HAB 621 Instrumentation and Measurement in Biomechanics

Çizim: De Motu Animalium G.Borelli (1680)

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Biyomekanik Araştırma Grubu

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- What is EMG
- Factors influencing the EMG Signal
- Instrumentation of EMG Signal Collection
- Processing EMG Signal

What is EMG?

Electromyography (EMG) is an experimental technique oncerned with the development, recording and analysis of myoelectric signals. Myoelectric signals are formed by physiological variations in the state of muscle fiber membranes.”

Electromyography…

“..is the study of muscle function through the inquiry of the electrical signal the muscles emanate.”

What is EMG?

Wide spread use of EMG

Medical Research

- Orthopedic
- Surgery
- Functional Neurology
- Gait & Posture Analysis

Rehabilitation

- Post surgery/accident
- Neurological Rehabilitation
- Physical Therapy
- Active Training Therapy

Ergonomics

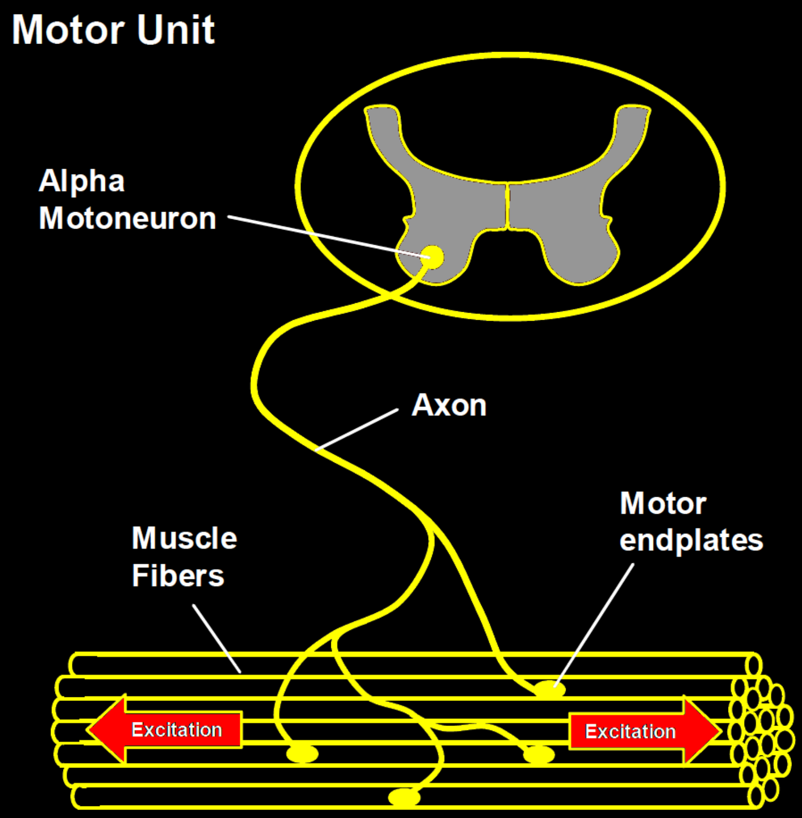
- Analysis of demand
- Risk Prevention
- Ergonomics Design
- Product Certification

Sports Science

- Biomechanics
- Movement Analysis
- Athletes Strength Training
- Sports Rehabilitation

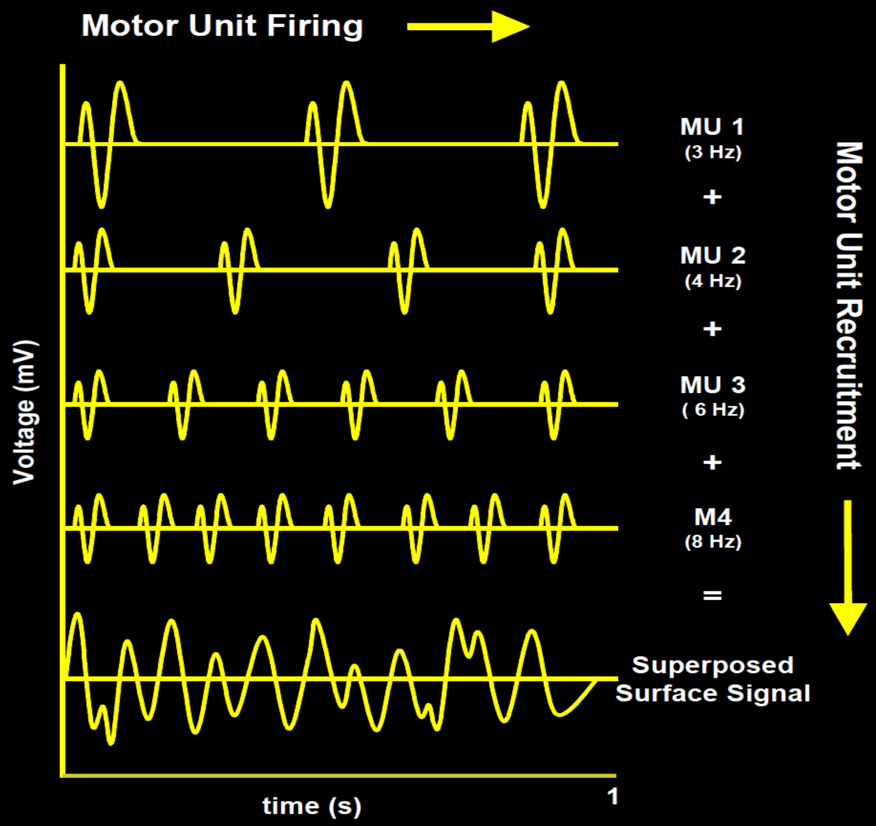
What is EMG?

The smallest functional unit to describe the neural control of the muscular contraction process is called a Motor Unit.



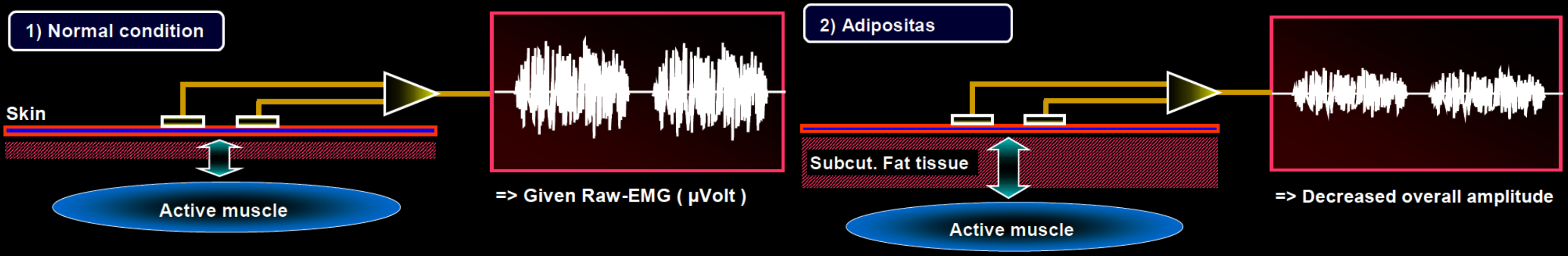
What is EMG?

The two most important mechanisms influencing the magnitude and density of the observed signal are the Recruitment of MUAPs and their Firing Frequency.



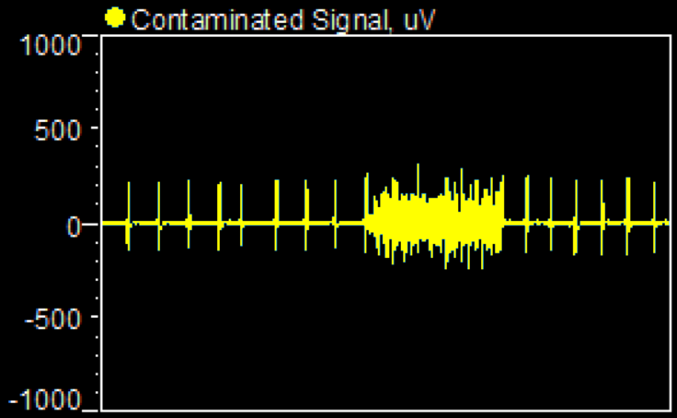
Factors Influencing the EMG Signal

Tissue characteristics: The human body is a good electrical conductor, but unfortunately the electrical conductivity varies with tissue type, thickness, physiological changes and temperature. These conditions can greatly vary from subject to subject (and even within subject) and prohibit a direct quantitative comparison of EMG amplitude parameters calculated on the unprocessed EMG signal.



