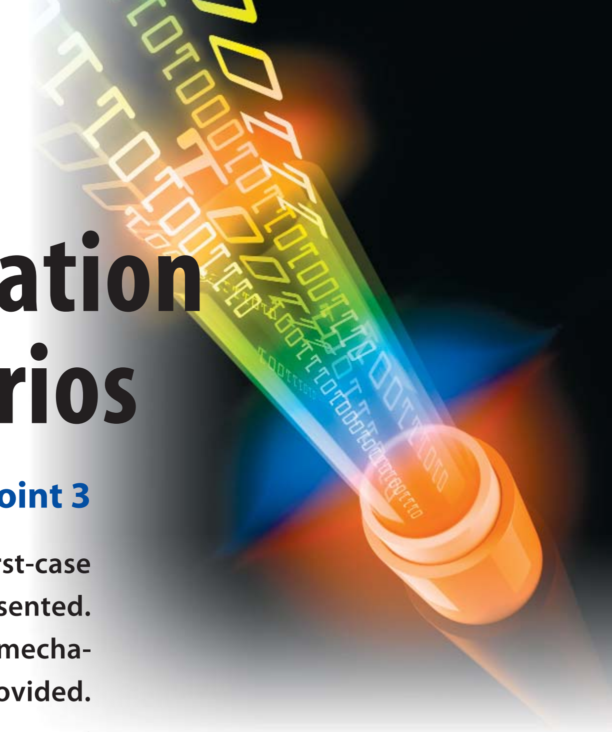

# Automated determination of worst-case scenarios

## For MOST optical physical layer specification point 3

**In this article an approach to determine and analyze the worst-case scenarios of the input to the specification point 3 (SP3) is presented. Besides the worst-case analysis infomation about degradation mechanisms due to the influence of the plastic optical fiber (POF) is provided.**

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Optical networks are immune to interferences from other electrical sources – an impact on signal integrity doesn't exist. However, limitations on the bandwidth of the optical transfer medium have an effect on the signal characteristics and need to be considered in specifications for optical links. MOST150-standard uses the identical POF as used in MOST25.

While in MOST25 the impact of POF bandwidth limitations was negligible, the higher speed of MOST150 requests a detailed investigation. The bandwidth limiting characteristic of the POF influences the transmitted signal. The fibers bandwidth depends on its length and the numerical aperture (NA) of the POF. A mathematical representation of the POFs transfer function was defined which is useful for prediction of degrading impacts on signal integrity. Additionally, transmitter properties such as launch NA and the pulse shape of the emitted optical signal directly influence the signal passing the fiber. Therefore, it is important to have knowledge of worst-case input scenarios and their effect on signal parameters after the data transmission.

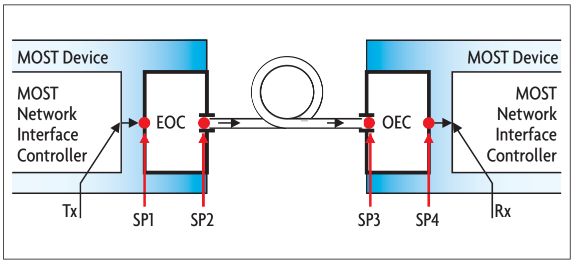

**Figure 1. Definition of the specification points.**

A profound analysis of extreme transmitter characteristics and their influences on the signal transfer through POF enables to specify the constraints on optical emitters as well as to predict worst-case input conditions for optical receivers.

## Introduction

The „MOST150 Optical Physical Layer Specification" provides a definition of the optical link by four specification points (SP1 to SP4) marking significant interfaces (**figure 1**). The optical input parameters for the optical electrical converter (OEC) are specified at SP3. The signal at SP3 is influenced by various sources. First of all, the output signal at the electrical optical converter's (EOC) output SP2 may vary in the given tolerance ranges. This includes variations in pulse shape, extinction ratio, timing distortion, optical output power and launch conditions. The transport medium POF may also influence the data signal. The dominant impact is the optical attenuation caused by the POF and optical interconnects. Another degradation of the signal quality comes with the bandwidth limitation of the POF, leading to degradation of transition times, inter symbol interference (ISI) and duty cycle distortion (DCD). The MOST specification defines a mathematical representation of the POF's transfer function, which was determined based on profound investigations and theoretical considerations.

To achieve a deeper understanding of worst-case scenarios at SP3 based on SP2 input conditions a simulation study was started. To find worst-case patterns for SP3 and to learn about degradation mechanisms was one target of this study. For the simulations, the fiber-length and launch NA was fixed as the worst-case settings of the MOST150 automotive optical physical layer.

For automated determination of worst-case scenarios for different parameter sets, a program based on Matlab was developed. Matlab is a numerical computing environment and programming language. The software generates separate pulse shapes for rising and falling edges where the full tolerance range given by the MOST physical layer specification is utilized. These edges are combined to a single signal by using valid MOST patterns, coded in DC Adaptive Coding (DCA). Then the impact due to the transmission media is simulated. The use of complete MOST frames guarantees that low frequencies are also included in the calculation. Afterwards the SP3 results are stored for visualization and analysis. These steps are iterated until the desired parameter coverage or cross-coverage is reached. The coverage is determined based on parameters for describing the pulse shapes of falling and rising edges.

