# IEEE802.3aq Channel model ad-hoc

## Task2: TP3 - ISI Generator Block for Stressed Sensitivity Test

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# 1. ISI Generator Block for Stressed Sensitivity Test

**Initial Goals**

- different impulse response shapes will exercise actual equalizers in different ways, more than one "synthetic" stressor will likely be needed,
- PIE-L and PIE-D are a good metric for fiber and stressor pulse response evaluation,
- we can group the modelled channel responses into groups such as precursor-heavy, quasi-symmetrical, and postcursor-heavy (can be a mirror image of precursor-heavy),
- analysis of three possible implementations (BT LPF, two peak impulse response, and three peak impulse response) as proposed in [aronson_2_0704],
- define reference fibre pulse response to be used for analysis based on available channel models (see Note 1),
- define optimum pulse shape to be used for two or three peak impulse response,
- find a minimum range of values for A1, A2 and $\Delta t$ and A0, A1, A2, $\Delta t1$ and $\Delta t2$, respectively, that will satisfy the majority of impulse response as defined by the channel model.

Note 1: We have to start with a limited number of selected fibres in order to understand the feasibility of implementation and how many sets of variables have to be defined. We can decide if we want to cover all channels or limited number of significant cases, based on the complexity and importance. The selected fibres are used to evaluate and validate the methodology. Depending on the evaluation results, a separate work is needed to define the actual fibre models.

Note 2: A detailed analysis, based on the initial goals, has been presented in the conference calls and the results can be found in channel_tp3.pdf.

# 2. ISI Generator Block for Stressed Sensitivity Test

## Evaluation methodology

- evaluate the possibility of using a BT LPF for ISI generator block.
- select a limited number of fibres with performance at the limit allowed in the current link budget. I will use representative fibres from the 65 fibres (Cambridge model, 300m) having PIE-L values between 4 and 5 dB).
- the final evaluation will have to include representative fibres selected from channel model group results at the target distances.
- use pulse shapes that can be generated in the lab with minimal new equipment.
- optimize A1, A2, and $\Delta t$ (A0, A1, A2, $\Delta t1$ and $\Delta t2$) for minimum square error (MSE), with reasonable resolution (2 or 3 digits).
- the optimization will be based on minimizing the peak error (errpk) and the relative error signal area (PSR)

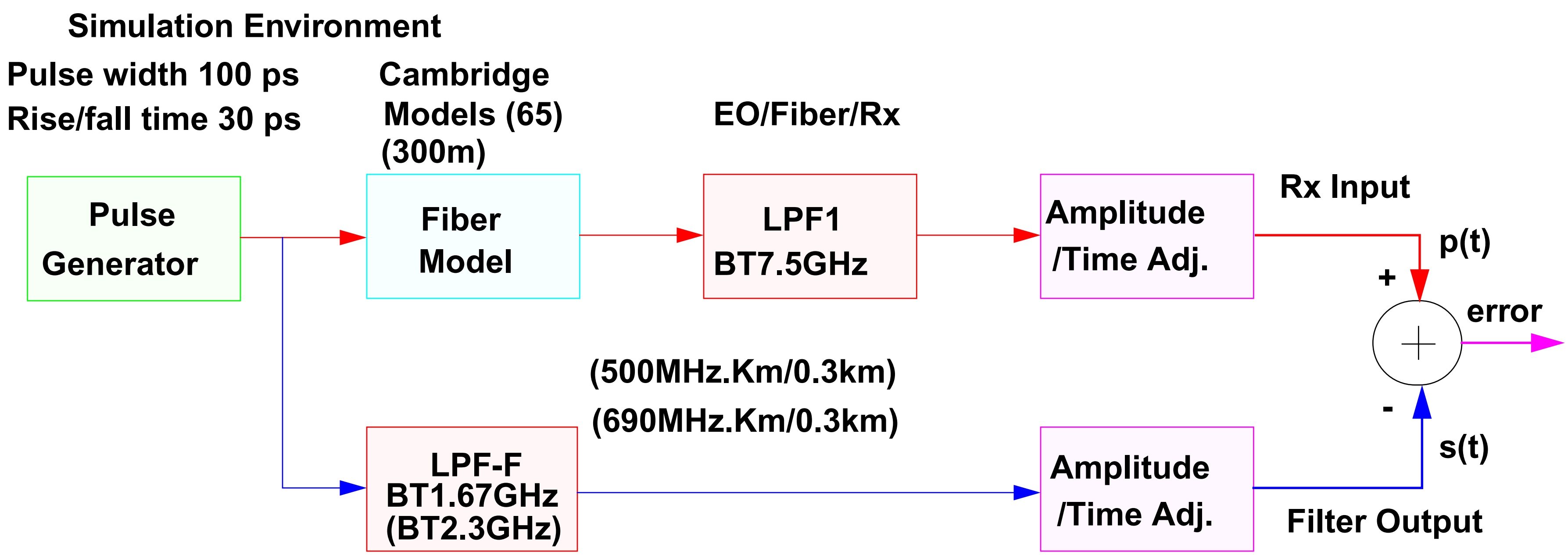
$$errpk = \frac{|p(t) - s(t)|_{pk}}{|p(t)|_{pk}}$$

