Four Wave Mixing Coupled with Stimulated Brillouin Scatting

Eugene (Yuxin) Dai

Cox Communications

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Background

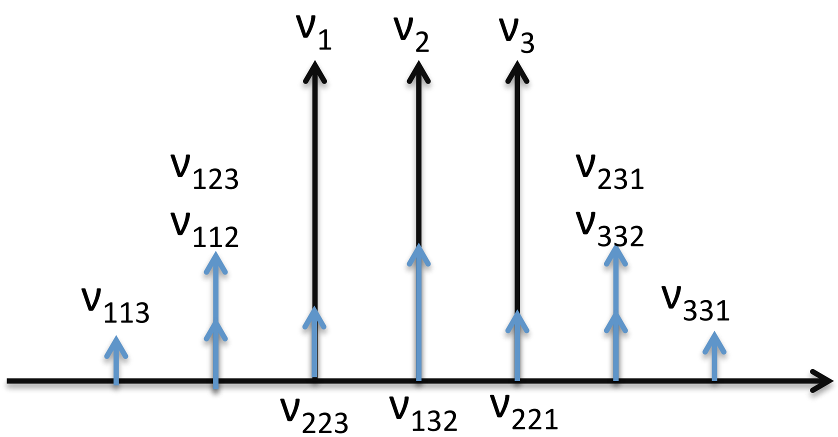
- At the San Antonia meeting in Nov. 2016, in contribution "dai_3ca_1(a)_1116.pdf", the issues with Huawei's simulation on all O band wavelength plan A were discussed.
- The contribution "dai_3ca_2(a,b)_1116 presented simulations results on the unconventional optical noises on signals when all FWM products are out of band. The origins of the observations and possible interplay of FWM and SBS effects were briefly discussed.
- This contribution presents studies on FWM coupled with SBS. The mechanism of optical noises, presented for the first time to the author's knowledge, was attributed mainly to the 2nd order Stoke waves when FWM coupled with SBS.

Outline

- Unconventional FWM noises when one WDM channel is in the zero dispersion regions
- Four Wave Mixing coupled with Stimulated Brillouin Scattering
- Optical noises generated by FWM coupled SBS

Conversional FWM Optical Noises

- In a WDM system, FWM creates new optical signals – FWM products
- If FWM products fall into the frequency band of original information carrying signals, inferences will happen

