Teaching aspects of MATLAB and Simulink in Communications

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Abstract: Understanding various analogue and digital modulation techniques and learning their practical application plays a key role in basic higher education in communications engineering and telecommunications. In modern engineering education, it is essential that students not only have a theoretical understanding of modulation techniques but also be able to simulate, analyze, and subsequently apply them in real-world systems. The operation of communication systems is based on several physical, mathematical, and algorithmic relationships that are difficult to understand without practical examples. In recent decades, the development of simulation tools has significantly changed the methodology of engineering education. MATLAB and Simulink are among the most widely used simulation platforms in engineering education, as they combine the flexibility and multi-level nature of mathematical modelling with visualization capabilities and real-time system-level simulation. They offer unique opportunities for the practical implementation and simulation of mathematically based theoretical descriptive models, interactive modification of characteristic parameters, and visualization of complex communication transmission systems. The effectiveness of the simulation options used in basic telecommunications training can be measured by the competencies students acquire in understanding and applying the modulation forms used in telecommunications. Another similar indicator of quality characteristic may be their support for students' more profound understanding of the operation and characteristics of the basic modulation modes used in telecommunications systems. At the same time, the necessary knowledge can be effectively transferred by leveraging the software's multi-level capabilities. [1] This study provides a comprehensive overview of the methodological and didactic aspects of teaching modulation techniques within the Communication Techniques courses on the MATLAB and Simulink platforms.

Keywords: Matlab, Simulink, level-based education, didactics, methodology

1. Introduction

Understanding modern telecommunications systems is essential for engineering students. Mastering the theoretical and practical aspects of modulation techniques – which encode the information of the base signal onto a carrier in various ways – is a fundamental prerequisite for students to design and analyze real systems. The tools of MATLAB and Simulink allow theoretical concepts to be presented in a practical, visually verifiable form. The methodological approach presented in the thesis aims to enable students not only to calculate the characteristics but also to understand their physical and system-level impact. [2]

Teaching modulation techniques in telecommunications poses both theoretical and practical challenges for engineering students. The mathematical background of modulation techniques is complex, and waveforms and spectral features are often presented only as abstractions in table explanations. Therefore, it is imperative to use an educational environment that can directly visualize the practical operation, parameter sensitivity and the effects of analogue and digital modulation.

The combined use of MATLAB and Simulink is an increasingly common solution for teaching communication systems. Together, the two platforms provide integration of numerical procedures, visualization, and block-level system modelling, which facilitates the experience of the relationship between theory and practice. [3]

2. The role of Matlab and Simulink in teaching signal modulation techniques

The main strength of MATLAB/Simulink-based teaching of modulations is that students can encounter the same model at different levels of abstraction. Theoretical knowledge built on mathematical formulas can be directly mapped to numerical experiments and then to block-level system models. This multi-step approach ensures that students not only see the waveforms but also understand the underlying processes. In the following, we will review in detail the role of MATLAB in the analytical and numerical visualisation of modulations and how it helps to deepen knowledge. [4] [5]

2.1. MATLAB as a tool for analytical thinking and numerical visualisation

The MATLAB environment primarily allows for code-level, parametric control. Students can directly modify the carrier frequency, modulation index, noise floor, or signal bandwidth while simultaneously observing the waveform and spectrum.

The functions for analogue modulation (e.g., *ammod, fmmod*, *amdemod*) and digital modulation (e.g., *pskmod*, *qammod*, *fskmod*) enable rapid verification of theoretical models. MATLAB thus develops mathematical model-based thinking, where the student creates the waveforms derived from the abstraction through code. [6]

2.2. Simulink as a basic environment for system and block modelling

Simulink provides block-based visual modelling, where the data flow of a communication system becomes "visible." This approach is particularly suitable for developing systems thinking and engineering design:

- block representation of AM, FM, DSB-TC systems
- digital modulation chains (e.g. BPSK, QAM) and channel models (Rayleigh, Rician)
- real-time testing: the simulation can be run, stopped and modified.

