DMT Measurement Considerations

Test & Measurement of Multilevel Signals for 400 GbE Discrete Multi-Tone and PAM-X

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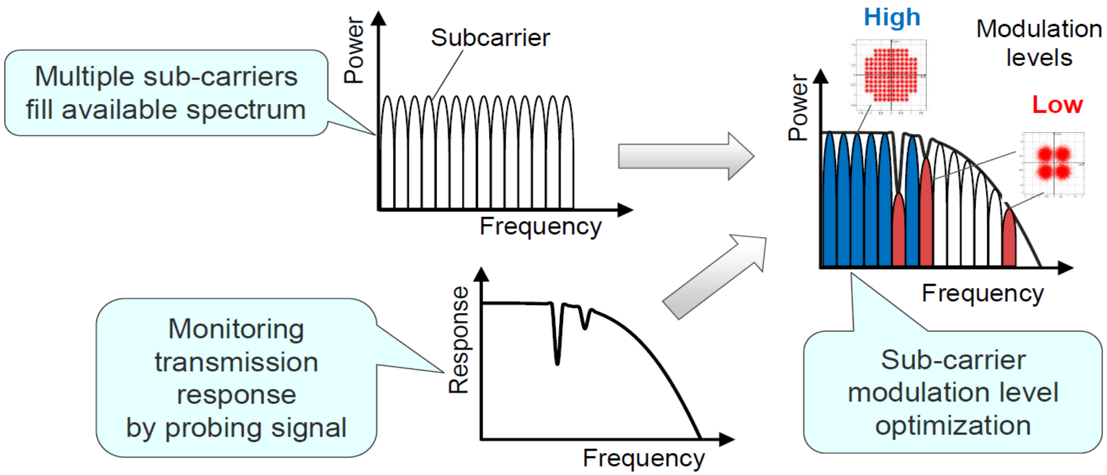
Principle of DMT (Recap)

- DMT (Discrete Multi-Tone) aka OFDM (Orthogonal Frequency Division Multiplex) is widely used in wireline (ADSL, VDSL, G-fast) or wireless (DAB, DVB-T, WLAN, 3GPP LTE, WiMAX, ...)
- Effective usage of impaired channels by the use of orthogonal subcarriers with individual bit and power allocation
- Test Solutions for standardized formats are available today



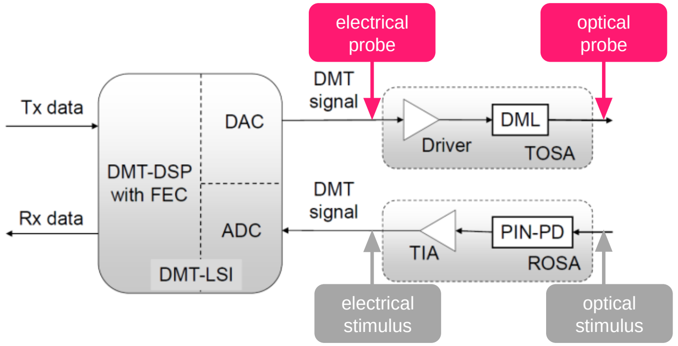
picture source: IEEE302.3 Norfolk interim meeting, Fujitsu presentation

DMT Test Challenge

- Complete solution includes analysis of both the receiver and the transmitter

➢ This presentation: ***Focus on characterization of the transmitter***

- Either optical or electrical signals can be acquired using a real time scope (see example below for a typical DMT time domain signal)



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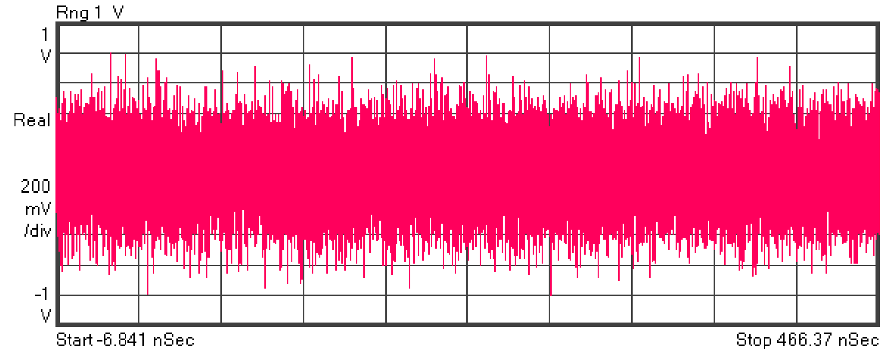


typical DMT signal

Conclusion: The raw measurement in time domain yields very limited information aside from an upper-bound to the optical modulation amplitude!

