SAW BANDPASS FILTER COMPONENTS FOR MICROWAVE SYSTEMS

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ABSTRACT

The rapid advancement of Surface Acoustic Wave (SAW) technology in recent years has significantly impacted the design of several microwave systems. In particular, current systems having IF or processing frequencies in the 100-1000 MHz range are likely to use SAW technology. This paper presents a discussion of recent microwave system developments which utilize SAW bandpass filters. In each case, performance, size and cost advantages are gained through the use of surface acoustic wave technology. It is concluded that SAW components are indeed very versatile, high reliability parts, which should be considered by microwave designers for providing many viable functions in new system developments.

Introduction

A large percentage of the microwave systems being developed for the government today are designed for either satellite communication links or for electronic surveillance and/or electronic warfare purposes. In the case of the satellite communication link, the microwave frequencies are often S-band or X-band with many of the frequencies involved in the frequency translation process being in the 100-1000 MHz range. This frequency range together with the filtering requirements for the frequency translation process, have proven to be an ideal application for surface acoustic wave bandpass filters. In the case of the electronic surveillance and/or electronic warfare systems, the equipment requirement usually reduces to that of detecting various threats in environments having emitter systems which continue to increase in number and sophistication. It is generally agreed that a properly organized wideband channelized receiver has the capabilities most nearly matching the requirements of modern ES and EW systems. Typically, the microwave frequencies are translated to multiple bands, each being about an octave in bandwidth, in the 200 to 800 MHz range. Signal sorting is then performed in these broad bandwidth channels using a large number of bandpass elements of precise frequency and shape factor. The channelized receiver represents another ideal application area for surface acoustic wave filters.

The intent of this paper is to summarize three representative surface wave filter applications which have been implemented at Motorola in the aforementioned system types within the past few years. The first system is the Voyager spacecraft transponder, the second is the Tracking and Data Relay Satellite System, and the third system is a frequency sorting receiver which is typical of those used in ESM and EW systems. It is especially intended that the significant impact on the performance, size, weight, and reliability of these systems be made known. Finally, the purpose of this paper is to aid system and module designers in making optimum decisions regarding component types, i.e. surface acoustic wave or otherwise.

Voyager System

Figure 1 shows a block diagram indicating the frequency synthesis scheme of a typical transponder. Shown are S-band receiver and exciter portions of the transponder for near earth and deep space missions, and an X-band exciter for deep space missions.

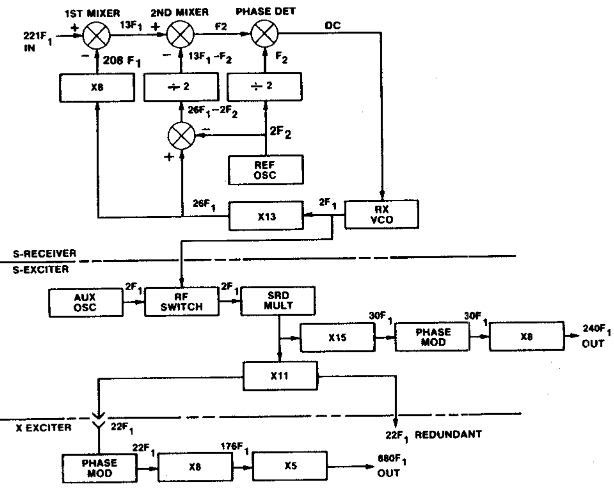

Figure 1. Frequency Scheme of Transponder

Surface acoustic wave filters are used in four different blocks of the diagram of Figure 1. The four uses of the filters are, in general, the same; the filters are used to separate a single frequency from a comb of frequencies which has a comb separation of about 19 MHz.

The functional locations and purposes of the SAWs are:

1) In the X11 multiplier, two SAW filters are used to select an f-value of about 210 MHz to drive the X-band exciter. This function is applicable only on deep space transponders in contrast to near earth applications.
2) In the X15 multiplier, two SAW filters are used to select an f-value of about 280 MHz to drive the S-band exciter for near earth transponders.
3) In the X13 multiplier, two SAW filters are used to select an f-value of about 240 MHz to drive the X8 RF converter.