Factors Influencing the EMG Signal

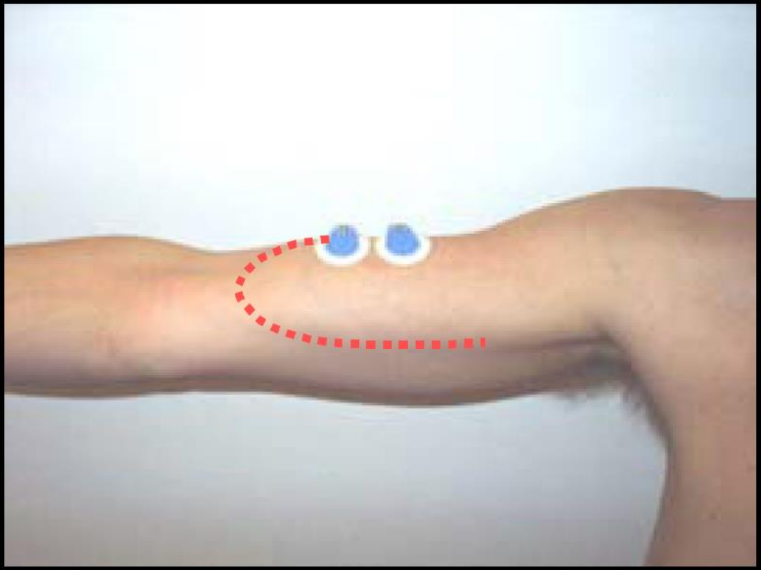
Physiological cross talk : Neighboring muscles may produce a significant amount of EMG that is detected by the local electrode site. Typically this “Cross Talk” does not exceed 10%-15% of the overall signal contents or isn’t available at all. However, care must been taken for narrow arrangements within muscle groups. ECG spikes can interfere with the EMG recording, especially when performed on the upper trunk / shoulder muscles.

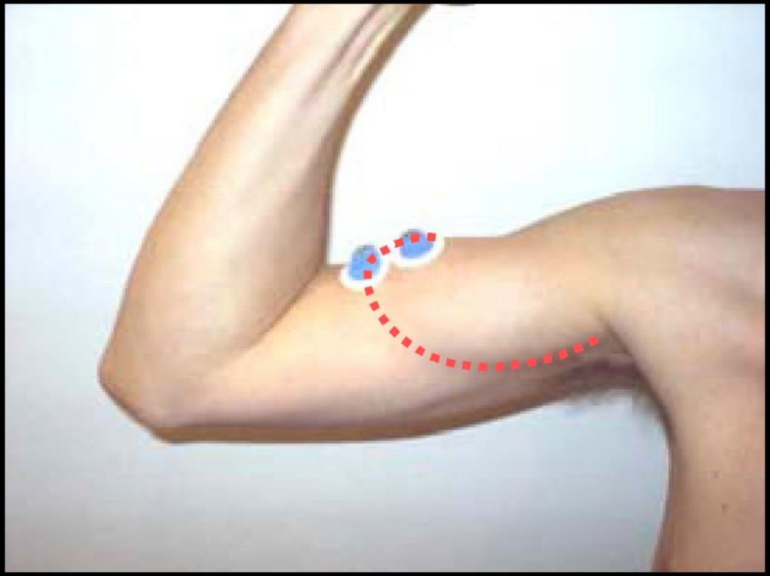


Raw EMG recording with heavy ECG interference

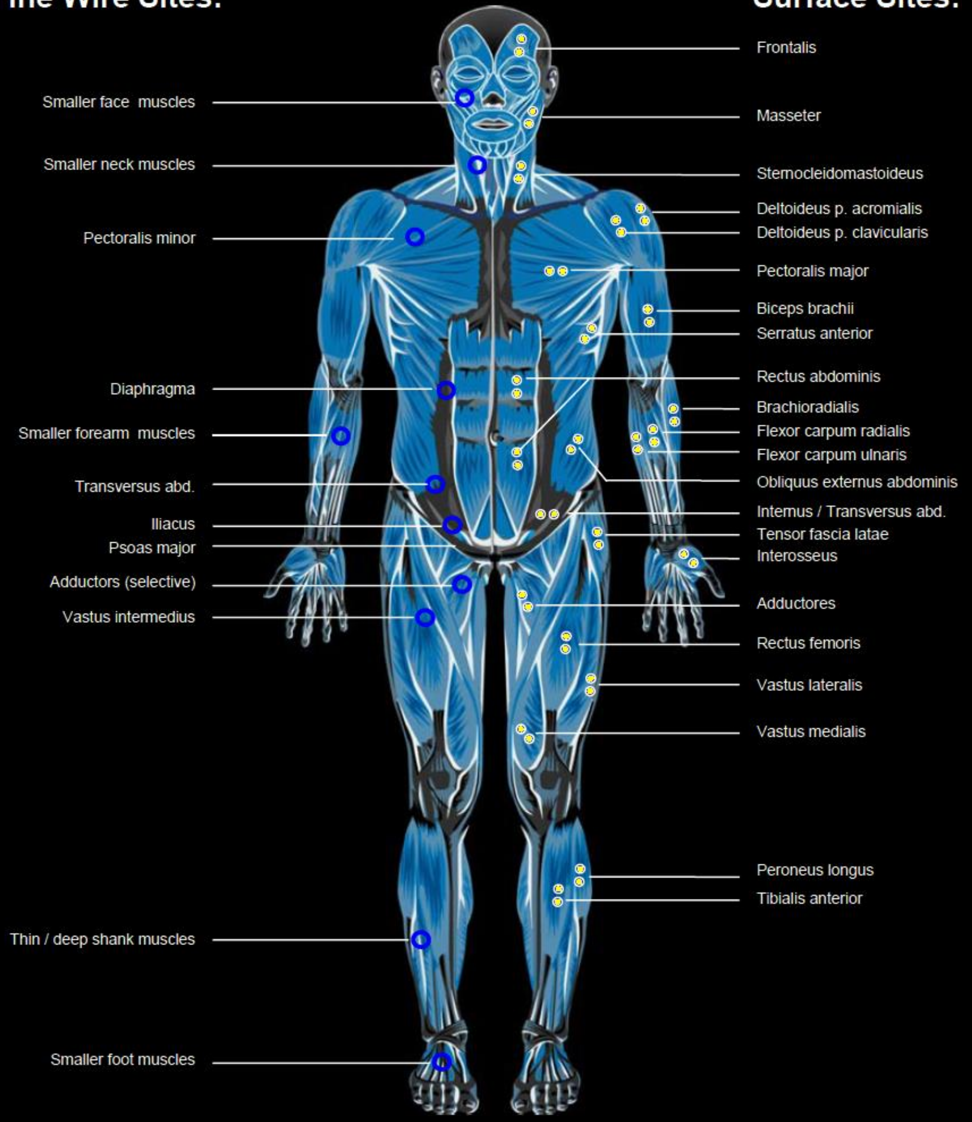
Factors Influencing the EMG Signal

Changes in the geometry between muscle belly and electrode site : Any change of distance between signal origin and detection site will alter the EMG reading. It is an inherent problem of all dynamic movement studies and can also be caused by external pressure.





