DMT measurement considerations
part 2: Receivers

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DMT Receiver Test Challenge

• Complete solution includes analysis of both the receiver and the transmitter
• Transmitter test discussed July 2014:

→ This presentation: *Focus on generation of electrical test signals*

Similar to analysis of DMT signals (required real-time analysis and significant post processing and analysis), generation of DMT test signals requires instrumentation very different from familiar tools used for simple intensity modulated systems.
DMT Receiver Test Challenge

- Electrical test signals can be generated using an arbitrary waveform generator (AWG), effectively a digital to analog converter (DAC).

- Optical signal generation requires an additional directly modulated laser or cw laser in combination with an intensity modulator (see example below for a typical DMT time domain signal).

![Diagram of DMT system](image)

picture source: IEEE802.3 Norfolk interim meeting, Fujitsu presentation

![Typical DMT signal](image)
DMT Test Transmitter Requirements

- To generate the signals the bandwidth of the digital-to-analog-converter (arbitrary waveform generator) should be at least the bandwidth of the DMT signal.

- AWG vertical resolution equal to the resolution of the real DMT transmitter considered to be sufficient (typically 8 bit)

- Sampling time to be able to encode $n_{\text{Sym}}$ DMT symbols ($n_{\text{FFT}} = \text{FFT size}$)

\[
t_{\text{sampling}} = \frac{1}{f_{\text{DAC}}} \cdot n_{\text{Sym}} \cdot n_{\text{FFT}} \cdot (1 + r_{\text{prefix}})
\]

- required number of samples

\[
n_{\text{sampling}} = f_{\text{ADC}} \cdot t_{\text{sampling}}
\]

DMT signal example:

- $n_{\text{Sym}} = 50$
- $n_{\text{FFT}} = 512$
- $f_{\text{DAC}} = 63 \text{ GS/s}$
- $r_{\text{prefix}} = 16/512$
- $t_{\text{sampling}} = 419 \text{ ns}$
- $f_{\text{ADC}} = 63 \text{ GS/s}$
- $n_{\text{sampling}} = 26400$
DMT Signal Synthesis Software

- Generation of DMT signals requires knowledge of bit allocation, subcarrier allocation, FFT size, cyclic prefix, system sampling frequency, and other parameters.

- Testing of the DMT link start sequence should be carefully defined or even removed from the test requirements to simplify implementation on general purpose arbitrary waveform generators.

- Until we have a standard, a **general purpose** DMT signal synthesis software (e.g. Matlab) in conjunction with an arbitrary waveform generator is used to generate the signals.
DMT Signal Synthesis Fundamentals

- Generate the bit stream (either a PRBS, random data or a special pattern defined in the standard) either per subcarrier or for all subcarriers together

- Convert per subcarrier the digital symbols into the complex amplitudes of each subcarrier, add pilot symbols as defined

- Calculate the inverse Fourier transformation to yield a real valued time domain waveform of the DMT symbol

- Add cyclic prefix to each DMT symbol

- Concatenate the DMT symbols
DMT Signal Measurement
114 Gbit/s electrical single lane back-to-back transmission

Example (Simulation)
- 63 GS/s system frequency
- complex FFT Size 512
- variable bit allocation
- colors encode modulation from QAM 64 (green), QAM 32 (dark blue), QAM 16 (light blue), QAM 8 (red) to QPSK (orange)
- two pilot tones (QPSK, white)
- ADC sampling frequency 80GS/s, 8 bit vertical resolution

Traces (top row)
A: constellation (all SCs)
F: received data stream
E: Data Info
G: Quality Metrics

Traces (bottom row)
H: Error Vector vs. Time
C: Error Vector vs. Frequency
B: Received Spectrum
D: Received Time Domain Signal
DMT Receiver Measurement Conclusions

- DMT Signals can be generated using high speed arbitrary waveform generators.
- Arbitrary waveform generators with sufficient sample rates for 400 Gb/s DMT are becoming available.
- If 802.3bs employs DMT, analysis is simplified if specific test modes are allowed that minimize or do not require link training to achieve a specific transmitter state.
Signal Synthesis for PAM-X

- For PAM-4 and PAM-8 commercial solutions based on high speed BERTs are available, but signals can also be generated using AWG technology.
- Generation of PAM-X signals requires knowledge of the number of signal levels, symbol rate, and possibly time domain pulse shaping if applicable.
- Transmission of 400 Gbit/s using e.g. PAM-4 requires an aggregate symbol rate of 200 Gbaud or 4 x 50 Gbaud or 8 x 25 Gbaud.
- PAM-X signals can be generated using high speed AWG’s for symbol rates up to 32 Gbaud today.
- Signal impairments like ISI, Jitter, or level interference can be easily added.
PAM-X Signal Generation using an AWG

- Adding impairments without external hardware
  - Transition times, ISI, Jitter, DCD, noise, …
- Clean & distorted signals up to 32 Gbaud

Variable transition times

Variable jitter

Variable ISI

Combination of impairments
Conclusion

• DMT and for PAM-X signals can be generated using high speed arbitrary waveform generators

• Support will be provided to the standard development to ensure testability of the signals.