FIBEROPTIC BASED RECIRCULATING MEMORY LOOP

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ABSTRACT

This paper presents the analysis and experimental results of a recirculating memory loop operating over 2-4GHz with delays up to millisecond using an adaptive gain equalizing technique. The effect of the number of recirculation on the fidelity of the coded microwave signals is studied. The spectral purity characteristic of recirculated signals are quantified for various recirculation times.

INTRODUCTION

Fiber optic based memory loops are used for recirculation of the incoming RF pulses [1]. The simplified schematic diagram of a fiber optic based recirculating memory loop is conceptually shown in Fig. 1. This system consists of four basic elements: a switch, an electrical amplifier, a fiberoptic time delay element, and a gain equalizer. The RF input pulse is routed through the switch to the time delay device. The switch closes the loop and thus controls the recirculation. As the signal reenters the microwave circuit, it is amplified and rerouted through the fiber. As a result, a pulse train is obtained that has a pulse repetition interval corresponding to one recirculation time through the loop.

In practice the number of recirculation is limited by: i) frequency response flatness of the closed loop system, ii) the noise figure of the fiber optic link, as shown in the equation for number of recirculation [1]. Solution to the flatness problem of the open loop frequency response is an adaptive gain equalization technique. An adaptive gain equalizer consists of several cascaded resonator in the feedback loop of a multi stage amplifier, and serves as gain controller over the bandwidth of interest. Each resonator has shunt combination of variable capacitor (varactor diode), a variable resistor (varistor), an inductor, and an RF sampler feeding a microwave detector. Both the varactor and the varistor are electrically controlled and can be tuned or adjusted within less than a microsecond, resulting in control of the resonance and the selectivity of each resonator. The adaptive gain equalizer has been designed over the frequency range of 2-4 GHz and the circuit implementation of the equalizer is in progress [2].

The present work concentrates on design of a low-loss, low noise figure fiber optic delay element at 1300 nm, capable of recirculating a short electrical pulse as long as a millisecond over the 2-4 GHz frequency band. In our present approach the adaptive gain equalizer is realized using a YIG tuned filter and a variable attenuator to demonstrate validity of this concept. While the RF pulses are recirculating in the system the noise level starts to buildup. By looking at the spectrum of the output signal the effect of the recirculation on the spectral purity of the microwave signals can be studied. The spectral of the recirculating signal are observed for various recirculation times. Also spectral purity characteristic of the frequency modulated signal are identified for various time delays.

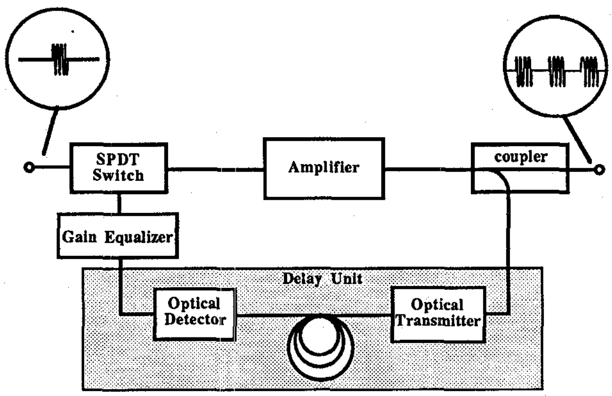

Fig. 1. Conceptual drawing of a fiber optic based recirculating delay line. It is composed of a SPDT switch, electronic amplifier, coupler, optical delay element, and gain equalizer. The gain equalizer in our experimental setup is composed of a YIG filter and an attenuator.

FIBEROPTIC LINK DEVELOPMENT

In the design of low-loss, low noise fiberoptic link, an InGaAsP laser diode was used in the reactively matched optical transmitter module as the optical source. This laser diode has modulation bandwidth of 8 GHz. An InGaAsP PIN photo diode with responsivity of 0.8 A/W at 1300 nm and capacitance of <0.2 pF was used in the actively matched optical receiver as optical detector. The fiberoptic link was characterized in terms of frequency response, noise figure and inter-modulation distortion.

The frequency response of the fiberoptic link has an insertion loss of -11dB with flatness of ±4 dB over the bandwidth of 2-4 GHz. The noise figure of the fiberoptic link has been measured to be 50 dB. The third order intercept point was identified using two tone intermodulation distortion measurement at frequencies of 3 GHz and 3.050 GHz.

