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Oscillators Using Magnetostatic-Wave Active Tapped Delay Lines

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Abstract—**A novel oscillator that combines a magnetostatic wave (MSW) tapped delay line with GaAs monolithic microwave integrated circuits (MMIC's) has been fabricated. This oscillator incorporates an external feedback loop which is extremely short and provides multiple outputs delayed in time by the MSW delay line. The oscillator is tunable from 2.76 to 2.95 GHz and the 3-dB bandwidth of the oscillation is approximately 10 kHz.**

I. Introduction

Devices based on the propagation of magnetostatic waves (MSW's) have the potential of performing signal processing at microwave frequencies, a frequency range where surface acoustic wave devices do not operate [1]. MSW delay lines provide useful time delays up to approximately 20 GHz, and because they are planar they can be integrated with other components, such as GaAs monolithic microwave integrated circuits (MMIC's). In particular, a tunable oscillator using MSW delay lines is attractive because of its simple structure, superior phase-noise characteristics [2], and large tunable bandwidth. Tunable oscillators using MSW delay lines, external amplifiers, and directional couplers have been reported [3], [4]. However, undesirable frequency jumping was observed within the frequency tuning range because of the electrical length of the feedback loop.

We have developed a novel tunable oscillator that integrates MESFET amplifiers and MSW transducers on a single GaAs chip. An active tapped delay line was realized using five GaAs MMIC chips and one gallium gadolinium garnet (GGG) substrate with an epitaxially grown yttrium ion garnet (YIG) film to support MSW propagation. An oscillator was formed by coupling the signal from the first tap to the input amplifier of the delay line. The additional delay-line taps provide time-delayed outputs of the oscillator. Because monolithic-circuit chips were used and no directional coupler is required, the oscillator is compact and the feedback loop is short. The time delay of the multiple outputs is determined by the spacing between taps and by the applied magnetic field. In this work we present a new approach to the fabrication of a tunable MSW oscillator and also demonstrate the feasibility of integrating MSW devices with GaAs MMIC's.

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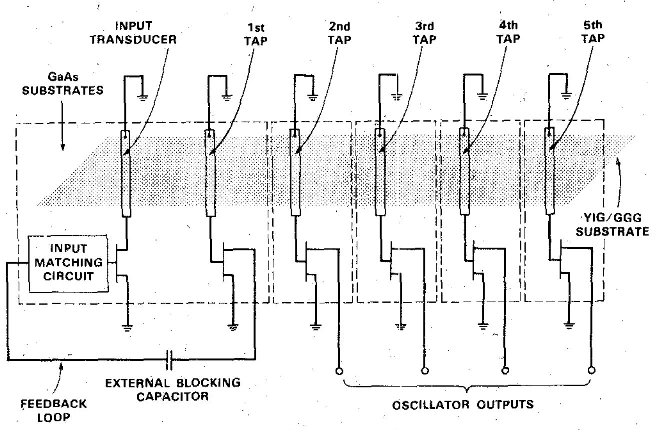


Fig. 1. Schematic diagram of the oscillator using an active tapped delay line.

II. Oscillator Design and Fabrication

The schematic diagram of the oscillator is shown in Fig. 1. The active tapped delay line was constructed using an input GaAs chip incorporating the input amplifier and output circuitry for the feedback tap (tap 1) and four other GaAs chips incorporating only the output circuitry for the oscillator outputs (taps 2–5). The circuit diagram and a photograph of the completed GaAs MMIC chip are shown in Fig. 2(a) and (b), respectively. The design and fabrication of the input amplifier have been previously reported [5]. The input circuitry consists of a 500-μm-wide MESFET (FET 3) with a distributed matching network connected to its gate and the input MSW transducer connected to its drain. This circuit provides convenient impedance matching to the MSW delay line and produces amplification of the input signal. The output transducer of the delay line is connected to the gate of FET 1 and gain modulation is provided by a shunting MESFET (FET 2), which is used as a variable resistor. The spacing between