Muscle Map Frontal



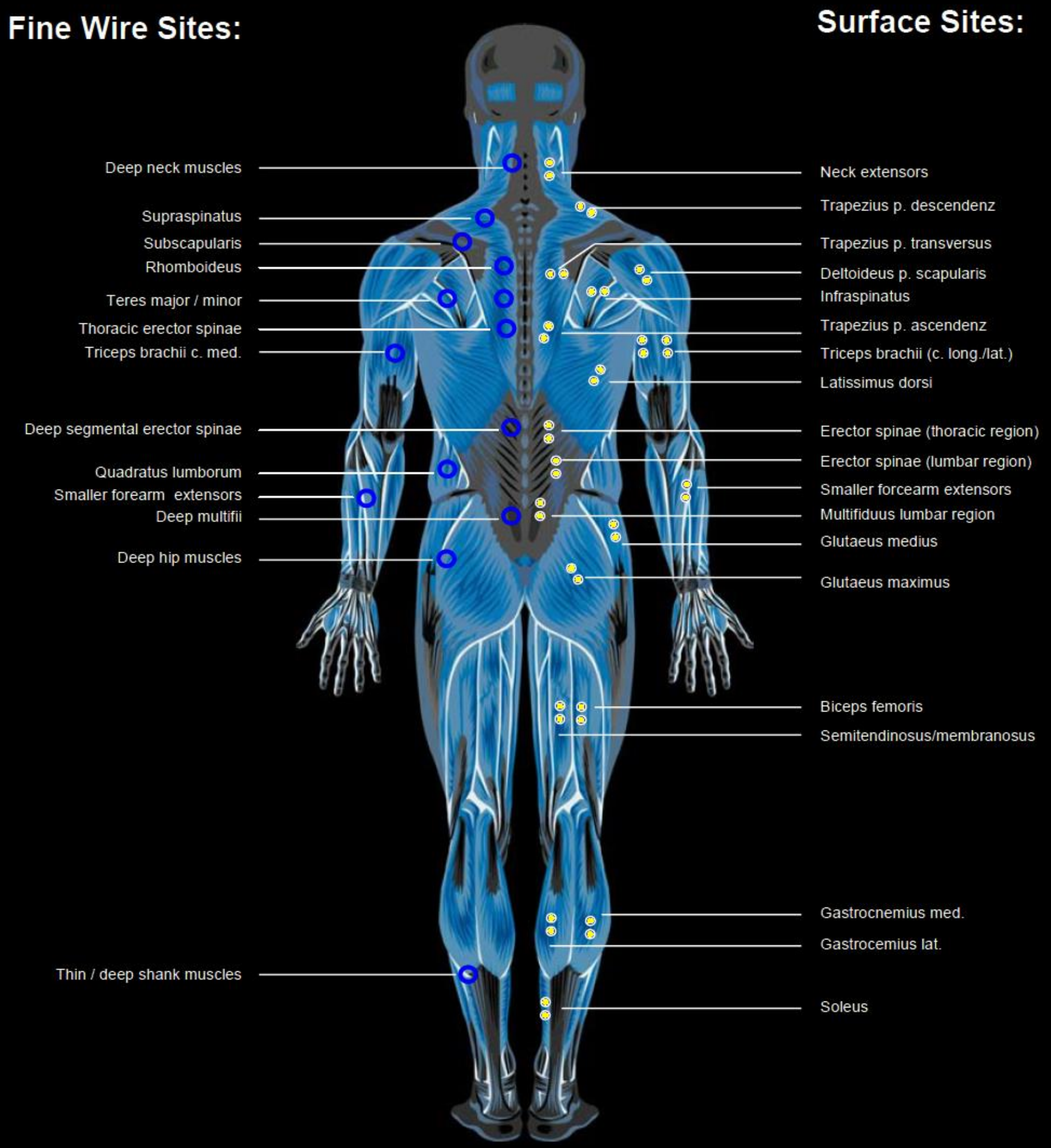
Fine Wire Sites:

- Smaller face muscles
- Smaller neck muscles
- Pectoralis minor
- Diaphragma
- Smaller forearm muscles
- Transversus abd.
- Iliacus
- Psoas major
- Adductors (selective)
- Vastus intermedius
- Thin / deep shank muscles
- Smaller foot muscles

Surface Sites:

- Frontalis
- Masseter
- Sternocleidomastoideus
- Deltoideus p. acromialis
- Deltoideus p. clavicularis
- Pectoralis major
- Biceps brachii
- Serratus anterior
- Rectus abdominis
- Brachioradialis
- Flexor carpum radialis
- Flexor carpum ulnaris
- Obliquus externus abdominis
- Internus / Transversus abd.
- Tensor fascia latae
- Interosseus
- Adductores
- Rectus femoris
- Vastus lateralis
- Vastus medialis
- Peroneus longus
- Tibialis anterior

Muscle Map Dorsal

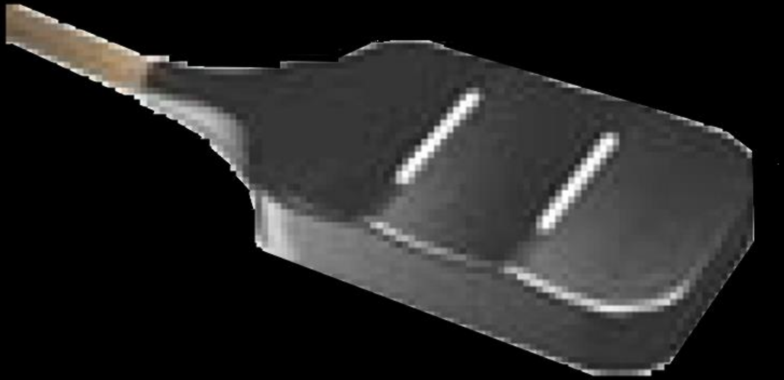


Instrumentation of EMG Signal Collection

EMG-amplifiers act as differential amplifiers and their main quality item is the ability to reject or eliminate artifacts. The differential amplification detects the potential differences between the electrodes and cancels external interferences out. Typically external noise signals reach both electrodes with no phase shift. These “common mode” signals are signals equal in phase and amplitude. The term "common mode gain" refers to the input-output relationship of common mode signals. The **"Common Mode Rejection Ratio" (CMRR)** represents the relationship between differential and common mode gain and is therefore a criteria for the quality of the chosen amplification technique. The **CMRR** should be as high as possible because the elimination of interfering signals plays a major role in quality. A value >80dB is regarded as acceptable.

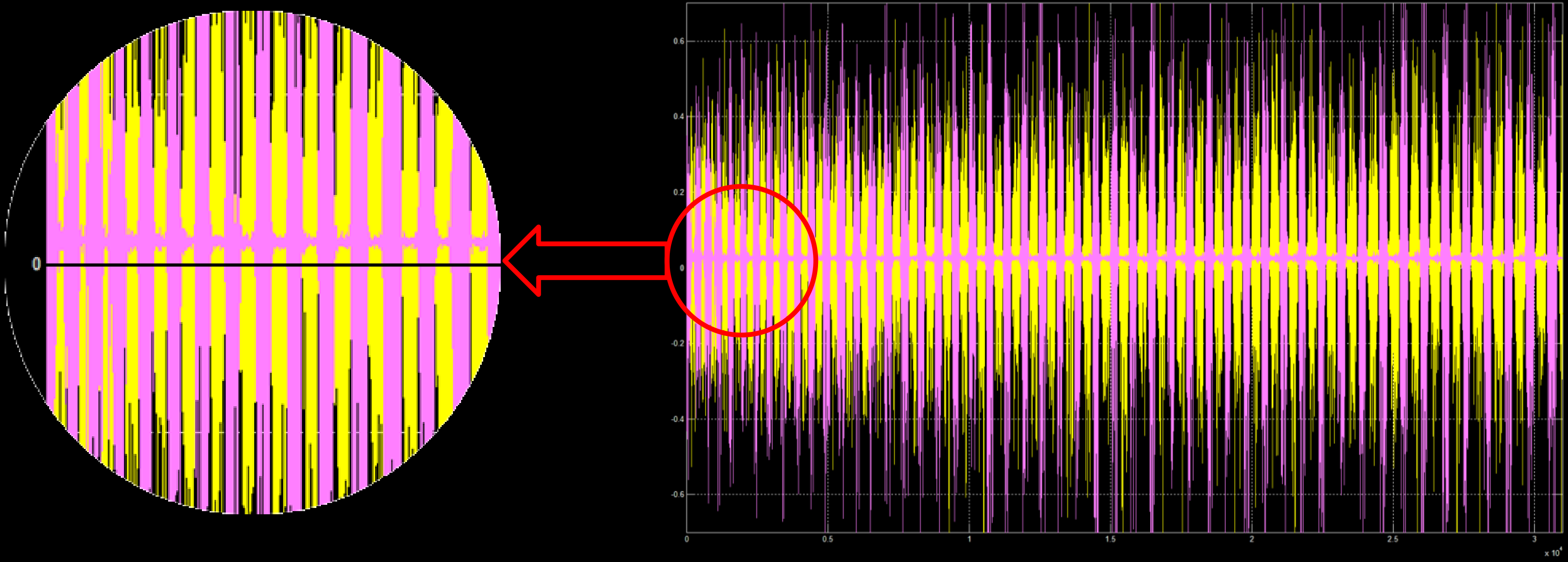
Instrumentation of EMG Signal Collection

State of the art concepts prefer the use of **EMG pre-amplifiers.** These miniaturized amplifiers are typically built-in the cables or positioned on top of the electrodes **(Active electrodes).** The un-amplified EMG signal on the skin has typical charges between a few microvolt and 2-3 millivolt. The signal is generally amplified by a factor of at least 500 (e.g. when using pre-amplifiers) to 1000 (passive cable units). The Input impedance of the amplifier should have a value of at least 10x the given impedance of the electrode.