, where p(t) is the fibre pulse response and s(t) is the stressor

$$PSR = 10x\log\left(\frac{\int_t |p(t)|^2 dt}{\int_t |p(t) - s(t)|^2 dt}\right)$$

- the initial resolution step for $\Delta t$ is 5ps.
- for a given set of amplitudes and delay times, we can calculate the effective errpk and PSR.

# 3. BT Low Pass Filter Option

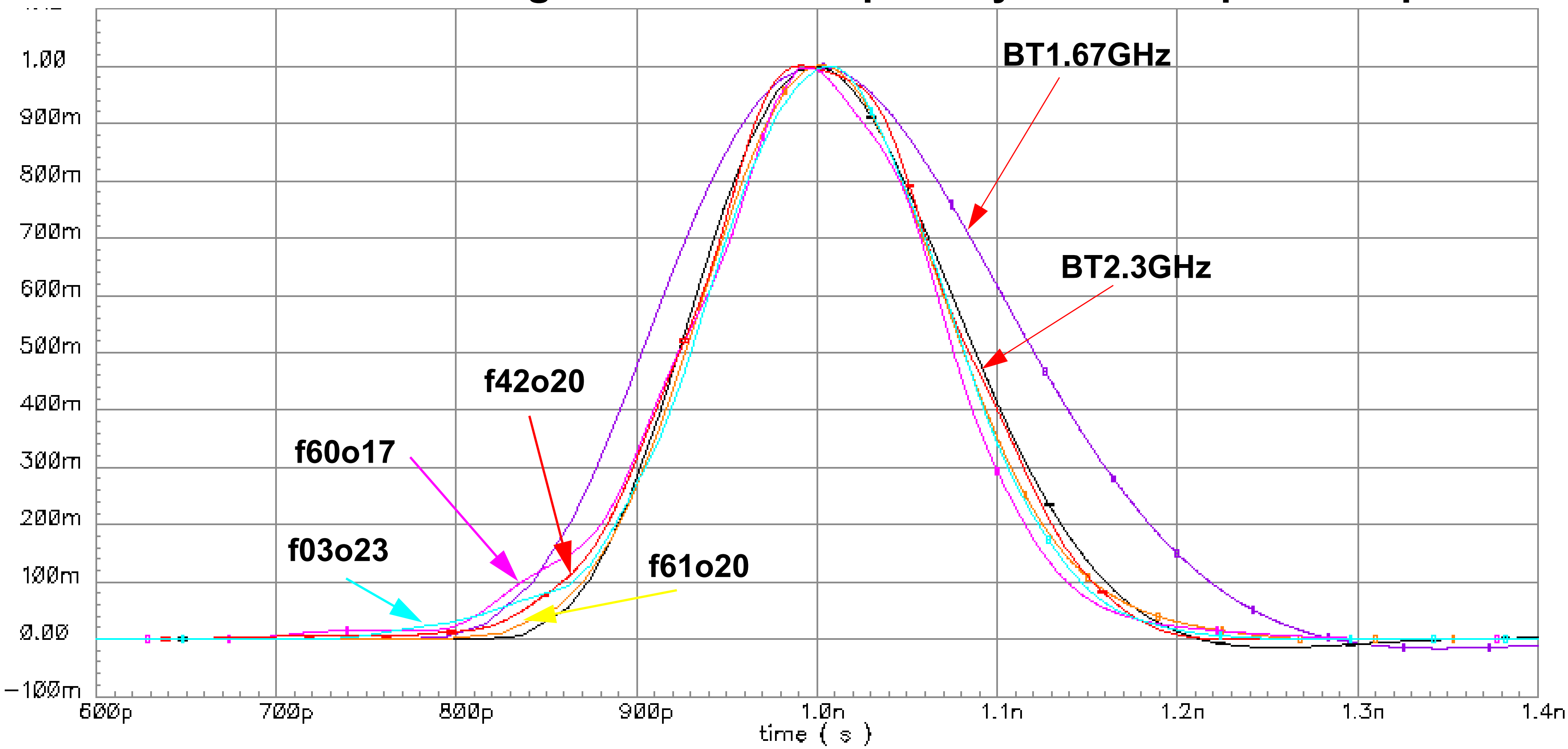



- Two simulations using selected models based on PIE-L value 4 to 5 dB and quasi-symmetrical impulse response, and two low pass filters (BT1.67GHz and BT2.3GHz).

