Problem 11.

String telephone

Idea

- Construct a string telephone
- Determine the relevant parameters
- Measure the characteristics of transmitted sound:
    - Resonance
    - Reflections
    - Damping
- Design an optimal system

Experimental approach

- Parameters inflencing the intensity of transmitted sound:

    String tension

    Sound frequency

    String dimensions

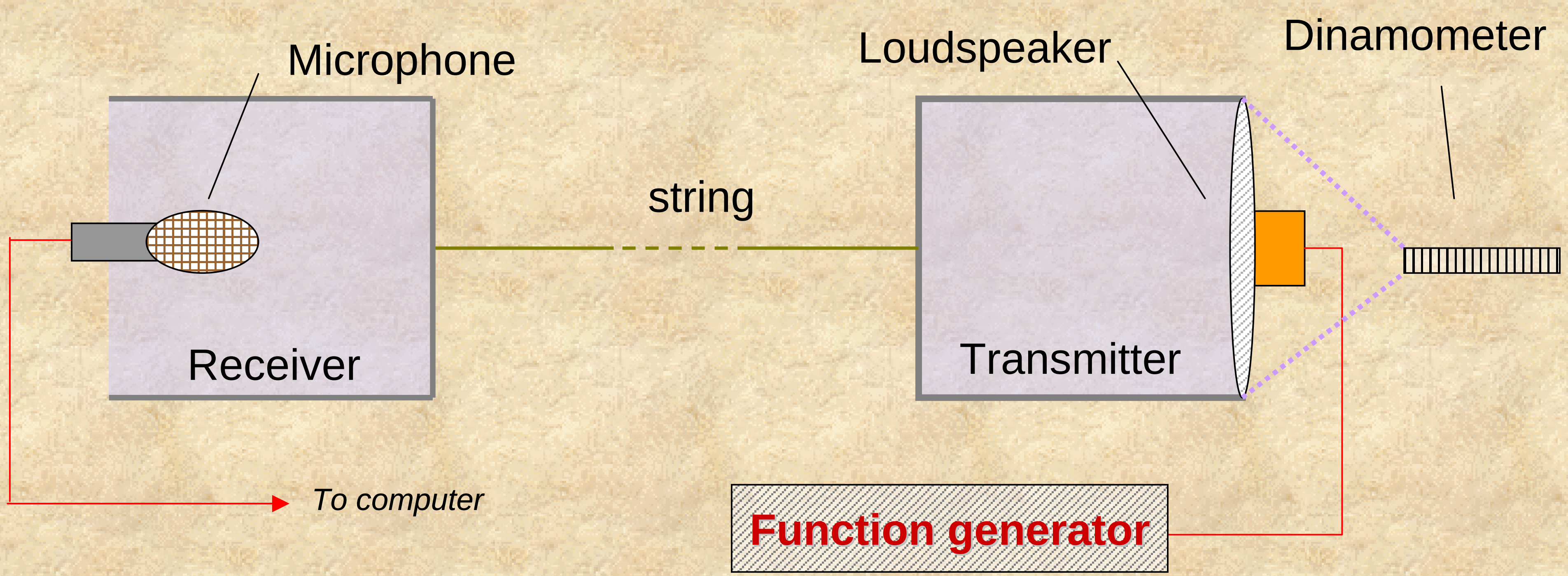
- Materials used for the string:

