PERFORMANCE EXPANSION OF ASTRAS PROGRAM PACKAGE

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Abstract

The ASTRAS program package is described briefly. The ASTRAS is able to simulate high complexity point to point radio communication systems. It is now extended to simulate optical communication systems, too. In this paper we present this new version of ASTRAS. The variable rise time/fall time model of optical sources is shown and the single-mode fibre modelling is analysed in detailed form. The description of optical receiver is given, too.

Keywords: simulation of optical systems, optical source modelling, fibre modelling, optical detector modelling.

1. Introduction

Computer simulation is an extremely effective tool in electrical engineering education and in the analysis, design and evaluation of communication systems. This fact has been recognized for a long time and many simulation program packages have been developed and applied with success. The ASTRAS (Analogue Simulation of TRAnsmission Systems) program package is a tool for the simulation and developing of digital data communication systems [1].

The simulated system is characterised by the transfer function of the building blocks. Communication systems are complex structures of many components, which have complex characters themselves. Due to the high complexity, an analytical treatment of their behaviour would be very difficult, on the other hand, experimental investigation would be extremely expensive. Computer simulation is therefore the preferable means of investigation. Further, simulation is a very effective tutorial means in explaining the system concepts and properties.

Parameters to be determined by simulation may contain virtually any performance parameter such as signal shape, spectral density, signal-to-noise ratio, error probability. In digital transmission systems, error probability and eye pattern are the most important parameters.

We have been developing the new version of the program package to expand its performance. The new version of ASTRAS will be able to simulate the point to point radio channel, the mobile and indoor radio channel and optical communication systems.

In this paper, after a brief discussion of some general problems in system simulation, the modelling of digital lightwave links for computer simulation will be dealt with.

2. Block Structures and Signal Representation

The building blocks of a typical communication system are arranged in series and parallel branches forming the structure to be simulated. The complex components of such a system are called blocks, having one or a few input ports and one output port. Blocks are defined by their input-output characteristics.

The signals can appear either as baseband signals or as modulations of the appropriate carrier. Bandpass signals can be represented by their complex envelopes, further either time domain or frequency domain representation is possible. FFT or IFFT serves for the conversion from one of these to the other one and vice versa.

3. The ASTRAS Program Package

ASTRAS has been developed to fulfil the following tasks:
  - to define the structure to be simulated;
  - to carry the signals generated by the main source through the structure, taking the transfer functions of the blocks as well as signals of disturbing sources into account;
  - to determine the appropriate measure of the transmission performance.
    The main features of ASTRAS are:
  - systems with virtually unrestricted complexity can be dealt with
  - it has a fully interactive character;
  - program run can be interrupted and resumed later.

Generality of the simulation is restricted in two points only: no feedback can be dealt with and only memoryless nonlinearities can be treated. In fact, the systems thus excluded are of marginal interest only. On the other hand, subassemblies containing feedback are better analysed via network analysis programs. From the simulation point of view, these are regarded as blocks with known transfer functions. Nonlinearities with memory
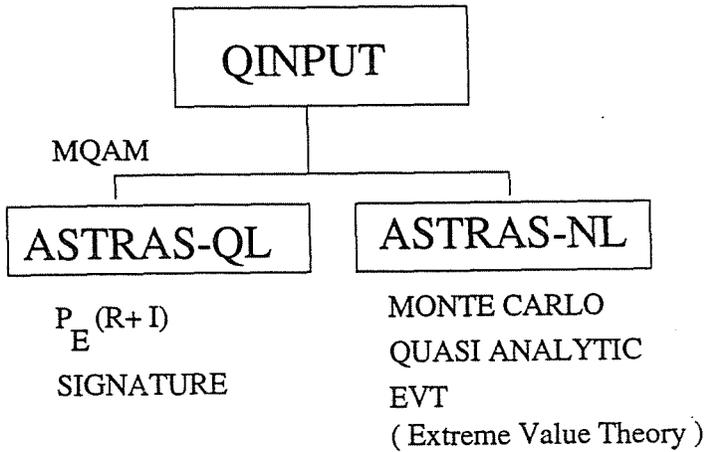
QINPUT

MQAM

ASTRAS-QL

ASTRAS-NL

$P_E(R+I)$

SIGNATURE

MONTE CARLO

QUASI ANALYTIC

EVT

(Extreme Value Theory)

Fig. 1. Structure of ASTRAS program system

can be modelled as a cascade of a memoryless nonlinearity and one or two filters. The program consists of three main parts and it is shown in *Fig. 1*.

