The Gunn oscillator

Principles

Microwave power, i.e. electromagnetic power in the GHz frequency range, may be generated using quite different physical phenomena. Some examples of this are vacuum-tube oscillators such as the klystron and the magnetron, or semiconductor oscillators such as the FET oscillator, the Gunn oscillator and the impatt oscillator. Some simple experiments for understanding Gunn oscillators are described below.

Gunn effect

In some semiconductor materials, such as Gallium Arsenide (GaAs), the mobility of the electrons (= the quotient of the drift velocity v and the electrical field strength E) decreases above a threshold value E_{TH} of the electrical field strength (see Fig. 1.1, left side). This is because, as the field strength increases more and more electrons “transfer” to a state in which their “effective mass” becomes greater, thus decreasing their velocity. For field strengths where $E > E_{TH}$ the electrons have a negative differential mobility, i.e. an increase in the field strength results in a decrease in the drift velocity.

When the electrical field strength in a homogeneously doped GaAs block (no barrier layer!) is greater than the threshold value E_{TH} “space charge instabilities” occur as a result of the negative differential mobility.

While any random local surplus or deficiency of electrons will disappear by itself when a positive differential mobility is present, this surplus or deficiency will increase under a negative differential mobility. In the upper right section of Fig. 1.1, a random surplus of electrons is assumed. The resulting increase in field strength on the anode side leads to a decrease in the drift velocity v_2 on the anode side relative to the drift velocity v_1 on the cathode side (decrease in field strength). This causes “bunching” and yields a carrier enhancement layer. The analogous effect occurs in the event of a random deficiency of electrons, in which case a depletion layer occurs (see Fig. 1.1, middle-right section). When the enhanced and depleted layers approach each other, they attract each other and jointly pass through the diode in the form of a “domain” (see Fig. 1.1, lower right section). The field in the interior of the domain can be so high that the field outside it falls below the threshold value E_{TH}. Thus no new domain can be formed until the existing one has disappeared at the anode.

If the Gunn element were not connected to a resonator (tuned circuit), the frequency of the microwave power generated would be determined by the time it takes for the domains (velocity approximately 10^7 cm/s) to pass through the diode (transit frequency). If, however, the Gunn diode is operated with a resonator, the resonator frequency can be “imposed” upon the Gunn diode. There are several operating modes here (delayed mode, quenched mode, LSA mode).

The delayed domain mode is briefly described here as an example. It occurs when the resonator frequency is lower than the transit frequency. At the moment in which the domain reaches the anode, the momentary value of the diode voltage (= bias voltage + RF voltage) is less than the threshold value. The formation of a new domain is

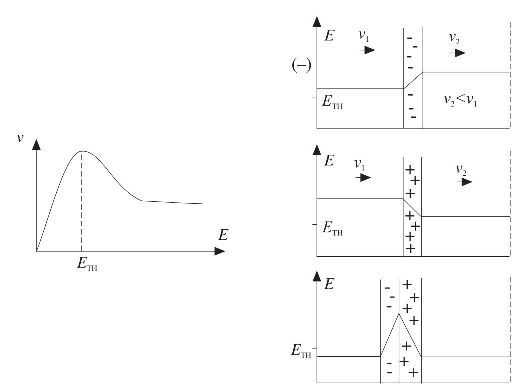

Fig. 1.1 Principle of a Gunn diode
left: *Drift velocity v* of the electrons as a function of the electrical field strength *E* for GaAs.
right: Formation of a domin (cathode (–) left and anode (+) right)

delayed until the voltage exceeds the threshold value, thus "imposing" the oscillator frequency of the resonator on the Gunn element.