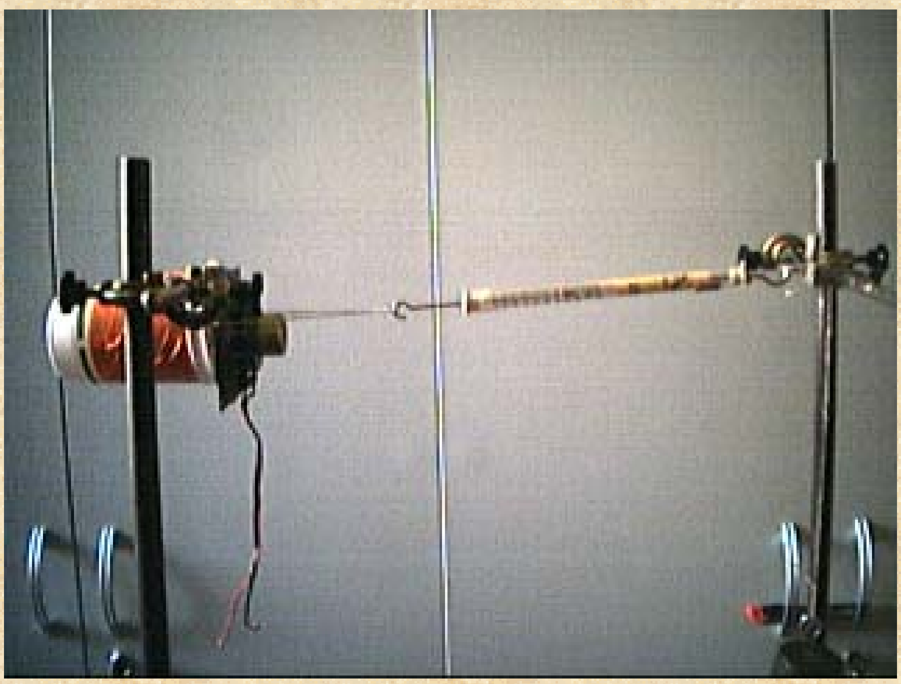
    Flax

    Wool

    Cotton

- The telephone consisted of
    - PS transmitters and receivers of different dimensions
    - Loudspeaker
    - Microphone
    - String
    - Dinamometers for determining string tension


Microphone
Loudspeaker
Dinamometer
string
Receiver
Transmitter
To computer
Function generator



Transmitter with loudspeaker

String tension measuring system

- Means of measurement:

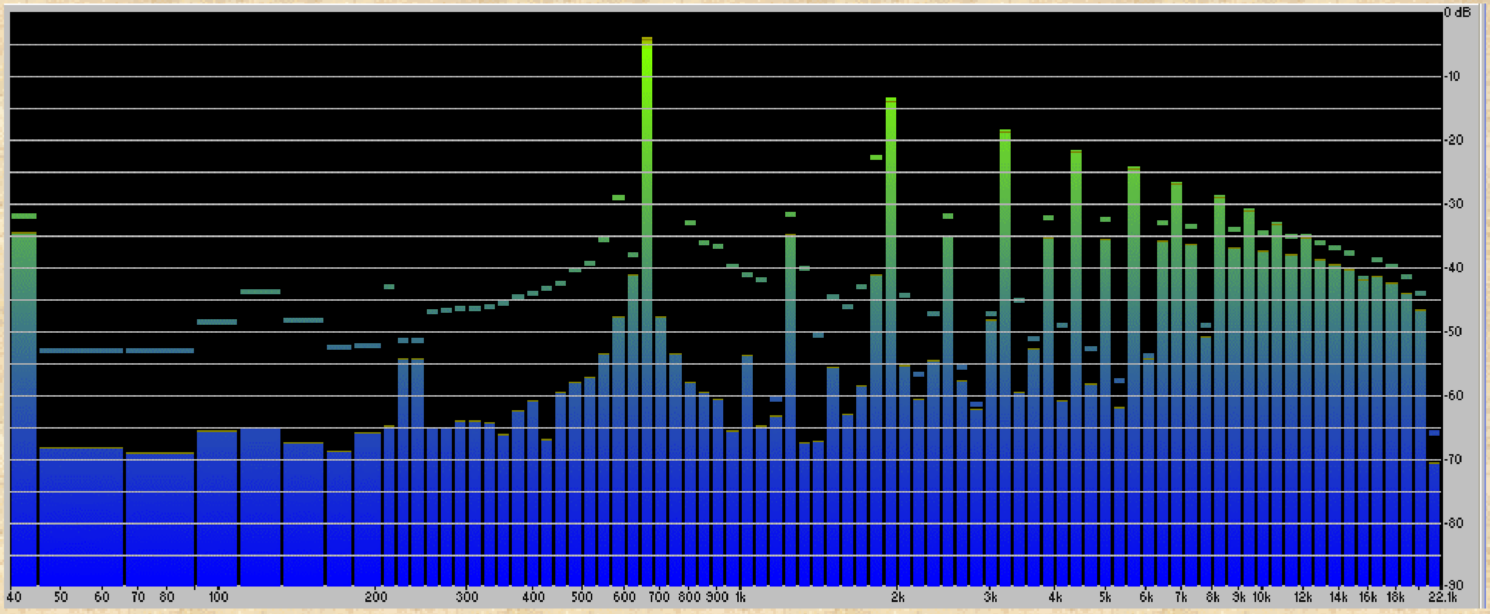
  Received sound spectrogramm

  Oscilloscopic pictures of the received wave

Properties of the received sound

1. <u>Resonance</u>

- At the resonant frequencies of the string the intensity of received sound magnifies and the overtones can be heard



