Basics of radio astronomy II

Assistent Professor for Astronomy
Dr. Jürgen Kerp
Bonn University

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James Clerk Maxwell

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

James Clerk Maxwell was a genius in the natural sciences.
In 1865 Maxwell discovered that **light and the electrical and magnetic phenomena of his time are two sides of the same coin!** He could summarize the observation findings in form of four equations. Here only the electric *E* and the magnetic fields *B* enter as well as the charge ρ and the current *J*.
From the time derivative of the equation follows a wave equation.
Maxwell recognized already, that these electron-magnetic waves propagate with the already known speed of light c.

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Heinrich Hertz

- **Heinrich Hertz** was a physicist with very good mathematical skills. These allowed him to develop physical experiments to study Maxwell's theory of electromagnetism.

- Hertz succeeded in building transmitters and receivers of electromagnetic waves and on November 13, 1886, he was the first to generate free electromagnetic waves.

- In addition, he was able to show that electromagnetic waves propagate at the speed of light and can be refracted, diffracted and polarized in a manner analogous to light.

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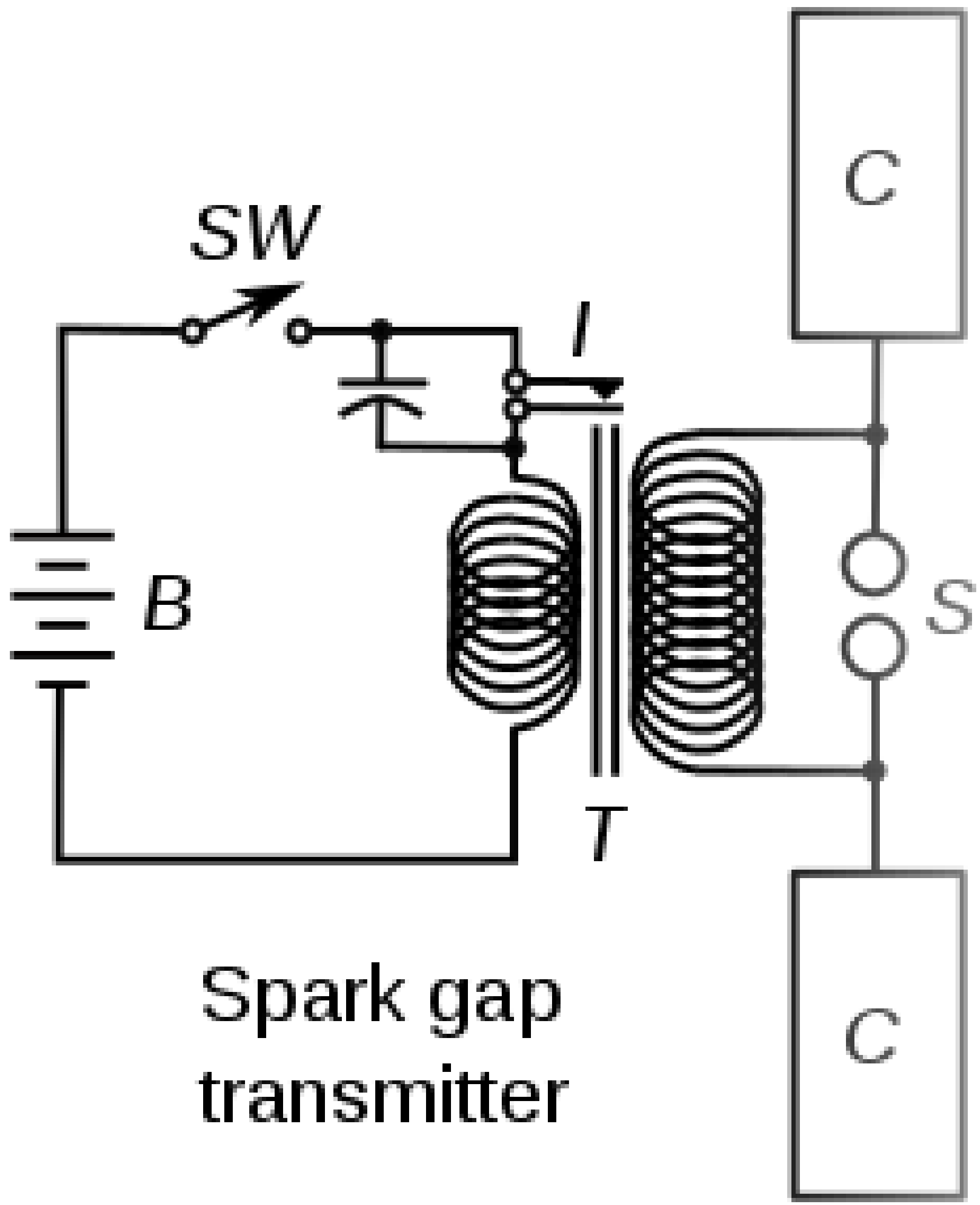

Hertz transmitter

Hertz's 1886 apparatus for generating and detecting radio waves: a spark gap transmitter (left), consisting of a dipole antenna with a spark gap (S) fed by high-voltage pulses from a Ruhmkorff coil (T), and a receiver (right), consisting of a loop antenna and a spark gap.

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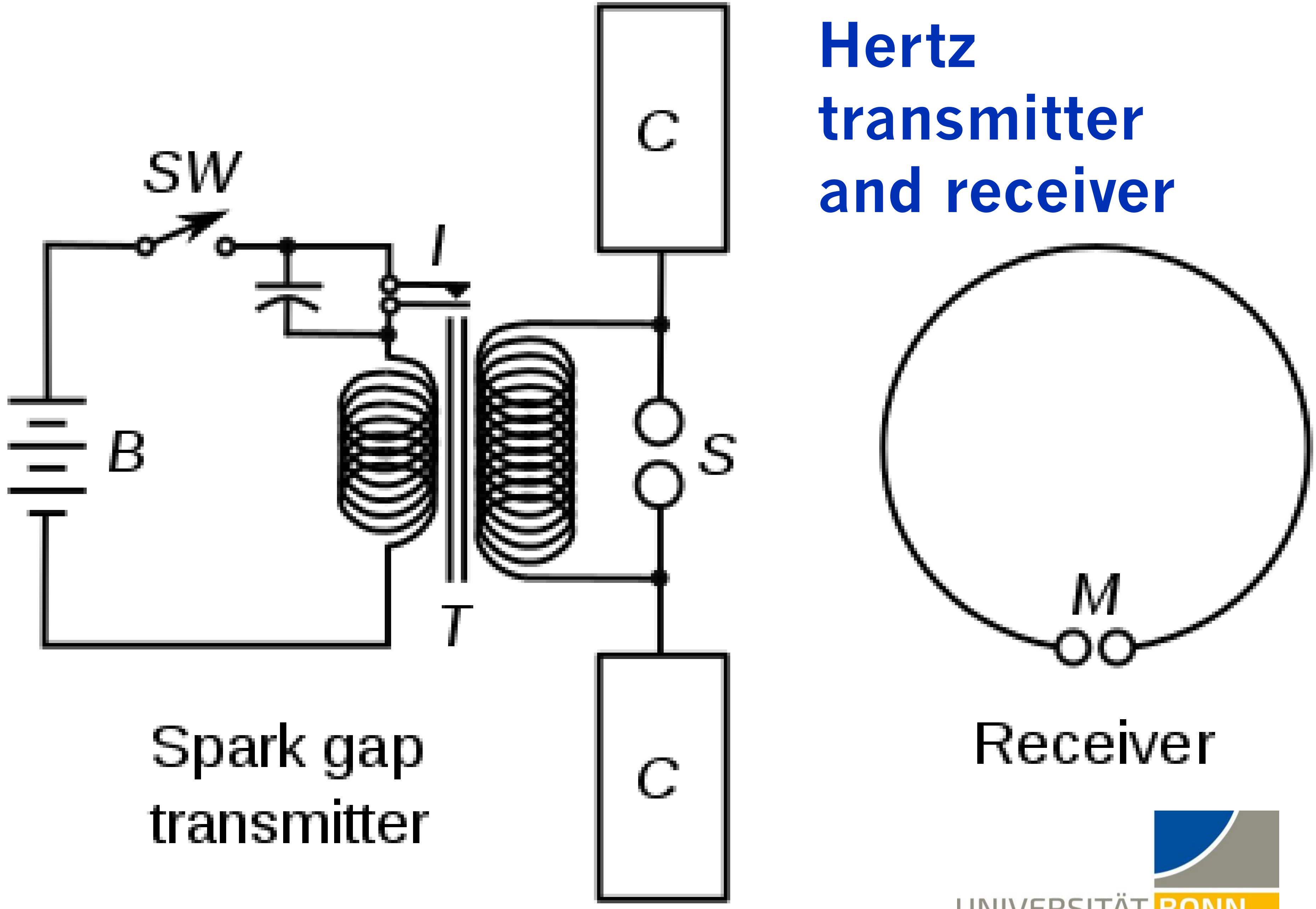
Hertz transmitter and receiver



