Linewidth Measurement

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Linewidth is often defined in terms of the full-width half-maximum (FWHM) of the optical field power spectrum. Grating-based optical spectrum analysers (OSAs) do not offer the measurement resolution required for laser linewidth measurement, so alternative characterisation methods must be used.

Width of laser line due to fluctuations in the phase of the optical field.

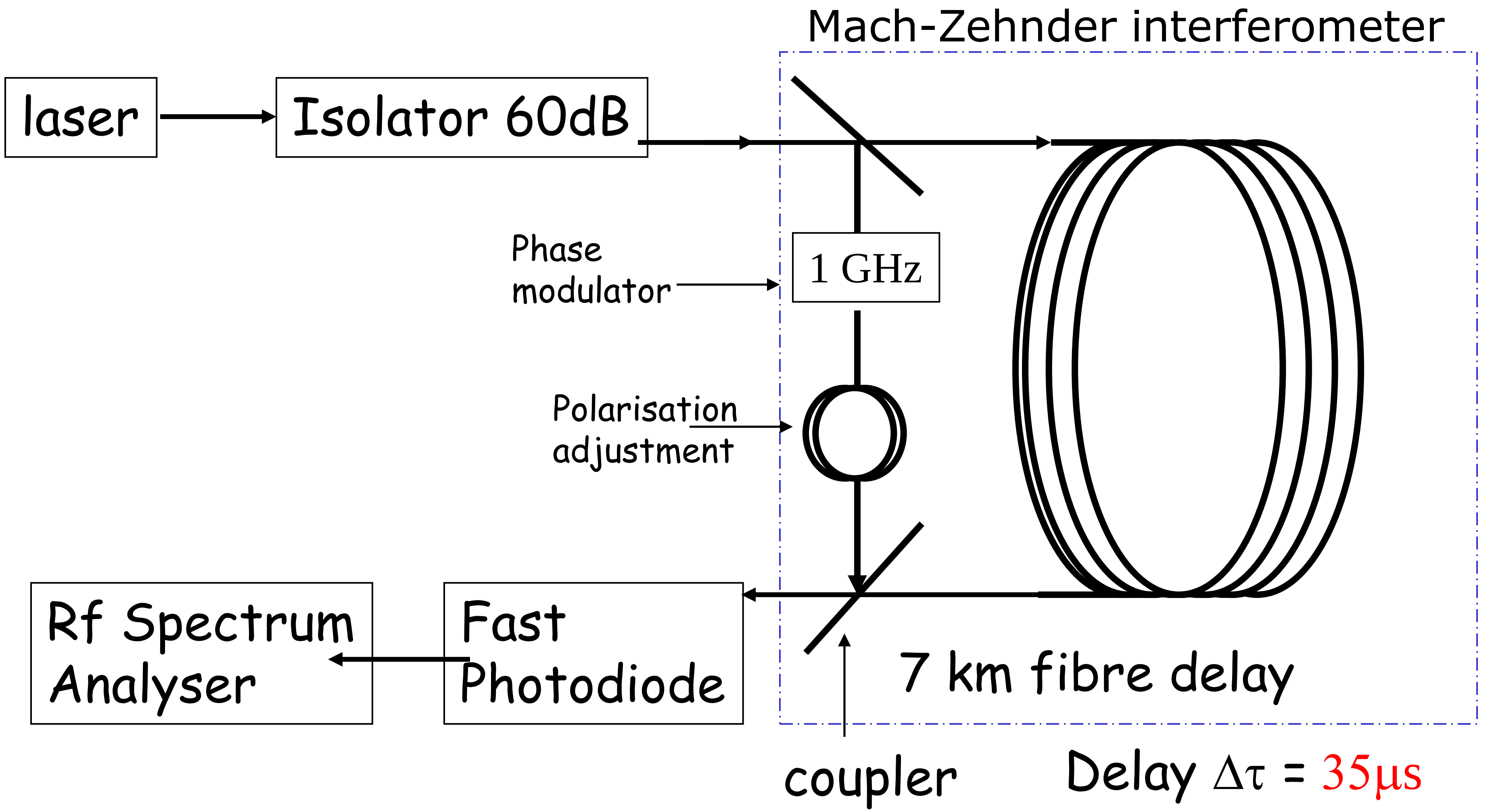
Fluctuations arise from two basic sources,

a) Spontaneous emission which alter the phase and intensity of the lasing field.

b) Carrier density fluctuations (unique to semiconductor's)

Measurement technique 1. Delayed Self-Heterodyne

Laser linewidth measurement: Delayed Self-Heterodyne



Incident light is split into 2 paths by the interferometer One path is sent through a delay line (7km of fibre) if this delay is longer than the coherence length of the laser the 2 combining beams interfere as if they are from 2 independent lasers offset by the 1GHz.

