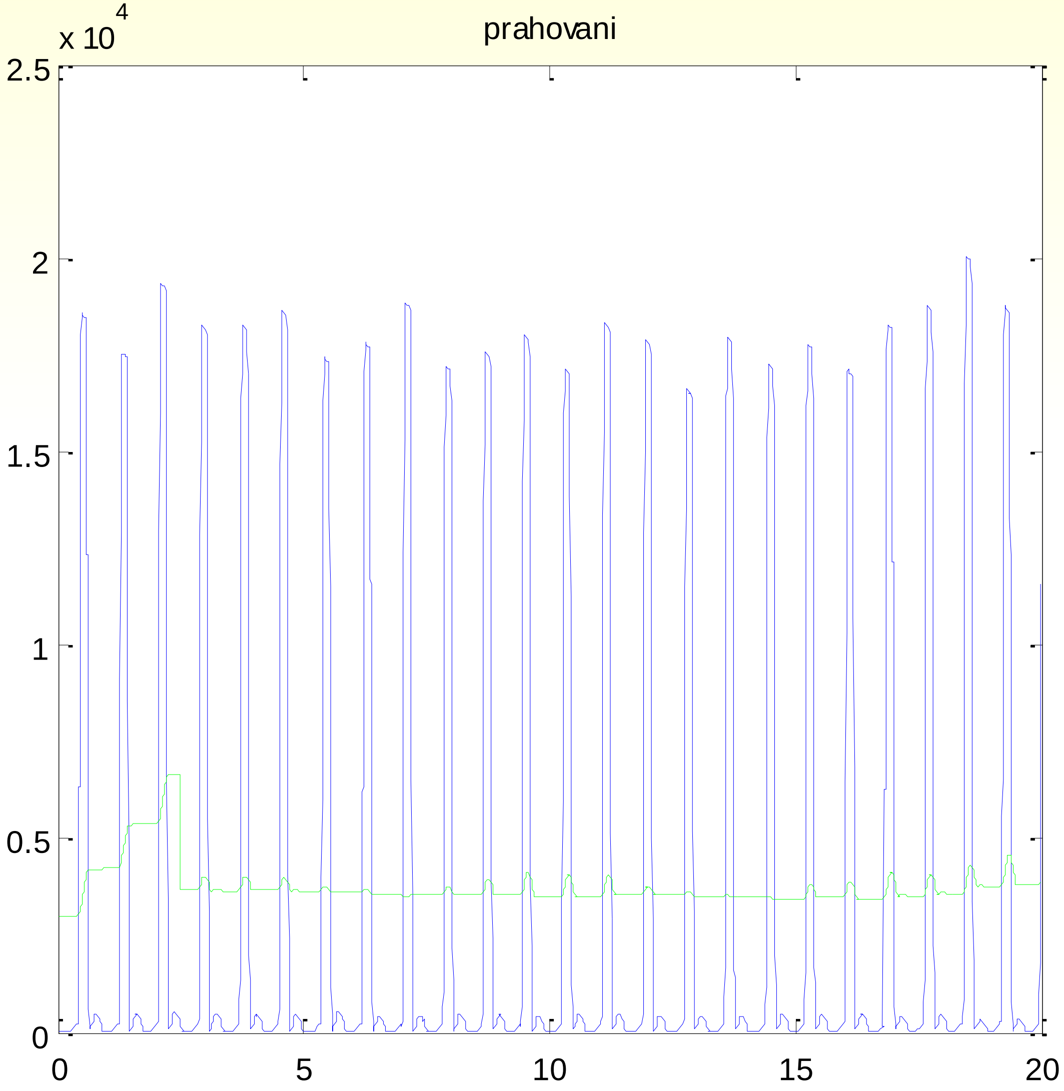
zvýraznění větších hodnot signálu a potlačení malých hodnot signálu



