Centre for Gravitational Physics

# Coherent readout and control of the impedance matching condition in resonant optical systems

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and David McClelland

# Readout and control of the impedance matching condition

## Impedance matching of resonant optical systems

- Impedance matching for optically resonant systems is a kin to that in electrical systems:
    - In electrical systems impedance matching provides optimum voltage, power, or current transfer.
    - In optical systems impedance matching provides the optimum electric field transfer.
- Interrogation and control of the impedance matching condition offers a new active feedback control technique that has potential applications within GW interferometry, absorption spectroscopy, and quantum optics experiments.

# Readout and control of the impedance matching condition

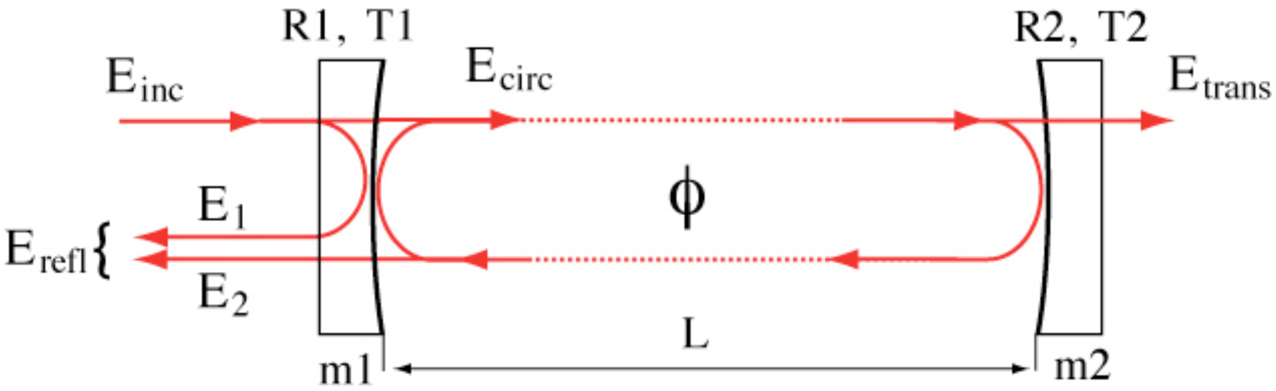
## The important parameters that active impedance matching optimises are:

- optimum electric field transfer through the optical system.
- ensures that the reflected electric field is zero and the circulating field to be maximised (assuming a back mirror who’s reflectivity is dominated by loss).

and

- by optimising the circulating power, the technique also optimises the signal sensitivity of the system.

# The impedance coupling of a Fabry-Perot

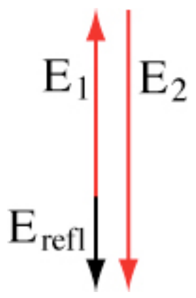


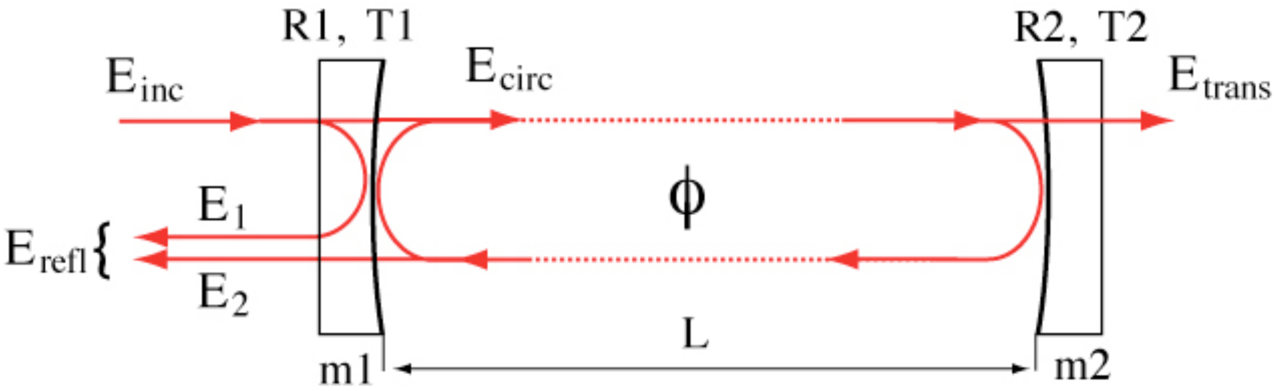
## The impedance coupling of a simple Fabry-Perot cavity

- The impedance condition of a cavity is often described by the reflected cavity electric field.
- The reflected cavity electric field is comprised of two terms:
    - The promptly reflected incident electric field E1
    - The circulating leakage electric field E2.
- This gives three impedance conditions, described by the mirror reflectivities; Over coupled, Under coupled, and impedance matched

# The impedance coupling of a Fabry-Perot

Over coupled





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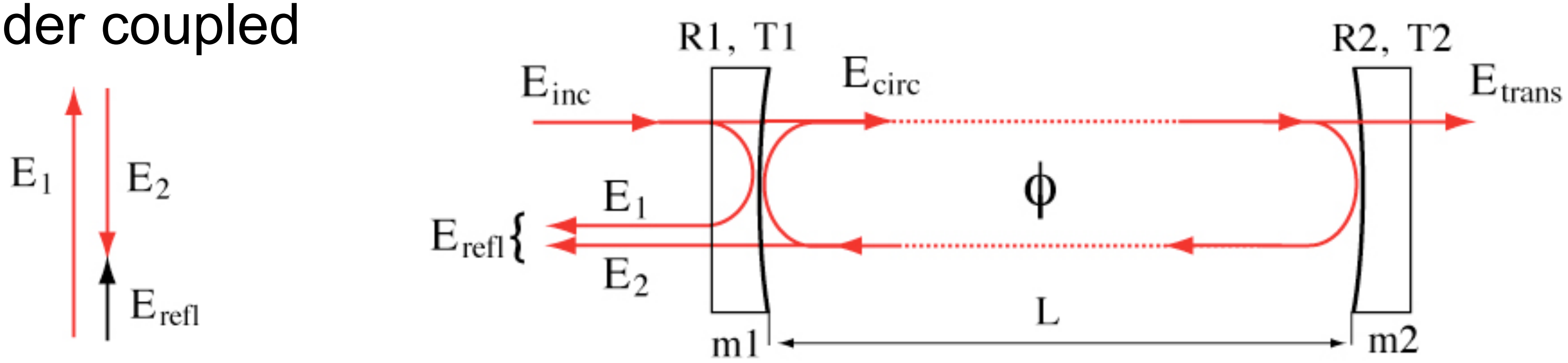
Under coupled



