Def Sci J, Vol 39, No. 2, April 1989, pp 157-164

Radio Link Simulator

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ABSTRACT

The need for transmission of data over HF and V/UHF radio is increasing. There is a major disadvantage in testing the link in a field trial as propagation condition of the medium (especially HF) can be unpredictable and link condition may never again be the same. A simulator to create the atmospheric conditions, repeatably as required, to test the system behaviour is evident. The various propagation effects can be mathematically modelled, to get the signal affected by the channel. Models for Gaussian, Rayleigh and Rice distributions and the implementation of the simulator using latest state-of-the-art DSP techniques are discussed.

1. INTRODUCTION

Ionospheric and tropospheric scatter communication media are characterised as fading channels in which the transmission characteristics of the propagation media are randomly varying with respect to time and frequency. Even the LOS, microwave, satellite channels have the problem of fading. The most important cause of fading is the random arrival of the received signals through different paths. These paths themselves exhibit the time and frequency dependent characteristics of their own and the number of paths may also vary with time. Fading is also caused by ionospheric layer height variation, and yet another cause for fading is the relative motion between transmitter and receiver where the antenna alignment cannot be at the maximum gain.

There is an increased need for reliable data communication over well-established radio links. This necessitates the use of high speed data modem for increased throughput. The data modulates the radio frequency (RF) signal and is transmitted. Apart from fading, the received RF signal also suffers from the path attenuation,

Received 6 July 1987

changes in path attenuation, absorption losses, atmospheric noise, man-made noise and scattering.

In order to characterise and evaluate the data communication equipment under the worst conditions of channel, it should be possible to introduce several vectors such as random attenuation and multipath delays on repeatable basis. For this purpose a radio link simulator is visualised.

2. EFFECT OF RF CHANNEL ON THE DATA TRANSMISSION

The transmitted signal can be represented by

$$z(t) = m_k\,(t) \cos \{ \mathrm{wt} + \theta_0 + \theta_m\,(t)$$

where m_k (t) is the amplitude modulation, θ_m (t) is the phase or frequency modulation, w is the carrier frequency and θ_0 is an arbitrary phase constant. When the signal is transmitted through the RF channel, it is affected by the channel due to the above mentioned parameters, the received signal can be represented by[1]

$$Y(t) = g\, m_k\,(t\text{–}D) \{ \cos [w_0\,(t\text{–}D) + \theta_0 + \theta_m\,(t) + \theta_{ch}\,(t)] \} + n(t)$$

where g, D and θ_m (t) represent attenuation, delay and phase factors introduced by the channel respectively.

In case of multipath, signal arriving through different paths have different values of g, D and θ_m. The received signal is linear sum of all the signals arriving through different paths.

Channel studies have indicated that signal fading follows a near Rayleigh distribution[2]. However, it has been reported that sometimes fading signal follows Rician distribution[2,3]. Gaussian distribution is assumed for the additive white noise $n(t)$ component of the received signal. For many independent paths of propagation the in-phase and quadrature components of the received carrier are Gaussian and the envelope has a Rayleigh fading characteristic given by

$$f(r) = r \exp\,(-r^2 / 2\sigma^2) / \sigma^2$$

where r is the envelope amplitude and σ is the standard deviation of the Gaussian distribution of the in-phase and quadrature components.

Rayleigh fading model is applicable in case of densely spaced signal paths, in which no particular signal component predominates. However, in some situations one particular signal component may predominate and other signal paths constitute the randomly fading signals. In this case the envelope distribution follows the Rician distribution characterised by

$$f(r) = \exp [- (r^2 + Ac^2_{2n}) / 2\sigma^2_{2n}] [I_{02}\,(rAc/\sigma^2)] / \sigma^2 \tag{4}$$

$$\text{and } I_0\,(z) \quad \sum_{n=0}^{\infty} z / [2(n!)] \tag{5}$$

where $I_0(z)$ is a modified Bessel function of first kind and order zero and r is the envelope amplitude.

$$\text{For } z << 1, \qquad I_0(z) = \exp(z^2/4) \tag{6}$$

3. MODELLING OF CHANNEL PARAMETERS

The channel parameters mentioned earlier are mathematically modelled and implemented in the simulator design.

The Rayleigh fading distribution basically represents a complex Gaussian process. The same is implemented by multiplying the in-phase input signal by a band-limited random variable and the quadrature component by another band-limited random variable. The resultant of the in-phase and quadrature vectors represents the Rayleigh fading skywave signal. The above mentioned random variables have the same variance and Gaussian distributions. The random variables are generated by passing the output of a software white noise generator through a digital filter.