4) In the LO-2 module, one filter is used to select an f-value of about 220 MHz which drives the second mixer. The latter two filter sets and functions are required on all transponders whether used for deep space or near earth applications.

The major considerations for using surface acoustic wave filters to perform the frequency selection function were their small physical size and narrow bandwidths. Other considerations were that the moderate insertion loss normally associated with SAW filters and the readily achievable shape factors (1.5 to 2.3) were totally acceptable. A final reason for selecting SAW filters was because phase linearity is required throughout the passband in some applications.

The basic transponder system necessitates several minimum electrical characteristics of the SAW filter. The exact requirements varied depending upon the particular program but typical requirements were:

a) An in-band maximum insertion loss of no greater than 12 dB,

b) An out-of-band minimum insertion loss described as:

   1) 62 dB minimum for: 10MHz $\leq f \leq$ (fo-19) MHz

   2) 62 dB minimum for: (fo+19)MHz $\leq f \leq$ (fo+100)MHz.

   3) 47 dB minimum for: (fo+100)MHz $\leq f \leq$ 1600 MHz, and

c) A linear phase versus frequency characteristic to within $\pm 5^{o}$.

The insertion loss requirements are readily understood. Minimum inband loss is desirable and the out-of-band rejection must be at least a certain amount to reject the 19 MHz comb frequencies. The phase linearity and phase stability requirement is essential for a transponder to provide accurate range and range-rate information. On the Voyager program this requirement also included phase variations between the S-band and X-band outputs.

The main impact that surface acoustic wave filters had on the Voyager transponder was in size and weight. An earlier similar transponder was 20 to 25% heavier (SAW filters resulted in a weight reduction of 1½ pounds), and it was 30 cubic inches greater in volume.

TDRSS System

This system used 140 SAW filters of 33 different designs for a multiple access receiver and master frequency generator. Many of the filters have similar purposes as those in the Voyager transponder. It also used SAW filters as the component which determined the bandwidth properties of the IF processing circuitry in the multiple access receiver. Here, bandpass amplitude flatness, delay flatness, and phase tracking from channel to channel are of utmost importance since the system is a multichannel phased array system. SAW filters, being non-minimal phase networks with linear phase slope throughout their entire passband, allowed the achievement of phase tracking, channel-to-channel.

To minimize the filter contributions to differential phase tracking errors between channels having different IF frequencies, the phase slopes of the various filters were scaled by the inverse frequency ratio. As a result two branches of the receiver operating at two different frequencies have equal phase shifts. Since the filters have identical temperature sensitivities in PPM/^{o}C, equal phase changes are produced as the filters are acted upon by the temperature environment.

In addition to the obvious impact that SAWs had on this system because of their linear phase and phase tracking capabilities, it is estimated that approximately 30% weight reduction was achieved as a result of the use of SAWs.

Figures 2 and 3 show measured data which are typical of the results of the IF filters. Figure 2 shows the amplitude characteristics of the filters. Figure 3 shows the time delay characteristics. The overall results of 70 dB of filtering with passband flatness of better than 0.55 dB and constant time delay within 32 nanoseconds (total time delay is 900 nanoseconds) was achieved in a volume of less than 0.02 cubic inches.