Design of the oscillator

One of the many possible resonator types in microwave technology is the rectangular cavity resonator. Fig. 1.2, left side, shows a rectangular cavity enclosed on all sides by metal walls. Just as in a resonant circuit built of a lumped inductance and capacitance, oscillations of the electrical field variables with a certain frequency (= resonance frequency f_0) can also exist in a cavity resonator. In this case, the energy is stored alternately in the electrical and the magnetic field. While an (ideal) resonant circuit has only one resonance frequency, the cavity resonator has an infinite number of oscillation types and resonance frequencies. Fig 1.2 (left) shows the electrical and magnetic fields for the oscillation type with the lowest resonance frequency (TE_{101} resonance) at three different points in time, at intervals of one quarter of the period $T = 1 / f_0$. A side view of the cavity resonator and the variations of the electrical field strength as a function of the coordinate z are reproduced in the middle of Fig.1.2. The resonance frequency of this oscillation type is calculated (for air) according to the formula:

$$\frac{f_0}{\text{GHz}} = 15 \cdot \sqrt{\frac{1}{(a'/\text{cm})^2} + \frac{1}{(s'/\text{cm})^2}} \qquad (1.1)$$

More specific details on cavity resonators are dealt with in Experiment Ex12.

The electromagnetic oscillations of the cavity resonator are attenuated due to losses occurring in the metal walls. After installing the Gunn element, which transforms DC power into microwave power, just enough microwave power is fed into the resonator to compensate for the wall losses and to achieve a continuous unattenuated oscillation. To obtain a microwave oscillator, the resonator must also have an "opening" through which power can be fed to a "load". In this case, the Gunn element must generate not only enough microwave power to compensate for the wall losses, but also the greater amount of power

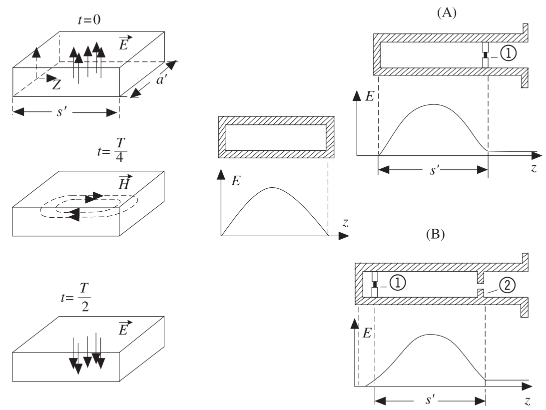

Fig. 1.2: Basic design of the Gunn oscillator
left: TE_{101} oscillation in a rectangular cavity resonator
middle: Dependency of the electrical field strength E on the longitudinal coordinate z for TE_{101} resonance
right: Two possible configuratios for the Gunn oscillators (1) Gunn diode (2) aperture Configuration B is used in these experiments and configuration A in MTS 7.4.6.

generally required by the load. Developing a Gunn oscillator from a cavity resonator requires (I) that the Gunn element be coupled to the resonator, and (II) that the load be coupled to the resonator. Fig. 1.2, right section, shows two possible configurations.

In configuration (B), the Gunn element is coupled to the resonator using a round metallic post, and the load is coupled using an aperture (hole or slot). From the sketch of the longitudinal electrical field distribution in configuration (B), we can see that the planes of the post axis and the aperture may be regarded as short-circuit planes for the purpose of estimating the resonance frequency.

In configuration (A) (Fig. 1.2, top right) the metallic post fullfils both functions, i.e. the coupling of the resonator to the Gunn element as well as to the load.

In the present experiment, an oscillator constructed according to configuration (B) is used. In contrast in experiments from MTS 7.4.6 a mechanically adjustable oscillator according to configuration (A) is assembled.

Required equipment

1 Basic unit	737 021
1 Gunn oscillator	737 01
1 Fixed attenuator	737 095
1 Transition waveguide/coax	737 035
1 Coax detector	737 03
1 Thumb screws (2 each)	737 399

Additionally required equipment

1 Oscilloscope	575 29
1 XY recorder (optional)	575 663
2 Stand bases	301 21
1 Support for waveguide components	737 15
1 Stand rod 0.25 m	301 26
2 Coax-cables with BNC/BNC plugs, 2 m	501 022
1 Slide caliper	

Experiment procedure

1. *Visually study the design of the disassembled Gunn oscillator (see also the instruction sheet to the device).*

1.1 Disassemble the Gunn oscillator by loosening the quick-release thumb screws. (Disconnect the back panel of the housing, diaphragm and waveguide terminating piece)

1.2 Consider the design of the Gunn element and compare it to Fig. 1.2 (right). Determine the waveguide width *a'* and the distance *s'* [see Fig. 1.2 right, configuration (B)] of the post axis to the flange plane (= location of the diaphragm) using a slide caliper.

