Cancelation of Displacement Noise using a Mach-Zehnder Interferometer

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● What is DFI?
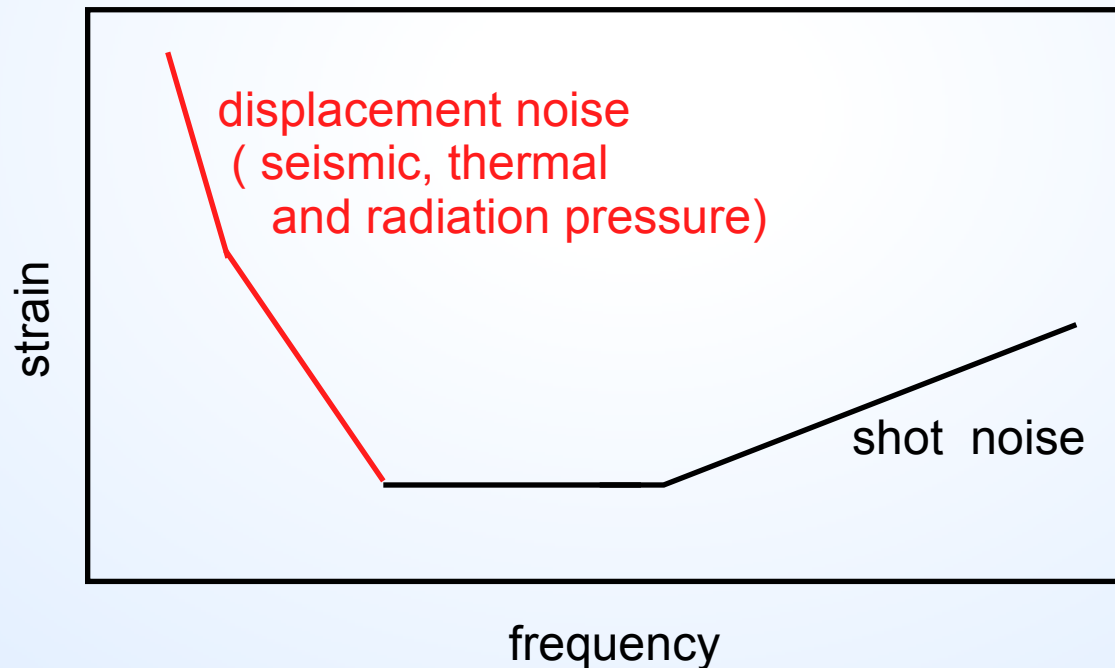
● Experiment

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● Summary

Introduction

Recently, the idea of the Displacement- and timing-noise Free Interferometer has been suggested

S.Kawamura & Y.Chen, PRL 93, 211103 (2004)
Y.Chen & S.Kawamura, accepted by PRL (gr-qc/0504108)

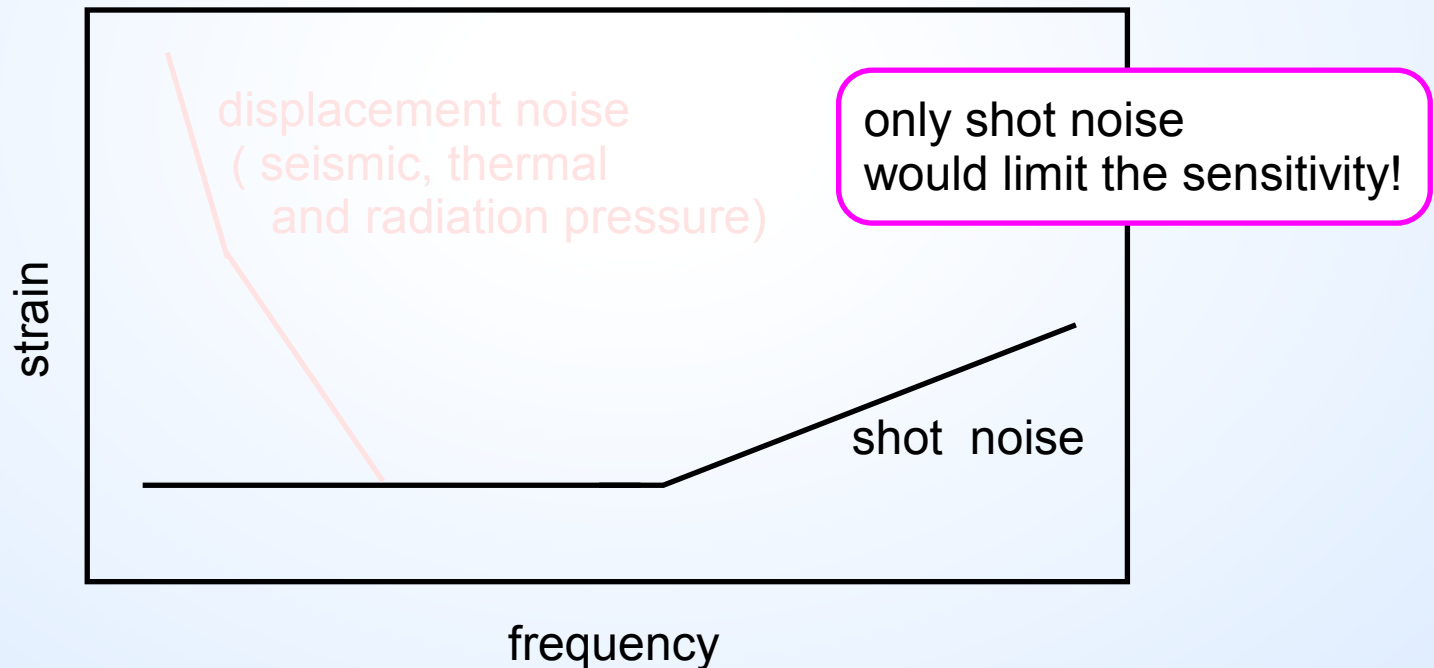DFI can take away all kinds of the displacement noises

Introduction

Recently, the idea of the Displacement- and timing-noise Free Interferometer has been suggested
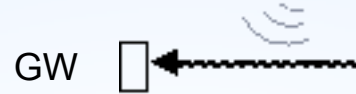
S.Kawamura & Y.Chen, PRL 93, 211103 (2004)
Y.Chen & S.Kawamura, accepted by PRL (gr-qc/0504108)

DFI can take away all kinds of the displacement noises

only shot noise
would limit the sensitivity!

