Course Control Engineering Spring/Summer 2018
ISE Bachelor in Mechanical Engineering

Univ.-Prof. Dr.-Ing. Dirk Söffker

Room: MB 243
Time: Mo 08.00 am - 11.00 am

Assistant:
Mr. Mark Spiller, M.Sc.

Additional: Tutorial/Practical exercise

www.uni-due.de/srs/v-ce.shtml

Manuscript

Sommersemester 2018

Course	**Control Engineering (2L, 1E, 1P)**
Target group	ISE Bachelor Mechanical Engineering
URL of the course	http://www.uni-due.de/srs/v-ce.shtml
Dozent/innen	Söffker
Assistant	Mark Spiller, M.Sc.
Place	MB 143
Day	Monday
Time	08.00am – 11.00pm
First course	April, 9th
Last course	July, 2nd
Consulting hours	Thursday, 10.00am-11.30am, MB 326
Literature	Textbook: Lunze, J.: Regelungstechnik 1, Springer, 3. Auflage, 2001. (available in the library) **> L** Recommended additional reading: Ogata, K.: Modern Control Engineering, 4th Edition, 2002. (available in the library) **> O** Franklin, G.F.; Powell, J.D.; Emami-Naeini, A.: Feedback Control of Dynamic Systems, Prentice Hall 2002 (available in the library) Dorf, R.C.; Bishop, R.H.: Modern Control Systems, Pearson, 2005. Unbehauen, H.; Ley, F.: Das Ingenieurwissen: Regelungs- und Steuerungstechnik, Springer Vieweg, 2014
Content	

Module	**Topic:**	**Literature:**
1	Frequency behavior and Laplace transformation	L 6.1-6. O2,O8.1 + Material
2	Characteristics of elements and of loops in the frequency domain	L 6.7 O5.5,O5.9 O8.2,O8.4 + Material
3	Stability of dyn. systems	L 8.1-8.4 + Material
4	Stability of dyn. systems	L 8.5 O6,O8.7-O8.9
5	Control Design	L 9.1-11.2 O7, O10
6	Modern Control methods	Material

General information	The lectures/exercises will be given with a suitable schedule, no strict distinction between lecture and exercise can be expected. The course starts with lectures, switches to lectures/exercises and ends with only exercises. The website http://www.uni-due.de/srs/v-ce.shtml offers actual information. The course material (as pdf-documents) is encoded with a password. It should be noted that the German spoken course REGELUNGSTECHNIK contains - the same material, - is organized with the same scheme, and - uses the same exercises. Both courses are open for both groups Bachelor.
Practical Exercise	The related practical exercise System Dynamics and Control Engineering will be organized separately; it is necessary to pass an attestation to take part. The practical exercise is an additional requirement and will be graded separately.
Exam	Written exam in english or german language, 90 minutes, closed-book, registration at the examination office.

