

Modelling and Simulation of Frequency Modulated Radio Channel Using Matlab and Simulink

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Abstract—This research presents a step by step approach in modelling and simulation of Frequency Modulated (FM) radio channel using MATLAB and SIMULINK. FM radio channels are designed to allow carrier frequencies between 88 and 108MHz. Building Frequency modulated radio channels is quite a demanding task. This is because hit and trial experimentation are too costly and problems encountered in such designs looks too complicated to be analyzed. Buying the real network devices and tools required to establish or deploy a complete system is very costly. To overcome these problems, researchers and software engineers developed different system simulation tools that can help design and simulate a complete network system before embarking on the actual prototype. The results obtained from the simulated models prove the capability of MATLAB and SIMULINK as a tool for adequately predicting performance and behaviour.

Keywords—Frequency, Channel, MATLAB, SIMULINK, Modulation, Radio

I. INTRODUCTION

In radio communication, Frequency modulation (FM) is the method of conveying information over a carrier wave by varying its frequency. This method is widely used in telecommunication devices to transmit voice without disturbances. In analogue applications, the instantaneous frequency of the carrier is directly proportional to the instantaneous value of the input signal. Digital data can be sent by shifting the carrier's frequency among a set of discrete values, a technique known as frequency-shift keying [1].

FM radio is one of the most prevalent forms of media communication in the world today. As listeners all over the world continue to buy and use FM radios, designers for portable devices such as MP3 players and mobile phones are increasingly including FM radio capability in their products. Understanding the basics of FM radio will assist designers in creating high performance products, be it traditional standalone radios, next-generation, or multi-use devices.

FM channels are designed to allow carrier frequencies between 88 and 108MHz, each radio station is assigned 200 KHz, to transmit a stereo audio. The left and right channels (each limited to 15 KHz) are multiplexed into a single baseband signal using amplitude modulation. FM frequency is widely used in telecommunication devices to transmit voice without disturbances [2][3].

Building Frequency modulated radio channels is quite a demanding task. This is because hit and trial experimentation are too costly and problems encountered in such designs looks too complicated to be analyzed. Buying the real network devices and tools required to establish or deploy a complete system is very costly [4]. In such situation, there is an urgent need to look at alternative method of design which will not only preserve the existing facilities, but also lessen the huge effort exhausted in design of the system and testing of the results [4]. System modelling and computer simulation of the real physical systems offer a better choice. System simulators enable researchers, network administrators, and other interested users to test new network technologies and protocols before using them on real networks; thus, saving a lot of time and money.

The history of computer simulation dates back to World War II when two mathematicians Jon Von Neumann and Stanislaw Ulam were faced with the puzzling problem of behavior of neutrons. Hit and trial experimentation were too costly and the problem was too complicated for analysis. Hence, the Roulette wheel technique was suggested by the mathematicians. The basic data regarding the occurrence of various events were known, into which the probabilities of separate events were merged in a step by step analysis to predict the outcome of the whole sequence of events. With the remarkable success of the techniques on neutron problem, it soon became popular and found many applications in the business and industry [5].

Today simulation is an important domain which attracts many researchers from several fields and disciplines [6].

Simulation software is based on the process of modelling a real phenomenon with a set of

mathematical formulas. It is essentially, a program that allows the user to observe an operation through simulation without actually performing that operation. Simulation software is used widely to design equipment so that the final product will be as close to design specification as possible without expensive process modification [7]. Simulation has proven to be a powerful tool in modelling a complete communication channels before embarking on the real prototype. In recent years, extensive research has been conducted in the area of simulation to model large complex systems like FM and understand their structures and behaviors. At the same time, a variety of design principles and approaches for computer-based simulation have evolved. As a result, an increasing number of computer simulation sub-fields and approaches have been proposed, as well as a large number of tools and applications having been designed and developed. The benefits of computer simulation are becoming more generally recognized in several domains and areas.

Some of the computer software packages usually used by Engineers for analysis and simulation of physical systems include: MATLAB/SIMULINK, RMxprt/Maxwell2D/3D, SIMPLORER, HFSSV10, XFDTD/Varipose/XGTD, COMSOL, 5SPICE, ANSYS, Electronic Workbench etc. The availability of these computer software packages is now reshaping the role and applications of computer laboratory projects to involve students in more intense problem-solving experience [8]. These user programs also provide an opportunity to easily conduct numerical experiments and to tackle realistic and more complicated problems.