I_z

I_s – intensity

ν - frequency

Basic frequency

overtones

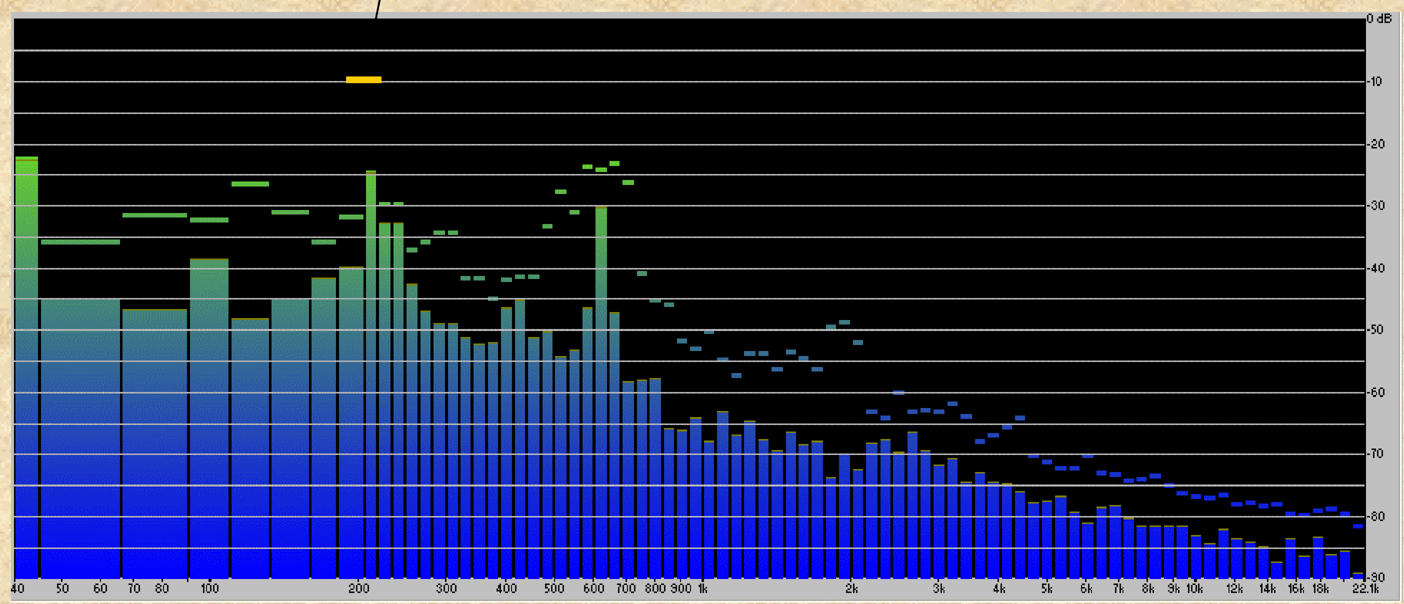
ν

2. Reflection

- On some frequencies destructive interference with the reflected waves decreases the received intensity significantly