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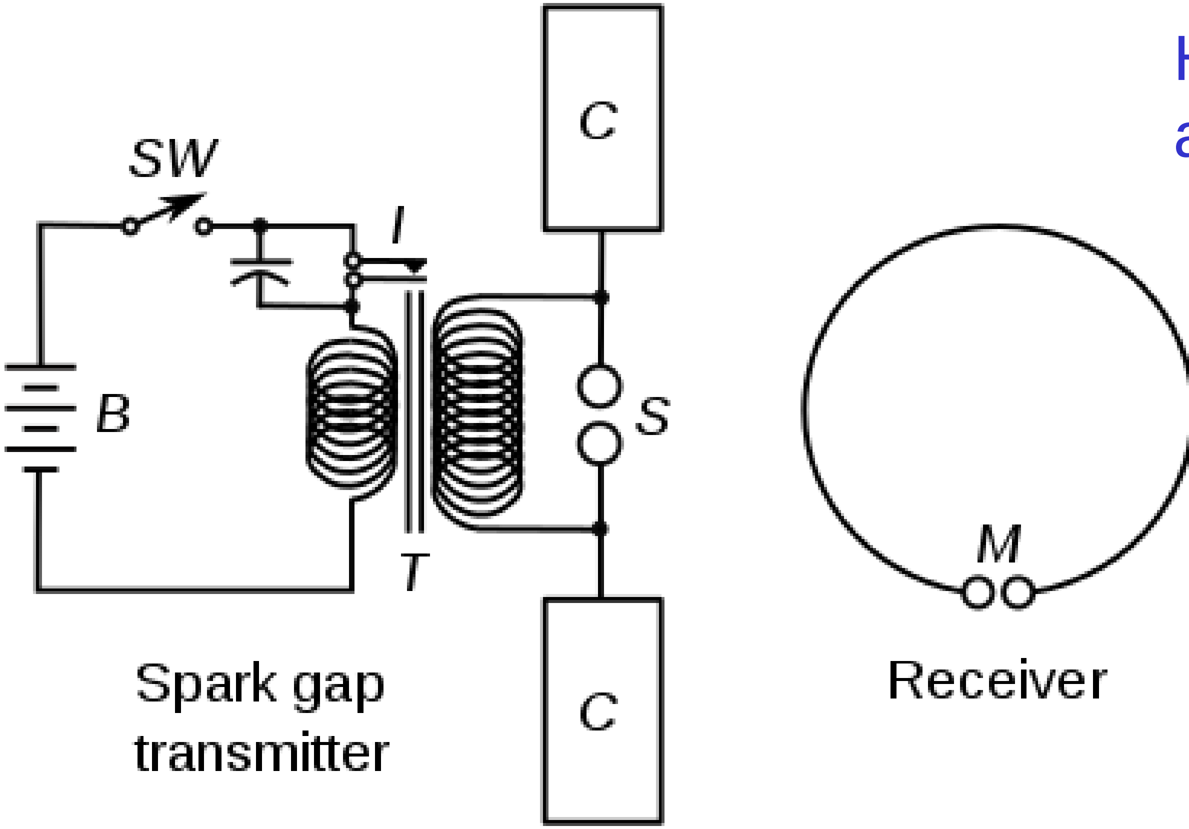
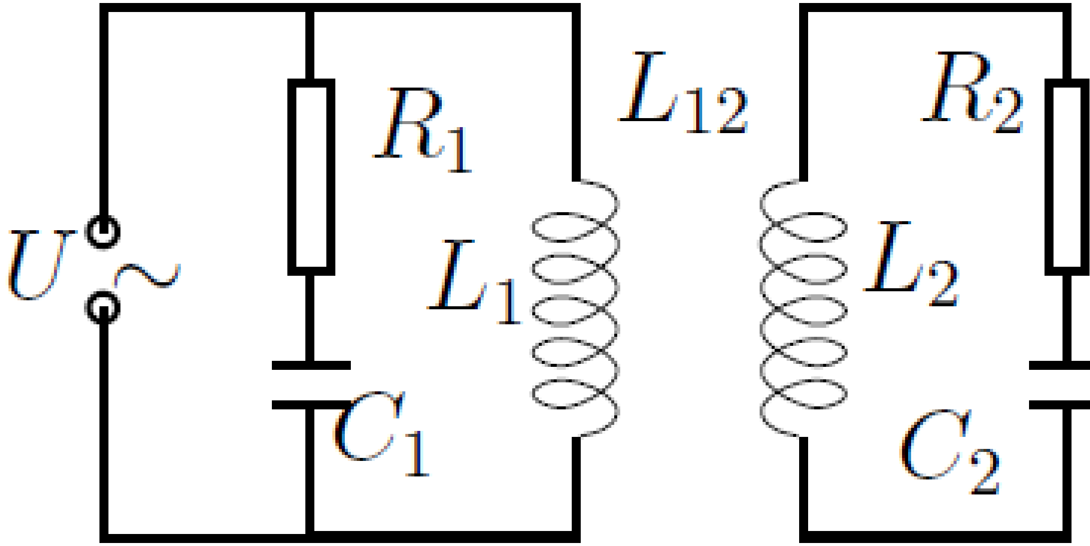
Hertz transmitter and receiver



Forced oscillation



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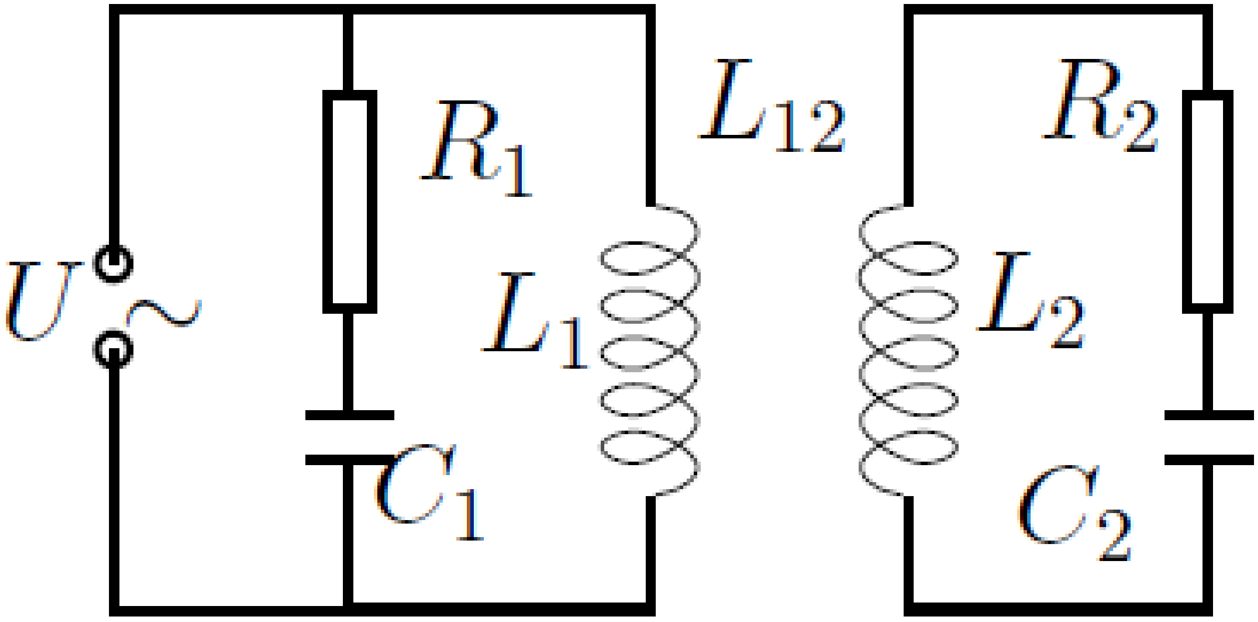

Emitter Receiver

We consider our antenna as an oscillating circuit (receiver) which is excited to oscillate by an external excitation (energy supply, emitter). Exactly like the oscillating circuit considered above, the receiver of our telescope consists of a capacitor C_2, an inductor L_2 and a resistance R_2.

