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Opto-Electronic Oscillator in the mm-W range for 5G Wireless and Mobile Networks: Design Challenges and Possible Solutions

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FiWiN5G

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Talk Outline

- Opto-Electronic Oscillator (OEO) in 5G
- Expected problems with the OEO in the mm-W Range
- Possible Solutions for
  - Improving Long-Term Stability (Avoiding Frequency Drift)
  - Attenuating Side Modes
  - Avoiding Chromatic Dispersion Effect
  - Reducing Rayleigh Scattering Effect
- Conclusion
- Future Work

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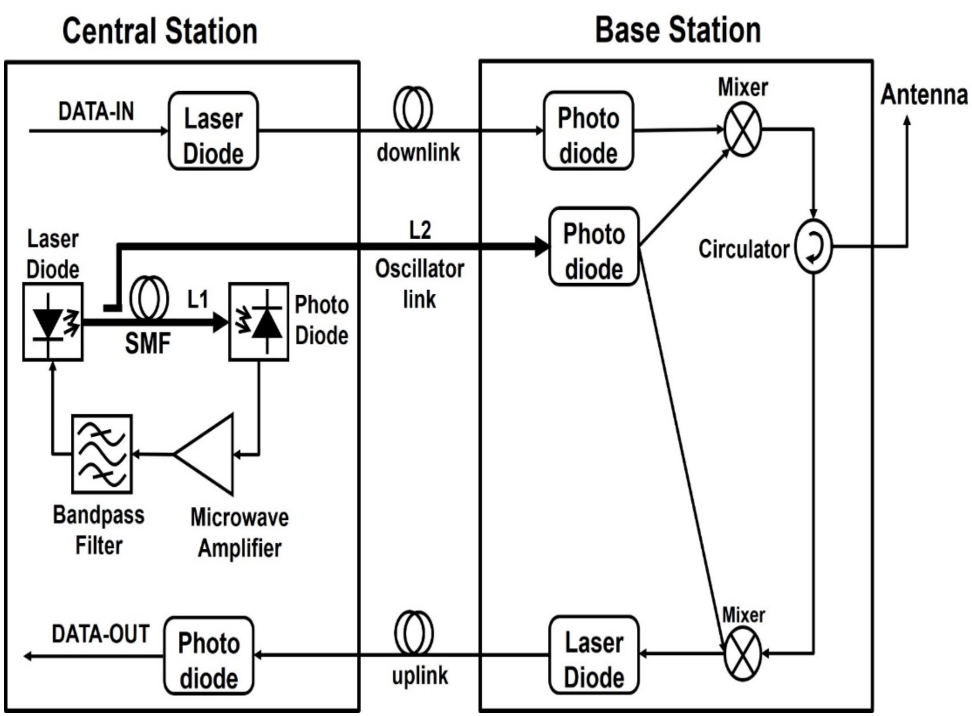
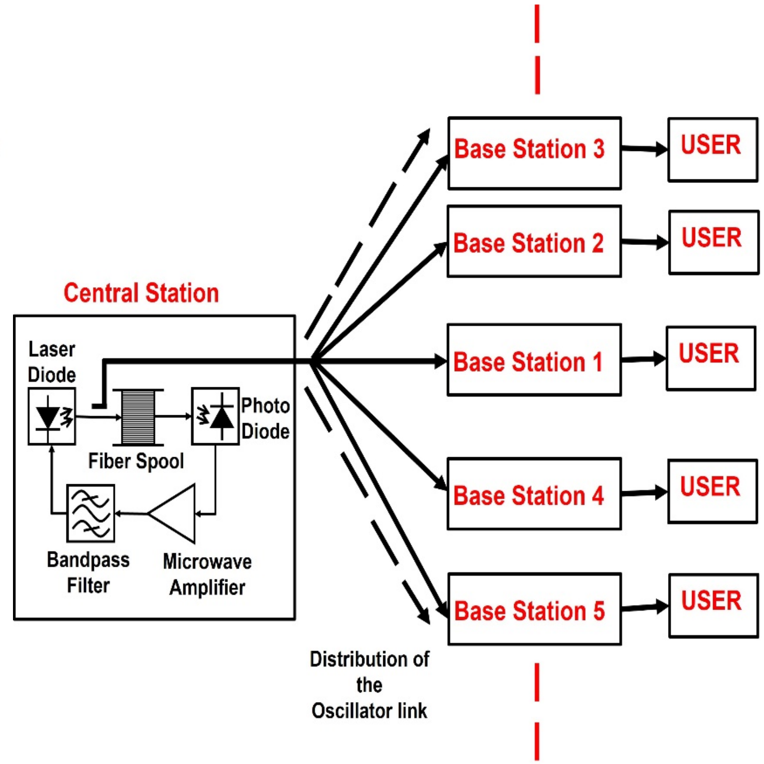
The OEO in 5G Technology