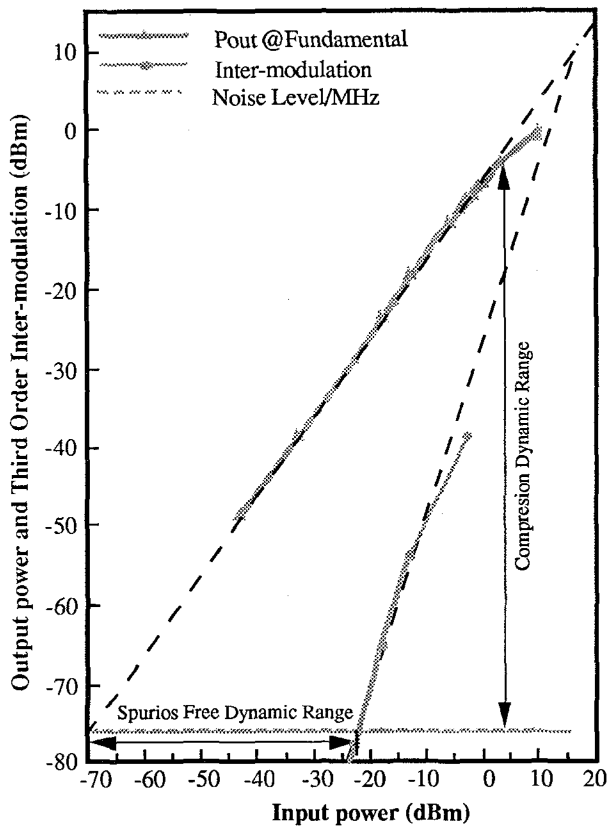

Fig. 2. Output power as a function of input power of the 2-4 GHz fiberoptic link at frequency of 3GHz, showing the linearity, third order intermodulation distortion and dynamic range.

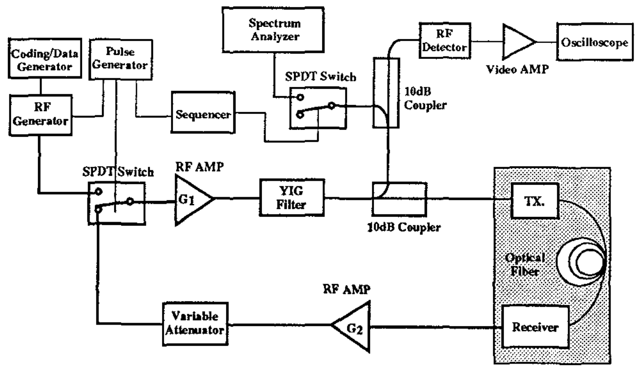

Fig. 3. Experimental set up to study Fiberoptic Based Recirculating Memory Loop.

The output power of the fiber-optic link was measured at fundamental and the third order intermodulation frequencies. A plot of the received power as a function of input power is shown in Fig. 2, where a 1dB gain compression point of 4 dBm at the frequency of 3 GHz is achieved. As shown in Fig. 2, the designed fiberoptic link has a compression dynamic range of 74 dB.MHz and spurious free dynamic range of 47 dB.MHz$^{2/3}$.

PULSE RECIRCULATION EXPERIMENTS

An experimental setup, similar to the conceptual drawing and shown in Fig. 3 was used to perform optical recirculation experiments. The fiberoptic delay element consists of the reactively matched optical transmitter, a 1 Km of single-mode optical fiber delay or a 100 m of multi-mode optical fiber, and the actively matched optical receiver. The envelope of the RF pulsed signal was monitored on an oscilloscope after detection, and the spectral power density of the signal was monitored on a spectrum analyzer. Envelop of modulated RF signal at 3 GHz after each recirculation is detected and shown in Fig. 4a as train of output pulses. A total time delay of over 600µs can be observed. A better time resolution of the recirculating pulse trains is depicted in Fig. 4b, where a 200 µs window is displayed.

In order to replicate the effect of adaptive gain equalizer in the system with nonflat frequency response, a tunable YIG filter was used. By adjusting the frequency response of the filter, the RF signal was recirculated at the peaks as well as at the valleys of the open loop frequency response for many times. In this experiment a 100 m of optical fiber corresponding to 500 ns has been used as a delay element in the link. Fig. 5 shows the train of the recirculating pulses at three different frequencies.