We use a 1GHz phase modulator to shift the detection frequency away from 0 were the RF analyser doesn't work too well.

Interference between two Optical fields

2 optical fields incident on photodiode ⇒

$$E_S(t) = \sqrt{P_S(t)}e^{i(2\pi\nu_S t + \phi_S(t))}$$

$$E_{LO}(t) = \sqrt{P_{LO}(t)}e^{i(2\pi\nu_{LO} t + \phi_{LO}(t))}$$

$\nu = 194$THz (1.55μm)

$\phi =$ optical phase (takes into account any phase noise)

$2\pi\nu t + \phi(t)$ changes at a rate much too fast for electronic instrumentation to respond!

Interference between two waves causes intensity variations that are detectable using a photodiode.

$$E_T(t) = E_S(t) + E_{LO}(t)$$

Since power is detected $P(t) = |E_T(t)|^2$

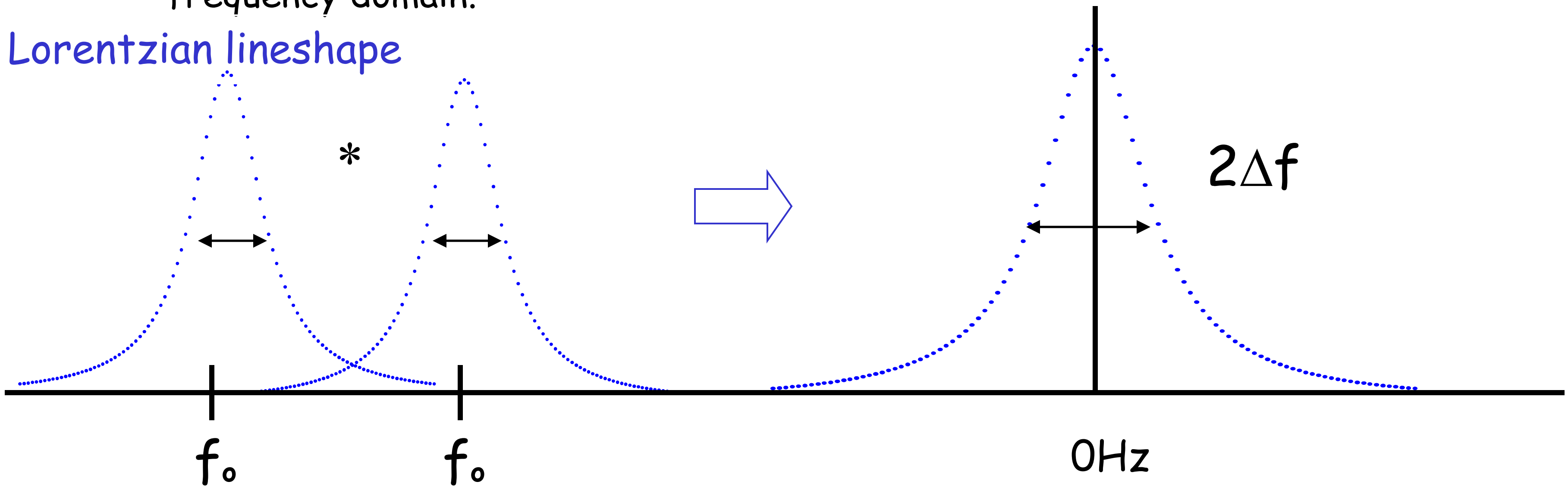
The photocurrent generated in the detector $i(t) = R|E_T(t)|^2$

$$i(t) = R\left[P_S(t) + P_{LO} + 2\sqrt{P_S(t)P_{LO}}\cos\left(2\pi f_{IF}t + \Delta\phi(t)\right)\right]$$

The first two terms correspond to the direct intensity detection, the third term is the important heterodyne mixing term. Note the actual optical frequency is gone and only the difference remains (f_{IF}).

Note: if either field were separately detected on the photodiode the resulting photocurrent would follow only the power variations P(t) and all phase info would be lost!