displacement noise
(seismic, thermal
  and radiation pressure)

strain

shot noise

frequency

Principle of DFI

● GWs and mirror motions affect the light differently

GW

mirror motion

● In the low frequency region, GW effects and mirror motions can not be distinguished,
but when the light trip time and cavity lengths are comparable, they can be distinguished
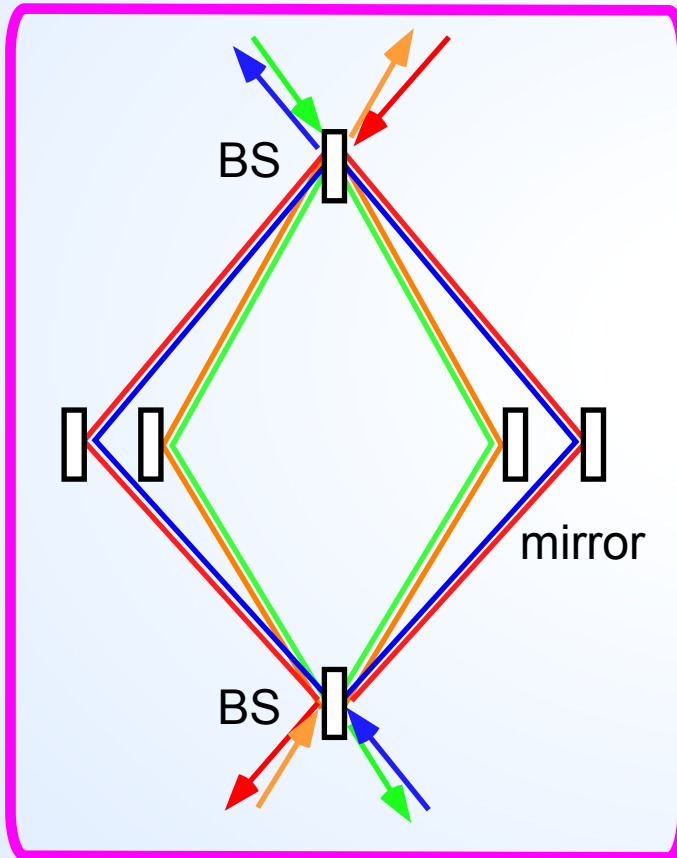
● multiple interferometers   ● combination of their outputs
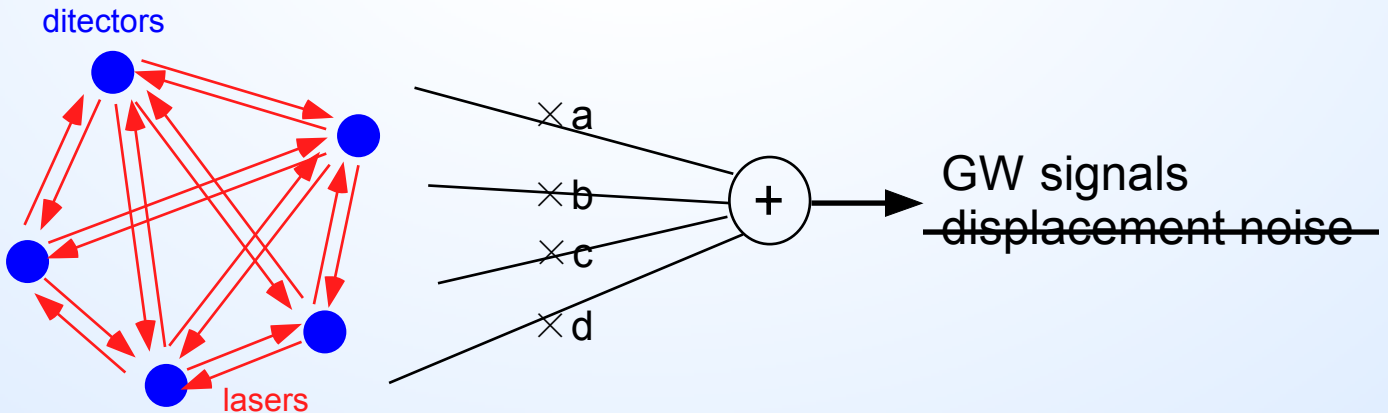
ditectors

×a

×b   GW signals
                      ~~displacement noise~~
×c

×d

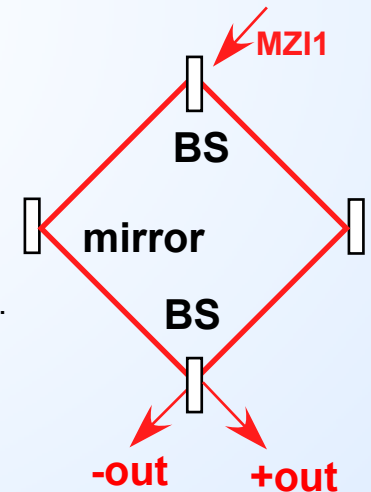lasers

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DFI configuration

Y.Chen, A.Pai, K. Somiya, S.Kawamura, S.Sato, K.Kokeyama, R.Ward, gr-qc0603054

● consists of 4 MZIs
● 2 MZIs on one square path
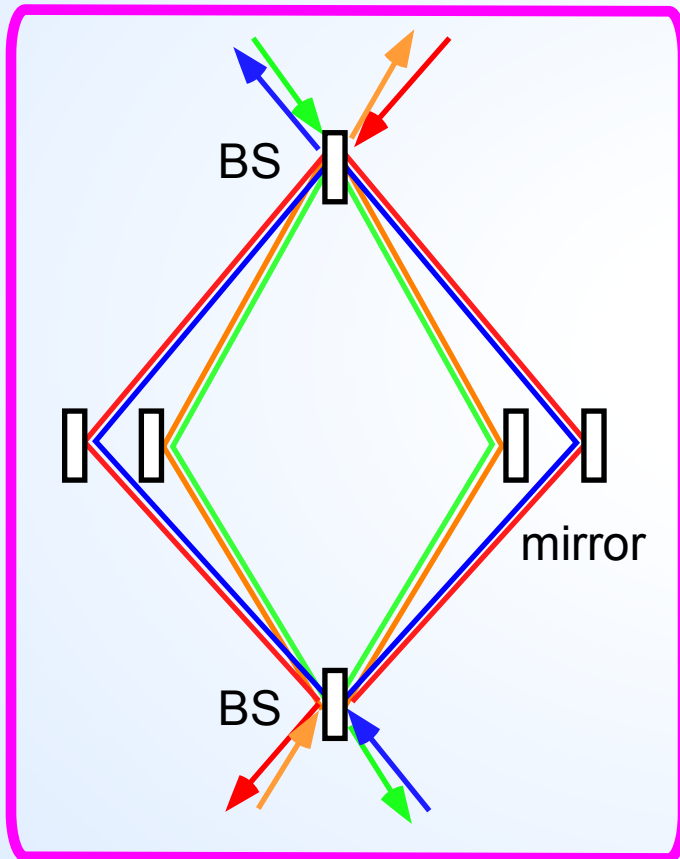**"Bi-directional MZI"**

This is a usual MZI.

The beam is splitted by a BS,
reflected by the mirrors
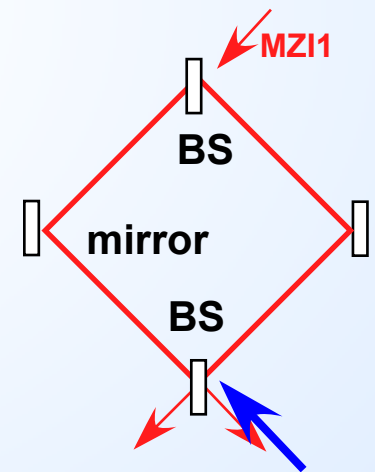and interfere after the end BS.
There are two output ports.

