PDV/MPDV APPs

Modeling Tools to Predict System Performance for Design and Experimentation

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Purpose: To predict system performance

What do we mean by system performance?

- **Sensitivity** … *Do we have enough optical (return) signal to see anything on the spectrogram (i.e., are we above the noise floor?)*?
- **Signal-to-noise ratio** … *How far above the noise floor is the anticipated optical signal?*

What can we apply this to?

1. **Fielding.** Given a PDV/MPDV system deployed to an experiment, the experimenter would like to know what kind of signal levels they can expect. ➡️ SHOT APP

2. **Design.** Design an MPDV system to your needs. ➡️ DESIGN APP
Architecture – progression of PDV to MPDV

Basic geometry and components that determine performance

PDV

Circulator

Detector

Digitizer

Detector + Digitizer
Architecture – progression of PDV to MPDV

Basic geometry and components that determine performance

PDV

- Circulator
- Detector
- Digitizer

Amplified PDV

- EDFA
- Filter
- Detector
- Digitizer

Digitizer + Detector

Digitizer + Detector + EDFA
Architecture – progression of PDV to MPDV

Basic geometry and components that determine performance

- **PDV**
  - Circulator
  - Detector
  - Digitizer
  - Digitizer + Detector

- **Amplified PDV**
  - Detector
  - EDFA
  - Filter
  - Digitizer

- **MPDV**
  - Detector
  - EDFA
  - Filter
  - τ
  - Local oscillator lasers allow heterodyne shift
  - \( V_{\text{ITU}} + \Delta V \)
  - Digitizer + Detector + EDFA + N x τ
**Dynamic Range: Scope**

Definition of dynamic range:
Full-scale power [dBm] minus minimum detectable signal [dBm]

For ‘minimum detectable signal’ at the digitizer, we need to measure PSD[dBm/Hz] and then convert to P[dBm] using the RBW[Hz]. We show 50 MHz as a typical value.

\[
\text{PSD} = \text{Power Spectral Density (dBm/Hz)}
\]
Dynamic Range: Scope & Photodetector

We expect the full-scale power to be the same in most cases.

\[ \text{RBW [Hz]} = 50 \text{ MHz} \]

We expect the noise floor and minimum detectable signal to vary depending on the PSDs of components in the system.

PSD = Power Spectral Density (dBm/Hz)
Dynamic Range: Scope, Detector & EDFA

PSD = Power Spectral Density (dBm/Hz)

Minimum detectable signal AT THE SCOPE increases; however, optical sensitivity (i.e., detection of photons returned from the target surface) may improve with application of EDFA.
Dynamic Range: Scope, Detector, EDFA & Multiplexing

We expect the noise floor to increase due to additional noise sources from MPDV multiplexing; LocOsc – ASE noise will typically dominate.

PSD = Power Spectral Density (dBm/Hz)
Today let’s look at **Sensitivity**: the Pmin APP

**What is the minimum optical power (Pmin) necessary to detect a signal, that is SNR = 1?**

**Calculate the Noise Floor**

We expect the noise floor to increase due to additional noise sources from MPDV multiplexing; LocOsc – ASE noise will typically dominate.
Let’s define Sensitivity and Visibility

Visibility: User-defined threshold for signal detection, $\text{SNR} > 1$

Sensitivity: $\text{SNR} = 1$

FFT Amplitude vs. Frequency
Inputs for Pmin APP

Pmin = minimum optical power reflected from the target surface (returning to the PDV/MPDV) necessary for SNR = 1. **THIS IS WHAT IS CALCULATED!**

**INPUTS**

Detector & Digitizer: noise floor PSDs, range responsivity, bandwidths, and sample rate

```
PDV

Circulator

Detector

Digitizer

Pmin

Return (Doppler-shifted) optical signal from target surface

This is what we’re calculating
```
Inputs for Pmin APP

**CALCULATE:** \( P_{\text{min}} = \text{minimum optical power for SNR} = 1 \)

**INPUTS**
- EDFA: Gain & Noise Figure
- Optical Filtering: optical bandpass
Inputs for Pmin APP

**CALCULATE:** $P_{\text{min}} = \text{minimum optical power for SNR} = 1$

**INPUTS**
- Local Osc Power
- Time delays ($\tau$) & associate fiber optics: Insertion Losses (IL) following EDFA

Diagram:
- PDV
  - Circulator
  - Detector
  - Digitizer

- Amplified PDV
  - Detector
  - Digitizer

- MPDV
  - EDFA
  - Filter
  - Local Oscillator
  - Optical Power
  - IL
**What does the APP look like?**