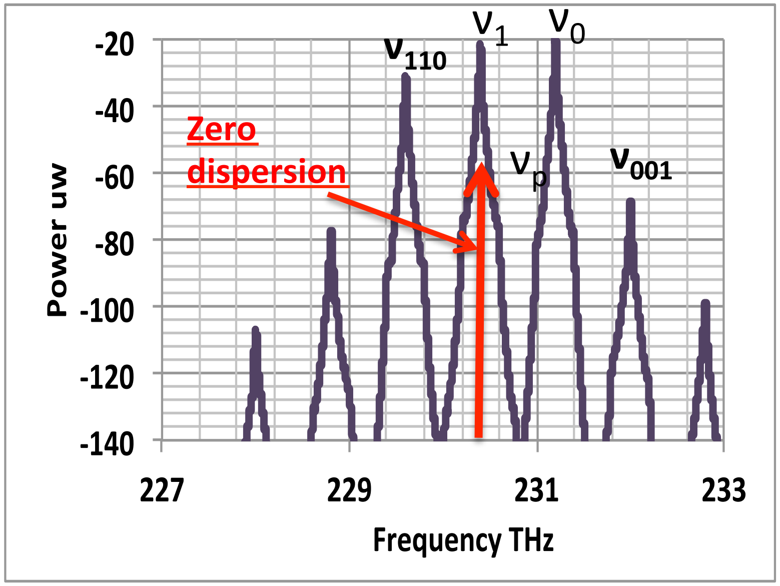


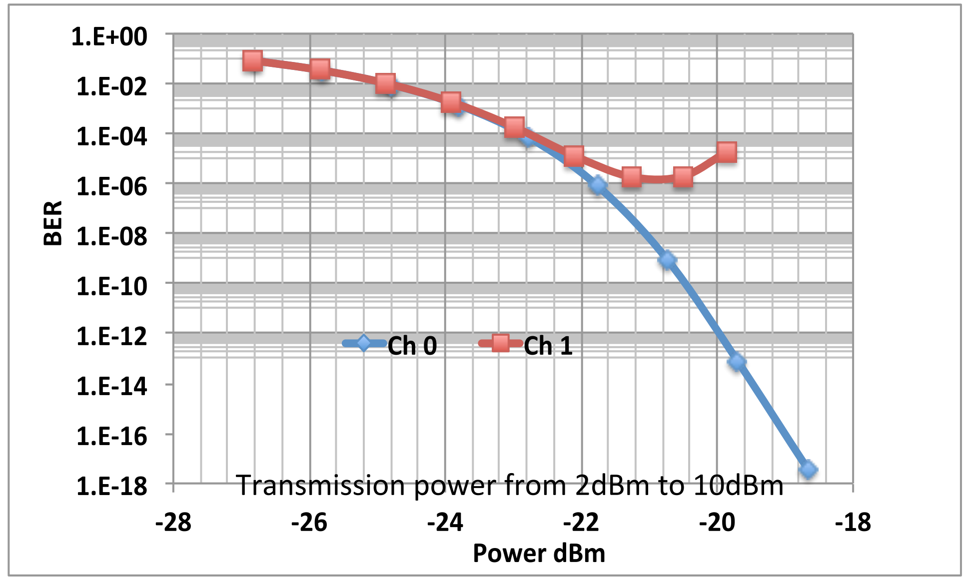
DWDM channels	FWM Products
2	2
3	9
4	24
8	224

It has been observed from simulation that under certain conditions strong optical noises could be observed in the original optical signal when no FWM products are in band