QINPUT defines the system in an interactive way by presenting the structure and the block parameters on the display. A menu is assigned to each block, its type and parameters chosen by an ergonomically designed dialogue. The offered blocks contain predefined and user-defined ones. Among the predefined ones there are binary and M-ary signal sources, standard filters, modulators, amplifiers, carrier and clock synchronisers, etc. User-defined block characteristics have to be given in a file.

ASTRAS-QL is used if QAM modulation is applied and the system contains linear blocks only. In the more general case, when the simulated system contains nonlinear blocks, ASTRAS-NL has to be used. Linear blocks are handled in the frequency domain and nonlinear blocks in the time domain. Linear and nonlinear blocks may follow each other in any sequence. ASTRAS-NL recognizes automatically the character of the block and executes FFT or IFFT as needed. Further, a special and efficient method is applied to deal with parallel branches.

4. Modelling of Digital Lightwave Links for Computer Simulation

Computer-aided techniques for digital communication systems fall into three classes: one of them based on analytical calculation, the other one based on time-domain Monte Carlo simulations, and the third one is a

hybrid approach based on a combination of simulations and analytical cal-
culations [2]. Analytical calculations are computationally very fast but are
limited in their applications. Time-domain simulations are most flexible
but Monte Carlo simulations of digital lightwave links operating at low
error rates require very long input sequences, so they have a very long
run time. We can overcome the computational limitations of Monte Carlo
approach and the inaccuracies of the purely analytical approximation ap-
proach by the combination of simulation and analytical approach. There
are some methods to improve the run time of performance estimation of
Monte Carlo simulation. E.g. quasi analytical method and EVT, as it was
shown in *Fig. 1* [3].

4.1. Simulation Model

The block diagram of an end to end single-mode digital lightwave system
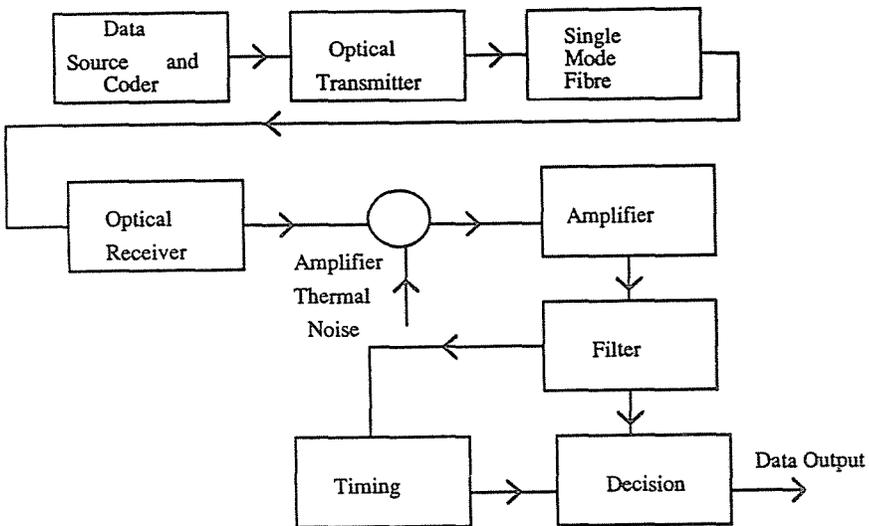is shown in *Fig. 2*.