(a)

(b)

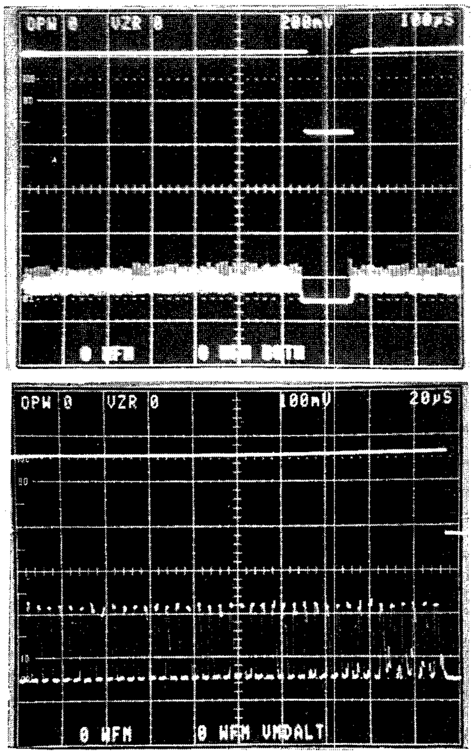

Fig. 4. (a) Train of output pulses for the input pulse at carrier frequency of 3GHz, using the 1 Km of fiber as the delay element (Horizontal scale 100µS/div, the lower trace is recirculation over 600 µS, and the upper trace is switching pulse). (b) Close up view of output pulses with horizontal scale of 20µS/div.

The train of recirculating pulses close to the peak frequencies of 2 and 3 GHz are represented in Figs. 5a and 5c respectively, whereas the train of the recirculating pulse at the frequency of 2.5 GHz is shown in Fig. 5b corresponding to the valley of the open loop frequency response. As these results show, modulated RF pulses over 2-4GHz can recirculate in the loop without oscillation build-up or decay, even for a nonflat link frequency response.

The signal spectral purity of the recirculated signal has also been studied. Since the spectrum analyzer shows the average spectrum of the out put pulses, a special switching time sequencer circuit was designed and fabricated to enable us to sample a particular microwave pulse after certain number of recirculation. The role of this sequencer circuit is to switch on the sampling circuit at a PRI repetition rate with a tunable initial delay. Hence a microwave pulse is inputted to the spectrum analyzer after a selected number of recirculation. We have looked at the the spectrum of the recirculating signal after several recirculation. The phase noise of the microwave signal has been measured after various recirculation numbers at 20, 50 and 100 Hz offset carrier of the microwave signal . The experimental results indicate that the RF signal degrades only by ~ 0.3 dB per recirculation.

In another experiment, coherency of a FM modulated signal was studied as a representative of the coding fidelity of recirculating RF pulses. In this experiment, the spectrum of the FM modulated signal at 3 GHz was monitored on the spectrum analyzer after a number of recirculation.

(a)

(b)

(c)

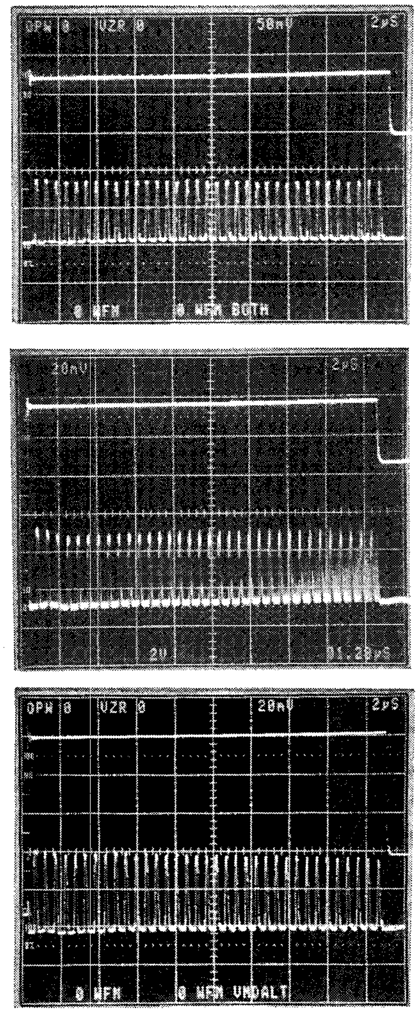

Fig. 5. Train of recirculating pulses, (a and c) close to the peak frequencies of 2 and 3 GHz respectively, (b) close to the valley of the frequency response at 2.5 GHz. (Horizontal scale 2µS/div, the lower trace is recirculating pulse and the upper trace is switching pulse)

