Hybrid Transversal Filter Utilizing MMIC and Optical Fiber Delay Lines

Tamera A. Yost, Peter R. Herczfeld, Arye Rosen, and Sarjit Singh

Abstract—**Conventional microwave transversal filters are hindered by bandwidth limitations and cannot provide long-time delays due to excessive propagation losses. Optical transversal filters lack the means to provide negative weighting coefficients. Therefore, a hybrid transversal filter that utilizes low loss, wide bandwidth optical fibers for the delays and microwave monolithic integrated circuits (MMIC's) for accurate weighting is investigated. Theoretical analysis of the noise performance, bandwidth, and delay line dispersion of a completed MMIC advanced transversal filter and the novel hybrid transversal filter are presented.**

I. Introduction

TRANSVERSAL FILTERS, as first described by Kallman [1] in 1940, are used in applications where even small amounts of phase distortion cannot be tolerated. The general structure of a transversal filter consists of tapped delay lines with a method of amplitude weighting and combining of the delayed signals.

The complex transfer function of the filter with $N+1$ elements is

$$H(\omega) = \sum_{n=-N}^{N} a_n e^{jn\omega\tau} \tag{1}$$

where a_n is the weighting coefficient and τ is the unit time delay.

Gweon [2] used a reflectively tapped fiber and high-speed semiconductor laser/photodetector combination to demonstrate transversal filter performance at 10 GHz and above. A fiber-optic programmable filter has been proposed by Capmany and Cascon [3], where the system parameters are changed by altering the pumping power of the optical amplifier in each tapped fiber rung. Problems with purely optical transversal filters include inaccurate weighting and the inability to provide negative weighting coefficients. Therefore, a hybrid filter that is comprised of a low loss, wide bandwidth optical fiber delay mechanism and an existing MMIC transversal filter, providing the necessary accurate positive and negative weighting, is reported here.

Manuscript received March 3, 1995. This work was supported by the National Science Foundation under Drexel University's Graduate Engineering Education Doctoral Fellowship Program for Women and Minorities (Grant #EEC-9116782).

T. A. Yost, P. R. Herczfeld, and A. Rosen are with the Center for Microwave and Lightwave Engineering, Drexel University, Philadelphia, PA 19104 USA.

S. Singh is with the Princeton Microwave Technology, Inc., Mercerville, NJ 08619 USA.

IEEE Log Number 9413482.

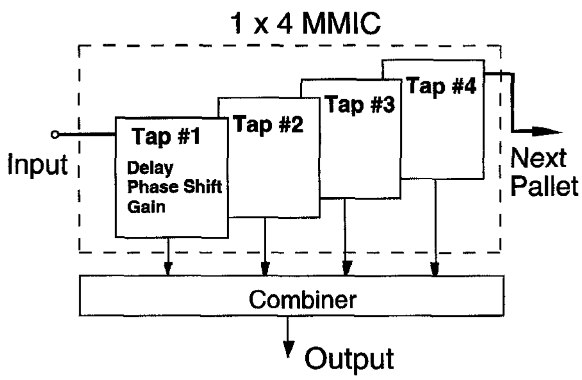

Fig. 1. Block diagram of the MMIC advanced transversal filter.

II. Hybrid Transversal Filter Utilizing MMIC and Optical Fiber Delay Lines

The hybrid transversal filter discussed in this paper is a combination of an MMIC filter and a fiber-optic feed network. The microwave adaptive transversal filter (MMIC ATF), comprised of individual tap elements cascaded in series, has been fully described in [4]. The performance goals for this 48-tap system, shown in Fig. 1, are an operating frequency band of 10–14 GHz, a 500 MHz–2 GHz signal bandwidth, 0 dB signal loss, and 40 dB minimum stop-band loss. The GaAs MMICs, bias boards, and alumina circuits were assembled on pallets, each with four individual tap elements.

Each tap consists of three functional blocks. The first comprises a 100 ps MMIC delay line, a power divider, and a compensation amplifier. The second contains a power divider/switched phase shift MIC that supplies positive or negative weighting. The final block is comprised of a single-pole double-throw (SPDT) switch, to select the polarity of the weighted signal, and a variable attenuator with a range of 20 dB, which sets the coefficient. Design simulations of the S-parameters were performed and the filter was tested for a variety of responses, including bandpass and notch tuned frequencies of 9.2, 9.7, 10.2, and 10.7 GHz at the David Sarnoff Research Center [4].

For the hybrid configuration, depicted in Fig. 2, the optical carrier is modulated by the input microwave signal, amplified in the optical domain, split into M fibers of appropriate lengths and fed to a photodetector, and the delayed input signals are applied to the 1×4 MMIC pallets. The length of the individual fibers is such that a uniform time delay is achieved from t_1 to t_n. The hybrid transversal filter with parallel signal feeding projects reduced overall noise level compared to the serial MMIC ATF configuration.

