Summer School on Optics & Photonics
Mitigating Transmitter Non-linearity and Fiber Impairments in Radio over Fiber Technology

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Outline

• RoF introduction
• Dispersion in optical fibers
• RoF OFDM transmission and reception using the conventional and modified SSB
• Analysis of HD2 due to MZM, chromatic and modal dispersion in SMF-MMF
• Conclusion and Future scope
• Publications
• References
Introduction

- The increasing consumer demands to access the internet requiring larger broadband network capacity should extend up to the feed fixed terminals at the customer premises

- Single mode fibers (SMF) are typically used in Wide Area Networks (WAN), Metropolitan Area Networks (MAN) and also find applications in Radio over Fiber (RoF) architectures supporting data transmission in Fiber to the Home (FTTH), Remote Antenna Units (RAUs)

- Multi-mode fibers (MMFs) with low cost, ease of installation and low maintenance are predominantly (85% to 90%) deployed in in-building networks providing data access in local area networks (LANs).
Direct Modulation

- The message signal (ac) is superimposed on the bias current (dc) which modulates the laser
- Robust and simple, hence widely used
- **Issues**: laser resonance frequency, chirp, turn on delay, clipping and laser nonlinearity
• Modulation and light generation are separated
• Offers much wider bandwidth → up to 60 GHz
• More expensive and complex
• Used in high end systems
Radio over Fiber technology

Local Exchange

- Laser
- OLT
- MZM

Downstream

- SMF
- MMF

Upstream

- Passive node

- Modal dispersion

- Chromatic dispersion

- Rayleigh backscattering and discrete reflections

Customer Premises

- Optical Amplifier
- Photodiode
- RF spectrum analyzer

ONU

Harmonic and Intermodulation distortion
Signal Distortion on Optical Fibers - Dispersion

Pulse Broadening due to Dispersion

(a) Separate pulses at time $t_1$
(b) Distinguishable pulses at time $t_2 > t_1$
(c) Barely distinguishable pulses at time $t_2 > t_1$
(d) Indistinguishable pulses at time $t_4 > t_3$

Output pattern

Intersymbol interference

Distance along fiber
Types of dispersion

- Intra modal or Chromatic dispersion
  - Material Dispersion
  - Waveguide Dispersion

- Inter modal dispersion
Optical modulator - MZM
System Setup

<table>
<thead>
<tr>
<th>System Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF frequency</td>
<td>18 GHz</td>
</tr>
<tr>
<td>Laser power, Linewidth, Wavelength</td>
<td>-2dBm, 10MHz, 1552nm</td>
</tr>
<tr>
<td>Switching voltage of MZM</td>
<td>4V</td>
</tr>
<tr>
<td>Bias voltage of MZM, Phase shift</td>
<td>2V and 1.33V for 90 and 120 degrees</td>
</tr>
<tr>
<td>Fiber length, dispersion &amp; attenuation</td>
<td>Up to 25Kms, 16.75 ps/nm/km and 0.2 db/km</td>
</tr>
<tr>
<td>PIN responsitivity</td>
<td>0.8 A/W</td>
</tr>
</tbody>
</table>
Optical Spectrum of conventional OSSB and proposed OSSB
Effect of DC bias voltage on 2\textsuperscript{nd} order sideband optical power for modified OSSB

\[ V_{dc} = \frac{V_{\pi}}{3} \]

\( V_{dc} \) is the DC bias voltage and \( V_{\pi} \) is the MZM switching voltage.

As ER increases from 5 to 25dB, the 2nd order optical SB power reduces from -28.4 to -48.5dBm.

