Development of Triple Resonant EOM for Advanced Detectors

40 Meter Lab.

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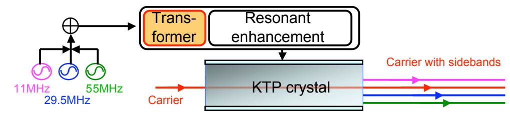
We have developed a triple resonant EOM which can impose a set of three phase modulation sidebands with one crystal. Essentially it works with a resonance enhancement circuit and a transformer to make it resonate at desired frequencies and to step up the voltage. So far we have made a prototype circuit that was tuned for an EOM made from KTP. We have successfully got triple resonance. A reasonable gain of 9 and 8 were obtained at 11 and 55MHz respectively.

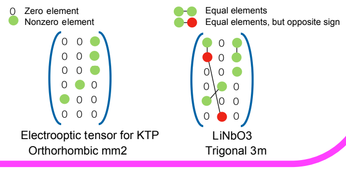
1. Motivation

- The **40m** is a prototype interferometer to develop **advanced interferometric configurations**
- In advanced and complex interferometers, multiple phase modulation sidebands are needed
- Avoid the parallel modulation style by Mach-Zehnder which leads to noise issues and complexities

2. Principle idea

- Use one EO crystal of KTP, a transformer and a triple resonant enhancement circuit
- Three phase modulation sidebands can be imposed with the thee different frequencies at once
- Univ. of Florida (UF) had developed a similar system, but they used three resonant circuits instead of one



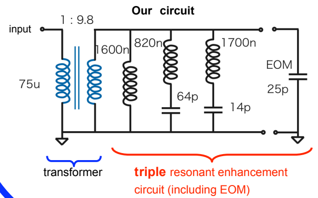


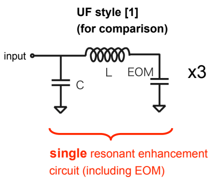
3. Utilize transformer

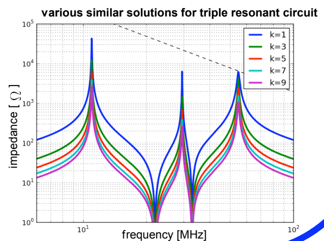
- Transformers **passively can step up the gain** proportional to the number of the turns ratio n
- Transformers lead to reduction of the impedance by a factor of $1/n^2$
- Optimum condition is found at $Z/n^2=50\Omega$ (impedance matching), where Z is impedance of the resonant circuit
- The maximum gain is represented as $G=n=(Z/50)^{1/2}$ under the optimum conditions
- Therefore **high Z is needed** to achieve the high gain at the resonances

4. Design of the resonant enhancement circuit

- LC pair creates a resonance so that it becomes high Z
- Since the resonant frequency is expressed by $f_0=(2\mathrm{pi}(LC)^{1/2})^{-1}$, it allows to have **similar solutions** (e.g. $L'=L/k$, $C'=kC$)
- To determine the set of optimum L and C from similar solutions, we searched for the highest impedance configuration by inserting the loss model
- Finally n=9.8 for the turns ratio of the transformer has been chosen
- UF employed **three separated resonant circuits** with a RTP crystal

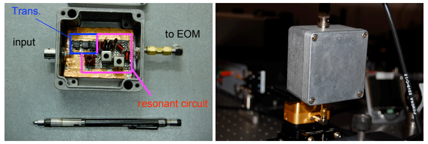






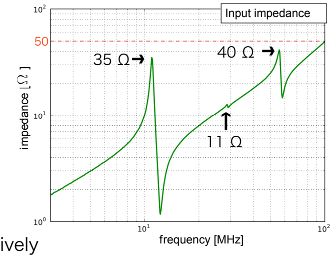
5. Assembly and health check of prototype

- The circuit is covered with a metal box to eliminate the radiation from the circuit
- The circuit is attached to the commercial EOM (NewFocus 4064) with a SMA cable as short as possible.



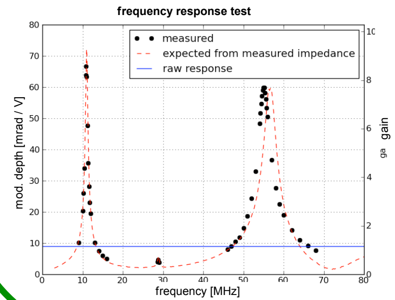
assembled circuit | the circuit attached with the EOM

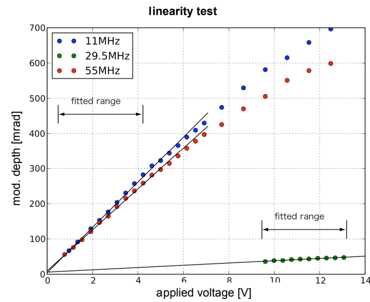
- To check the health of the system, the **input impedance** had been measured.
- An input impedance of 35, 11 and 40Ω at each of the resonances were yielded, these are close to 50Ω



6. Performance tests of prototype

- Optical tests by using an optical spectrum analyzer
- Obtained the triple resonances at designed frequencies successfully
- The reasonable gain of 9 and 8 were achieved at 11 and 55MHz respectively
- Although modulation depth at 29.5MHz is low, however this is for the MC lock and is fine





- modulation efficiency

11MHz: 64mrad/V (G~9)

29.5MHz: 3.3mrad/V (G~0.5)

55MHz: 58mrad/V (G~8)

- UF modulation efficiency with RTP [2]
(for comparison)
24.5MHz: 74mrad/V
33MHz: 28mrad/V
61.2MHz: 28mrad/V

7. Considerations

- The losses in the circuit are somehow underestimated in the model calculation
- The transformer seems to have an unexpected insertion loss
- It is hard to match the impedances of all three resonances to 50Ω

8. Next steps

- Final design and assembling onto a RF-quality printed circuit board
- Installation of the triple resonant EOM at the 40m

References [1] V.Quetschke et al., "High power optical components for enhanced and advanced LIGO", LIGO-G070117-00-R
[2] V.Quetschke "Electro optic modulators and modulation for enhanced LIGO and beyond", LIGO-G080406

LIGO-G1000297-v1