Digital simulation in the teaching of telecommunication system engineering

by
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I. Introduction

ONE problem encountered by telecommunication engineering graduates in their first experience of the telecommunication systems industry lies in the difficulty of analysing and/or designing systems which factor in the greatest possible number of variables for producing alternative solutions to specific physical situations. Two possible ways of dealing with this problem are simulation—digital, analogue or hybrid—and the development of laboratory prototypes.

Both these solutions are valid from the standpoint of training future engineers. At least two difficulties arise, however, as systems become more complex: it is harder to analyse and/or design them because of the growing number of parameters and variables that have to be taken into account in approximating the real situation, while training centres are not usually well enough endowed to subsidize the development of prototypes or models that can cope with the widening range of telecommunication systems.

This article discusses an alternative approach consisting in digital computer simulation and its inclusion in the instruction curriculum for the analysis and/or design of telecommunication systems.

As will be seen from what are regarded as some of the most useful works on transmission systems [1-3], the use of computers as an aid to the teaching of telecommunication engineering dates from the 1970s.

This paper begins with a justification of the uses of digital simulation and highlights its advantages over the method involving the development and handling of methods.

Section III contains a brief commentary on the methodology for planning experiments that can be conducted by digital simulation.

Section IV deals with aspects of the software simulation techniques applied to the specific case of digital transmission systems.

A simple experiment is discussed in section V, in which it is suggested that greater complexity can be simulated not only for a very modest investment in time and money but to the advantage of the educational system itself by improving the cost/benefit ratio of the equipment used in training graduates in telecommunication systems.

II. Importance of digital simulation in teaching

In itself, the use of digital simulation, i.e. *a digital technique for conducting experiments with a digital computer, minicomputer or micro-computer—which requires certain types of logic and mathematical models describing the performance of a system or some of its components over extensive periods of time,* [4] does not exhaust the necessary objectives of organized training in telecommunication systems.

Some of the following should also be taken into account in training a systems engineer:

— developing his ability to *seek interrelations* between the different component parts of the system;

— enhancing his capacity *for understanding the context* within which any system has to be defined;

— improving his skill at breaking down a system *bearing in mind the hierarchical relationships* between its constituent parts;

— expanding his capacity to *generate different alternatives* to enable him to take a decision or solve a specific problem.

Although these are not the only skills to be developed, they lend themselves perfectly to improvement by means of a tool as powerful as digital simulation; proof of this is to be seen in the current interest in software engineering. [5]

The scientific and technical training of a graduate as a future designer is usually based on a learning process applying the conventional step-by-step method:

1. observation of the physical system (reality);

2. formulation of a hypothesis to explain the observations made on the system;

3. prediction of the system's performance from the hypothesis by logical or mathematical deduction, i.e. by deriving solutions from (a) mathematical model(s);

4. conducting experiments to test the hypothesis or mathematical model.

Sometimes, however, it is inconvenient to follow these four steps in view of the difficulties involved. In such cases, digital simulation may be regarded as a satisfactory substitute for some of the steps described.

What are the reasons supporting these claims in favour of digital simulation? There are at least three outstanding ones, namely:

a) it may be extremely costly to observe certain transmission systems in real life (e.g. radiocommunication systems);

b) the system observed may be too complex to be described in terms of a system of mathematical equations offering analytical solutions suitable for prediction;

c) even when a mathematical model can be formulated to describe a system, it may not be possible to obtain a solution from the model by direct analytical techniques nor, consequently, to predict the system performance.

These are not the only reasons, nor are they exhaustive. The following may also be quoted:

1. digital simulation makes it possible to study and experiment with the complex interactions occuring within a given system;

2. detailed observation of the system simulated leads to a better understanding of the system and offers suggestions for improving it which could not otherwise be obtained;

3. digital simulation can instil a basic knowledge of theoretical analysis, statistical analysis and decision-making in turn;

4. the experience gained in designing a simulation model with a computer may be more useful than the actual simulation. The knowledge acquired in designing a simulation study often suggests changes in the system. The effects of such changes can be demonstrated by simulation before the changes are actually introduced;

5. digital simulation can be used for experimenting with new situations on which little or no information is available, with a view to teaching graduates to anticipate the unforeseen;

6. simulation gives specialists a grasp of general engineering. The analyst is obliged to make an appraisal and understand all aspects of the system, with the result that his conclusions will be less coloured by his personal inclinations and less likely to prove impracticable within the configuration of the system. [6]

The above reasons suggest that the versatility of digital simulation gives engineers greater stimulus to creativity than does the development of model prototypes, by offering them a broader canvas to work on.