Sampled input signal can be delayed by nT where n is an integer and $1/T$ is the sampling frequency. The path delay can be simulated by varying n. Controlled attenuation can be imposed on the signal by multiplying the input sampled signal by a known constant.

3.1 Frequency Offset

The frequency offset is affected by convolving the spectrum with a delta function at the desired frequency offset. Equivalently the offset can be obtained by multiplying the time domain signal with $\exp(j2\pi ft)$ where f is the desired frequency offset.

4. REALISATION OF MODEL USING DIGITAL SIGNAL PROCESSORS

It is evident that a digital design is needed for realising the simulator. The nature of the signal processing, generation of the random signals and implementing the mathematical models can best be met by state-of-the-art digital signal processor (DSP) VLSIs. The TMS32010 is the first member of the new DSP family which supports wide range of high speed numeric intensive applications, thus offering an inexpensive alternative to multichip bitslice architecture[4]. Table 1 provides the specifications of the radio link simulator under discussion.

4.1 DSP Architecture

TMS 320 family utilises a modified Harvard architecture for speed and flexibility (Fig. 1). On-chip hardware 16-bit multiplier enhances throughput of the chip with multiplication time of 160 ns. The 32-bit arithmatic logic unit (ALU) and accumulator supports the double precision arithmetic. A barrel shifter is available for left shifting data (0 to 15 places) before it is loaded into, subtracted from or added to the accumulator. TMS320M10 is equipped with 1536 words of on-chip ROM and can address 2560 words of off-chip memory at full speed. It can address 4096 words of off-chip memory at full speed. Its comprehensive instruction set supports both the

Table 1. Specifications of the radio link simulator

Type of fading	Rayleigh, Rician and Gaussian
Number of signal paths	4 skywave paths and 1 ground path
Number of interference signals	One
Signal bandwidth	30–3000 Hz
Multipath delay (programmable)	0.1–11.6 ms
Fade rate/frequency spread	0.001–100 Hz
Frequency offset	0.1–75 Hz
Dynamic range of input signal/ interference signal	40 dB; typical input 1 V (rms)
Audio output level	0 dBm/600 Ohms
Computer interface	IEEE-488/RS 232C