MZI1

BS

mirror

BS

-out   +out

BS

BS

mirror

DFI configuration

Y.Chen, A.Pai, K. Somiya, S.Kawamura, S.Sato, K.Kokeyama, R.Ward, gr-qc0603054
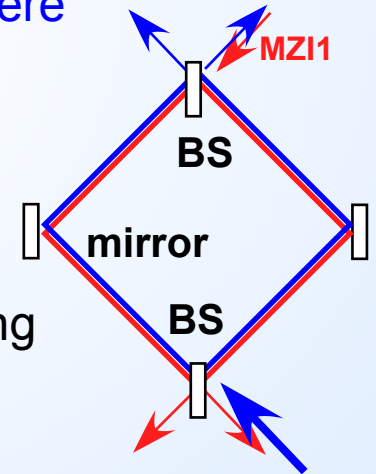

● consists of 4 MZIs
● 2 MZIs on one square path
"**Bi-directional MZI**"

MZI1

BS

mirror

BS

input the other beam

4

DFI configuration

Y.Chen, A.Pai, K. Somiya, S.Kawamura, S.Sato, K.Kokeyama, R.Ward, gr-qc0603054

BS

BS
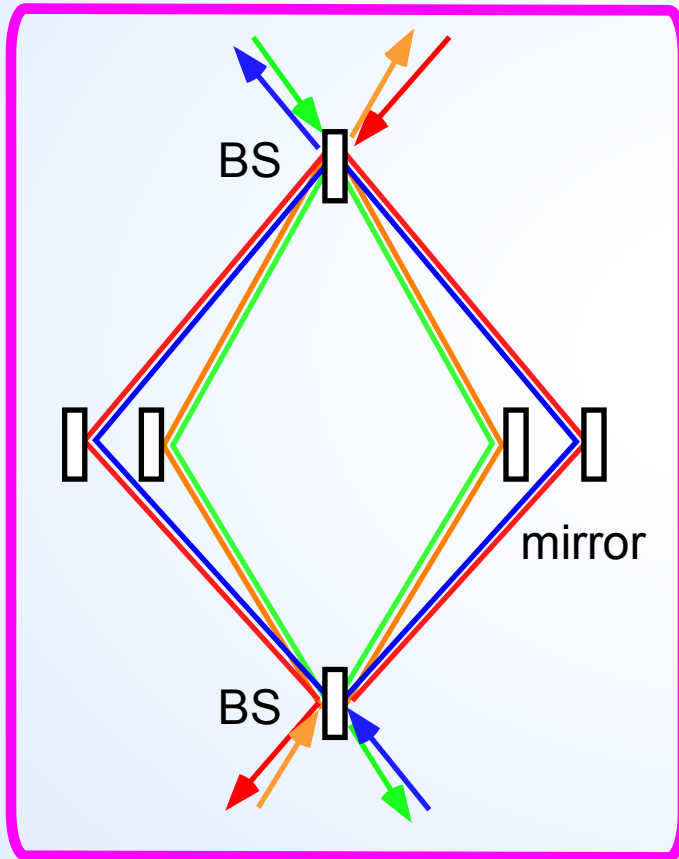
mirror

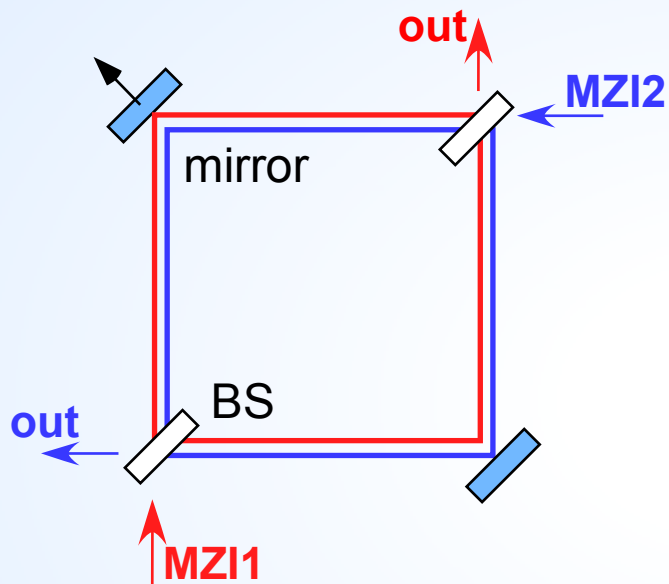● consists of 4 MZIs
● 2 MZIs on one square path
"**Bi-directional MZI**"

They interfere here

MZI1

BS

mirror

BS

2 beams are counter-propagating one square path

BDMZI is free from the mirror motions

out

MZI2

mirror

BS

out

MZI1

$$\text{out} = + \Delta L_{out}$$
$$\text{out} = + \Delta L_{out}$$

$$\Delta L_{out} - \Delta L_{out} = 0$$

- both of the MZIs respond the same way to mirrormotion of the mirror at the midpoint

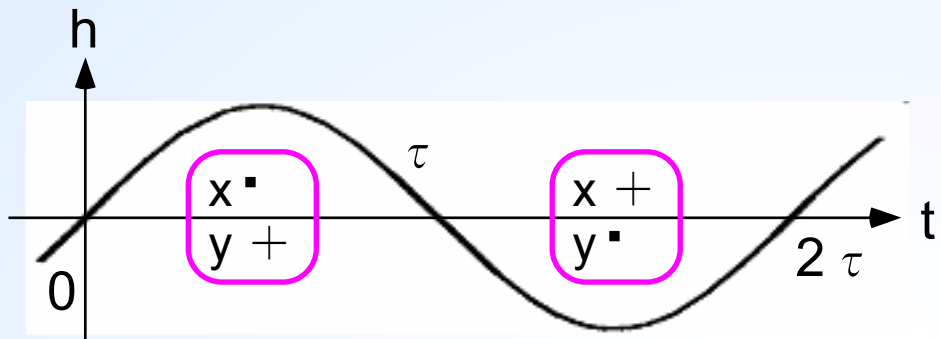The mirror motions can be canceled by subtracting the two outputs

- BS motions can NOT be canceled because they are not at the midpoint of the paths
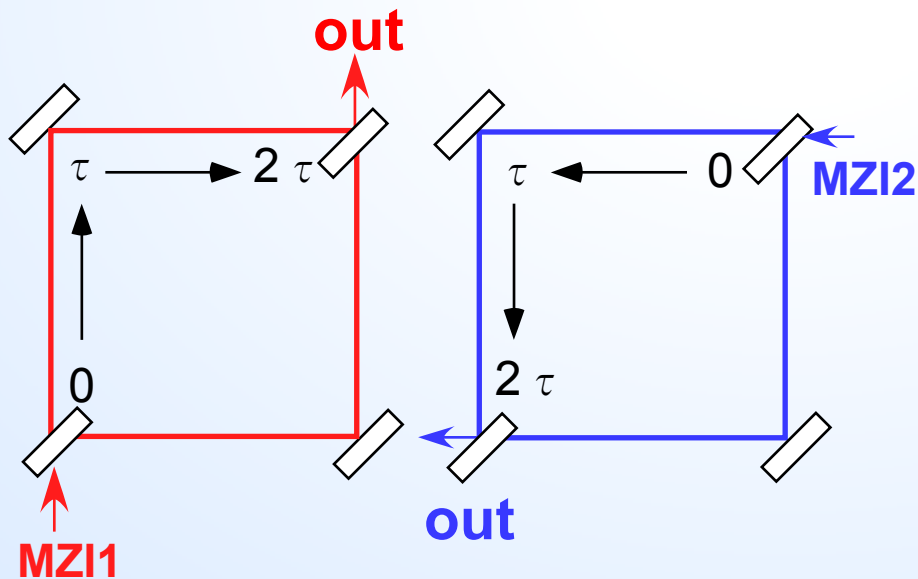
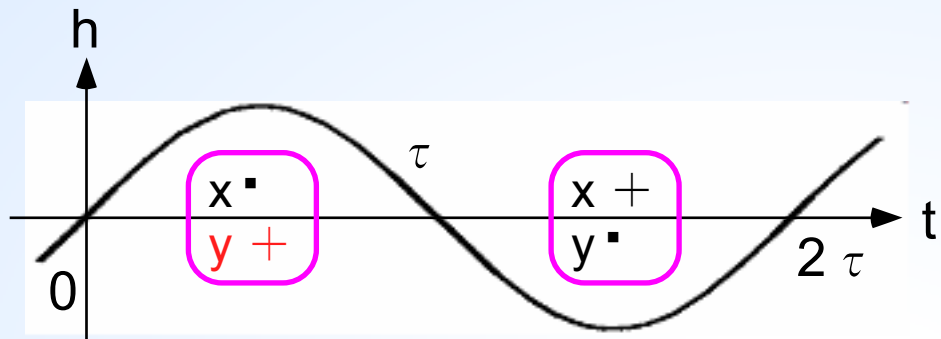5