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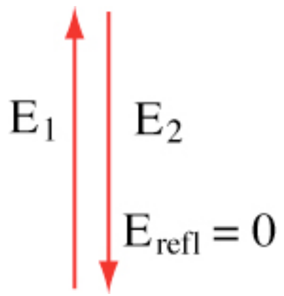
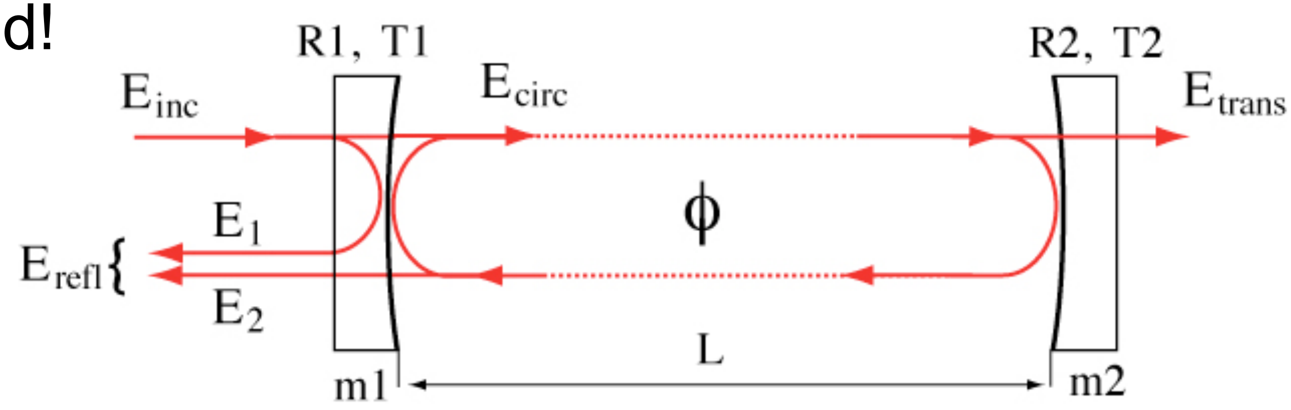
# The impedance coupling of a Fabry-Perot

Impedance matched!





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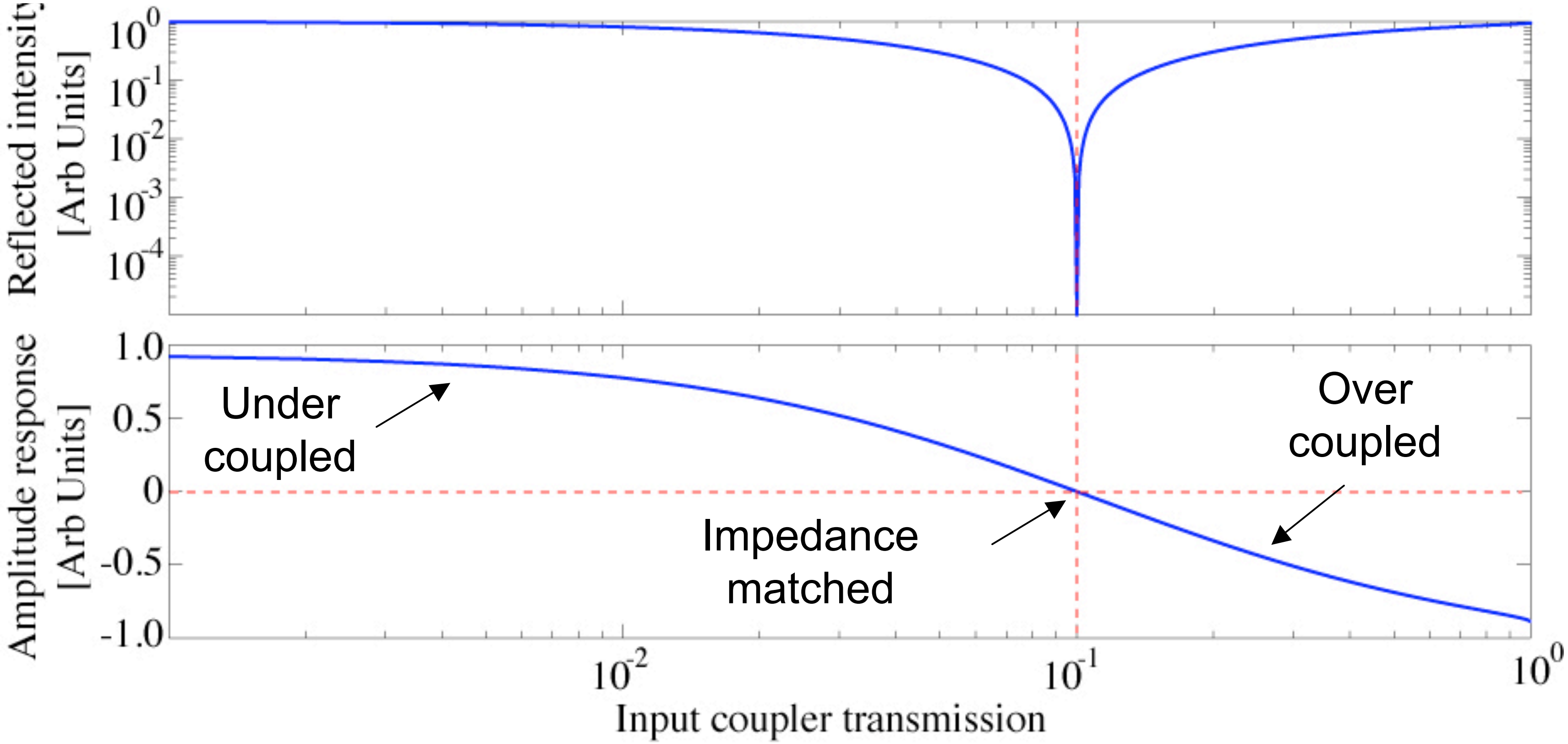
# Cavity transfer functions