**Note: The second Low-Pass Filter (BT7.5GHz LPF) is not needed, the fiber emulator filter (LPF-F) has a much lower bandwidth.**

- The amplitudes and timing are adjusted for minimum error value and minimum error signal area.
- The error signal is evaluated relative to the signal peak amplitude (%) and signal area relative to the error signal area (PSR).
- The synthesised stressor signal, s(t), includes the pulse shaping and E/O conversion.

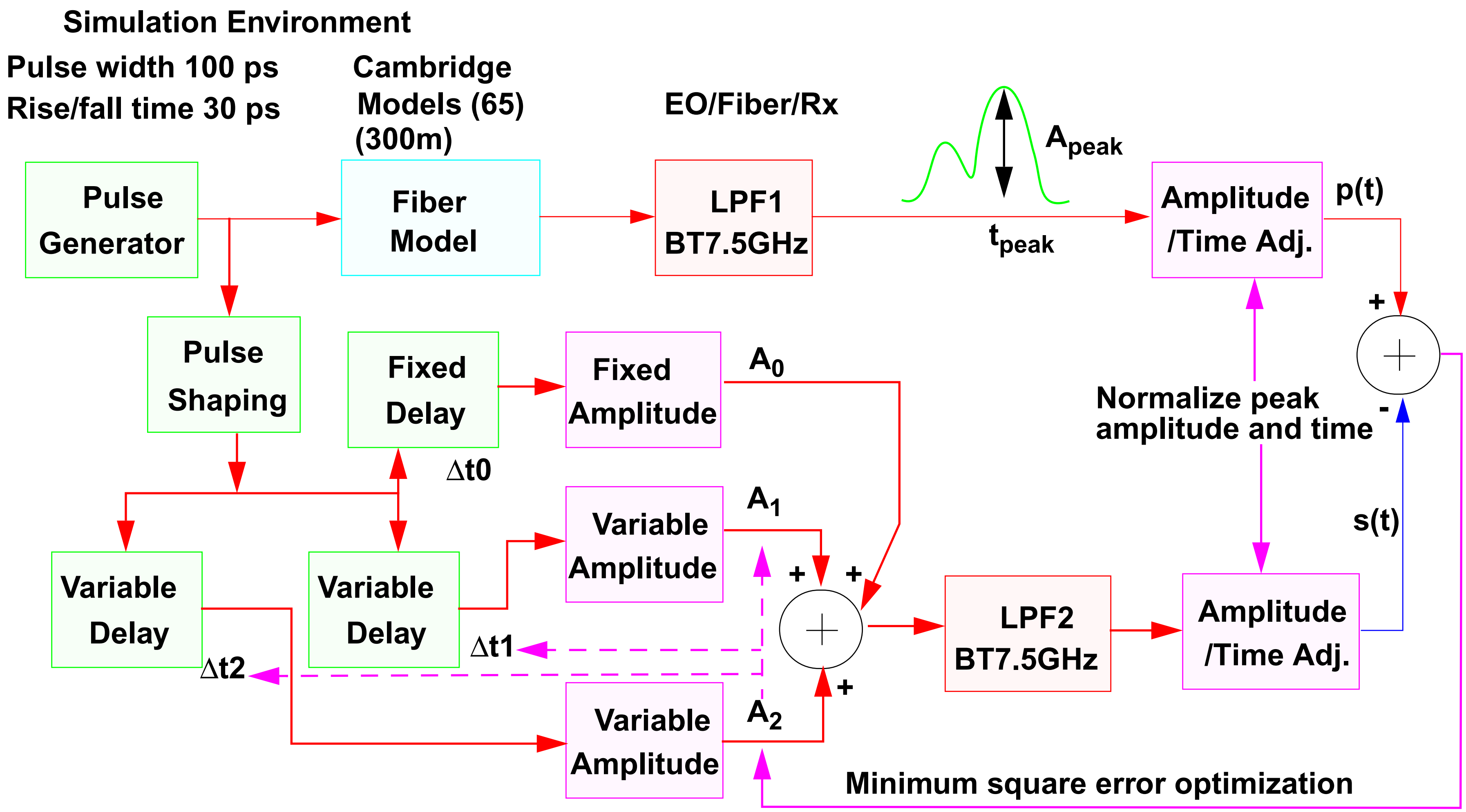
# 4. ISI Generator Block using BT Filters and quasi-symmetrical pulse response