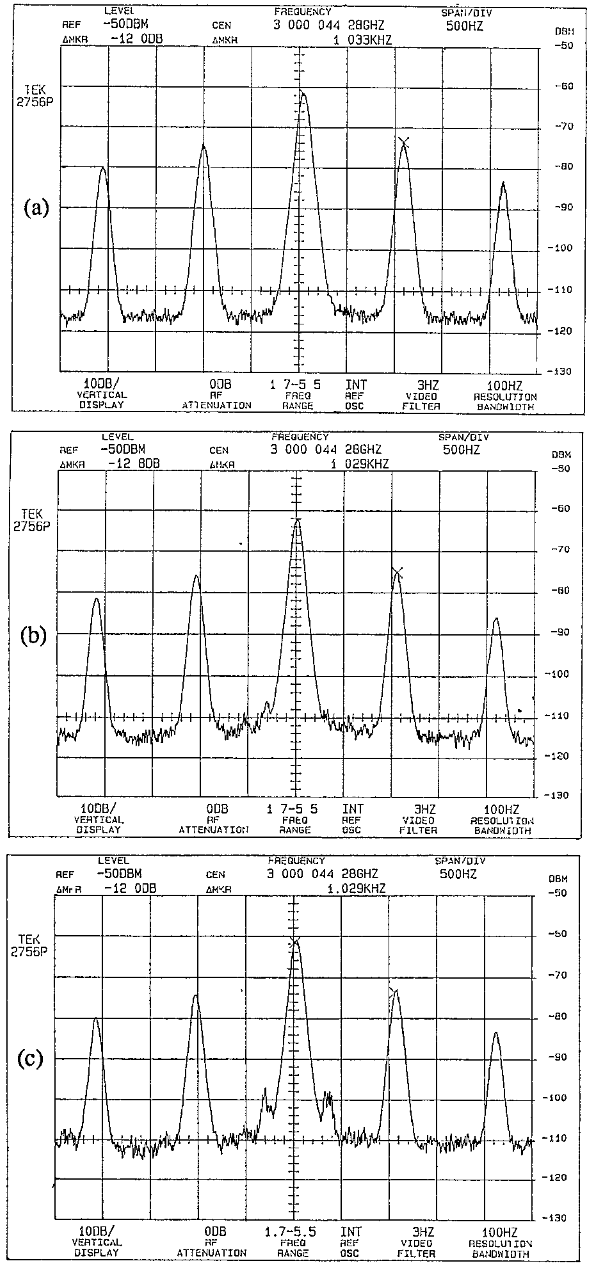

Fig. 6. Spectral of the frequency modulated microwave signal (a) after single recirulation (b) after 10 recirulation (c) after 30 recirulation (Vertical scale of 10dB/div, horizontal 500 Hz/div, resolution bandwidth 100 Hz, video filter 3Hz, and the reference value of -50 dBm)

The RF source was frequency modulated with a modulation index of $\beta \sim 0.5$ at a 1 KHz rate. The frequency of the RF signal was varied over the 2-4 GHz bandwidth. As an example, a plot of the output signal spectrum is shown in Fig. 6, where the spectrum of the FM modulated 3 GHz signal after single, 10 , and 30 recirculation is shown.

As Fig. 6 shows the frequency modulated signal does not change significantly, even though the noise power level of the signal increases after several recirculation. Our analysis indicates that after 30 recirculation, the noise buildup in the memory loop increases the total output noise power reaches -108 dBm/Hz. By taking into account the pulse repetition rate and the duration of sampling window, the noise level of the output is calculated to increase by 4.85 dB from -54.3 dBm for 10 recirculation to -49.4 dBm for 30 times. This analytical prediction matches with measured results of ~ 5 dB.

CONCLUSION

The experimental results of fiberoptic memory loop demonstrate that a millisecond delay over broad band microwave frequencies can be achieved using custom designed low noise FO link, a long delay element, and adaptive gain equalizer. The maximum number of recirculations and time delay can be increased by reducing insertion loss and noise figure of the fiber optic link, and flattening the frequency response of the closed loop system. Even though we have demonstrated the use of the adaptive gain equalization technique for broad bandwidth operation, however other methods such as hybrid optical pulse recirculation is being considered.

The spectrum of the output signal shows that the frequency modulated signal does not change very much, whereas the amplitude noise of the signal enhances after several recirculation. The phase noise measurements for 100 Hz offset carrier of the microwave signal show that the RF signal degrades only by 0.3 dB per recirculation. The phase noise degradation of the modulated signal can be more significant, depending on the operating frequency and the laser diode modulation index [3].

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