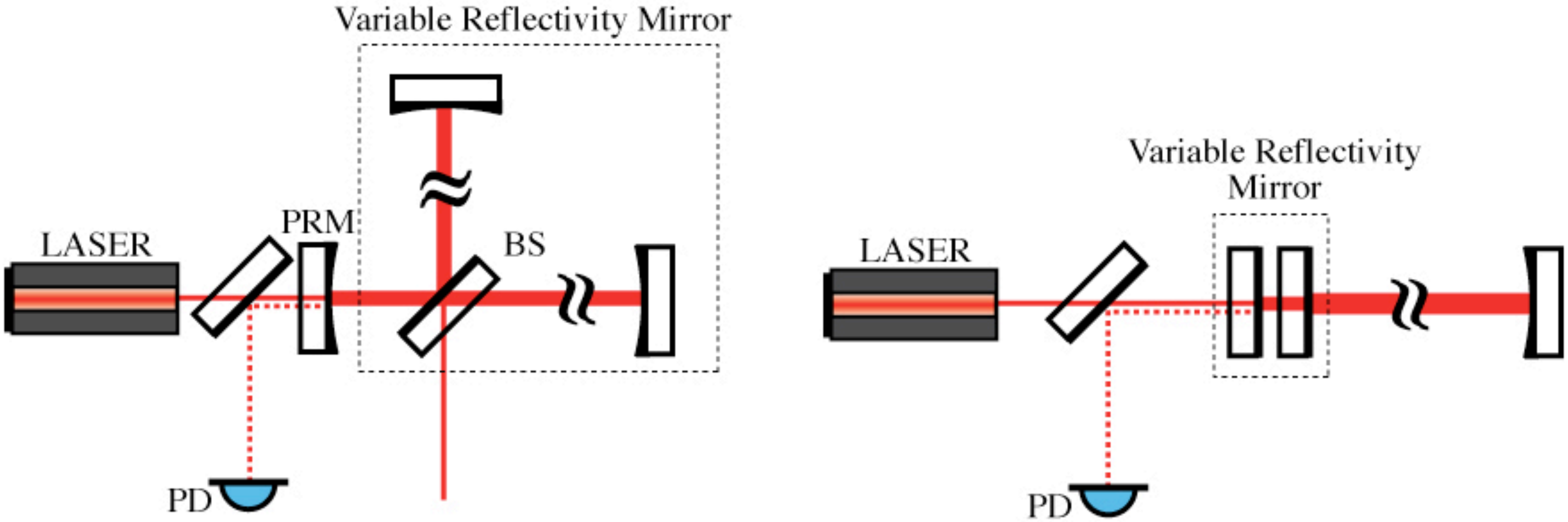
Complex reflection coefficient: $|R_{cav}|^2 = |E_{refl}/E_{inc}|^2$

and amplitude response: $Re(R_{cav})$



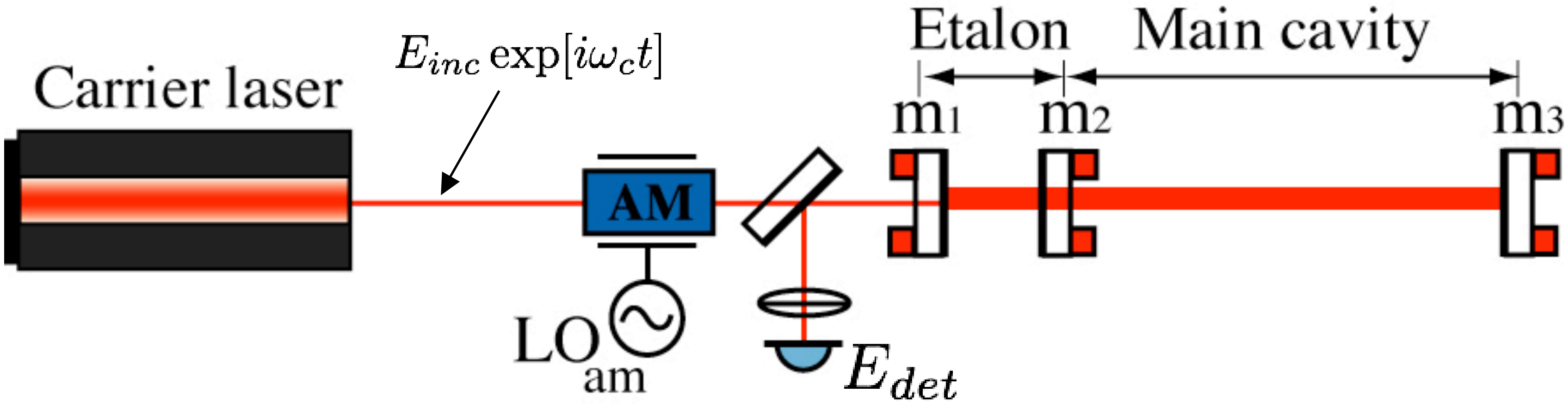
# Varying the impedance coupling

## So how can we vary the impedance coupling



- We can use a Michelson as a variable reflectivity mirror.
- Or we can use a Fabry-Perot cavity as a variable reflectivity mirror.