`normal` value of intensity

I_z



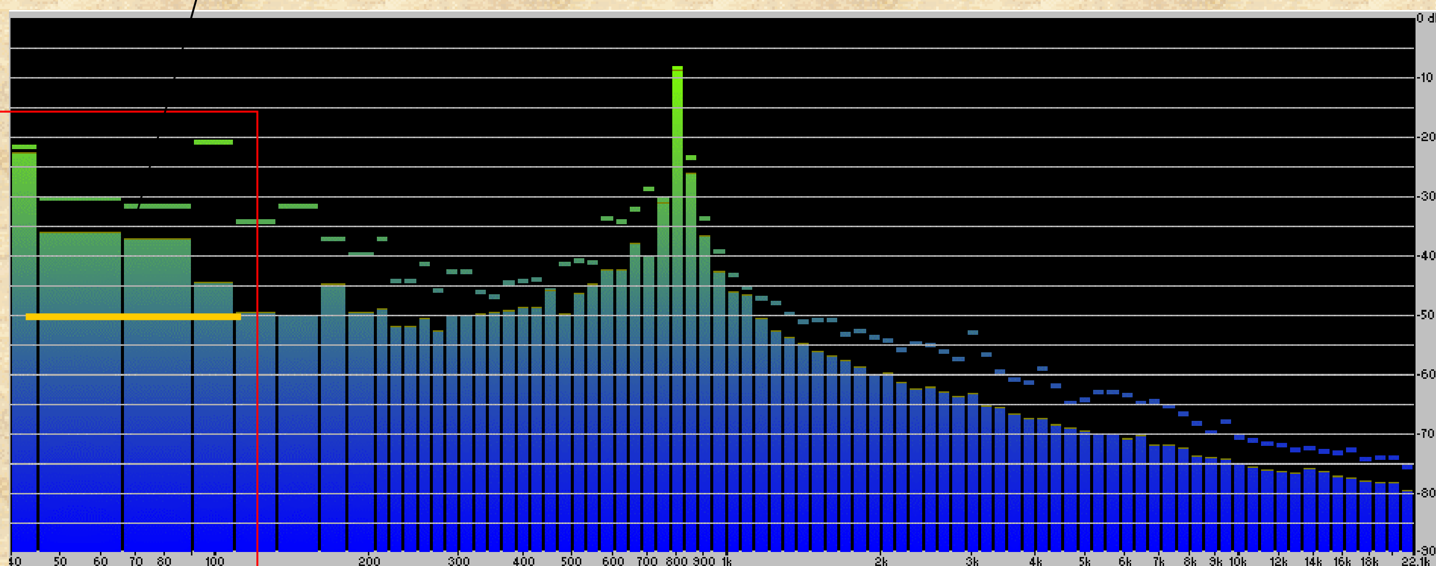
Basic frequency

ν

3. Disturbances

- At certain frequencies the deep tones are louder, probably due to disturbances in the system

Normal value



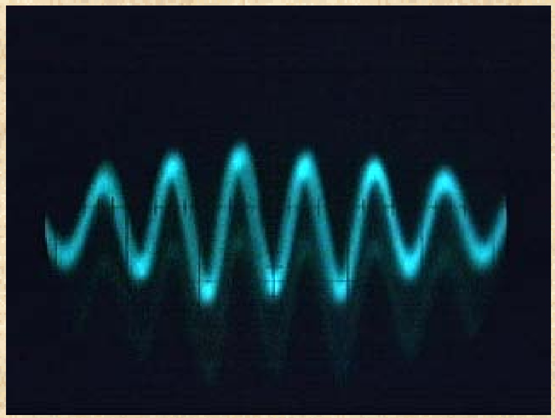
I_z

ν

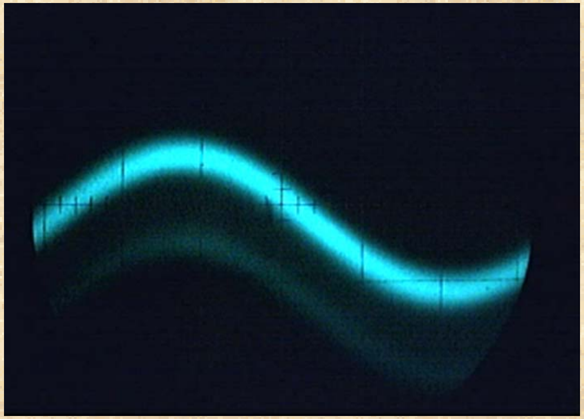
More intense low frequencies

4. Signal deformation

- By transmitting differently shaped waves through our telephone, we discovered that the system ″rounded up″ the signal