Sommersemester 2018

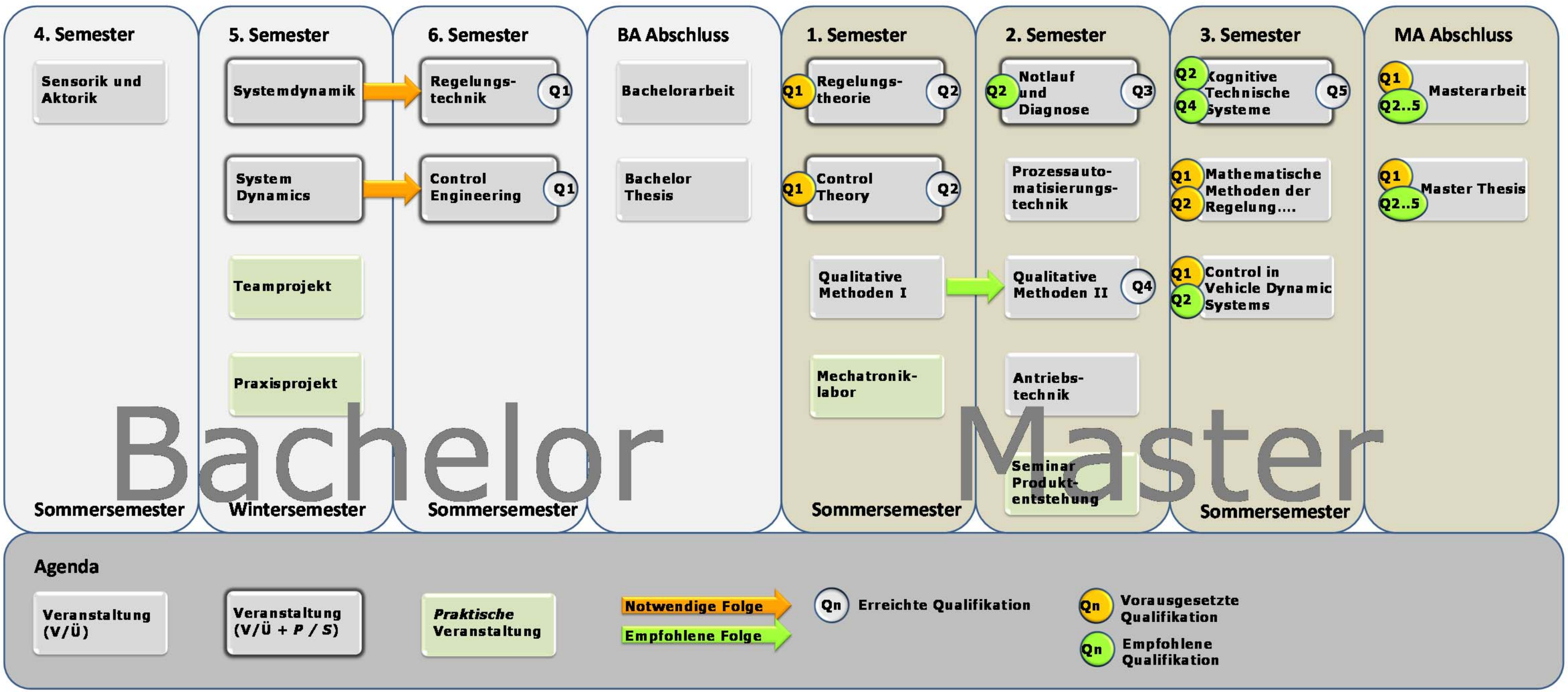
Course	**Practical Exercise** **System Dynamics und Control Engineering (1P)** consisting of three experiments (Scripts in german language): • Modellbildung und Simulation (ms) (**SoSe**) • Druckregelung (dr) (**SoSe**) • Elektrohydraulisches Servosystem (hs) (**WiSe**)
Attendance mandatory:	Students Mechanical Engineering (Bachelor) PO08, PO15 Students Mechanical Engineering (ISE) Bachelor PO08, PO15
URL of the course	http://www.uni-due.de/srs/v-ce-an1-Praktikum.shtml
Lecturer	Ph.D. students
Coordination	Friederike Kögler, praktikum-srs@uni-due.de
Attestation date	**ms/dr-resits (PO08) (System Dynamics):** April, 13th, 5.45pm, Room MC122/MD162 **hs-experiment (PO08) (Control Engineering):** June, 8th, 4.00pm, Room MC122/MD162 **ms/dr-experiment (PO15) (System Dynamics):** June, 8th, 4.00pm, Room MC122/MD162
Place (Labs)	MB 325 (dr), MB 323 (ms), MB 028 (hs)
Day	Daily
Time	Appointments between 8.00am-05.00pm
First dates	ms/dr-resits (PO08): 16th calendar week hs-experiments (PO08): 25th calendar week ms/dr-experiments (PO15): 25th calendar week
Last dates	28th calendar week
Consulting hours	Thursday, 10.00am-11.30am, MB 326
Skripts	Scripts for each experiment are located on the SRS homepage. Those have to be worked through until the attestation date as they are the basis for the attestation.
Attestation	You have to succeed one central attestation for the experiments in System Dynamics and one central attestation for the experiment in Control Engineering in order to