- For quasi-symmetrical pulse response fibres, the filter approximation BT1.67GHz is to pessimistic.
- The error for filter approximation using BT2.3GHz

| Fiber model | f03o23 | f42o20 | f60o17 | f61o20 |
|---|---|---|---|---|
| Peak Error | 8.6% | 7% | 12% | 6% |
| PSR | 19.7dB | 23.2dB | 16.1dB | 23.2dB |

# 5. Three peak impulse response ISI generator block




- There are three delay blocks in the simulation environment. We can adjust Δt1 and Δt2 relative to Δt0 such that the two peaks can be symmetrical relative to the main pulse $A_0$, or on the same side (pre-cursor or post-cursor).
- The synthesised stressor signal, s(t), includes the pulse shaping and E/O conversion.

# 6. ISI Generator Block using Three Peak Impulse Response Approximation

- The simulation environment is shown in slide 4.
- The pulse shaping circuit is a Low Pass Filter BT 9 GHz, forcing the rise and fall times (20% to 80%) to be ~30 ps.
- Two Low Pass Filters (LPF1 and LPF2) BT 7.5 GHz are used to model the receiver (ROSA). The pulse responses and the respective synthesised pulse responses are evaluated at the receiver output.
- The optimization algorithm is based on minimum square error, or maximum PSR as defined on slide 3. If more than one set of values is found, the set of values with minimum peak error (errpk, as defined in slide 3) will be used.
- Two sets of values, normalized forcing $A_0$ to 1, and $A_1$ and $A_2$ lower than 1 (no amplification) and normalized forcing $A_0$ to 1 and $\Delta t_0$ to 0, as proposed in [aronson_2_0704], have been discussed.
- One alternative is to select only a limited number of pulse responses (possible 3, quasi-symmetrical, post-cursor and pre-cursor type pulse response) and have the ISI block generator with fixed delays and amplitudes.

| Fiber | type | A0 | A1 | A2 | $\Delta t_0$ [ps] | $\Delta t_1$ [ps] | $\Delta t_2$ [ps] | PSR [dB] | P_LE error | P_DFE error |
|---|---|---|---|---|---|---|---|---|---|---|
| f18o17 | post-cursor | 1 | 0.51 | 0.325 | 0 | 110 | 240 | 18 | +12% | +10% |
| f48o17 | pre-cursor | 1 | 2.907 | 1.39 | 0 | 280 | 155 | 15 | +22% | %14% |
| f42o20 | symmetrical | 1 | 1.063 | 0.606 | 0 | 60 | 115 | 21 | -8% | -7% |

