

Theory, Practice, and Systems—A New Approach to Teaching Electronic Communications with MatLab*

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Two important aspects of training future engineers are a thorough understanding of the theories behind engineering problems, and practical experience in implementing solutions to these problems. Theoretical knowledge can be best comprehended and acquired from a systems perspective. Experiential knowledge of engineering implementation and problem-solving can be best understood and obtained through practical data. Because of its strong computational and modeling capabilities, MatLab is an excellent tool to help engineering students further their theoretical and practical knowledge in the context of engineering systems. In this paper, we propose a new method of teaching the 'Introduction to Electronic Communications' course from a systems perspective using MatLab.

INTRODUCTION

DURING the past decade, MatLab has become a predominant simulation tool for engineering education. It has mainly been used to enhance and consolidate students' understanding of engineering theory through simulation. In industry, MatLab has also become a powerful verification tool to analyze design concepts. This is especially true in communications engineering. Because MatLab is a model-based simulation tool for practical applications, it is imperative to utilize this tool as a bridge to connect theory and practice in communications engineering. To achieve this goal, the most effective way is to teach communications courses with the 'systems approach'.

The systems approach is a method of teaching communications theories from a systems perspective. It focuses on how a signal is processed in each communications block within the system, rather than cover various modulation schemes and receiver structures as has been done traditionally. The systems approach only uses FM and QPSK to illustrate communications concepts such as occupied bandwidth and to exemplify how a signal is processed in each block and the significances to the performance of communications systems. Detailed description of this approach can be found in [1].

Within the context of teaching communications systems, MatLab is used as a tool to augment effectiveness of teaching and learning. However, students are not completely convinced by pure MatLab simulations. Using MatLab to analyze real-world data, and comparing the results with

lab results can further help the students bridge the gap between theory and practice [2].

This article discusses a method of using MatLab as a tool to connect the students' classroom theory experience and their lab practical experience. The novelty of this approach is reflected from the following two aspects:

1. Use lab-captured data for MatLab analysis. This allows the students to use their lab experience as a reference to match mathematically processed or simulated results. Consequently, the students gain better understanding of communications theories taught in classes.
2. Because MatLab analysis is performed with real-world data, the results can be used to help solve issues in practical design implementation of communications systems.

USING MATLAB TO ILLUSTRATE COMMUNICATIONS THEORY

Somewhat simplified transmitter and receiver functional blocks of a typical communications system are shown in Figs 1 and 2. In our approach, data is gathered from each block and used as inputs for MatLab analysis. With the help of MatLab, most of the communications theories can be introduced more effectively. In this section, we demonstrate how MatLab can be used to teach theoretical concepts of bandwidth.

It has been observed that the concept of bandwidth is relatively hard for students to understand because of various definitions and the complicated nature of this concept. There are eight different definitions of bandwidth in [3] and some of them

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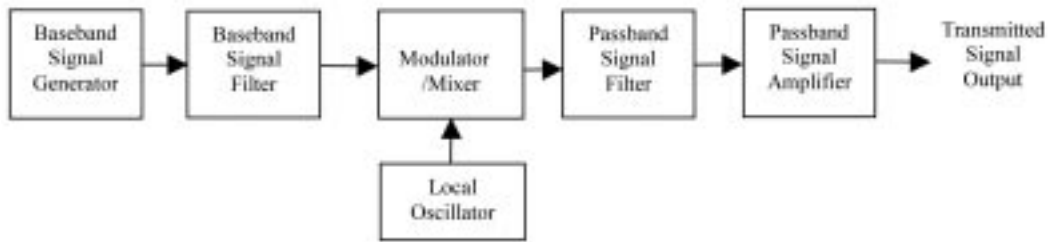


Fig. 1. Transmitter blocks of a typical communications system.

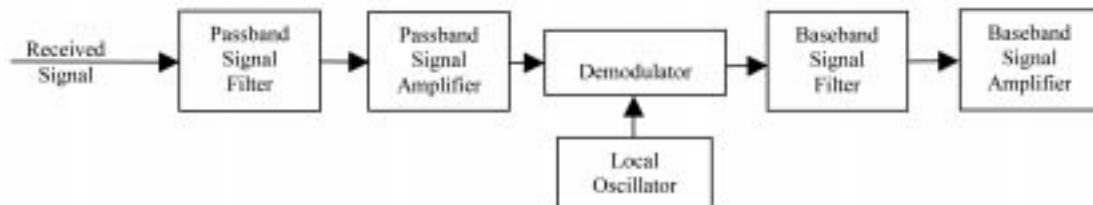


Fig. 2. Receiver blocks of a typical communications system.