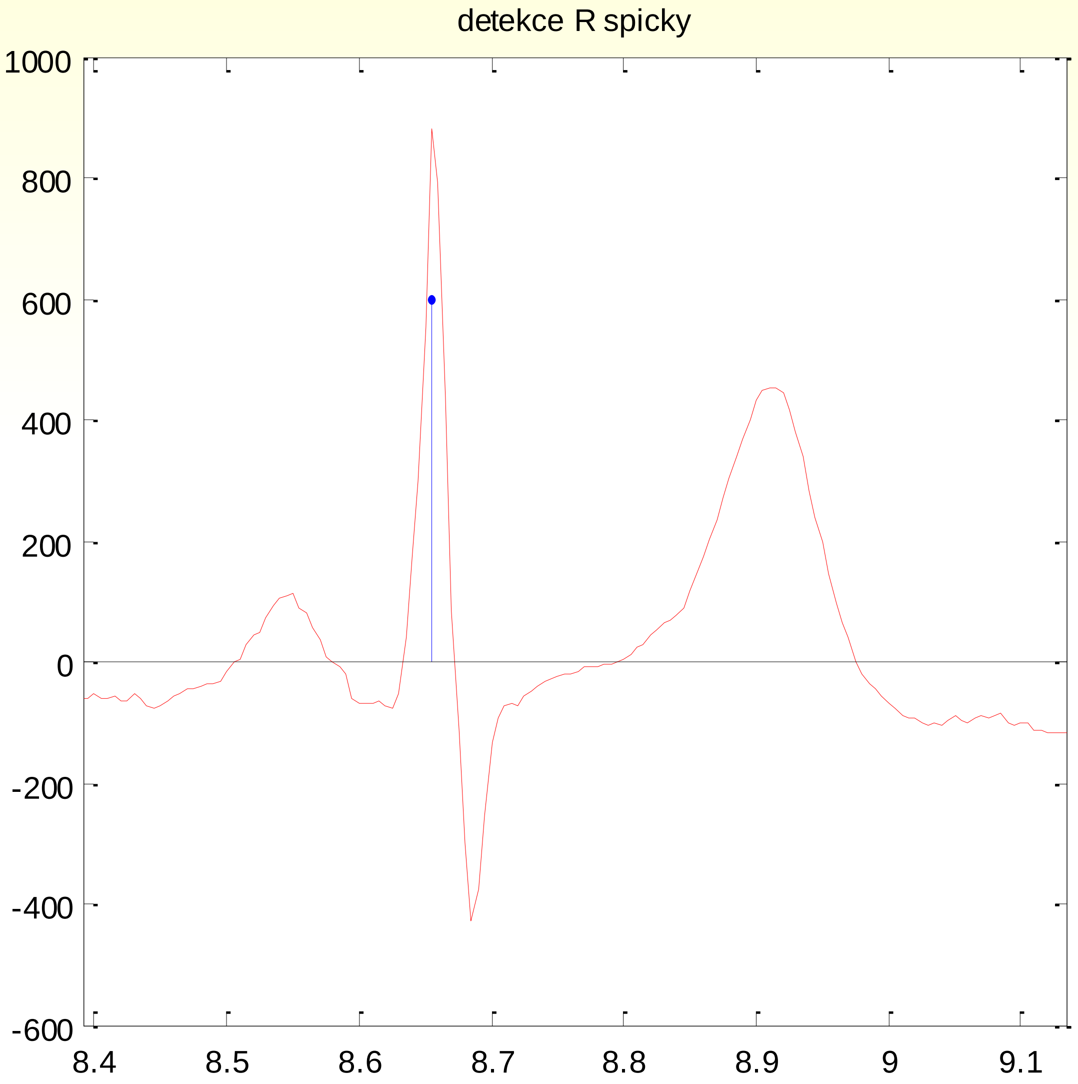
4. vyhlazení MA filtrem



5. prahování



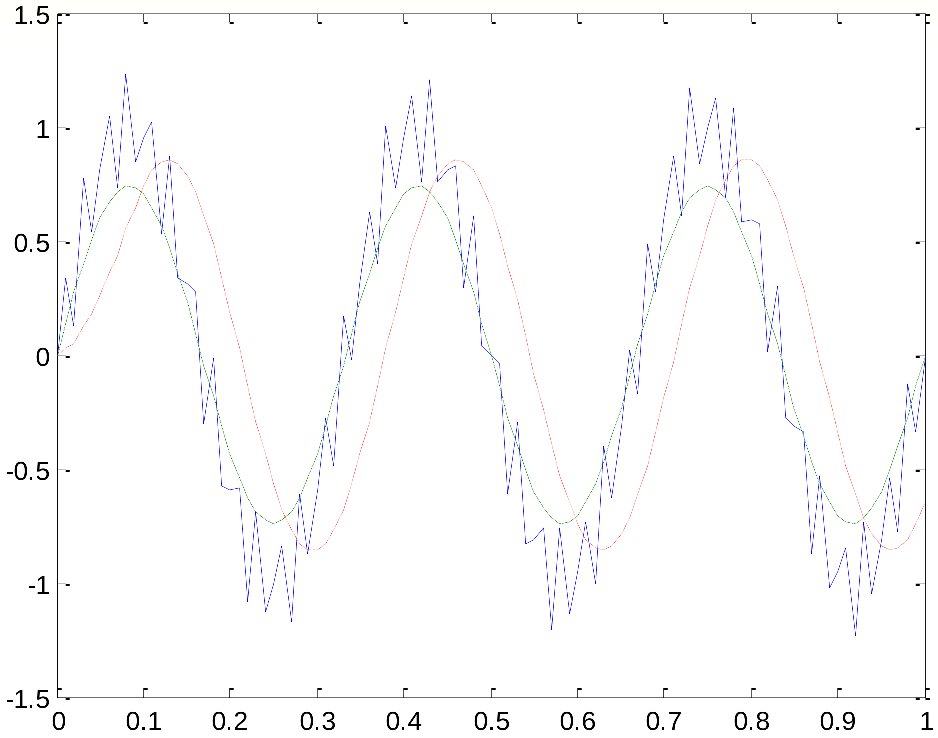
6. detekce R špiček



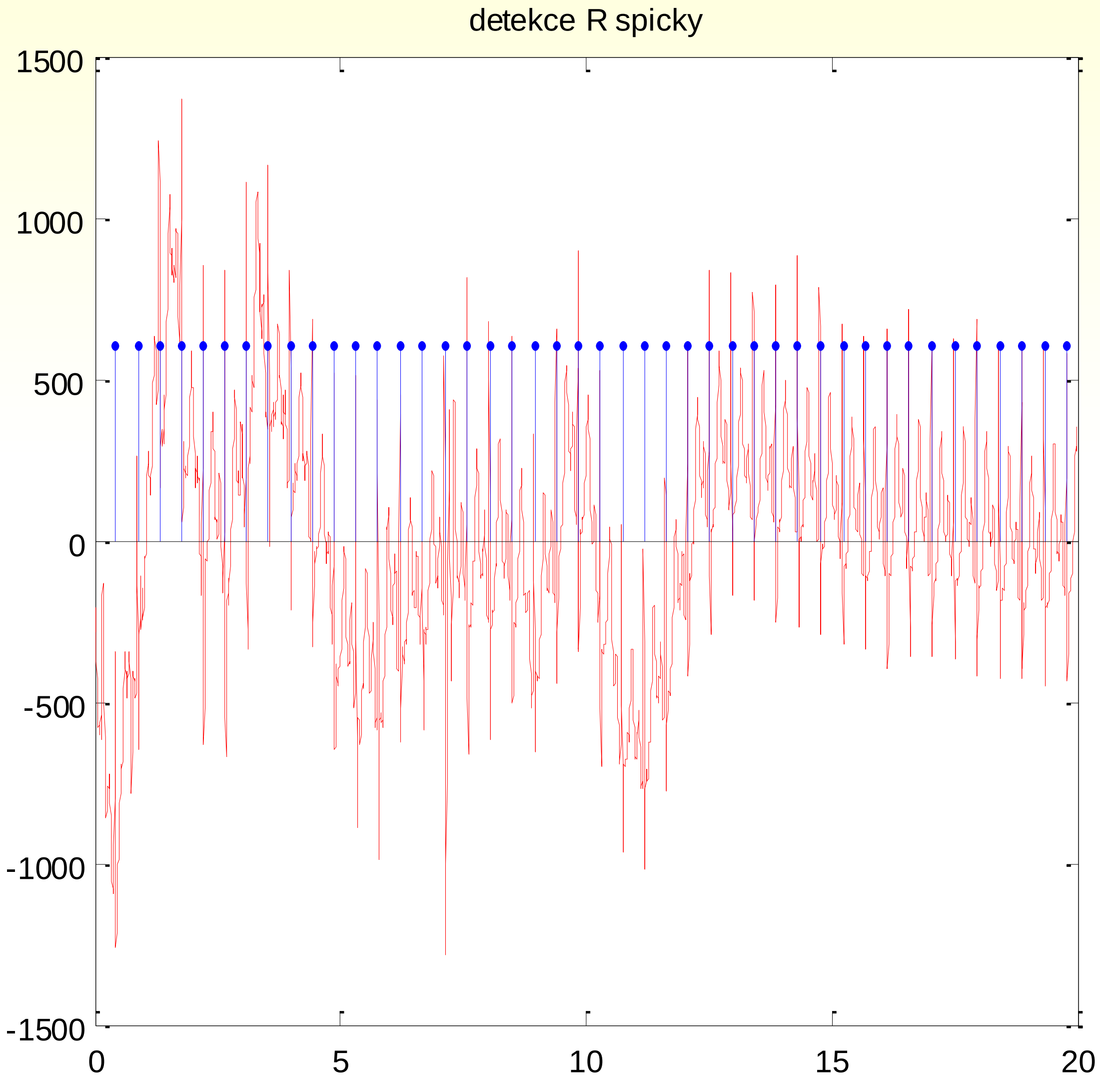
```
function r=spicky(signal,fs)
% Implementace algoritmu pro detekce QRS komplexu v EKG signalu
% fs vzorkovaci kmitocet
signal= signal-mean(signal);            % odstraneni ss slozky
N     = length(signal);                 % delka signalu
x_osa = [1:length(signal)]./fs;         % horizontalni osa
[b,a] = butter(2, [4 30]/(fs/2));       % pasmova filtrace
signalf  = (filtfilt(b,a,signal));      % filtrace s nulovym f.p.
sig_dif=[diff(signalf);0];              % diferenciace EKG
sig_2  = (sig_dif).^2;                  % umocneni signalu
sig_ma = filtfilt([ones(1,160/160],1,sig_2);% klouzavy prumer
prah   = mean(sig_ma);
kpp=find(diff(sig_ma>prah)==1);
kpn=find(diff(sig_ma>prah)==-1);
if kpn(1) > kpp(1)
for i=1:length(kpn)
    [m,nr(i)]=max(signal(kpp(i):kpn(i)));% vypocet presne pozice
end ;
else
for i=1:length(kpp)
    [m,nr(i)]=max(signal(kpn(i):kpp(i)));% vypocet presne pozice
end;
end;
r=kpp+nr'-1;
```

