A Ku BAND MSW DELAY LINE

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ABSTRACT

A MSW delay line operating at 14.4 GHz has been developed. The delay line has a minimum insertion loss of 15 dB and a VSWR of less than 2.0:1 across a 600 MHz bandwidth. This unit, including the biasing magnet, occupies a volume of four cubic inches and weighs less than one pound. A comparable coaxial delay line is 15 meters long, occupies 200 cubic inches and weighs 60 ounces. This paper presents the design techniques and data.

INTRODUCTION

Magnetostatic waves, which propagate in magnetically biased yttrium iron garnet (YIG) film, are slow waves (10 cm/s) and substantial delay can be obtained in a short distance. Therefore, delay lines are a natural application of MSW technology (1). The MSW delay has advantages over coaxial delay lines in that it has comparable delay and insertion loss in a smaller volume with lighter weight.

Much work has been done on MSW devices, but little work has been done above 10 to 12 GHz. The objective of this work was to develop a small, low loss delay line having a minimum of 75 nanoseconds of delay, operating at 14.4 GHz, with a bandwidth of 600 MHz.

DESIGN

The MSW delay line is composed of an epitaxial YIG film grown on a gadolinium gallium garnet (GGG) substrate, input and output transducers and magnetic bias field source. The transducers couple the electromagnetic energy into the YIG film, and a permanent magnet provides the magnetic bias.

Since the objective is the construction of a small, low loss delay line, trade-offs must be made between the electrical and magnetic design. These trade-offs and the design techniques are discussed in the following paragraphs.

Electrical Design

Magnetostatic waves propagate in three different modes depending on the orientation of the magnetic bias vector. The Magnetostatic Forward Volume Wave (MSFVW) was chosen because it offers a wide bandwidth (> 1 GHz) at high frequencies and its magnetic bias orientation is perpendicular to both the direction of propagation and the plane of the YIG film, allowing for simple and efficient bias magnet design since the film lies parallel to the biasing magnet's pole faces.

Obtaining the correct delay is straight forward because the dispersion relation for the MSFVW mode has been derived and experimentally verified (2). The group delay can be calculated from the dispersion relation by the differentiation of the wave number with respect to the angular frequency.

Two parameters that strongly affect the delay are 1) the distance between the transducers and 2) the YIG film thickness. Thicker YIG film allows better coupling of the magnetostatic wave from the transducer and therefore, offers less loss. However, the delay is also shorter and must be compensated for by using a greater transducer separation, which requires a larger magnet size. To obtain the required delay of 75 nanoseconds, a small size bias magnet and an acceptable insertion loss, a transducer separation of 1 cm, and a YIG film thickness of 20 microns was chosen. The theoretical insertion loss and group delay responses are shown on Figures 1 and 2, respectively.

The microwave energy is coupled into the MSFVW mode by transducers. Much work, both empirical and theoretical, has been done on transducers (3). Efficient and easy to fabricate, transducers are narrow microstrip lines either open circuited and one quarter wavelength long or short circuited and much less than one wavelength long because the YIG film must be placed over a current maximum. The open circuited transducer was chosen because its longer length was easier to trim. The open circuit excites a standing wave with a current maximum one quarter wavelength from the open. The current maximum couples to the magnetically dominated magnetostatic wave. Figure 3 shows the transducer pair used to couple

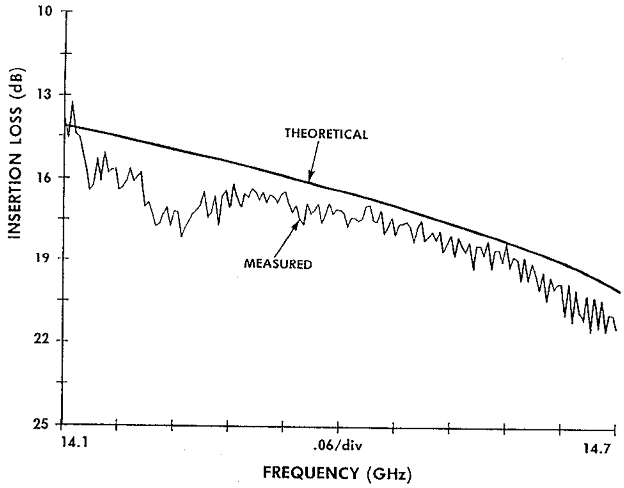

Figure 1. Theorectical and Measured Insertion Loss

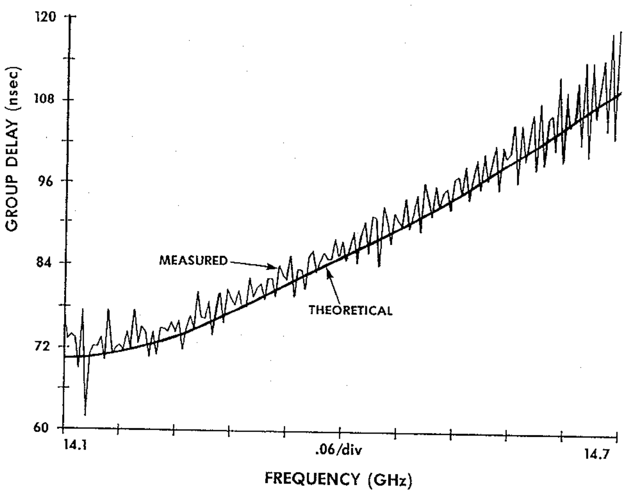

Figure 2. Theoretical and Measured Group Delay

into and out of the YIG device. The YIG film is laid directly on the transducers. These transducers were fabricated on a 10 mil quartz substrate. A quartz substrate was used because its low dielectric constant ($\epsilon r=4$) causes the transducer to have a larger geometry and therefore, the placement of the YIG device is not as critical.

