Pulses in Fibers

Advanced Lab Course

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Contents

Abstract

In this experiment the pulses in coaxial cables and optical fibers are investigated. In the first part of this manual the theory behind the experiment is presented. It will help to understand the basic concepts, interpret the obtained experimental results and avoid the possible errors in measurements. In the second part signal propagation in different types of coaxial cables and optical fibers is presented. The main focus of the experiment is the determination of the transmission function of coaxial cables and optical fibers using data analysis software. In the appendix the literature of the relevant topics is given.

1 Theory

1.1 Electricity

1. **Signal propagation in coaxial cables**

   (a) Discuss the characteristics of coaxial cables such as characteristic impedance, attenuation and dispersion (without calculations, only functional relations).

   (b) Describe the relationship between the characteristic impedance and the wave reflection at the end of an electrical cable (reflection coefficient).

2. **Example: Power splitter with 50Ω- resistance (no imaginary part)**

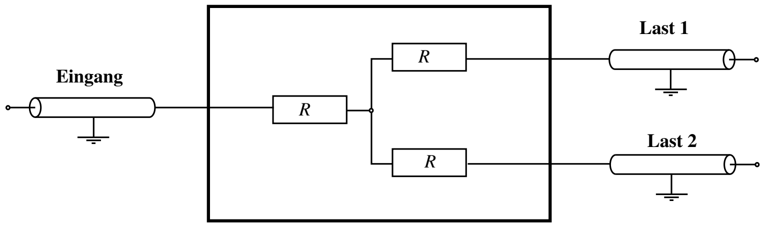

Figure 1: Schematic of resistances of the power splitter

   (a) Describe the operation of power divider with 50Ω impedance matching (Fig.1). Draw the equivalent circuit diagram for the above figure and calculate the value of resistance R for 50Ω impedance matching.

   (b) What happens if only one of the outputs (of the power splitter) is connected to the 50Ω cable and the other one is open?

1.2 Optics

1. **Glass Fibers**
   (a) How are glass fibers constructed and what types do exist?
   (b) What are the typical values (diameter and refractive index of the core and cladding) of step-index multimode and single-mode fibers?

2. **Numercial Aperture**
   (a) Describe the mechanism of the light propagation in a glass fiber.
   (b) How is the numerical aperture of a glass fiber defined and what is its physical meaning?
   (c) What is the typical value of the numerical aperture for the fibers used in this experiment?

$$n = \frac{n_1 + n_2}{2} \approx 1.465, \qquad \frac{n_1 - n_2}{n} \approx 0.01$$

   What is value of the critical incident angle?

3. **Modes**
   (a) What is mode?
   (b) How many modes do exist in a fiber (described in problem 2) with a core diameter of $d = 50\mu$m and an input wavelength of $\lambda = 650$nm? No need to derive the mathematical relation.

4. **Signal Propagation in Optical Fibers: Dispersion**
   (a) Describe briefly the different types of dispersion (intermodal dispersion, material and wave dispersion) that occur in optical fibers. Give a brief outline of what dispersion type(s) are important in multimode fibers (step and gradient refractive index) and in single-mode fibers.
   (b) Intermodal Dispersion:
   The propagation time difference of different modes in multimode fibers is an important parameter for calculating the rate at which the information can be transmitted (bandwidth). Calculate the propagation time difference between the fundamental mode and the mode with Φ_{krit} reflection angle in the step-index fiber.
   (c) Why is the propagation time difference in the fiber with gradient refractive index much smaller than that in the step-index fiber?
   (d) What is the relation between propagation time difference and the transmission capacity (bandwidth) of the fiber?
   (e) Why are single-mode fibers commonly used in telecommunication?

5. **Rectangular Pulses**

(a) Calculate the spectrum of an ideal rectangular pulse (Fourier transformation). How does the spectrum change (qualitatively) when instead of an individual rectangular pulse infinite number of pulses at a constant distance (in the experiment: pulse to pulse interval $\gg$ pulse duration) are considered?

(b) How can the bandwidth be estimated from these measurements?