Simulink enhances the engineering systems approach and provides capabilities for parametric troubleshooting, channel modelling, and error rate (BER/SER) analysis. [7]

3. Didactic comparison of MATLAB and Simulink

In the teaching of modulation procedures, it is crucial how students' theoretical knowledge is connected to the applied simulation tools. MATLAB and Simulink represent different learning approaches, and therefore their didactic effects are also different. While MATLAB primarily helps to establish the mathematical foundation of phenomena, Simulink develops visual and system-oriented thinking. The two approaches cannot be considered alternatives to each other, but rather complementary pedagogical tools. From the point of view of the learning process, it is less important whether the student first encounters modulation models in formulas or blocks. Numerical programming requires code-based thinking, which helps to accurately understand the mathematical model. In contrast, block simulation shows the spectacular, functional logic of the system as a whole. Based on student feedback, it is particularly motivating that the visual block diagram demonstrates the change in the signal shape and spectrum in real time. At the same time, the blocks themselves can also function as "black boxes" if they are not supplemented with the underlying mathematical knowledge. Therefore, the principle of gradual complexity is essential, on which the presented characteristics and arguments are based. [8] [9]

Applying the methodological approach in the right order ensures that the student first understands the concept of modulation and then observes its behavior with varying parameters. MATLAB's mapping capabilities are excellent for modeling the effects of carrier frequency, modulation depth, or noise. Simulink makes these effects visible at a system level, thus supporting network thinking and engineering problem solving. Code-based modeling in particular develops students' analytical skills, while block-based visualization provides a visual and intuitive learning experience. This dual development can result in a complex learning environment that simultaneously activates deductive and inductive thinking. In this way, not only the result of modulation becomes tangible for students, but also its operating logic. Methodological comparison is therefore crucial, as it helps to determine the role of an effective learning path in developing theoretical and practical competencies. The following table presents this dual approach, highlighting how MATLAB and Simulink contribute to the development of different dimensions of modulation knowledge. The comparison presented does not only focus on technical differences, but also extends to the shaping of student thinking. This allows us to examine how the simulation environment helps deepen knowledge, reflective thinking and independent modeling. Taking all this into account, it can be stated that the following didactic table juxtaposes not just tools, but pedagogical strategies. [10] (Table 1)

Table 1

Didactic comparison of Matlab and Simulink platforms

Aspect	MATLAB-based education	Simulink-based training
Cognitive focus	Analytical thinking, mathematical abstraction	Systems approach, visual logic
Interactivity	Parametric, code-based manipulation	Real-time, graphical modification
Handymanship type	accurate modeling in code	block connections and data flow
Student activity	code development, use of own functions	block modeling, parameter experimentation
Theory–practice relationship	mathematical comparison	visual inspection of spectrum and constellation
Motivation	gives competence, but can be abstract	a working system experience, a strong motivating element

The effectiveness of learning can be achieved at an optimal level if the use of the two environments is linked to each other in a gradual complexity. The correct didactic sequence for the level-based methodology of teaching modulation techniques can be achieved in the following steps:

- Basic level (Applying MATLAB code with AM, FM formulas, then built-in functions)
- Intermediate level (Simulink blocks in AM DSB-TC, FM block-based modeling)
- Advanced level (Hilbert-transformed analytical signal analysis)
- Digital modulation branch (BPSK, QAM, BER, constellation diagrams)

This hierarchical structure gradually leads from mathematical abstraction to the intelligence-based approach of engineering systems thinking. In parallel, competence development also plays a role as a pedagogical added value. At the same time, MATLAB–Simulink-based education creates a complex learning environment that can simultaneously develop the

- integration of theoretical knowledge (understanding mathematical models),
- practical problem solving (system-level modeling),
- creative thinking (parametric experiments, independent models).

The condition for this is a clear demonstration of the instructor's role, meaning that the student should not only run the codes, but also explain and evaluate what they sees, why and how the shape of the signal or the constellation image of the signal form changes.

Summary

Teaching modulation procedures in MATLAB and Simulink environments provides the following learning curve:

- theoretical understanding → mathematical formulation → simulation validation → system design experience
- develops analytical and visual thinking together
- creates a motivating, interactive and debugging-friendly environment.

The two platforms can work effectively by complementing rather than replacing each other.

Conclusions

MATLAB–Simulink-based education provides a space for testing theory while shaping a high-level engineering perspective. The key to methodological success is gradual complexity and reflective feedback, where the student is not a passive participant but an active interpreter. The didactic demonstration of modulations thus integrates scientific modeling and engineering design in a unified educational framework. Traditional lecture-based education often does not provide enough interactivity and realism to allow students to intuitively grasp the spectral and temporal behavior of modulations. The combination of Simulation-Based Learning (SBL) and project-based education is a powerful tool for teaching complex systems. The MATLAB/Simulink platform can be integrated into courses so that lab tasks are built gradually, starting from the basics (AM/FM) to complex systems (OFDM, MIMO, and channel estimation). [11] [12]

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