Course Control Engineering **Winter 2019/20**
ISE Bachelor in Mechanical Engineering

Dr.-Ing. Sandra Rothe

Room: MB 144
Time: Mo 08.00 am - 11.00 am

Assistant:
Dr.-Ing. Fateme Bakhshande

Additional: Tutorial/Practical exercise

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

Manuscript

Chair of
Dynamics and Control

Course Control Engineering
D. Söffker
LU-0-1: Frequency domain and Laplace transformation

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
Lecturer	Dr.-Ing. Sandra Rothe/Univ.-Prof. Dr.-Ing. Dirk Söffker
Assistant	Dr.-Ing. Fateme Bakhshande
Place	MB 144
Day	Monday
Time	08.00 am – 11.00 pm
First course	October, 14th
Last course	January, 20th
Consulting hours	Thursday, 10.00 am-11.30 am, 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

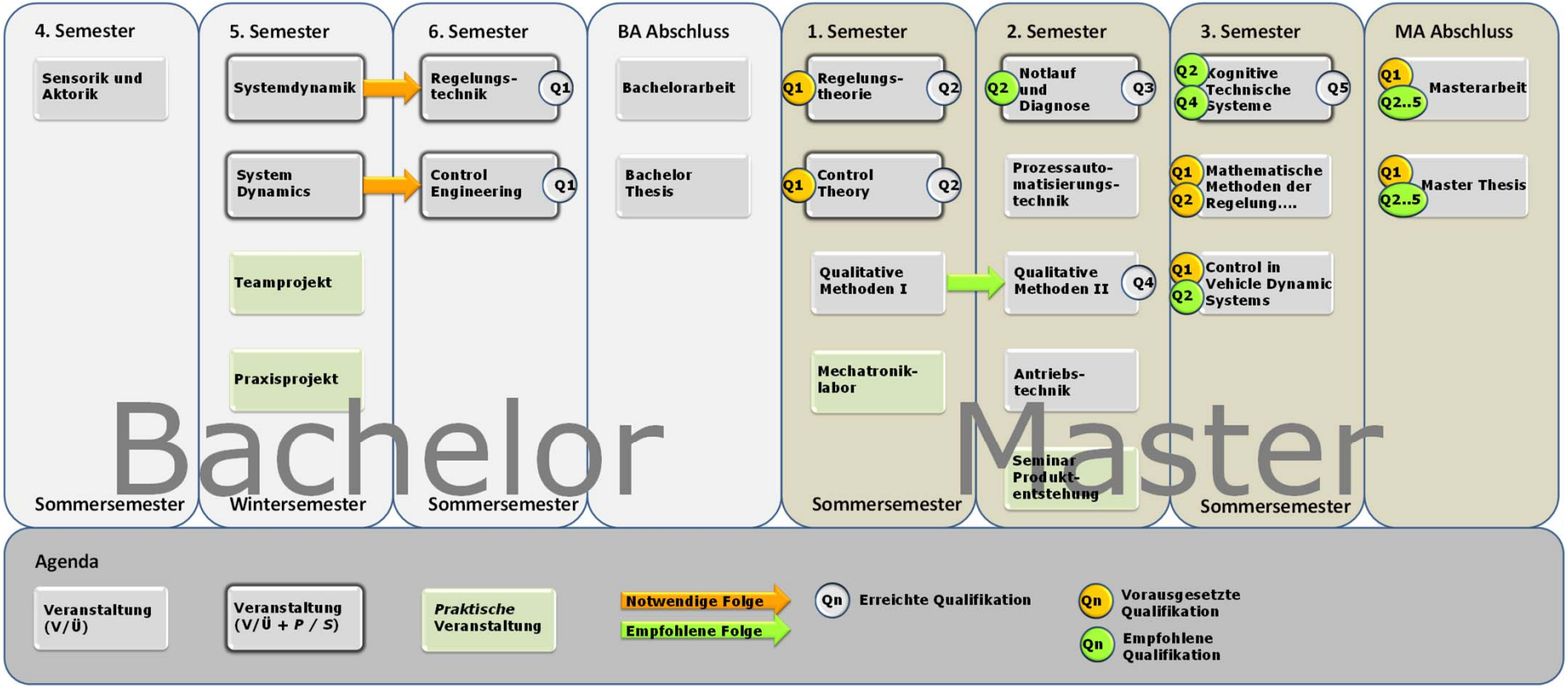
General information	The lectures/exercises will be given with a suitable schedule, no strict distinction between lecture and exercise can be expected. The course starts with lectures, switches to lectures/exercises and ends with only exercises. The website http://www.uni-due.de/srs/v-ce.shtml offers 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.