1.3 Linear Transfer Systems

Linear transfer systems such as optical fibers or coaxial cables can be characterized given the link (function) between a transmitter (input) and a receiver (output). Denoting the output signal $s_2(t)$ (system response) as a function of input signal $s_1(t)$ and knowing the transfer function h, $s_2(t)$ can be calculated by the convolution product of $s_1(t)$.

$$s_2(t) = \int_{-\infty}^{\infty} h(\tau) s_1(t-\tau) d\tau$$

The transfer function h can be calculated using the convolution theorem for Fourier transformations. Detailed theory of the latter can be found in literature given in Appendix.

1.3.1 Theoretical Exercises

1. When is the transfer system considered linear, causal, stable?
2. How does the frequency spectrum of a signal change when the time is shifted by $s(t) \rightarrow s(t - t_0)$?
3. Derive the convolution theorem.

2 Experiment: Coaxial Cables

2.1 Material

- **Pulse generator**:
  The pulse generator (Avtech AVO-9) shown in Fig.2 generates pulses of variable amplitude with pulse duration between 10 ns and 100 ns and repetition frequencies between 100 Hz and 100 kHz.
  On its back side the signal output (type SMA) and a monitor output (BNC type) for the trigger signal can be found.

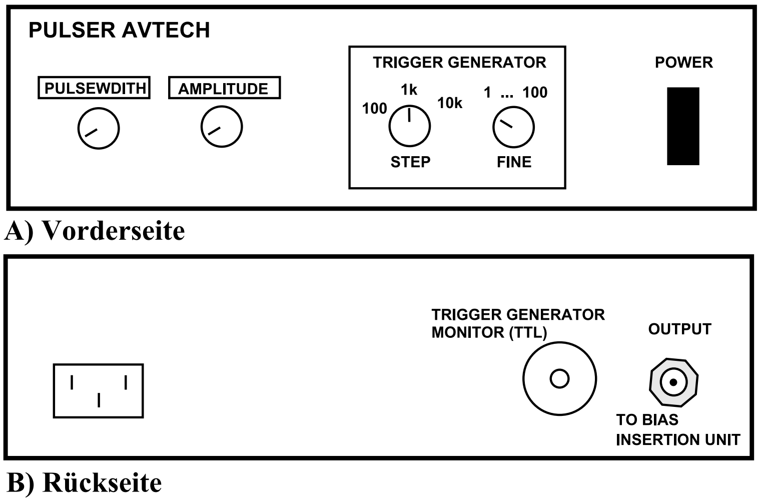

Figure 2: Pulsgenerator Avtech AVO-9

- **Digital Storage Oscilloscope DSO**
  Mr. Wúthrich from the IAP-electronics lab (room A18) will give a brief introduction and borrow the DSO for a short usage. You should make an appointment with him.
- **Coaxial Cable**
  There are many coaxial cables of different lengths in the inventory.

2.2 Experiment

2.2.1 Pulse Broadening, Signal Attenuation, Bandwidth

- Measurement of pulse broadening and signal attenuation of pulses after propagation through different lengths of coaxial cable (use 6 dB power splitter).
- What is the bandwidth of different cables?

  Note: The bandwidth of the pulses used should not be much smaller than the expected bandwidth of the cable (so, use appropriate short pulses).

2.2.2 Calculation of Transfer Function of Coaxial Cables

Save the data of input and output pulses at DSO in ASCII format to disc. These data will be used for the calculation of transfer functions of different coaxial cables.

3 Experiment: Glass Fiber

3.1 Material

- **Laser Diode**
  The laser diode (PicoQuant PDL800, $\lambda = 634nm$) is used as a light source. The minimum pulse duration is 50 ps and maximum repetition rate is 80 MHz. The repetition rate can be reduced by the factors of 2/4/8/16.
  Directly at the output of the laser diode the coupling interface of the single-mode fiber is attached. Together with the Laser diode pump it forms a complete unit. Find specifications of the laser diode in the ”Operation Manual and Technical Data”.