III. Planning digital simulation experiments

Conducting an experiment by using a digital computer as the simulation instrument, as described above, means applying a *modus operandi* which may be summarized as follows:

1. Definition of the simulation objective

The problem must be defined. Once this has been done, the following questions must be asked:

a) what is the aim of simulation?

b) what degree of accuracy is required to meet the objectives of the simulation study?

2. Block diagram of a system

Block diagrams are needed to represent most complex systems.

The interrelationships between the system's different blocks may be obvious. Graphic representation is one of the most useful means of understanding the subdivision of the system into component blocks.

3. Subdivision of the system

Once the system has been interpreted as a set of blocks, the next step is to understand its physical operation. The manner in which the set is divided into parts conducive to the achievement of an objective is sometimes not so obvious. Its subdivision may depend on the objectives of the study and on the actual physical system.

4. Modelling the blocks

Mathematical and/or logic models of the blocks form the very nucleus of simulation. The mathematical tool used for constructing the model is usually based on the finite method.

5. Assembly of the system model

The different block models combine to constitute a complete model of the system.

In an academic situation, this is the point at which it becomes necessary to verify the terms employed by the members of a team carrying out a digital simulation experiment.

6. Analysis of the system model

The model must be analysed to achieve the project objective before the final design can be established for a system similar to that under consideration.

7. Documentation

Every step taken must be carefully documented during the simulation. This is a very useful phase in graduate training.

IV. Simulation of telecommunication systems

Blocks and models were referred to in section III as necessary elements of simulation exercises.

Digital simulation involves the use of a computer together with a model program to translate aspects of the situation studied. In the case discussed in this article, reference is made to simulation techniques suitable for the design of transferred-band binary transmission systems; its application to multilevel systems presents no difficulty.

The usual blocks to be considered in the simulation are the following:

a) wanted signal source,

b) noise source,

c) transmission channel,

d) received signal demodulation stage,

e) system behaviour evaluator.

a) Wanted signal source

The wanted signal sources take the form of sub-routines which generate sample trains of the signal produced by any source.

A modulated signal can be generated in the following stages:

— the digital data obtained from a random number generator. The sub-routine causes numbers uniformly distributed in the interval (0,1) to appear;

— one-to-one correspondence is then established between bits and modulating waveforms. This requires a sequence of samples for each bit. The choice of sampling speed is important, since it determines the number of samples that must be used to represent each symbol (in this case, bit) to be transmitted over the channel.

b) Noise source

The simplest noise to simulate, although not the only one, is white "gaussian" noise generated as a sequence of random numbers. Within the group of possible random number generators, preference is given to one which produces repeated