GW signals are not canceled by BDMZI

For GW propagation into or out of plane

2τ : Time period of the GWs
τ : trip time from the BS to the mirror
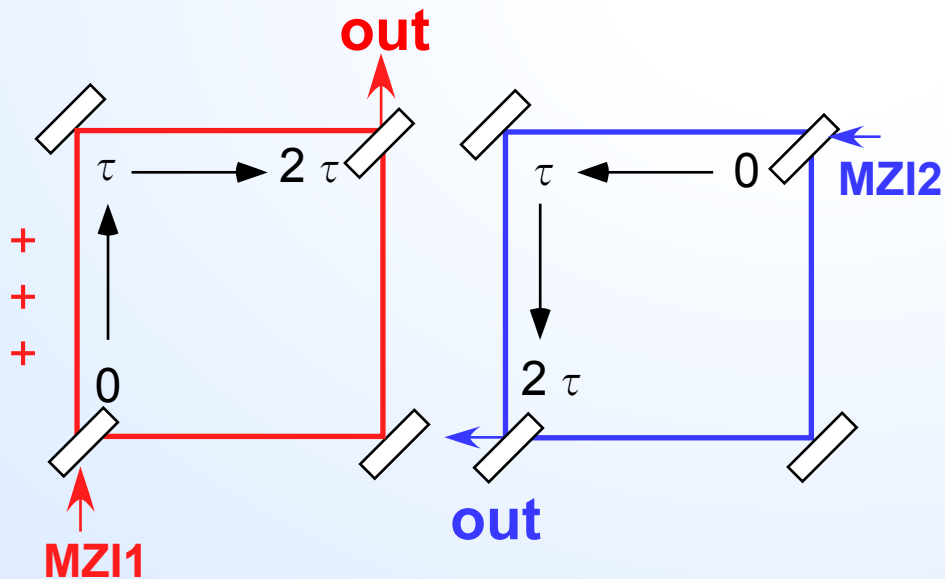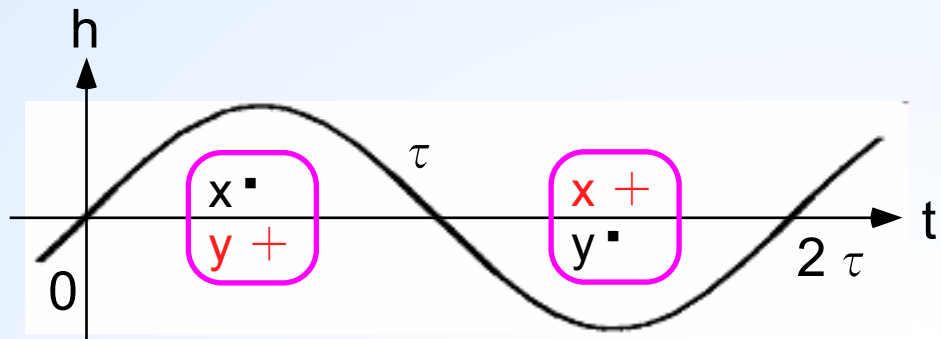
GW signals are not canceled by BDMZI

For GW propagation into or out of plane

2τ : Time period of the GWs

τ : trip time to the mirror from the BS

GW signals are not canceled by BDMZI

2τ : Time period of the GWs
τ : trip time to the mirror from the BS

For GW propagation into or out of plane

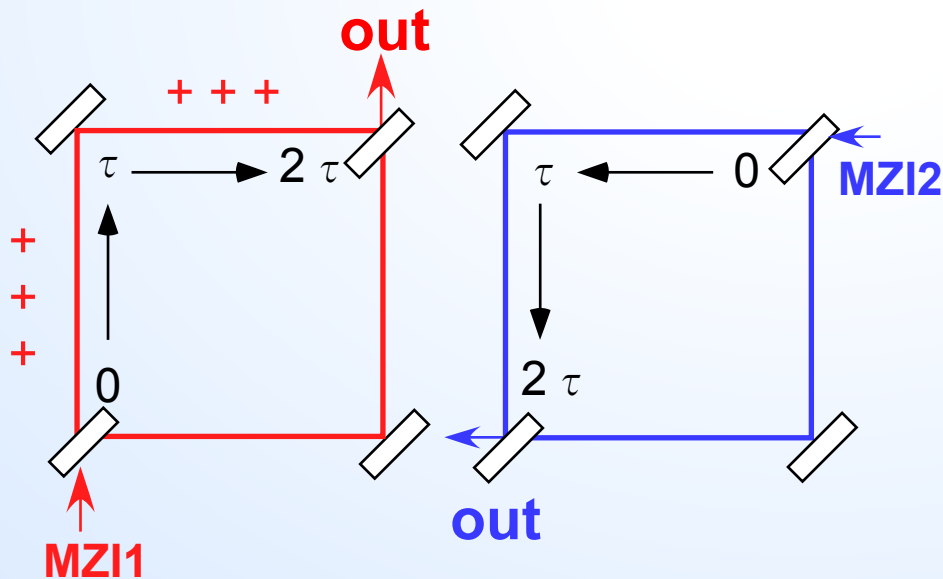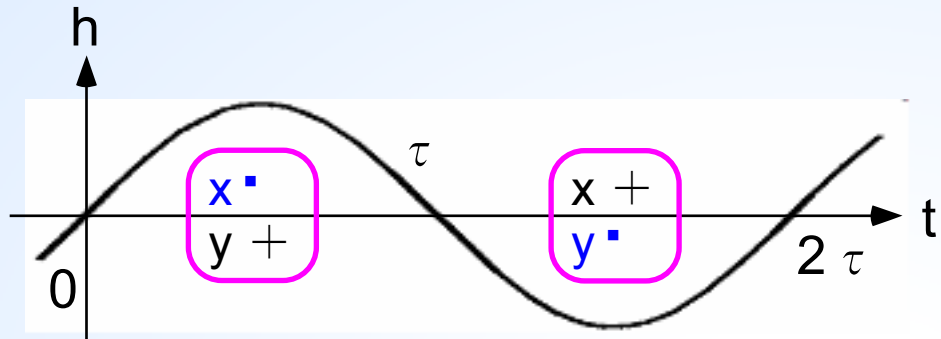out = + δ L