In this research, we studied Frequency Modulated radio channel, modeled and simulated it using MATLAB and SIMULINK tools to predict adequately its performance and behavior.

II. MODELLING AND SIMULATION CONCEPTS

Modern engineering would be inconceivable without computers to gather data and run model simulations. Whether it involves bringing back pictures of the surface of the planet Mars or detailed images to guide brain surgeons, computers have greatly extended our knowledge of the world around us and our ability to turn ideas into engineering reality. Modelling is the process of generating abstract, conceptual, graphical and/or mathematical models. Science offers a growing collection of methods, techniques and theory about all kinds of specialised scientific modelling. A model in general is a pattern, plan, representation (especially in miniature), or description designed to show the main object or workings of an object, system, or concept. Simulation is used in different ways by different people. As used here, simulation is defined as the process of creating a model (i.e., an abstract representation or exact copy) of an existing or proposed system (e.g., a project, a business, a mine, a forest, the organs in your body, etc.) in order to identify and understand

those factors which control the system and/or to predict (forecast) the future behaviour of the system. Almost any system which can be quantitatively described using equations and/or rules can be simulated.

The underlying purpose of simulation is to shed light on the underlying mechanisms that control the behaviour of a system. More practically, simulation can be used to predict (forecast) the future behaviour of a system, and determine what you can do to influence that future behaviour. That is, simulation can be used to predict the way in which the system will evolve and respond to its surroundings, so that you can identify any necessary changes that will help make the system perform the way that you want it to. Thus modelling and computer simulation are important interdisciplinary tools.

A. Reasons For Computer Simulation

Gaines in [9] stated a number of good reasons for using computer simulation as a problem-solving tool. In the following points, we list the main reasons:

(1) The physical system is not available : Often, computer simulations are used to determine whether or not a projected system should ever be built; so obviously, experimentation is out of the question. This is common practice for engineering systems (e.g., an electrical circuit) with well-established and widely applicable meta-knowledge. It is rather risky to rely on such a decision in the case of systems from soft science (the so-called ill-defined systems) since the meta-knowledge available for these types of systems is usually not validated.

(2) The experiment may be dangerous : Often, simulations are performed in order to find out whether the real experiment might 'blow-up', placing the experimenter and/or the equipment under danger of injury/damage or death/destruction (for example, an atomic reactor, or an aircraft flown by an inexperienced person for training purposes).

(3) The cost of experimentation is too high : Often, simulations are used when real experiments are too expensive. The necessary measurement tools may not be available, or are too expensive to buy. It is possible that the system is used all the time, and taking it 'off-line' would involve unacceptable cost.

(4) The time constants of the system are not compatible with those of the experimenter : Often, simulations are performed because the real experiment executes so quickly that it can hardly be observed (for example, an explosion), or because the real experiment executes so slowly that the experimenter is long dead before the experiment is completed. Simulations allow us to speed up or slow down experiments at will.

(5) Control variables, and/or system parameters may be inaccessible : Often, computer simulations are performed because they allow us to access *all*

input (variables), whereas, in the real system, some inputs may not be accessible for manipulation.

B : Stages in simulation

Fig.1 below shows a generic stages in the simulation research process.

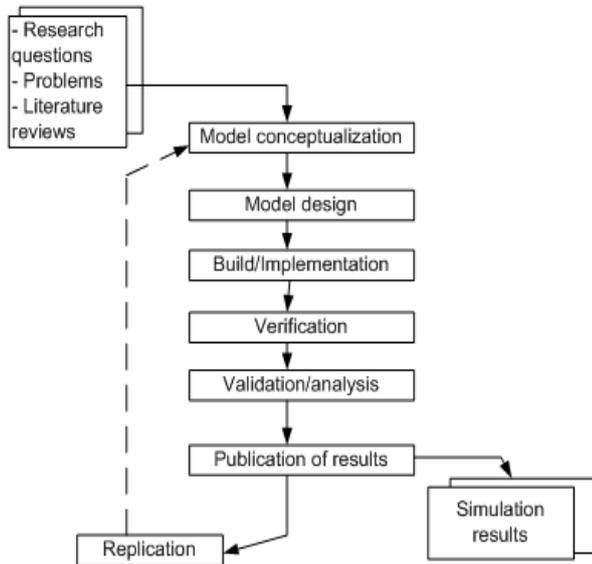


Fig. 1 : A generic stages in the simulation

The stages of the process are the following:

- **Model conceptualization:** Once a 'puzzle' (a question or problem whose answer is not known), is identified, conceptualization consists of defining and scoping the target (or problem area) for modeling. This stage may also include some observations of the target, in order to provide parameters and initial conditions required for the model.