- **Photodiode HP4220**
  Due to its short rise time this photodiode is well suited to detect short light pulses. Because of its small active area one needs to focus the beam into it. One disadvantage is its small spectral responsivity. The photodiode is operated with a bias voltage of +20 Volt.

- **Avalanche Photodiode APD, C30902S**
  The **most expensive!** Photodiode of the experiment. Short rise time with higher spectral sensitivity allows to measure short pulses with smaller power/energy. **Important**: The Avalanche photodiode should not exceed 50mV voltage at the input DSO impedance of 50Ω! Whie measuring the pulses before they enter the fiber, ensure that gray filters attenuate the laser beam. The avalanche photodiode is operated with a bias voltage of 201.6 V. A specific power supply is connected to provide that particular voltage, which is operated via a LEMO connector cable for APD.

- **Glass Fibers**
  Two types of glass fibers are available: Step-index and gradient-index fibers. They are rolled on the large styrofoam.

3.2 Experiment

The measurements can be carried out with step-index or gradient index fibers. As in coaxial cables, the propagation of pulses in glass fibers will be investigated.

3.2.1 Coupling with Optical Fiber

In order to achieve the highest possible experimental coupling efficiency, the divergent laser beam from the fiber-coupled laser diode must be optimally coupled with the investigated glass fiber. For that reason, first the laser beam is collimated so that it can be optimally focused to the fiber. Collimating and focusing can be efficiently reached with the microscope objectives. The endings of the investigated glass fibers should be cut. The fiber ending is optimized, when face of the core and the outer shell (cladding) of the fiber are flat and perpendicular to the fiber axis. Various methods can be used for that purpose, which should be discussed with the assistant.

- **Measurement of laser pulses before entering the glass fiber**
  Measure the laser pulse before coupling into the fiber with the Avalanche Photodiode. **Important**! The Avalanche photodiode should not exceed 50mV voltage at the input DSO impedance of 50Ω! The laser pulses in the collimated region should be optimally attenuated with gray filters (total transmittance 1 per thousand).
  Determine the pulse width and the rise time of the laser pulse with an appropriate criterion.
  Save the pulses in ASCII format on the disc.

- **Measurement of the laser pulse after the optical fiber**
  Measure again the laser pulses with Avalanche photodiode after the glass fiber and determine the pulse width and the rise time. From the pulse broadening and/or the change in the rise time the delay dispersion can be calculated.

- **Signal propagation time**
  Determine the signal propagation time of the laser pulses in the fiber. Use the Sync pulse of the diode controller as a start signal.
  Calculate the length of the glass fiber from the signal propagation time.

3.2.2 Calculation of the transfer function of coaxial cables and glass fibers

The data of inputs and outputs stored in the initial part of the experiment for the coaxial cables and glass fibers will now be used to calculate the transfer functions.

- Use a data analysis software (eg Matlab, Mathematica or IDL) and convolution theorem to calculate the transfer functions.

- What is the physical interpretation of the transfer function in coaxial cables and glass fibers?

4 Literature

Internet searching is very helpful tool to find relevent modern literature and explenations on all the topics used in this experiment.
Additionally, in the EXWI-Library:

Glass fibers:

E.G. Neumann: Single Mode Fibers (TDK116) (the bible!)
Hans Georg Unger: Optische Nachrichtentechnik (TDK129)
Dietrich Marcuse: Principles of optical fiber measurements (TDK133)
Timmermann: Lichtwellenleiter (beim Versuch)

Pulses in coaxial cables:

Schlegel, Nowak: Impulstechnik (PEJ131, PFH121)
J.A. Coekin: High speed pulse techniques (PFH150)
W. Meiling, F.Stary: Nanosecond pulse technique (PFH135)
I.A.D. Lewis, F.H. Wells: Millimicrosecond pulse technique (PFA194)

Laser diodes and photodiods

S.M. Sze: Physics of semiconducter devices (VND117) J.I. Pankove: Optical processes in semiconducters (VNA132)

5 Appendix (downloaded seperately from www)