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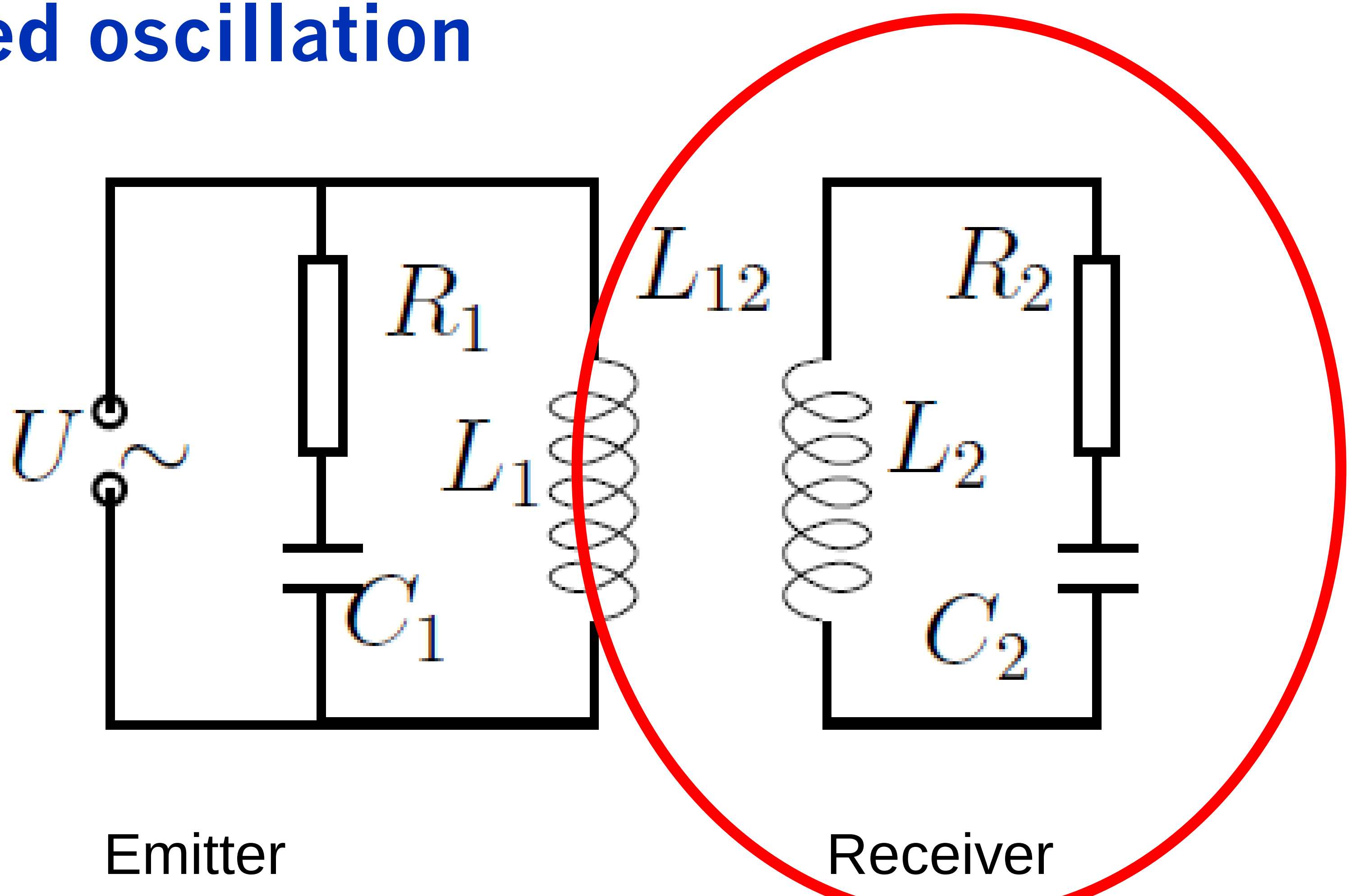
Forced oscillation



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Oscillating circuit

Oscillating circuit

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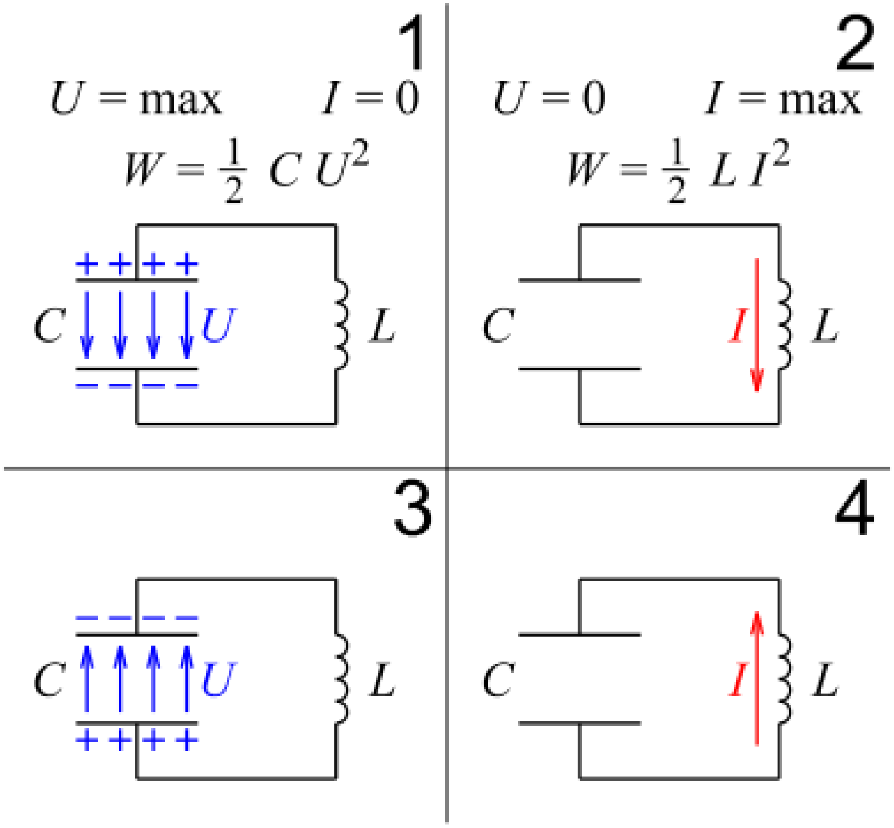
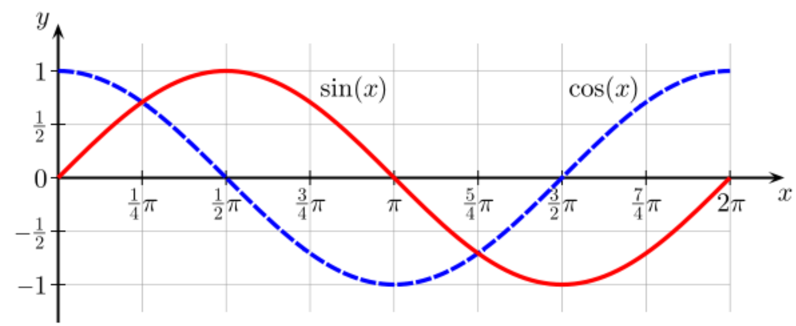


1) Capacitor fully charged:
   U=maximal; *I*=0.
2) Capacitor discharged, current at maximum through inductor:
   U=0; *I*=max.
3) Capacitor again fully charged but with opposit polarity:
   U=max.; *I*=0
4) Capacitor again de-charged, current at maximum through inductor in opposite direction:
   U=0, *I*=max.



