Microwave Filtering Realized Through Incoherent Optical Processing

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Abstract—**Analogue microwave filters can be produced using optical components when the microwave signal is modulated onto an optical carrier wave, processed optically, and then recovered electrically. The fiber-optic network presented here displays a bandpass filter response to the modulating signal. The processing operation is based on the transversal tapped delay line technique forming an infinite impulse response structure. By employing an incoherent optical carrier wave for signal transmission, the structure's responses are modelled using linear discrete signal-processing techniques.**

Index Terms—**Microwave filtering, optical processing.**

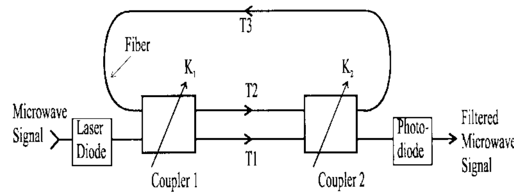

Fig. 1. A two-coupler multiple delay line single-recursive loop fiber-optic network. K_1 and K_2 are crossed output coupling coefficients; $T1$, $T2$, and $T3$ are delay lengths.

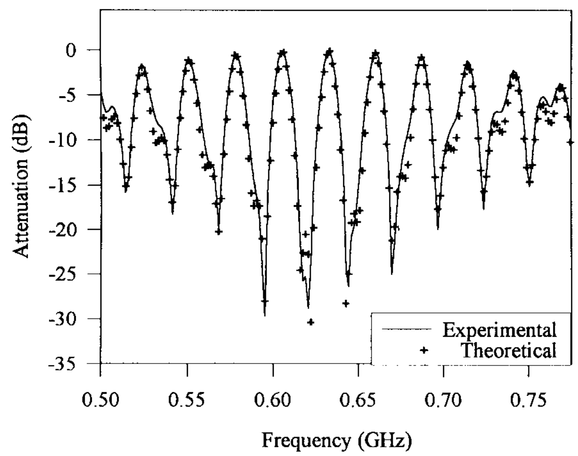

Fig. 2. Frequency response of the network configuration in Fig. 1. $K_1 = 70\%$, $1 - K_1 = 17\%$, $K_2 = 26\%$, and $1 - K_2 = 61\%$, $T1{:}T2{:}T3$ in the ratio 12.03:5.09:2.5.

I. Introduction

With the extension of electrooptic device modulation bandwidths to 20 GHz [1], [2] and above [3], the transmission of analogue microwave signals optically is now possible. Single-mode optical fiber cable offers superior performance over other microwave frequency waveguide media in terms of speed, available signal bandwidth [4], and reduced signal degradation [5] to the data transmitted. To fully exploit the benefits of such links, optical processing of the transmitted signal would be advantageous. Central to any processing system is signal filtering. Moslehi *et al.* [6] demonstrated a simple fiber-optic loop configuration, exhibiting a notch filter response to the analogue signal modulating the incoherent optical carrier wave. Further fiber-optic networks may be designed which realize various filtering functions to such modulated optical waves. Fig. 1 illustrates one such fiber-optic network configuration. This fiber-optic network may display a bandpass filter response. It consists of two 2×2 fiber-optic couplers, two feed-forward delay lines, and a feedback delay line. The input signal is initially divided into four signals through couplers 1 and 2. Their amplitudes are weighted by the respective crossed coupling coefficients and their phase delayed by the path lengths travelled. The delayed signals are coupled into the same output line as previous divided and delayed input signals. The recombination of these various signals at the photodetector's surface produces the network's frequency response to the input-modulating signal.

II. Experimental Results

A directly modulated optoelectronic link was employed to investigate the fiber-optic network's frequency responses. The source was a HP LSC4110-FP laser diode with a modulation bandwidth of 1.4 GHz. The photodetector was a Hamamatsu G3476-01 p-i-n diode with a bandwidth in excess of 1 GHz. The optical network's microwave S-parameter frequency responses to the modulated optical carrier wave were measured on a HP8720A network analyzer. The measured de-embedded attenuation versus frequency response of the optical network in Fig. 1 is shown in Fig. 2. The modelled results are plotted for comparison, confirming the viability of the applied theoretical models and predicted results in the following sections.