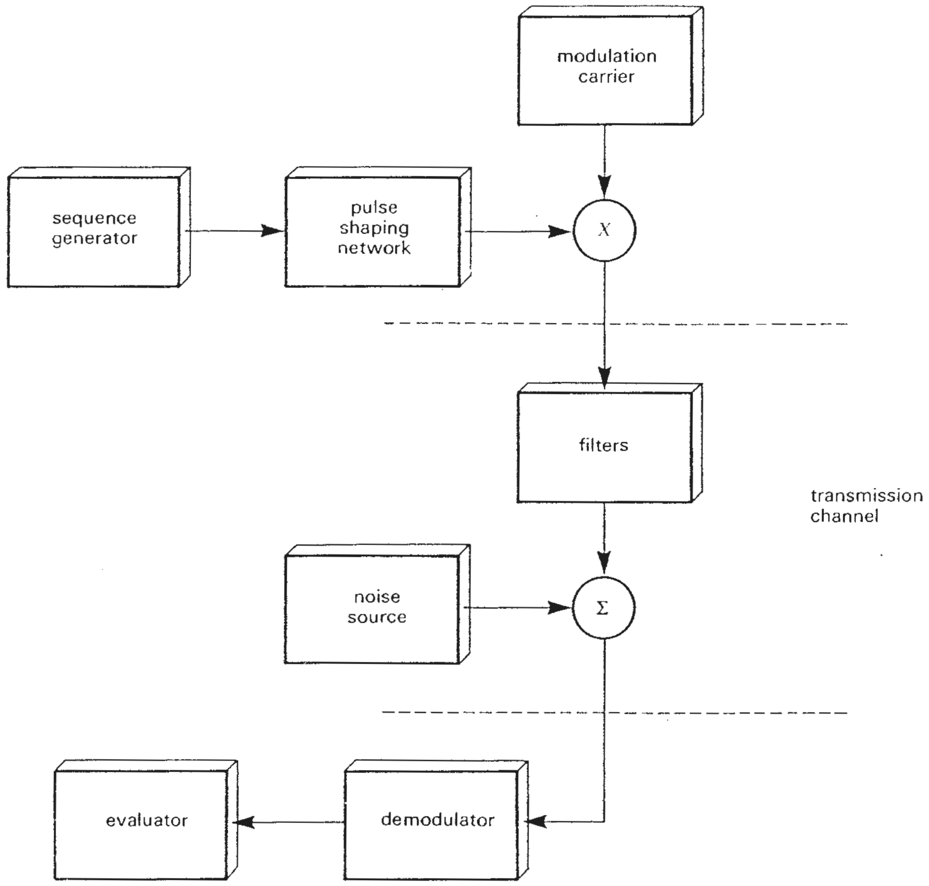

Figure 1—Block diagram of a telecommunication transmission system

outputs; another advantage of such generators is that they make it possible to detect repetition of the experiment and simulation faults.

c) Transmission channel

The channel components also appear in the simulation program as modules which accept sample trains at their input and process them to produce a sample train at their output. These components may lack memory or introduce it when they filter the samples present at their input; if they lack memory, relatively simple components which add these signals are found. Figure 1 indicates such a block and the signals it adds.

The filters are among the most complicated channel elements. The usual technique (if they are not digital filters as such) is to synsthesize digital filters from analogue filters.[7] This feature offers advantages as regards channel modulation since the effects of distortion and intersymbol interference have to be reproduced.

d) Received signal demodulation stage

This stage is usually alinear and may be simulated in two ways: by implementing the circuits which alinearly process the signals [8] or simply by performing the function which carries out the stage.

If the second alternative is chosen, the output from the demodulator is a sequence of samples representing the signal recovered from one which has been distorted. In simulation, most of the operations effected by a demodulator are performed at digital data transmission speed since the execution time of the program corresponding to the model of this stage is not the main contributor to the total processing time.

e) System behaviour evaluator

The last step in a simulation exercise is to evaluate or measure the system behaviour. Some form of "instrumentation" at the functional level must be modelled and simulated. For instance, there is the measuring method known as the "eye diagram" which provides qualitative information on the performance of the digital transmission system.

V. An experiment. PCM/AM transmission with envelope detection

The experiment described below is perfectly suitable for inclusion in courses on telecommunication systems and has been welcomed by students attending the annual course on telecommunication systems at the Advanced Technical School for Telecommunication Engineers at Barcelona.

The methodology for constructing the different models to be simulated follows the principles outlined above.

The block diagram of the system on which the experiment is based is given in figure 2.

The source of information (not shown in figure 2) creates a pseudo-random bit sequence which is made to correspond to a waveform sequence whose time pattern may be rectangular (pulse generator) or of any other type, e.g. enhanced cosine.

The next (modulating) block has to multiply the signal pulsed by the carrier signal.

The following procedure may be followed for the filter. First, the block diagram is represented by the differential equation expressing the relation of input to output; these blocks must contain the different transfer functions. [9] The equations and blocks with their interrelationships are then programmed by computer. Representing a digital filter in the computer means finding an algorithm for processing the input samples to the filter so as to obtain the corresponding output samples; the **Z** transformation is a valid algorithm. In this experiment the filter is depicted as two resonators in cascade.

