MOEMS RING RESONATORS AND WAVEGUIDES AN OPTICAL APPROACH

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Abstract-WDM networks use high speed MOEMS ring resonators. Due to the substrate loss the regular tuning of the rings is not possible, hence we need a specialized tuning element for the same. As the advantages increases so does the complications and the costs. These difficulties are sparsely overcome by MOEMS technology. The tolerance in fabrication is overcome by embedding the MOEMS actuator with automatic tuning element, this is briefed in this paper. This newly developed fine tuning concept enables the network operator to easily and remotely reconfigure the access network. The catering to various users in the network is made possible by the method. The work focuses on medium carrying multiple wavelength channels (WDM) and supports broadband flexible network infrastructure. The fabrication is done such that the number of channels can be increased at any time, eventually allowing hundreds of channels per chip. By the introduction of auto tuning, the errors and delay in manual adjustments is rather reduced

Index Terms-**WDM network, MOEMS, Microring resonator, Tuning.**

I. INTRODUCTION

Optical ring resonators consist of a waveguide in a closed loop coupled to one or more input/output (or bus) waveguides. When light of the appropriate wavelength is coupled to the loop by the input waveguide, it builds up in intensity over multiple round-trips due to constructive interference. It can then be picked up by a detector waveguide. Since only some wavelengths resonate within the loop, it functions as a filter.The major benefits of phased-array antenna based WDM systems are their high gain and possibility of electronic beam steering and shaping (together called beam forming). A phased-array antenna based WDM system consists of multiple antenna elements with corresponding tunable phase shifters or delay elements, and some splitting/combining circuitry. Delay elements need to be used instead of phase shifters when it is applied to broadband beam forming based WDM network. The steering resolution for the system then depends on the tuning resolution of the delay elements. The optical beam forming network based WDM system offers certain advantages such as (i) the system will be immune to electromagnetic interference and (ii) will have a high bandwidth and low loss and (iii) will be compact with less weight.

II. PREVIOUS WORKS

M. A. Piqueras, et al., [3] presented optically beamformed beam-switched adaptive antennas for fixed and mobile broad-band wireless access networks. However, switchable true time delay (TTD) arrays, has the disadvantage of beam squint or limited tuning resolution. An alternative that does offer both continuous tunability and TTD is based on chirped fibre gratings (CFGs), but the tradeoff is that it requires bulky optical components and a tunable laser. A. Meijerink, et al., [1] presented phased array antenna steering using a ring resonator-based optical beam forming network (OBFN). The core section is the optical signal processing which is preformed by an OBFN. They propose a complete system using an ORR-based OBFN, filter-based optical SSBSC modulation, and balanced coherent detection. Richard Sekar [4] presented that New VDSL2 standard will bring fiber fast Broadband. Schemes for combining FTTC (Fiber-to-the-Curb) or FTTB (Fiber-to-the-Building) with VDSL (Very high bit-rate Digital Subscriber Line) were proposed. Also, using this network, operators can provide more economically high bandwidth connections since, not every subscriber requires a (costly) direct fiber connection. G. Grosskopf, et al., [2] presented a beamformer circuit for phased array antennas in the optical domain. It offers several advantages like compactness, small weight, low loss, frequency independence, high bandwidth, and EMI immunity. Most known approaches are based on optical phase shifters. L. Zhuang, et al., [5] presented Single-chip ring resonator-based 1 × 8 optical beam forming network in CMOS-compatible waveguide technology. The measured optical group delay responses showed good agreement with theory, and were later extended to a 1 × 8 OBFN. B. E. Little, et al., [8] presented Microring resonator channel dropping filters. When such cavities in the form of circular rings or disks are coupled to single/dual bus waveguides they act as wavelength filters. Due to high Q and compactness of these filters, they are explored for dense WDM in integrated optics. A study on the use of microcavity resonator for application as filters for wavelength division multiplexing systems is discussed by Noran Azizan Cholan, et al., [7]. The work reports the design and analysis of square resonator as an add /drop filter for CWDM system. However, the work was only done using simulation study on a silicon waveguide-coupled square resonator. A dual mode dual band, band pass filter with two transmission poles in both pass bands using a single ring resonator was proposed by Sha Luo, et al., [6]. The dual band ring resonator filter with centre frequencies at 2.4 and 5.8 GHz was designed and fabricated. The design was done on a single layer substrate.