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 (ISE) Bachelor
URL of the course	http://www.uni-due.de/srs/v-ce-an1-Praktikum.shtml
Examiners	Ph.D. students/scientific co-workers
Coordination	Dr.-Ing. Sandra Rothe, praktikum-srs@uni-due.de
Attestation date	**System Dynamics resits (ms/dr):** October 14th, Room MC 122/MD 162 **Control Engineering (hs):** December 2nd, Room MC 122/MD 162 **Exact times and seat numbers are published in advance on our homepage.**
First lab dates	**System Dynamics resits (ms/dr):** 43nd calendar week **Control Engineering (hs):** 50th calendar week
Last dates	5th calendar week 2020
Place (Labs)	MB 323 (ms), MB 325 (dr), MB 025 (hs)
Lab days	Daily
Time	Appointments between 8.00 am - 05.00 pm
Consulting hours	Thursday, 10.00 am - 11.30 am, MB 326
Scripts	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	The mandatory registration at the examination office has to be realized in the 5th and 6th week of the past summer semester. This registration is valid also for the lab of Control Engineering in the current 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 is only possible via email to praktikum-srs@uni-due.de latest 1 week (full 7 days) before the attestation 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, but a **change-of-dates-forum is arranged in moodle** (Systemdynamik und Regelungstechnik – Pflichtpraktikum (WiSe 19/20)). 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.
Grading / fail	Your performance will be graded: **Criteria** / **Grade** - All attestations (SDe, CE) were successful at the first attempt **and** - Active participation at the lab. — 1,0 - One attestation failed once and successfully passed in the second attempt **or** - Passed attestations but no active participation at the lab. — 3,0 - Two attestations failed, **or** - 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 and in the beginning of the labs. 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 WiSe 2019/20
Winter term time table
(Leitung/Head: Univ.-Prof. Dr.-Ing. Dirk Söffker) (V0, August 2019)

Lehrstuhl Steuerung, Regelung und Systemdynamik
Chair of Dynamics and Control

Verantaltung Course	**Kalenderwoche** Calendar week	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**2**	**3**	**4**	**5**	**Prüfung** Exam
Systemdynamik	v-sd															**Schriftlich** Written
Control Engineering	v-ce															**Schriftlich** Written
Control Theory	v-cth															**Schriftlich** Written
Functional Safety	v-fs															**Schriftlich** Written
Notlauf und Diagnose (Söffker/Wolters)	v-ndts															**Schriftlich** Written
Prozessautomatisierungs-technik (Jelali)	v-pat															**Schriftlich** Written
Advanced Control Lab 1*	p-ac1															**Antestat+Bericht** Attestation+Report
Praktikum/Practical Exercise SD/CE*	p-rt															**Antestat** Attestation
Praktikum/Practical Exercise CTh/RTh*	p-cth/rth															**Antestat** Attestation
Vorbereitungspraktikum/ Preparatory Practical Exercise CE	p-pce															-
Mechatroniklabor/ MachineLab/ Teamprojekt/ Praxisprojekt	l-me/ma/te/pr															**Abschluss-präsentation** Final presentation

Legende:

Vorlesung,Übung/Lecture,Exercise	
Veranstaltung, geblockt/Blocked course	
Praktika/Practical Exercises	
Labor/Labs	
Prüfung,Antestat/Exam,Attestation	

* **Bitte beachten Sie den gesonderten Veranstaltungsablauf für die Praktika Regelungstechnik und Systemdynamik, Regelungstheorie sowie Advanced Control Lab.**
Please consider the separate time table for the practical exercises Control Engineering and System Dynamics, Control Theory as well as Advanced Control Lab.

