A 13-CHANNEL MAGNETOSTATIC WAVE FILTERBANK

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ABSTRACT

The magnetostatic wave filterbank shows particular promise as a key component in high dynamic range channelized receivers for future electronic warfare systems. It consists of an array of narrowband magnetostatic wave delay lines which have a common microstrip input transducer and separate output transducers. The center frequency of each channel is determined by a magnetic bias field supplied by a permanent magnet with a linear field gradient. This paper describes the construction and performance of an improved version of a 13-channel filterbank operating at S-band with a 24 MHz (3dB) channel bandwidth and a 50 dB dynamic range. A comparison of present and projected performance data is given.

INTRODUCTION

Previous magnetostatic wave (MSW) filterbanks which operated in X-band[1] and S-band[2] showed non-uniform channel spacings and high out-of-band spurious responses which limited the dynamic range to <35 dB. A 13-channel filterbank was recently described which operated in S-band with greater than 50 dB two-tone dynamic range and 3 dB channel bandwidths of 25 MHz[3]. This type of filterbank shows great promise for application in broadband channelized receivers for future E.W. systems because of its demonstrated high dynamic range, small size, and freedom to operate at any microwave frequency. In this paper improvements in performance of the 13-channel filterbank are discussed which were subsequently obtained in the areas of passband shape, time domain spurious signals and temperature stability.

The filterbank consists of 13 narrowband MSW delay lines arranged along a microstrip input transducer, or manifold. Each channel consists of a strip of Yttrium Iron Garnet (YIG) film, 1-mm wide, grown by liquid-phase epitaxy on a Gadolinium Gallium Garnet (GGG) substrate, and each has a separate output transducer. The center frequency of these narrowband filters is determined by the strength of the magnetic bias field, which is applied normal to the YIG films to excite magnetostatic forward volume waves. The delay lines are identical except for a gradient in the bias field so that each delay line experiences a different bias field and hence has a diffrent center frequency. In the earlier 13-channel device[3] the even numbered channels had an attenuation notch on their low frequency skirts. This is a non-reciprocal effect which is not understood at present, but which can be removed by reversing the input and output ports, the magnetic bias field direction or the direction of power flow along the input manifold. The notch was removed from the current device by using a U-shaped input manifold which enabled all the channels to be in the same relationship to the critical geometric parameters affecting the notch. This is in contrast to the earlier device where a linear manifold was used and hence had alternate channels in a different relationship between the propagation direction and power flow in the input manifold.

CONSTRUCTION AND PERFORMANCE

Figure 1 is a photograph showing the interior of the filterbank and a part of the magnet yoke structure. The brass housing enclosing the YIG filter elements was designed to minimize the microwave feedthru between input and output ports and also between adjacent output ports through the use of internal walls. Measurements of this feedthru showed it to be -75 to -80 dB. The long U-shaped microstrip line formed a common input feed to all 13 channels and was fabricated on a high dielectric substrate - Trans Tech D-8623 (ϵ=75). The intrinsic impedance of the 0.5-mm wide input manifold line, 12.3 ohms, was matched to 50 ohms at each end of the U shape by quarter wavelength matching sections fabricated on an alumina substrate butted to the high dielectric substrate. Thus the input port was connected to one end of the U shape and, adjacent to it, a 50-ohm chip resistor terminated the other end of the U shape. Both input and output ports used miniature 47-mil O.D. semi-rigid coaxial lines terminated with SMA female connectors.

The output transducers also used 0.5-mm wide microstrip lines on the D-8623 substrate material and were in the form of a short U shape with each filter element located over the mid section of

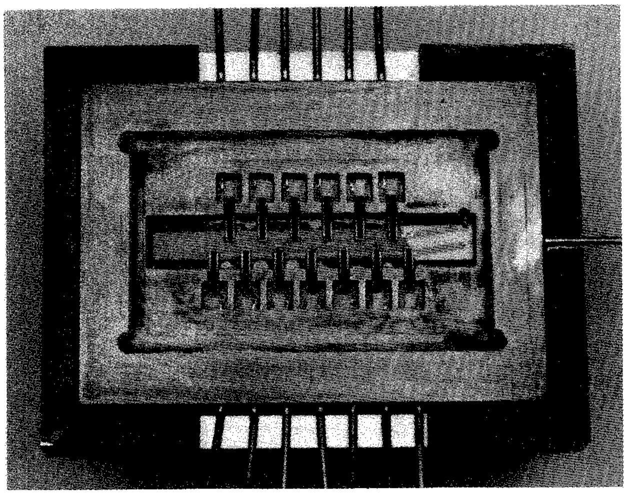

Figure 1. A photograph of the filterbank interior.