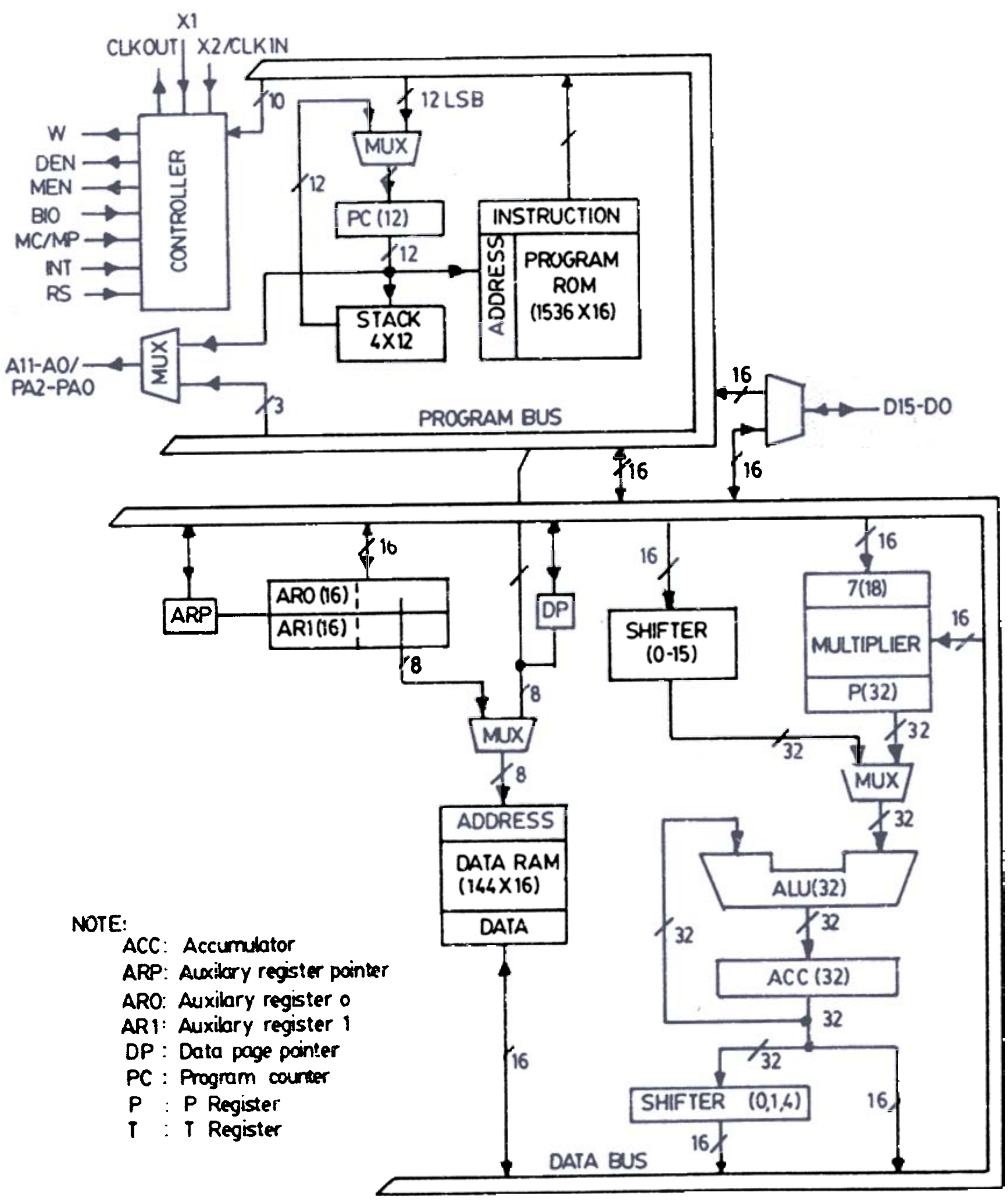

Figure 1. TMS32010 digital signal processor.

numeric intensive operations such as digital processing (digital filters) and general purpose operations, like high speed control[5].

5. SIMULATOR DESCRIPTION

The input signal is amplified and sampled in a sample and hold circuit and converted by an analog-to-digital convertor (ADC) into a 12-bit word. These signal samples are stored in DSP buffer memory. The DSP functions are realised by use of 16-bit/32-bit ALU in TMS32010 DSP. All DSP functions are software/firmware implemented. Block diagram of the simulator is shown in Fig. 2.

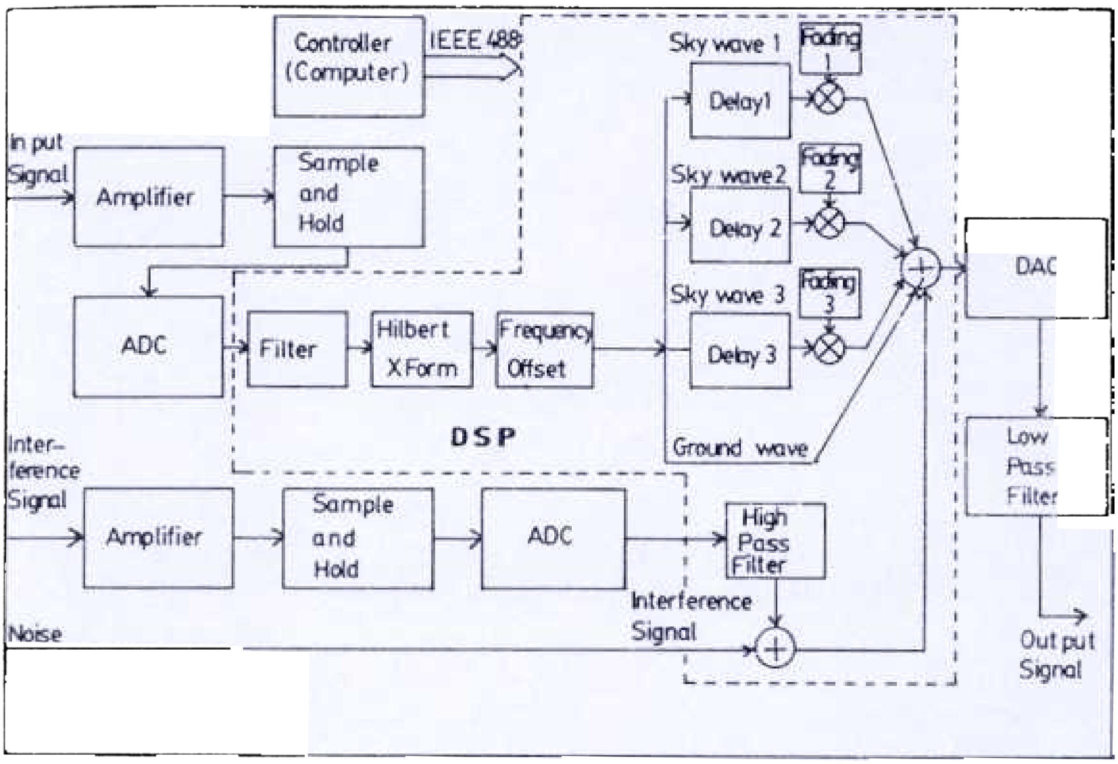

Figure 2. Simulator.