# Interrogating the impedance condition



## How do we interrogate the impedance coupling

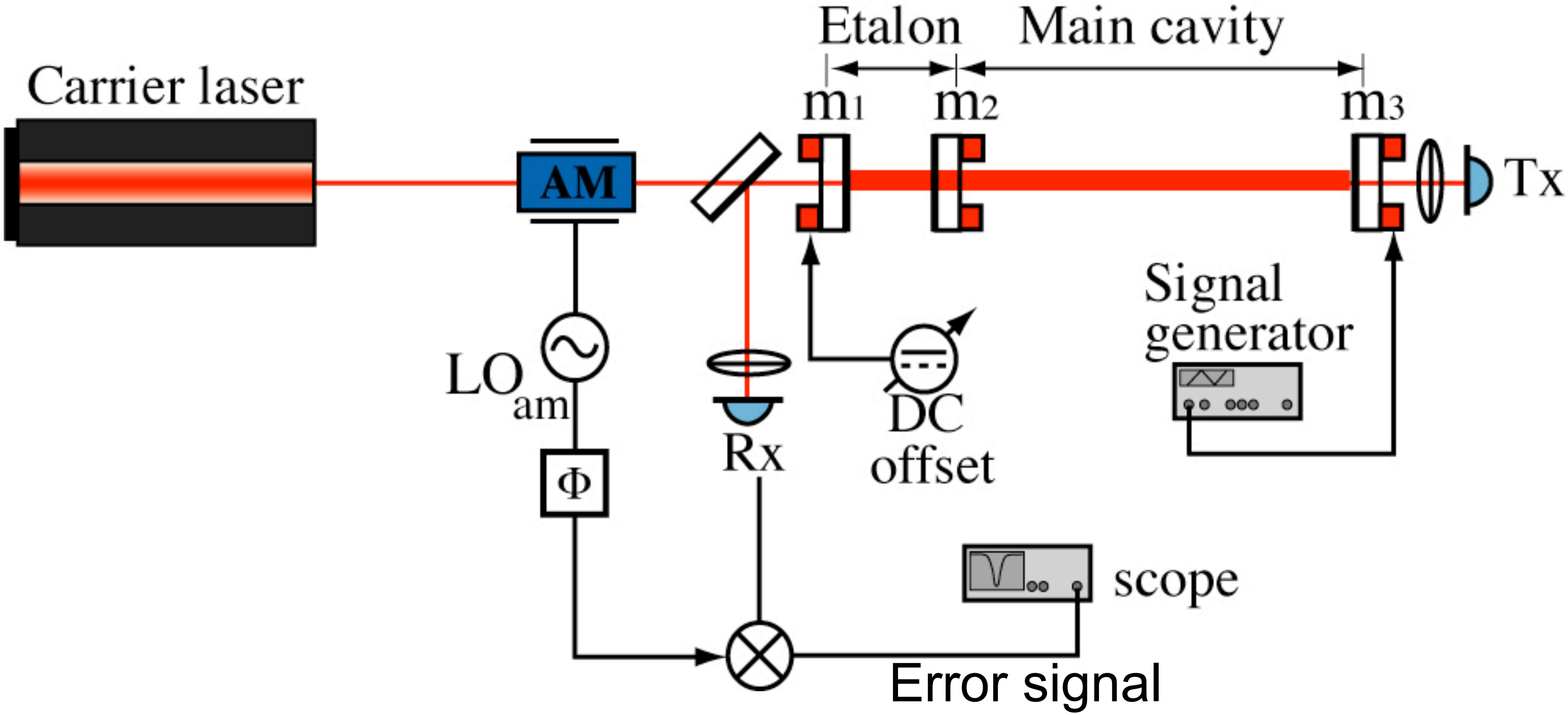
- By monitoring the beat signal between the carrier and a set of amplitude modulated sidebands which are outside the coupled cavity linewidth, we can obtain a signal which is proportional to the reflected electric field amplitude:

$$E_{det} = E_{inc}\exp[i\omega_c t]\left[R_{cav} + \beta/2\exp[i\omega_m t] + \beta/2\exp[-i\omega_m t]\right]$$

- Subsequent demodulation allows to extract a signal which is linearly dependent on the reflected amplitude response of the coupled cavity.