the U shape. One end of the U shape was terminated in an open circuit to give a current maximum at the filter element placed one quarter wavelength away. The other leg of the U shape was also one quarter wavelength long to match the output impedance of the filter-element-plus-microstrip-line to 50 ohms. In practice the matching was not perfect but it transformed a typical transducer impedance of 3.2+j3.2 ohms to 23+j0.5 ohms. This could, no doubt, be improved. Each output microstrip line was designed to operate at the respective channel center frequency.

The filter elements were defined photolithographically on the YIG wafer and then cut with a semi-conductor dicing saw to give the individual structure shown in Figure 2. The inner, darker, tapered shape of Figure 2 is the YIG filter element and the outer rectangular shape is the Gadolinium Gallium Garnet substrate material on which the YIG was grown. The YIG film thickness was 12.7 microns. In order to suppress undesired higher order magnetostatic width modes the filter elements were tapered along their length, as can be seen in Figure 2. Additionally, an array of aluminum strips 500-Angstroms thick was evaporated across the width of each element from the wide to the narrow end. Previous work[4] had established that a 5-mil wide strip, 5-mil wide space, together with the YIG tapering, gave an optimum suppression of the width modes to the -75 dB level of the microwave feedthru. Each YIG element was examined optically to be crystallographically defect-free and free of edge roughness prior to insertion in the filterbank. Both crystal defects and any roughness along the edges degraded the passband shape of the filter.

The common input manifold couples MSWs into the appropriate YIG element. The channel bandwidth was determined by the YIG film thickness and the spacing of the YIG above the microstrip, which in this device was set at 160 microns by the use of a microscope cover glass slide spacer. The reflection of the backward-going MSW component from the square end of the YIG was deliberately designed to interfere with the forward-going component in such a way as to sharpen the high frequency side of the filter skirt[3]. The receiver microstrip converted the in-coming MSW back to a microwave signal and, again, reflections from the end of the YIG aided in sharpening the high frequency skirt. The frequency of operation of each channel was determined by the applied static bias magnetic field which had a linear gradient of about 3 Oersteds/mm from channel to channel, due to the use of a tapered magnet pole cap. This field gradient produced a 20-MHz shift in center frequency for adjacent channels. All components of the magnet and magnet yoke structure had to be flat and parallel to 1 micron tolerances to guarantee the performance of the filterbank. Figure 3 is a photograph of the finished device.

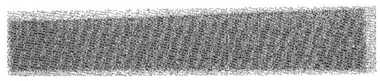

Figure 2. A photograph of a YIG filter element.

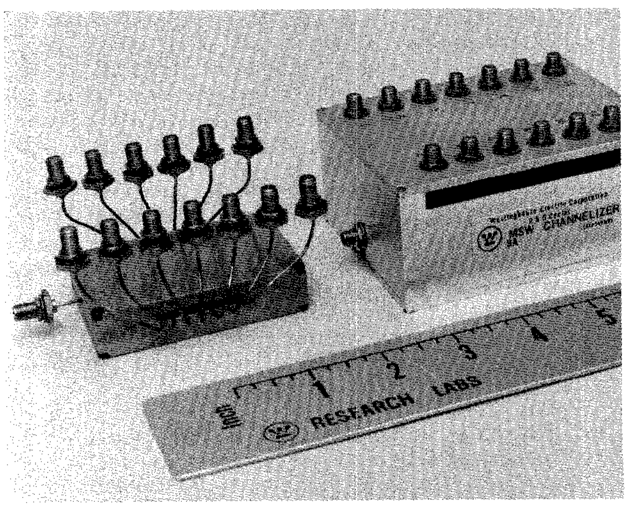

Figure 3. A photograph of the exterior of the filterbank and its housing.

A composite response for all 13 channels is shown in Figure 4 taken from measurements on a Hewlett-Packard 8510 network analyzer. About 50 dB of dynamic range is observed for each channel with uniform separation in frequency. The variation in insertion loss from channel to channel most likely results from a non-uniform current distribution along the transmitter microstrip. Improvements in the impedance matching would be expected to decrease this variation. Figure 5 is a plot of the channel center frequency versus channel number with the straight line a least squares fit to the data points. The slope of this line is 20.07 MHz per channel showing that the average channel separation is very close to the design value of 20 MHz.