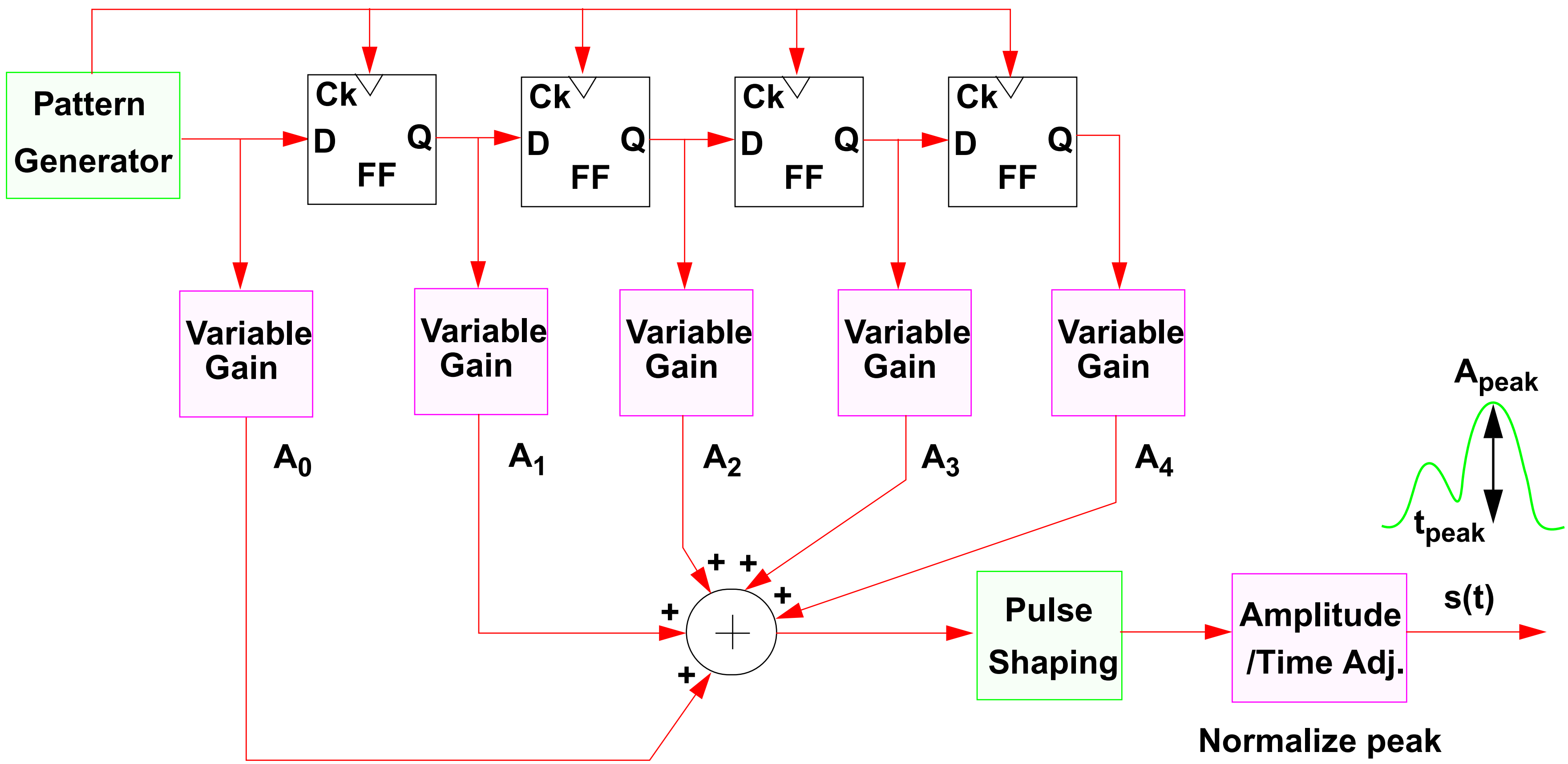
- This is a summary of results reviewed in the conference calls (channel_tp3.pdf, posted in the public area). The results have shown that is possible to generate the desired impulse response using three peak ISI generator block.
- In the conference call, a request was made to find a solution that has fixed delays and variable amplitudes. This solution will be presented in the following slides.

# 7. ISI Generator Block Using Fixed Delay and Variable Amplitudes

- The ISI Generator Block implementation can be simplified using fixed delays. One simple implementation is to use 1 UI delay circuits.
- The implementation becomes more robust if we use flip-flops to implement the delay circuits. The results are less dependent on the instrument used. The stressor generation is fully controlled in the ISI generator block.
- The amplitude error will have a single source (variable gain stages) and will can be better controlled.
- A calibration procedure is easy to define and implement.
- The precursor-heavy and postcursor-heavy type impulse responses of interest (PIE_L between 4 and 5 dB) have a pulse width of ~ 5 UI. The most accurate implementation will require five pulses.
- The analysis will review the results for 3, 4, and 5 pulses.
- The optimization will be based on minimizing the peak error (errpk) and the relative error signal area (PSR), same as the optimization algorithm used for three peak ISI Generator Block.
- The P_LE and P_DFE comparison (fiber pulse response and stressor pulse response) will be reviewed for evaluation.