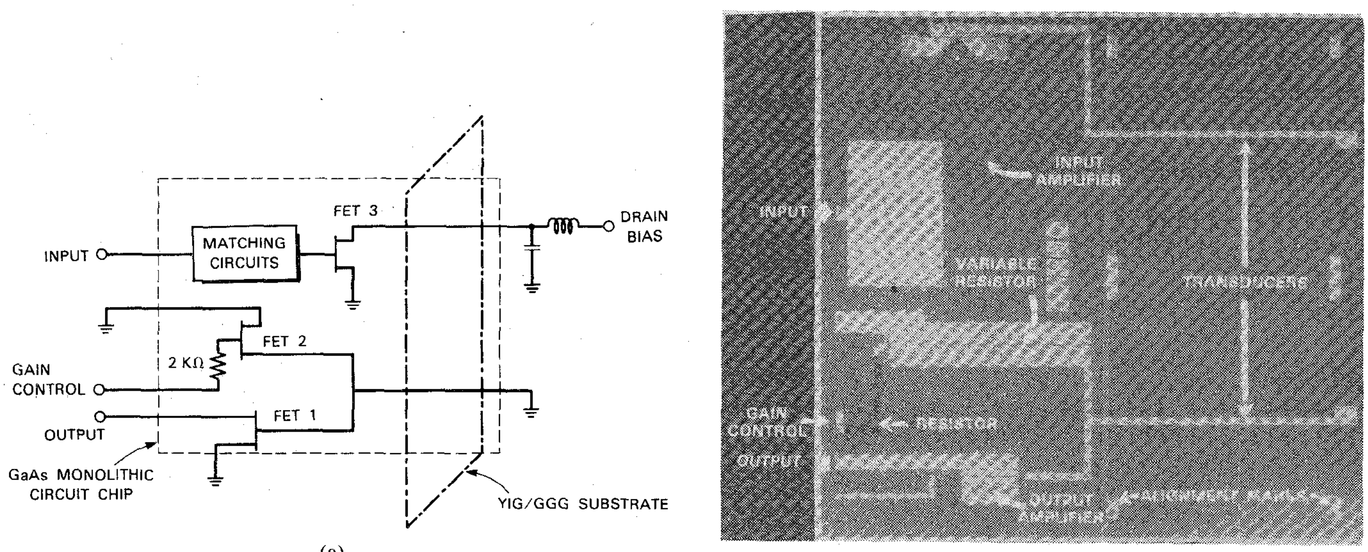


Fig. 2. GaAs MMIC used for the MSW active delay line. (a) Circuit diagram. (b) Photo of the completed chip. Chip size is 4.5×4.5 mm^2.

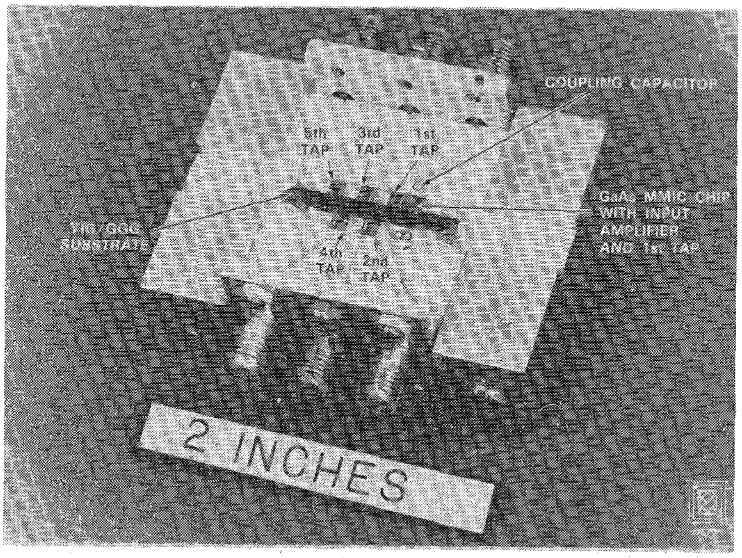


Fig. 3. Assembled MSW active tapped delay line using GaAs MMIC chips and a YIG/GGG substrate. The smaller GaAs chips, which are the output portion of the complete circuit, are used for taps 2–5.