Unconventional FWM Optical Noises –Example 1

Degenerated FWM in a 2-channel system with zero dispersion at center of ch 1

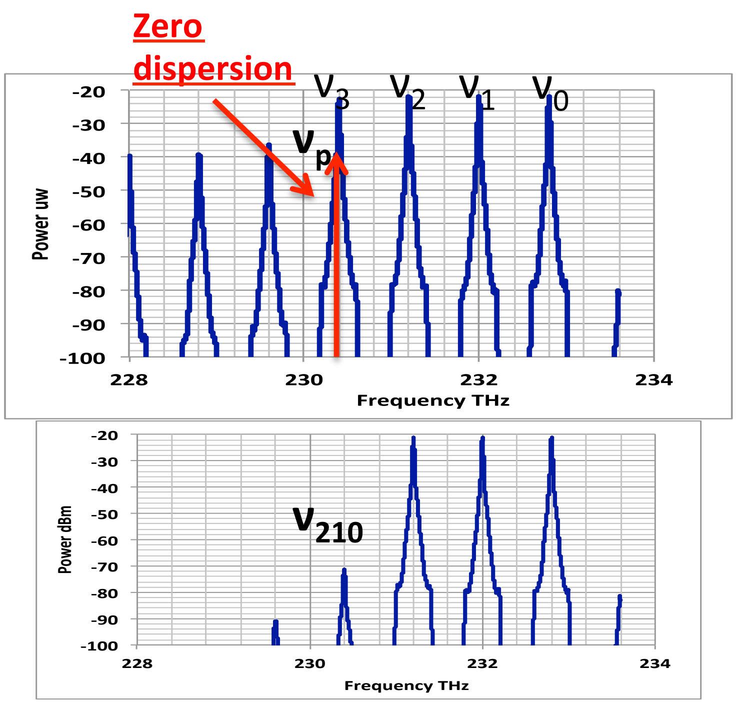


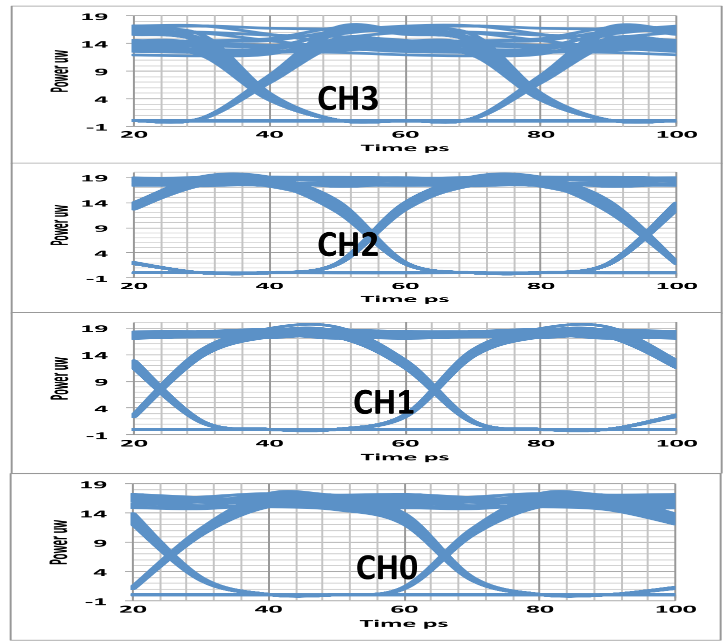


In a 2-channel system, there is no primary FWM products that fall under channel 1. However strong optical noises that have significant impacts on BER were observed in simulation

Unconventional FWM Optical Noises –Example 2

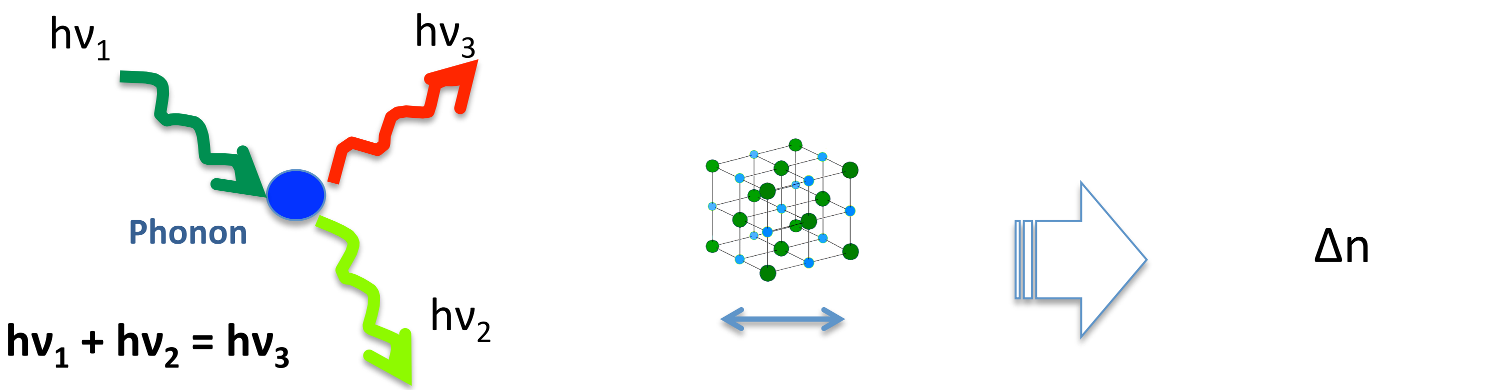
Degenerated FWM in a 4-channel system with zero dispersion at center of ch 3





- **Strong FWM noise is observed in channel 3.**
- **The non phase matched FWM product ν_{210} is under channel 3, however it is relatively weak and insignificant**