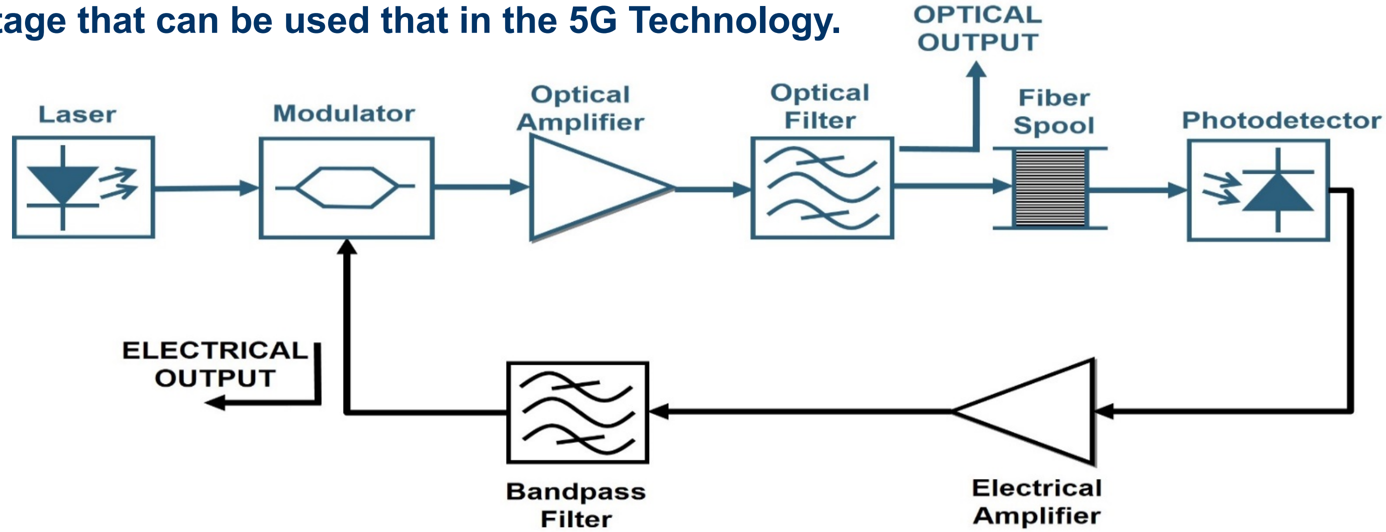
- The OEO is placed in the central station instead of Local Oscillator in base station.
- The signal was produced by the OEO is transmitted via separate optical fiber link to the base station.





Opto-electronic Oscillator

- The main component of the OEO is a low-loss optical fiber, which acts as very long delay line.
- It consists of optical and electrical outputs simultaneously. Therefore there is no e/o conversion required.
- Optical part generates large delay time and electrical part is a feedback of the loop.
- Main benefit is that the phase noise is a frequency independent which brings a good advantage that can be used that in the 5G Technology.



Main Challenges of OEO in mm-W range:

- Long-Term Stability of mm-W due to temperature instability,
- Multi-mode operation due to non-ideal filtering,
- Chromatic dispersion of optical fiber,
- Rayleigh/Brillouin scattering in the optical fiber.

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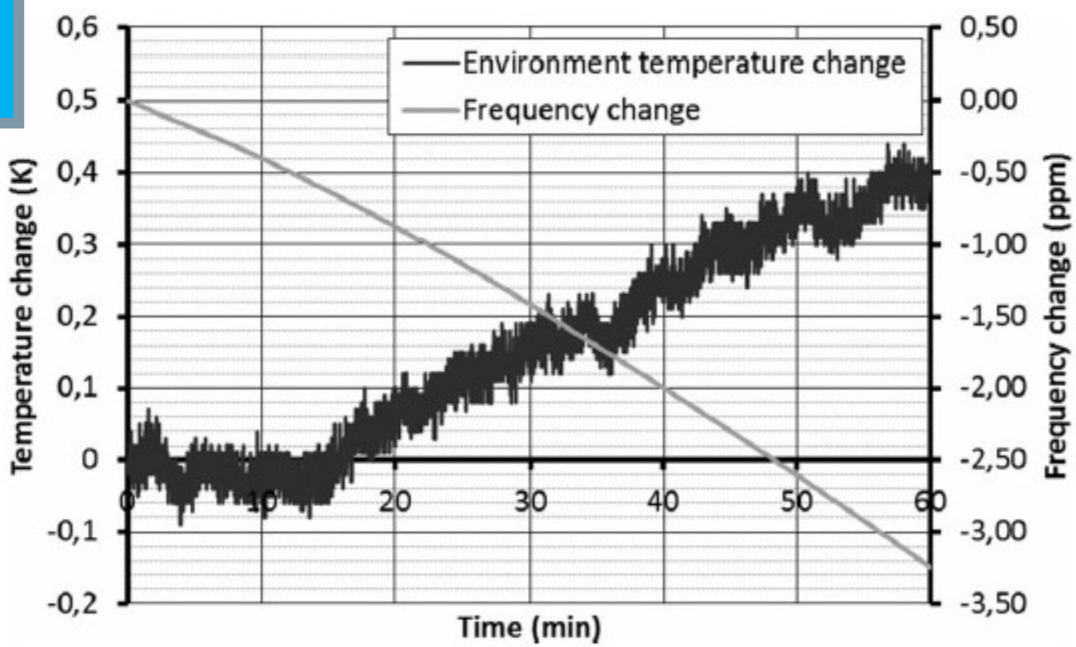
Frequency Drift

- Frequency drift is a result of the refractive index's temperature coefficient.