GW signals are not canceled by BDMZI

2τ : Time period of the GWs
τ : trip time to the mirror from the BS

For GW propagation into or out of plane

out = + δ L
out = - δ L
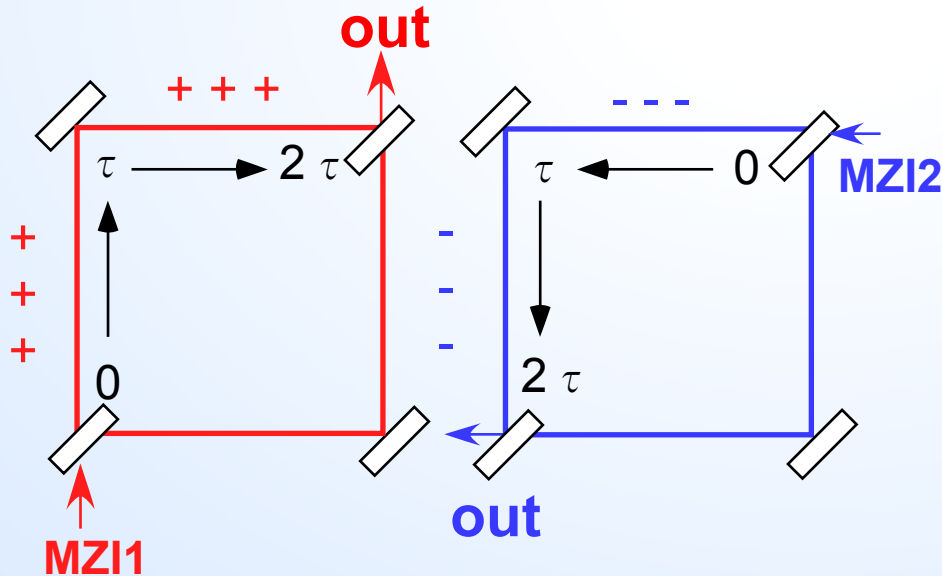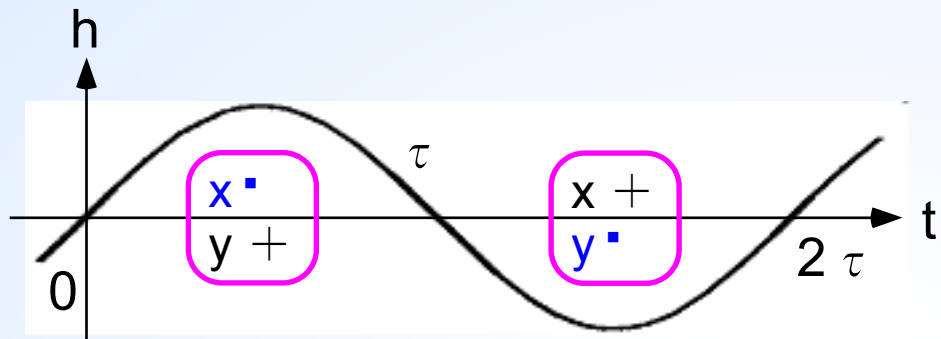
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GW signals are not canceled by BDMZI
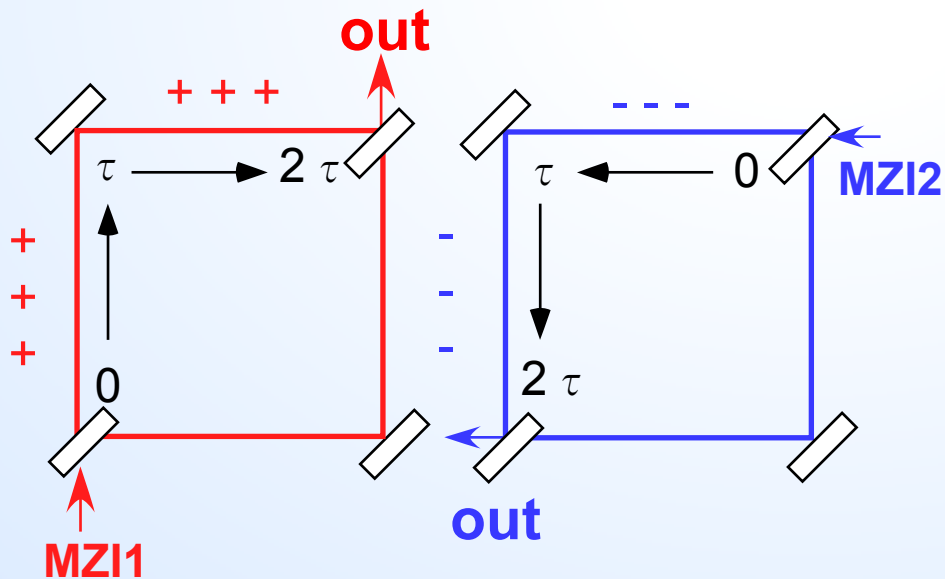

2τ : Time period of the GWs
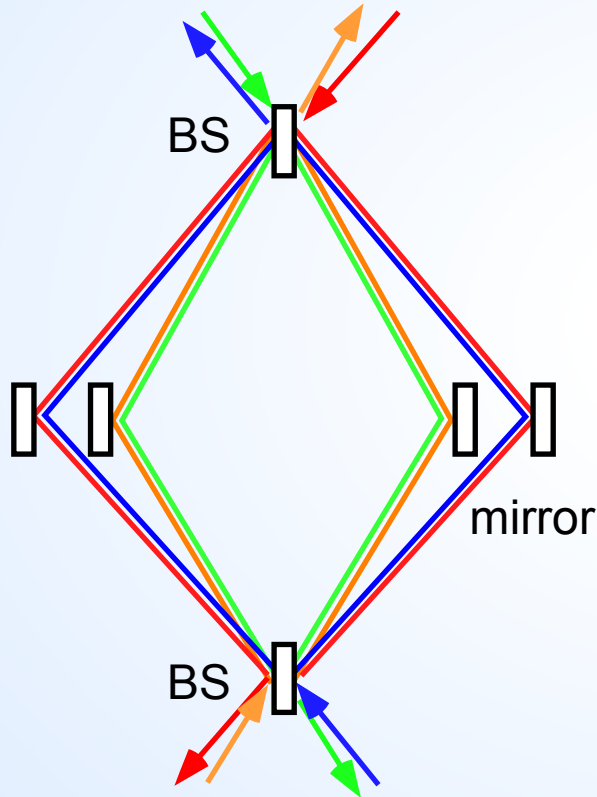
τ : trip time to the mirror from the BS