Local Refraction Index Fluctuation Caused by FWM



FWM: Photon-phonon interaction

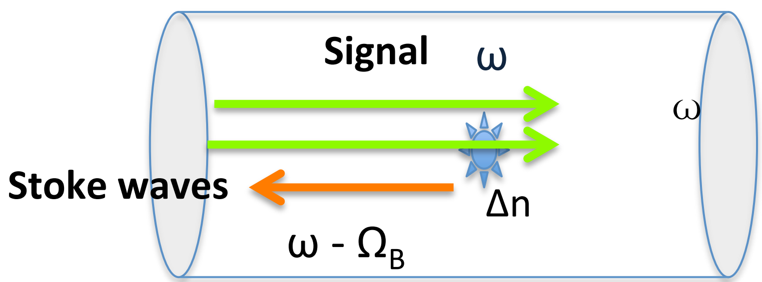
Crystal lattices oscillation

Refraction index changes

$h = 6.626 \times 10^{-34}$ J •s is Plank's constant

- **Photons interact with crystal lattices in a silicon fiber via acoustics phonon exchanges that create lattice oscillations, which causes a local refraction index change**
- **Local fluctuation of the refraction index could generate Stimulated Brillouin Scattering (SBS)**
- **FWM could coupled with SBS**

Stimulated Brillioun Scattering



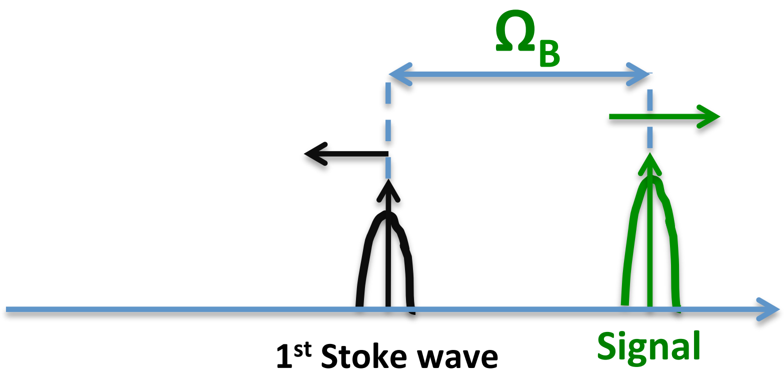
$\Omega_B \approx 10$GHz for glass

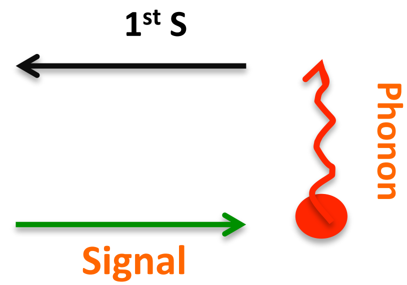
SBS in optical fiber

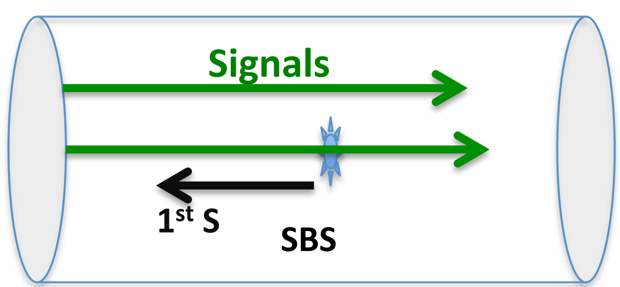
- SBS is a nonlinear optical phenomenon due to interaction between photons in incident light and acoustic phonons from lattice oscillations. The process requires phase matching (energy and momentum conservation)
- Energy conversation requires $\omega_S = \omega - \Omega_B$, where ω is the incident signal frequency and the Ω_B is the acoustic phonon frequency
- Momentum conversation requires scattered light (Stoke wave) to counter propagate in reference to the incident light

In a optical fiber, Stoke waves counter propagate with frequency down shifted $\Omega_{B.}$ The Stoke waves (1st order) will not be received by the receiver, but causes optical signal energy depletion