- **Model design:** Involves making decisions about the type of overarching simulation approach to be followed (e.g., participatory or 'user-centered', conventional or 'researcher-centered', etc.); what to omit and what to include in the simplified version of the target to be modelled (model specification); the assumptions, selection of a software and hardware platform, etc.

- **Model construction or build:** This stage refers to the activities involved in writing and testing the computer-based programs necessary to implement the model.

- **Verification:** This stage is concerned with the correctness of the transformation from the abstract representation (the conceptual model) to the program code (the simulation model). That is, with ensuring that the program code faithfully reflects the behavior that is implicit in the specifications of the conceptual model.

- **Validation/Analysis:** While verification concerns whether or not the program is working as the researcher expects, validation considers whether or not the simulation is a good model of the target. A

model that can be relied upon to reflect the behavior of the target can be considered 'valid'. Validity refers to two aspects: a) 'internal validity', which concerns the correspondence between the theoretical or abstract model to be simulated, and the implementation; and

b) 'external validity', or the degree to which the model and simulation correspond to the real world.

- **Publication of results:** The final stage is the sharing, or publication, of results. This signifies, putting the results of the research into a format ready for consumption by the scientific or the practitioner community, or both (e.g., presenting the research at conferences, publishing in a paper, or electronic based journal, on the Internet, etc.).

- **Replication :** Replication involves confirming that the claimed results of any given simulation are reliable, in the sense that they can be reproduced by anyone starting from scratch. Ideally, published simulations should be presented in sufficient detail for this to be achieved.

III: FREQUENCY MODULATION

In angular modulation, the angle of the carrier signal is varied according to the amplitude of the message (modulating) signal. Angular modulation consists of the Frequency Modulation and Phase Modulation. The time domain representation of an angle modulated signal can be expressed as:

$$S(t) = A_c \cos(\theta_i(t)) \quad (1)$$

In the FM modulation technique, the frequency of the carrier signal is modulated in proportion to the baseband signal. In other words, the frequency of a modulating signal is used to directly vary the frequency of a carrier signal. Bearing in mind that an angle modulated signal $S(t) = A_c \cos(\theta_i(t))$, then for FM signal, $\theta_i(t)$ is given by $\theta_i(t) = 2\pi f_c t + \beta \int m(t) dt$.

Then a Frequency modulated (FM) signal is given by:

$$S(t) = A_c \cos(2\pi f_c t + \beta \int m(t) dt) \quad (2)$$

where $m(t)$ is the modulating signal, A_c and f_c are the carrier amplitude and frequency respectively, and β is a frequency modulation index. Depending on the value of β , FM can be either narrowband or wideband. For a small value of β ($\beta \ll 1$), FM is known as Narrowband and for a large value of β ($\beta \approx 1$), it is known as a Wideband.

A. Demodulation of FM

From equation 2, we know that the FM modulated signal is:

$$S(t) = A_c \cos(2\pi f_c t + \beta \int m(t) dt) \quad (3)$$

Then, this signal can be demodulated by finding the derivative of the modulated signal, $s(t)$ [10], and then passed through an envelope detector to produce the desired output [11].