Praktikum Systemdynamik (SD)/Regelungstechnik (RT) **Lehrstuhl Steuerung, Regelung und Systemdynamik**
Practical Exercise System Dynamics (SDe)/Control Engineering (CE) Chair of Dynamics and Control
(Leitung/Head: Univ.-Prof. Dr.-Ing. Dirk Söffker) (V0, August 2019)

Wintersemester 2019-20 / Winter term 2019-20

Semesterwoche/-week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Anmeldung/Registration					MB: HISinOne		ISE: Registrations in summer term also valid for following winter term.								
Antestat/Attestation	Wiederh./ Resits (RT, SDe)							SD, CE							
Versuche/Labs		Wiederh. /Resits (hs, ms, dr)							SD (ms, dr)/CE (hs)						
Vorlesung/Lecture	Vorlesung SD/Lecture CE														

Sommersemester 2020 / Summer term 2020

Semesterwoche/-week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Anmeldung/Registration					ISE: HISinOne		MB: Anmeldungen des WiSe gelten auch für das folgende SoSe.								
Antestat/Attestation	Wiederh./ Resits (SD, CE)								RT, Sde						
Versuche/Labs		Wiederh. /Resits (hs, ms, dr)								RT (hs)/SDe (ms, dr)					
Vorlesung/Lecture	Vorlesung RT/Lecture SDe														

Wichtig! In der 5. und 6. Semesterwoche muss die **Anmeldung im Prüfungsamt** zum Praktikum erfolgen. **Ohne gültige Anmeldung ist keine Teilnahme am Praktikum möglich!** Eine Abmeldung vom Praktikum ist nur bis spätestens 1 Woche vor dem Antestattermin per Mail an praktikum-srs@uni-due.de möglich.

Important! In the 5th and 6th week of the term you have to **register at the Examination Office** for the practical exercise. **Without valid registration a participation in the labs is not possible!** You may unsubscribe from the labs date at least 1 week before the attestation date only by mail to praktikum-srs@uni-due.de.

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

- Modeling using automata
- Adaptive and reliable classification, able to learn
- Observers
- Nonlinear dynamics
- Power management of hybrid powertrains/ wind energy systems

Structural Health Monitoring

- Acoustic Emission
  > Sensors
  > Filters
  > Fault diagnosis
  > Prognosis
- Fault detection and fault diagnosis methods
- Wear and aging
  > Data-driven modeling
- Safe- und lifetime-oriented operation

Cognitive Technical Systems

- Knowledge-based and individualized assistence of HMS (example: driver assistance)
- Situation recognition of complex situations
- Situated automata, able to learn
- Safe actions and interactions

1.0 Frequency domain and Laplace transformation
1.0 Illustrative example

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1.0 Illustrative example

1 Frequency domain and Laplace transformation

1.1 Fourier analysis > Sum of periodic signals

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

Key idea of Fourier analysis:

$$u(t) = \sum u_i(t) = u_1(t) + u_2(t) + u_3(t) + \dots$$

$$y(t) = \sum y_i(t) = y_1(t) + y_2(t) + y_3(t) + \dots$$

$$u_1(t) \rightarrow y_1(t)\,,\ \dots\ ,\ u_n(t) \rightarrow y_n(t)$$

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

$$u_i(t) \rightarrow y_i(t) = a \cdot u_i(t + \varphi) \qquad \left.\begin{matrix} a(w) \\ \varphi(w) \end{matrix}\right\} u(t) \rightarrow y(t) = a(w) \cdot u\left(t + \varphi(w)\right)$$

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

> characteristics of periodic signals (periodicity)

$$f(t) = f(t + lT_0)\,; \quad l = 0, 1, 2, 3, \ldots$$

Period time: T_0 [s]