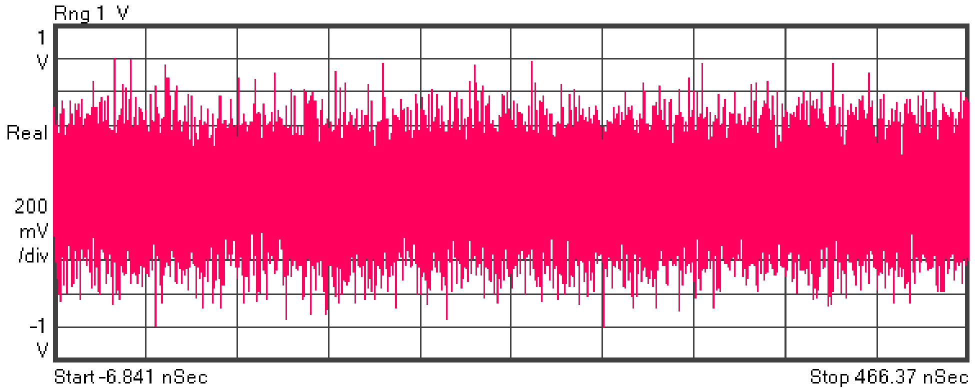
Useful information is obtained through post processing the time record

DMT Test Receiver Requirements

- To receive the signals the bandwidth of the digitizer (real-time sampling scope) should be at least the Nyquist frequency of the DAC that was used to generate the DMT signal.
  For a 63 GS/s DAC (number from JDSU's presentation) the bandwidth of the digitizer should be ≥ 31.5 GHz
- Scope vertical resolution equal to the resolution of the DAC generating the signals is considered to be sufficient (typically 8 bit)
- Sampling time to be able to decode n_{Sym} DMT symbols (n_{FFT} = FFT size)

  $t_{sampling} = 1/f_{DAC} \cdot n_{Sym} \cdot n_{FFT}$
- required number of samples

  $n_{sampling} = f_{ADC} \cdot t_{sampling}$



DMT signal example:

$n_{Sym} = 50$
$n_{FFT} = 512$
$f_{DAC} = 63$ GS/s

$t_{sampling} = 406$ns

$f_{ADC} = 80$GS/s
$n_{sampling} = 32480$

DMT Analysis Software

- Physical layer testing and analysis of DMT signals requires to know bit allocation, subcarrier allocation, FFT size, cyclic prefix, system sampling frequency, and other parameters
- Without standardization any DMT link start sequence should be excluded from physical layer testing

➢ **Because we are lacking a standard a <u>general purpose</u> DMT (OFDM) decoder is required to be able to analyze the signals**

DMT Analysis fundamentals

- Resample the data to the DMT system sample frequency
- Find the FFT frames using a suitable synchronization method (for non-bursted signals w/o preamble take advantage of cyclic prefixing of the FFT frame)
- FFT on raw waveform record, the resulting coefficients are the raw complex amplitudes of each subcarrier
- Add a linear phase (mathematically equal to adjusting the sampling phase) to correct the phase of the known pilots
- Equalize for amplitude and phase response, take advantage of the fact that the modulation is known for pilots and data subcarriers
- Extract quality metrics like EVM
- Virtually identical to methods used to analyze signals in LTE, WLAN 802.11, WiMAX 802.16
- Analysis tools already exist and require minor modification for DMT analysis

DMT Analysis Results

Typical results available from T&M OFDM decoders

- constellation diagram per subcarrier (SC)
- channel response (amplitude and phase from equalizer)
- received spectrum and time domain waveform
- received data stream (→ path to BER testing)
- error vector magnitude (EVM) vs. time
- EVM per SC
- ...