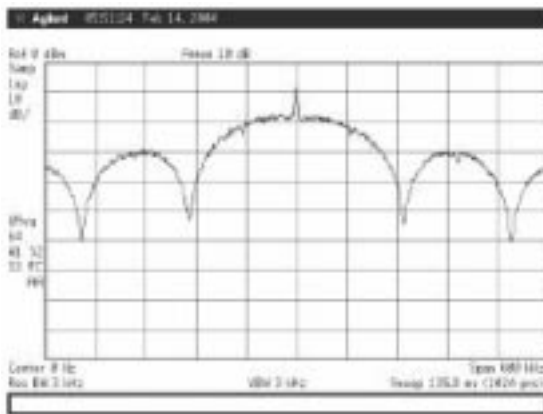


Fig. 3. Lab captured null-to-null bandwidth.

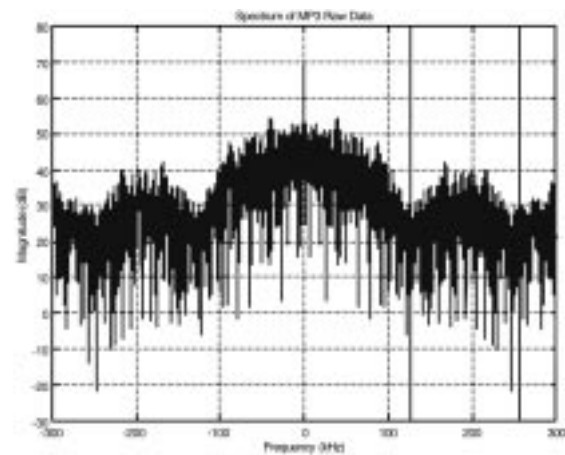


Fig. 4. MatLab simulated null-to-null bandwidth using fast Fourier transform.

are purely mathematical and too abstract for students to understand. In our approach, we put various definitions under different communication blocks. Time-domain waveforms are captured at different blocks and used as inputs to MatLab for simulation. The simulation results are then compared with the lab results captured by a spectrum analyzer.

For example, 'null-to-null bandwidth' gives a theoretical definition of bandwidth while 'fractional power containment bandwidth' gives a more practical definition of the concept. In our systems approach, these two concepts are introduced at different blocks of the communications system: null-to-null bandwidth is introduced at the output of the message generator as shown in Fig. 1, and fractional power containment bandwidth is introduced at the output of the baseband signal filter shown in Fig. 1. Spectrum analyzer captured results are compared with MatLab simulated results using waveform data captured by an oscilloscope. These results are shown in Figs 3 to 6.

This approach also provides two bonuses that a traditional teaching method is hard to achieve:

- The match between the simulated and practical results strengthen students' theoretical understanding of bandwidth and signal spectrum.
- Because the simulated spectrum is obtained through Fast Fourier Transform (FFT) of lab captured time domain data, it furthers students' understanding of the relationship between time domain signal waveform and its frequency domain representation of power spectrum. This helps students better grasp the mathematical implication of FFT.

PROBLEM-SOLVING USING MATLAB

When implementing a communications system, there are some practical issues associated with system design and implementation. Some of issues can be hard for an apprentice engineer to solve. This section gives an example of how to use MatLab as a tool to guide the students' design/experimentation process, and how to use

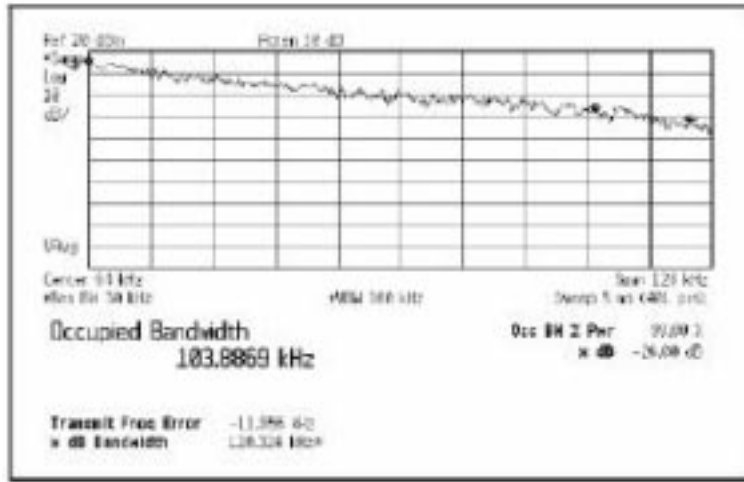


Fig. 5. Lab captured fractional power containment bandwidth.