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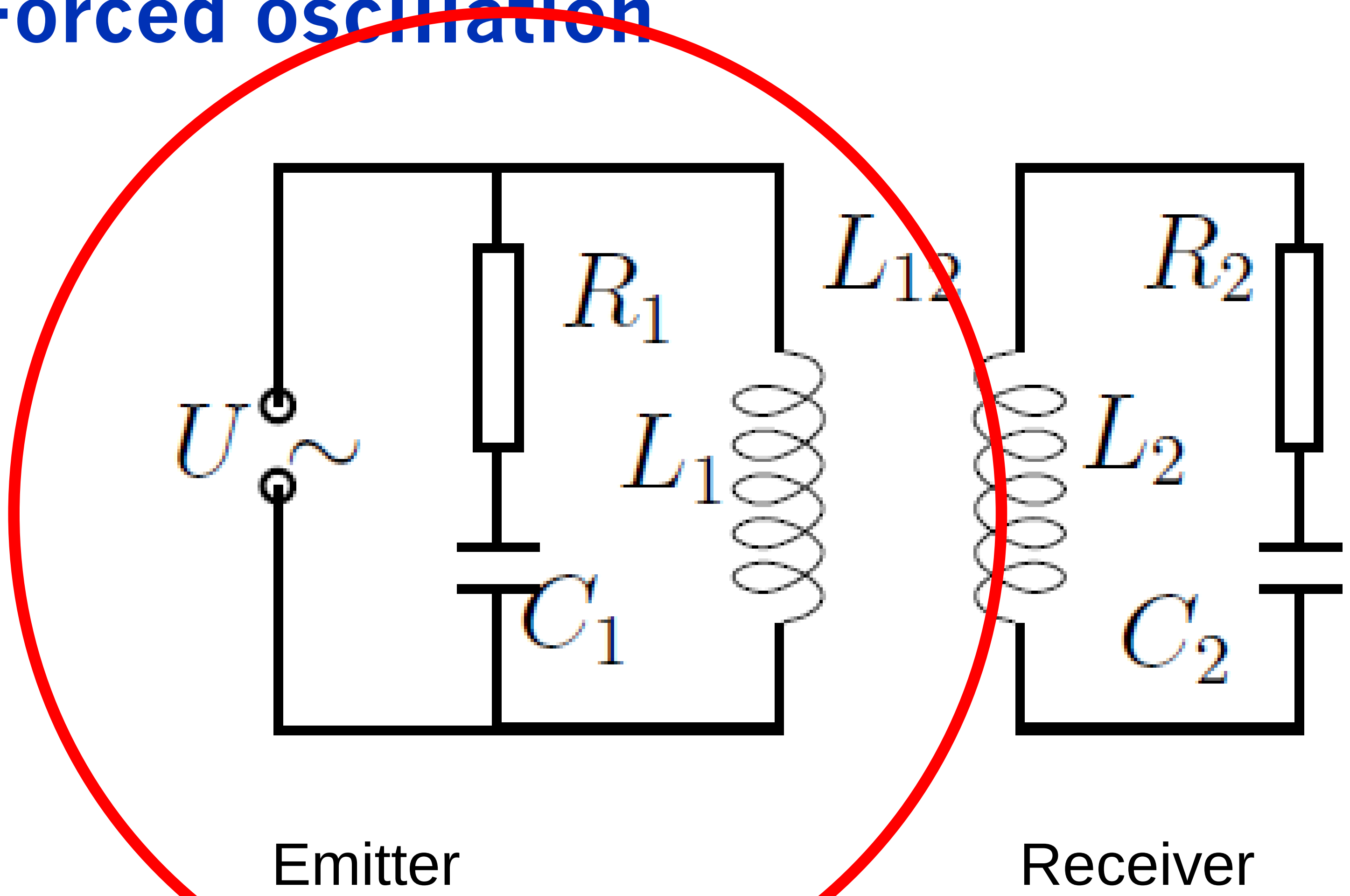
Damped oscillating circuit

Forced oscillation



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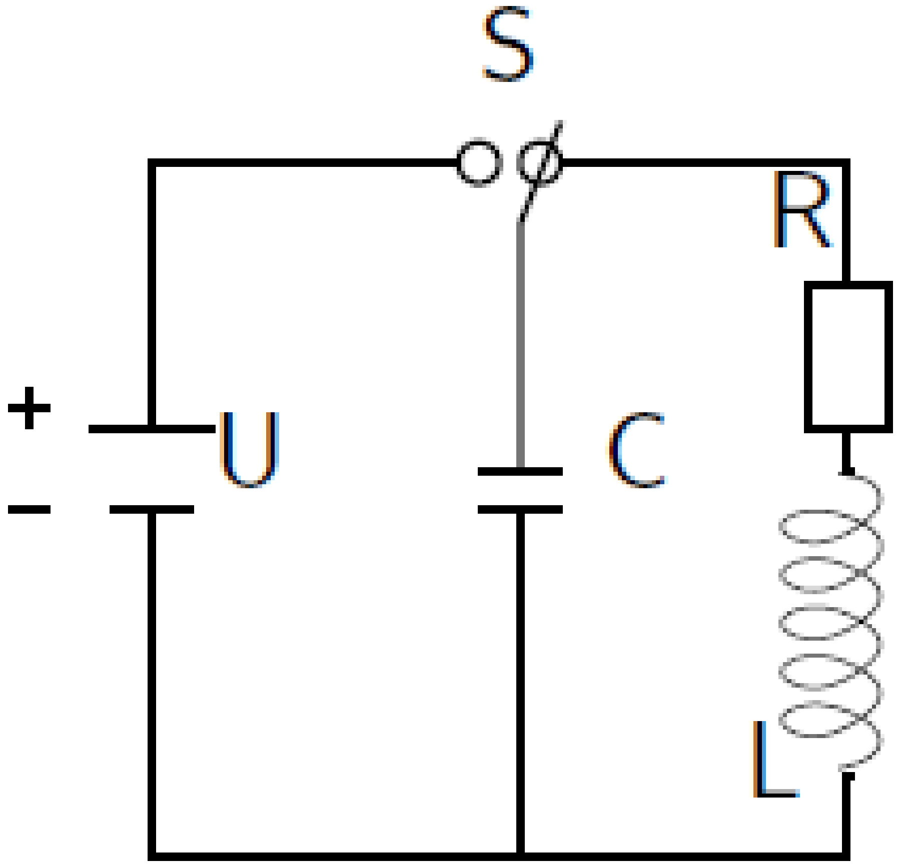
Damped oscillating curcuit



A real oscillating circuit has **ohmic losses**. Part of the **energy is converted into heat**. We attribute this loss to the resistor *R*.
In the adjacent circuit diagram, we have a DC voltage source *U*, which supplies the capacitor *C* with charge via the switch *S*. The capacitor *C* is then discharged. If we flip the switch *S*, the capacitor discharges, a current *I* runs through the resistor *R* and the coil with the inductance *L*.
How does the **amplitude** of the oscillating behave?