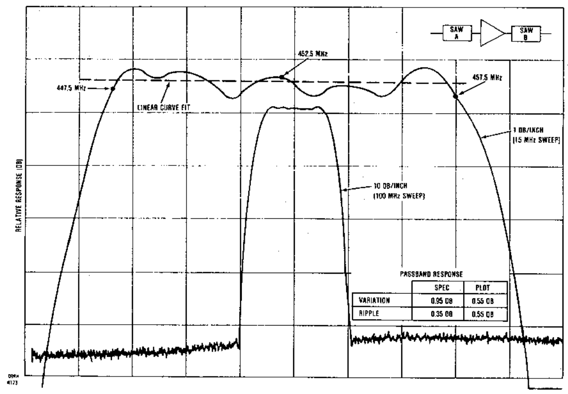

FIGURE 2. Amplitude Characteristics of SAW Filter

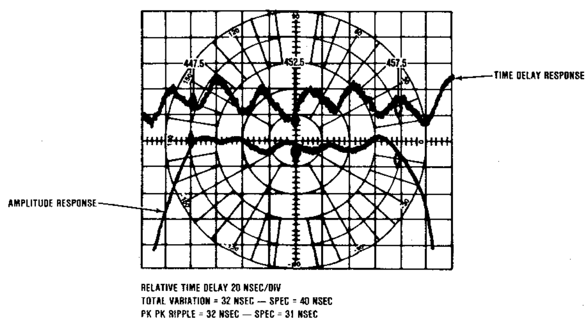

FIGURE 3. Delay Characteristics of SAW Filter

Frequency Sorting Receiver

The frequency sorting receiver developed by Motorola included a pulse frequency measuring (PFM) subsystem. Figure 4 illustrates the topology of the PFM subsystem. The requirement of major interest is that frequency determination decisions must be made for pulses having duration times as short as 100 nanoseconds. In the operation of the PFM subsystem, a 2 GHz bandwidth microwave signal is accepted by the input. This is divided into eight 250 MHz wide sections by means of stripline microwave bandpass filters. Each 250 MHz wide band is subsequently frequency-translated to the first intermediate frequency of 625 MHz. Each of the eight outputs having frequencies somewhere in the 500 to 750 MHz range is incident on a multiplexed bank of contiguous SAW filters, with each filter having a 3 dB bandwidth of 31.25 MHz. The outputs of these coarse frequency discriminating (CFD) SAW filters provide initial frequency information which is additionally processed and used to set six single-pole, eight-throw switches. Three of the switches operate at the first intermediate frequency (625 MHz) with the RF outputs of the switches being a time-delayed replica of the input to the CFDs. The time delay function is provided by SAW delay lines. The other three switches supply the appropriate local oscillator frequency to the second mixer. The local oscillator frequencies are selected from a comb of frequencies by means of SAW filters. The switches are set to direct the three strongest CFD outputs to three sets of surface acoustic wave delay line discriminators. The outputs of the discriminators are digitally processed to give a final frequency resolution of 1 MHz.

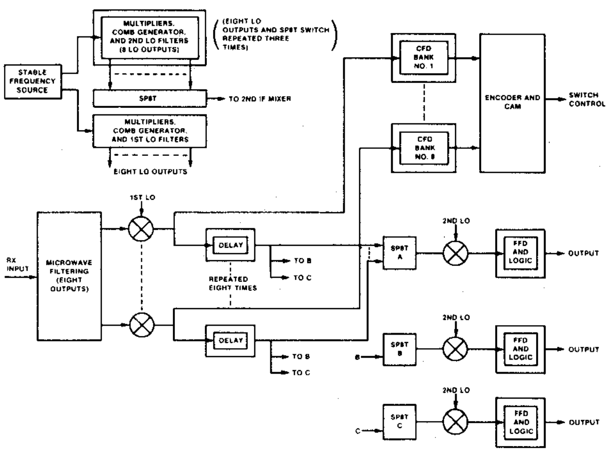

FIGURE 4. Partial Block Diagram of PFM Subsystem

Of the 24 SAW designs used in the PFM, eight are local oscillator selecting filters, nine are coarse frequency determing filters, two are delay lines, and five are delay line discriminators. The local oscillator selecting filters are ST-cut quartz designs; the delay line designs utilize YZ-lithium niobate.

The PFM subsystem had been designed earlier using conventional (other than SAW) techniques. The use of the SAW components resulted in a reduction of volume from 16.8 cubic inches to 4.6 cubic inches (~72%) while maintaining the high level of performance required.

Summary and Conclusion

Surface acoustic wave (SAW) components have been utilized in various microwave systems over the past several years. The requirements of typical satellite communication radios, electronic surveillance systems and electromagnetic warfare systems have resulted in proving that SAW technology can result in typical weight and size reductions of 25% in the signal processing portion of these systems. The system types within which the SAW components have been utilized are very high-reliability systems.

It is concluded that the system designer should consider surface acoustic wave technology as being capable of providing a viable answer to many system signal processing requirements.