**Pmin SHOT APP**


**Variables:** system insertion loss (following EDFA), EDFA gain, & Photo-diode Responsivity

<table>
<thead>
<tr>
<th>OPTICAL SYSTEM INPUTS</th>
<th>Pmin Shot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Signal Power,</td>
<td>( P_{\text{sig}} = \text{N/A} )</td>
</tr>
<tr>
<td>LocOsc Power (at PD)</td>
<td>dBm</td>
</tr>
<tr>
<td>System Insertion Loss*</td>
<td>3.0 dB</td>
</tr>
<tr>
<td>Bandwidth (optical filter), ( B_0 )</td>
<td>1.00E+11 Hz</td>
</tr>
<tr>
<td>EDFA Gain</td>
<td>23.0 dB</td>
</tr>
<tr>
<td>EDFA Noise Figure</td>
<td>4 dB</td>
</tr>
<tr>
<td>Fiber-optic combiner</td>
<td>( \varepsilon / f(o) = 0.5 ) ratio</td>
</tr>
</tbody>
</table>

* Insertion Loss is after EDFA, Not including f/o combiner

<table>
<thead>
<tr>
<th>PHOTO-Diode &amp; Digitizer Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scope Range, V(max) = 1.00 V/W</td>
</tr>
<tr>
<td>Scope Sample Rate = 50 (Gs/s)</td>
</tr>
<tr>
<td>P-D Responsivity, ( R = 1800 ) V/W</td>
</tr>
<tr>
<td>Photo-diode noise, PSD = -125 (dBm/Hz)</td>
</tr>
<tr>
<td>Scope noise, PSD = -135 (dBm/Hz)</td>
</tr>
<tr>
<td>Bandwidth (elec), ( B_e = 2.00E+10 ) Hz</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ANALYSIS INPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N(\text{FFT}) = 1024 ) pts</td>
</tr>
<tr>
<td>RBW = 97.7 MHz</td>
</tr>
</tbody>
</table>

**SENSITIVITY (SNR = 1)**

<table>
<thead>
<tr>
<th>PDV</th>
<th>MPDV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.09E-09</td>
<td>7.33E-11 W</td>
</tr>
<tr>
<td>-56.8</td>
<td>-71.4 dBm</td>
</tr>
</tbody>
</table>

Sensitivity = minimum optical signal necessary for SNR = 1 (mean of noise floor)

<table>
<thead>
<tr>
<th>VISIBILITY (Min. Detectable Optical Signal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDV</td>
</tr>
<tr>
<td>Pmin</td>
</tr>
<tr>
<td>-45.8</td>
</tr>
<tr>
<td>Visibility Factor = 11 dB</td>
</tr>
</tbody>
</table>

User inputs for the optical system

User inputs for the photodetector, digitizer, and FFT analysis

User input visibility factor

Calculated values for sensitivity & visibility
What does the APP look like?

Pmin DESIGN APP


variables: system insertion loss (following EDFA), EDFA gain, & Photo-diode Responsivity

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<th>OPTICAL SYSTEM INPUTS</th>
<th>PHOTO-DIODE &amp; DIGITIZER INPUTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Signal Power,</td>
<td>Scope Range, V(max) = 3.00</td>
</tr>
<tr>
<td>P(0) = 20.0 dB</td>
<td>Volt Full Scale (V/dB)</td>
</tr>
<tr>
<td>LogOsc Power (at P(0))</td>
<td>Scope Sample Rate = 20</td>
</tr>
<tr>
<td>B_L = 1.00E+11 Hz</td>
<td></td>
</tr>
<tr>
<td>EDFA Gain G = 20.0 dB</td>
<td></td>
</tr>
<tr>
<td>EDFA Noise Figure F =</td>
<td></td>
</tr>
<tr>
<td>Fiber-optic combiner</td>
<td></td>
</tr>
<tr>
<td>r(0/0) = 0.5 ratio</td>
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</tr>
</tbody>
</table>

* Insertion Loss is after EDFA, Not including f(0) combiner
Calculation approximation: Strong Local Oscillator (P(0/0) >> P(signal))

Sensitivity vs. Insertion Loss: Minimum Optical Power for SNR=1
EDFA Gain Fixed (user input)

Pmin vs. IL

Sensitivity vs. EDFA Gain: Minimum Optical Power for SNR=1
Insertion Loss Fixed (user input)

Pmin vs. Gain

Sensitivity vs. PD Responsivity: Minimum Optical Power for SNR=1
Insertion Loss & EDFA Gain Fixed (user input)

Pmin vs. PD

Nevada National Security Site
Managed and Operated by National Security Technologies, LLC
Let’s try it (time permitting)…
Audience interactive session