Fig. 2. Block diagram of digital lightwave link

The input to the optical transmitter is represented by the coded output of
a data coder. This signal may be binary or multilevel. Although at present
time radio frequency data communication systems usually use sophisticated
modulation methods (e.g. 64–QAM), in most of the optical systems the
simple binary intensity modulation is adopted. The electronic signal is

transferred to the optical signal by the optical transmitter (OE converter). The optical signal goes through from the transmitter to the receiver in the single mode fibre. The optical detector in the receiver converts the optical power into electronic current. The received signal is filtered, sampled, and compared against a threshold to determine the transmitted level.

4.1.1 Data Source and Coder

The input data is a random data sequence, possibly coded to achieve a particular spectral shaping. The simulations are driven using a pseudorandom sequence with binary values 0 and 1, and the word lengths sufficient to analyse the individual effect or combination of effects being studied. Line coding can be used to minimise the occurrence of long sequences of ones and zeros and shape the spectral density of transmitted waveforms simplifying the transmitter and receiver circuits. Three kinds of waveforms are used in practice in lightwave systems. These are shown in *Fig. 3*.
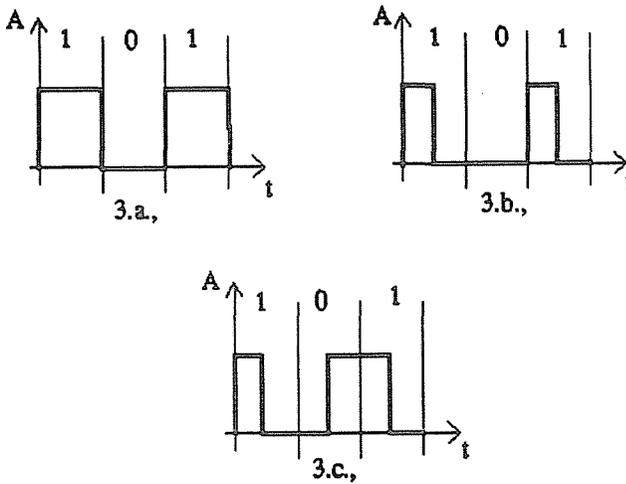

Fig. 3. Output waveform of data generator.a) NRZ. b)RZ., c) Manchester code

NRZ codes are simple and easy to implement. The RZ and Manchester codes increase the bandwidth, but this is not a serious problem at present with single-mode optical fibre transmission.

4.1.2 Optical Source Modelling

The optical spectrum and the optical waveform are the most important things in modelling an optical transmitter. We have to know the source optical spectrum to calculate the single-mode fibre transfer function. The optical output waveform depends on two things. One is the speed of response of the driving circuits and the other is the speed of response of the diode. The transmitter turn-on and turn-off responses (rise and fall times) are modelled by two parallel filters (*Fig. 4*) [4].
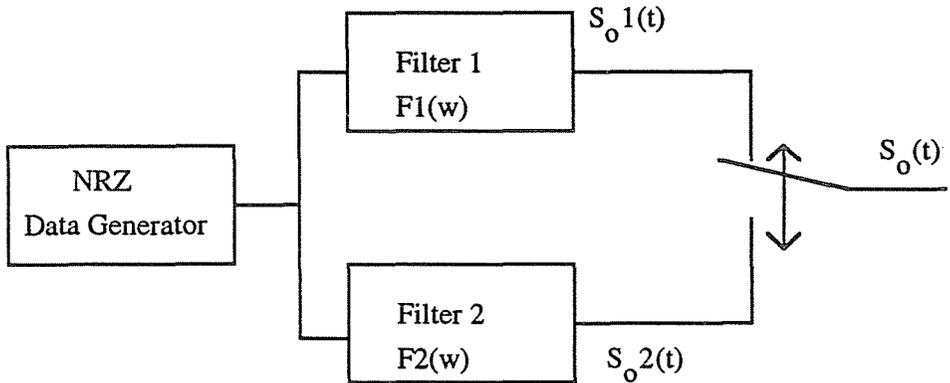

Fig. 4. Variable rise time/fall time model

Two filters are applied, F1(w) and F2(w), defined by the user. The outputs, $S_0 1(t), S_0 2(t)$ of the filters are obtained by convolving the input data with the impulse response of each filter. Filter F1 is chosen such that the rise time of $S_0 1(t)$ is equal to the rise time of the LED or LASER diode and filter F2 is chosen such that the fall time of $S_0 2(t)$ is equal to the fall time of the LED or LASER diode. $S_0(t)$ is obtained by combining the two waveforms. Although $S_0 1(t)$ and $S_0 2(t)$ individually have equal rise and fall times because they are the outputs of linear systems, the combined output $S_0(t)$ does not have this property, and the optical source can be modelled as a nonlinear subsystem.