8 ppm/K for SMF

Problem:
fiber refractive index + temperature drift = frequency drift

Mode Hopping



*L. Bogataj, *J. Lightwave Technol.*, vol. 32, no. 20, pp. 3690-3694, Oct. 2014

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Side Modes

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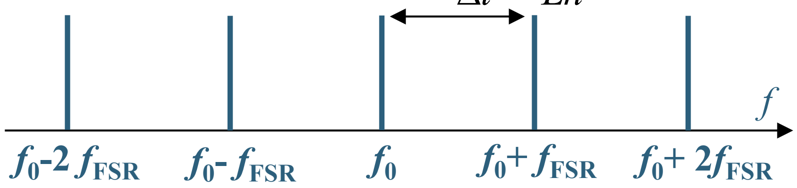
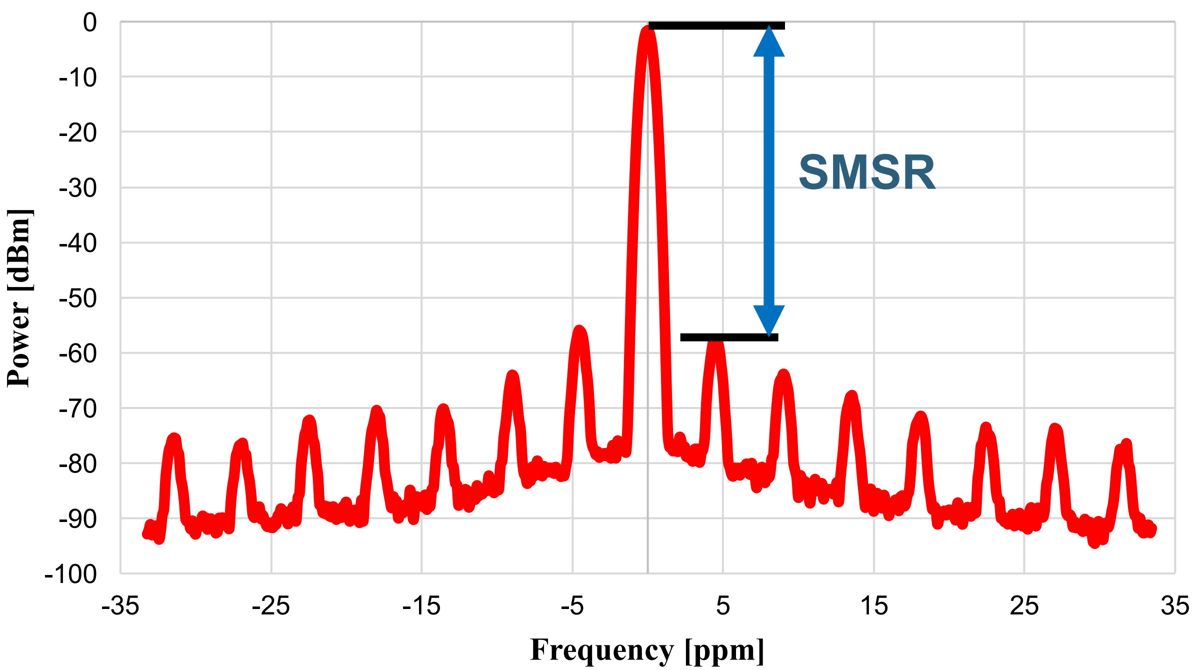
- The OEO generates signals with a **comb frequency spectrum.**
- With the filter, only a single frequency is chosen, while the others are attenuated, but they could still be noticeable.
- **FSR: Frequency spacing between the modes.**

$$\mathrm{FSR} = \frac{1}{\Delta t} = \frac{c_0}{Ln}$$





Rayleigh Scattering Effect

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- Rayleigh Scattering occurs in the optical fiber to degrade the power of the light.
- Reasons ; imperfections of the optical fiber and/or reflection at optical connectors or fiber splices.
- The scattered light is converted to RF amplitude or phase noise due to light interference between the scattered and non-scattered light at the PD.
- In general, the scattered light in the optical fiber is converted to the phase noise and increase the total phase noise of the OEO.

Chromatic Dispersion Effect

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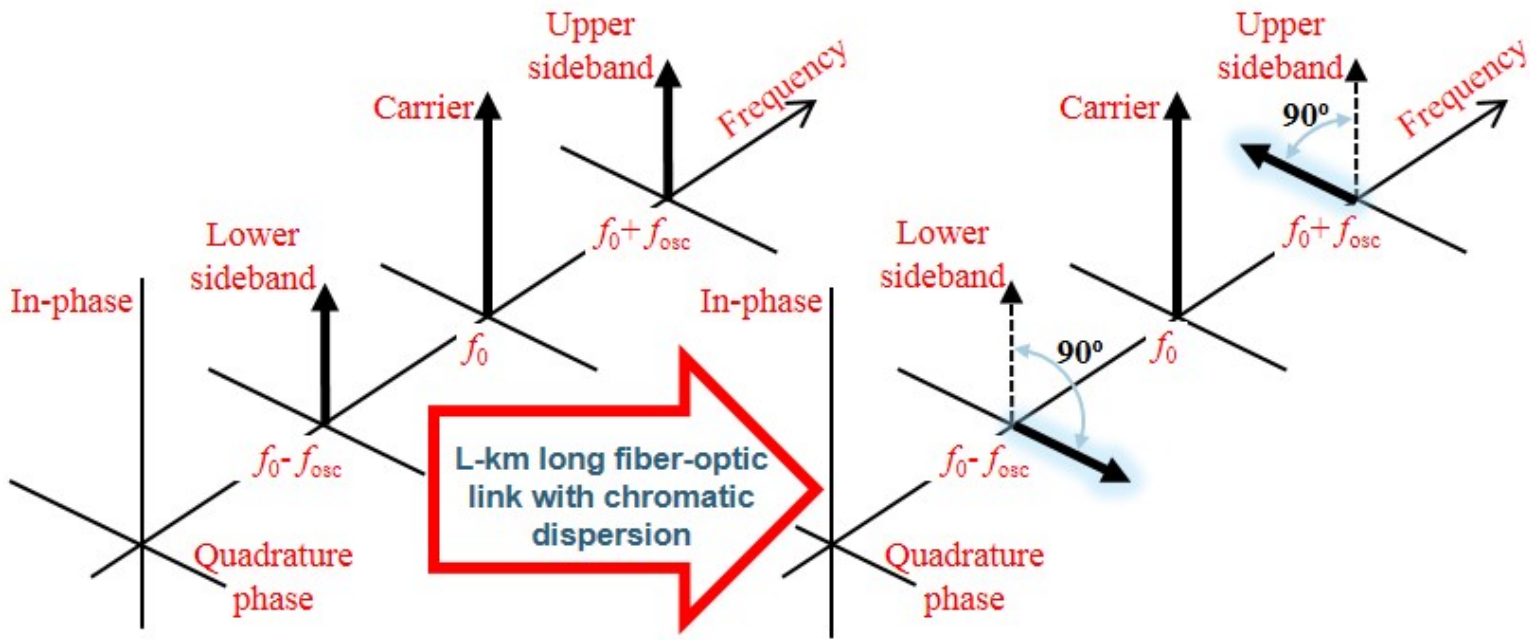
- Chromatic Dispersion can limit the transmission of the signal transmitted by a single-mode optical fiber.
- Chromatic Dispersion causes a different phase shift on each of the optical spectral components (the carrier and double sidebands).