## SP3 input pattern calculation

All patterns are generated using normalized amplitude and normalized time-scale. The amplitude is based on the steady state high- and low-level of the optical signals (B1, B0). A specific method for achieving these parameters is given in the MOST specification. Amplitude value 1 represents steady state B1; an additional overshoot up to 1.4 is permitted (**figure 2**). Amplitude 0 represents steady state B0, which doesn't mean zero necessarily. A small bias level is possible; a limitation is given by the parameter extinction ratio. Time scale is defined in Unit Intervals (UI), derived from the network bit rate. Due to the coding scheme, the shortest pulse width is 2 UI. There are further pulse types with pulse length up to 6 UI.

The SP3 input pattern calculation is divided into three main steps. These steps are described in detail in the following three sections.

## Rising and falling edge generation

The generated transitions represent pulse shapes of a length of 2 UI. Rising edges start with amplitude 0 and end with amplitude 1, falling edges start with 1 and end with amplitude level 0.

A rising and a falling edge is described by four parameters. These parameters are edge, surface, offset and depth for the falling edge or height for the rising edge. Before generating an edge the minimum and maximum values of these parameters can be defined, to generate edges with special properties.

- Edge: transition time between 20 and 80 % of the normalized amplitude.
- Surface: accumulated power within the surface over or under the normalized amplitude.
- Offset: time deviation between transition and zero point on the time scale measured at amplitude level 0.5.
- Depth, Height: peak amplitude of the generated rising or falling edge pattern.

For generating pulse shapes, coordinates at start and end of the curve are fixed, while sample points in between are generated randomly. In order to control the process of generating random coordinates, boxes are defined wherein one random coordinate per trial is generated. Then curves are fitted through the sample points using Matlab Polyfit in which basic polynomial and spline interpolation is possible. The timing resolution of 30 samples/UI was chosen.

The method of limiting the degree of freedom by introducing the boxes helps to avoid unrealistic pulse shapes and allows an adaptation to the needs of the chosen fit-algorithm. The random ranges for polynomial interpolation are shown in **figure 3** . After a calculation run, the pulse shape is checked for consistency with the SP2 requirements and the user defined parameter range. If all constraints are matched, the pulse shape is accepted or else the algorithm runs through 10,000 trials.

## Combining the rising and falling edge with a pre-defined bit pattern

For creating a SP2 pattern, pulse sequences of rising and falling edges are consecutively combined. The data structure is defined by a pattern file providing binary data sequences in UIs. The MOST stress pattern as well as user defined bit pattern can be used. The bit pattern must be offset free and the starting point must be equal to the end point to avoid dirac impulses while using FFT. For every SP2 pattern (**figure 4**) one particular pulse shape of each, rising and falling edge, is used. Pulses of the pattern which are greater than 2 UI are connected by padding with either „1“ or „0“ between the rising or falling edges.

Though all specifications for SP2 are fulfilled and the additional constraints are matched, the resulting pattern might be idealistic compared to real optical transmitters used in the network. The bandwidth capabilities of optical transmitters is limited, the calculated patterns however might easily exceed this natural limitation. Besides all efforts to create worst-case patterns according to SP2 specification and to avoid unrealistic pulse shapes, the final database will contain scenarios that need to be excluded manually.

## Calculation of the SP3 pattern

A prediction for the scenario at the fiber output is calculated as the convolution of SP2 pattern and the POF's transfer characteristic. The generated SP3 pattern (**figure 5**) can be visualized and used for further analysis. A data set, containing characteristic parameters for input and output parameters, is stored. This allows loading and also recalculation of the SP3 pattern together with any bit pattern.

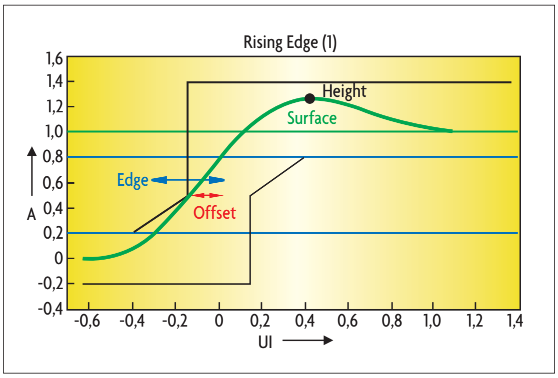

Figure 2. Pattern parameter.

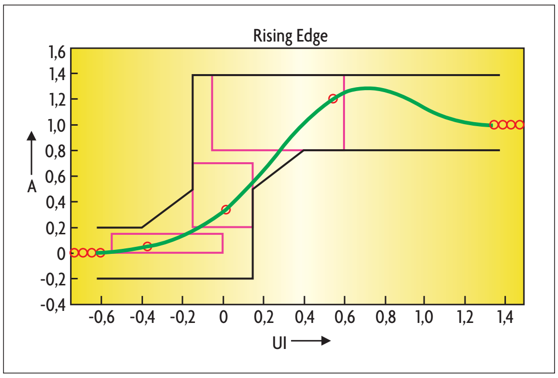

Figure 3. Polynomial interpolation for a rising edge pattern.