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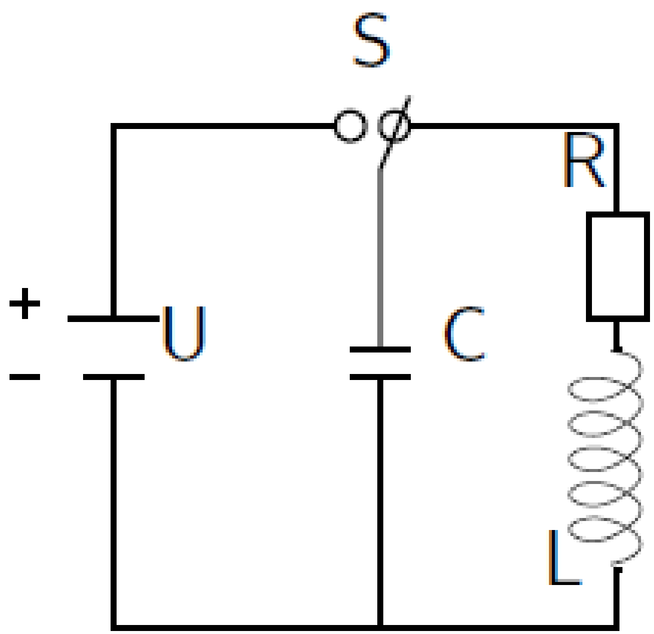
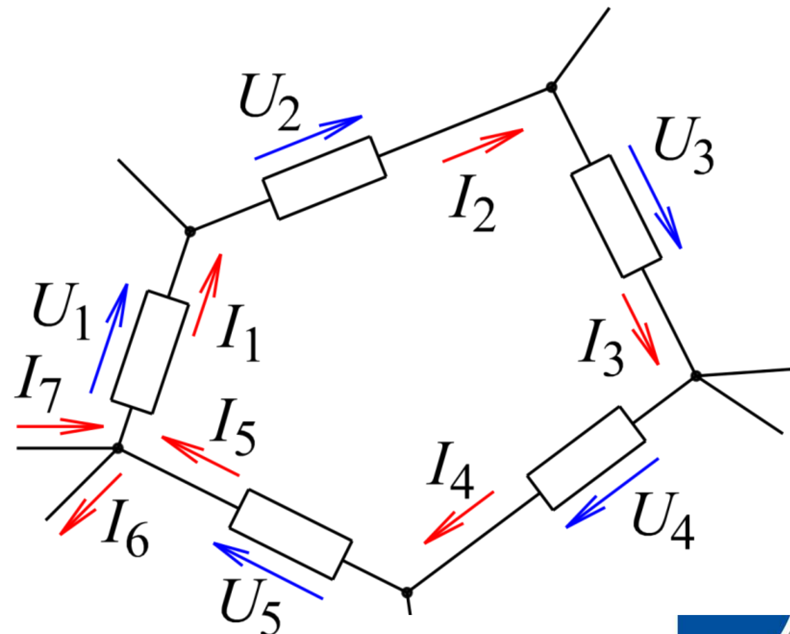
Damped oscillating curcuit

- We now use Kirchhoff's mesh rule. Since the components are all arranged in a mesh, the sum of all voltages is zero.
- The voltage *U* across the components are in a mesh is zero!





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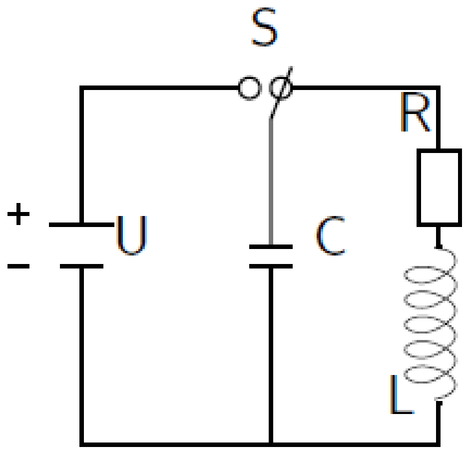
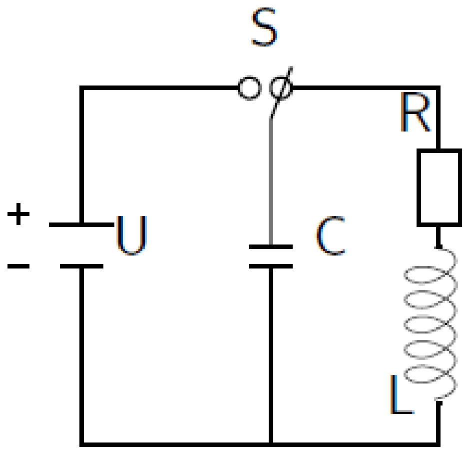
Damped oscillating curcuit



Kirchhoff's mesh rule: the voltage *U* across the components are in a mesh is zero!

$$U_L + U_R + U_C = 0,$$

Damped oscillating curcuit



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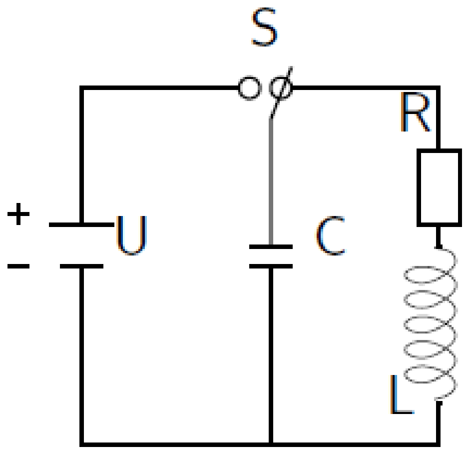
$$U_L + U_R + U_C \quad = \quad 0,$$

$$U_C = C \cdot Q$$

$$U_R = R \cdot I = R \cdot \frac{dQ}{dt}$$

$$U_L = L \cdot \frac{dI}{dt} = L \cdot \frac{d^2Q}{d^2t}$$

Damped oscillating curcuit



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$$U_L + U_R + U_C \quad = \quad 0,$$

$$L\frac{\mathrm{d}^2Q}{\mathrm{d}t^2} + R\frac{\mathrm{d}Q}{\mathrm{d}t} + \frac{Q}{C} = 0,$$

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Damped oscillating curcuit

$$L\frac{\mathrm{d}^2Q}{\mathrm{d}t^2} + R\frac{\mathrm{d}Q}{\mathrm{d}t} + \frac{Q}{C} = 0,$$

For Q we now have a linear homogeneous differential equation.

Damped oscillating curcuit

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$$\frac{d^2Q}{dt^2} + \frac{R}{L}\frac{dQ}{dt} + \frac{1}{LC}Q = 0$$

The solution to this equation is
$Q(t) = A \cdot e^{\lambda \cdot t}$

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Its a simple quadratic equation

Damped oscillating curcuit

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Its a simple quadratic equation

$$\lambda_{1/2} = -\frac{R}{2L} \mp \sqrt{(\frac{R}{2L})^2 - \frac{1}{LC}} \qquad {\omega_0}^2 = \frac{1}{LC} \qquad \delta = \frac{R}{2L}$$