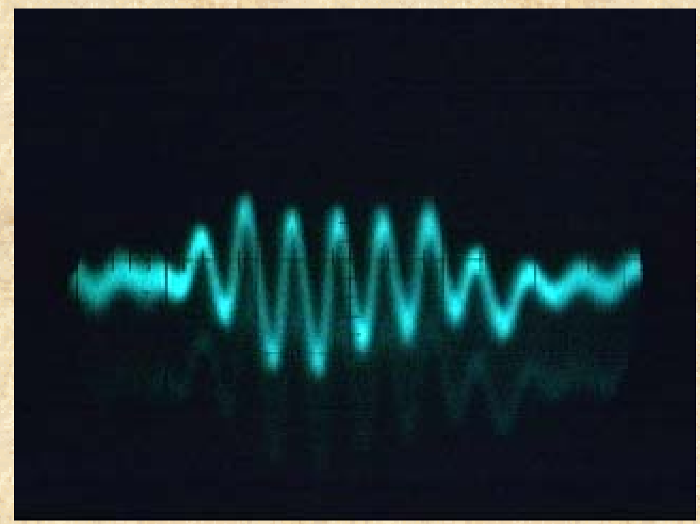
88 Hz



201 Hz

Received waves at different frequencies. The initial wave was a saw

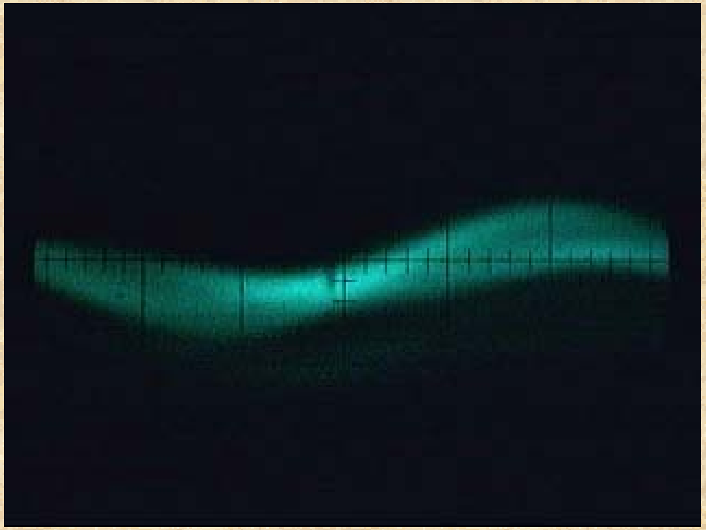
- The cause of the rounding up is probably the shape of the receiver and the inertia of string and transmitting membranes
- There are many other, irregular deformations of the signal due to multiple reflections and disturbances in the system, especially at low frequencies:

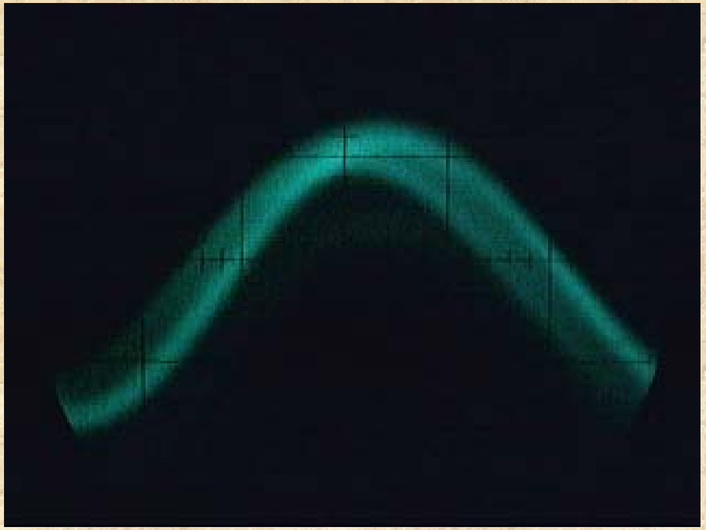


Received wave, deformed

50 Hz

- The greatest deformations occur at resonance because of the vigorous string/transmitter vibrations





600 Hz

- At resonance even transversal vibrations may occur, deforming the signal additionaly

Theoretical approach

- The sound is transmitted via longitudinal waves in the string
- We will discuss
    - Damped waves in the string
    - Losses on the transmitter and receiver membranes
    - Amplification of the receiver
    - Additional effects (reflections, resonance…)

Damped waves in the string

- Because of string imperfections there is a loss of energy during the wave motion
- From the wave equation – spatial part of wave decays exponentially:

$$X(x) = Ae^{-\frac{k}{2\rho}x} \cos 2\pi \frac{x}{\lambda_0}$$

X – spatial part of wave

k – damping coefficient

ρ – density of string

λ_0 – wavelength of source wave

A – amplitude of source wave

- Waves move in one dimension
- The source is a pure cosine wave

- The amplitude can be approximated by the forced oscillator amplitude:

$$A = \frac{A_0}{\sqrt{\left(\omega_0^2 - \omega^2\right)^2 + \left(\frac{k\omega}{\rho}\right)^2}}$$