B. MATLAB Model for Frequency Modulation

Assuming that a message signal with a frequency of 1Hz, carrier frequency of 10 Hz and the constants $\beta = 5$ are used, we will now consider how MATLAB and SIMULINK can be used to model the frequency modulation system discussed above. In this model a built-in filter called Butterworth is used. The FM signal is formed based on equation 2. In this process, the integral of the message signal is added to the carrier angle to alter the carrier signal. On the other hand, on the receiver side the modulated signal is differentiated and passed to envelope detector followed by a low-pass filter. Figure 2 below shows the MATLAB model for Frequency Modulation

```

clear;
clear all;
close all;

fc = 10; fm = 1;
tp = [0:0.001:10]';
message = cos(2*pi*fm*tp); % Modulating signal, fm is message frequency
fm = cos(2*pi*fc*tp + 5.*sin(2*pi*fm*tp)); % FM is Modulated signal

figure(1);
subplot(3,1,1)
plot(tp, message);
title('Original Signal');
xlabel('Time');
ylabel('Amplitude');

subplot(3,1,2)
plot(tp, fm);
title('FM Signal');
xlabel('Time');
ylabel('Amplitude');

dy = diff(fm)./diff(tp);
xd = tp(2:length(tp)); % Backward difference tp values
subplot(3,1,3)
plot(xd,dy)
title('Signal after Differentiator');
xlabel('Time');
ylabel('Amplitude');
grid on;
%
figure(2);
envelope = abs(dy);
subplot(3,1,1)
plot(xd, envelope);
title('Rectified Signal');
xlabel('Time');
ylabel('Amplitude');
grid on;

% Low Pass filter
cutoff_f = 6; fs=1000;% cutoff frequency
k = cutoff_f/(fs/2); % normalized cut off frequency
[b1,a1] = butter(2,k, 'low'); % Butterworth Low pass filter
output = filtfilt(b1,a1,envelope); % Filtered signal

subplot(3,1,2)
plot(xd, output);
title('Demodulated Signal');
xlabel('Time');
ylabel('Amplitude');
grid on;
    
```

Figure 2: MATLAB Model for Frequency Modulation

C. SIMULINK Model for Frequency Modulation

Different SIMULINK blocks are included to form the complete model for an FM system. In this model, a simple MATLAB code shown below is used as input to SIMULINK. This code provides the carrier angle and message signal to the SIMULINK block.

Figure 3 shows the SIMULINK model of Frequency Modulated channel

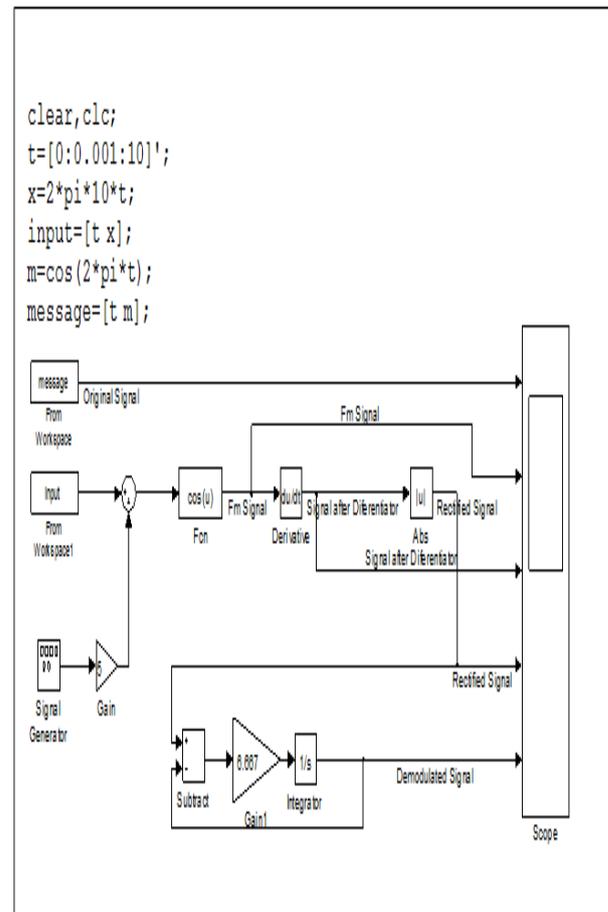


Fig3. SIMULINK Block diagram for FM channel

IV. SIMULATED RESULTS AND DISCUSSIONS

We have designed a Frequency modulated channel using MATLAB and SIMULINK. In modelling the channel, similar parameters have been used in both tools. In each tool, the integral of the message signal was used to modulate the frequency carrier signal. The modulated signal was passed through a differentiator followed by the envelope detector and then to a low-pass filter to produce the desired demodulated signal. As a result, the outputs are identical. The difference we can observe is the low-pass filter used in the MATLAB version. In the MATLAB model, a built-in low pass filter called Butterworth is used to filter the signal after rectification. The reason for using a built-in filter with the MATLAB version is that the numerical differentiation is found to be difficult to solve in MATLAB as compared to SIMULINK. This is because; the built-in function called diff computes differences between elements in an array [12]. However, the function that solves the ODE provides scalar values. Figure 4 and 5 below shows the relationship between the message signal, carrier signal, modulated signal, and FM signal, after differentiator and the final output in MATLAB and SIMULINK respectively.