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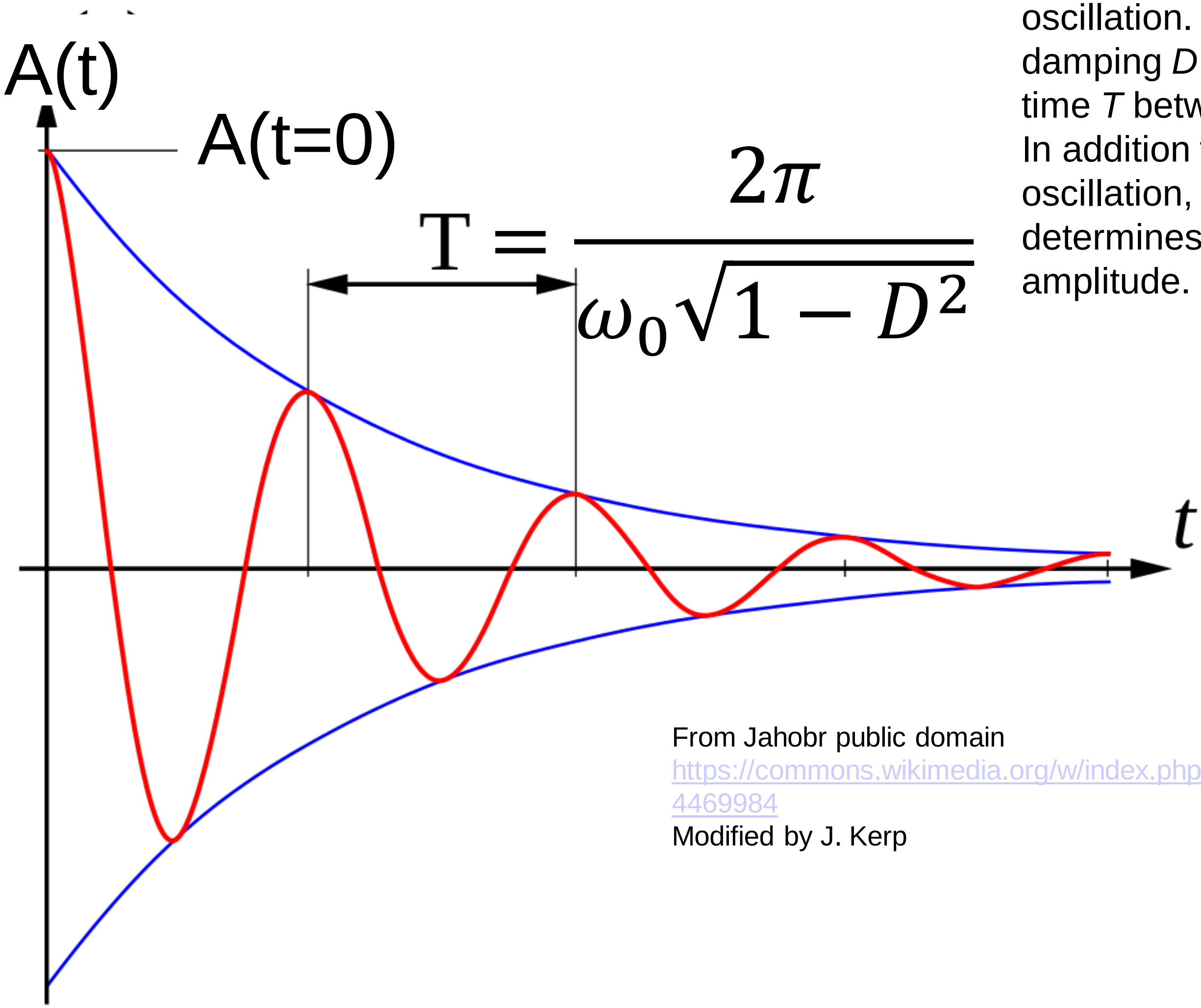
Damped oscillating curcuit



The time course of the amplitude *A* of a damped oscillation. The higher the damping *D*, the longer the time *T* between the maxima. In addition to the period of oscillation, the damping *D* also determines the decrease in amplitude.

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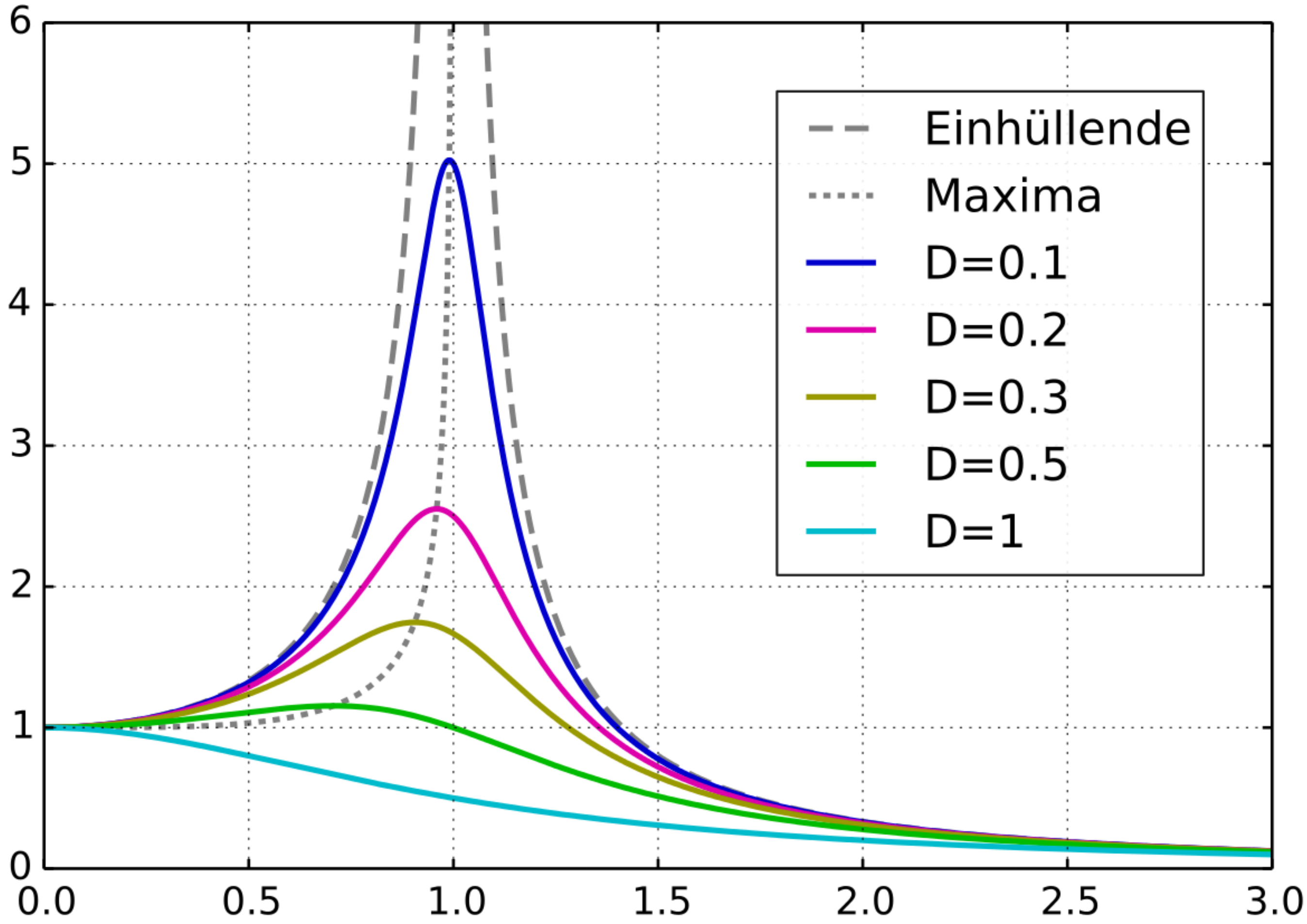
Damped oscillating curcuit



In order to achieve the best possible detection of a source, tune our receiver so that it is in resonance with the source.

This with a minimum of damping *D*.

