Analog Optical Links for Wide Bandwidth Radar Receivers

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MQP Presentation

Group 33

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Motivation

• Replace coaxial transmission line in radar receiver with analog optical link to:
  – Receive full bandwidth signal at the control center
  – Improve accessibility of receiver hardware
  – Allow remoting of radar back-end hardware
Goals & Objectives

• Goal
  – Determine feasibility of using an analog optical link for transmission of a received radar signal

• Objectives
  – Conduct a cost-benefit analysis of coaxial cable vs. analog optical links
  – Create tools that model the performance of the receiver side of a radar system
  – Become familiar with a commercial analog optical link
  – Determine if a design can be realized with a currently available commercial analog optical link
Technical Overview

• Receiver Side of Radar System

Antenna In → LNA → Receiver → Output to ADC

Front-End Loss

Cable Loss

= Attenuation

• Analog Optical Link

Specifications to Meet

- Instantaneous Dynamic Range (50 dB)
  - Saturation
  - Noise Figure
Specifications to Meet

- Instantaneous Dynamic Range (50 dB)
  - Saturation
  - Noise Figure
- Sensitivity (30 dB signal-to-noise ratio (SNR) for 1m² target at distance of 1000 km)
  - Noise Figure

![Single-Sided Amplitude Spectrum](image)

**Frequency (GHz)**

-90 -80 -70 -60 -50 -40 -30 -20 0 dBm
Coax vs. Analog Optical Links

- Performance Analysis
  - Attenuation

Coax vs. Analog Optical Links

• Performance Analysis
  – Attenuation
  – Coax Attenuation Slope

*Approximation of data provided by IW Microwave for IW4806 Cable
Coax vs. Analog Optical Links

- Performance Analysis
  - Attenuation
  - Coax Attenuation Slope
  - Noise Temperature

Overall Noise Temperature of Receiver (K)

Coax vs. Analog Optical Links

MITEQ LBL-10M4P5G Analog Optical Link
MITEQ SCML-100M11G Analog Optical Link

Coax
-20 -15 -10 -5 0 5 10 15 20
Overall Noise Temperature of Receiver (K)

Gain of Link (dB)

Coax

Noise Figure of Link (dB)

Gain of Link (dB)

Coax

Noise Figure of Link (dB)

Gain of Link (dB)
Coax vs. Analog Optical Links

- Performance Analysis
  - Attenuation
  - Coax Attenuation Slope
  - Noise Temperature

SNR (dB) for 1 m² target at a distance of 1000 km versus noise temperature

Gain of Link (dB) vs. Noise Figure of Link (dB)

Coax
MITEQ LBL-10M4P5G Analog Optical Link
MITEQ SCML-100M11G Analog Optical Link
Coax vs. Analog Optical Links

- Performance Analysis
  - Attenuation
  - Coax Attenuation Slope
  - Noise Temperature

- Economic Analysis

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**Cost vs. Distance for Coaxial and Analog Optical Link**

- IW 4806 Coax with Equalizers and Amplifiers
- SCML-100M11G Analog Optical Link & Tyco 1664095-5 Fiber
>> RadarReceiver

Signal Setup:
- Frequency of Main Signal (GHz): 10
- Average Power of Main Signal (dBm): -19
- System Bandwidth (GHz): 1

Plot signal and amplitude spectrum of initial signal? (y/n): y

![Graph of Initial Signal and Amplitude Spectrum](image-url)
Antenna In -> LNA -> Receiver

Front-End Loss

Cable Loss

Front-End Parameters
Gain of Front-End (dB): -1
Noise Figure of Front-End (dB): 1
System Bandwidth (GHz): 1

Plot signal and amplitude spectrum of current signal? (y/n): y
LNA Parameters
- Gain of LNA (dB): 30
- Output P1dB of LNA (dBm): 10
- Noise Figure of LNA (dB): 2
- System Bandwidth (GHz): 1

Plot signal and amplitude spectrum of current signal? (y/n): y
Specifying the Type of Link:

1) Coaxial
2) Analog Optical (Component Level - External Modulation)
3) Analog Optical (Component Level - Direct Modulation)
4) Analog Optical (Link Level)

Enter #: 4

- Attenuation
Analog Optical Link Parameters

Attenuation Before Link
Gain (dB): -24
Noise Figure (dB): 24

Signal after Link

Single-Sided Amplitude Spectrum After Link
Modeling

Link
- Gain (dB): 18
- Output P1dB (dBm): 4
- Noise Figure (dB): 20

Antenna In → LNA → Receiver → Output to ADC

Signal after Link

Single-Sided Amplitude Spectrum After Link
Attenuation After Link

- Gain (dB): -4
- Noise Figure (dB): 4
- System Bandwidth (GHz): 1

Plot signal and amplitude spectrum of current signal? (y/n): y
Modeling

RCVR Parameters
- Gain of RCVR (dB): 10
- Output P1dB of RCVR (dBm): 10
- Noise Figure of RCVR (dB): 7
- Output Frequency of RCVR (MHz): 70
- System Bandwidth (MHz): 20

Plot signal and amplitude spectrum of final signal? (y/n): y

![Diagram of antenna input to output through LNA and receiver, with front-end loss and cable loss.]

![Graphs showing final signal waveform and single-sided amplitude spectrum of final signal.]

\( \Rightarrow \) = Attenuation
Direct Modulation Analog Optical Link

Parameters:
- Relative intensity noise (RIN) of transmitter (-150 dB/Hz)
- Laser slope efficiency (0.15 W/A)
- Laser bias current (0.07 A)
- Laser threshold current (0.012 A)
- Fiber attenuation (0 dB/km)
- Length of fiber (0 km)
- Other excess losses – including coupling losses (0 dB)
- Photodiode responsivity (0.85 A/W)

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<th>Component</th>
<th>Parameter</th>
<th>Expected Value</th>
<th>Simulated Value</th>
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<tbody>
<tr>
<td>LBL-10M4P5G Analog Optical Link with no external circuitry and negligible fiber loss</td>
<td>Gain (dB)</td>
<td>-22 to -23</td>
<td>-17.9</td>
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<td>Noise Figure (dB)</td>
<td>45 to 50</td>
<td>43.2</td>
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Modeling

External Modulation Analog Optical Link

Parameters:
- Total excess modulator loss (4 dB)
- $V_\pi$ (5.5 V)
- DC bias voltage of modulator (2.75 V)
- Optical output power from CW laser (0.01 W)
- Fiber attenuation (0 dB/km)
- Length of fiber (0 km)
- Photodiode responsivity (0.5 A/W)

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<th>Component</th>
<th>Parameter</th>
<th>Expected Value</th>
<th>Simulated Value</th>
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<tr>
<td>Mach-Zehnder Modulated Analog Optical Link with no external circuitry and negligible fiber loss</td>
<td>Gain (dB)</td>
<td>−34</td>
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<td>Noise Figure (dB)</td>
<td>49</td>
<td>40</td>
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<td>Output P1dB (dBm)</td>
<td>−17</td>
<td>−16.1</td>
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Testing

- MITEQ LBL-10M4P5G Analog Optical Link
Testing

Frequency (Hz) vs Amplitude (dB)

- 50 m long fiber
- 2 m long fiber
- Difference in attenuation slope between two fibers

The graph shows the comparison of amplitude versus frequency for two different fiber lengths (50 m and 2 m) and the difference in attenuation slope between the two fibers. The data is plotted on a logarithmic scale for both frequency and amplitude to clearly illustrate the trends across a wide range of frequencies.
Conclusions

• Using MITEQ SCML-100M11G analog optical link dynamic range specification is met, sensitivity specification is not
• To meet sensitivity, link must have lower gain or lower noise figure
• By adjusting component parameters a link can be built to meet both dynamic range and sensitivity specifications
• Improvement in performance for analog optical link over coaxial cable only occurs once a certain distance is reached
• Analog Optical Link is only cost-effective for long distances (greater than \(\approx 300\) ft)
Acknowledgements

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Questions