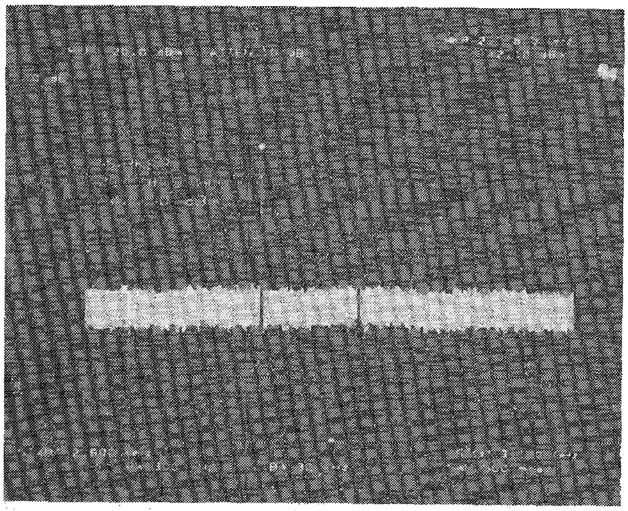
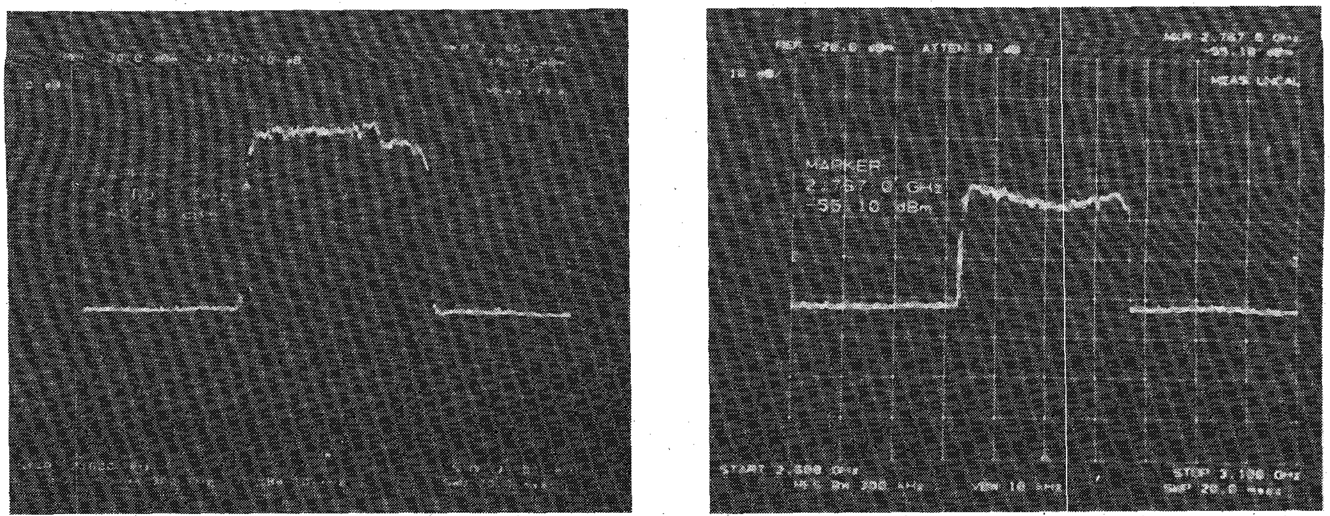


Fig. 4. Oscillator output taken from tap number 2. Two oscillation modes are separated by 100 MHz in frequency.

the input and output transducers on the input GaAs chip is 2.5 mm.

As shown in Fig. 3, the GaAs chips were mounted on a metal shim with all the transducers aligned to a 2-mm-wide YIG/GGG substrate, which was placed on top of the transducers with the 50-μm-thick YIG film facing down. The distance between each output tap was 2 mm and the end of each transducer was grounded by bond wires. The gap between the transducers and the YIG film was determined by small GaAs chips that supported the YIG/GGG substrate at both ends. For this tapped delay line the gap was approximately 20 μm. The magnetic field was provided by an electromagnet and was parallel to the YIG film, so that only the magnetostatic surface wave propagated. The feedback loop for the oscillator was completed by bonding wires from the output of the first tap to the input amplifier through a blocking chip capacitor as illustrated in Fig. 1.



(a) (b)

Fig. 5. Measured tunable range of the oscillator using a spectrum analyzer. A maximum-hold feature, which stores the greatest signal measured at each frequency as the magnetic field is increased, is used to show the oscillation frequency range. (a) Tap 2. (b) Tap 4.