III. TREE TOPOLOGY BASED WDM NETWORK

When all the delay elements and splitting/combining circuitry are realized in the optical domain and integrated onto one chip, an integrated WDM network using optical beam forming network (OBFN) is obtained. An example of a 1x4 WDM network using OBFN, based on a binary tree topology is shown in Figure 1.

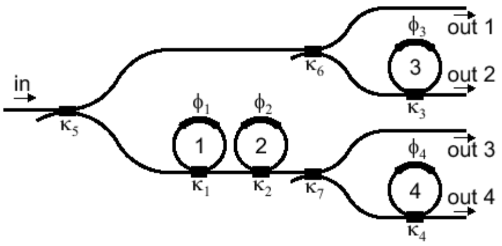

Fig.1. 1 x 4 binary tree OBFN

The major advantage of using a binary tree structure is that lesser rings are required to get four different outputs. Since each output has one ring more in the optical path than the previous one, the delay can be selected in steps.

III-1. DELAY RIPPLE AND PHASE ERRORS IN WDM NETWORK

The goal of this assignment is to design a subsystem which converts a desired delay value to a set of Φs and k_s in such a way that an optimal response results. This section describes the effects of errors in the phase response. The delays are required to aim the phased array antenna in a certain direction. So only with correct delays the signals will have optimal constructive interference resulting in the highest output power. It is observed that the input pulse is severely distorted when the DE has a large ripple. Also the transient time will be much longer which could be a source for Inter Symbol Interference (ISI). The expression for the desired signal is

$$s(t) = \sum_{n} r_n(t) \cos\left(2\pi f_{\mathrm{IF},=} t + \psi_n(t)\right) \qquad \text{…. (1)}$$

The set 'n' represents the different sub-carriers in the spectrum considered and f_{if} are the carrier frequencies. The amplitude $r_n(t)$ and phase $\psi_n(t)$ depend on the modulation type of the signal. When all the carriers are summed, the desired signal results. In fact this can be seen as the input for the system. To get the strongest field and thus output current, the proportionality constant should be maximized with respect to the phase error. Errors in the phase response cause a lower output power, but, that could also be seen as a gain reduction. When the phase errors are bounded by $\pm\Delta\Phi_{max}$, the worst case occurs when half of the errors are $+\Delta\Phi_{max}$ and the other half are $-\Delta\Phi_{max}$. The gain reduction in dB then becomes.

$$P_{\mathrm{gain}} \leq -20 \log \left[\cos \Delta\phi_{\mathrm{max}}\right] \qquad \text{…. (2)}$$

It can be seen that the gain reduction caused by phase errors is not very severe, since, the penalty is still below 0.7 dB with a phase error of Π/8.

IV. TUNING A 1 X 4 WDM NETWORK CHIP AT ONCE

The high levels of integration required for a large scale WDM network on chip is obtained through the use of microring resonators that are designed to perform wide range of optical functions at typical dimensions less than few µm. This subsection discusses the problem of tuning of an integrated WDM network chip at once. This is done with an objective to minimize the delay ripple and phase errors. The implementation is a quite easy step when starting from the three ring situation. Since the only thing which has to be done is to add the two ring objective function to the three ring one. The objective function of the one ring section does not need to be added for tuning the complete chip at once. Since there are two separate one ring sections, so when tuning a complete ring the results can still be used as part of the optimal solution. The results obtained are presented in Table 1. The one ring section was tuned in the center with a slightly more peaky tuning than the one ring section of tuning. This is one of the advantages of taking a look at tuning all rings at once, since now a different value for the one ring section is chosen. Although the deviation is small, it is in contradiction with the manual tuning rules, which assumed that both one ring sections should be tuned the same way.

Table 1 Tuning results for the whole chip at once

Target delays (ns)	Two ring κs	Two ring ϕs	Third ring κ	Metric value (ns^2)
0.6 and 0.4	0.6235	-0.4302 and 0.4486	0.7777	$5.6 \cdot 10^{-3}$
0.5 and 0.4	0.6505	-0.4094 and 0.4278	0.9831	$2.0 \cdot 10^{-3}$