V. CONCLUSION

In this research, we have demonstrated the basic utility of MATLAB and SIMULINK as a modeling and simulation tool using modulation/demodulation methods as case studies. We carried out this study in the context of a FM modulated channel. MATLAB and SIMULINK have got rich libraries and built-in functions that can be used to ease the whole modeling process. For example, when we consider SIMULINK, if we know how to configure different parameters for each block in the system, it needs less energy and time to build the whole system as compared to hit and trial experimentation always encountered by our various system designers.

Therefore, in order to mitigate the notion of try and error encountered during design, designers of frequency modulated radio channels should take advantages of MATLAB and SIMULINK as a modeling and simulation tool.

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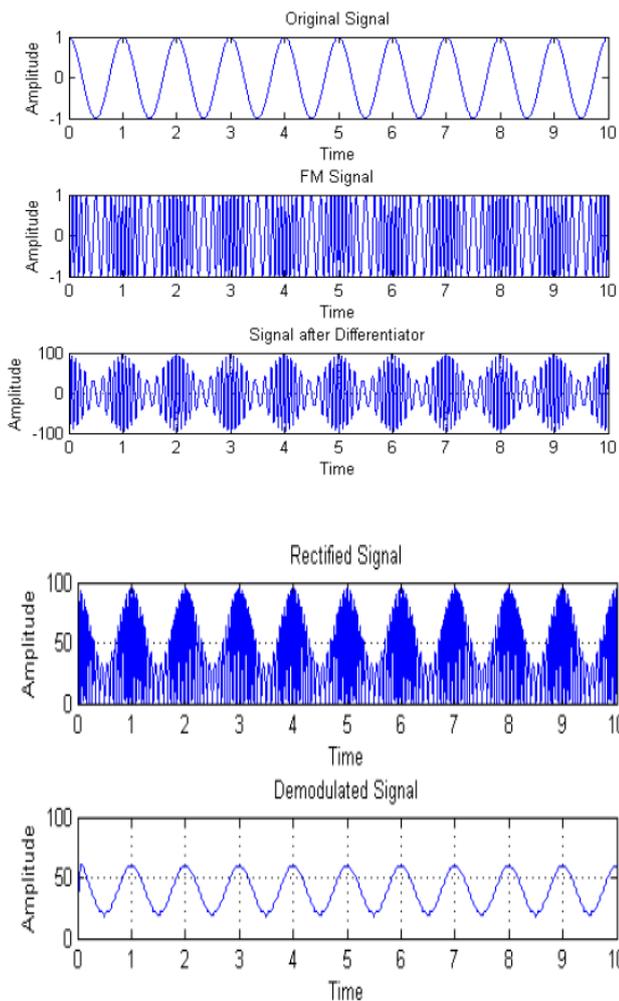


Figure 4: Output of the MATLAB Model for Frequency Modulation

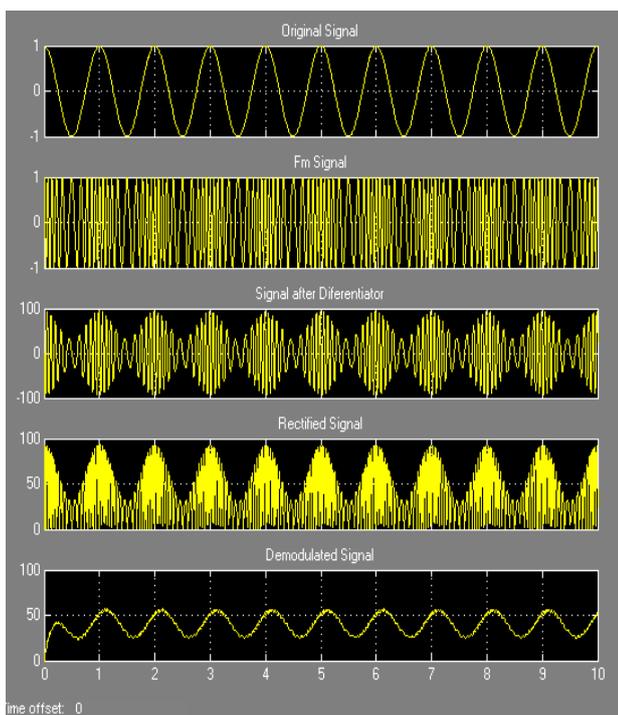


Figure 5: Output of the SIMULINK Model for Frequency Modulation