Filtrace IIR filtry off-line

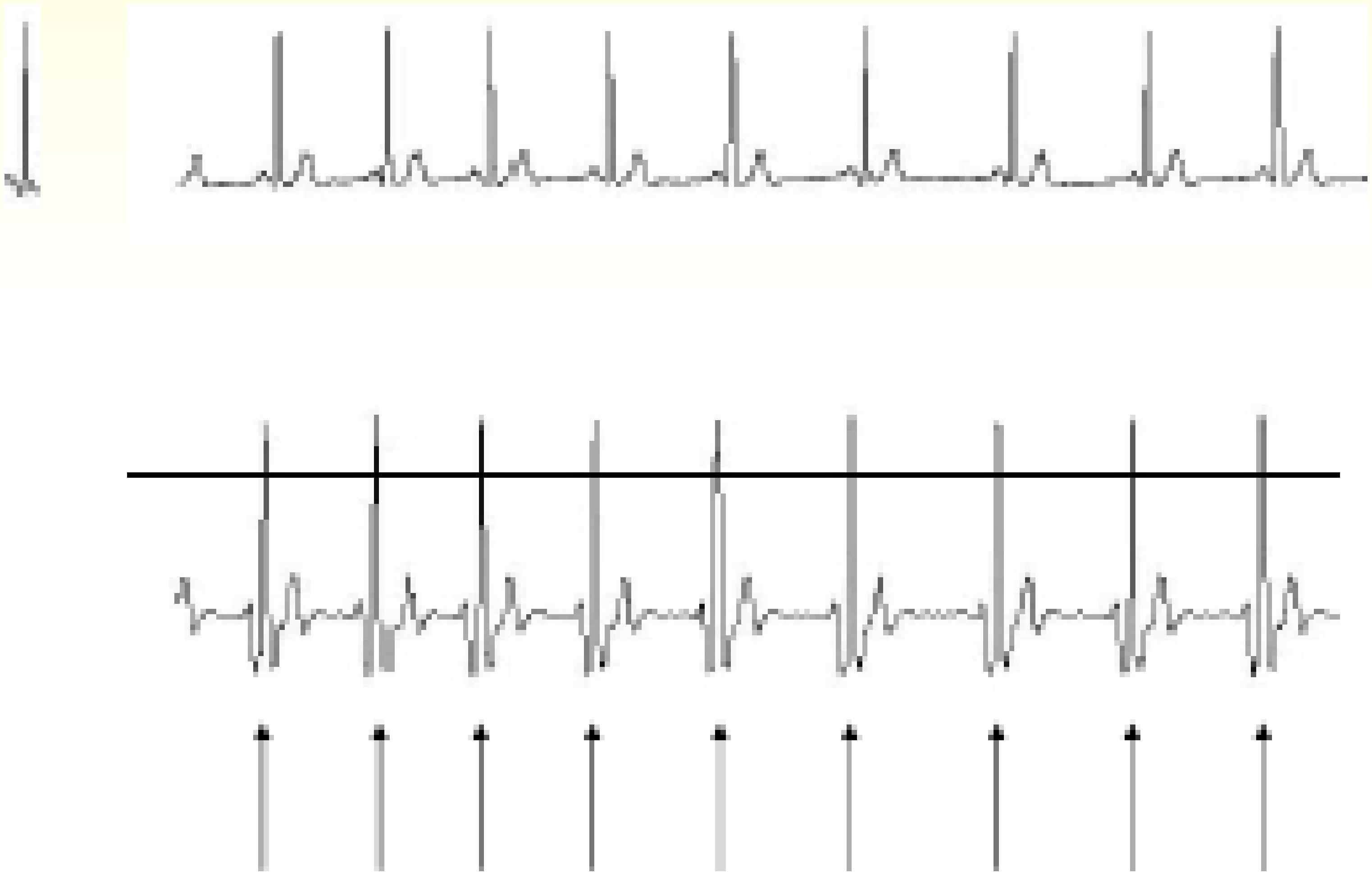
```
fs = 100;
t = 0:1/fs:1;
x = sin(2*pi*t*3)+.25*sin(2*pi*t*40);
b = ones(1,10)/10;
y = filtfilt(b,1,x);          % Nekauzalni filtrace
yy = filter(b,1,x);           % Normalni filtrace
plot(t,x,t,y,'--',t,yy,':')
```