The input signal is passed through a programmable gain amplifier (40 dB dynamic range) in order to obtain a constant average level. This signal is then passed through an anti-aliasing filter before it is digitised in ADC to get a 12-bit word. This input stream is filtered by a digital high-pass filter with a cutoff of 30 Hz to eliminate any DC component, which could otherwise affect fading and frequency offset.

The filtered signal is now offset in frequency as required. The signal is split into in-phase and quadrature components by operating the samples on Hilbert filter. These signal samples are then multiplied with two independently generated Gaussian random variables to obtain Rayleigh/Rician characteristics, as discussed earlier. This results in a simulated fading signal over one path (Fig. 3). In order to obtain multipath faded signal it is necessary to subject the incoming signal samples through varying delays and affect them individually with different fading functions (different set of random variables). All these signal components are summed up alongwith direct signal and also an additive Gaussian white noise component to give channel affected time samples. Each of the signal paths have programmable attenuators. The characteristics of the

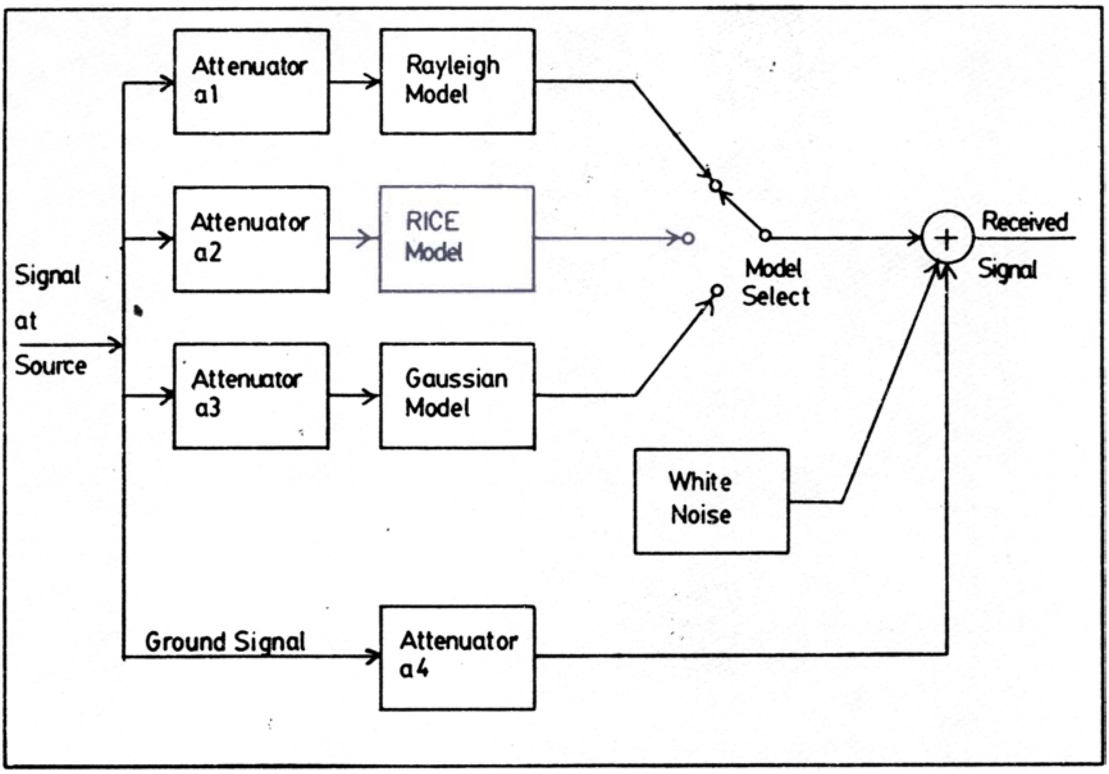

Figure 3. Integrated model of the simulator (single channel).