Optical OFDM generation, transmission, and direct detection

Diagram showing the process of optical OFDM generation, transmission, and direct detection.
Mathematical modeling

1. Generation of the OFDM signal
2. Consideration of all the Laser and MZM parameters to generate the corresponding SSB OFDM signal
3. Taking Fourier Transform of the generated signal and expansion using the Bessel function
4. Transmission of the optical SSB signal through the SMF considering all the non-linear properties. Multiply the frequency transfer function of dispersive and nonlinear SMF with the optical SSB signal
5. Conversion of the received signal back to time domain by Inverse Fourier transform
6. Conversion of the optical signal back to electrical by multiplying the Responsitivity of the photodiode with the modulus squared of the optical signal
Optical spectrum of SSB signal using 90° hybrid coupler with ER = 6 dB

Optical spectrum of SSB signal using 90° hybrid coupler with ER = 30 dB.

Optical spectrum of SSB signal using 120° hybrid coupler with ER = 6 dB

Optical spectrum of SSB signal using 120° hybrid coupler with ER = 30 dB.

5.6.2017
EVM analysis for 4 QAM OFDM transmission

EVM analysis for 16 QAM OFDM transmission

- EVM (dB) vs Fiber Length (km)
- SSB with 90° Hybrid Coupler
- SSB with 120° Hybrid Coupler

(a) SSB with 90° Hybrid Coupler
(b) SSB with 120° Hybrid Coupler
(c) SSB with 90° Hybrid Coupler
(d) SSB with 120° Hybrid Coupler
EVM analysis for 64 QAM OFDM transmission

(a) SSB with 90° Hybrid Coupler
(b) SSB with 120° Hybrid Coupler
(c) SSB with 90° Hybrid Coupler
(d) SSB with 120° Hybrid Coupler

EVM (dB)

Fiber Length (km)
OFDM drive power and MZM non-linearity

Threshold point = 9.98dBm
EVM vs received optical power

ECMA threshold = -14.5dB

Improvement in receiver sensitivity = 4.77%

5.6.2017
Generation of $m$-QAM OFDM signal and transmission through SMF-MMF fiber link
Mathematical modeling

The output optical signal from the SMF is multiplied with the transfer function of the MMF

Conversion of the optical signal back to electrical by multiplying the Responsivity of the photodiode with the modulus squared of the optical signal

Differentiating the current equation into two parts based on normalized field distribution in same mode and in neighboring modes

Expanding the current equation up to second order where one part represents the HD2 due to MZM non linearity and other part represents HD2 due to modal dispersion of the MMF

The Equation can be split into three parts considering the beating components formed due to beating of carrier and the first-order harmonic, carrier and the second-order harmonic, first-order and the second-order harmonic for both the MZM and modal dispersion

The HD2 is calculated individually for MZM non linearity and modal noise by using Total Harmonic Distortion formula
Influence of the modulation index on HD2 on conventional SSB

Optical spectrum of the SSB technique with 90° hybrid coupler for different MZM modulation index.

(a) MI = 0.1  
(b) MI = 0.5  
(c) MI = 1

5.6.2017  
Summer school on optics and photonics, Oulu, Finland
Influence of the modulation index on HD2 on modified SSB

(a) MI = 0.1  (b) MI = 0.5  (c) MI = 1

Optical spectrum of the SSB technique with 120° hybrid coupler for different MZM modulation index.

5.6.2017
Effect of HD2 due to MZM non-linearity and modal dispersion over different MMF length

At length 500m, the SSB with 120° hybrid coupler provides a suppression of the HD2 by 12 dB more than the conventional one.

Conclusion and future scope

- The optimum OFDM drive power is calculated for all the MZM modulation techniques such that the MZM non-linearity is minimum.
- The SSB technique using the 120° hybrid coupler improves the receiver sensitivity as compared to the all other MZM modulation techniques.
- Problems of chromatic dispersion, modal dispersion is reduced by employing SSB technique using the 120° hybrid coupler in SMF and MMF fibers.
- The SSB technique using the 120° hybrid coupler can be employed in bidirectional systems to reduce the impact of Rayleigh backscattering and discrete reflections.
Publications


References


Thank you for the patience