Note:

Make sure that you DO NOT touch the Gunn diode with the slide caliper.

2. *Determine the dependency of the DC current I_G flowing through the Gunn element and (in the case of oscillation) the microwave signal generated by the supply voltage U_G (when the diaphragm is attached).*

2.1 Reassemble the Gunn oscillator dismantled in part 1 of the experiment, i.e. reattach the back panel of the housing and the waveguide to the Gunn element module.

2.2 Screw the fixed attenuator and waveguide/coax transition onto the open end of the waveguide (Fig. 1.3).
The attenuator keeps the detector in the square-law characteristic range (see MTS 7.4.5 and Experiment 4 of this book) and attenuates undesired reflections]

2.3 Set up the equipment configuration on the lab bench using the stand rods.

2.4 Connect the basic unit (set the rotary knob for the Gunn diode supply voltage U_G to "0") to the Gunn oscillator using the coaxial cable.

2.5 Attach the coax-detector to the waveguide/coax transition (making sure here that the thread does not get jammed)

2.6 Connect the detector to the oscilloscope (not contained in the measurement station). Set the oscilloscope to DC and the measurement range for the following measurements to approx. 2 to 100 mV.

2.7 Switch on the Gunn power supply unit. Increase the supply voltage U_G from 0 to 10 V in steps of 0.5 V. At the same time read off the Gunn element's DC current I_G and the receiving voltage U_D proportional to the raiated microwave power and enter the results in columns 2 and 3 of Table 1.1. Draw the findings in Diagram 1.1. Connect the points representing the measurements from Table 1.1 with straight lines.

Note:

If an XY recorder is available, the function $I_G = I_G\ (U_G)$ can also be recorded directly.

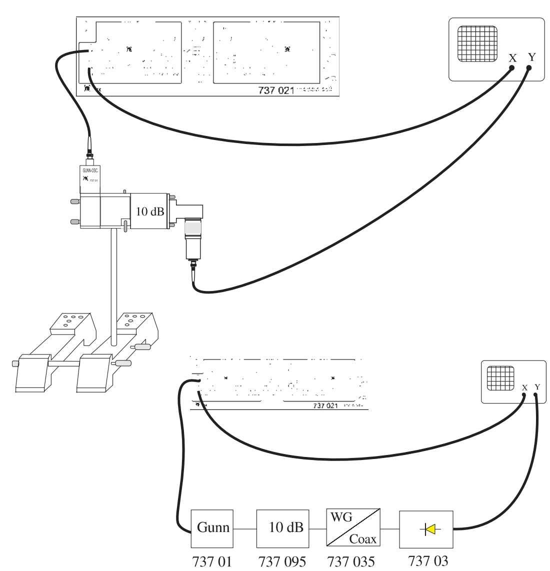

Fig. 1.3: Experiment setup

In this case the appropriately designated sockets **X** and **Y** of the Gunn power supply of the basic unit are connected to the X and Y inputs of the XY recorder. Likewise the function $U_D(U_G)$ can be recorded. The Y-input of the recorder must be connected to the coax detector (Since U_D is negative, interchange the "+"- and "–" input).
For the recording of the characteristic the Gunn voltage is to be increased slowly by turning the 10-turn potentiometer. You can also use a digital storage oscilloscope instead of the XY recorder. In this case an additional triangular function generator (0 to 10 V) is required for wobbling the characteristics. A very low wobble frequency must be selected here, because the **RECORDER** outputs **X** and **Y** have lowpass filters. The advantage of a continuous increase of U_G as opposed to a step-by-step increase (0.5 V steps) lies in the fact that the "steps" (discontinuities) in the characteristics are easier to discern.

3. *Repeat part 2 of the experiment but without the diaphragm.*

3.1 To remove the diaphragm loosen the thumb screws, take out the diaphragm and then reassemble the waveguide adapter (including the waveguide/coax transition).