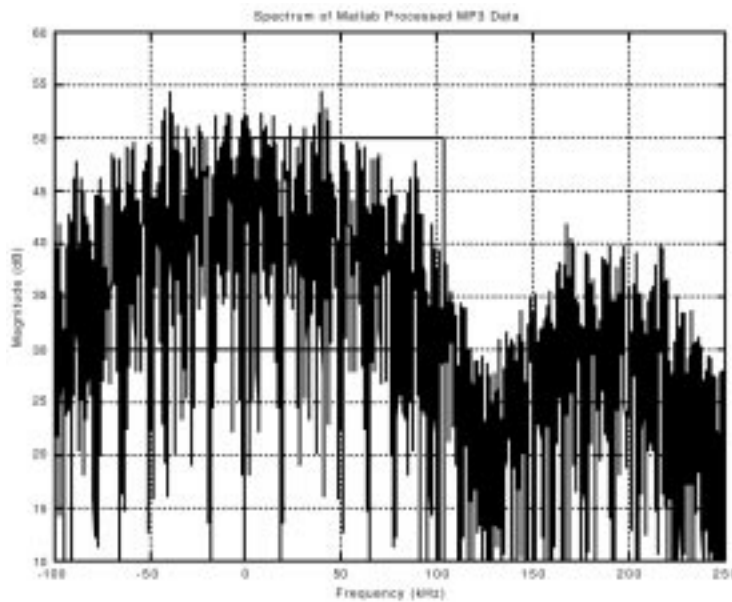


Fig. 6. MatLab simulated fractional power containment bandwidth.

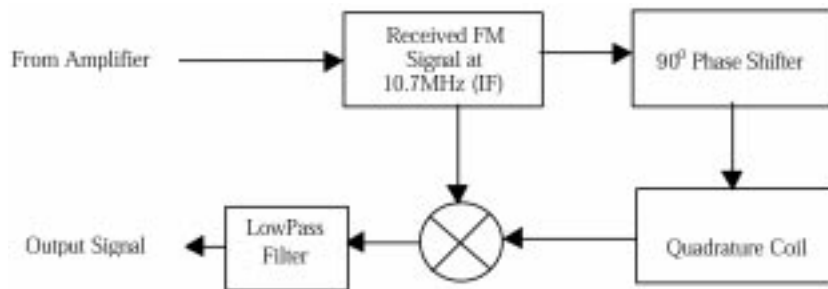


Fig. 7. Block diagram of a quadrature detector.

the simulated results to solve practical implementation issues.

The implementation issue is posed from a system performance perspective and is described as follows: the experimental setup uses FM to transmit MP3 digital music. The FM receiver uses a quadrature detector for FM demodulation

as shown in Fig. 7 [4, 5]. The intermediate frequency (IF) is set at 10.7 MHz. The structure and theory of operation of a quadrature detector were introduced in the classroom, which are detailed in [2]. By deliberately offsetting the 90° phase shifter caused a receiver sensitivity loss of 1.5 dB. Figure 8 shows the original MP3 waveform

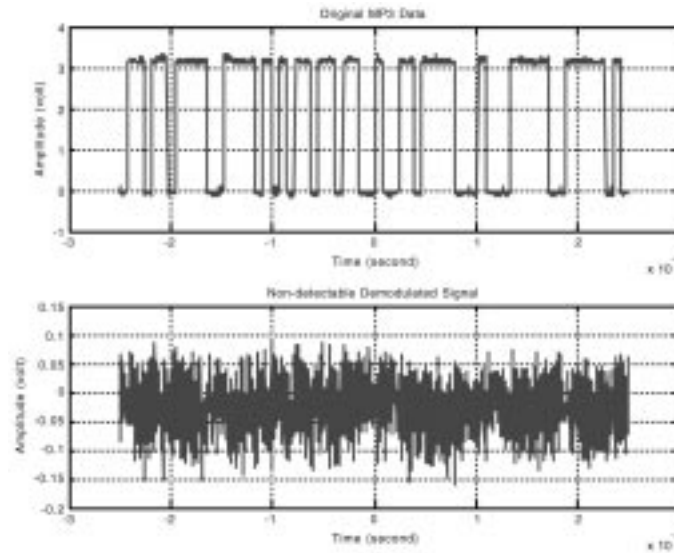


Fig. 8. Non-detectable MP3 data with modified phase shift network.