Processing EMG Signal

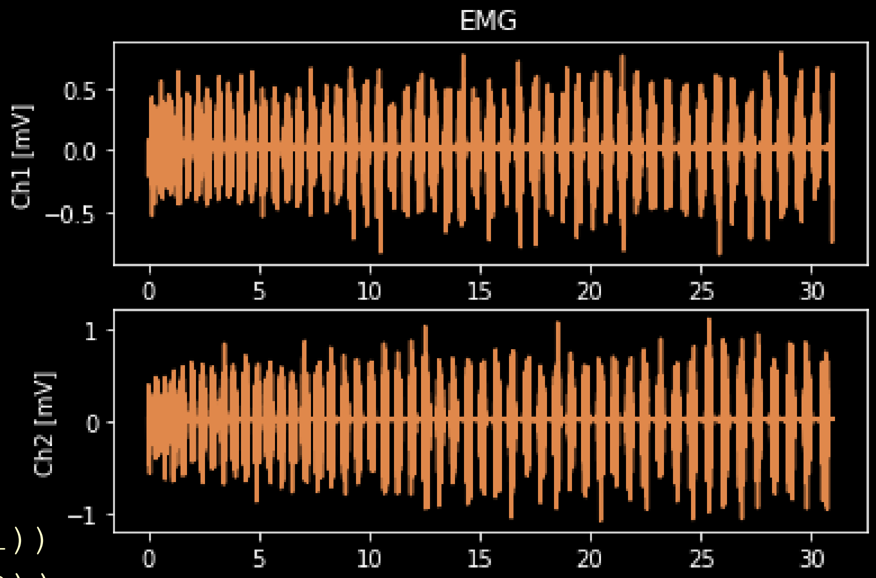
Most amplifiers work with an auto offset correction. However, it is possible that the EMG baseline is shifted away from the true zero line (*test: mean value of the raw EMG ≠ zero*). If not identified and corrected, all amplitude based calculations are invalid for that record.



Processing EMG Signal

test: mean value of the raw EMG ≠ zero

```
from pylab import loadtxt, linspace, figure, subplot, plot, title, ylabel, xlabel
import numpy as np
#  EMG recording of right and left vastus lat. m
ch1, ch2 = loadtxt('EMGveri.txt', unpack = True)
n = len(ch1)
delta_t = 1/1000       # 1000 Hz
time = linspace(0, (n-1)*delta_t, n)
figure(1)
subplot(2,1,1)
plot(time, ch1)
ylabel('Ch1 [mV]')
title('EMG')
subplot(2,1,2)
plot(time, ch2)
ylabel('Ch2 [mV]')

print("Mean Value Ch1 : ", np.mean(ch1))
print("Mean Value Ch2 : ", np.mean(ch2))
```



```
Mean Value Ch1 :  0.022551929114927097
Mean Value Ch2 :  0.025813884140990964
```

Processing EMG Signal

test: mean value of the raw EMG ≠ zero

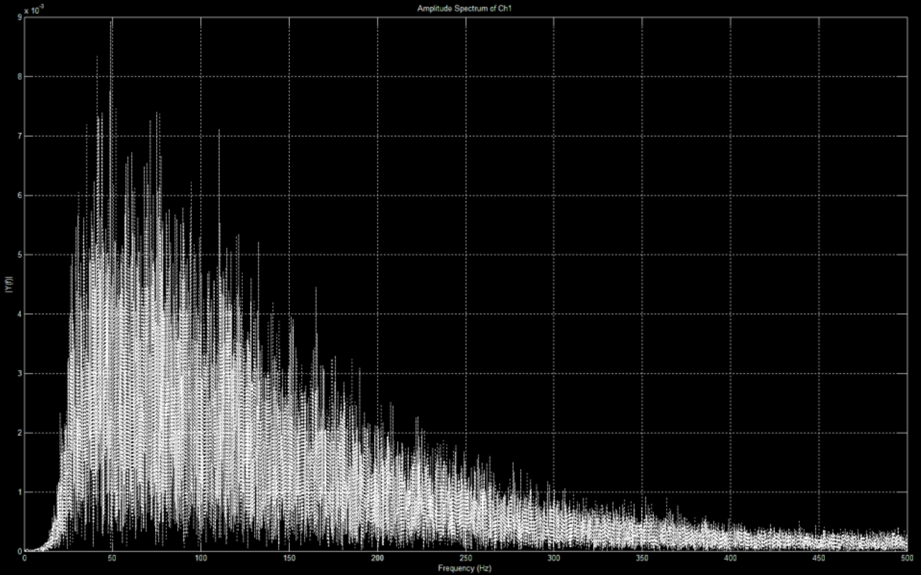
```
from scipy import signal

ch1_dtrend = signal.detrend(ch1)
ch2_dtrend = signal.detrend(ch2)

print("Mean Value After deTrend Ch1 : ", np.mean(ch1_dtrend))
print("Mean Value After deTrend Ch2 : ", np.mean(ch2_dtrend))
```

```
Mean Value After deTrend Ch1 :  -9.319068814119741e-17
Mean Value After deTrend Ch2 :  -1.521677049598133e-17
```

mean value of the raw EMG = almost zero

Processing EMG Signal

The most of the surface EMG frequency power is located between 10 and 250 Hz. This power distribution can be calculated by the "Fast Fourier Transformation" (**FFT**) and graphically presented as a Total Power Spectrum of the EMG signal**,** which shows the frequency power distribution (Y-axis) in ratio to the frequency band (X-axis). The precise shape of the total power spectrum can vary widely, depending on the FFT-settings and the measurement conditions (especially muscle type, muscle length and tissue/skin filter effects).



FFT Leakage

- There are no limits on the number of data points when taking FFTs in NumPy.
- The FFT algorithm is much more efficient if the number of data points is a power of 2 (128, 512, 1024, etc.).
- The DFT assumes that the signal is periodic on the interval 0 to N, where Nis the total number of data points in the signal.
- Care needs to be taken to ensure that all waves in the signal are periodic within the interval 0 to N, or a phenomenon known as leakage will occur.

```
import math

def NextPowerOfTwo(number):
    # Returns next power of two following 'number'
    return math.ceil(math.log(number,2))
```