III. Experimental Results

The output gain at each tap of the delay line can be varied by changing the drain–source resistance of FET 2 or the bias applied to the drain of FET 1. When a signal was applied to the input amplifier with the feedback loop disconnected, a maximum gain of 3.5 dB was measured at the first tap of the delay line at 2.5 GHz. The measurement was performed with 200 G of applied magnetic field. Therefore, GaAs MESFET's provided the net gain needed to sustain the oscillation. More than 12 dB of gain variation was achieved by changing the drain bias of FET 1 from 3 to 0.2 V. At the same frequency an average time delay of 7.8 ns between each tap was measured, and as expected, did not change with the bias applied to the drain of the output FET.

Because all the components are assembled inside a small package and no directional coupler is used, the electrical length of the feedback loop is extremely short. From measured amplifier data, this external electrical delay is estimated to be 0.1 ns, which is approximately 1 percent of the total time delay of the MSW delay line. For comparison, the external delay was approximately between 10 and 20 percent of the total time delay in a previously reported work [4] in which an external amplifier and a directional coupler were used.

The outputs of the oscillator were obtained from taps 2 through 5. The phase difference between these outputs is determined by the propagation delay of the MSW between the taps. Fig 4 shows the oscillator output taken from tap 2. Two oscillation modes are observed, separated by approximately 100 MHz. These two modes exist because the single-line wide-band transducers which were used do not provide adequate frequency discrimination. The measured output power of the oscillation at 2.78 GHz is -42.1 dBm and the 3-dB bandwidth is approximately 10 kHz, demonstrating that this is a high-Q oscillator. The frequency of the oscillator can be tuned continuously from 2.76 to 2.95 GHz by changing the applied magnetic field from 210 to 280 G. No frequency jumping was observed and we believe that this oscillator can operate over a much wider frequency range without frequency jumping because of the short length of the external circuit. The current tuning range of 190 MHz was limited by the gain and bandwidth of the amplifiers in the feedback circuit. By reducing the gain from the first tap, the second oscillation can be suppressed and a single-mode oscillator can be created at the expense of a smaller tunable range.

Spectrum analyzer displays in Fig. 5(a) and (b) show the measured outputs from taps 2 and 4, respectively, as the magnetic field varies from 210 to 280 G. Notice that the tunable range of the two taps is nearly identical, while the average output power from tap 4 is approximately 14 dB lower than that from tap 2. This attenuation is estimated to arise from the nonuniformity of the magnetic field (~ 8 dB), the power coupled to tap 3 which lies between taps 2 and 4 (~ 2 dB), and the propagation loss of the 4-mm-long MSW delay line between taps 2 and 4 (~ 4 dB).

IV. Conclusions

We have, for the first time, fabricated a GaAs MMIC designed specifically for use with MSW devices and demonstrated that the performance of MSW devices can be greatly improved by integrating them with GaAs MMIC's. This new combination of MSW devices and GaAs MMIC's has been used to construct a five-tap MSW active delay line and to realize a novel MSW delay-line oscillator by feeding the signal from the first tap back to the input amplifier. This provides a high-Q tunable oscillator with multiple outputs having a built-in time delay. This unique property of the oscillator may be very useful in phased array technology [1]. Because of the use of GaAs

MMIC's and the elimination of the directional coupler, the external electrical length is extremely short. Therefore, this oscillator is expected to operate in a large frequency range without frequency jumping. The performance of the current oscillator is limited by unoptimized amplifier and transducer designs. If a wide-band amplifier is used, an MSW delay-line oscillator with tunable bandwidth beyond 20 GHz is feasible [3], and a single-mode oscillator can be achieved by adopting multi-finger narrow-band transducers [6].

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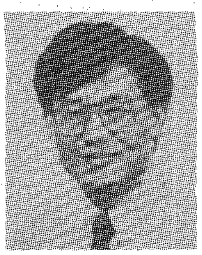

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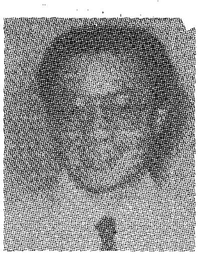

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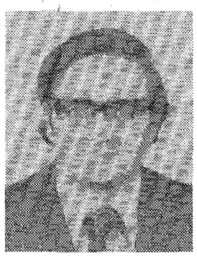

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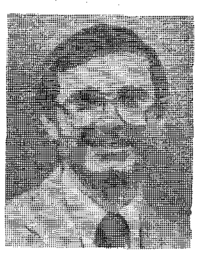

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