# Varying the impedance coupling

## Bring the etalon from anti-resonance into resonance



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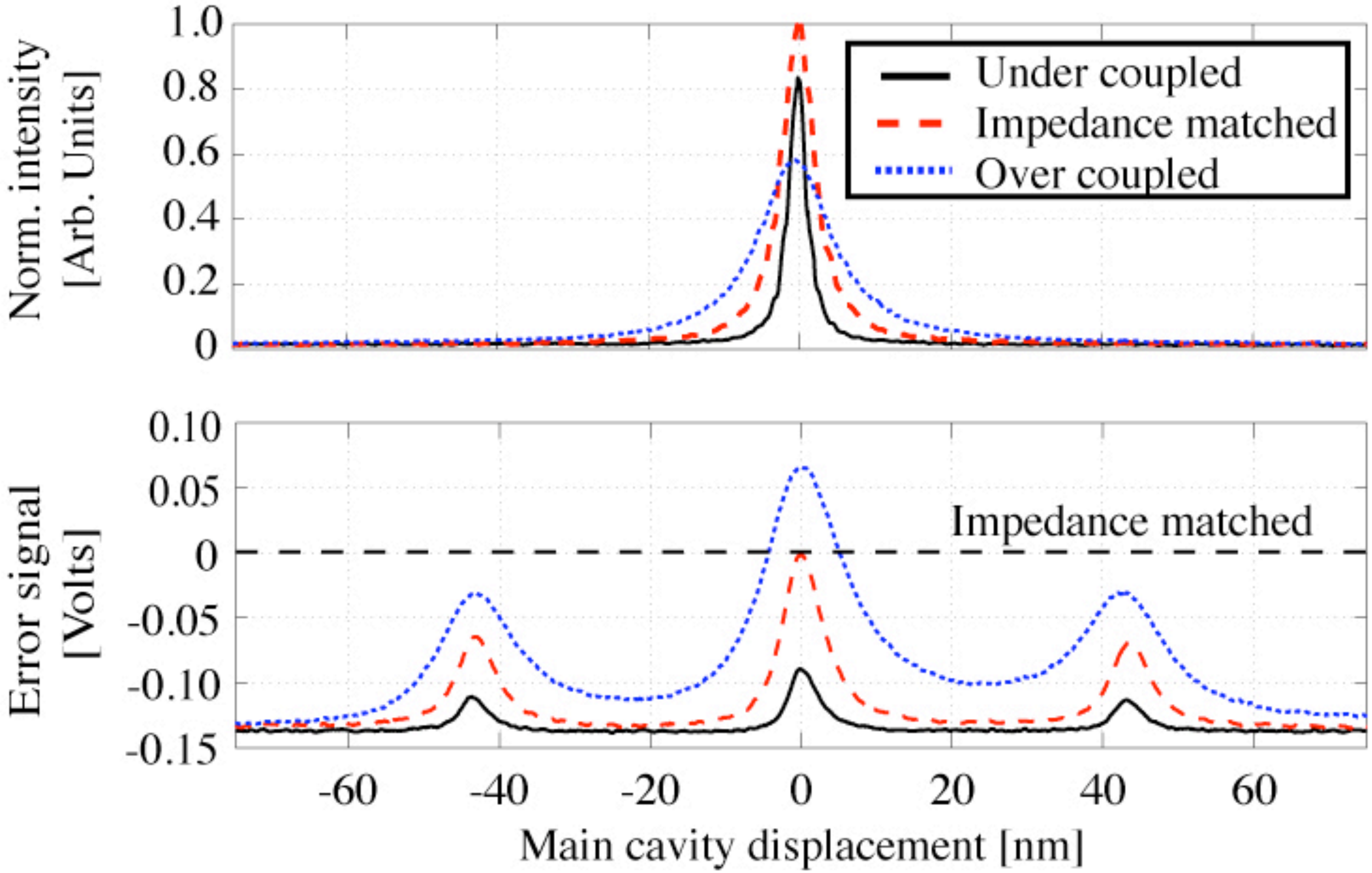
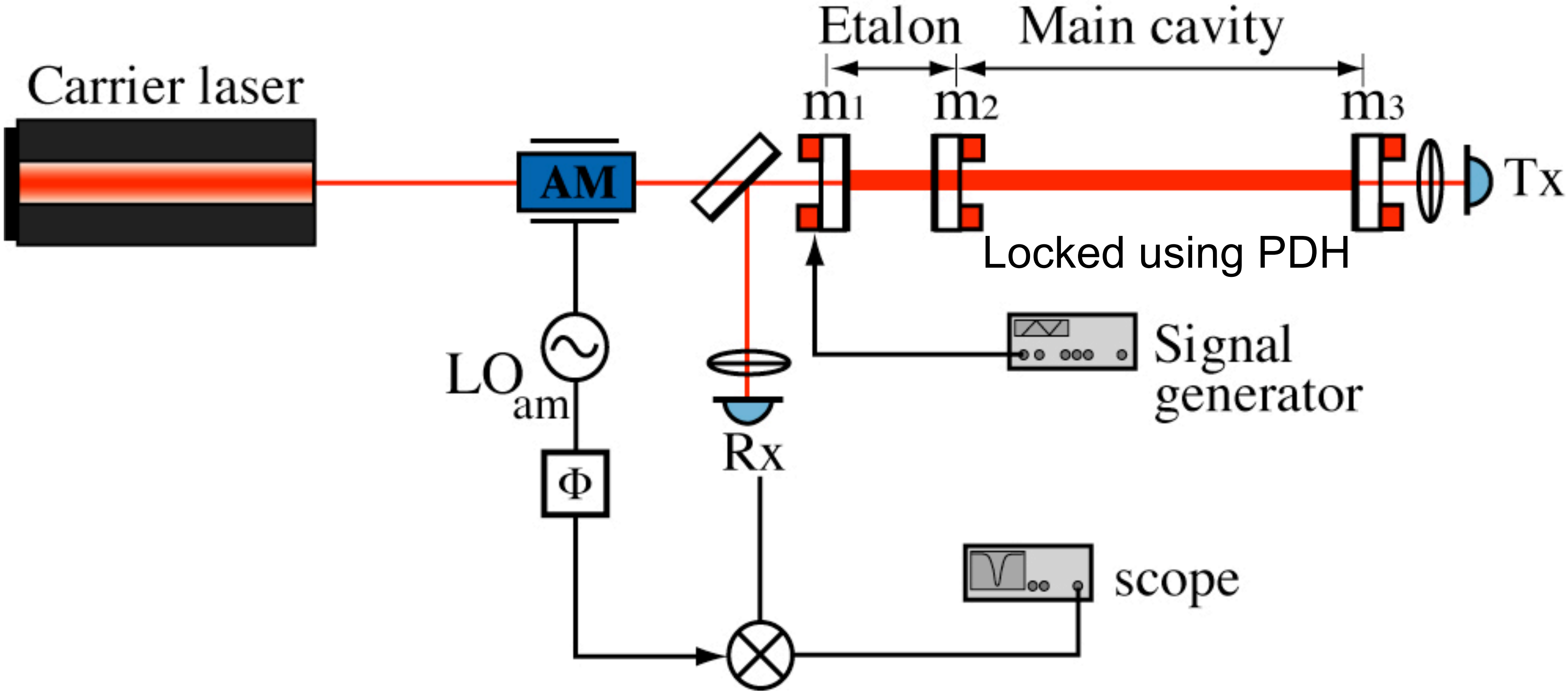
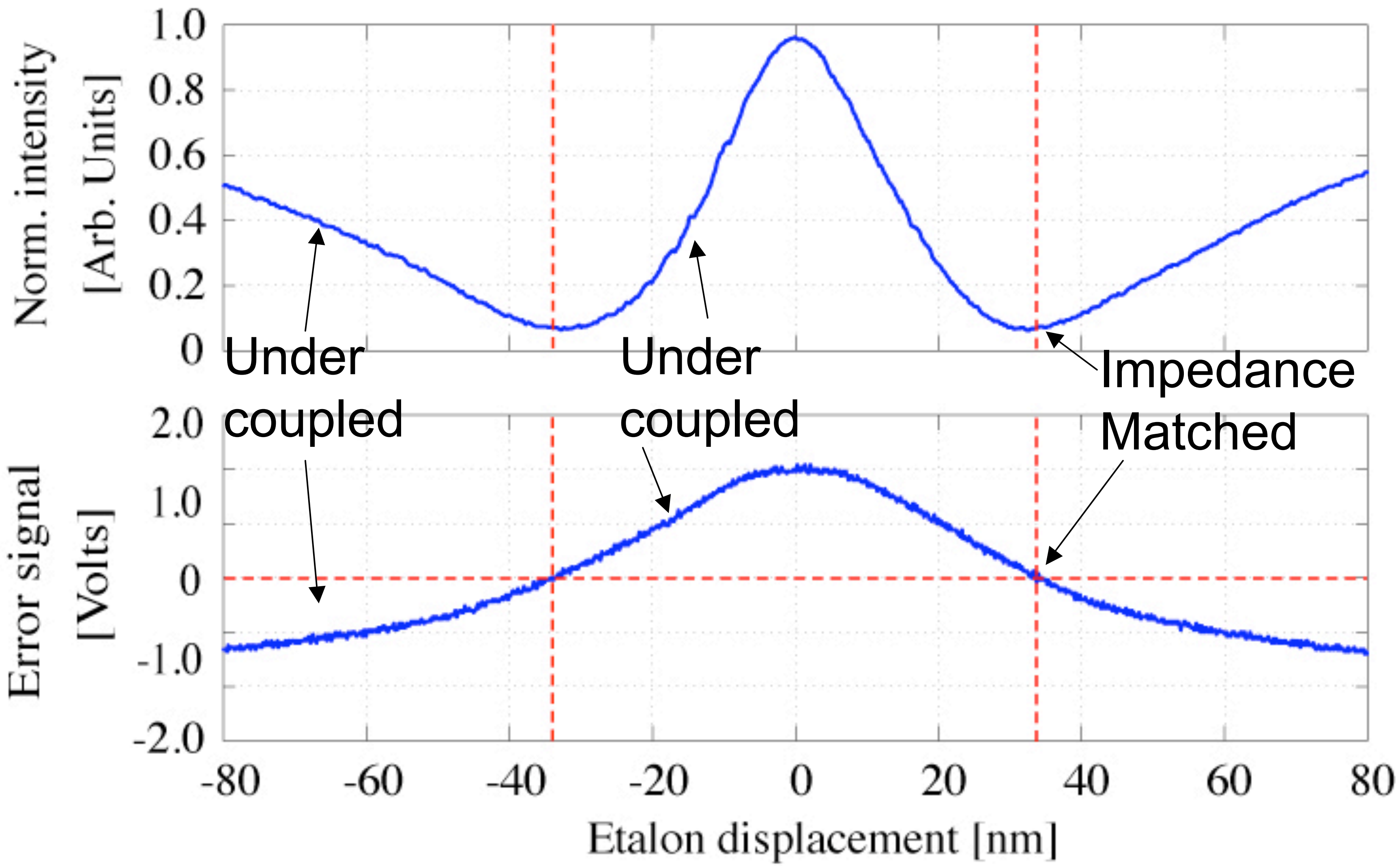