The delay line is optimized for minimal insertion loss by varying the length of the trans-

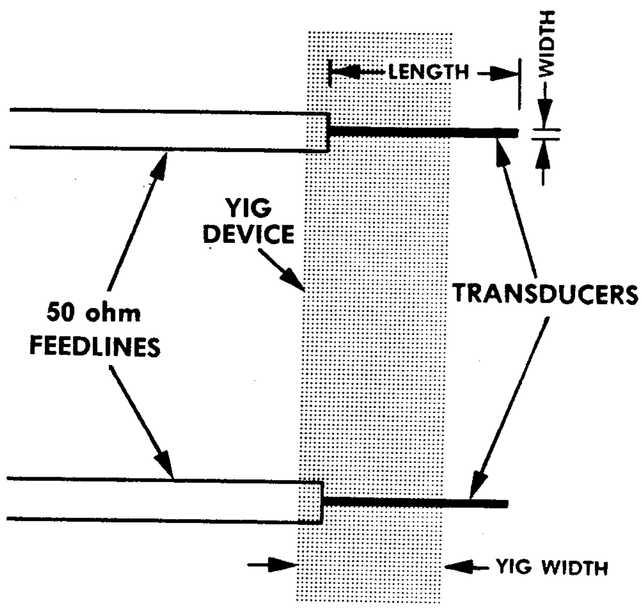

Figure 3. The MSW Circuit Showing The Transducers and Feedlines Relative To The YIG Device

ducers, the width of the YIG device and its placement on the transducers. The YIG device is placed over the transition where the 50 ohm feedline ends and the transducer begins, as shown in Figure 3. The YIG device's position is varied until the insertion loss and the ripple are minimized. A series of measurements were made for a variety of YIG device widths. Next, the transducers were trimmed to a new length and the process was repeated. The process stopped when the insertion loss and the ripple were minimized. At 14.4 GHz, a transducer length of 125 mils and a YIG device width of 105 mils gave the best results.

Reducing the insertion loss with this technique also lowers the MSW delay line's VSWR. The GGG, which composes the majority of the YIG device, has a very high dielectric constant ($\epsilon r=15$). The overlap of the YIG device onto the 50 ohm line increases the series capacitance of the transducer/feedline interface, compensating for the series inductance of the transducer. The resulting match was good enough that no extra matching network was needed or used.

An empirical design technique was used to determine the transducer's width. If the transducer is too narrow, the resistive losses in the transducer are high, resulting in an unacceptable insertion loss. If the transducer is too wide, the excitation current is non-uniform resulting in poor coupling to the MSFVW mode and some coupling to width modes. Poor coupling to the MSFVW mode causes a decrease in bandwidth and coupling to width modes increase ripple. The optimum transducer width was found to be between 3/4 and 1 mil.

The 1 mil width was used for the final unit.

Ripple caused by the magnetostatic wave reflecting off the ends of the YIG device was reduced to less than 1 dB by the use of bevels and soft iron wire placed at the ends of the YIG device. The bevels were ground into the ends of the YIG device with an optical grinding compound. The transition to the bevel must be smooth or the bevel itself will cause reflections. The bevel must also be shallow to prevent reflections and therefore, a one degree bevel was used. The bevel gradually reduces the thickness of the YIG film to zero. At zero thickness, both the delay and the attenuation are infinite, which prevents reflections. The soft iron wire reduces the magnetic field in the end region of the YIG film, which increases the propagation delay and attenuation.

Magnetic Design

The YIG must be immersed in a 6700 gauss magnetic field to allow propagation at 14.4 GHz. A permanent magnet was designed by using Rotor's equivalences (4) to supply the required bias. Because the bias magnet contributes almost all of the weight and volume of the delay line, it must be made as small as possible. The magnet's weight and volume can be minimized by using a low loss magnetic conductor, a permanent magnet material with a high energy product, and the smallest possible gap.

The yoke and tapered pole pieces were constructed of soft iron. Tapered pole pieces concentrate the magnetic flux to a 1 X 3/4 square inch area. Neodymium iron boron, the permanent magnet material, has an energy product of 27 MGOe, the highest available at the time of this study.