	participate at the labs. The attestations are only offered at the a.m. dates. Participation at the labs without a successfully passed attestation is not possible.
Registration	**PO08:** The mandatory registration at the examination office <u>had</u> to be realized in the 5th and 6th week of the <u>past</u> winter semester. An anew registration in the summer term is neither necessary nor possible. ONLY officially registered participants are allowed to take part in the attestation. **PO15:** The mandatory registration at the examination office <u>has</u> to be realized in the 5th and 6th week of the <u>current</u> summer semester. This registration is valid also for the lab of Control Engineering in the next winter term. An anew registration in the winter term is neither necessary nor possible. ONLY officially registered participants are allowed to take part in the attestation. A deregistration for individual practical labs is only possible via email to praktikum-srs@uni-due.de latest 2 weeks (full 14 days) before the labs' date. Nonappearance leads to the grading fail for all three experiments. After participation at the attestation a deregistration from the entire practical exercise is not possible.
Realization of labs	The experiments are held in English language. The participants are grouped in teams of 5 students and assigned to fixed lab dates. A central date exchange service by the chair will not be provided; the participants are allowed to switch their dates with another accepted student on their own risk. If the switching party does not participate, the original advised student loses the right to participate. The doctoral candidate conducting the lab has to be informed at the beginning of the experiment about a date's switch. All participants will be checked if their participation is accepted. Not accepted students are not allowed to take part. Following rough guideline is used for the times of experiments: First the dates for the German spoken course will be implemented. In the last 1-2 weeks of the exercises mainly English spoken labs (ISE) will be conducted.
Grading / fail	Your performance will be graded:

Criteria	**Grade**
a) All attestations (ms, dr, hs) were successful at the first attempt **and** a) active participation at the lab.	1,0
b) One attestation failed once and successfully passed in the second attempt **or** c) Passed attestations but no active participation at the lab.	3,0
a) Two attestations failed, **or** b) Nonappearance/delay.	5,0 (failed)

	Grading with 5,0 (failed) all experiments and the attestations have to be repeated. Grades will be reported to the examination office like other examination results. The experiments have to be completed within one calendar year (in the sequence System Dynamics – Control Engineering). Single labs of earlier terms expire. Grades are 1,0 or 3,0, or all experiments have to be repeated completely. The pass of the practical exercise is connected with: 1) Attestation: Each participant has to succeed the central written attestations for the experiments in order to participate at the labs. 2) Verification of identity: Participation at the attestation is only possible if your identity can be verified. For verification of your identity you have to show your Student-ID, or your passport, or your Aufenthaltstitel at the attestation date. If the ID cannot be accepted or is not correct, the student loses the right to participate. 3) Presence: The exercise starts exactly at the announced time. Participants who are not present until 5 minutes after start of the exercise will be graded as being "not present", regardless of reasons. Nonappearance leads to the grading fail for all three experiments. 4) Active participation at the practical experiment.
Further information	It is strongly recommended to conduct the experiments in the proposed order and terms because failed attempts lead to worse grades or failed trials.

Lehrangebot Lehrstuhl SRS (empfohlene Veranstaltungsfolge, Stand 03.11)



Veranstaltungsablauf SoSe 2018
Time table Summer Term 2018

Lehrstuhl Steuerung, Regelung und Systemdynamik
Chair of Dynamics and Control

(Leitung/Head: Univ.-Prof. Dr.-Ing. Dirk Söffker) (vfinal, März 2018)

Veranstaltung Course	**Kalenderwoche** Calender Week	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**Prüfung** Exam
Regelungstechnik	v-rt																**Schriftlich**
Control Engineering	v-ce																**Written**
System Dynamics	v-sde																**Written**
Sensorik u. Aktorik: Teil Aktorik	v-sua																**Schriftlich**
Regelungstheorie	v-rth																**Schriftlich**
Kognitive Techn. Systeme	v-kts																**Schriftlich**
Praktikum RT/SD, CE/SDe*	p-rt																**Antestat**
Praktikum CTh/RTh*	p-cth/rth																**Antestat**
Praktikum SuA (Aktorik)	p-sua																**Antestat**
Mechatroniklabor/ MachineLab/ Teamprojekt/ Praxisprojekt	l-me/ma/te/pr																**Präsentation Presentation**