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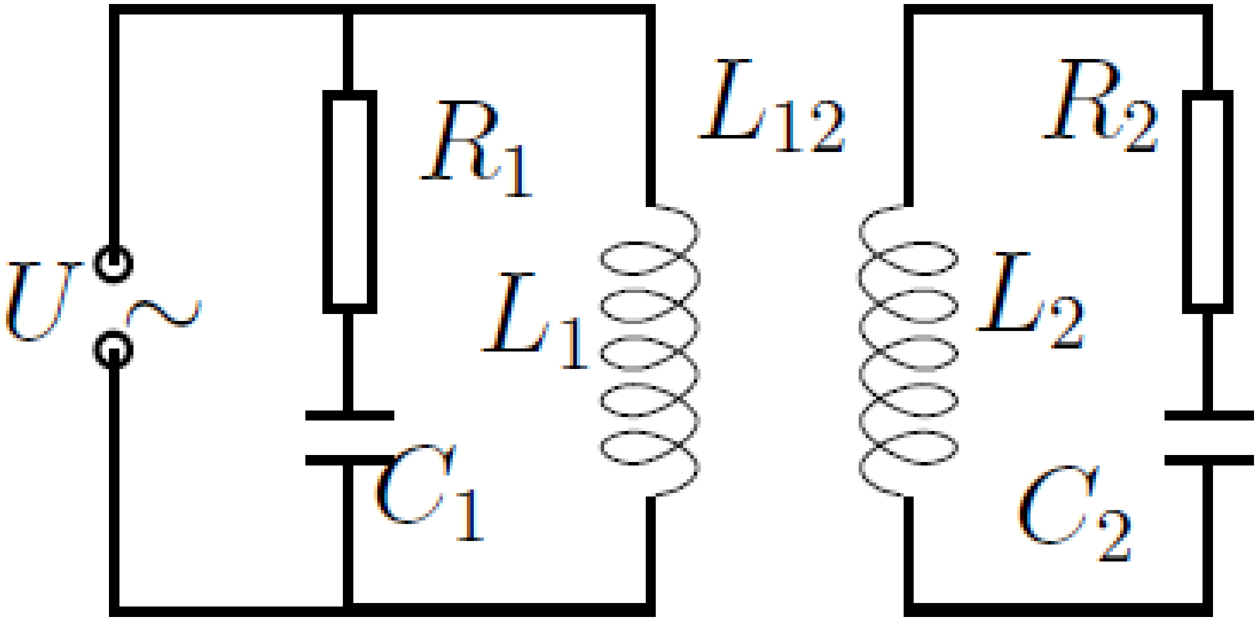
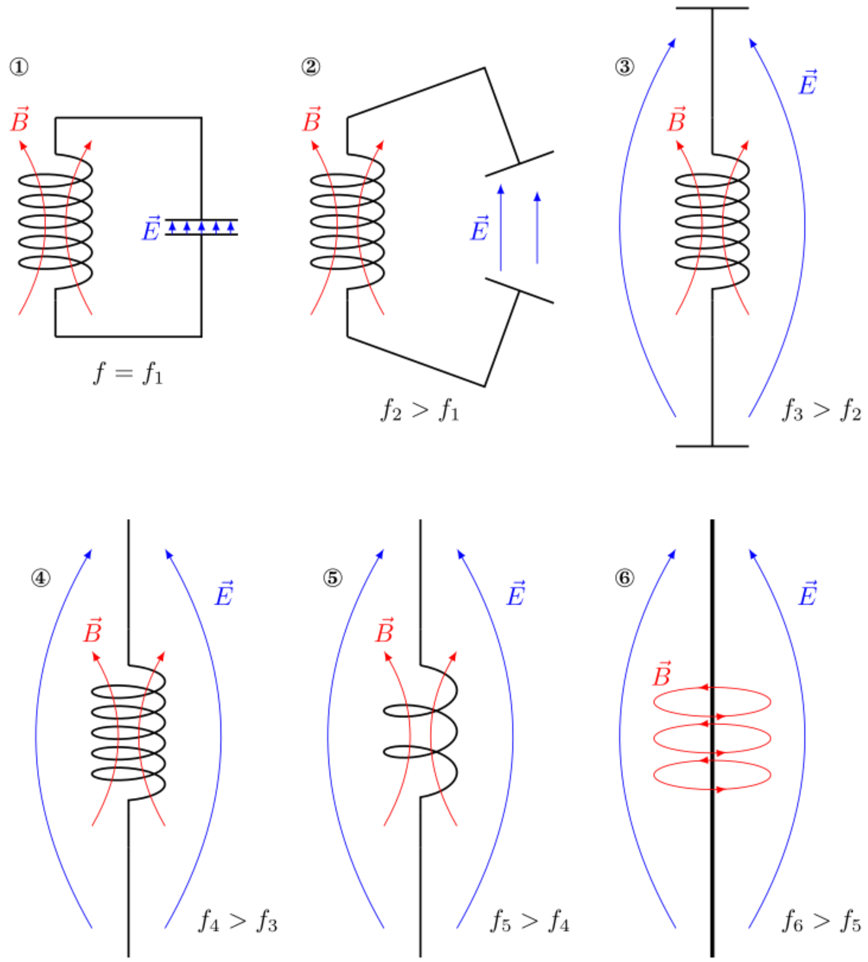
Forces oscillation



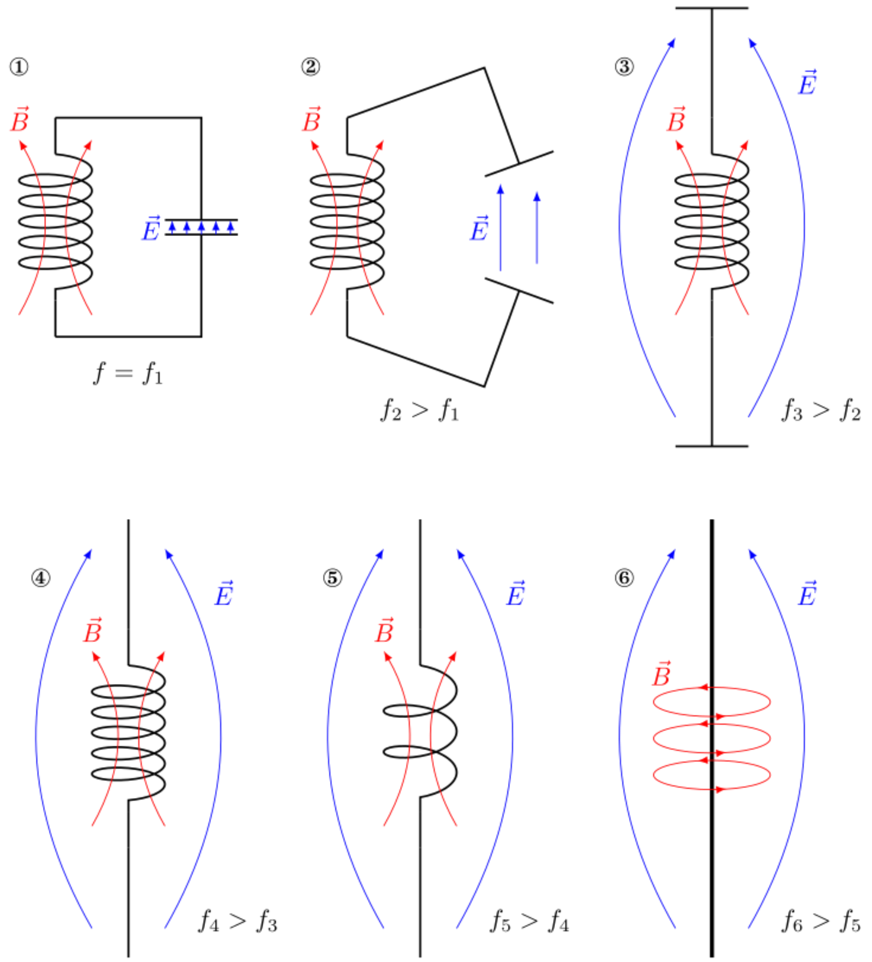
Astronomical source Telescope

Oscillating circuit



If we physically bend a resonant circuit apart, i.e. we increase the distance of the capacitor plates and decrease the inductance of the coil, we get from the resonant circuit to the Hertzian dipole.

Oscillating circuit



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$$\omega_0{}^2 = \frac{1}{LC} \qquad \delta = \frac{R}{2L}$$

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Antenna (Yagi-Uda Antenna)

1. Dipole that receives the radiation
2. Reflector
3. Dipols to focus the radiation
4. High frequency cable

The arrangement of the dipoles of this antenna cause a higher directivity (angular resolution). The electrons in the dipoles are set into forced oscillations by the EM wave.