# Locking the main cavity and scanning the etalon



Locked using PDH

# Locking the main cavity and scanning the etalon

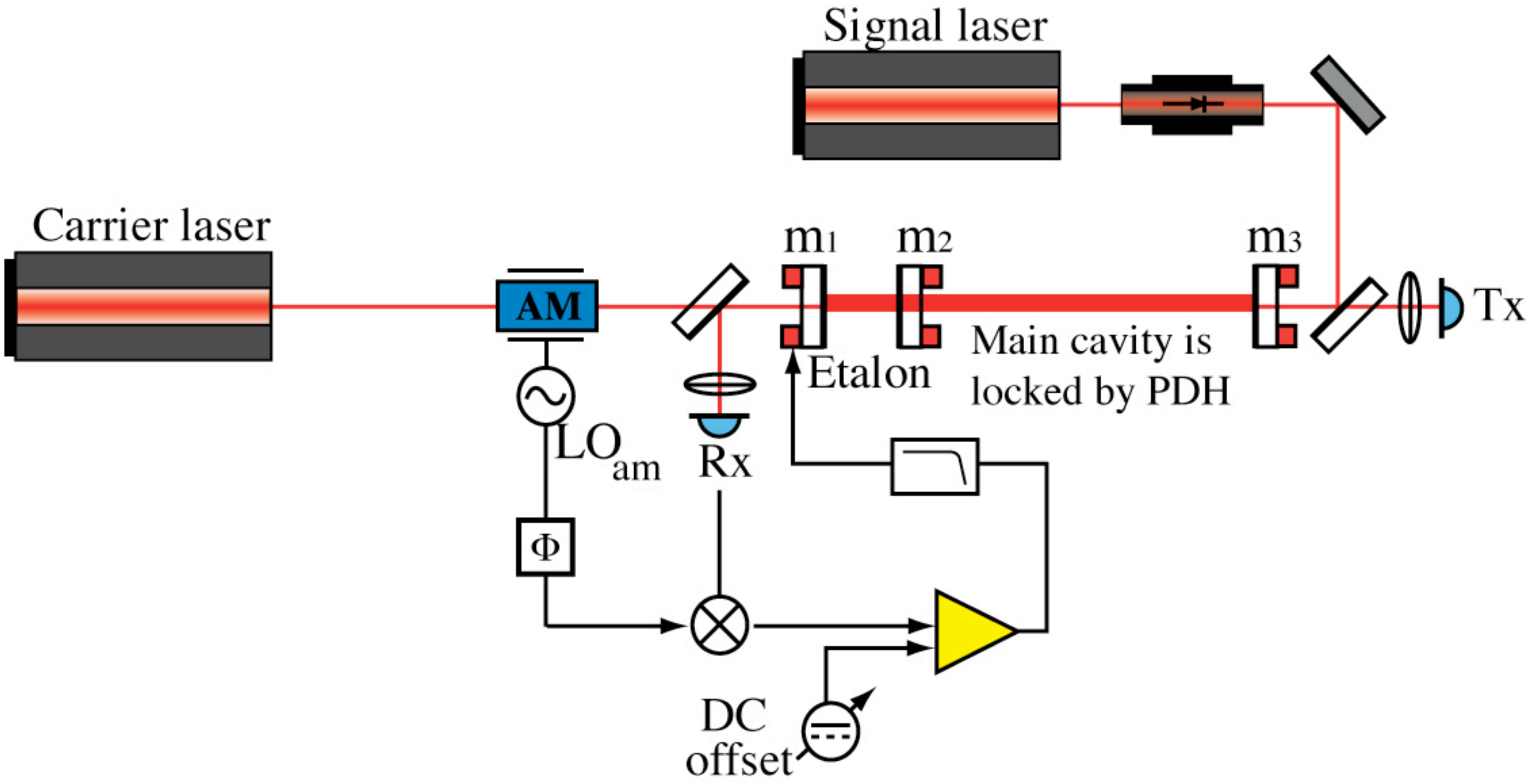


Under coupled

Under coupled

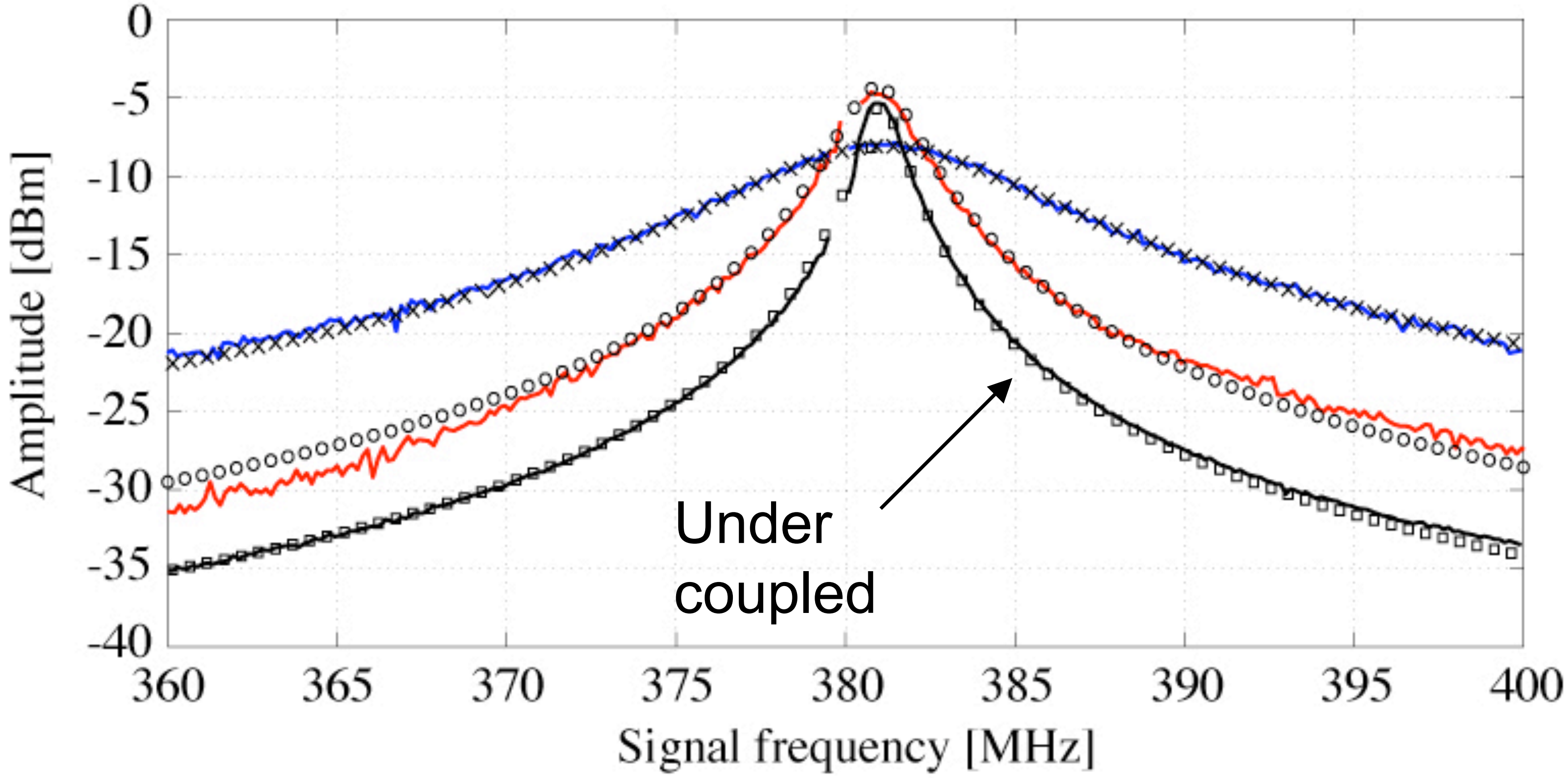
Impedance Matched

# Signal response of the coupled cavity system



# Signal response of the coupled cavity system

A signal is injected to investigate