# 8. DFE Based ISI Generator Block for Stressed Sensitivity Test

## Simulation Environment




Normalize peak amplitude and time

- The analysis will include three ($A_4$=$A_3$=0), four ($A_4$=0) and five taps stressor generation.
- Minimum square error will be used for optimization.
- The pulse shaping circuit will be the same BT 9GHz, forcing rise and fall times (20% to 80%) to be limited to ~30 ps and having good phase linearity for no additional pattern dependent jitter.
- The synthesised stressor signal, s(t), includes the pulse shaping and E/O conversion.

# 9. Optimization Results

Table 1: Five taps stressor results

| Fiber | type | $A_0$ $\Delta t=0$ | $A_1$ $\Delta t=1$ UI | $A_2$ $\Delta t=2$UI | $A_3$ $\Delta t=3$ UI | $A_4$ $\Delta t=4$ UI | PSR [dB] | P_LE error | P_DFE error |
|---|---|---|---|---|---|---|---|---|---|
| f18o17 | post-cursor | 1 | 0.39 | 0.25 | 0.125 | 0.047 | 25.9 | -8% | -7% |
| f48o17 | pre-cursor | 0.077 | 0.19 | 0.282 | 0.41 | 1 | 19 | +2% | -3% |
| f42o20 | symmetrical | 0 | 0.19 | 1 | 0.45 | 0 | 18.3 | +26% | +19% |