## Simulation and analysis

The simulation program can generate multiple randomized rising and falling edges at once. Afterwards different SP2 patterns are generated using all permutations of the rising and falling edges

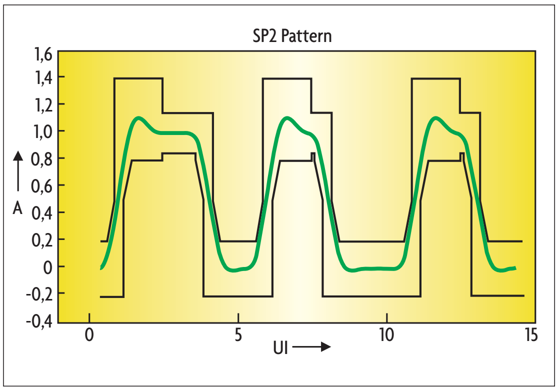

Figure 4. Generated SP2 pattern.

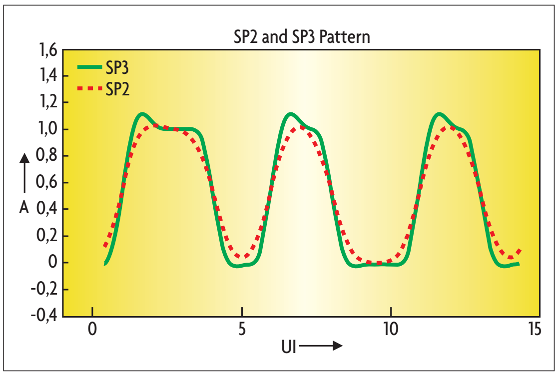

**Figure 5. SP2 and SP3 pattern.**

together with a loaded pattern automatically. From this set of input pattern approximately 40,000 corresponding SP3 pattern can be calculated by a modern computer in one day. This leads to the calculation of millions of different SP3 pattern using multiple computers within a few days. The resulting pattern can be stored after simulation for further analysis and visualization.

Different parameters have been defined for SP3 pattern assessment. These parameters are calculated for each SP3 pattern. Afterwards a defined number of worst-cases for each parameter are stored during simulation. If distributed calculation is used, the different simulations results can be merged.

- Edge min: minimum transition time of the SP3 pattern.
- Edge max: maximum transition time of the SP3 pattern.
- Delta edge: describes the maximum degradation in transition time.
- Duty cycle: maximum pulse width of a high or low pulse of the SP3 pattern.
- Delta duty: describes the maximum change in pulse width.
- ISI low: amplitude deviation of SP3 pulses form steady state B0.
- ISI High: amplitude deviation of SP3-pulses form steady state B1.

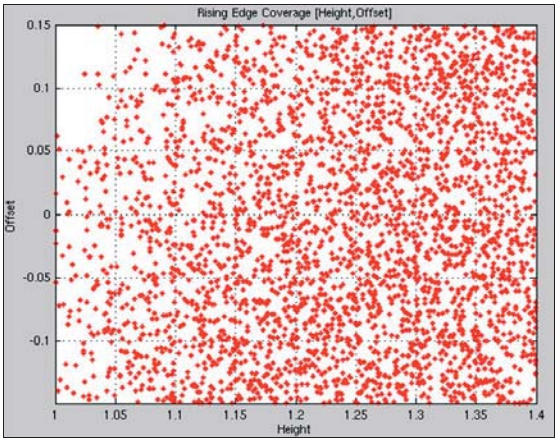

**Figure 6. Rising edge cross-coverage for height and offset.**

As the determination of the worst-case pattern cannot be done analytically, all simulated patterns need to be investigated with respect to their coverage. Different plots are provided to analyze and to visualize the coverage for the rising and falling edges as well as for the cross-coverage of the combined edges (**figure 6**). In case of lacks in coverage, additional simulation runs with closed parameter bounds can be performed.

The simulation was performed for worst case POF conditions to find extreme input conditions for the optical receiver. The chosen cut-off frequency represents the maximum specified fiber length of 15 m and a numerical aperture of 0.5 for the launching condition at the fibers input.

Due to the low-pass nature of the POF, degradation in transition times is visible. In extreme scenarios ISI was observed. Here, slow transition times are the root cause for reduced amplitude swing with short pulses, while longer pulses still achieve full amplitude swing.

These effects may have negative impact on the conversion in the optical receiver following the POF. Signal/noise-ratio is directly degraded by ISI, additional jitter may be generated in the optical electrical conversion due to the slow transitions and ISI. A direct influence on signal timing due to the POF's bandwidth limitations was also detected. For instance, SP2 patterns with significant overshoots are supporting pulse spreading for positive pulses, which end up in a notable increase in DCD.

The detailed results of the simulation give indications on parameter variation and worst case scenarios. It also delivers SP3 test patterns which can be used for testing of optical receivers. *bg*

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