1^{st} Order Stoke wave from FWM coupled SBS

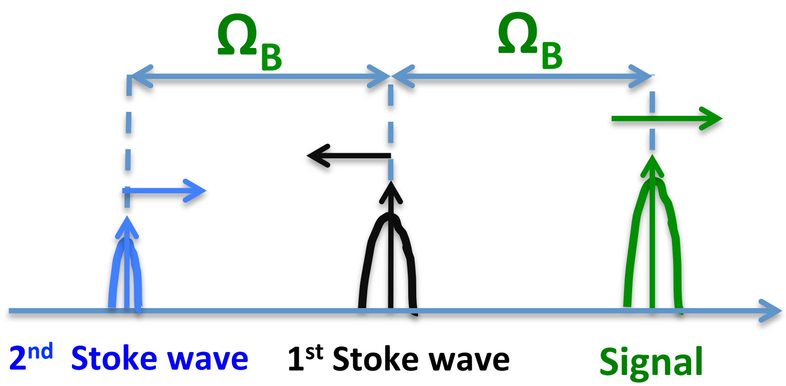


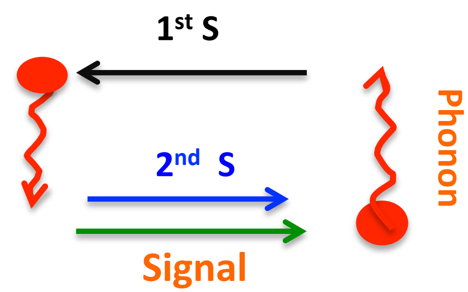


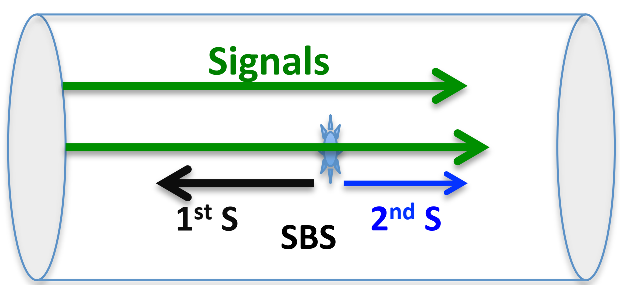


- FWM causes lattice vibration
- Incident photons are scattered by phonons
- 1^{st} order Stoke waves counter propagate