III. Theory

By employing an incoherent optical carrier wave the design and analysis of the optical networks is simplified by removing the need to consider optical coherence effects. The networks may then be analyzed by representing the optical radio frequency (RF) modulation signal through the z-transform [7]. Applying the theory and rules developed for the z-transform [8] and its accompanying matrix representation [9] to the network's signal flow graph representation allows ease of

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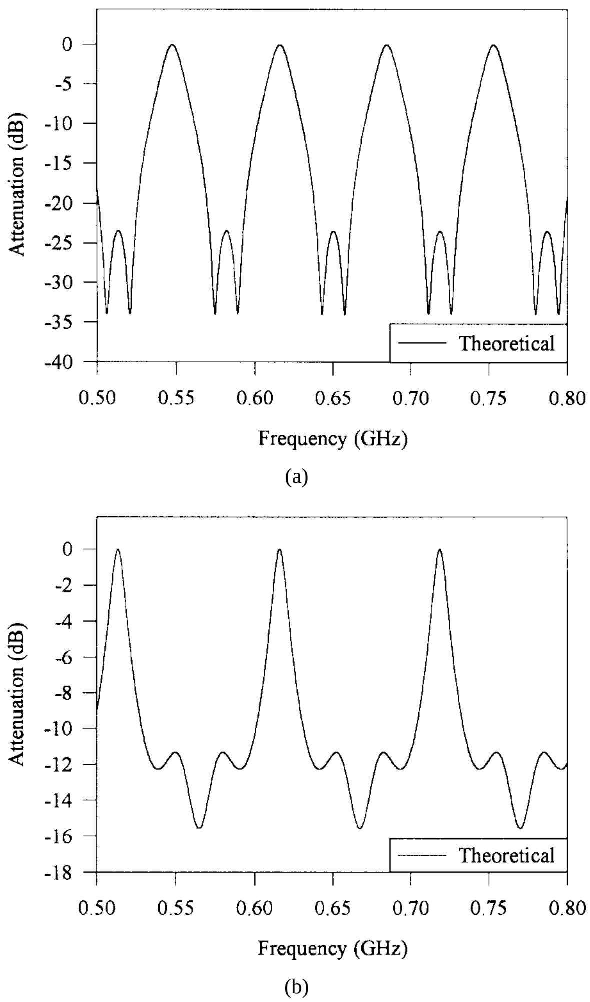

Fig. 3. Predicted theoretical magnitude responses for the network of Fig. 1 with the microwave filter composed of fiber-optic elements. (a) $K_1 = 22\%$, $K_2 = 66\%$, $T1{:}T2{:}T3$ at 5:2:1. (b) $K_1 = 33\%$, $K_2 = 55\%$, $T1{:}T2{:}T3$ at 5:3:1.

inclusion and manipulation of lossy and gain elements in the circuit modelling. Due to the discrete repetitive nature of the optical network's impulse response in the time domain, the corresponding frequency domain response has a repetitive baseband. The bandwidth of the baseband is determined by the optical delay lengths in the network. As such, the optical delay lengths specified are determined by the microwave modulation frequencies which require filtering. The maximum baseband bandwidth is ultimately limited by the minimum length of the fiber-optic cable employed [10]. The frequency response shape of a particular network configuration is determined by the optical coupling coefficients, the ratio of the circuits optical delay lengths, and any optical gain present. The circuit presented in Fig. 1 allows the possibility of two different coupling coefficients, three different time delays, and three optical gain elements to control the frequency response shape.

IV. Recursive Fiber Loop Filter Designs and Modelled Results

By adjusting the coupling coefficients K_1 and K_2 and the delay length ratios $T1{:}T2{:}T3$ for the network in Fig. 1, the magnitude transfer functions $|H(\omega)|$ of Fig. 3 may be obtained for the ideal (lossless) circuit.

The response of Fig. 3(a) has a baseband of 69 MHz with a passband −3-dB bandwidth of 12 MHz. The stopband bandwidth at −20 dB is 24.5 MHz.

The response of Fig. 3(b) has a baseband of 102 MHz with a passband −3-dB bandwidth of 9.75 MHz. The stopband bandwidth at −10 dB is 73 MHz.

V. Conclusions

Fiber-optic network designs have been presented which are capable of providing various bandpass filter responses. Good agreement between the experimental results and theoretical modelling has been demonstrated for the fiber-optic elements utilized. By adjusting the interconnection, ratio of the delay lengths, and coupling coefficients filter bandshapes may be ascertained. The low baseband frequency results presented here may then be directly translated to higher frequencies through reduction of the fiber delay lengths. The use of an optically incoherent carrier wave allows a fiber-dispersion-limited modulation signal bandwidth in excess of 10 GHz. These filters are simple to implement, circumventing the design complexity and fabrication of high-frequency electrical filter devices. However, the recursive nature of these designs means that a nonlinear phase response is obtained across the baseband. Increasing the number of couplers, coupled outputs, and detector outputs may allow variations in the responses obtained here, however, at greater complexity while increasing system losses.

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