A_0 – source amplitude

ω_0 – resonant frequency of the string

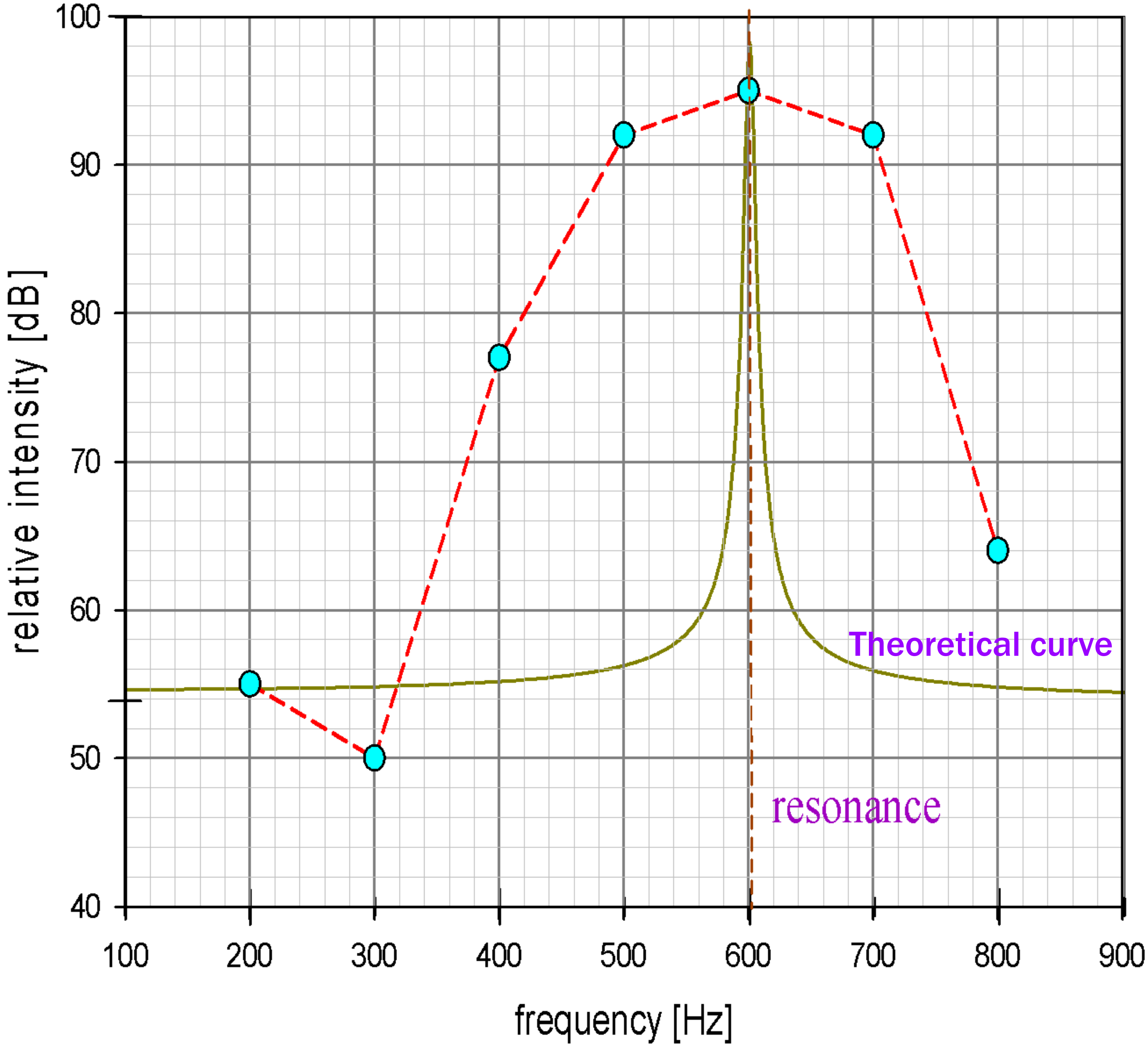
ω – frequency of source

k – damping coefficient

ρ – string density

(normalized to unit volume)

- The amplitude depends on frequency
- At resonance a jump is observed



100
90
80
70
60
50
40
relative intensity [dB]
Theoretical curve
resonance
100
200
300
400
500
600
700
800
900
frequency [Hz]

Reflections

- The waves on the string are reflected off the membrane
- This causes interference with incoming waves:
  - Constructive – the reflected waves amplify the incoming
  - Destructive – the amplitude of the incoming waves diminished
- Depend on phase at membrane