3.2 Repeat the experiments in accordance with point 2.7. Enter the results for I_G and U_D in columns 4 and 5 of Table 1.1

Table 1.1 *a'=________ mm* *s'= ________ mm*

	with diaphragm with rear panel		without diaphragm with rear panel		with diaphragm without rear panel	
U_G / V	U_D / mV	I_G / mA	U_D / mV	I_G / mA	U_D / mV	I_G / mA
0.0						
0.5						
1.0						
1.5						
2.0						
2.5						
3.0						
3.5						
4.0						
4.5						
5.0						
5.5						
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9.5						
10.0						

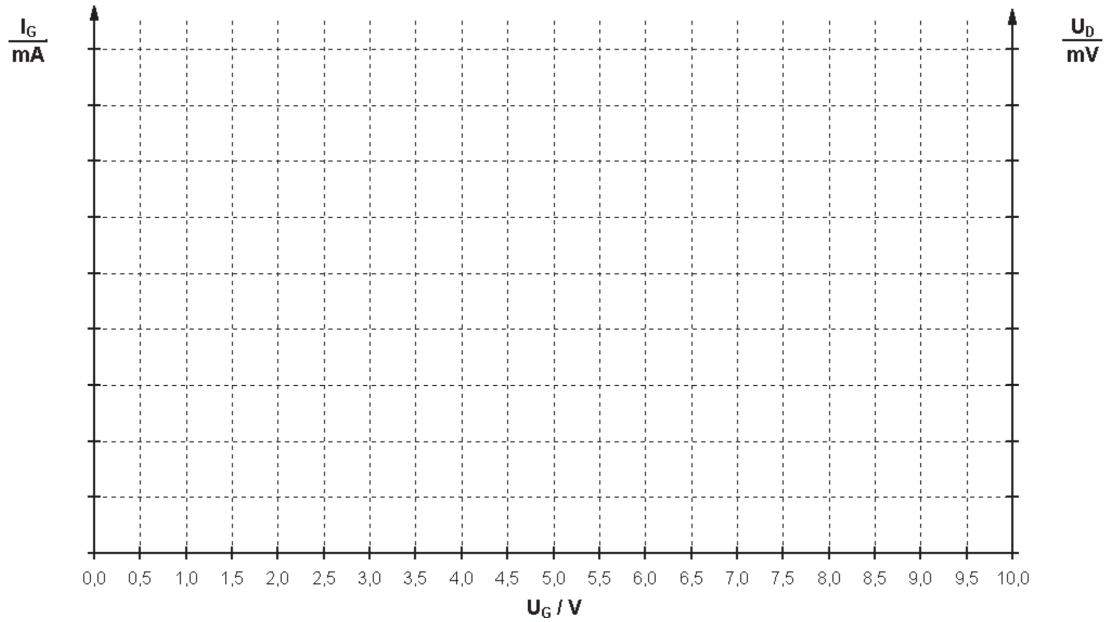

Diagram 1.1: For the graphic representation of the measurements values from table 1.1

4. *Repeat part 2 of the experiment, but without the rear panel.*
4.1 Reinsert the diaphragm. Remove the rear panel.
4.2 Repeat the experiment according to point 2.7. Enter the results for I_G and U_D in columns 6 and 7 of Table 1.1

Questions

1. Calculate approximately the oscillator frequency according to the Equation (1.1) specified above for the resonance frequency of a rectangular cavity resonator. For this use the geometrical data determined in experiment part 1.2. Here you may assume a $\boldsymbol{TE}_{101}$ resonance with “effective short-circuit planes” at the location of the post axis and the diaphragm (see also Fig. 1.2, lower right).

2. Assuming that the active GaAs layer has a thickness of 10 µm, determine from the value for the threshold voltage $\boldsymbol{U}_{TH}$ (= voltage above which the differential mobility becomes negative) the threshold value $\boldsymbol{E}_{TH}$ of the electrical field strength in kV/cm. The voltage drop outside the active layer may be ignored here, and you may assume a homogenous spatial distribution of the field strength.

3. Assuming a domain velocity of 10^7 cm/s, determine the transit frequency of the Gunn element.

4. Explain the different responses obtained in experiment parts 2 (with diaphragm and rear panel), 3 (without diaphragm, with housing rear panel) and 4 (with diaphragm, but without rear panel).

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