Theory, Fabrication and Applications of a Novel Archetype Semi-Ring Fabry-Perot (SRFP) Resonator, and New Tiltmeters

Thesis by

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Submitted in Partial Fulfillment of the

Requirements for the Degree of

Doctor of Philosophy
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Dedication

To my father who said: "Go and become strong since in the reign of nature the rights of weakers are wiped out" and "The one who lets his rights to be taken is more guilty than the one who actually takes them away".

Acknowledgments

The acknowledgments, though written last in a thesis, are located at the beginning. This corresponds very well to the fact that by far this is the most interesting part and the most read since it adds a personal touch. My stay at Caltech has been a great source of learning not only from a technical point of view but also in terms of human elements and has certainly helped me to grow more mature and strong. I also learned that the academic environment is like any human social structure subject to human goodwill or personal behavior fluctuation. I would certainly not be able to write this thesis without the help of Professor Hoffman, who beyond any professional obligation gave me the opportunity to defend my ideas. I also have to thank Dr. Jakob Van Zyl, my co-advisor, who despite having high responsibility in the hierarchy of JPL shows extremely high technical skill and human skill. I also have to thank Prof. Bruno Crosignani, Prof. Vahala and Prof. McGill for their encouragements. I am also indebted to Prof. Psaltis and Prof. McEliece to have kindly agreed to be on my thesis defense committee.

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Shervin Taghavi Larigani, Pasadena, California, USA, 2 November, 2005.

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ABSTRACT OF

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Abstract

The first instinct of any animal (including human) is surviving, which implies security. It impacts how we perceive the whole universe. The best way of satisfying this need, consists of being able to control situations in which we are immersed. One way of doing so, consists of predicting future events. That is why we perceive and model our environment based on cyclic and periodic events, going back to the earliest civilizations.

Few examples of such periodic events are:

- The rotation of earth around the sun, which illustrates a spatial cyclic event.
- The alternate of day and night, which illustrates a temporal cyclic event.

So modeling any sort of event happening in our environment by repetitive events allows us to enforce a secure feeling, since (periodic, cyclic) events have the advantage of being able to be foreseen, which provides the advantage of being well understood. Most of the devices fabricated by human beings are inspired by the perception of its environment, and somehow in most cases we just copy nature. Few examples are:

- Airplanes are similar to birds.
- Submarines are similar to whales or sharks.

That is why basic tools of many applied and engineering sciences are resonators, which are engineered devices that generate or sustain periodic or cyclic events. One example of a resonator is a guitar. The string can just take a certain finite number of shapes since it is bounded on its two extremes. Any excitation of the string can be decomposed as the excitation of each one of these shapes, which would repeat itself

after one round trip. These shapes are called the resonant mode of the string. Each note (the music coming out of it) of the guitar corresponds to one of its resonant modes. The same way that we use a basis to describe a vector (for example x and y in the case of two dimensional vector), we can use the resonant modes as a basis to describe any intensity within the resonator. Therefore in the case of the guitar, any vibration of the string can be decomposed on a set of vibrations of each resonator mode, where the intensity of vibration of each mode is independent of the others. What differentiates any vibration of the string from another is the intensity with which this vibration couple, to each resonant mode. The same way that the guitar is a mechanical resonator, we can think of an electromagnetic resonator. The same way an electromagnetic resonator has different resonant modes, and each intensity couple to the resonator can be decomposed on a set of intensity of each resonant mode. Another example is at the atomic scales, where the atoms within a molecule have specific repetitive vibration and rotation patterns, which are called the resonant modes.

The overall concept of a resonator is the same whether it is mechanical or electromagnetic one. The basic concept of a resonator is based upon a feedback, which guarantees the repetition of an event. At the root there are no more than two ways of obtaining such feedback.

1 The first idea consists of forcing the feedback. Due to this feed back the same event would happen at the same time if it is a temporal event or at the same location if it is a spatial event.

By confining the event within a (temporal or spatial) barrier, and by being sure that the event would bounce back at that barrier, we would have created such a feedback. Such a specific barrier is often called a reflector. In the case of a mechanical resonator, such a reflector could be a wall. As an example, when someone talks within a confined structure, their voice gets echoed or resonates and in some cases the voice generated by the speaker would get back to him. This is a resonant phenomenon. Another example is if someone who is confined in a medium separated by two walls throws a ball to one of the walls. In a specific case, where the trajectory of the ball repeats itself, we talk about resonance. The same structure is also used in an electromagnetic resonator where the two reflectors are now electromagnetic reflectors. In the case of optics, the reflectors would be mirrors. In that case, the feedback would be obtained by confining an optical medium (a waveguide) within two optical reflectors (mirrors). Such a structure is the most basic archetype resonator in optics and was invented 100 years ago, and was named after its inventors Fabry-Perot. Fundamentally, this structure is very similar to the mechanical resonator obtained with the help of two walls.

2 Another way of thinking of such a feedback is by assuring that either the temporal or spatial path used by the events would be repeated. This can be obtained if the path shape is closed. An example of such structure is a circular shape.

In this thesis, we present a completely novel resonator that in addition to having both the advantages of the first and the second types of resonators, has its own specific features. We have called this resonator a Semi-Ring Fabry-Perot (SRFP) resonator. In order to better understand this resonator we will focus ourselves in the field of optics, which emphasizes the best on the wave particularity of resonators. As we will see almost all optical resonators could be modeled as combinations of Fabry-Perot and ring resonators. These devices are the most important letter of the alphabet of the optics, where any device behaves like a word obtained with the combinations of the letters composing the alphabet, similar to introducing a new letter to the alphabet. Thus, we can with the use of this new letter create new words, which are new devices and could be useful. The benefit of the novel resonator that we introduce is beyond the scope of this thesis, where mostly optical applications of the resonator have been introduced.

At the end of the thesis, we will introduce a novel way of measuring the incidence tilt of a field using a resonator.