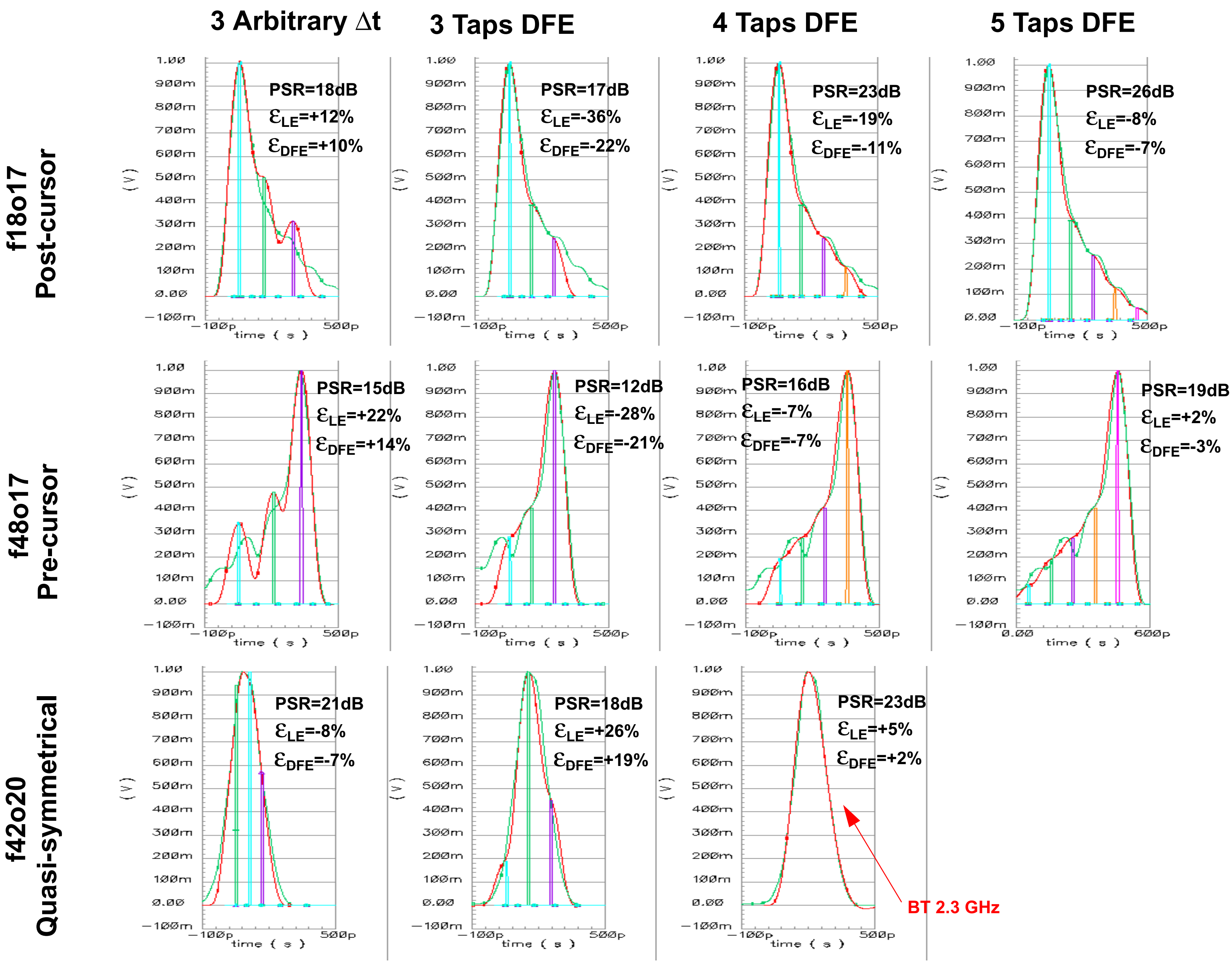
Table 2: Four taps stressor results

| Fiber | type | $A_0$ $\Delta t=0$ | $A_1$ $\Delta t=1$ UI | $A_2$ $\Delta t=2$UI | $A_3$ $\Delta t=3$ UI | PSR [dB] | P_LE error | P_DFE error |
|---|---|---|---|---|---|---|---|---|
| f18o17 | post-cursor | 1 | 0.39 | 0.25 | 0.125 | 23 | -19% | -11% |
| f48o17 | pre-cursor | 0.19 | 0.282 | 0.41 | 1 | 16.5 | -7.2% | -7.2% |
| f42o20 | symmetrical | 0 | 0.19 | 1 | 0.45 | 18.3 | +26% | +19% |