the signal response of the system for different coupling.



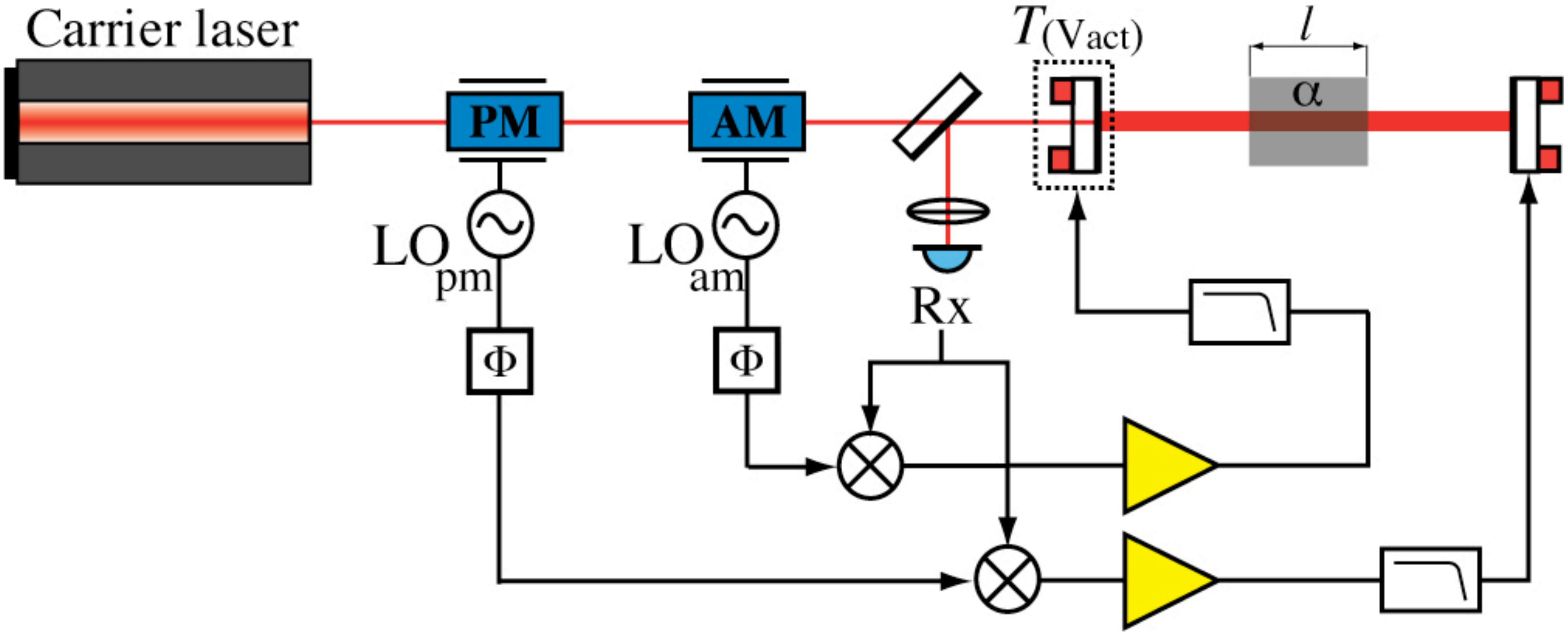
Under coupled

# Applications of this technique

## What can impedance matching locking be used for

- We recently demonstrated the technique for absorption spectroscopy using a fiber ring resonator.