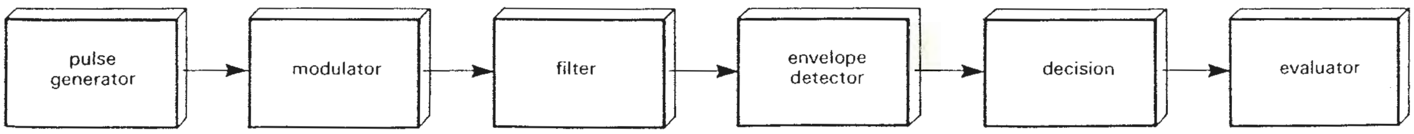

Figure 2—PCM/AM system with envelope detection—simulation model

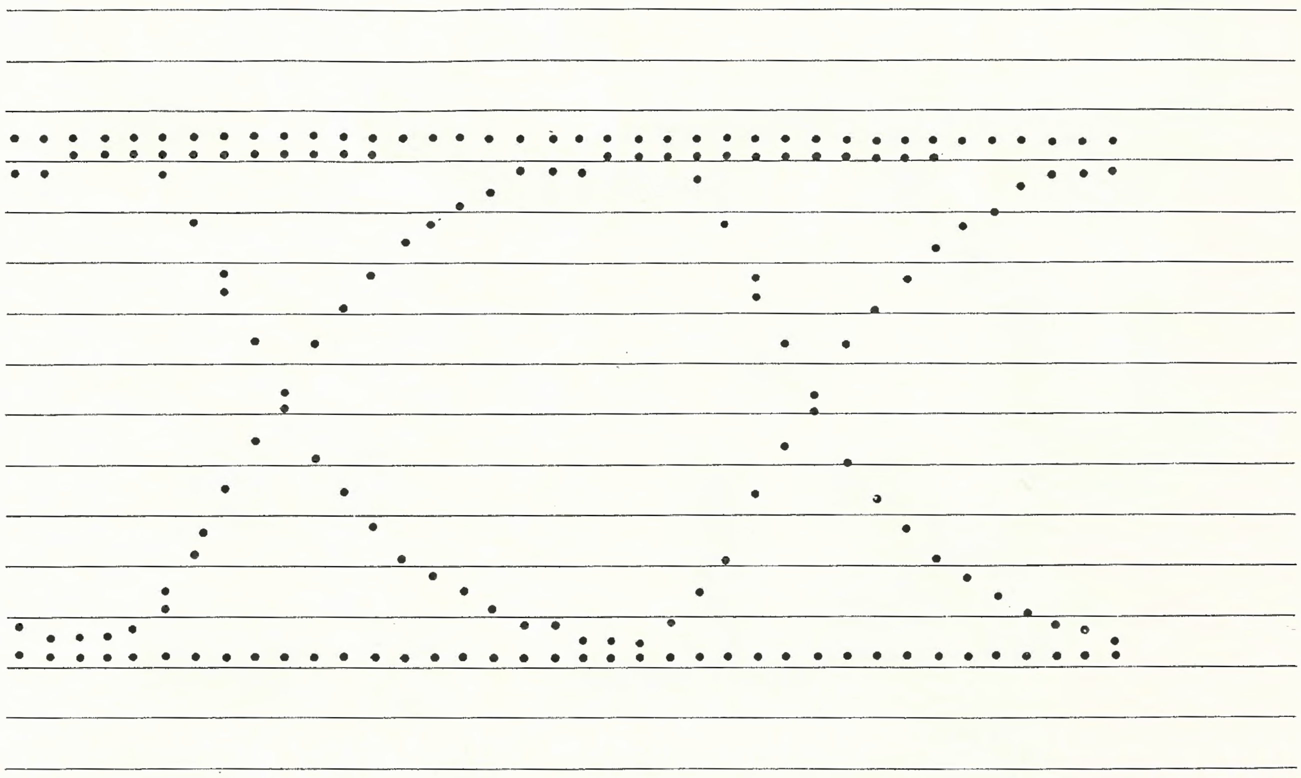

Figure 3—"Eye diagram" at the output from the detection block in the simulated PCM/AM system

The sampling frequency is chosen once the frequency response of the digital filter has been compared with that of the analogue filter to be simulated. [7]

The demodulation stage is depicted by an envelope detector. The signal production by the detector is simulated by the computer. The output from the detector in the model is a sequence of samples representing the distorted signal corresponding to a pulse train representative of the data.

The last block to be simulated corresponds to the evaluation stage. This is the most important part of the simulation method and must be properly designed to take advantage of the flexibility offered by simulation techniques. This experiment uses the criterion of evaluating system performance by means of the "eye diagram" without noise, although the presence of noise does not increase the difficulty of simulation. [9-11] Figure 3 illustrates an "eye diagram" compiled at the demodulator output; it is similar to what may be observed on the laboratory oscilloscope.

Such simulation can use FORTRAN IV programming and a medium or large computer (UNIVAC 1108 is used in this experiment).

VI. Conclusions

The purpose of this article was to describe a methodology for training in telecommunication transmission systems based on the digital simulation of specific systems. Its main asset is its versatility in invention and innovation in transmission situations. Moreover, it enables any complex system to be analysed and/or designed by a team.

(Original language: Spanish)

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