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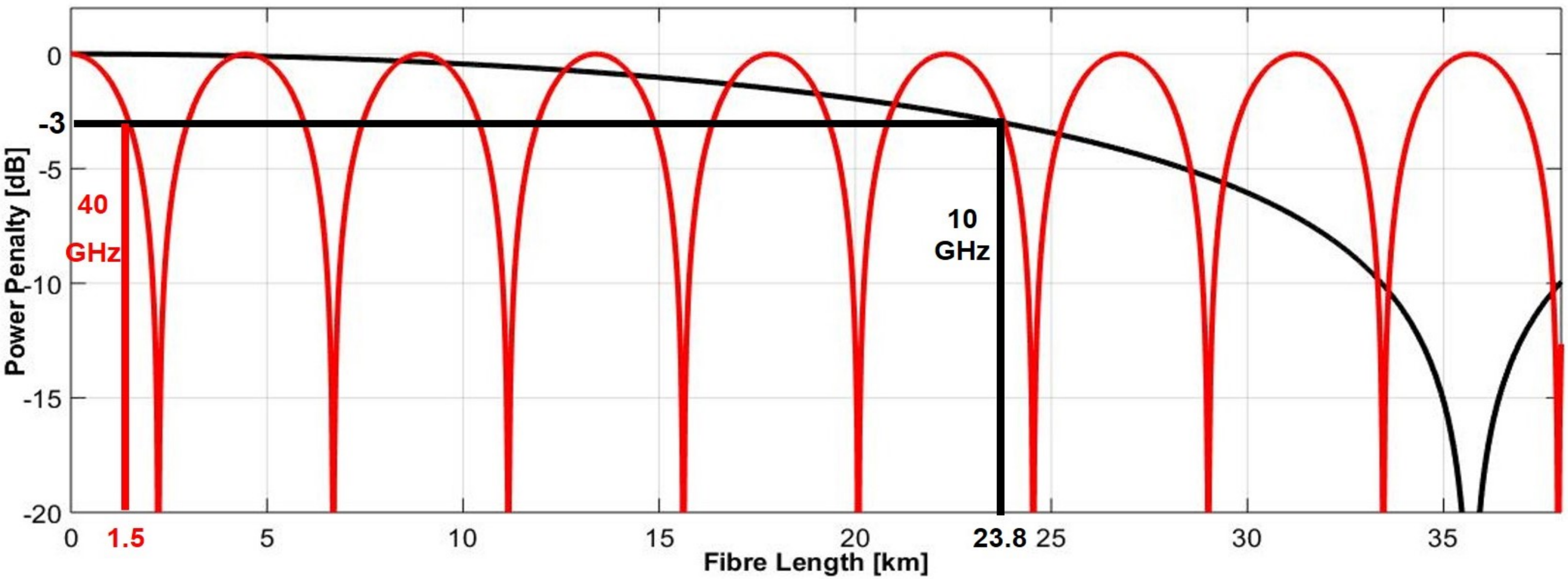
Power Penalty

- **Chromatic Dispersion degrades the signal over the optical fiber's length.**
- **Power Penalty => modulation format, frequency of RF signal, laser wavelength, chromatic dispersion, and length of optical fiber.**

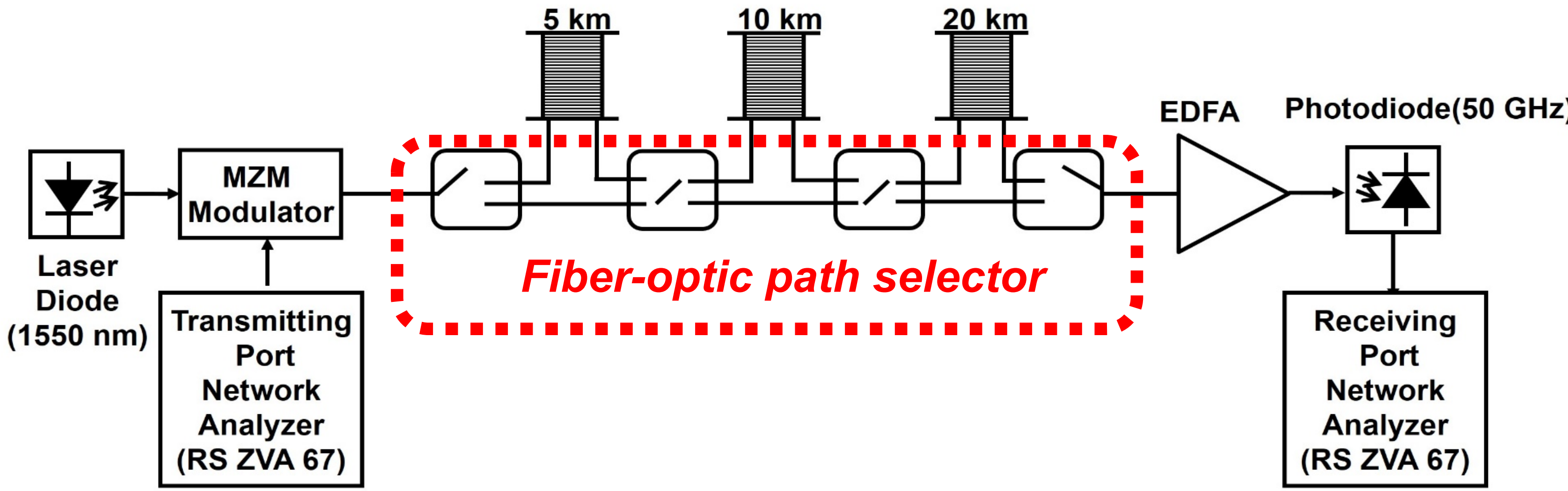
$$P_{osc}(L, f_{osc}) \propto 20\log\left(\cos\left(\frac{\pi \cdot L \cdot D}{c_0}(\lambda_0 \cdot f_{osc})^2\right)\right)$$