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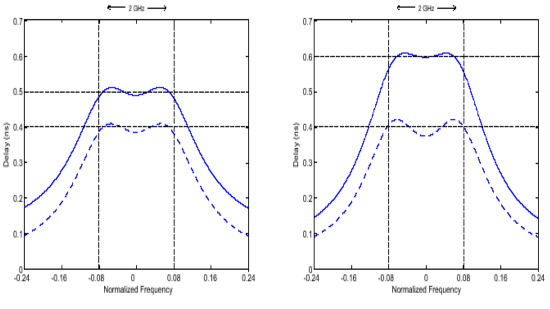
The optimizations were repeated for 0.5ns as three ring delay and 0.4ns as two ring delay. Again the one ring section was tuned in the center with a *k*, which is also slightly more peaky then the separate one ring tuning. The responses are shown in Figure 2. From the results it can be concluded that the optimal tuning for the whole chip is somewhere in between the tunings for two rings and one ring separately and three rings at once. However, it is closer to the two and one ring solutions than to the three ring solution.



(a) (b)

Fig.2. Group delay response optimized for the complete chip at once. Both the three ring (solid lines) and two ring outputs (dashed lines) are shown. In (a) the target delay was 0.5ns for the three ring output and in (b) 0.6ns. In both cases the target for the two ring output was 0.4ns.

V. EXPERIMENTAL RESULTS

V-1. TUNED WDM NETWORK RESPONSE

The response of the fabricated two-pole quasi dual mode filter for WDM network was obtained by performing measurements from 1 to 10 GHz using a S-parameter network analyzer and microwave probes. Two DC probes were used for actuating the thermal actuator. Fig. 3 shows the filter response without tuning. From the response, it can be observed that the center frequency of the filter is 5 GHz and the insertion loss is 2 dB at the center frequency. The fractional 3-dB bandwidth is 7.35%.

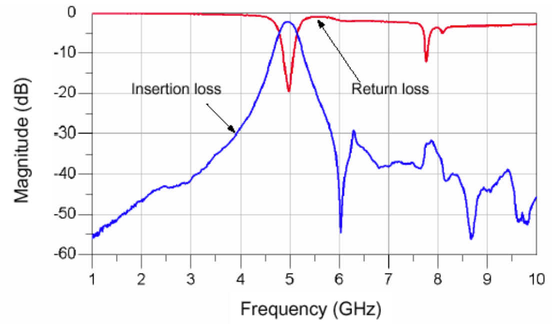


Fig.3. The test results of a micromachined 2-pole quasi dual-mode filter without tuning

The out-of-band rejection is better than 30 dB from 4 GHz to 1 GHz and 6 GHz to beyond. A comparison of the filter responses with and without tuning is presented in Fig 4.

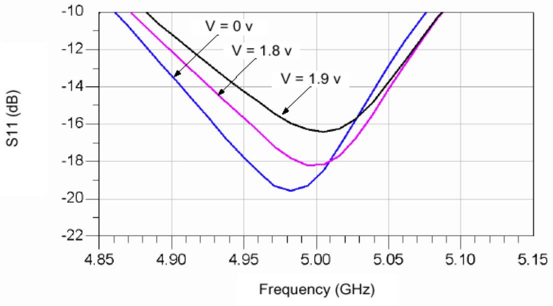


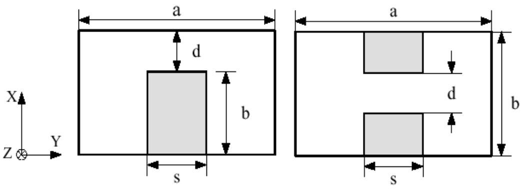
Fig 4. A comparison of the return loss responses of the designed filter at different tuning voltages

V-2. RESULTS WITH FINE TUNING

Ridge waveguide filters exhibit the following advantages:

(i) a low insertion loss,
(ii) high spurious performance and
(iii) are compact in size.

The cross sections of two typical ridge waveguide structures are shown in Fig. 5, where their length extends in the Z direction. When the ratio of 'a/s' is fixed, ('a' is the width of the cavity and 's' is the width of metal ridge), the cut-off frequency is determined by the ratio of 'd/b', ('d' is the gap between the top cover of the cavity and the top surface of the metal ridge and 'b' is the height of the metal ridge). The smaller the ratio of 'd/b', the higher is the cut-off frequency. This relationship indicates that a lower resonance frequency is possible by using smaller ridge waveguide structure, as long as the ratio of 'd/b' is small enough. Traditional fabrication techniques have limited capabilities for providing a low value of'd/b', restricting the size reduction of the ridge waveguide filters. However, micromachined ridge waveguide filters have a huge advantage with the MOEMS fabrication techniques; i.e., a gap as small as a few micrometers and a ridge as high as a few hundred micrometers can be created. This implies that the ratio'd/b' can be as low as a few one hundreds.