We can calculate the optical power from single-mode rate equations that describe the laser by its dynamic features as expressed in [5]

$$\frac{dN(t)}{dt} = \frac{I(t)}{qV} - \frac{N(t)}{\tau_n} - g(N(t) - N_t)(1 - \varepsilon S(t))S(t), \qquad (1)$$

$$\frac{dS}{dt} = \Gamma g(N(t) - N_t)(1 - \varepsilon S(t))S(t) - \frac{S(t)}{\tau_p} + \Gamma \beta \frac{N(t)}{\tau_n}. \qquad (2)$$

$N(t)$ is electron density, $S(t)$ is photon density, $I(t)$ is the current through the active layer of the laser, q is the electron charge. Typical single-mode semiconductor laser parameter values used in this analysis are presented in *Table 1*.

The optical electric field at the output of the laser facet is expressed by

$$E_{in}(t) = k\sqrt{S}(t)\exp\Big(j\varphi(t)\Big), \tag{3}$$

where the phase is given as

$$\varphi(t) = -\int_0^t 0.5\alpha\Gamma g\Delta N(t')dt', \tag{4}$$

where ΔN is the incremental change in carrier density and k is a proportionality constant. The magnitude of the fibre input is squared to produce the incident optical power into the fibre.

Table 1
Semiconductor LASER parameter values

Active-layer volume (m^3)	$V = 90 \times 10^{-18}$
Spontaneous emission factor	$\beta = 4 \times 10^{-4}$
Optical confinement factor	$\Gamma = 0.44$
Optical gain constant (m^3/sec)	$g = 3 \times 10^{-12}$
Gain compression factor(m^3)	$\varepsilon = 3.4 \times 10^{-23}$
Linewidth enhancement factor	$\alpha = -5$
Differential quantum efficiency	$\theta = 0.1$
Transparency carrier density (m^{-3})	$N_t = 1.2 \times 10^{24}$
Carrier lifetime (sec)	$\tau_n = 3 \times 10^{-9}$
Photon lifetime (sec)	$\tau_p = 1 \times 10^{-12}$
Resonance frequency (GHz)	$f_r = 5.1$

4.1.3 Single-mode Fibre Modelling

We are going to examine two kinds of processes of single-mode fibre models. One of them is based on the optical power domain and the other on the optical field domain. The first model assumes that the fibre is a linear system in the optical power domain. It allows attenuation and dispersion dependencies on wavelength to be fully taken into account, that is necessary, for example, when analysing wide spectrum (LED) transmission on

single-mode fibres. The baseband transfer function of the single-mode fibre power domain model is given by [4]

$$H(f) = \int\limits_{-\infty}^{\infty} S(\lambda)L(\lambda)\exp[-j\omega l T(\lambda)]d\lambda, \tag{5}$$

where $S(\lambda)$ is the source spectrum versus wavelength, l is the fibre length

$$\omega = 2\pi f,$$

$L(\lambda)$ is fibre attenuation for length l versus wavelength, $T(\lambda)$ is fibre group delay per unit length versus wavelength.