- **D= Dispersion Coefficient, L= optical length, λ_0= wavelength of the laser, f_{osc}= frequency of RF signal**



Analog Optical Link Setup

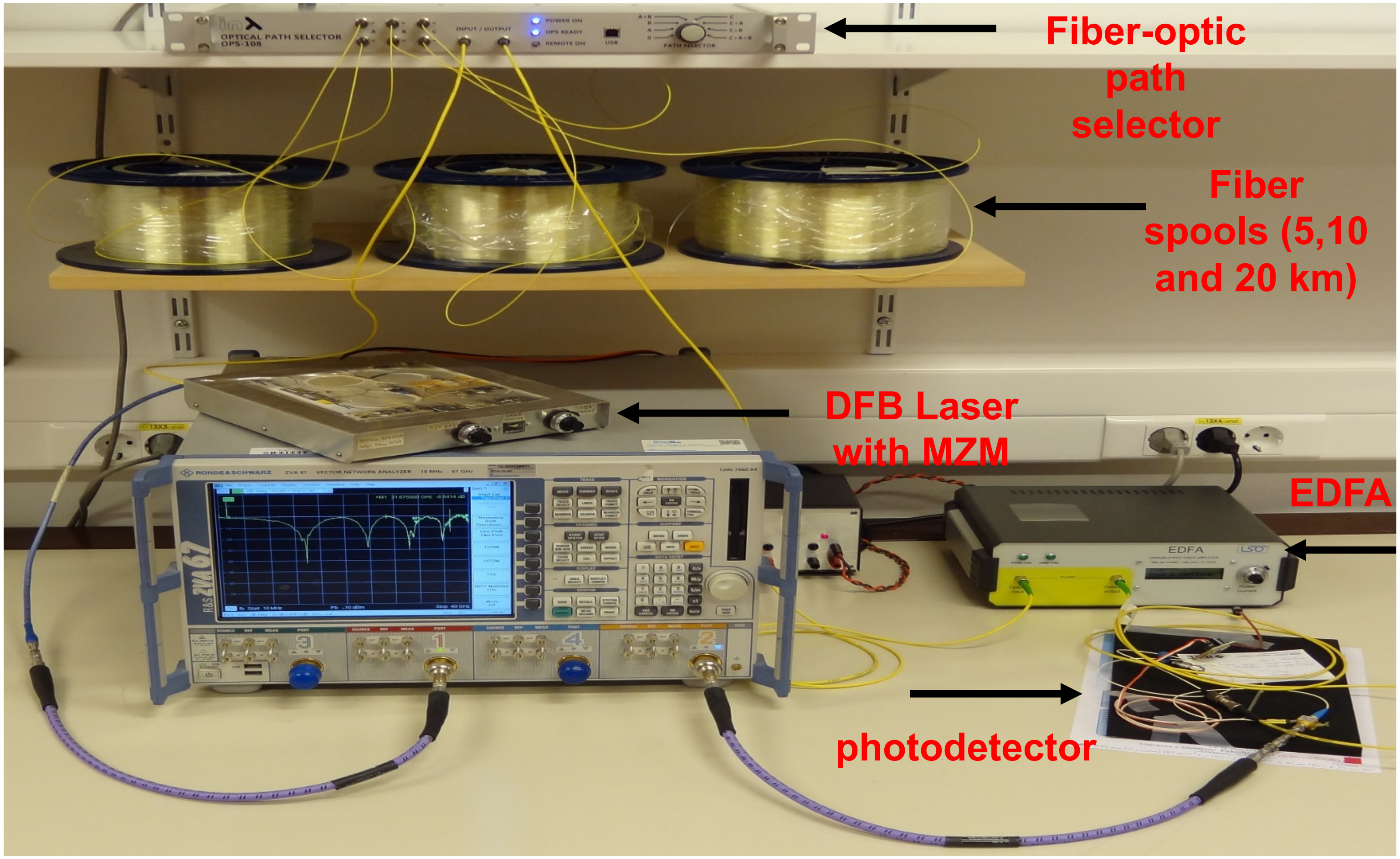
- Analog Optical Links with a DFB Laser to measure the power of the signal with different frequencies starting from 10 MHz to 40 GHz with different optical fiber lengths.



- Experimental setup is composed of Vector Network Analyzer, DFB Laser, Mach Zehnder Modulator, fiber-optic link (5 km, 10 km, 15 km, 20 km, 25 km, 30 km and 35 km) and photodiode.