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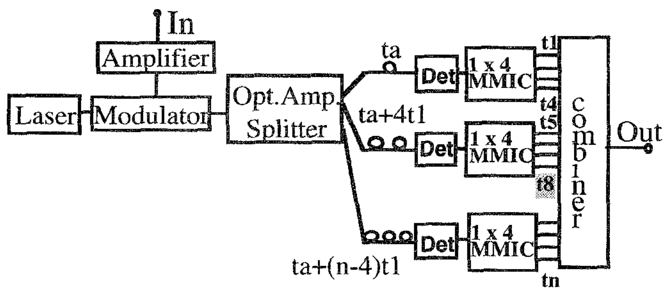

Fig. 2. Hybrid transversal filter block diagram.

III. Noise Analysis of the Hybrid Transversal Filter

The CAD program Libra was used to generate noise and performance data of the MMIC ATF by creating a microwave circuit component file equivalent to the tap element. Each MMIC component was analyzed separately and then all components were connected to simulate the particular tap element. The S-parameters of interest, noise figure, and gain were calculated for all components.

The input signal is S_i and there are three simulated output signals, S_d, S_{w1}, and S_{w2}. The output signal S_d is the delayed and compensated version of the input signal S_i that is fed to the next tap element. The output signals S_{w1} and S_{w2} are the delayed, compensated, and weighted versions of the input signal, with a relative phase difference of 180°. The SPDT switch selects only S_{w1} or S_{w2} to be fed to the 20-dB output coupler.

At the center frequency of 12 GHz the noise figure and gain of S_d are 6.552 and −0.058 dB, respectively. The noise figure and gain of the output signal S_{w1} are 20.357 and −19.920 dB, and for S_{w2} are 20.507 and −20.101 dB, respectively. These values are used to calculate the noise figure of the two filters for any number of taps.

Linear cascaded two-port network analysis is employed to compute the noise figure and gain for the output path, S_{wn}, of the nth of m identical cascaded taps. For this model the total added noise at the output of the combiner is simply the sum of the noise present at the output of each tap. The overall gain of the filter is also the sum of the individual gains for N elements. The noise figure is NF (dB) = Total Added Noise (dB) − Gain (dB). The noise figure of the MMIC ATF was calculated over the 10–14 GHz band with a minimum (18.75 dB) occurring at 14 GHz for one tap and a maximum (30.39 dB) at 10 GHz for 128 taps. At the center frequency of 12 GHz and for 48 taps, the noise figure is 23.44 dB.

The noise performance of the hybrid was calculated assuming that the overall gain of the fiber optic feed network is 0 dB, which implies a 30 dB output amplifier following each detector, as seen in Fig. 2. The model further assumes the modulator, optical splitter, and optical amplifier are noiseless devices, the laser RIN level is −150 dB/Hz, and the p-i-n photodetectors are shot noise limited with a level of −170 dB/Hz. The input amplifier to the modulator has a 6.5 dB noise figure and for low power levels is the dominant source of noise in the link [5]. The minimum noise figure (19.01 dB) occurs at 14 GHz for one tap and a maximum (21.26 dB) at 10 GHz for 128 taps. At the center frequency of 12 GHz and for 48 taps,

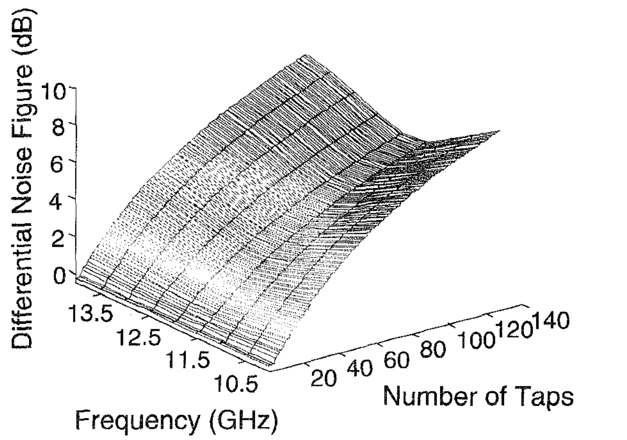

Fig. 3. Differential noise figure versus number of taps over 10–14 GHz band.

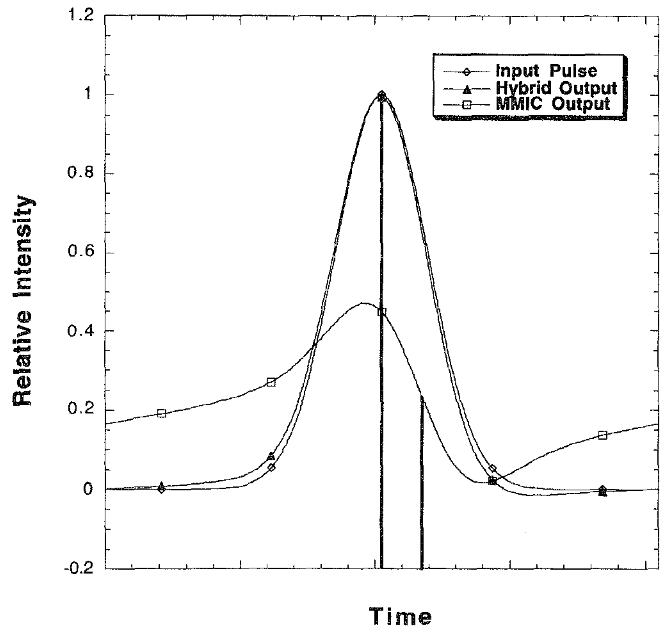

Fig. 4. Pulse distortion in MMIC ATF and hybrid filter delay lines.