For physical layer testing EVM is a widely used metric also in other OFDM based standards

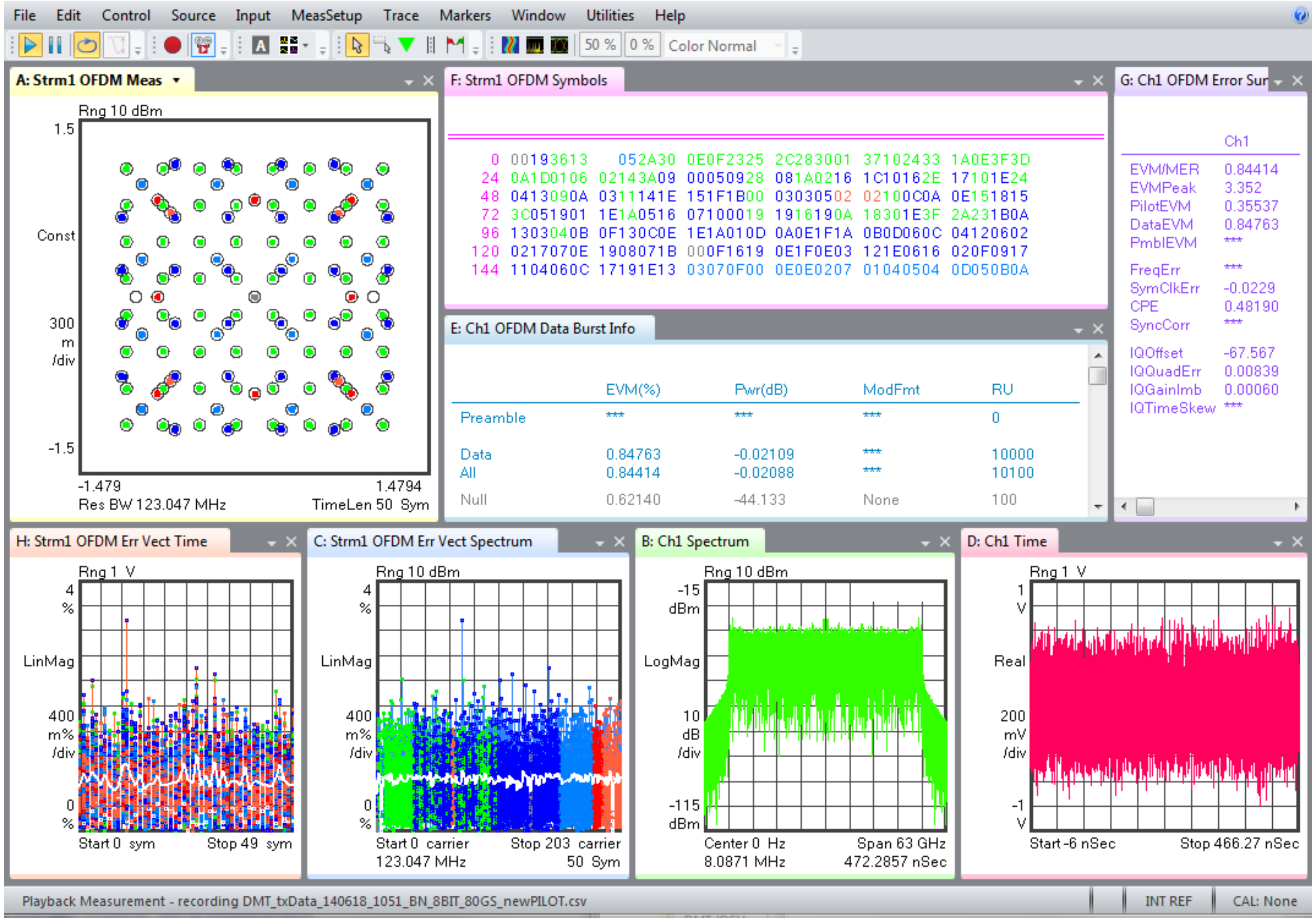
DMT Analysis Software Example

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



Note: Analysis performed using existing software analysis tools

DMT transmitter measurement conclusions

- DMT signals require different test and analysis methods compared to more common optical communications signals
- Existing test solutions developed for similar technologies can be leveraged for DMT analysis
- 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

Extending DMT measurement process to PAM

- Physical layer testing and analysis of PAM-X signals requires knowledge of the number of signal levels, symbol rate, and possibly time domain pulse shaping if applicable
- Oscilloscopes will evolve to provide fundamental PAM-N analysis as system and component designers along with T&M providers determine essential metrics

➢ DMT analysis process configured with available custom IQ decoders allows PAM-X decoding

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PAM-X Analysis Results

Typical results available from T&M Custom IQ decoders

- channel response (amplitude and phase from equalizer)
- received spectrum and time domain waveform
- received data stream (→ path to BER testing)
- magnitude error vs. time
- SNR
- Likely provides a complementary set of measurements to those provided by sampling and real-time oscilloscopes