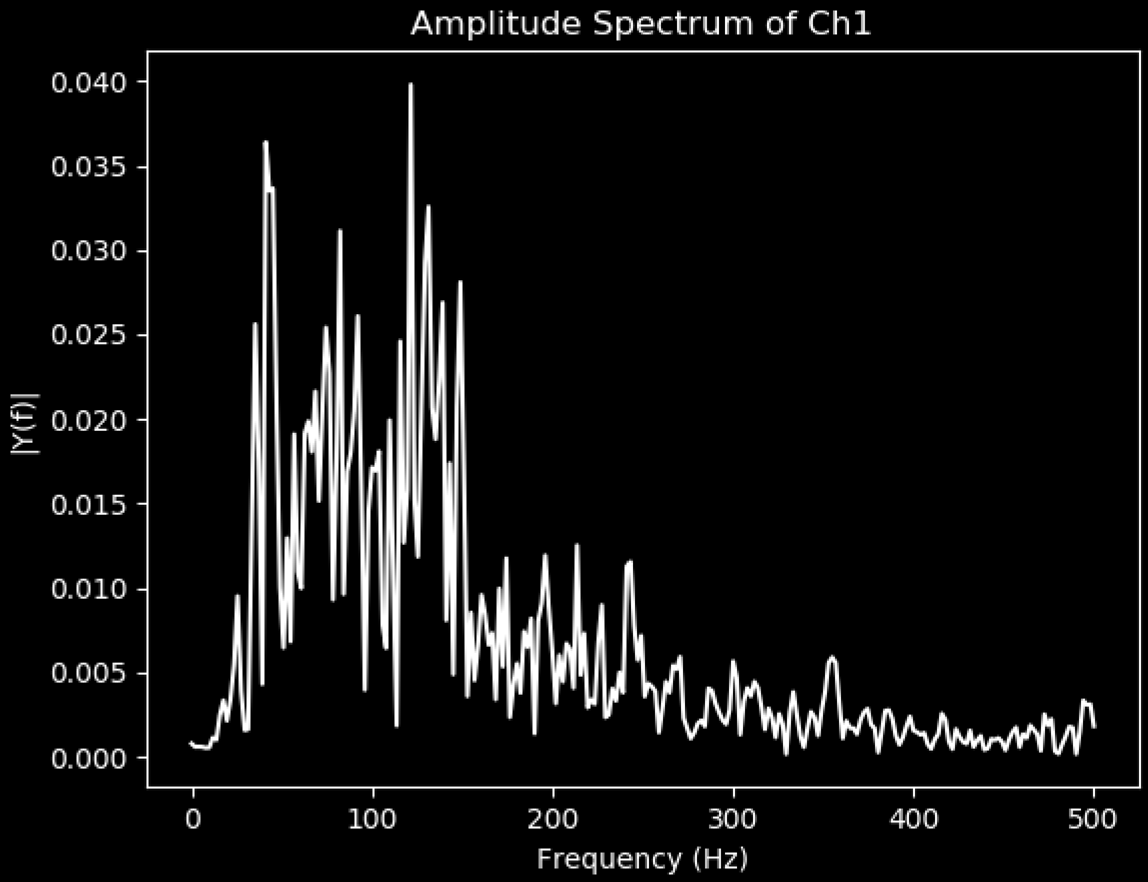
Processing EMG Signal

Fast Fourier Transformation (FFT)

```
def calculate_emg_fft(emg, freq):
    T = 1/freq                          # Sample time
    L = len(emg)                        # Length of signal
    L = 2**NextPowerOfTwo(L);
    Y = fft(emg)
    f = linspace(0.0, 1.0/(2.0*T), L/2)
    return Y, f

L = len(ch1_dtrend[:512])
Y, f = calculate_emg_fft(ch1_dtrend[:L], 1000)
# Plot single-sided amplitude spectrum.
figure(2)
plot(f, 2.0/L * abs(Y[:L//2]),'k-')
title(['Amplitude Spectrum of Ch1'])
xlabel('Frequency (Hz)')
ylabel('|Y(f)|');
```

Processing EMG Signal

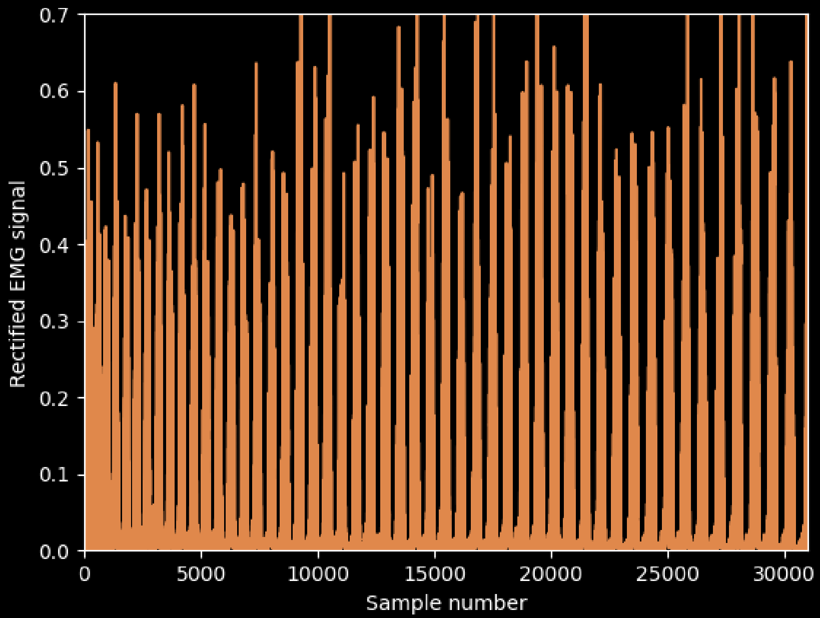
Fast Fourier Transformation (FFT)



Processing EMG Signal

Full Rectification of the EMG signal

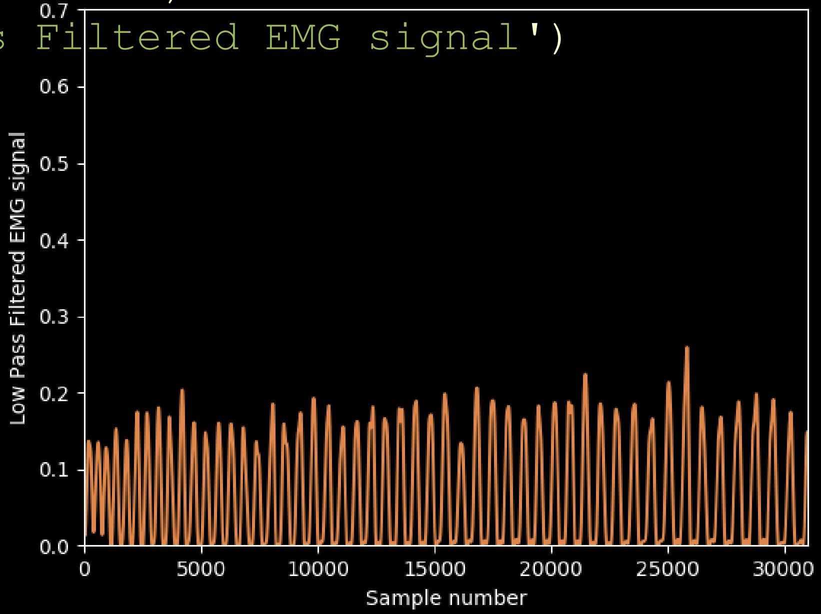
```
# Rectification of the EMG signal
rec_emg=np.abs(ch1_dtrend);
figure(3)
plot(rec_emg)
axis([0, len(ch1_dtrend), 0, 0.7])
xlabel('Sample number')
ylabel('Rectified EMG signal')
```



Processing EMG Signal

Linear Envelope of the EMG signal

```
# Need to construct a low pass filter of a cut off frequency of say, 10Hz.
# The sampling frequency is 1000Hz, and we use the 3th order filter.
b, a = butter(3, 10/1000, 'low');
# The next step is to filter the signals to obtain the linear envelope.
filter_emg = filtfilt(b, a, rec_emg);
figure (4)
plot(filter_emg)
axis([0, len(ch1_dtrend), 0, 0.7])
xlabel('Sample number')
ylabel('Low Pass Filtered EMG signal')
```