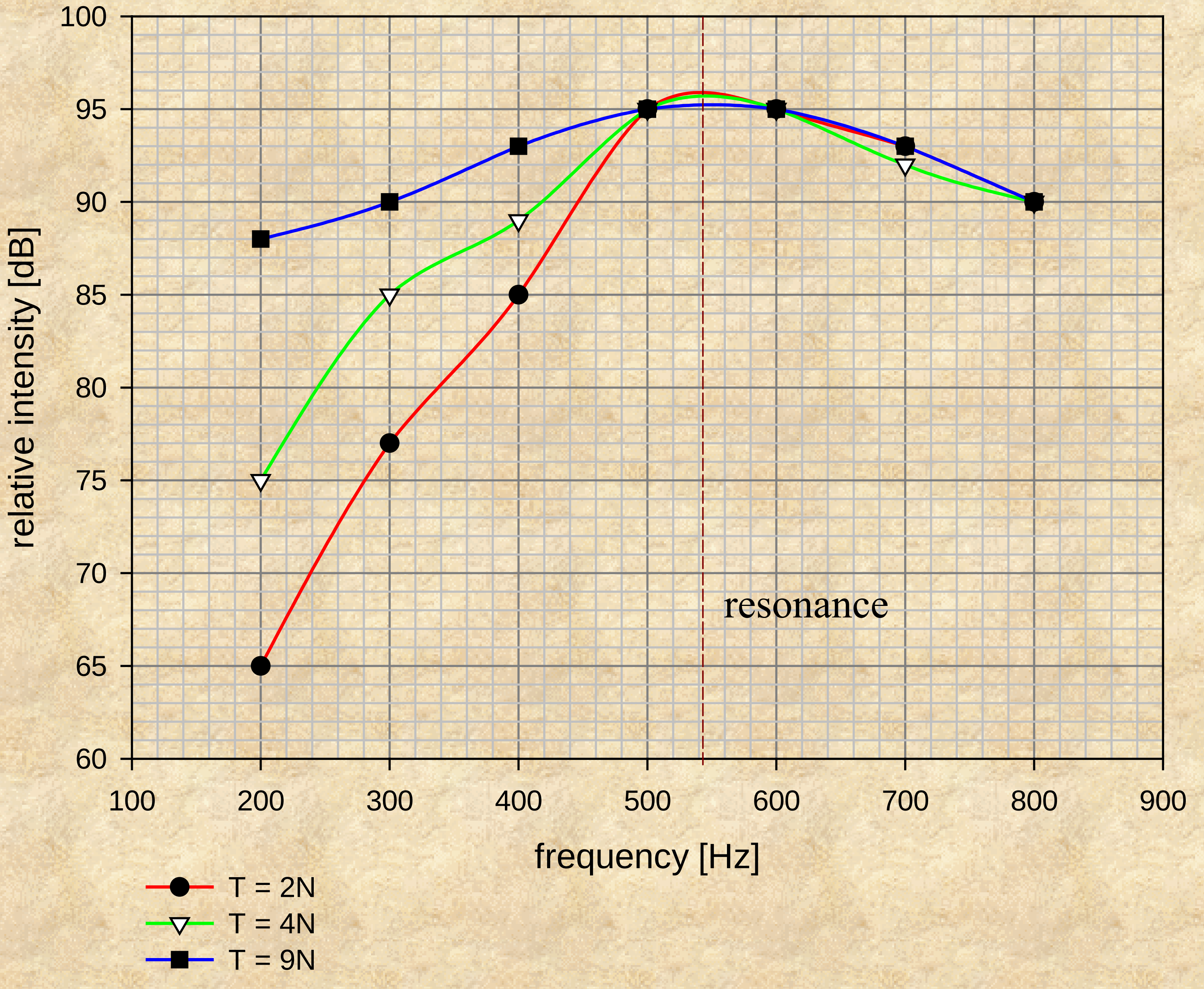
4. String tension

- The received sound intensity shows a specific dependence on string tension:

  To a certain tension the signal amplitude grows fast

  When the tension extends this critical value the amplitude remains constant

- Cause:
  - The strained elastical bonds in the string transmit longitudinal waves faster than the unstrained
  - The strain has has a critical value above which the influence stagnates



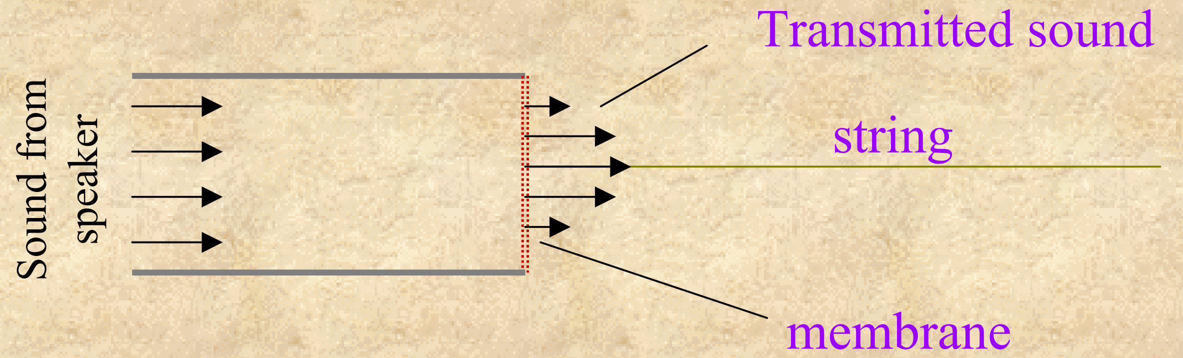
100
95
90
85
80
75
70
65
60
relative intensity [dB]
resonance
100
200
300
400
500
600
700
800
900
frequency [Hz]
T = 2N
T = 4N
T = 9N

Transmitter and receiver

1. Amplification
   - The sound emmited into the transmitter/receiver is almost completely transferred to the membranes and string
   - Cause: multiple reflections – the concentration of energy is great (small volume!)
   - Losses occur on
     - Material
     - Membrane damping