The magnet's gap must accommodate the substrate, the YIG film, and provide a separation of ten times the substrate thickness (10 mils) between the YIG film and upper pole piece. The upper pole piece acts as a ground plane and as this ground plane moves closer to the YIG film, the bandwidth narrows. The separation of ten times the substrate thickness electrically locates the ground plane at infinity. By using the lower pole piece as a carrier for the substrate, the minimum gap size (110 mils) is realized. A brass extension added to the lower pole piece which supports the feed lines and provides mounting for the SMA launchers. Brass was used because it is nonmagnetic and nonferrous, and therefore, does not disturb the magnetic field in the gap.

The bias magnet was designed to develop a slightly higher bias field than required. After the transducers and YIG device were mounted in the magnet, it was tuned to the correct bias field by the use of soft iron wires which were placed on the magnet in shunt.

RESULTS

Figure 4 shows the completed MSW delay line. The delay line weighs less than 16 ounces and occupies a volume of 2 X 2 X 1 cubic inches. The transducers and YIG device are contained in the magnet's air gap. The soft iron wire, which reduces reflections, is epoxied on to the magnet's

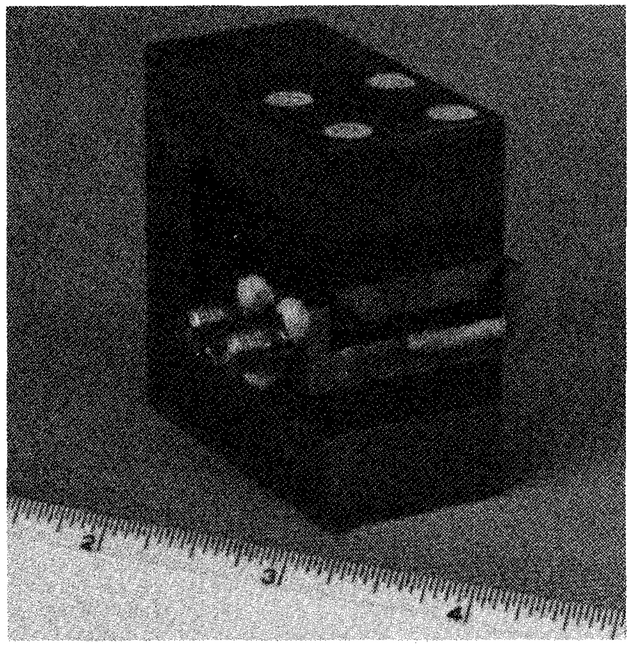

Figure 4. The Final MSW Delay Line

lower pole piece at the end of the YIG device. Figure 1 shows the insertion loss, which lies between 15 and 21 dB across the 600 MHz band. The fine grain ripple, which is caused by end reflections or reflections off of the transducers, is 1 dB or less. The theoretical plot assumes a YIG film having a ferromagnetic resonance line width of 1.1 Oe at 10 GHz and zero loss due to transducer mismatch. (Commercially available YIG was used.) Lower insertion loss is possible if better quality YIG material is used. As Figure 2 shows, the measured group delay tracks excellently with theory. The 72 nanoseconds of delay were measured instead of 75 nanoseconds because the YIG film was 22 microns thick instead of 20 microns. The theoretical plot used a 22 micron thickness for comparison. Figure 5 contains a plot of the input reflection coefficient, S11. This plot demonstrates that the VSWR is less than 2.0:1 across the 600 MHz band.

This delay line is usable over a 1 GHz bandwidth if a degrated performance is acceptable. Over this bandwidth, the maximum insertion loss is 26 dB and the VSWR is less than 3.0:1.

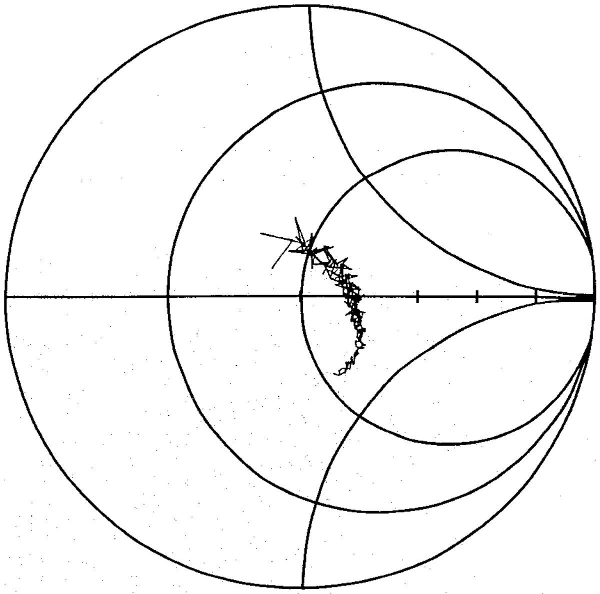

Figure 5. Input Reflection Coefficient, S11, Measured from 14.1 GHz to 14.7 GHz

CONCLUSION

This MSW delay line finds applications in systems that require microwave signals to be delayed many nanoseconds. This delay line offers delay and insertion loss comparable to a coaxial delay line's, in a much reduced volume and weight. One possible application is a channelized ESM receiver system where the delay line stores RF information while a decision is made concerning what channel to process.

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