Frequency: $f_0 = \dfrac{1}{T_0}$ [1/s] $\rightarrow w_0 = 2\pi f_0$

Fourier theorem:

$$f(t) = \frac{A_0}{2} + \sum_{k=0}^{\infty} A_k \cos\left(k w_0 t\right) + \sum_{k=1}^{\infty} B_k \sin\left(k w_0 t\right)$$

$$A_k = \frac{2}{T_0} \int_0^{T_0} f(t) \cdot \cos\left(k w_0 t\right) \mathrm{d}t, \quad k = 0, 1, \ldots$$

$$B_k = \frac{2}{T_0} \int_0^{T_0} f(t) \cdot \sin\left(k w_0 t\right) \mathrm{d}t, \quad k = 1, 2, \ldots$$

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

> Alternative, brief description:

$$f(t) = C_0 + \sum_{k=1}^{\infty} C_k \sin(k w_0 t + \phi_k)$$

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

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

$$\phi_k = \arctan \frac{A_k}{B_k}, \quad k = 1, 2, \ldots$$

$k = 1: w_0 \rightarrow$ Fundamental wave

$k > 1: w_i \rightarrow$ Harmonic frequencies of higher order

> Division of a periodic signal with different harmonic signals I

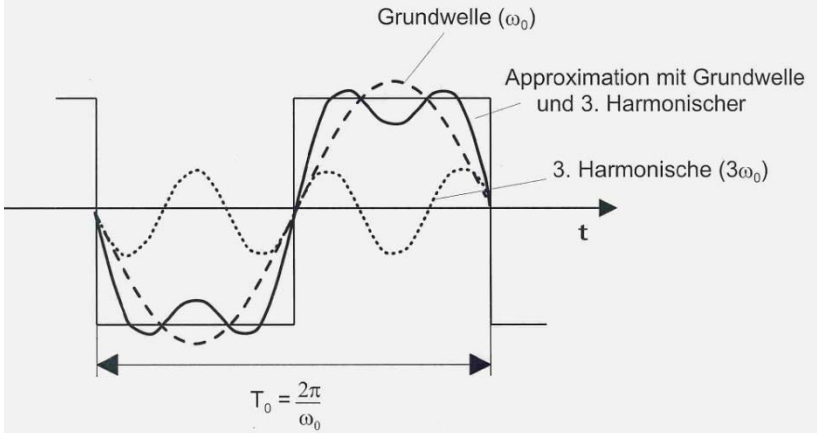


Abb. 6.1: Zerlegung einer Rechteckschwingung in Sinusschwingungen

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

$$
\begin{aligned}
f_1 &= C_1 \cdot \sin\left(w_0 t \ + \phi_1\right) \\
f_3 &= C_3 \cdot \sin\left(3 w_0 t + \phi_3\right) \\
f &= f_1 + f_3 \\
f &= f_1 + f_3 + f_5 + f_7 + f_9 + \ldots
\end{aligned}
$$

> Alternative, brief description: pointer description

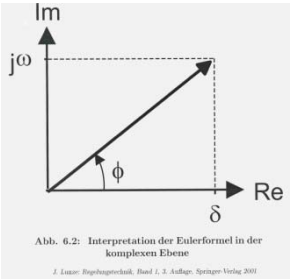


Abb. 6.2: Interpretation der Eulerformel in der komplexen Ebene

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

> Euler formula
brief description based on complex pointers

$$\delta + \mathrm{j}w = k \cdot \mathrm{e}^{\mathrm{j}\phi} = k\left(\cos\phi + \mathrm{j}\sin\phi\right)$$

$$k = \sqrt{\delta^2 + w^2}$$

$$\phi = \arctan\frac{w}{\delta}$$

$$\cos\left(kw_0t\right) = \frac{1}{2}\left(\mathrm{e}^{\mathrm{j}kw_0t} + \mathrm{e}^{-\mathrm{j}kw_0t}\right)$$

$$\sin\left(kw_0t\right) = \frac{1}{2\mathrm{j}}\left(\mathrm{e}^{\mathrm{j}kw_0t} - \mathrm{e}^{-\mathrm{j}kw_0t}\right)$$

$$\Rightarrow f(t) = \sum_{k=-\infty}^{\infty} F_k \mathrm{e}^{\mathrm{j}kw_0t}$$