For GW propagation into or out of plane

out = $+ \delta L$

out = $- \delta L$

out = out - out = $2 \delta L$

GW signals survive after the subtraction
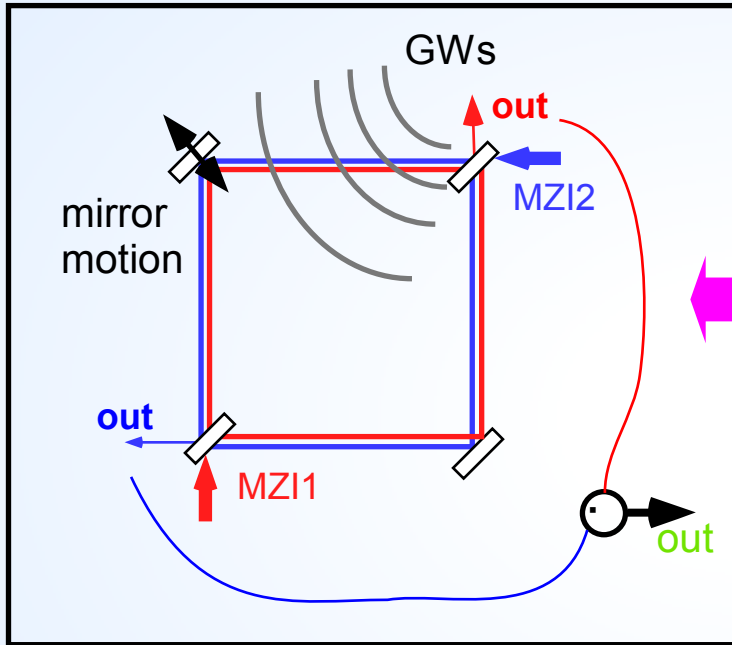
DFI configuration

BS

BS

mirror

○ BDMZIs are free from mirror motions

○ BS motions can be canceled
by two BDMZIs

○ GW signals are not canceled

We tested the operation
of one BDMZI as a part of a DFI

Bi-directional MZI experiment
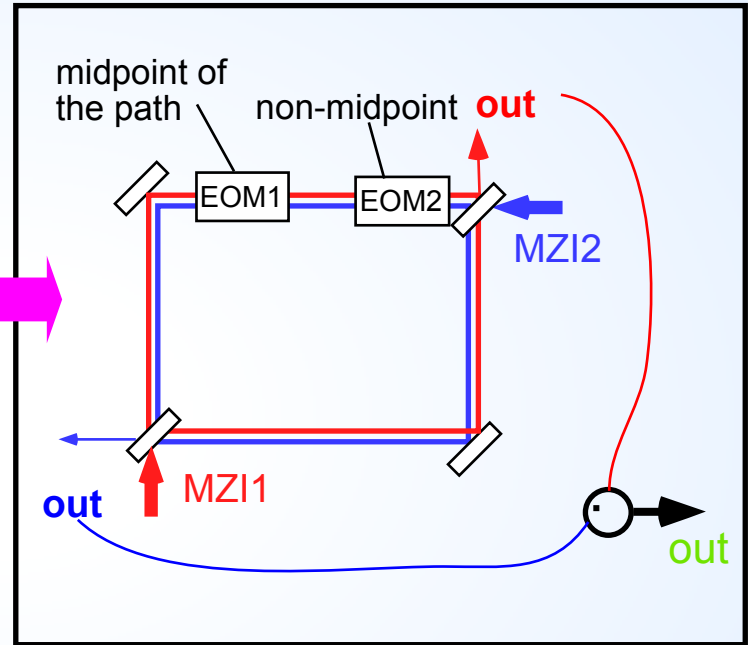
out = out - out

In the **out signal,** we looked for;

> 1. cancelation of the mirror motion
> 2. non-vanishing GW-like signals

Experimental Setup

midpoint of the path

GW-like signals

dump

+Out
RF PD

HWP PBS

EOM1   EOM2   FI   MZI2

3.6m

-Out
DC PD

mid fringe control

3.6m

PZT

FI

HWP PBS

MZI1

RF PD

+Out

dump

subtraction

Out - Out

= out

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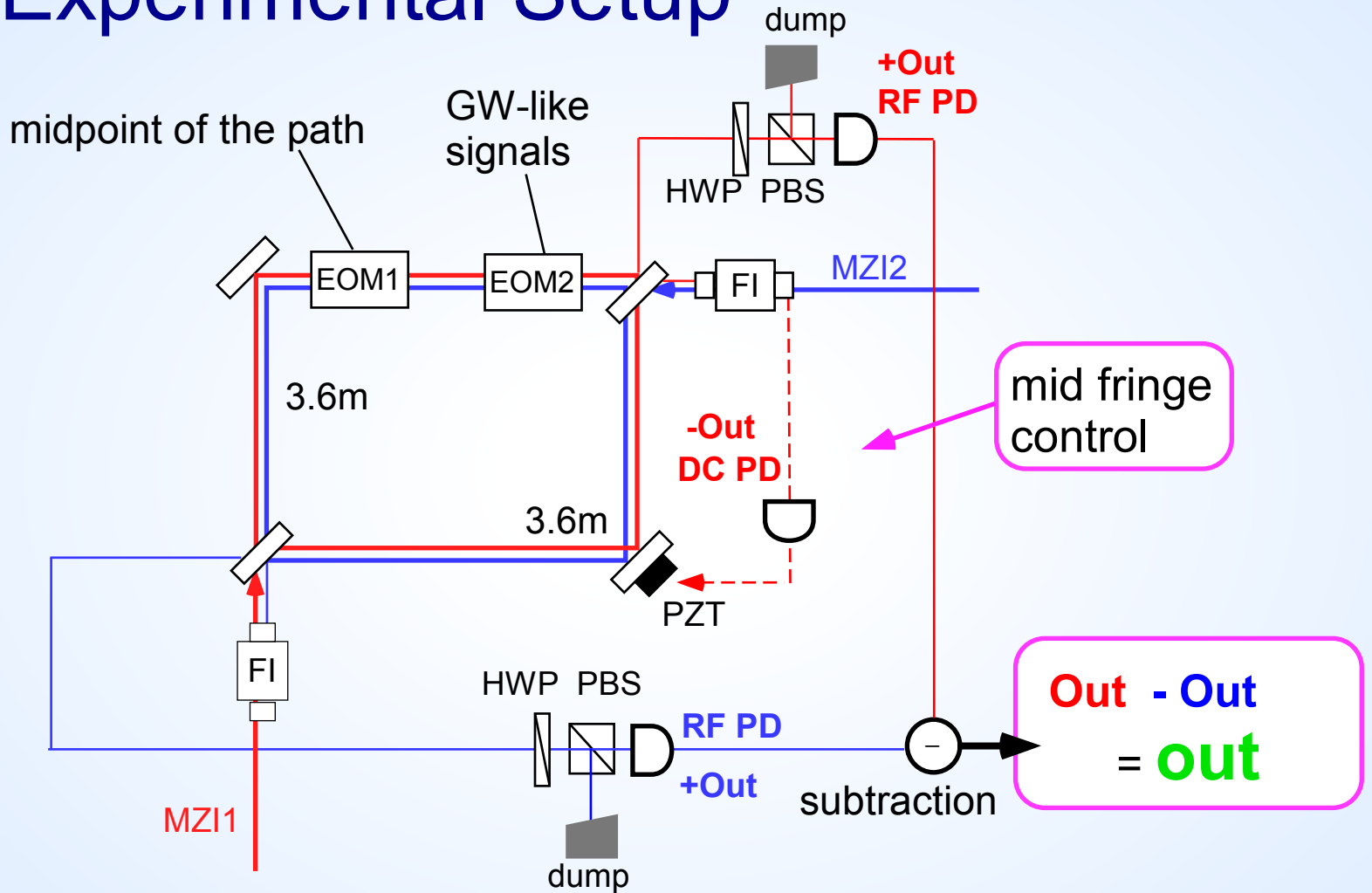# Expected response of BDMZI