Legende:

Veranstaltungszeit (Vorlesung/Übung) / Courses (Lecture/Exercise)	
Veranstaltung, geblockt ; Blocked course period	
Praktika/ Practical Exercises RT, SD, Cth, Rth	
Labor/Labs	
Prüfung/Exam	

*: **Bitte beachten Sie den gesonderten Ablauf für die Praktika Regelungstechnik, Systemdynamik und Regelungstheorie.**
Please consider the separate time table for the practical exercises Control Engineering, System Dynamics, and for Control Theory.

Methods (Control, Diagnosis, Automated Systems)

- Observers, Control, Fault Detection, Fault Diagnosis
- Cognition (Integrated Learning, Planning, Decision Making, ...)
- Filtering, Classifikation, Fusion (signals, information, ...)

> Robustness
> Modeling
> Reliability, Safety

Methods/ Mechatronics/ System Dynamics	**Structural Health Monitoring**	**Cognitive Technical Systems**
- Modeling using automata - Adaptive and reliable classification, able to learn - Observers - Nonlinear dynamics - Power management of hybrid powertrains/ wind energy systems	- Acoustic Emission > Sensors > Filters > Fault diagnosis > Prognosis - Fault detection and fault diagnosis methods - Wear and aging > Data-driven modeling - Safe- und lifetime-oriented operation	- Knowledge-based and individualized assistence of HMS (example: driver assistance) - Situation recognition of complex situations - Situated automata, able to learn - Safe actions and interactions

Goal: Description of transmittance behavior independent from time

-

> now: ...

Key words:

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-
-
-

- Assumption of a linear system implies => division of input signals / transfer of individual signals / addition of (individual) output signals

$$u(t) = \sum u_i(t) = u_1(t) + u_2(t) + \dots$$

$$y(t) = \sum y_i(t) = y_1(t) + y_2(t) + \dots$$

$$u_1(t) \rightsquigarrow y_1(t) \; ; \; \dots \; u_n(t) \rightsquigarrow y_n(t)$$

- Transmittance: amplification and time delay (denoted as phase shift) (transmittance of a periodic signals is described only with two parameters (gain / phase shift)

$$u_1(t) \to y_1(t) = a \cdot u_1(t+\varphi) \qquad \left.\begin{matrix} a(\omega_0) \\ \varphi(\omega_0) \end{matrix}\right\} u(t) \rightsquigarrow y(t) = A(\omega)\cdot u(t+\varphi(\omega))$$

Engineering-oriented mathematical background of the Fourier- and Laplace transformation:

> characteristics of periodic signals (periodicity)

$$f(t) = f(t + \ell \cdot T_0) \quad ; \ell = 0, 1, 2, 3, \ldots$$

$$T_0 \ [sec.]$$

$$f_0 = \frac{1}{T_0} \left[\frac{1}{sec.}\right] \Rightarrow \quad \omega_0 = 2\pi \cdot f_0$$

Fourier theorem:

$$f(t) = \frac{A_0}{2} + \sum_{k=0}^{\infty} A_k \cos(\omega_0 k t) + \sum_{k=1}^{\infty} B_k \sin(\omega_0 k t)$$

$$A_k = \frac{2}{T_0} \int_0^{T_0} f(t) \cdot \cos k\omega_0 t \, dt, \quad k = 0, 1, \ldots$$

$$B_k = \frac{2}{T_0} \int_0^{T_0} f(t) \cdot \sin k\omega_0 t \, dt, \quad k = 1, 2, \ldots$$

- Interpretation of the absolute term A_0, of the coefficients A_k B_k

> Alternative, brief description:

$$f(t) = C_0 + \sum_{k=1}^{\infty} C_k \sin(k\omega_0 t + \phi_k)$$

$$C_0 = \frac{A_0}{2}$$

$$C_k = \sqrt{A_k^2 + B_k^2}, \quad k = 1, 2, 3, \ldots$$

$$\phi_k = \operatorname{atan} \frac{A_k}{B_k}$$

$k = 1$:

$k > 1$:

> Division of a periodic signal with different harmonic signals I

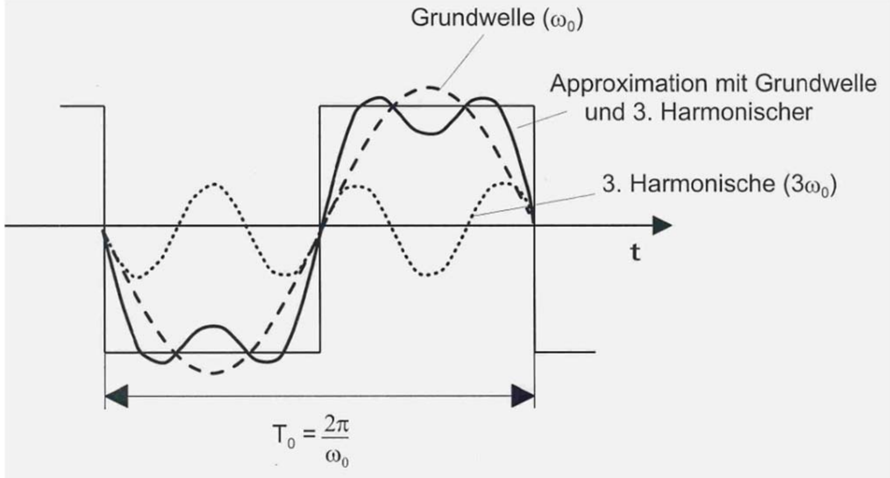


Abb. 6.1: Zerlegung einer Rechteckschwingung in Sinusschwingungen

J. Lunze: Regelungstechnik, Band 1, 3. Auflage, Springer-Verlag 2001

> Alternative, brief description: pointer description

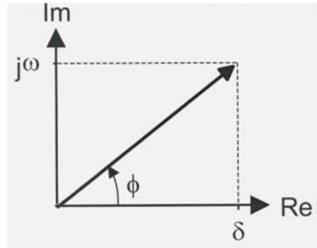


Abb. 6.2: Interpretation der Eulerformel in der komplexen Ebene

J. Lunze: Regelungstechnik, Band 1, 3. Auflage, Springer-Verlag 2001

> Euler formula
> brief description based on complex pointers

$$\delta + j\omega = K \cdot e^{j\phi(t)} = K(\cos\phi + \sin\phi)$$

$$K = \sqrt{\delta^2 + \omega^2}$$

$$\phi = \operatorname{atan}\frac{\omega}{\delta}$$

$$\Rightarrow f(t) = \sum_{k=-\infty}^{\infty} F_k e^{jk\omega_0 t}$$

$$\cos k\omega_0 t = \frac{1}{2}\left(e^{jk\omega_0 t} + e^{-jk\omega_0 t}\right)$$

$$\sin k\omega_0 t = \frac{1}{2j}\left(e^{jk\omega_0 t} - e^{-jk\omega_0 t}\right)$$

$$F_k = \frac{1}{2}(A_k + B_k)$$

$$F_k = -F_k \Rightarrow |F_k| = |-F_k|;\ \arg F_k = -\arg F_k$$

> Arbitrary (period.) signal as a sum of periodic signals

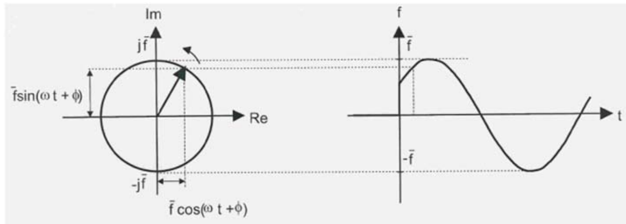


Abb. 6.3: Erzeugung der Funktion $f(t)$ durch einen rotierenden Zeiger

J. Lunze: Regelungstechnik, Band 1, 3. Auflage, Springer-Verlag 2001

$$F_k = \frac{1}{t_0}\int_{t_0}^{t_0+T} f(t) \cdot e^{-jk\omega_0 t}\, dt,\quad k = 0, \pm 1, \pm 2, \ldots$$