- Optical power depletes in signal light

2^{nd} Order Stoke wave from FWM coupled SBS







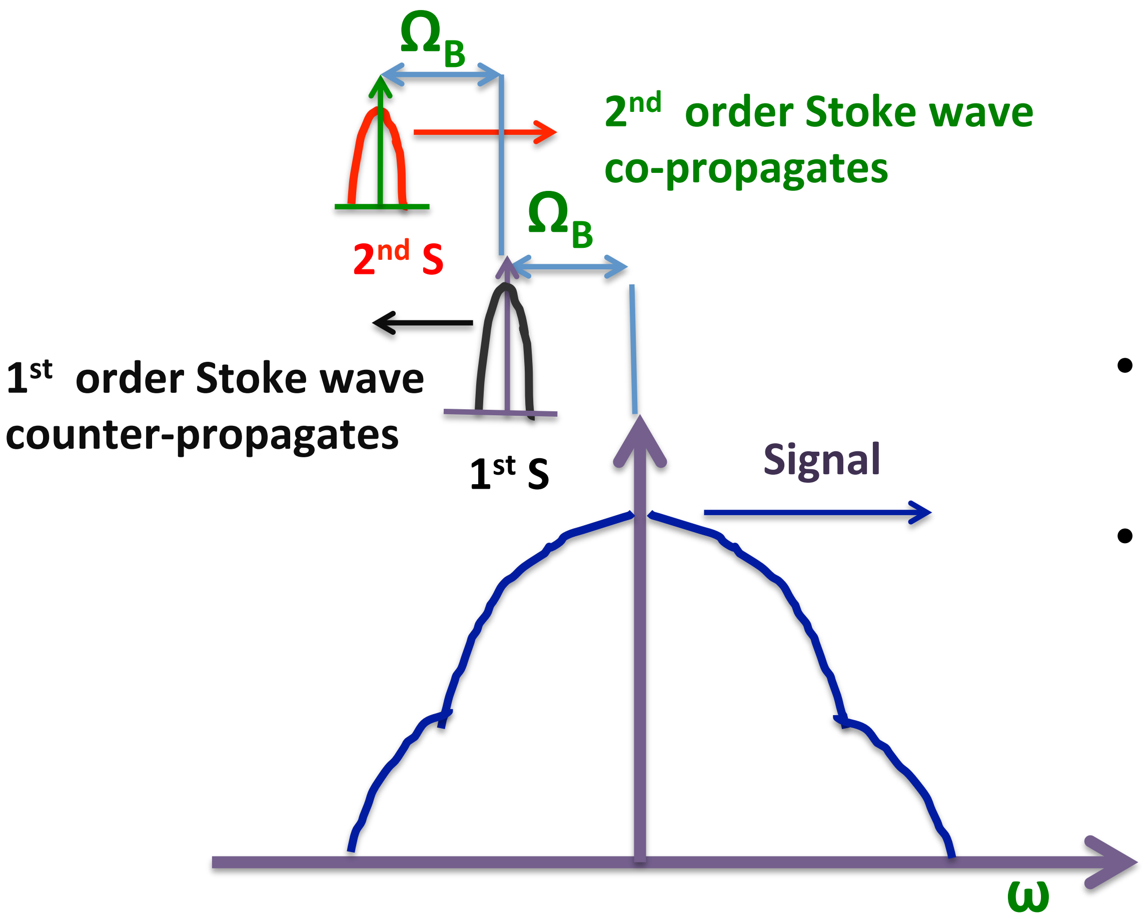
- FWM caused lattice vibration
- 1^{st} order Stoke waves been scattered from phonons
- 2^{nd} order Stoke wave co-propagates with incident signal light