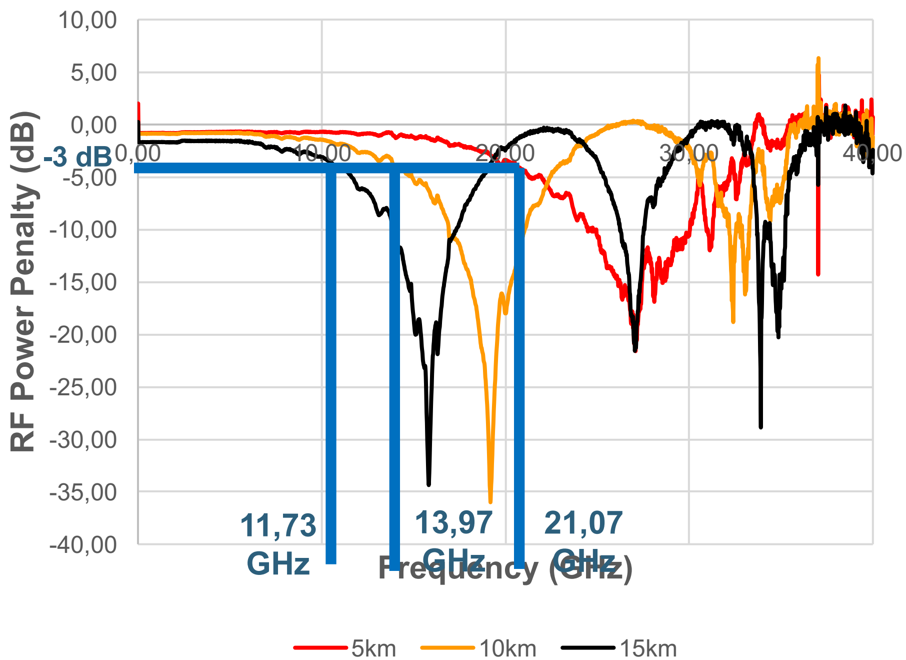
Experimental Work

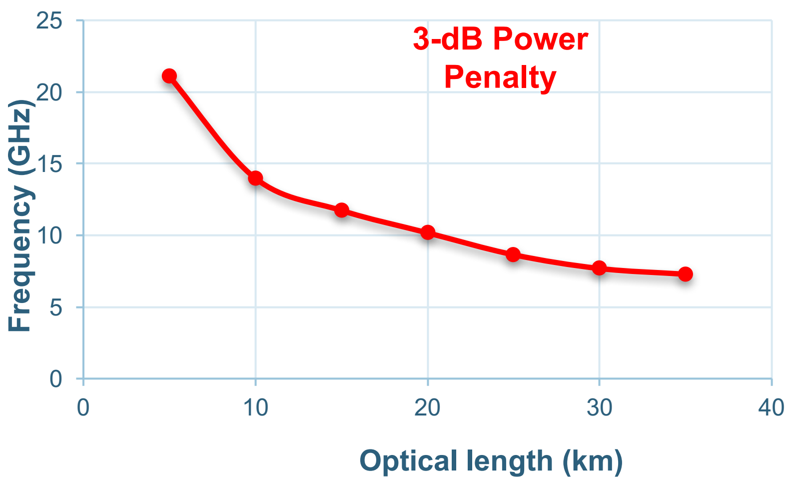
- **Chromatic Dispersion effect from 5 to 35 km optical length on the frequency between 10 MHz to 40 GHz.**



Experimental Evaluation

- Chromatic Dispersion effect on the 5, 10 and 15 km on the frequency between 10 MHz to 40 GHz.
- 3-dB Power Penalty of the transmitted signal over optical length from 5 km to 35 km.



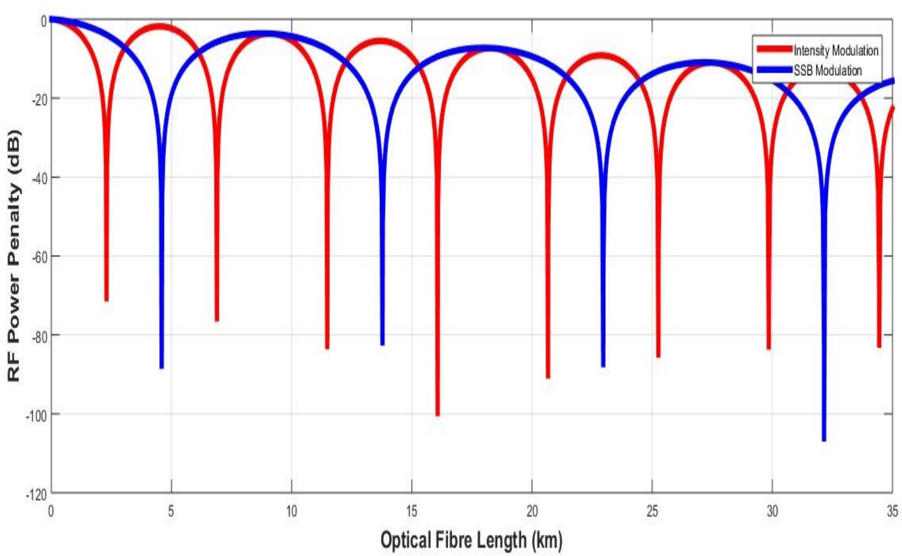


Proposed Solutions

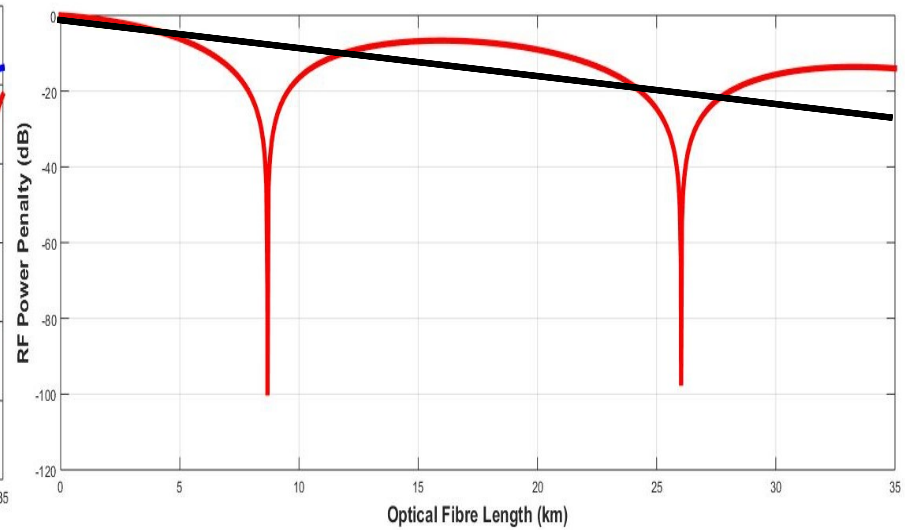
Chromatic Dispersion

- To use dual drive MZ Modulator to produce SSB.
- Dispersion-shifted fiber.
- Changing wavelength of the laser.