> Arbitrary (period.) signal as a sum of periodic signals

$$F_0 = C_0$$

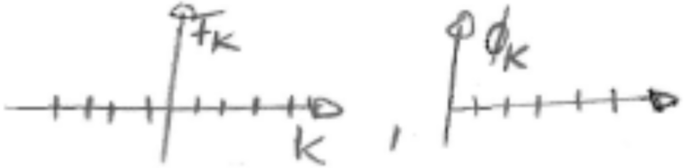
$$|F_k| = \frac{1}{2}|C_k| \qquad (k \geq 1)$$

$$\arg F_k = \phi_k \qquad (k \geq 1)$$

> Please note: - two values describe the signal behavior
- periodic signals will be described by the sum of indiv. signals

> discrete spectrum of amplitudes and phases

$$|F_k|,\ \arg F_k \longrightarrow f(t) \longrightarrow$$



$$|F_k| = [-\infty, \ldots, +\infty] \quad :$$

$$\arg F_k = [\ \ldots\ldots\ ] \quad :$$

> Division of a periodic signal with different sinus signals of different frequencies and amplitudes II

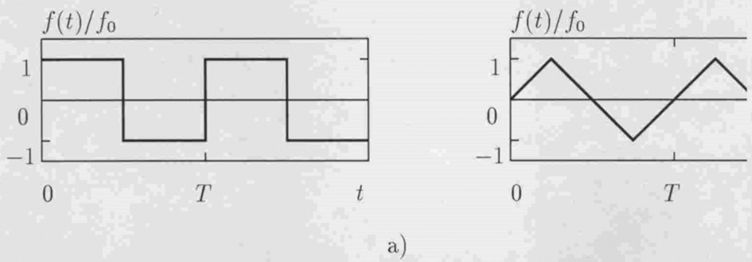


Abbildung 6.7: Beispiel periodischer Funktionen
a) Rechteckfunktion b) Dreieckfunktion

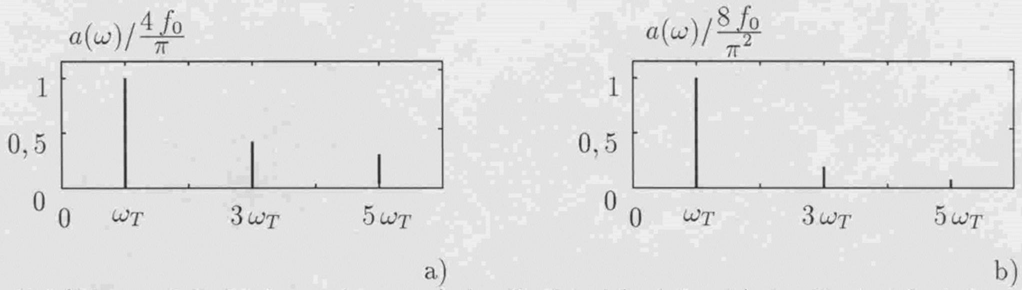


Abbildung 6.8: Linienspektrum a) der Rechteckfunktion b) der Dreieckfunktion

Die Fourier–Entwicklung lautet

für die Rechteckfunktion:

$$f(t) = \frac{4f_0}{\pi}\left(\sin(\omega_0 t) + \frac{1}{3}\sin(3\omega_0 t) + \frac{1}{5}\sin(5\omega_0 t) + \cdots\right),$$

und für die Dreieckfunktion:

$$y(t) = \frac{8y_0}{\pi^2}\left(\sin(\omega_0 t) - \frac{1}{3^2}\sin(3\omega_0 t) + \frac{1}{5^2}\sin(5\omega_0 t) + \cdots\right).$$