In an optical fiber, the 2^{nd} order Stoke waves will be received at the receiver as optical noises, causing optical signal degradation

Degenerated FWM coupled with SBS

- Unconventional FWM noises were only observed in DFWM
- Zero dispersion creates exact phase match in DFWM
    - Creates strong DFWM
    - Creates lattice variations (acoustic phonons)
- The origin of the strong unconventional FWM optical noises observed are related to SBS induced by FWM due to the changing of the refraction index and the low threshold of SBS
- The main contributor to the optical noises are from the co-propagating 2nd Stoke waves

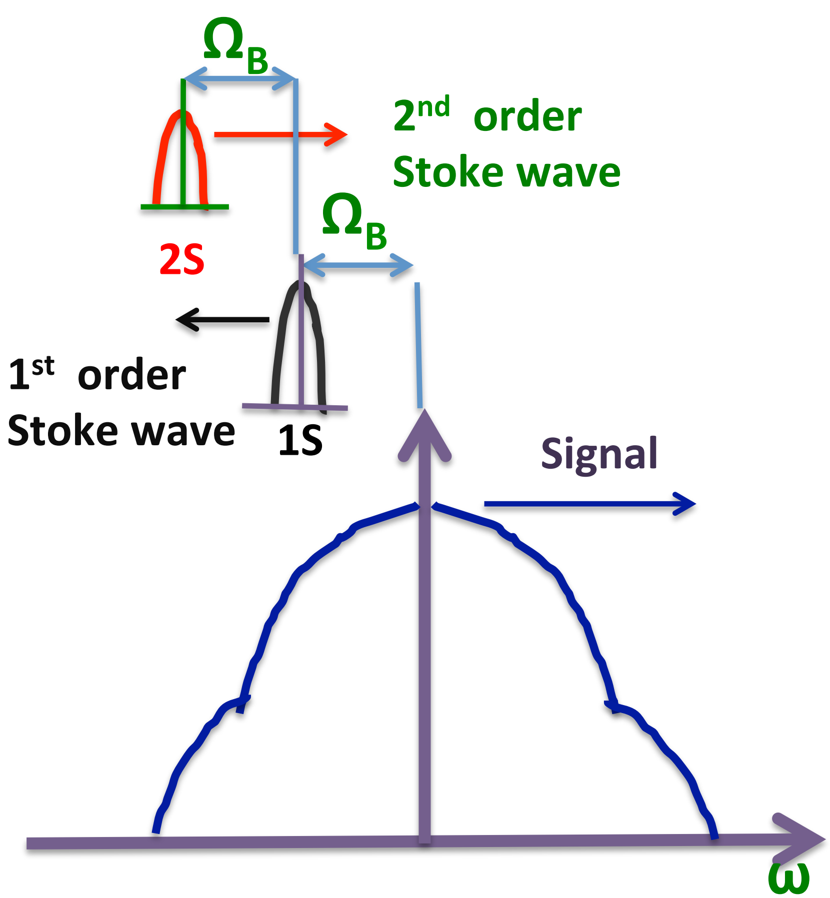
Relations of Stoke Waves and the Signal



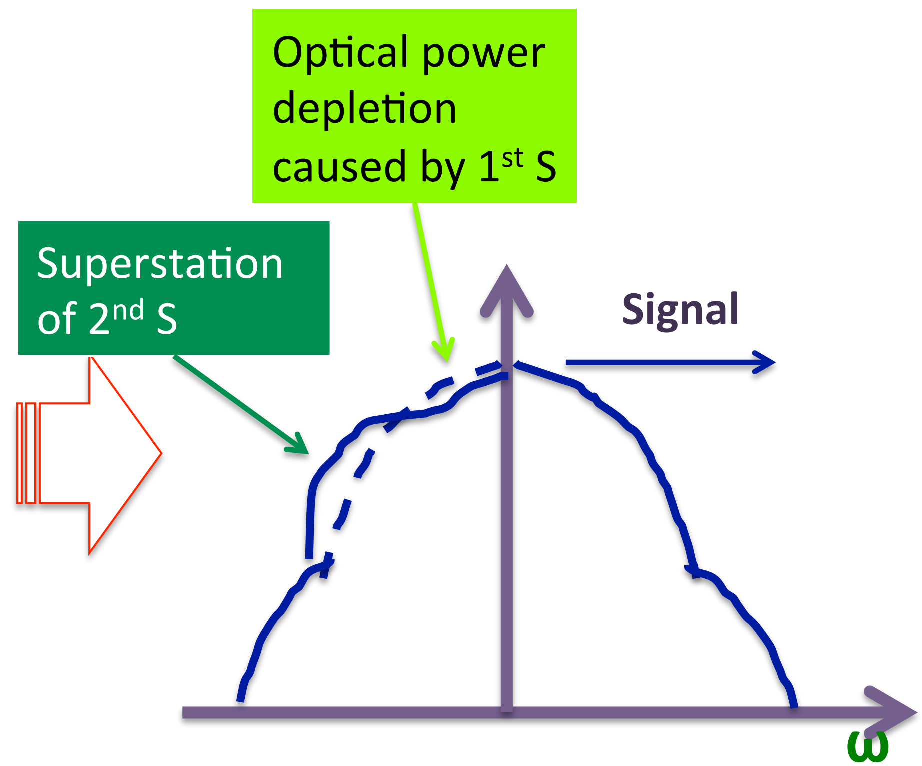
- In an optical fiber, Stoke waves are down shifted ~ 10GHz from the signal
- If the signal spectra width is greater than 20GHz, the 2nd order Stoke overlaps with the signal

For wide channel spacing WDM systems, which is the case for 100G EPON, 2nd Stoke waves generated by FWM coupled with SBS create optical noises