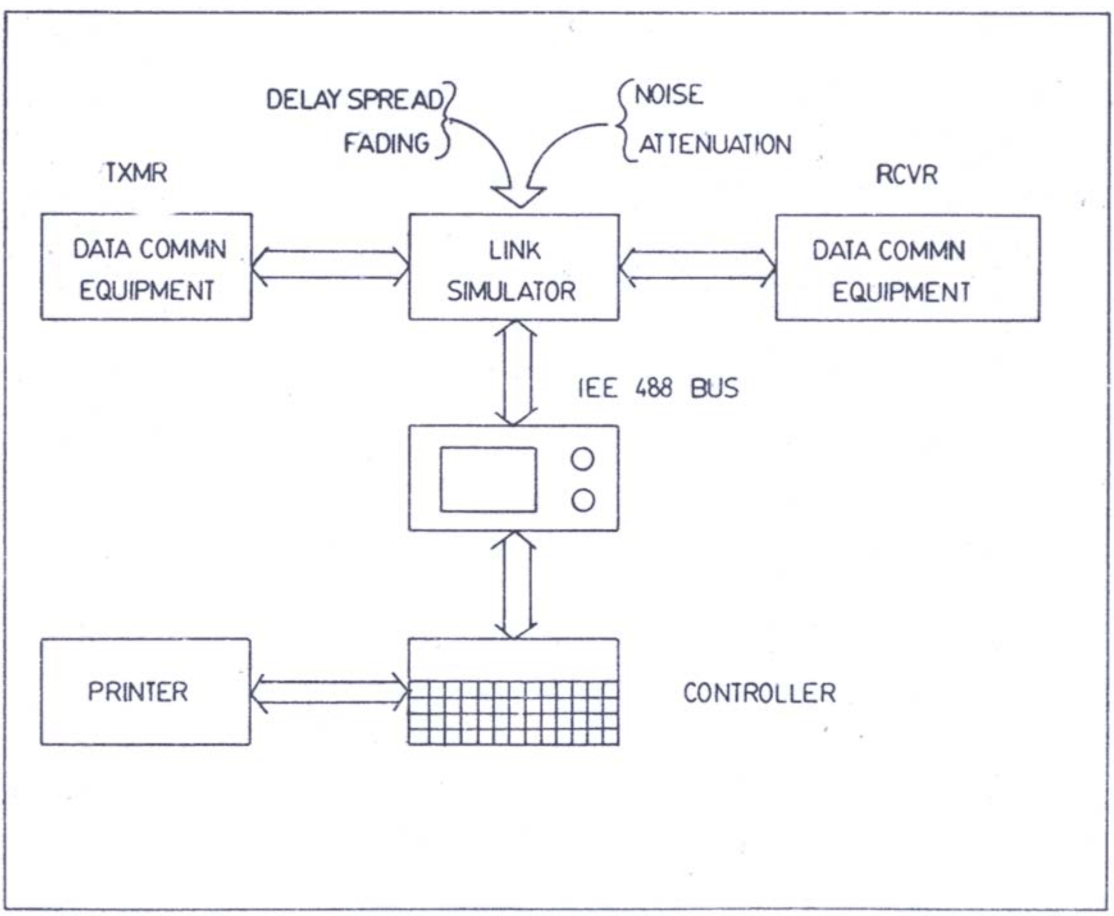

Figure 4. Data communication equipment evaluation.

random variables, i.e., Gaussian amplitude and frequency distributions are programmable. This gives flexibility to simulate various dynamic channel conditions. These samples are converted back to analog domain by a digital-to-analog convertor and filtered to give the simulated channel output.

6. DATA COMMUNICATION SYSTEM EVALUATION USING SIMULATOR

The simulator can be effectively used in evaluation of a data communication equipment[6]. Representative channel condition can be created on a repeatable basis. Thus it can be used to evaluate and compare performance of data communication systems under identical channel conditions (Fig. 4). The equipment designer can thus optimise the equipment under different operating conditions, that is, the suitability of a particular error correcting code can be deduced under the worst expected simulated channel conditions.

The simulator is controlled via IEEE-488/RS 232C bus, which makes it compatible with standard instrumentation. Selection of parameters is by software-driven menu on the visual display unit of computer, for any of the inbuilt models. By appropriately changing the firmware/software, data modems based on various working principles can be tested, for example, multitone[7], two tone, frequency and phase shift key modems. The simulator can also be used for training radio operators for a wide range of ionospheric conditions.

7. CONCLUSION

In this paper the need for radio link simulator has been discussed. Some of the models can be applied to the link, for example, Gaussian, Rayleigh and Rician. Latest state-of-the-art VLSIs, for example, programmable DSPs offer tremendous flexibility in implementing the models. A simulator scheme using the DSP (TMS32010) has been presented and basic specifications of the system have been indicated.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to Wg. Cdr. S. Roy Choudhuary, General Manager (Designs), Avionics Design Bureau, HAL, Hyderabad for the encouragement given. They also thank Ms Pannageswari, Dy. Manager, AvDB, HAL, Hyderabad for her technical help.

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