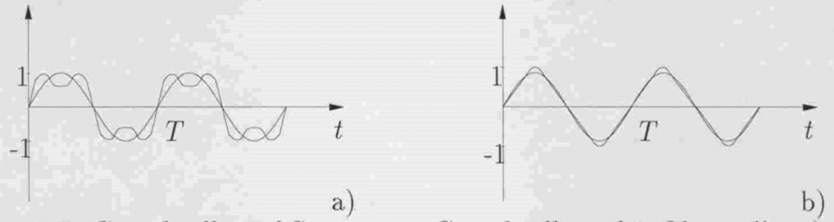


Abbildung 6.9: Grundwelle und Summe aus Grundwelle und 1. Oberwelle a) zur Rechteckwelle b) zur Dreieckfunktion

Up to now: Signal f(t) as a function of time

Now: Signal as sum of periodic parts, described with individual frequency and phase shift

Result: A discrete amplitude- und phase spectrum describes the signal characteristics (in the frequency domain)

1.2 Division of non-periodic signals

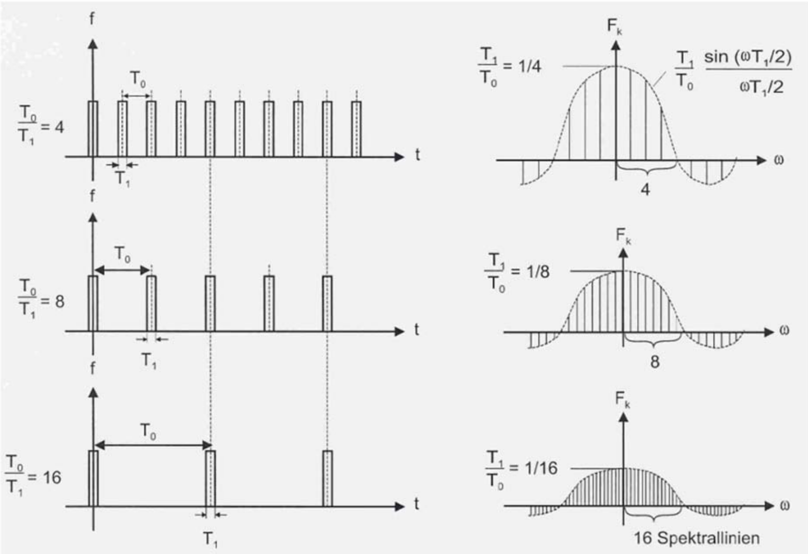


Abb. 6.4: Spektrum von Pulsfolgen verschiedener Tastverhältnisse $\frac{T_0}{T_1}$

J. Lunze: Regelungstechnik, Band 1, 3. Auflage, Springer-Verlag 2001

> discrete description >> continiuous description

Example:

What can be seen here?

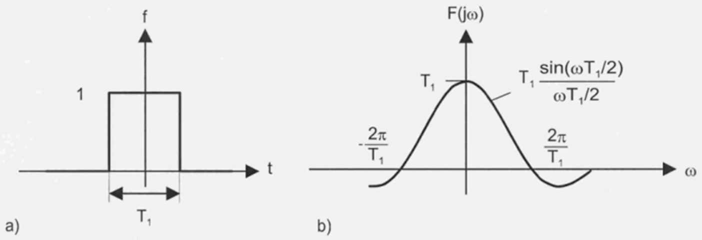


Abb. 6.5: Zeitverlauf (a) und Amplitudendichtespektrum (b) für einen Impuls

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$$T_0 \to \infty$$

$$\omega_0 = \frac{2\pi}{T_0} \to d\omega \qquad f_0 = \frac{1}{T_0} = \frac{\omega_0}{2\pi}$$

$$\Rightarrow k\omega_0 \to \omega$$

$$F(j\omega_0 k) = \frac{F_k}{f_0} = \frac{F_k}{\frac{\omega_0}{2\pi}}$$

$$= \int_{-\frac{T_0}{2}}^{\frac{T_0}{2}} f(t) \cdot e^{-jk\omega_0 t}\, dt \Rightarrow F(j\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t}\, dt$$