2. Transmitting to/from the string

- The sound from the transmitter is transferred to the membrane in contact with the string

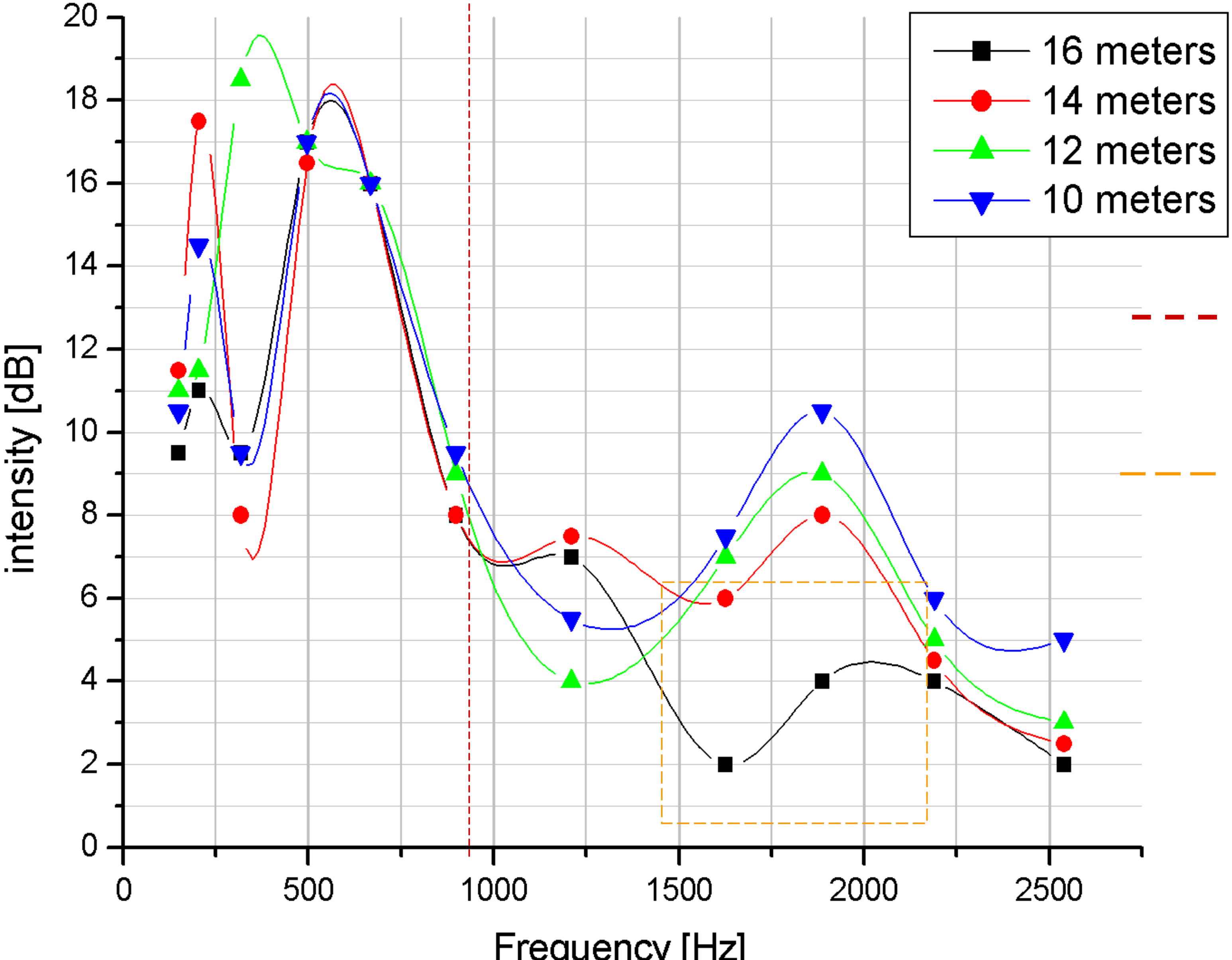


- On the receiver the string vibrates the receiving membrane and the air inside the receiver

3. Resonance

- The air column in the transmitter/receiver also has its own resonant frequencies
- At resonance frequencies received sound intensity grows significantly
- If the transmitter and receiver are similar, beats can be heard
- The signal at resonance is quite distorsed because of the harmonics

Instead of a conclusion – summary of effects



Transmitter resonance

Destructive interference (minima)

String resonance?

Exponential intensity growth with length decrease

Conclusion

- Parameters affecting the intensity and quality of transmitted sound have been investigated
- An optimal string telephone should have:
    - Relatively short string
    - Large plastic or metal transmitter/receiver
    - Tense string