A transfer function of a single Mach-Zehnder Interferometer is similar to that of a Michelson interferometer.

$$H \propto \exp \left[i \frac{L\,\omega}{c} \, t \right]$$

We have two MZIs, so their responses are;

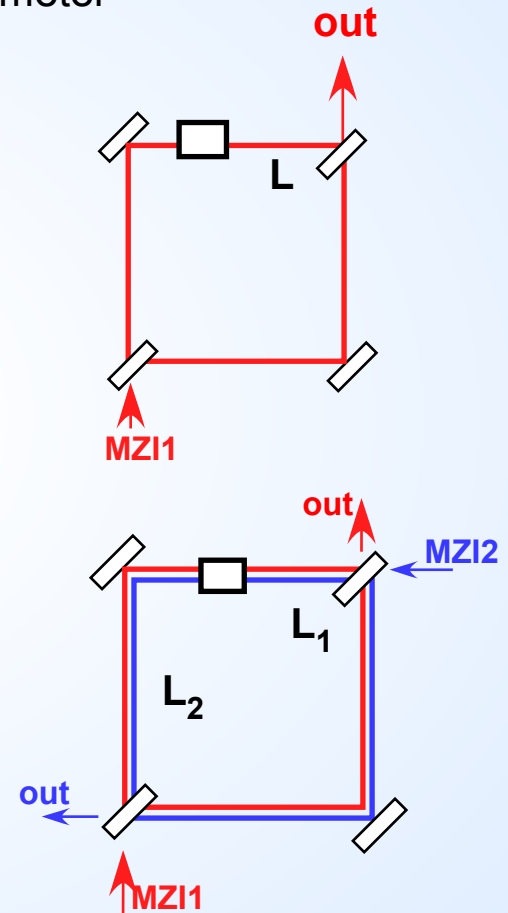$$H_1 \propto \exp \left[i \frac{L_1\,\omega}{c} \, t \right]$$

$$H_2 \propto \exp \left[i \frac{L_2\,\omega}{c} \, t \right]$$

The final output of the BDMZI is;

$$H_{out} = H_1 - H_2$$

For mirrors at the midpoint, $L_1 = L_2 \rightarrow H_1 = H_2$

$$H_{out} = 0 \ !$$

10

Expected response of BDMZI

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We have two MZIs, so their responses are;

$$H_1 \propto \exp\left[\, i\, \frac{L_1\,\omega}{c}\, t \,\right]$$

$$H_2 \propto \exp\left[\, i\, \frac{L_2\,\omega}{c}\, t \,\right]$$

The final output of the BDMZI is;

$$H_{out} = H_1 - H_2$$

For mirrors at the midpoint, $L_1 = L_2 \rightarrow H_1 = H_2$

$$H_{out} = 0\ !$$

out

L

MZI1

out

MZI2

L_1

1. Cancelation of the mirror motion

out

MZI1

10

Expected response of BDMZI

A transfer function of a single Mach-Zehnder Interferometer is similar to that of a Michelson interferometer.

$$H \propto \exp\left[i \frac{L\,\omega}{c} t \right]$$

We have two MZIs, so their responses are;

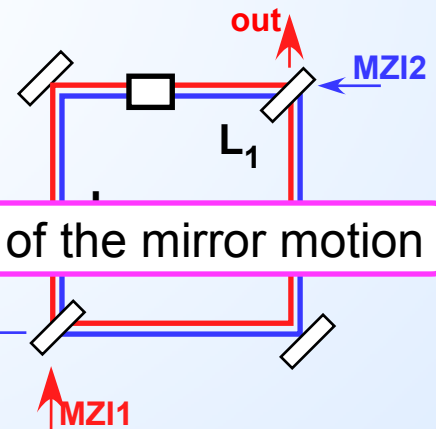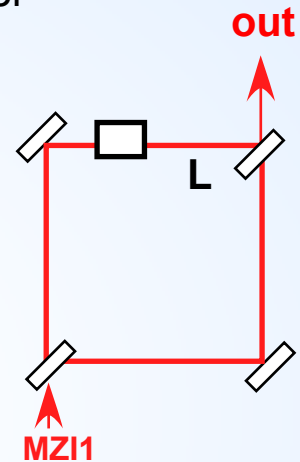$$H_1 \propto \exp\left[i \frac{L_1\,\omega}{c} t \right]$$

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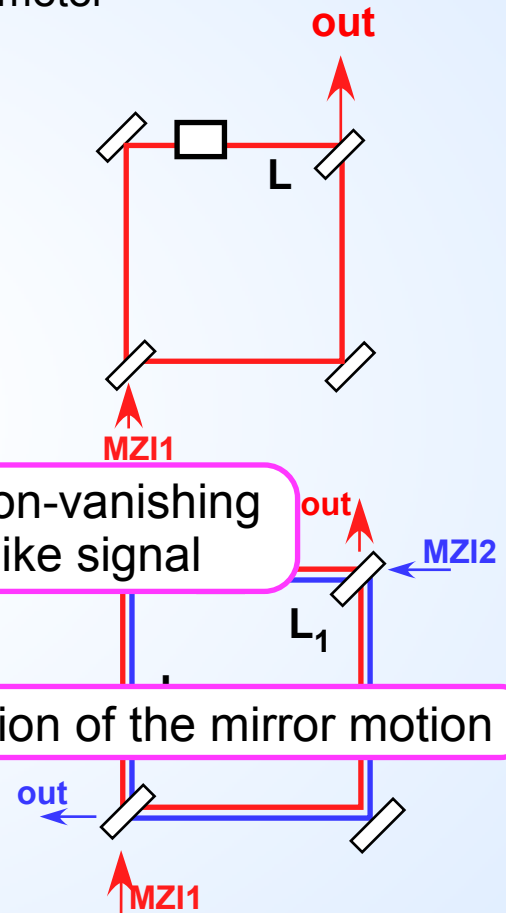
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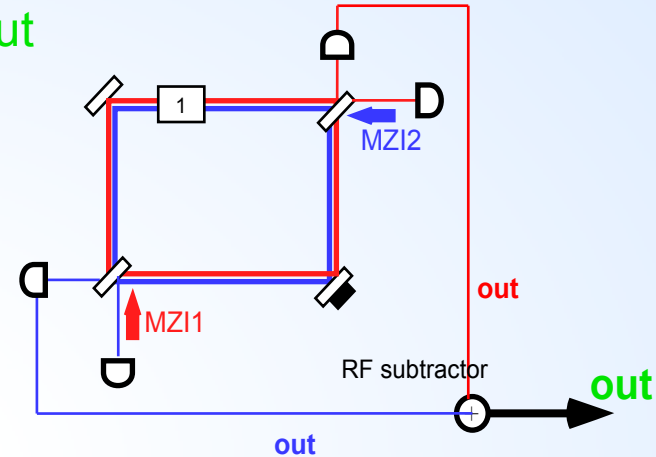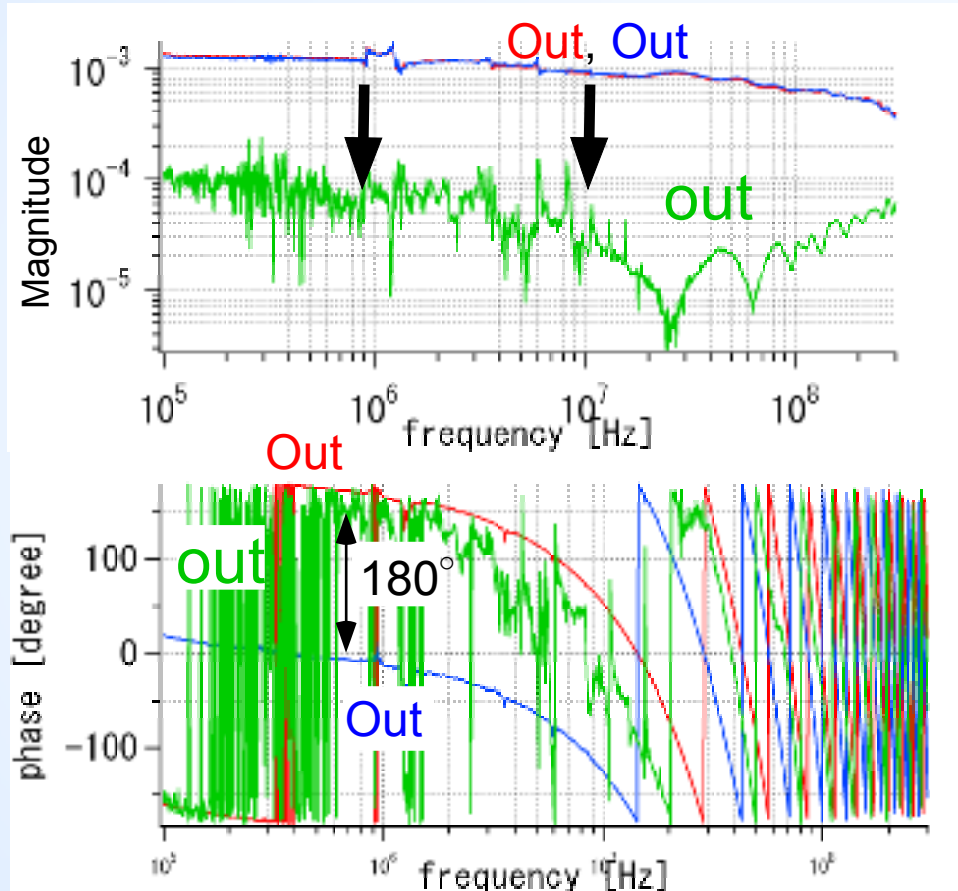We simulated the GW-like signal by putting EOM at the non-midpoint.