(a) (b)

Fig 5. (a) a cross section of a single ridge waveguide structure and (b) cross section of a double ridge waveguide structure

V-3.RESONANT FREQUENCY RESPONSE

Figure 6, depicts the response obtained between the resonant frequency of a ridge waveguide resonator and the ratio of 'd/b' with 'a/s' fixed. For a Δd/b of 1% (fine tuning), the corresponding Δfr is about 200 MHz and for most commercial fabrication foundries this 1% fabrication tolerance is quite reasonable. The specifications of the two-pole filter are given in Table 2. The two-pole filter has a center frequency of 26.9 GHz and is predicted to have a 10% bandwidth with an insertion loss of 1.8 dB at the mid-passband. When the tuning elements are fully inserted into the cavity, they can shift the centre frequency of the filter up to 200 MHz and maintain the filter's bandwidth with every little change, as observed in Figure 7.

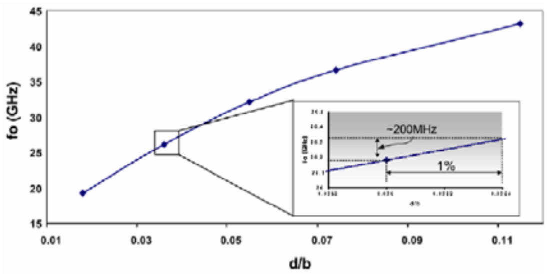


Fig 6. A ridge waveguide resonance frequency vs. the ratio of ‘d/b’ when ‘a/s’ is fixed

Table 2 Specifications of the two-pole filter

Tuning elements Position	Center Frequency	Bandwidth	Insertion loss at mid-pass Band
Initial	26.9 GHz	10%	1.8 db
Fully inserted into cavity	26.9 GHz +200 MHz	10% (No change)	

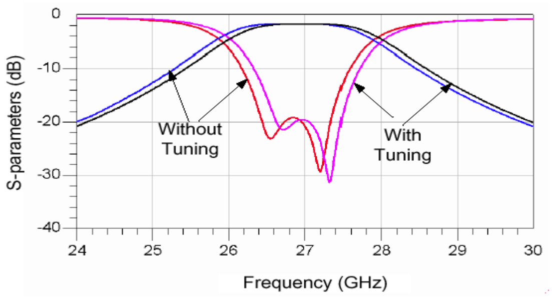


Fig 7. A comparison of the simulated responses of a two-pole filter with and without tuning elements

VI. REULTS WITH AUTOMATED AND POWER TUNING

This criterion is based on delay responses and relies solely on the output power from the system. This is in fact the final metric of the system performance. However the phase error is kept under limitations. A maximum of π/16 was proposed, and this should be checked once the optimization has taken place. Another difference with the previous criterion is that the mutual relations between the different outputs are now taken into account. This means that looking at individual output is meaningless and therefore only results for the whole chip at once are presented.

Results: Table 2

Target delays(ns)	One Ring K	Two Ring K	Two Ring Ø	Third Ring K	Total Error(dB)
0.6,0.4,0.2	0.7898	0.6689	0.3990	0.7898	-61.73
0.6,0.4,0.1	0.9868	0.6450	0.4189	0.7898	-68.21
0.5,0.4,0.2	0.7898	0.6945	0.3714	0.9867	-68.56
0.5,0.4,0.1	0.9868	0.6697	0.3994	0.9867	-92.97

Results for Automated and Power tuning for different target delay values. The total error is the averaged power loss per point in dB over 10.000 points.

From these results it can be seen that when the total error and the loss of power is very small.

VII. CONCLUSION

In this work, two types of micromachined bandpass filters suitable for WDM network was presented. One is a quasi dual-mode microstrip line filter and the other is a ridge waveguide cavity filter with a coplanar input and output interface. The concepts presented in this work, can assist in multiple users (for ex: upto 1024) to get connected in a single network topology. Also, a reconfigurable WDM access network can be developed so that a congestion-free access and exchange of abundant amounts of information is possible. The delay responses are also studied for automated and power tuning and the power loss and total error were considerably reduced.

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VIII. BIOGRAPHIES

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