$$|F_k| = \frac{1}{2}\sqrt{A_k^2 + B_k^2}$$

$$|F_k| = |F_{-k}|$$

$$\arg F_k = -\arg F_{-k}$$

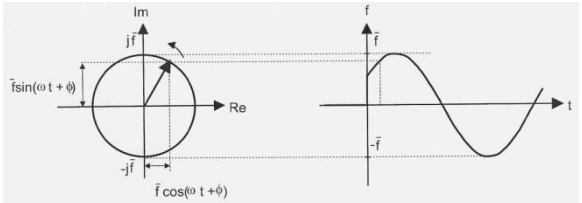


Abb. 6.3: Erzeugung der Funktion $f(t)$ durch einen rotierenden Zeiger

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

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

$$F_k = \frac{1}{T_0}\int_{t_0}^{t_0+T_0} f(t) \cdot \mathrm{e}^{-\mathrm{j}kw_0t}\,\mathrm{d}t, \quad k = 0, \pm1, \pm2, \ldots$$

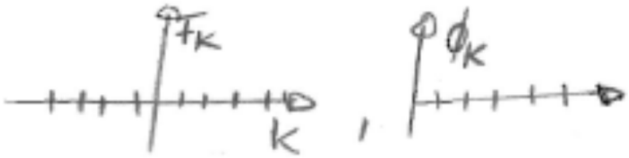
> Arbitrary (period.) signal as a sum of periodic signals

$$
\begin{aligned}
F_0 &= C_0 \\
|F_k| &= \tfrac{1}{2}|C_k| \qquad (k \geq 1) \\
\arg F_k &= \phi_k \qquad (k \geq 1)
\end{aligned}
$$

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

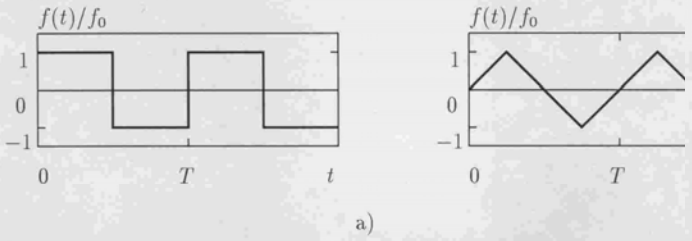
> discrete spectrum of amplitudes and phases

$|F_k|, \arg F_k \rightarrow f(T) \rightarrow$



$$
\begin{aligned}
|F_k| &= [-\infty, \ldots, +\infty] \ : \\
\arg F_k &= [-\infty, \ldots, +\infty] \ :
\end{aligned}
$$

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



a)

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

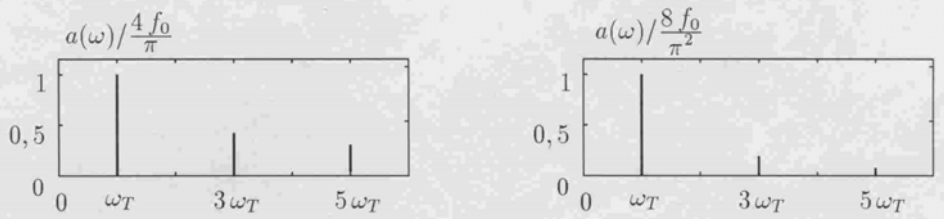
Die Fourier–Entwicklung lautet

für die Rechteckfunktion:

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

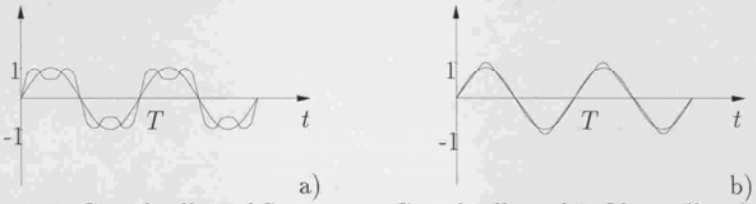
und für die Dreieckfunktion:

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



a) b)

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



a) b)

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