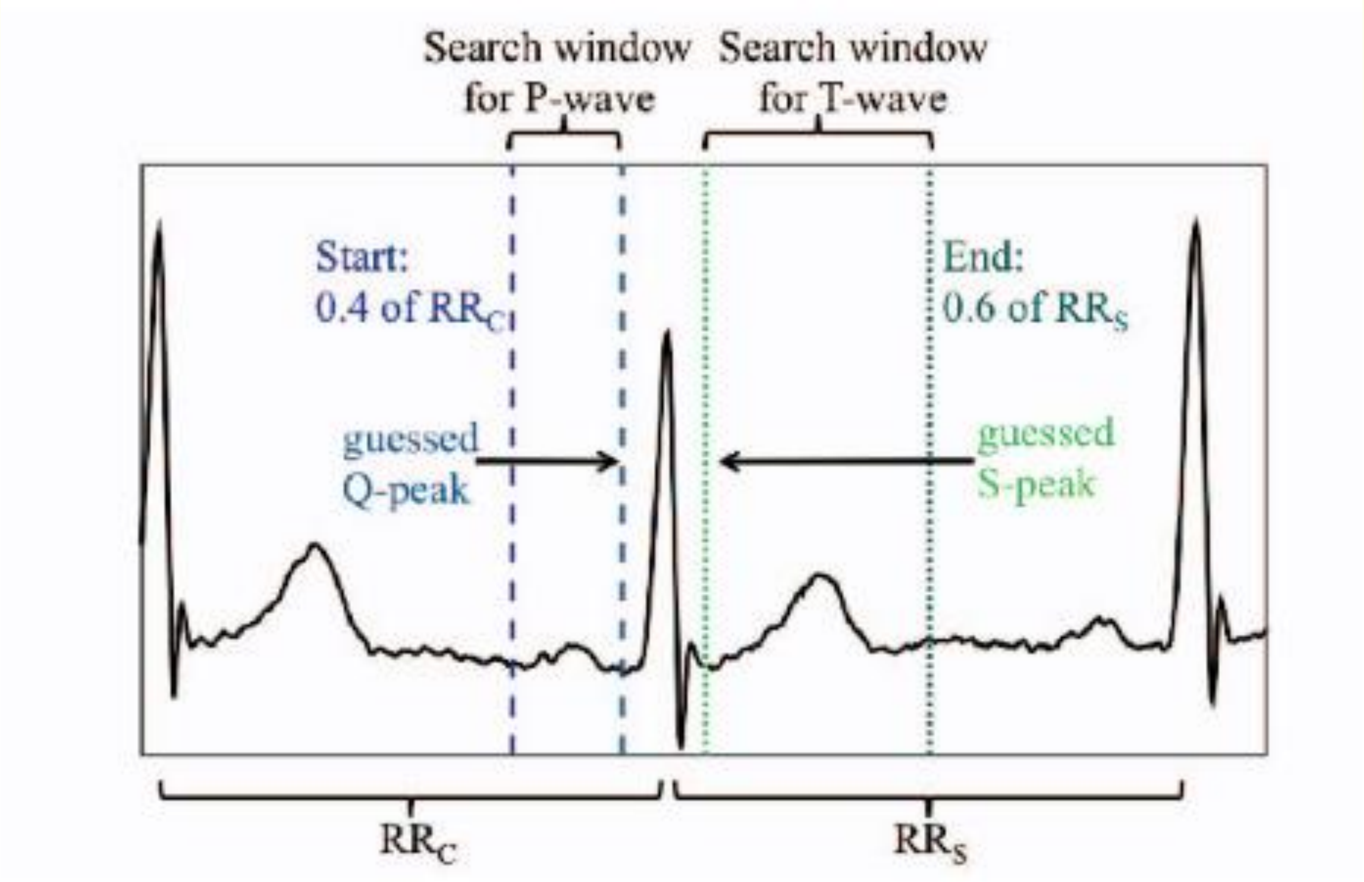
Analýza EKG signálu



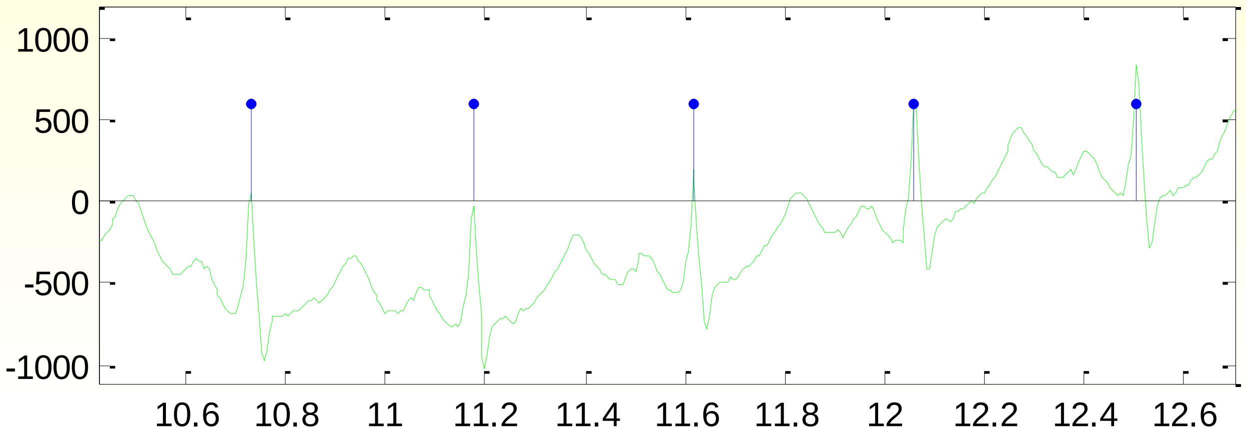
Hledání R špiček pomocí vzájemné korelace