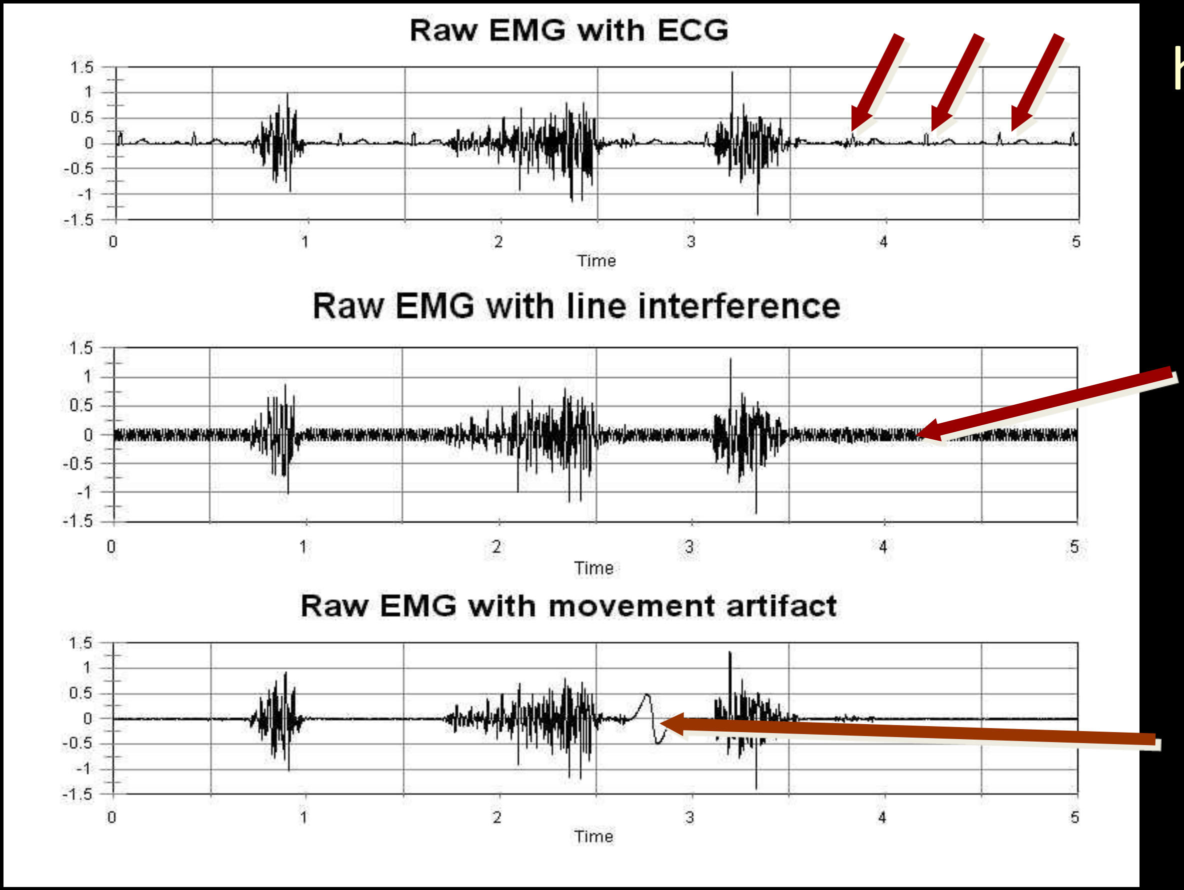
Processing EMG Signal

What is Noise?

- Noise is the part of a waveform that is not signal!
- unwanted error in a waveform
- Noise can be random (white) or have a statistical distribution
- Noise can be due to interference from another signal (called **cross-talk**) or induced by physical devices near the medium carrying the waveform (e.g., electric motors, radiation, power cords, radio waves).
- Noise can occur at random intervals (e.g., bumping of electrodes, power surges, floor impacts nearby) or regular (50/60 Hz line interference) or irregular intervals (e.g., ECG or EEG interference of EMGs).
- Noise may have frequencies inside or outside the frequency range of the signal (if outside, filtering can effectively reduce the noise).

Processing EMG Signal

Examples of Noise in an EMG signal



heart rate detected

50 Hz noise

an impact spike

Processing EMG Signal

Digital Filtering

- Used on data that have been sampled with fixed time intervals.
- Types:
  - low-pass, high-pass, band-pass, band stop and notch (single or small band-stop filter, useful for AC interference)
- Designs:
  - Butterworth (optimally flat in bandpass), critically-damped, Chebyshev etc. (sharper cutoffs), Generalized Cross-validation (GCV also called Woltring filter, 1986)
- Problems:
  - Noise spikes alter a localized period in the signal
  - Phase distortion (usually phase-lags occur)
  - Does not reduce size of data file

Processing EMG Signal

Fourier Reconstruction

- Once a Fourier series has been extracted from a waveform many cycles may be created
- Requires signal to be cyclic or made cyclic with “windowing” functions (Hamming, Blackman, Cosine bell etc.)
- Can reduce a complex signal to a very few number of coefficients
- Problems:
  - Noise spikes can significantly alter overall cyclic pattern
  - Can distort signal in unpredictable ways

Processing EMG Signal

How to Decide on the Best Technique?

- Visually compare original noisy signal with smoothed signal (Pezzack *et al.* 1977). Smooth signal should pass through middle of the noisy waveform without distorting peaks and valleys.
- Evaluate smoothing technique against known mathematical functions (e.g., Robertson & Dowling 2003)
- Evaluate smoothing technique against published data (e.g., Wood & Jennings 1979; Hatze 1981; Lanshammar 1982; vs. Pezzack *et al.* 1977)
- Evaluate residuals mathematically (e.g., Jackson 1979; Winter *et al.* 1984).
- Simulation (Walker 1998, Nagano *et al.* 2003)

Processing EMG Signal

Removing High Frequency Noise

- Essential for data that are to be doubly-differentiated (computing acceleration from displacement data)
- Low-pass filtering is the most common (Winter 1974, Pezzack *et al.* 1978)
- Need to select an appropriate cutoff and roll-off (filter order)
- Critically-damped may be better for rapid transients (Robertson & Dowling 2003)
- Butterworth filters have better roll-offs
- Zero-lag can be achieved by filtering forwards and backwards

Processing EMG Signal

Removing Low Frequency Noise

- Essential for doubly-integrating data (e.g., integrating force to obtain displacement)
- Bias removal is critical
- High-pass filters (Murphy & Robertson 1992)
- End-point problems need to be considered (pad with means, zeros, reflexively, e.g., Smith 1989, Walker 1998)

Processing EMG Signal

Removing Noise Spikes

- Low-pass filtering may not be effective, perhaps use higher order, Butterworth filter
- Interpolate across spike or artefact
- Moving median (use smallest window possible)

Processing EMG Signal

How to Prevent Phase Distortion

- Centrally weighted moving averages
- Filter in both directions (Winter *et al.*1974)
- Zero-lag filters (b-splines, Woltring 1986)

Processing EMG Signal

How to Prevent End-point Transients

- Collect extra data before and after critical period
- Padding points
  - zeros
  - means
  - reflexive (Smith 1989)
  - linear extrapolation (Vint & Hinrichs 1996)
- Windowing functions are useful for Fourier analysis

