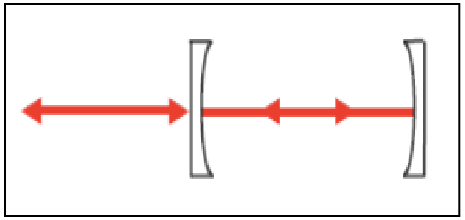
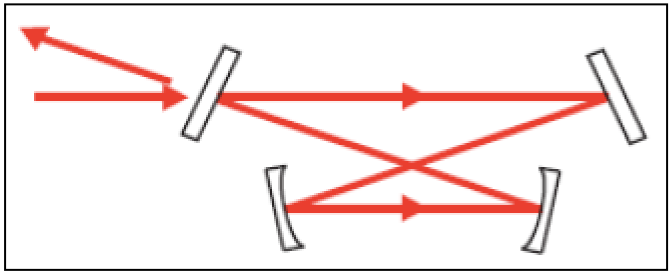
Linear & Bow-tie cavity





Linear cavity (standing wave design) advantages

- **Reduced number of HR and AR surfaces per round trip** (reduction of intra-cavity losses and so **increase of the escape efficency**)
- **Mechanical stability** (smaller number of optical components, fixed cavity geometry).
- **Isolation by air current and thermal fluctuations** (this implies both a long term and short term stability)
- **Less space required**
- **NO astigmatism**

This is one of the problem of the bow-tie configuration; it is due to the fact that one of the two curved mirror reflects the beam at an angle different from zero respect to the normal direction. The astigmatism can cause a problem of mode-matching between squeezed beam and the beam coming from the ITF. In extreme case, it could reduce the non-linear coupling between intra-cavity fields.

Bow-tie (travelling wave design)advantages

- **Locking more flexible:** due to the presence of more mirrors (more locations for the input and output of optical field).

- **Replacement of the crystal:** in case of damage, it is possible to replace the crystal without altering any mode matching; furthermore it is possible to change the distances between the mirrors in case one wants to use another nonlinear material (with another refrative index).

- **Isolation to backscattering:** in a bow-tie configuration the ITF backscattered beam reflected by the cavity has a direction that prevents its re-entering into the ITF; also, light entering the cavity is in an opposite direction respect to the that of the pump beam so that it cannot seed the OPO.

Escape efficiency (disadvantage for bow-tie)

$$\eta_{escape} = \frac{T}{T+L}$$

T = power transmittance of the outcoupler mirror
L= intra-cavity losses

It is a measure of the efficiency that squeezed light can exit the OPO.

This quantity give us an idea of how many times the field inside the cavity will interact with the loss sources (HR and AR surfaces) before it *escapes* through the outcoupler mirror.

The squeezed beam experiences this losses several times, due to its high number of round trips. The escape efficiency limits the maximum amount of squeezing that is possible to produce with an OPO.

Improvement of the escape efficiency:

a) Reduction of the intra-cavity losses (L)

b) Reduction of the outcoupler mirror reflectivity at the fundamental wavelength.

a) Reduction of the intra-cavity losses

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Reduction of the number of surfaces (especially AR coatings) that the intra-cavity field interacts with.

Cavity	NUMBER OF SURFACES PER ROUND TRIP		
	HR	AR	TOT
Monolithic (linear)	1	NO	**1**
Hemilithic (linear)	1	2	**3**
Bow-tie	3	2	**5**

In the bow-tie cavity there are more mirrors with respect to the linear cavity (larger number of HR and AR surfaces per round trip).

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more intra-cavity losses → decrease of the escape efficiency

b) Reduction of the outcoupler mirror reflectivity at the fundamental wavelength.

This solution implies the change of also other parameters.

Reduction of the input coupler mirror reflectivity → The Finesse of the cavity is reduced; as conseguence the FWHM of the cavity increases and a greater threshold power is needed to obtain the suitable level of squeezing.

A solution can be to move to a **doubly resonant** system that allow us to reduce the required pump power.

<u>In theory</u> a good solution should be a DOUBLY-RESONANT LINEAR CAVITY

LINEAR → **Reduction of intra-cavity losses**

DOUBLY-RESONANT → **Possibility to use outcoupler mirror with lower reflectivity at the fundamental frequency (so a lower finesse cavity) without a considerable increase of the pump beam threshold**

In theory, with a linear cavity is it possible to reach higher levels of squeezing; but it is true <u>only if the losses of the non-linear crystal are not dominant</u>.

<u>In fact, experimetally it is found that LINEAR AND BOW-TIE CAVITY CAN REACH THE SAME RESULT</u>

Astigmatism (disadvantage for bow-tie)

Bow-tie cavity waists →

- one internal to the crystal (between the two curved mirrors)
- another external to the crystal (between the two flat mirrors)

internal waist: for several distances between the curved mirrors, there are no astigmatism

external waist: larger than the internal one, it is affected by astigmatism. This implies an astigmatism also on the field exiting the cavity.
This is due to the fact that the beam, trasmitted by coupling mirror, has the same mode shape of the beam in the cavity, and so, outside the cavity, it has the same waist, at the same distance from the mirror.
This will be the shape of the squeezed light exiting the cavity that must be **mode-matched** to the interferometer output beam.

Backscattering (disadvantage for linear cavity)

Some scattered light by the ITF can be reflected by the output Faraday Isolator and then it can reach the squeezer.

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Linear cavity: all reflected light comes back to the ITF and can be detected as a spurious signal

Bow-tie configuration: the beam is reflected at an angle that prevents it to enter the ITF (it can be dumped to ensure that it doesn't scatter again).

Also, for the bow-tie (unlike the linear configuration), the backscattered light, entering the OPO, has not the same direction of the pump beam, and so it can't seed the OPO (evoiding that it becames an OPA!).

Due to the intra-cavity scattering (by mirrors and AR crystal faces) it is possible that the backscattered light can propogates in the same direction of the pump beam (*forward travelling mode*), this light can seed the OPO and enter the ITF. But it was demonstated that with a bow-tie configuration a forward-reverse mode isolation equal to that of a good Faraday Isolator can be reached. This isolation can increase using different crystal geometry and super-polished optics.

Bow-tie: one Faraday Isolator is needed

Linear: two Faraday Isolators

What is the **effect of adding a Faraday Isolator**?

Introduction of losses: **for AdV 2% of losses are estimated**.

$$V_{\text{after FI}} = \eta V_{\text{produced}} + (1-\eta)$$

$\eta = 1 - \mathrm{Loss}$ Measurement Efficiency

$V_{\text{produced}} = \langle \Delta X_{\text{produced}} \rangle^2$ Produced Squeezing Variance

Our goal: **-10 dB** of squeezing produced.

Loss=2% ⟶ η = 98% ⇒ After the FI the degree of squeezing is of **-9.3 dB**

Starting from a level of squeezing of 10 dB, the introduction of one FI, with estimated losses of 2%, implies a decrease of the squeezing degree of **0.7 dB**.

The conclusion is that there are, in theory, some motivations for which one configuration is better than the other. But, in practice, they reach the same result.

I have this last but (I think) not less important consideration:

We already have a prototype of linear cavity.

If we choose to use a bow-tie configuration how many time we will spend in time for design, simulations, machining and optical component purchase?