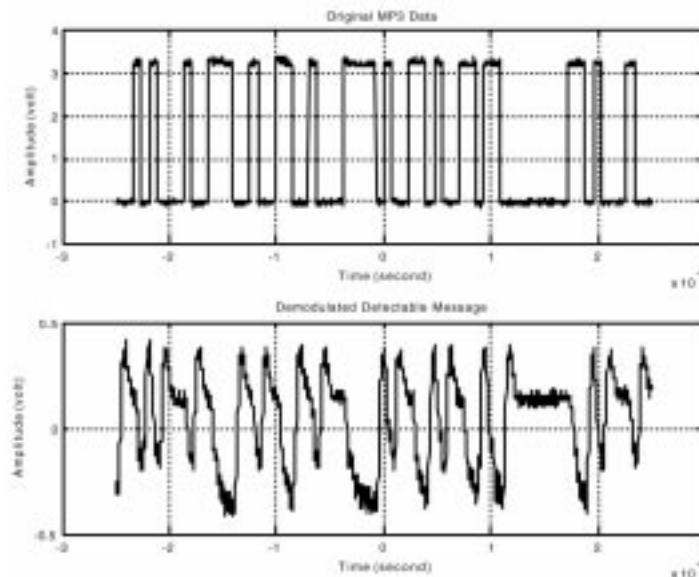


Fig. 9. MatLab demodulated MP3 message signal.

and the demodulator output with modified phase shifter network. It is observed that the output in Fig. 8 is no longer detectable.

When the signal is undetectable, the received FM signal before the phase shifter is captured with an oscilloscope, which is the output of the pass-band signal amplifier as shown in Fig. 2. This experimental waveform is used as the input to MatLab for simulation. The 90° phase shifter can be precisely simulated in MatLab by taking the imaginary part of the Hilbert transform of the received signal. The phase characteristics of the quadrature coil are captured using a network analyzer. The phase-frequency response of this quadrature coil can be applied in MatLab as follows: simply use the $\text{filter}(b, a, r_{x2})$ function, where b is the phase response of the quadrature coil, r_{x2} is the 90° phase shifted IF signal, and

$a=1$. Through this operation, the additional phases that correspond to FM instantaneous frequencies that correspond to FM instantaneous frequencies can be added to the modulated experimental signal captured earlier. It is worth noting that the MatLab function 'filtfilt' should not be used here because this command ignores any additional phase shift that is added to the signal by the quadrature detector.

Use multiplication in MatLab to mix the original FM signal with the signal obtained from above. This simulates the demodulator block shown in Fig. 2. The output of the mixer is then filtered by a low pass filter, and the output of the lowpass filter is the desired message signal. The demodulated message signal is shown in Fig. 9. It is seen that the MP3 music signal is successfully demodulated using MatLab. It is obvious from Fig. 9 that the demodulated signal has a very low

amplitude. Without sufficient sensitivity, the hardware was not able to demodulate this signal. However, with the experimental data and the ideal environment in MatLab (90° phase shift), the message is successfully demodulated.

Because our MatLab simulation uses experimental data (the received signal, the phase response of the quadrature detector), and the only difference between the hardware and the simulation is the 90° phase shifter (where MatLab used an exact 90° phase shift via Hilbert transform), the simulated results help the students investigate the phase shifter hardware and eventually solve the sensitivity issue.

From this practice, the following pay-off can be expected:

- Students will be able to investigate system performance parameters and find potential system blocks where problems are generated.
- Students will be able to use MatLab as an analysis and guided-design tool to solve practical system problems by comparing simulation results to lab experimental results.

CONCLUSIONS AND FUTURE WORK

The proposed new method of teaching an introductory course to electronic communications takes a systems approach with the emphasis on the functionality of communications system blocks. MatLab is used as a tool to introduce important communications theories and as a guide to solve practical system implementation issues. One important key of this approach is to use lab captured experimental data as inputs for MatLab analysis which improves students' understanding of theories and problem-solving skills. Utilizing this new way of teaching communications systems with MatLab, the following goals are achievable:

1. Helps students understand communications

concepts from a systems perspective more effectively.

2. Improves understanding of functionality, design, and related issues concerning communication system blocks.
3. Helps consolidate student knowledge in electronic circuits and their applications in communication systems.
4. Improves understanding of the issues caused by the interconnection of communications blocks.
5. Helps students understand and consolidate their theoretical knowledge by using practical data.
6. Helps extend student abilities to use theories and simulation results as a guide for practical implementations of engineering designs.

Assessment plan for this teaching approach is also an important part of this project. This teaching method was implemented in a one-semester course titled 'Electronic Communications Fundamentals'. Preliminary implementation of this method has shown potential positive impact on students' learning activities of communications theories using MatLab in conjunction with lab experiments. Taking into account that this course is only offered once a year, and most students taking this course are not proficient in MatLab programming, more time is needed to collect data and measure the effectiveness of this approach.

Implementation of this method to teaching an introductory communications course is just a start. More effort is needed to make this method more efficient and more effective. Currently, experimental data are captured using lab equipment such as oscilloscope, spectrum analyzer, and network analyzer. These data are called into MatLab manually. Future work will include integration of other data acquisition tools such as LabView[®] to improve the efficiency of this new teaching method. Furthermore, more integrative and innovative labs need to be developed to improve effectiveness of this teaching method.

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