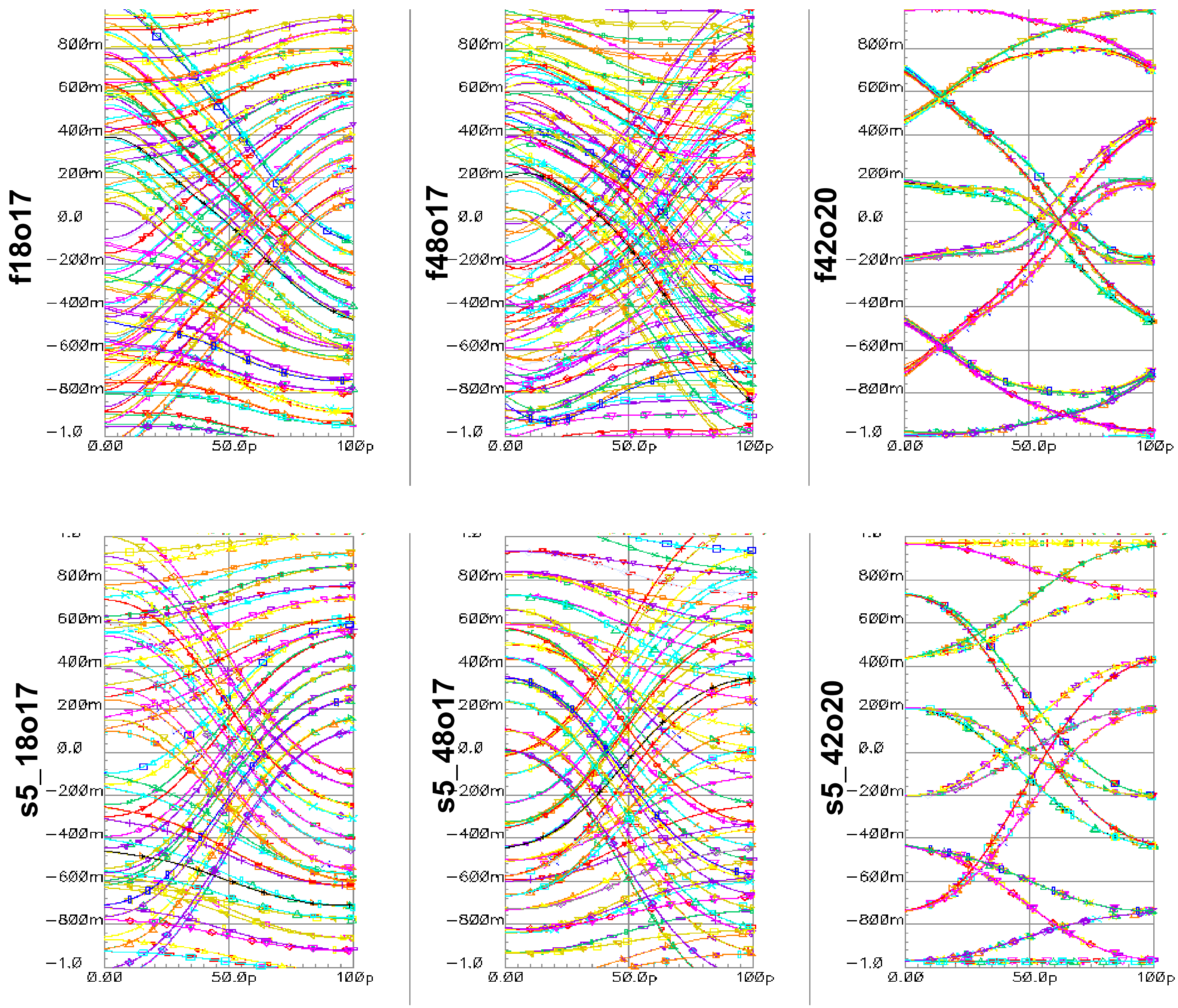
Table 3: Three taps stressor results

| Fiber | type | $A_0$ $\Delta t=0$ | $A_1$ $\Delta t=1$ UI | $A_2$ $\Delta t=2$UI | PSR [dB] | P_LE error | P_DFE error |
|---|---|---|---|---|---|---|---|
| f18o17 | post-cursor | 1 | 0.39 | 0.25 | 17 | -36% | -22% |
| f48o17 | pre-cursor | 0.282 | 0.41 | 1 | 12.6 | -28% | -21% |
| f42o20 | symmetrical | 0.19 | 1 | 0.45 | 18.3 | +26% | +19% |

# 10. Stressor (red) and Fiber (green) Pulse Response



# 11. Fiber and Stressor (5 taps) Eye Diagrams (PRBS $2^7$-1)



# 12. Summary

- The analysis presented in this contribution assumes that the stressed sensitivity test must be based on pulse responses reproducing the actual fiber model pulse response. Based on this assumption, three types of pulse response have been defined: precursor-heavy, quasi-symmetrical, and postcursor-heavy
- An optimization methodology, based on minimum square error and minimum peak error, has been developed and used to evaluate different solutions for ISI Generator Block for Stressed Sensitivity Test. A measure of the accuracy (PSR) was defined.
- A group of fibres, having the PIE_L between 4 and 5 dB, has been selected from the Cambridge models (65 fibres, 300m) to investigate the accuracy of stressor pulse response synthesis.
- The forth order low pass filter BT 2.3 GHz is a good approximation for quasi-symmetrical pulse response fibres, with PSR values between 16 dB and 23 dB.
- Three peak impulse ISI block generator can be used for stressed sensitivity test, assuming that the delays and amplitudes can be made programmable.
- A summary of simulation results using a five, four, and three tap DFE based ISI generator block for stressed sensitivity test and three fibre pulse responses (precursor-heavy, quasi-symmetrical, and postcursor-heavy) have been presented.
- The results for the three tap stressor generator are marginal. Adding the fourth tap, results in significant improvement for precursor-heavy and postcursor-heavy type pulse response. As expected the five tap DFE gives the best results.

# 13. Conclusions and Future Work

## Conclusions

- Three ISI types of signals are needed for stressed sensitivity test.
- The five tap ISI generator block gives the overall best performance and flexibility. It has the advantage of simple and robust implementation with good calibration and reproducibility capability. On my opinion, is the best candidate for ISI generator block.
- The five tap ISI generator block, shown in slide 9, can be used also for jitter tolerance and noise sensitivity test.
- The resolution of the five tap ISI generator block can be used for continuous changes in the pulse response, from precursor-heavy through quasi-symmetrical to postcursor-heavy including intermediate pulse responses, for adaptation speed test. On my opinion, the adaptation speed test requires to move the pulse response between ISI maximum limits.

## Future Work

- Evaluate the accuracy of the optimization methodology for various pulse response types as defined by the Channel Model Group, and make the required improvements.
- Define the ISI limits based on the results from Channel Model Group.
- Improve the ISI Generator Block for stressed sensitivity test to include the results from the Time Variation and Modal Noise Study Group.