Superstations of Stoke Waves and the Signal

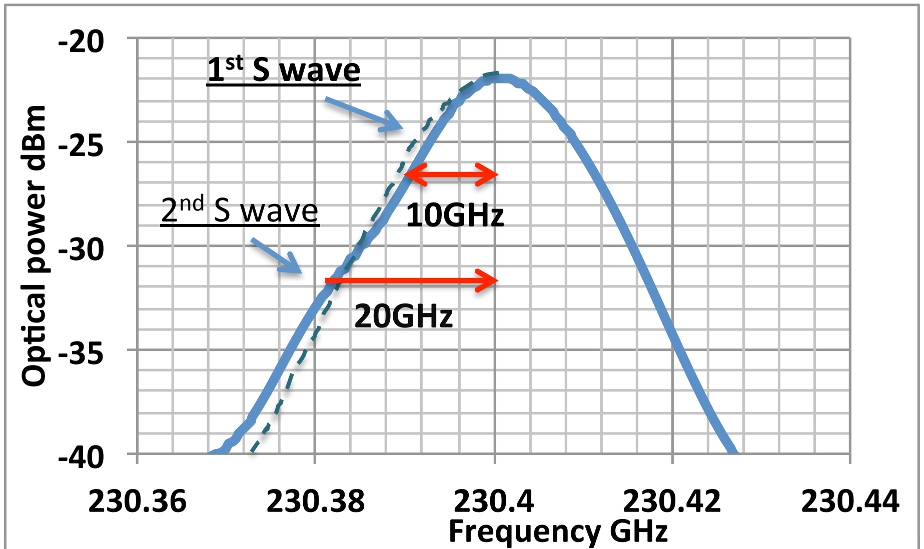


Signal and stoke waves

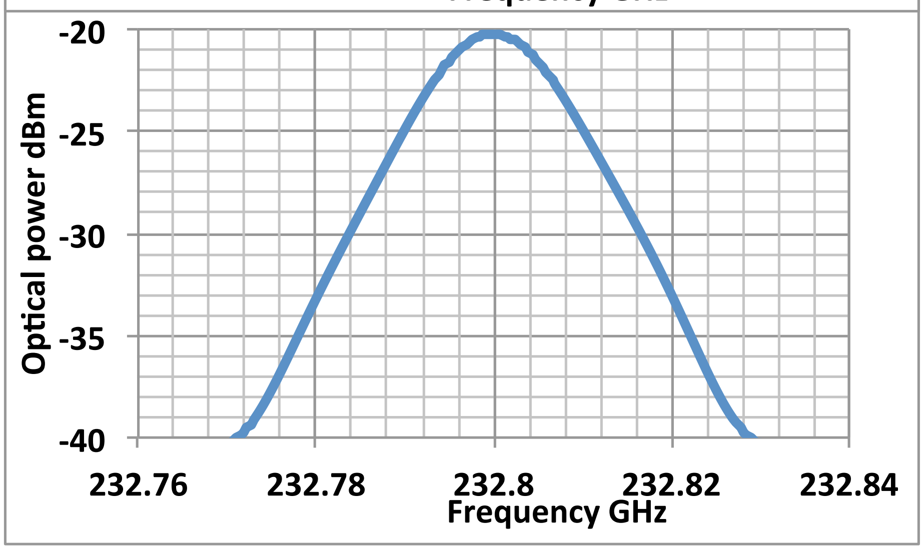


Superstations of of signal
and stoke waves

Superstations of Stoke Waves and the Signal - Simulation



- A WDM channel with zero dispersion at center
- Strong optical noises were observed
- The spectrum is asymmetric
- Low frequency left part of the spectrum shows impacts from 1st S Wave and 2nd S wave



- A WDM channel in non-zero dispersion region
- The spectrum is symmetric
- No unusual optical noises were observed

Conditions for FWM Coupled SBS

- Zero dispersions are at center of a channel or in the middle of any WDM channels that cause degenerated FWM
- DFWM creates lattice variations the leads to local refraction index changes
- 1^{St} order Stoke wave is generated
- The 1^{st} order Stoke wave further interacts with phonons that generate 2^{nd} order Stoke

Discussion

- Zero dispersion at a channel center or in the middle of any channels in a WDM system will suffer from FWM coupled SBS
- In the 800GHz all O band(johnson_3ca_1a_0916.pdf) the zero dispersion could be in the center of channel 3 or in the middle of channel 2 and channel 3, and therefore will suffer from FWM coupled SBS
- The 400GHz all O band wavelength plan (dai_3ca_3a_1116) is placed entirely out of zero dispersion regions of SFM
- Therefore, a all O band wavelength plan is still possible with 400 GHz channel spacing that avoids FWM coupled SBS

Conclusion

- We reported, for the first time, simulation studies on the 2nd Stoke waves generated by FWM coupled SBS. Optical noises on the original signal were observed.
- The unconventional optical noises were only observed when DFWM happens
- An all O band wavelength plan is still possible with 400 GHz channel spacing

Thanks

Eugene.dai@cox.com