Frequency :40 GHz



Frequency :40 GHz



Proposed Solutions-2

Rayleigh Scattering

- Optical fiber with less dopants added in the core of optical fiber. More transparent fiber core.
- Use optical fiber with a pure silica core since it has a low Rayleigh scattering noise.
- The fiber with lower glass fictive temperature should be used.
- Use higher wavelength of laser.
- Decrease the average optical power (duty cycle of the power).
- Using AM of the laser with the modulation depth of 100%.

Proposed Solutions-3

Frequency Drift

- The OEO with optical fiber and bandpass filter temperature stabilized.
- The monitoring signal can be implemented.
- Special building blocks can be used.

Side Modes

- Multi-loop OEO.
- Injection-locked dual OEO.
- The OEO where a Fabry-Perot etalon is used.

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Feedback Control Loop

- **Frequency Discriminator (FD) makes the group delay of the oscillator's loop constant.**

SOLUTION

Frequency measurement via filter's phase shift

↓

laser temperature changes

↓

light wavelength changes

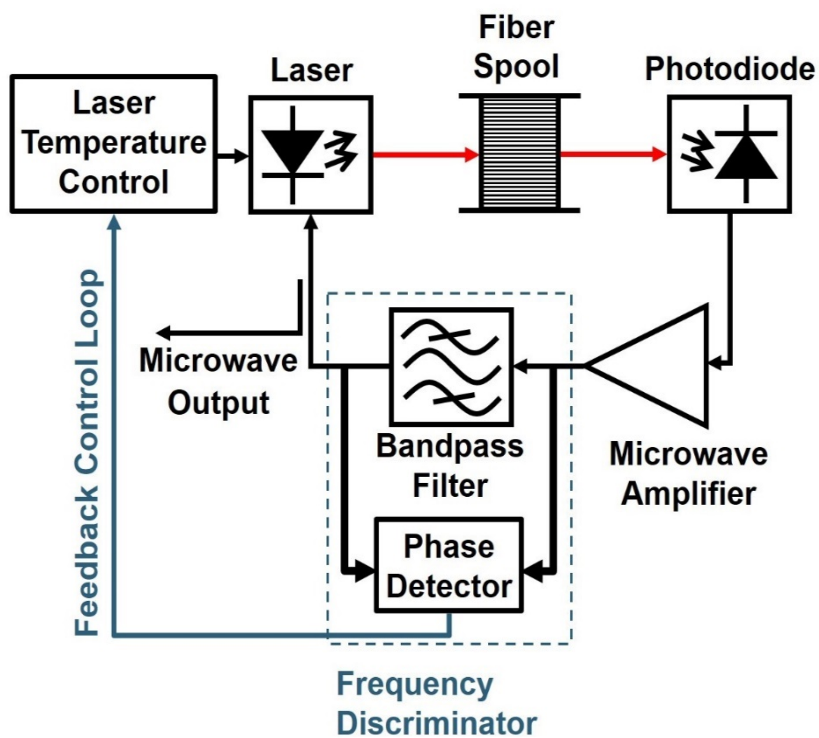
↓

fiber refractive index changes

↓

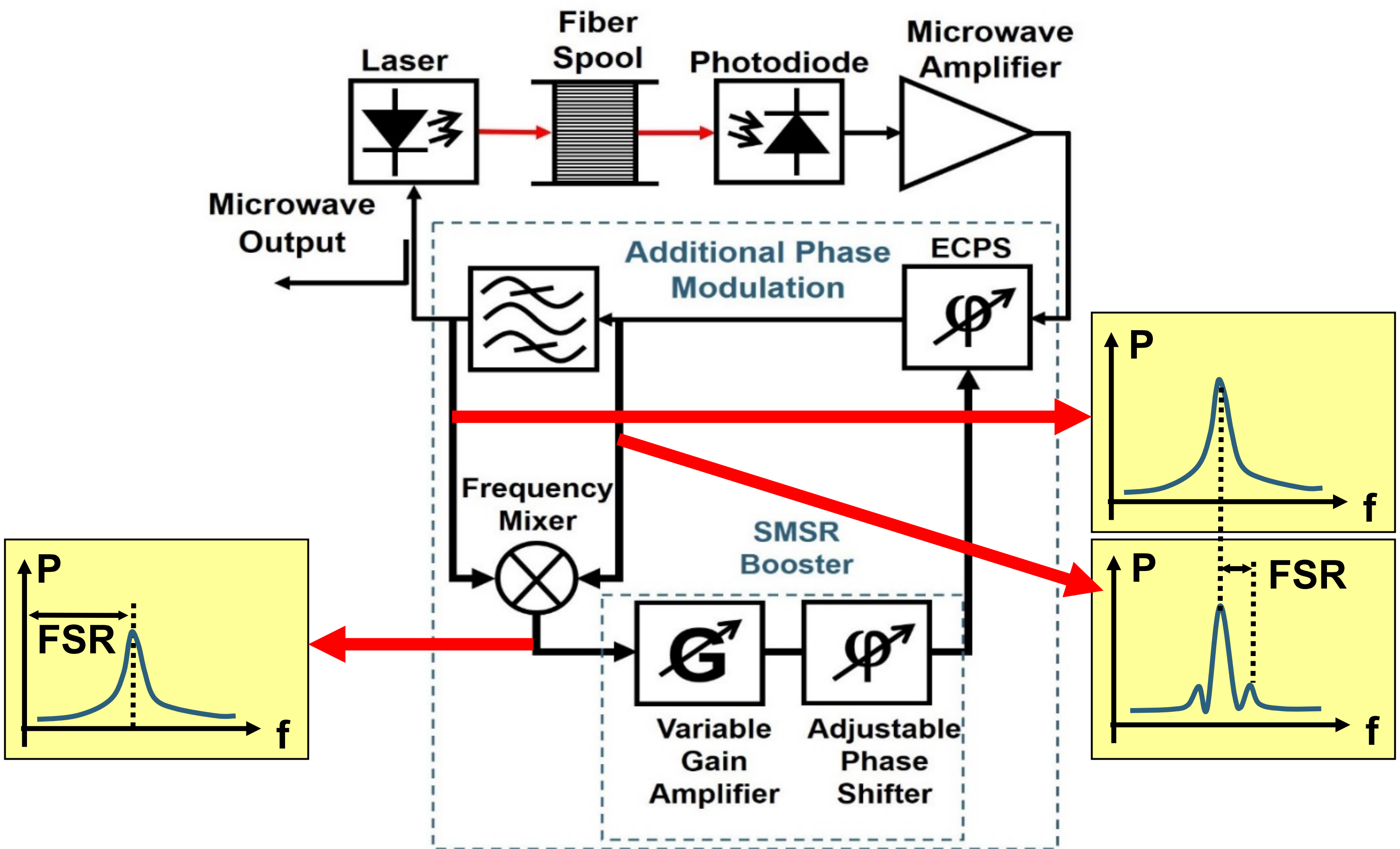
frequency changes

PI Controller drives the temperature of laser and fix the output of FD.



Additional Phase Modulation

- Electrically controlled phase shifter (ECPS) is placed in the OEO loop.
- With correctly tuning of ***SMSR Booster***, the OEO's SMSR will be improved.



Quality Multiplier (QM)

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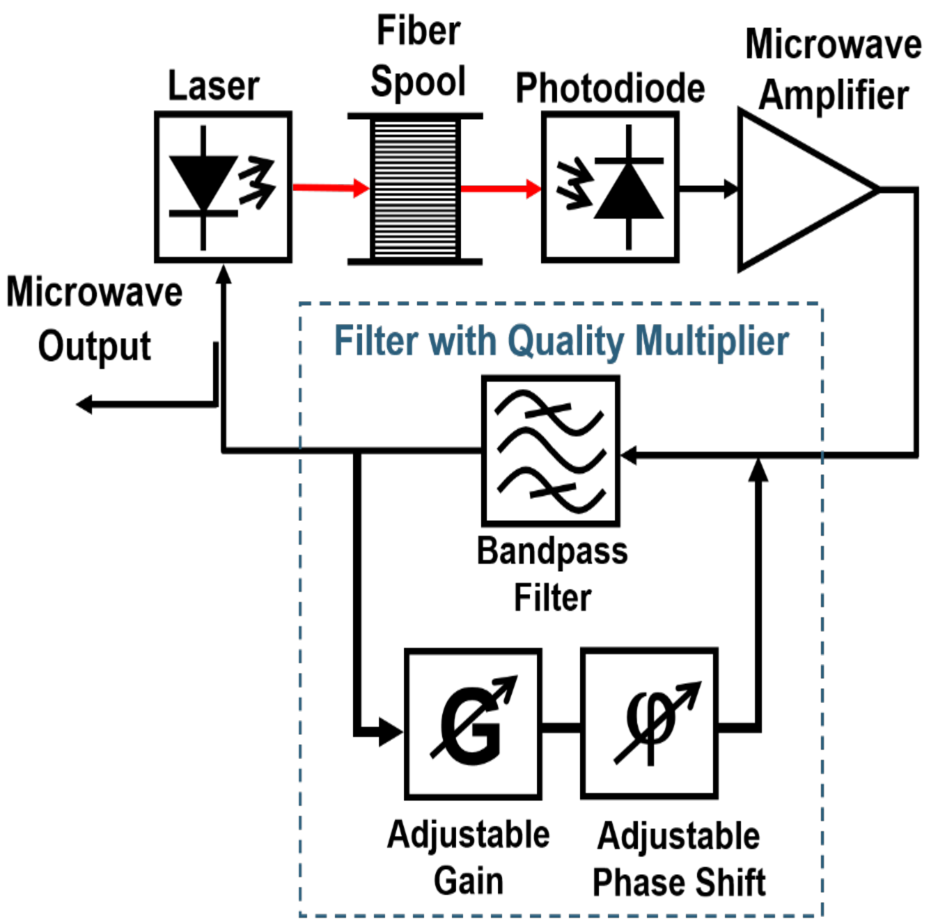
- An electrical circuit is added to a bandpass filter in loop to increase the Q factor of the OEO.