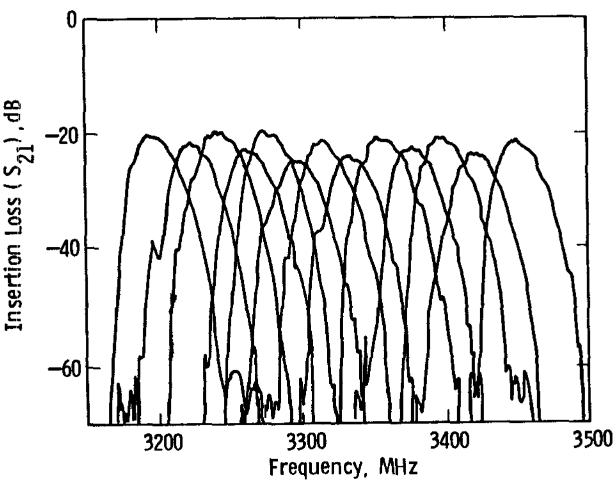

Figure 4. The insertion loss (S_{21}) versus frequency for the 13 channels of the filterbank.

An important requirement for filterbanks to be used in channelized receivers is a low level of spurious signals in the time domain response. Figure 6a shows this time domain response obtained by fast-Fourier-transform of the frequency domain data for one particular channel. The series of decaying signals beyond the first main signal has been identified as due to acoustic shear waves being launched into the GGG substrate by magneto-acoustic coupling in the YIG. These are potentially serious for filterbank applications but, fortunately, can be suppressed by roughening the back surface of the GGG substrate to diffusely scatter them. Figure 6b shows the effectiveness of this roughening procedure.

Temperature stability is another important parameter which requires the channel center frequency to be constant on heating or cooling of the filterbank. Temperature shifts in frequency arise

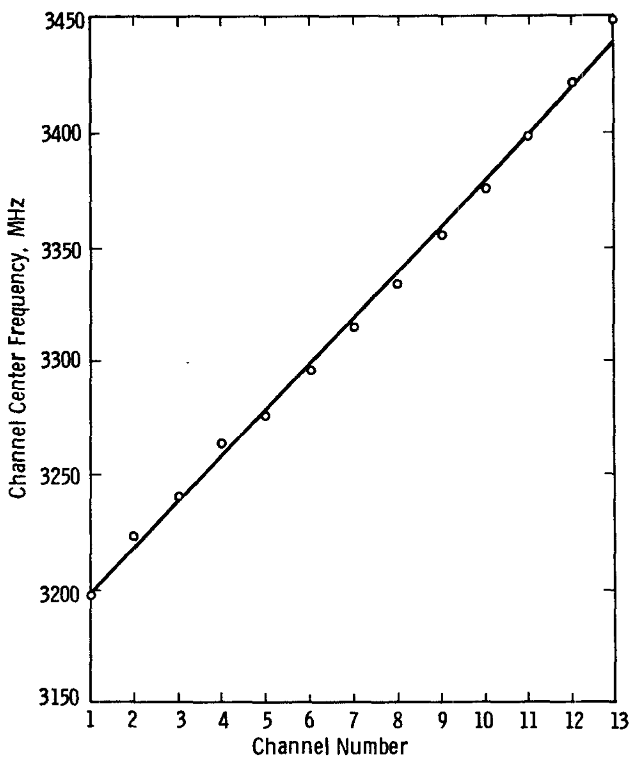

Figure 5. The channel center frequency versus channel number for the filterbank.

predominantly from the temperature coefficient of the YIG, 8.7 MHz/Deg. C. It turns out that the temperature coefficient of the bias magnet coercive field is of the opposite sign to that of the YIG and thus can, partially at least, compensate for the YIG[5]. Figure 7 shows the measured effect of temperature on a filterbank using Samarium-Cobalt magnets -circular dots. The compensation achieved is incomplete, with a net temperature coefficient of 6.2 MHz/Deg. C. Neodymium-Iron-Boron magnets have a larger temperature coefficient than those made of Samarium-Cobalt and so provide a greater degree of compensation, as shown by the measurements (square dots) in Figure 7. The net coefficient is reduced to 2.2 MHz/Deg. C. However, this is as far as we can compensate using commercially available permanent magnets alone. Further temperature compensation can be achieved with the combination of Nd-Fe-B magnets and a part of the magnet yoke structure made from a temperature dependent permeability material such as Carpenter "32" type 1 - calculations of this are shown by the triangular dots of Figure 7. We note that the compensation is a frequency dependent feature which, for the results shown here, applies to filterbanks operated at about 3000 MHz.