The effect of shaping due to optical filtering and/or wavelength division multiplexing (WDM) is modelled by modifying the $S(\lambda)$ term with the appropriate transfer function.
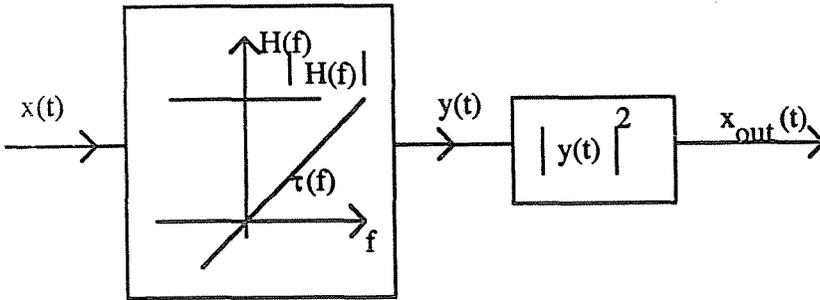

Fig. 5. A low pass equivalent single-mode fibre model in the electric field domain

In the field domain model, the fibre is modelled as a bandpass filter with flat amplitude and linear group delay (*Fig. 5*) over the modulation baseband signal bandwidth and expressed by [6]

$$H(f) = \exp\left[j\gamma\left(\frac{\pi f}{B}\right)^2\right], \tag{6}$$

where **B** is the modulation rate and γ the chromatic dispersion index. γ is defined as

$$\gamma = \frac{1}{\pi}D(\lambda)\lambda^2\frac{l}{c}B^2, \tag{7}$$

where $D(\lambda)$ is the single-mode fibre dispersion $D(\lambda) = dT(\lambda)/d\lambda$, λ is the laser wavelength, c is the speed of light.

The optical electric field at the fibre output is

$$E_{out}(t) = F^{-1}\{H(f)E_{in}(f)\}, \tag{8}$$

where $E_{in}(f)$ is the Fourier transform of fibre input optical electric field.

4.1.4 Photodetector Modelling

In optical receivers, the first element is a photosensitive detector that converts photons to electrons. This can be either a p-i-n diode that does not amplify or an APD (avalanche photodetector) that has built-in gain.

The current generated by the p-i-n diode is a time-varying Poisson process resulting from random arrivals of photons at the detector. If the detector is illuminated by incident power $P(t)$, then the average number of electron-hole pairs $\bar{N}$ generated in time Δt is

$$\bar{N} = \frac{\eta}{h\nu}P(t)\Delta t + \lambda_0 \Delta t, \tag{9}$$

where λ_0 is the dark current in number of pairs/s,
ν is the optical frequency,
η is the quantum efficiency,
h is Planck's constant.

The actual number of electron-hole pairs generated in time Δt is Poisson process, where

$$P(n) = \frac{(\bar{N})^n \exp(-\bar{N})}{n!}, \tag{10}$$

where $P(n)$ is the probability that n pairs are generated in Δt.

The current generated from the p-i-n diode can be expressed as

$$i(t) = \frac{qn}{\Delta t}, \tag{11}$$

where q is the electron charge.

For APD model, $i(t)$ is expressed by

$$i(t) = \frac{q\sum_{l=1}^{n} g_l}{\Delta t}, \tag{12}$$

where g_l is the number of secondary pairs generated by every primary pair n in the Δt interval. (g_l includes the primary pair also.) g_l is an integer random variable, with a probability density that can be expressed by [4]

$$P(g_l = m) = \frac{(1-k)^{m-1}\Gamma\left[\frac{m}{1-k}\right]\left[\frac{1+k(G-1)}{G}\right]^{[1-k(m-1)]/1-k}}{[1+k(m-1)](m-1)!\Gamma\left[\frac{1+k(m-1)}{1-k}\right]}\left[\frac{G-1}{G}\right]^{m-1}, \tag{13}$$

where G is the average gain of APD,
k is the ionisation ratio defined by

$$< g^2 >= \left[kG + \left(2 - \frac{1}{G}\right)(1-k)\right]G^2. \tag{14}$$

5. Summary

An effective simulation program package has been developed and applied to various communication and educational tasks. Time domain models for optical sources, single-mode fibres, p-i-n and APD detectors have been given. Based on the shown models we are developing a new version of ASTRAS simulation program package. The new version will be able to handle optical blocks too, it will be available by the end of this year.

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