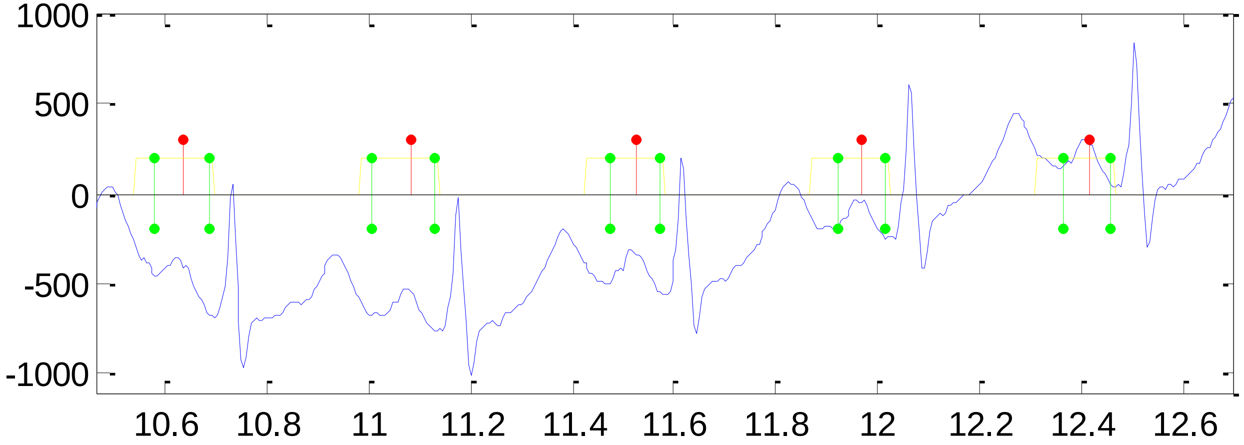
Detekce signálů v EKG detekce T vlny



Detekce P vlny

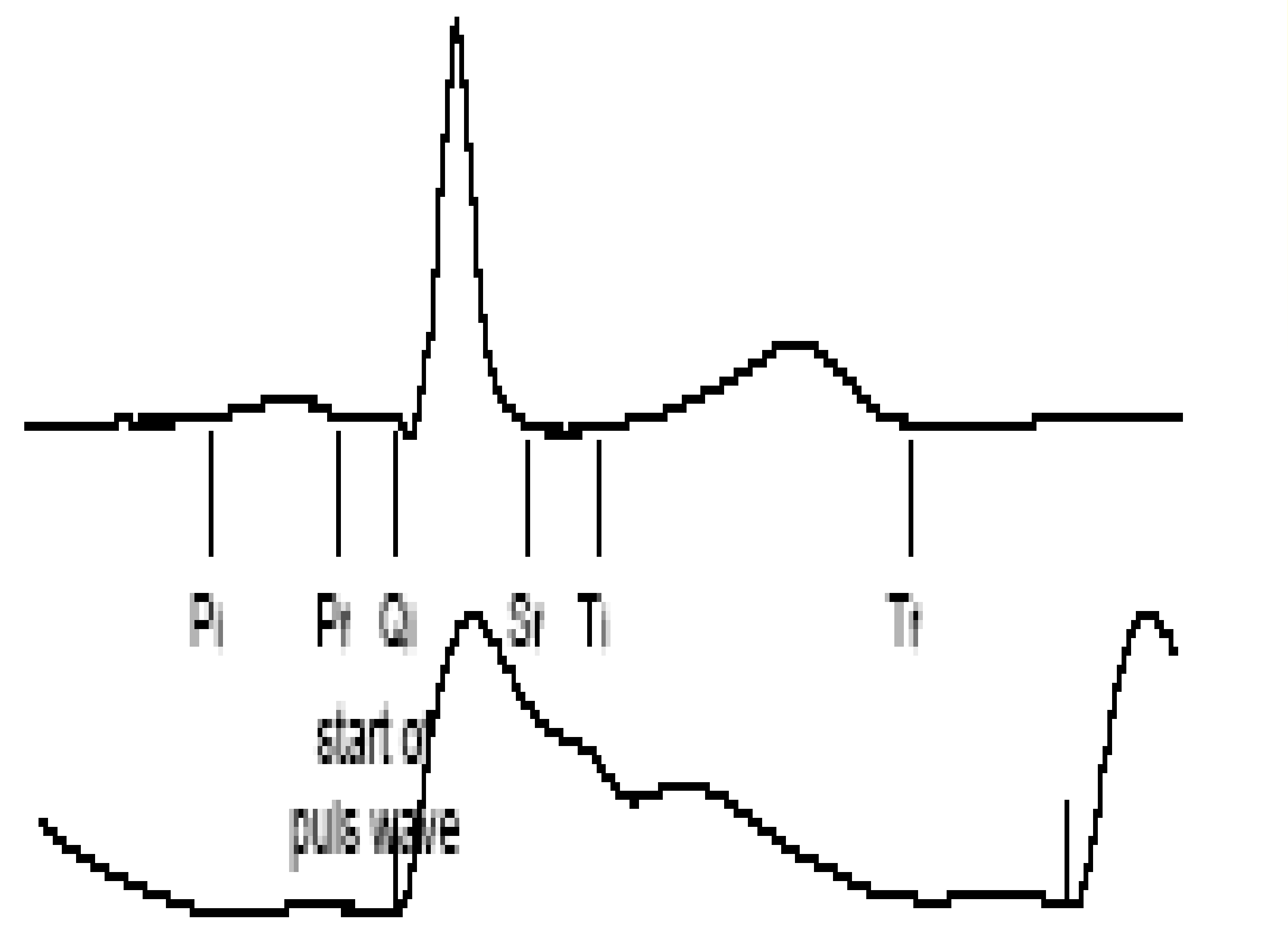


detekce QRS komplexu