the noise figure is 20.26 dB. It is relatively flat over the 10–14 GHz band for any number of taps. The differential noise figure, defined as the difference between MMIC ATF and hybrid filter noise figures, is depicted in Fig. 3. It is evident from Fig. 3 that the hybrid configuration has a better noise figure over the operating band of 10–14 GHz. The real advantage of the hybrid configuration is the ability to realize a filter with a large number of taps, while maintaining a relatively constant noise figure of approximately 20 dB, compared to that of the MMIC ATF whose noise figure is approximately 30 dB for 128 taps and grows as the number of taps is increased.

IV. Dispersion in the MMIC Advanced and Hybrid Transversal Filters

The microstrip delay line dispersion of the MMIC ATF configuration is a concern due to the serial feed of taps. The dispersion characteristics of the 48 tap delay line were simulated using the expressions for the effective dielectric constant

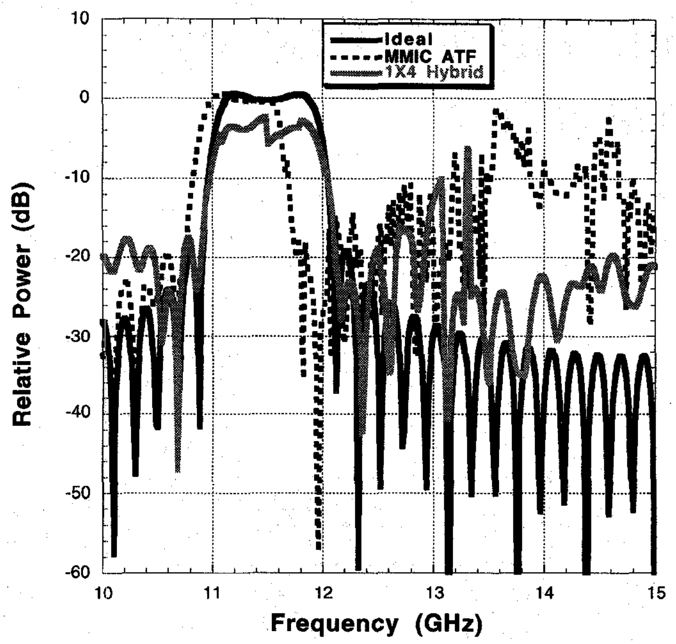

Fig. 5. Ideal, MMIC ATF, and hybrid filter frequency response comparison.

of the GaAs substrate developed by Kobayashi [6]. As far as the dispersion is concerned, total length of microstrip delay line for the hybrid filter corresponds to four taps because of the parallel feed configuration. Fig. 4 shows a 10-ns Gaussian input pulse and the output pulses from the 48th tap of the MMIC ATF and hybrid filters. The signal degradation of the hybrid filter is negligible compared to that of the MMIC ATF.

The effect of dispersion on the overall frequency response of the MMIC ATF and hybrid filters was simulated and compared to that of an ideal response, which was calculated using (1), where the weighting (Fourier) coefficients are calculated for a specific frequency response and for a uniform time delay of 100 ps. The MMIC ATF filter response was calculated using the same weighting coefficients, however the time delays per tap are no longer constant. As the frequency increases above 11.5 GHz, the effective delays vary, significantly degrading the filter response. The degradation increases with the number of taps. For the hybrid filter, the time delay per tap is calculated by feeding each 1×4 pallet with the required constant delay from the feed network.

The results are shown in Fig. 5. Fig. 5 shows the frequency response for the 48 tap MMIC ATF, hybrid filter, and ideal system with a center frequency of 11.5 GHz and a bandpass region of 1 GHz. The hybrid approaches the ideal with the exception of some degradation above 11.5 GHz due to the microstrip delay line in the 1×4 pallet.

V. Conclusion

A hybrid transversal filter has been proposed that utilizes both wide bandwidth, low-loss optical fiber delays and an existing MMIC advanced transversal filter to provide weighting. Theoretical analysis of the noise performance of the hybrid transversal filter is significantly better than the MMIC advanced transversal filter, allowing a large number of taps with a relatively constant noise figure. The input signal distortion caused by delay line dispersion is negligible for the hybrid transversal filter, allowing close correlation between desired ideal and actual response curves. The bandwidth of the hybrid transversal filter is limited by the MMIC circuitry. The hybrid transversal filter is a viable alternate configuration to purely optical or microwave implementations.

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