Processing EMG Signal

References

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Processing EMG Signal

References

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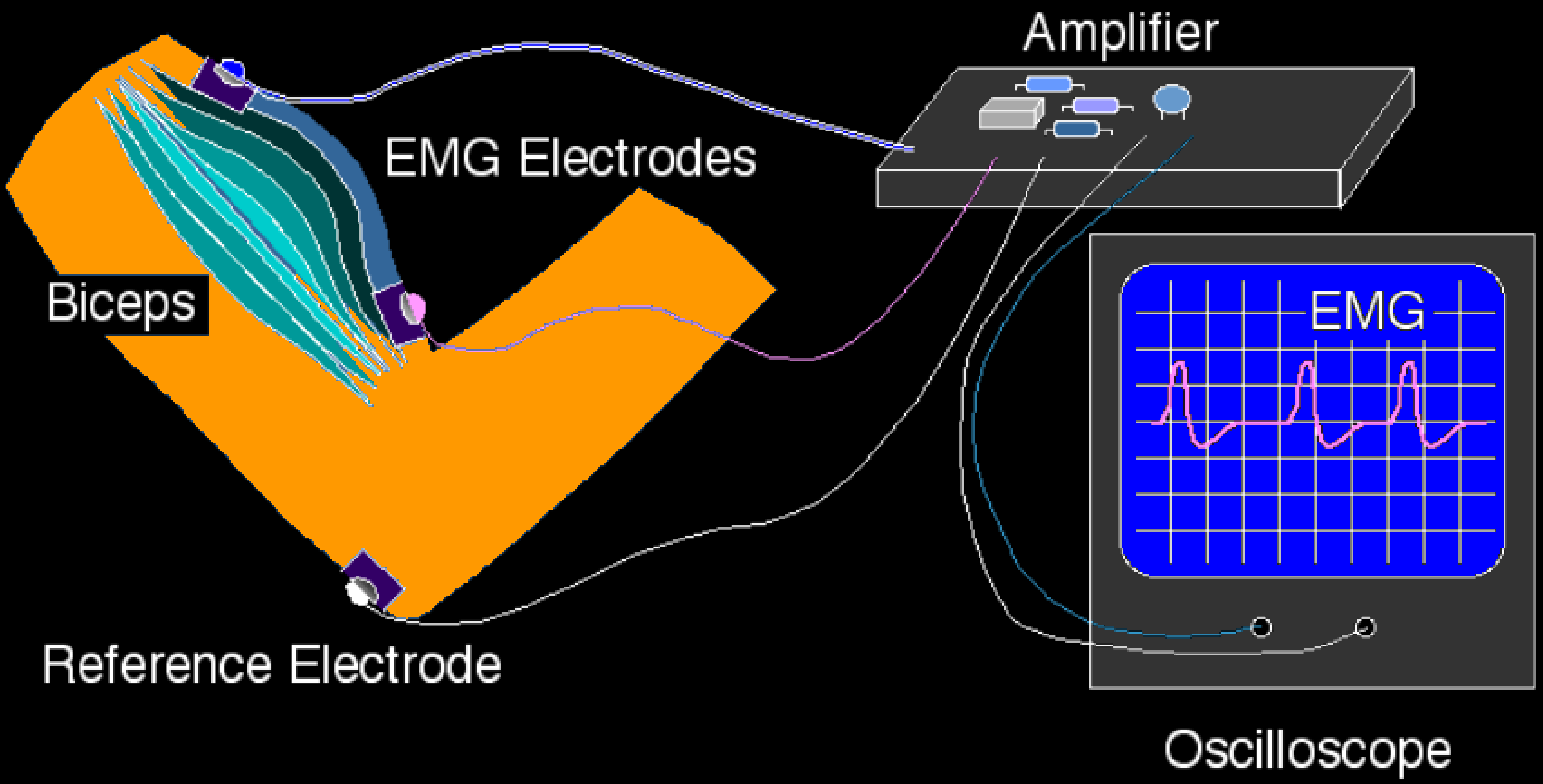
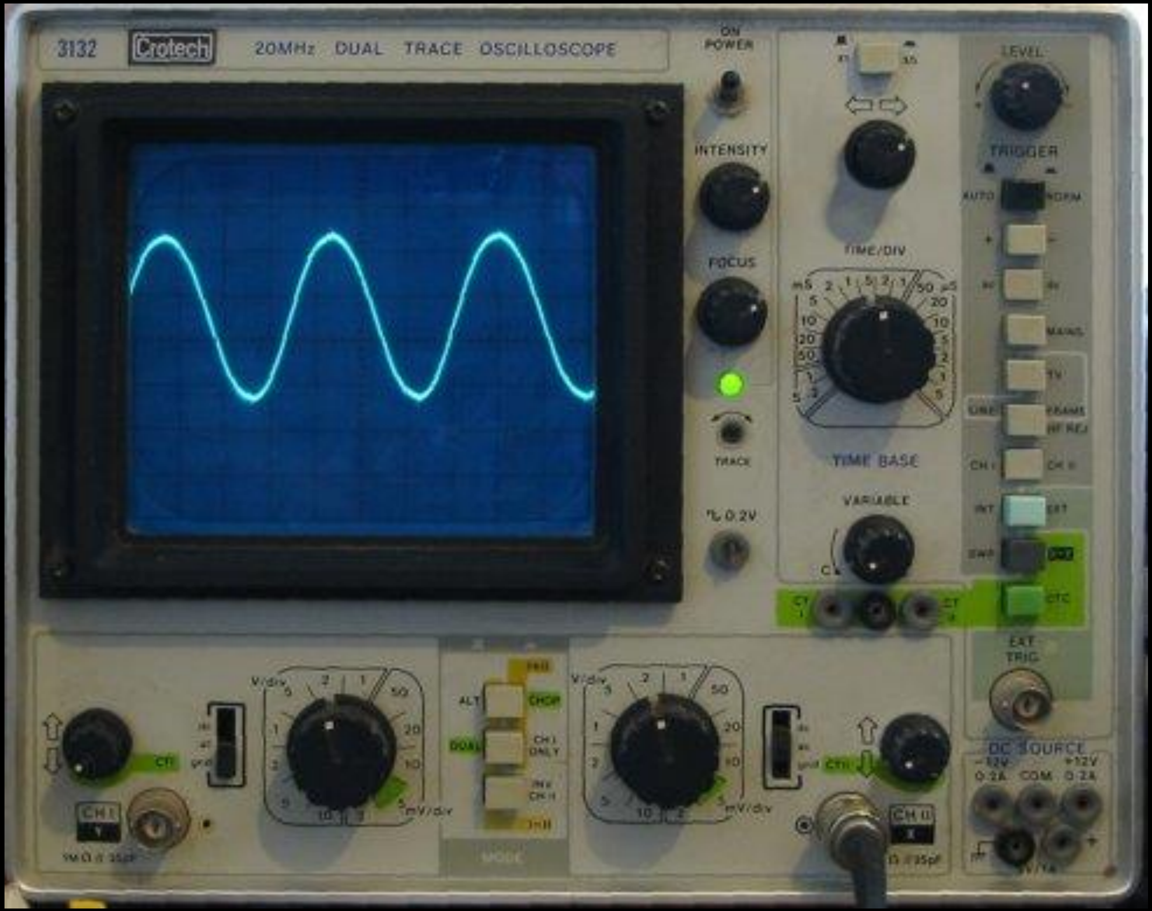
Oscillography



Oscillography

Oscilloscope: -cathode ray tube (CRT) with controls for displaying analog waveforms (continuously varying voltages)