out

L

MZI1

2. This is the non-vanishing GW-like signal

out

MZI2

L₁

1. Cancelation of the mirror motion

out

MZI1

10

Result 1 - displacement response

Transfer function from EOM1 to Out, Out and out
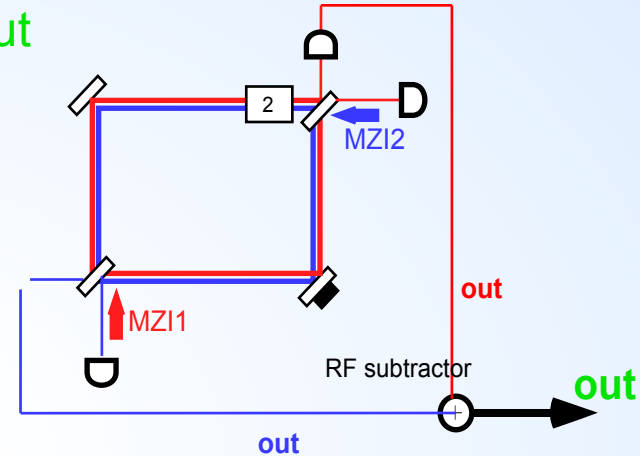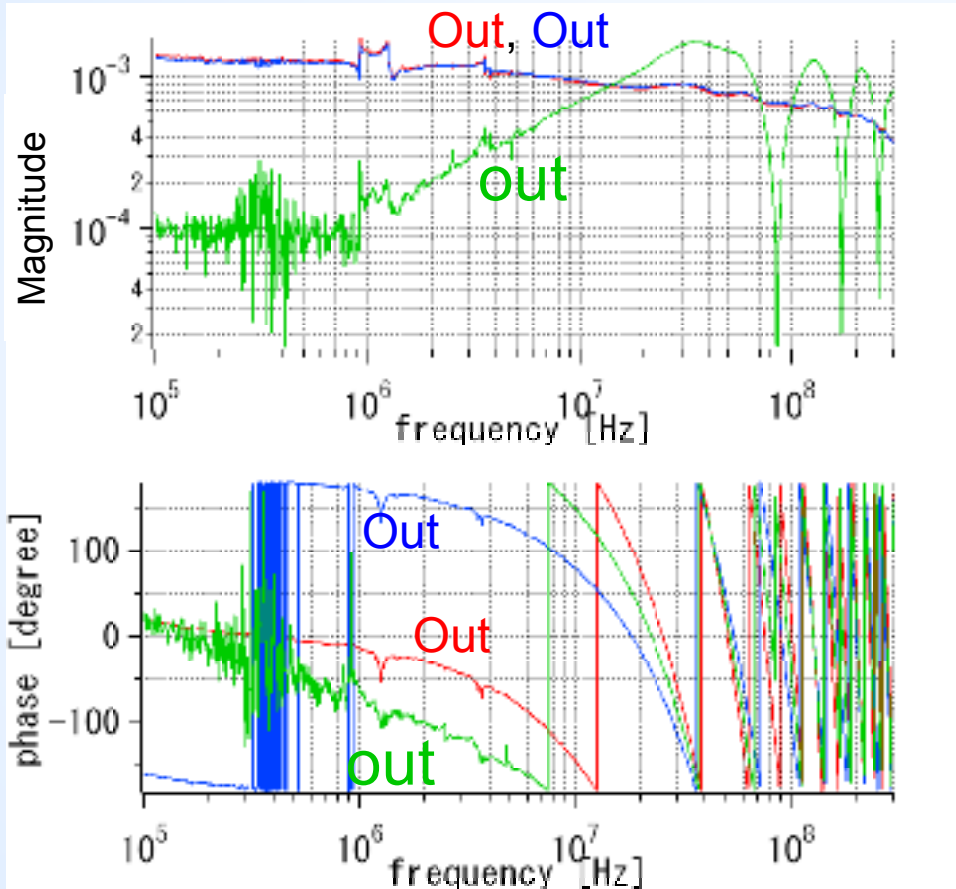

signal→ Out (MZI1)

signal→ Out (MZI2)

signal→out (after subtraction)

The subtracted output had lower displacement response by about 35 dB

Result 2 - GW-like signal response

Transfer function from EOM2 to Out, Out and out

signal→ Out (MZI1)

signal→ Out (MZI2)

signal→ out (after subtraction)

we could see the signal
after the subtraction

Summary of the experiment

● A bi-directional MZI was demonstrated as a part of a DFI

● Displacement noise suppression of
about 35dB was attained

● non-vanishing GW-like signals were verified

● can estimate the real GW effect based on the result

Next step

● make one more BDMZI and cancel the BS motion
-> real 'displacement-noise-free' configuration

终

END

The actual experimental plan is 3D.
Same size BDMZI x 2
No phase compensate
when the subtraction