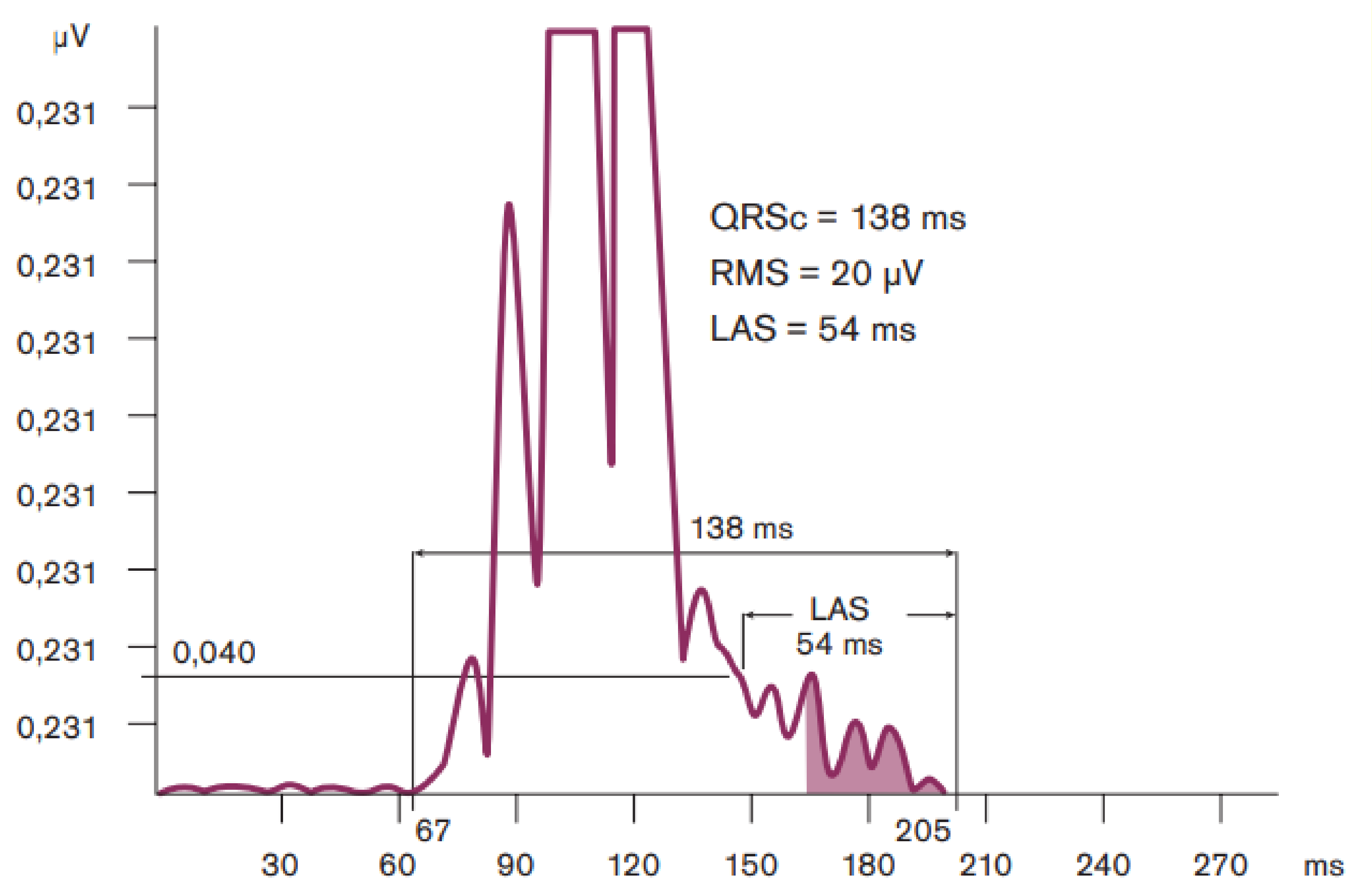


detekce P vlny

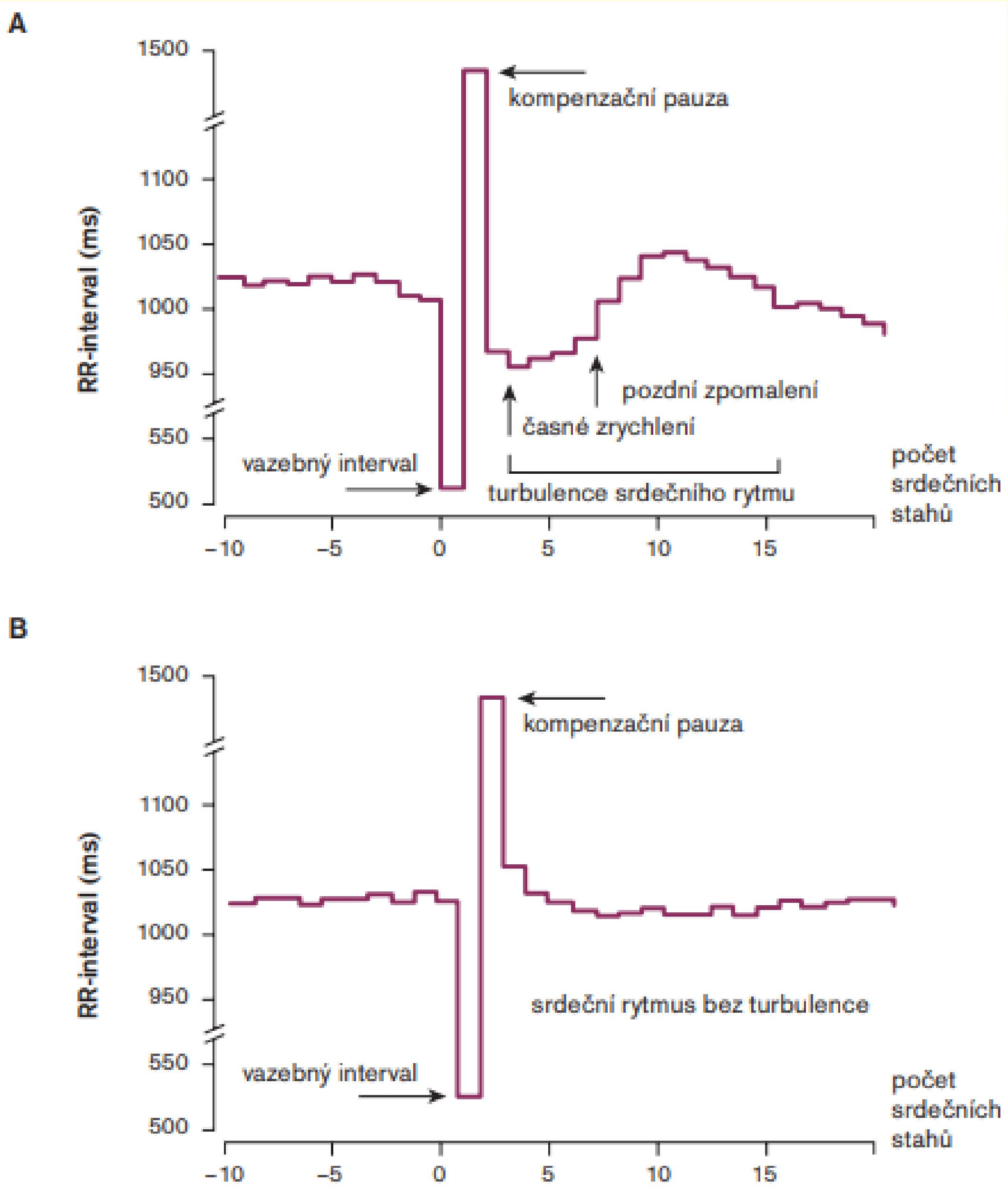
Určení začátků a konců vln



Speciální metody - pozdní potenciály



Speciální metody - turbulence srdečního rytmu



Speciální metody

Alternace T vlny

Hodnocení komorové depolarizace

– délka intervalu QT
– variabilita intervalu QT