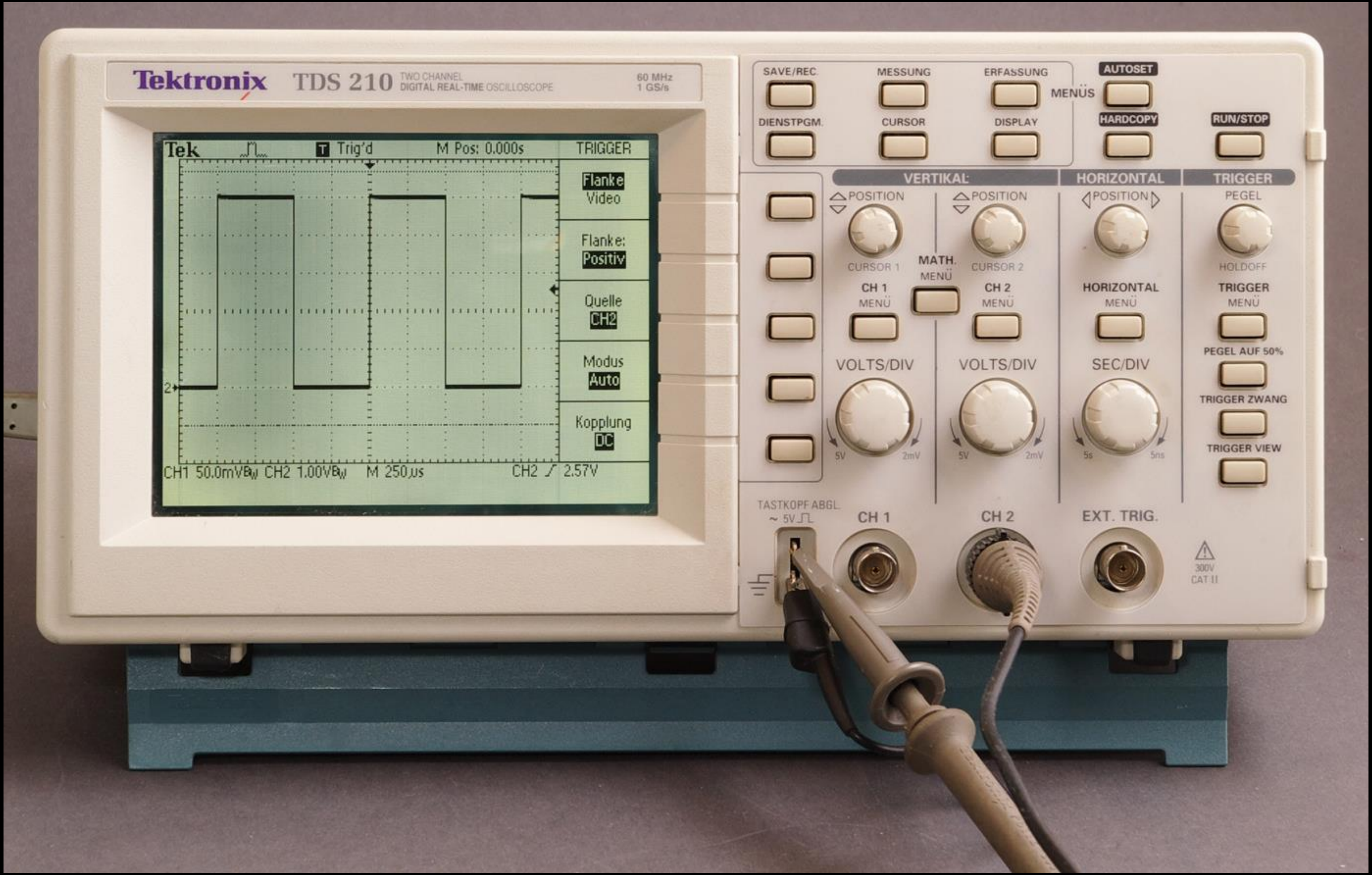
Oscilloscope

The timebase sets the time that the beam is scanned from left to right on the screen and it's calibrated in horizontal divisions (the black grid on the front of the screen).

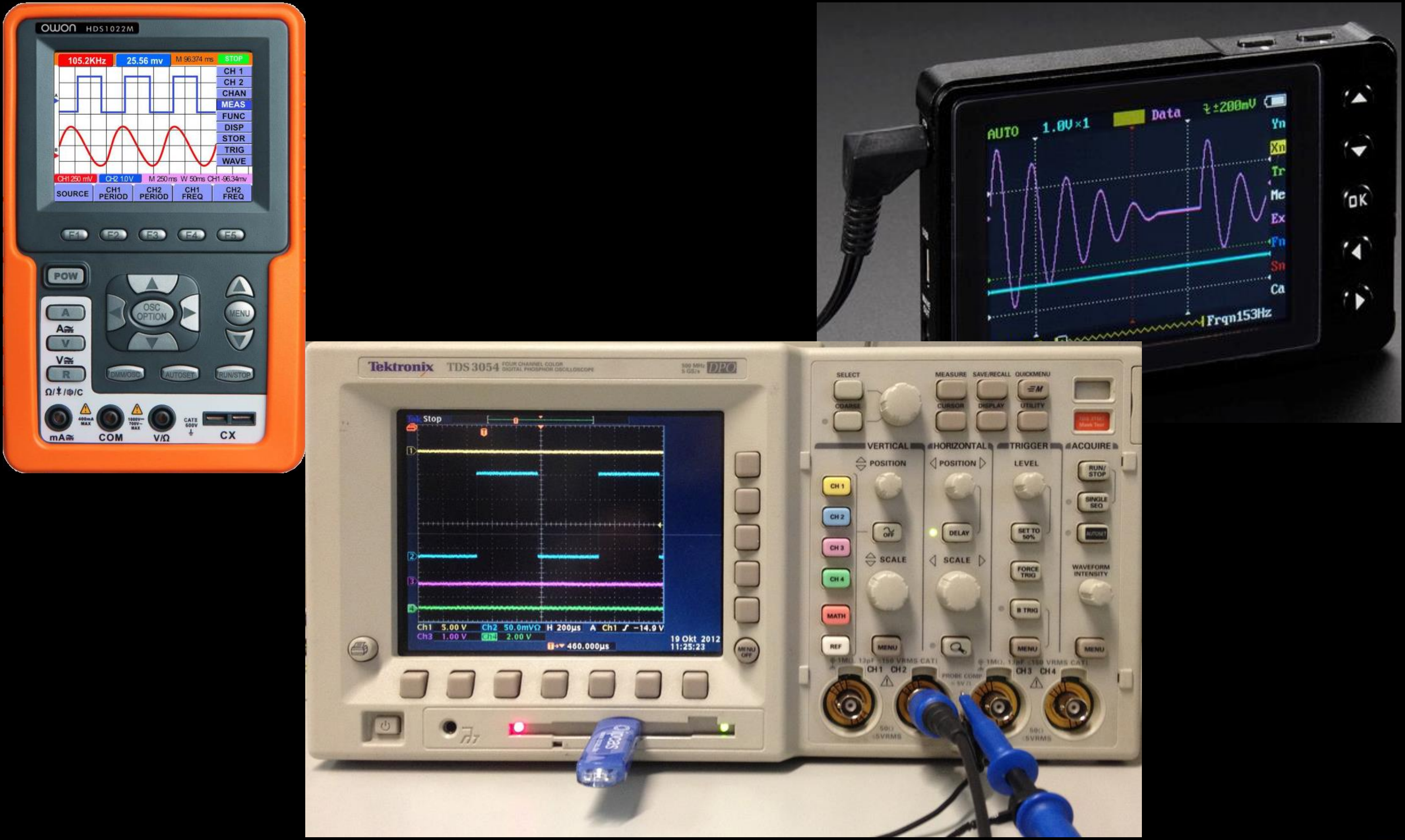
Each channel on the oscilloscope is really just a high quality amplifier with low noise, high bandwidth and selectable gain which connects to the vertical deflector in the oscilloscope.

The trigger detects when to start moving the beam to the right across the display. Setting this to Auto makes the beam trigger continuously.

Oscilloscope



Oscilloscope



Oscilloscope Controls

Vertical section

- controls for amplitude of input(s),
- coupling (AC or DC), ground,
- single-ended or differential,
- invert signal and some allow multiple inputs (2 or 4)

Horizontal section

- time base or X-Y mode,
- horizontal start position,
- sweep speed,
- For multiple waveforms select alternate or chopped sweep depending upon sweep speed

Trigger section

- determines when beam starts its sweep across CRT or LCD.
- Source may be from an input of the vertical section, internal triggering, external triggering or line frequency.

Oscilloscope Controls

Coupling

Ground:

- shorts input (0 volts) to enable vertical positioning of beam

AC

- removes DC component of waveform. Useful for EMG waveforms because it keeps waveform centered around 0 volts, like a high-pass filter.

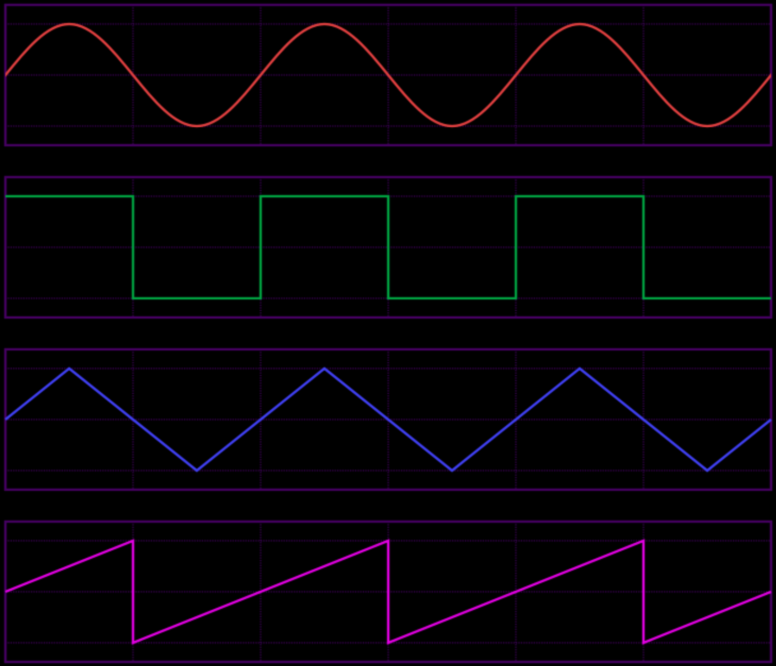
DC

- on some scopes labelled AC/DC. Waveform unaffected before amplification. Must be used for force and displacement waveforms.

Try: Use a signal generator to show how AC-coupling influences a sine wave that has a variable DC offset (or bias).

Function Generator

A function generator is usually a piece of electronic test equipment or software used to generate different types of electrical waveforms over a wide range of frequencies. Some of the most common waveforms produced by the function generator are the sine, square, triangular and sawtooth shapes.



Function Generator

an arbitrary waveform sequence