- Self Homodyne can be described mathematically as a single-delay autocorrelation. The optical spectrum at f_o autocorrelates with the delayed version of itself to produce a time-fluctuating spectrum centred at 0Hz. The Convolution originates from the multiplication of the time-varying local oscillator field with the signal field in the photodetector.
- Multiplication in the time-domain is equivalent to convolution in the frequency domain.

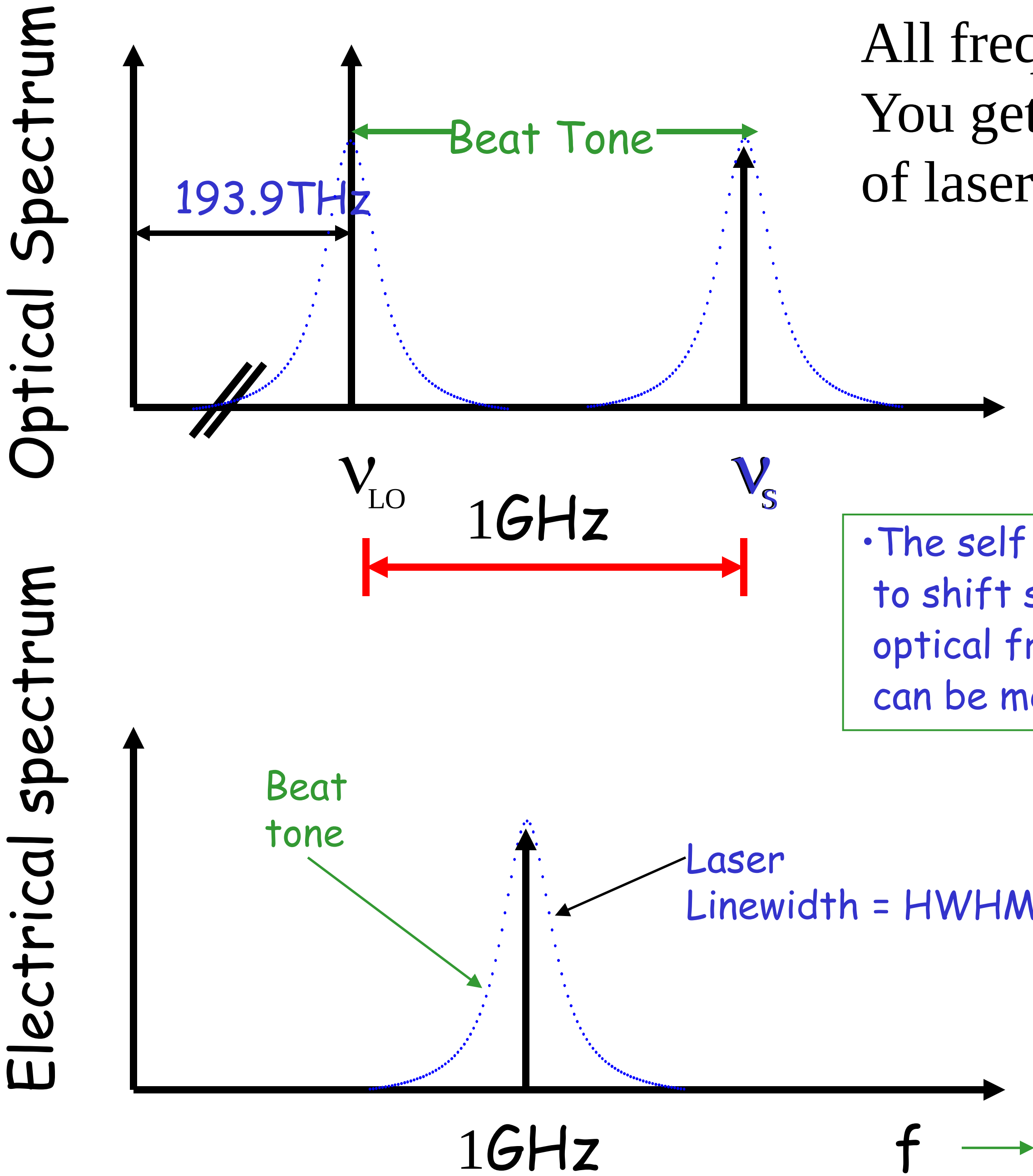


* indicates correlation

For the case of Lorentzian lineshape the autocorrelation function is also Lorentzian and has a linewidth exactly twice that of the original lineshape.