  J. Chow, I. Littler, D. Rabeling, D. McClelland, and M. Gray, *"Using active resonator impedance matching for shot-noise limited, cavity enhanced amplitude modulated laser absorption spectroscopy*," Opt. Express 16, 7726-7738 (2008).



# Applications of this technique

## What can impedance matching locking be used for

- The interrogation of impedance coupling of Micro cavities

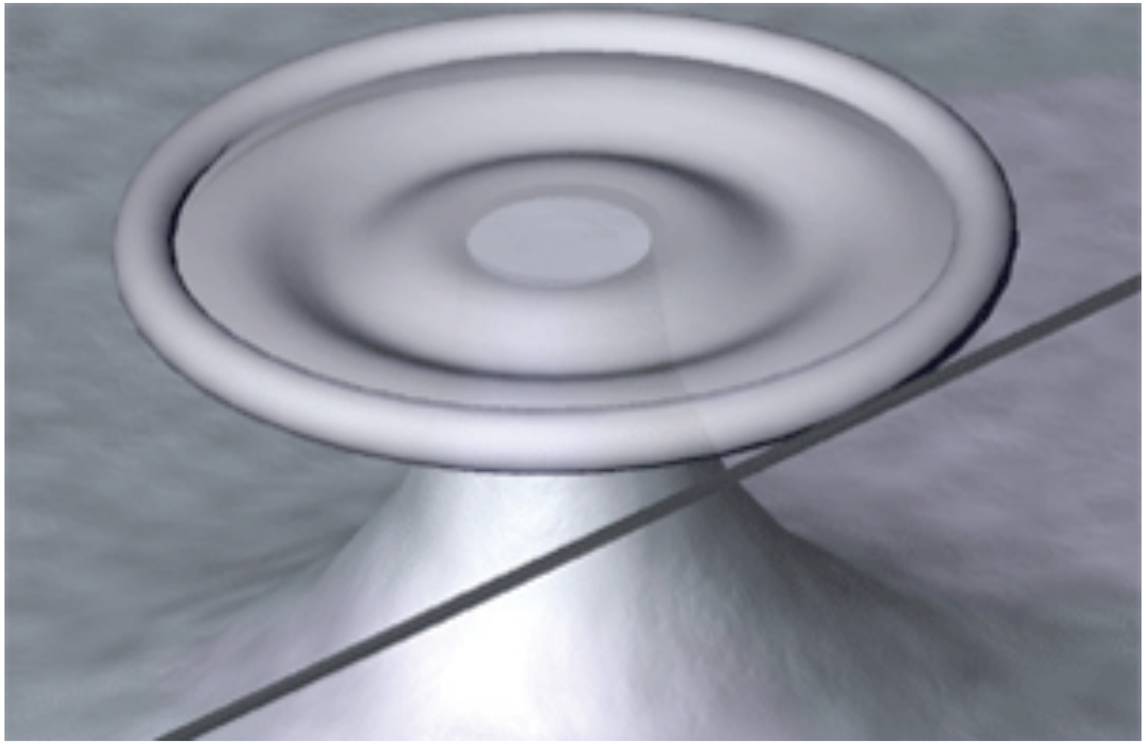


Image with permission from Prof. K. Vahala: http://www.vahala.caltech.edu/

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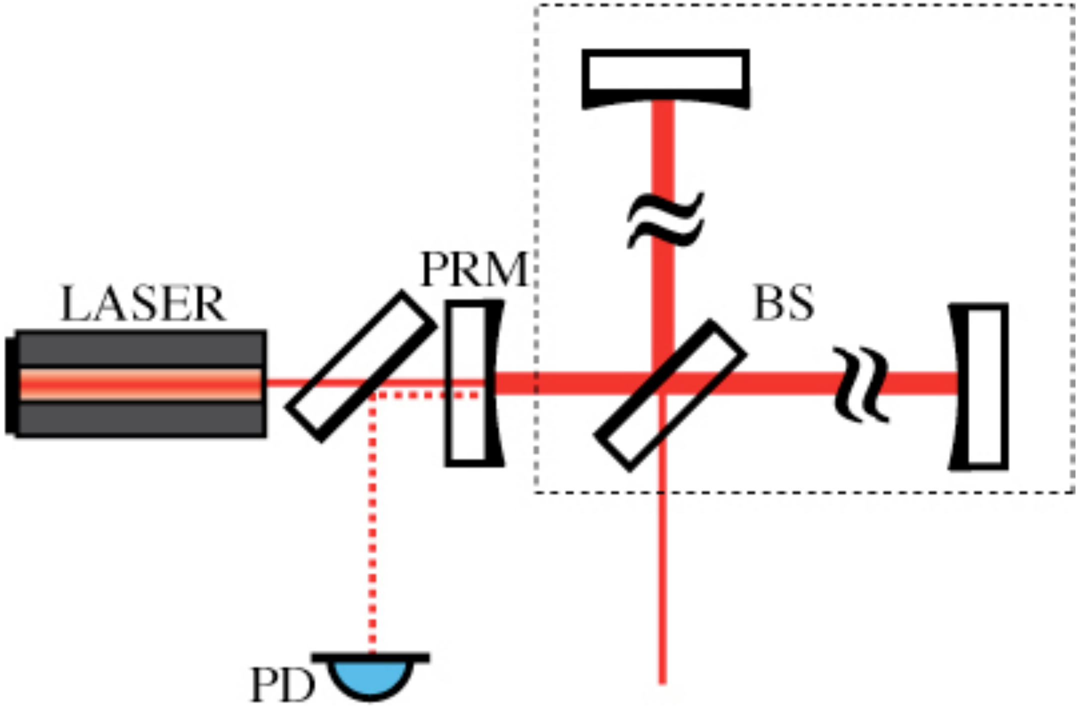
## What can impedance matching locking be used for

- Differential Michelson readout and control



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- Other application:

  - Optimising the circulating power in cavity enhanced SHG.
  - Radiation pressure experiments.