- **Main purpose** : Decrease the OEO bandwidth and increase the SMSR.



SOLUTION

Quality Multiplier
+
Bandpass Filter
=
Narrower Bandpass Filter

Filter with QM

- Open loop gain less than unity.
- Phase shift is equal to 2π at oscillator frequency.

Comparison of Methods done in LSO

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Feedback Control Loop;

- \+ No need for external reference
- \+ No phase noise increase
- − Limited range
- − Precise temperature stabilization of the frequency discriminator

Additional Phase Modulation;

- \+ Low phase Noise increase
- \+ Integrated Circuit Implementation
- \+ Low Frequency Circuits
- − Low SMSR increase

Quality Multiplier;

- \+ High Increase in the SMSR
- \+ No need for High Q Filter
- − Increased phase noise

Conclusion

- The OEO brings an advantage that the phase noise does not depend on the frequency.
- Frequency drift is a result of temperature coefficient of the optical fiber.
- Spurious modes occur due to the result of multimode operation of the OEO.
- Rayleigh scattering induces the phase noise in the OEO.
- Chromatic Dispersion over the optical fiber should be taken into consider to avoid the power penalty.

Future Work

- Implement some methods (Feedback Control Loop, Quality Multiplier) to lower frequency drift and increase the SMSR.
- Take care of the chromatic dispersion with using advanced modulation technique and/or different solutions.
- Put the OEO in the central station to generate high frequency signals in the mm-W for 5G Technology with the help of radio-over-fiber.

ANY QUESTIONS ?

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