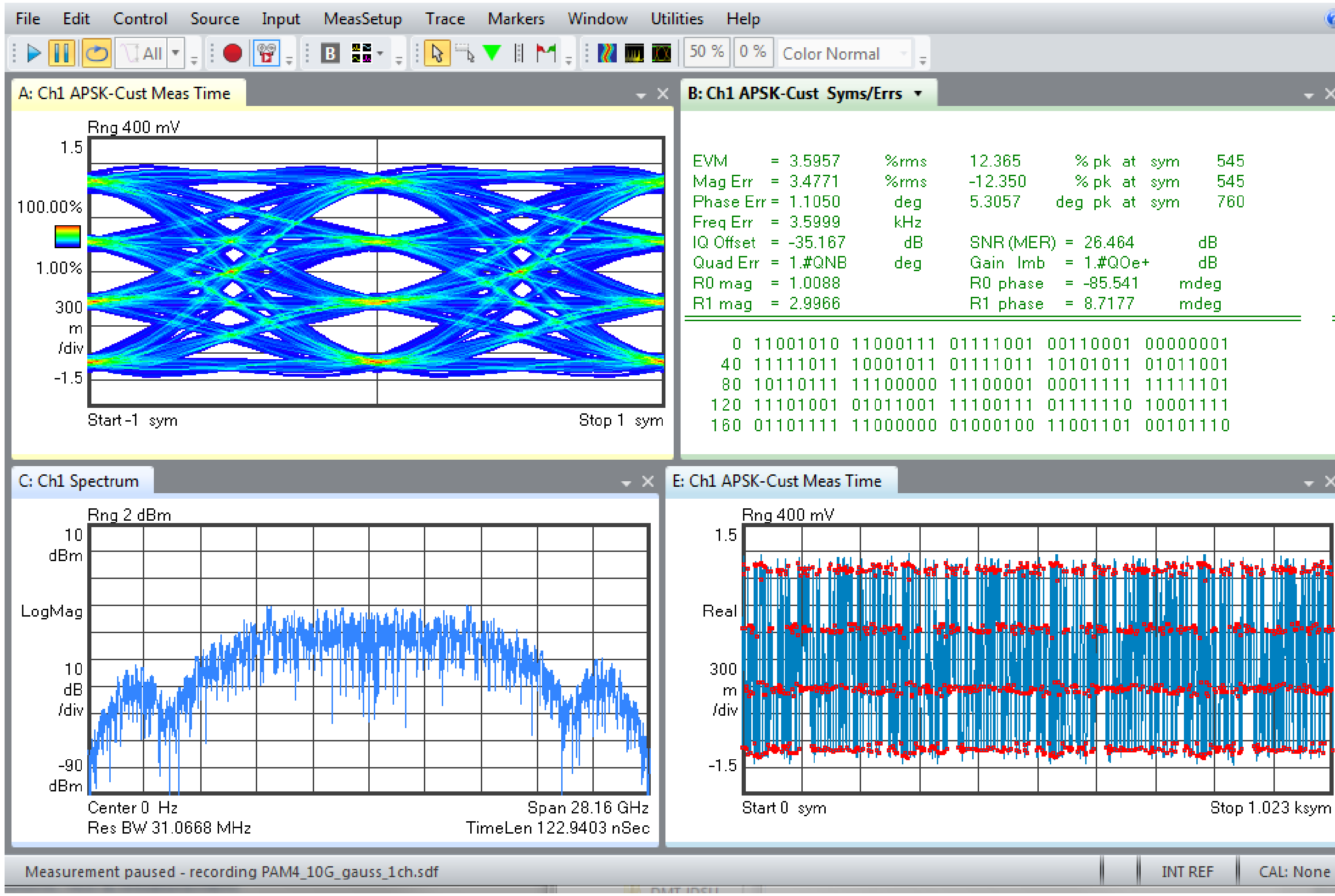
PAM-4 Analysis Software Example

Example (Measurement)

- 10 GBaud symbol rate
- NRZ-OOK with no pulse shaping

Traces (top row)
A: Color coded eye diagram
B: signal metrics and received data stream

Traces (bottom row)
C: Received signal spectrum
E: Received Time Domain Signal



Note: Using existing software tools

Conclusion

- Test and solutions for DMT signals are available today (and can be extended to PAM-X)
- Support will be provided to the standard to ensure testability of the signals.