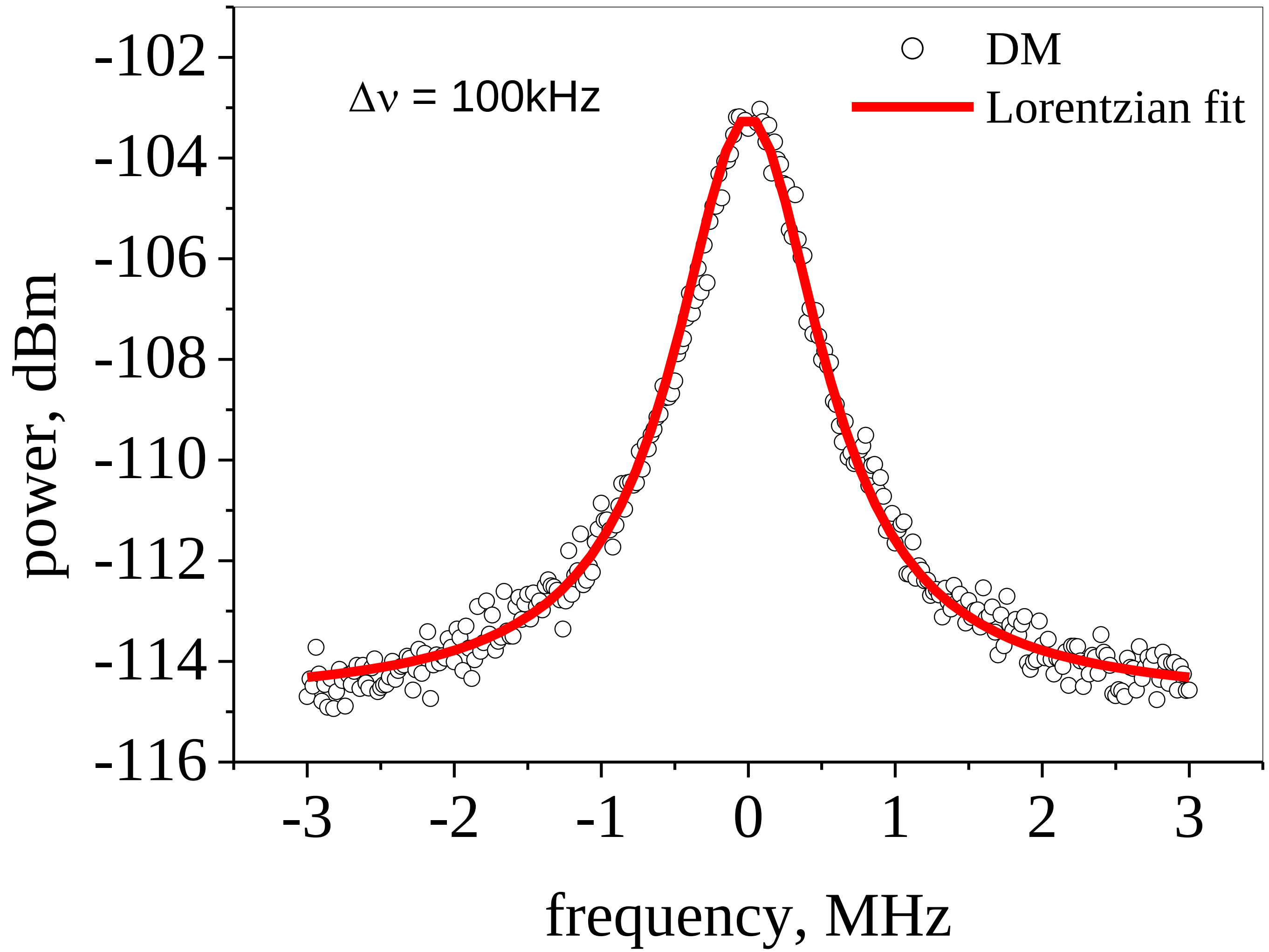
The self-Homodyne is the same technique except there is no phase
Modulator shifting the detection frequency away from zero.
Disadvantage harder to fit the spectrum as RF analyser has poor response at
Low frequencies also you loose half the spectrum below zero so makes fitting harder.

All frequencies will beat so
You get a beat tone 2 x linewidth
of laser under test



- The self Heterodyne method is able to shift spectral information from high optical frequencies to frequencies that can be measured with electronics.

Delayed self-heterodyne measurement of DM laser with Lorentzian fit to extract linewidth



FWHM of this spectrum is equal to twice laser linewidth