CONCLUSIONS

The current and projected performance of MSW

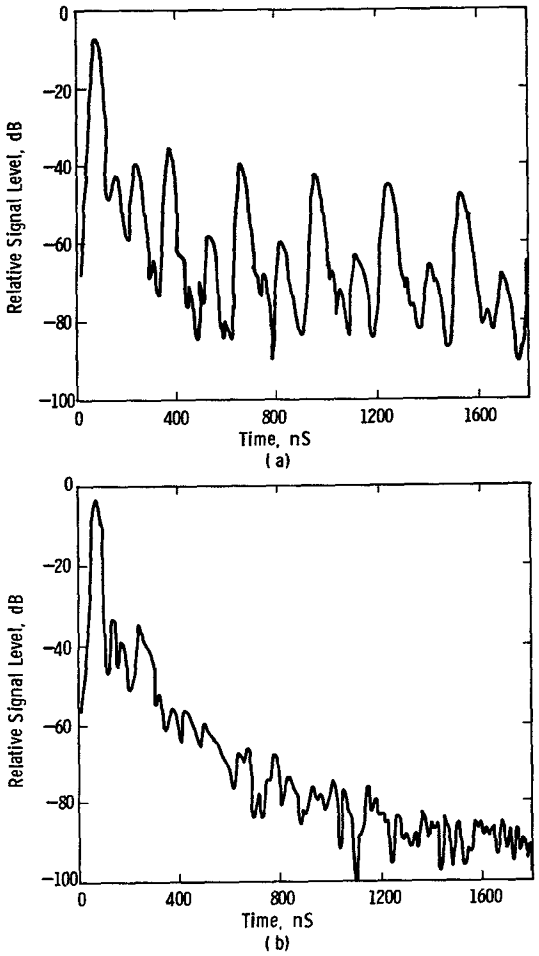

Figure 6. The time domain response of the filterbank showing: (a) the presence of acoustic shear wave signals; and (b) their removal.

filterbanks is summarized in table 1. MSW filterbanks have been demonstrated with 50 dB dynamic range in the frequency domain and also in the time domain beyond 400 nS. Further work will result in a similar performance in the time domain beyond 100 nS. Thus the MSW filterbank represents an attractive component for use in compact, low cost, broadband channelizer systems for future E.W. systems application.

TABLE I
MSW FILTERBANK PERFORMANCE

Parameter	Current	Projected
Bandwidth	260 MHz	few GHz
Channel bandwidth (3dB)	24±2 MHz	10-50 MHz
Center frequency	3300 MHz	2-18 GHz
Number of channels	13	20-100
Insertion loss	22±2 dB	<15 dB
Single-tone dynamic range	68 dB	75 dB
Two-tone dynamic range	>50 dB	70 dB
channel volume density	3.6/in^3	20/in^3

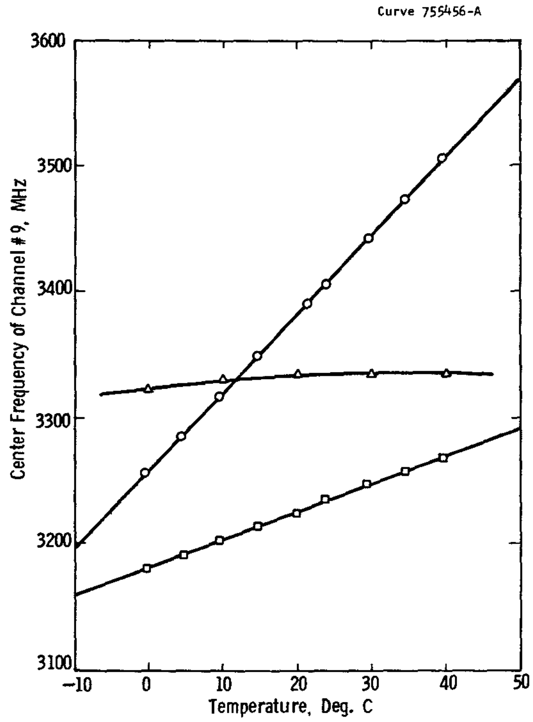

Figure 7. The center frequency of a channel of the filterbank versus temperature using different types of bias magnets (circles & squares) and a temperature compensated response (triangles).

ACKNOWLEDGMENTS

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