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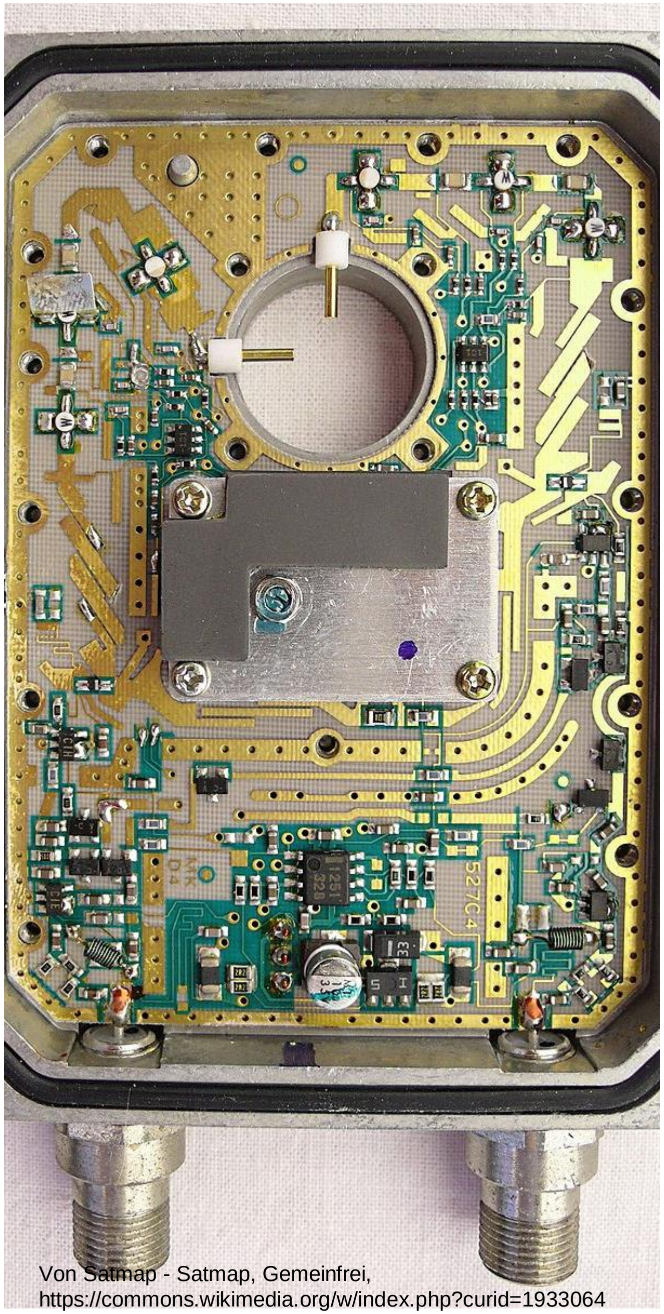

The most widespread form of radiometer is certainly the low-noise block (LNB) as used for receiving satellite television. It is used between 10.7 and 12.75 GHz. Therefore, all its components in their design and their corresponding lines are microstrip, the signal converted to a lower frequency (mixed) is transmitted by means of coaxial cable.

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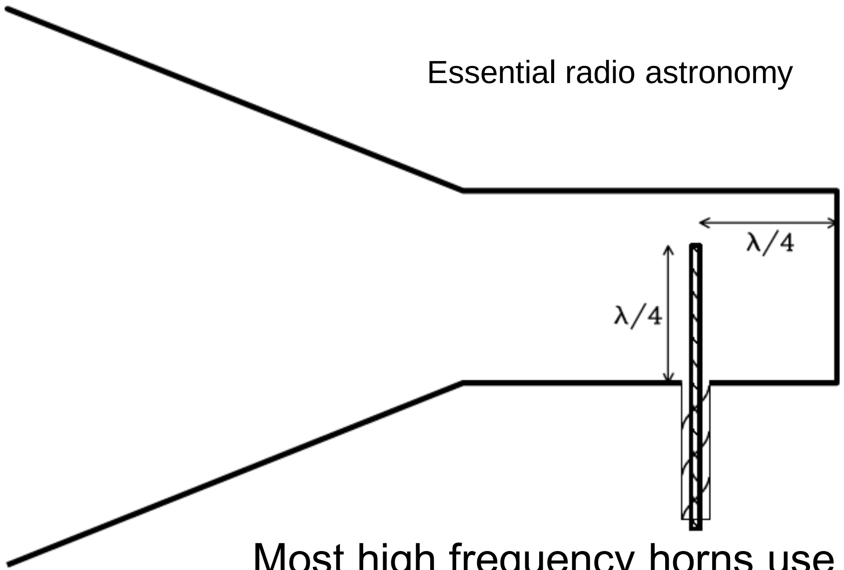
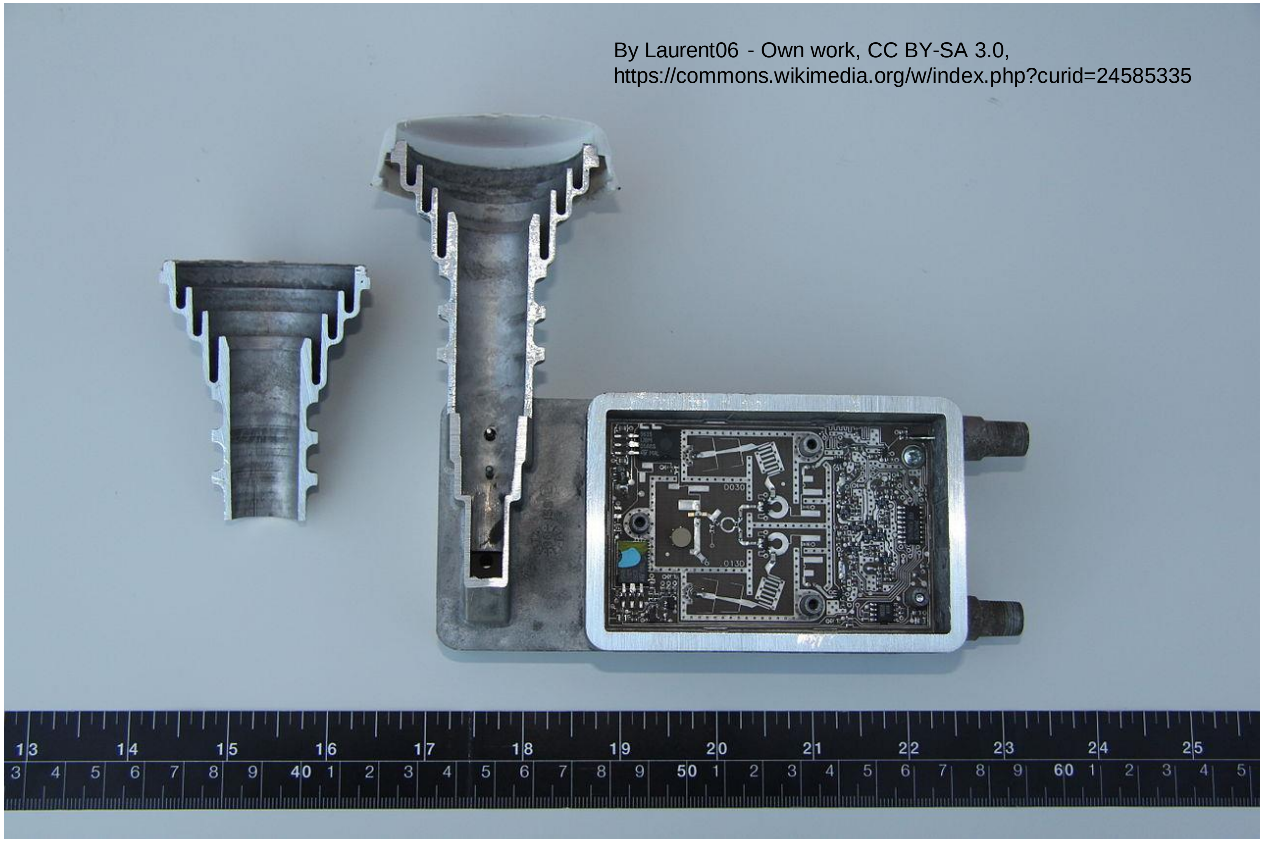
Feed

Essential radio astronomy



Most high frequency horns use λ/4 waveguides. The actual receiver is the Hertzian dipole which resonantly receives the EM wave with λ/4. The short has a distance of λ/4 from this dipole to not allow standing waves. The dipole converts the space wave into an electric wave which can then be transmitted by means of a cable or waveguide.

Feed



Above you can see a cut through a LNB. In the LNB you can see the dipole antenna, which picks up the EM wave from the horn. The horn focuses the signal to the dipole antenna. Via waveguides this signal is transmitted to the board with the microstrip conductor.

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We are on the way to the radio Universe

Thank you!

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