JTIDS Modular Design to Use SAW Devices

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INTRODUCTION. The Joint Tactical Information Distribution System (JTIDS) concept is designed to integrate the military's needs for communication, navigation and identification equipments into a cost-effective avionic suite. A key element to be used in achieving these goals is the surface acoustic wave (SAW) bandpass filter...in the form of a bandwidth selectable module. In order to satisfy the JTIDS requirements of today, as well as the Tactical Information Exchange Systems (TIES) of the future, it is necessary to utilize state-of-the-art SAW resonator/filter designs ... in conjunction with more conventional SAW bandpass filter technology. It is this approach that will make possible the quality performance required in a small, low cost module.

The JTIDS Architecture. The basic structure of the JTIDS/TIES system can be broken down into essentially three subsystem areas; the Frequency Conversion Subsystem, the Signal Distribution Subsystem, and the Signal Conversion Subsystem.

First, there is the Frequency Conversion Subsystem which provides the antenna-end hardware used for transmission or reception, as well as a variety of signal processing functions. These functions include filtering and frequency synthesis.

The Signal Distribution Subsystem provides the flexibility required of a Frequency Domain Multiplex (FDM) System. This is accomplished by providing the capability of connecting any one of many input signals to any output port. The heart of this subsystem is a wideband FDM system ...analogous to existing, low cost CATV distributors' systems.

The third and final subsystem, for signal conversion, provides the functions of conventional MODEM...in an almost totally digital format.

It is the Frequency Conversion Subsystem that is of most interest to the Surface Acoustic Wave (SAW) technology. The technology thrust envisioned for this subsystem will be "programmable analogue hardware"...implemented through modular IF strips, bandpass and programmable matched filters.

SAW MODULAR FILTER BANK. The current JTIDS program concept provides for transeivers which operate line-of-sight in L-band, between 962 MHz and 1215 MHz. The design approach incorporates both the IFF and TACAN functions, which also operate in this frequency band. The receiving requirement of a particular frequency range is satisfied by cascading the RF front end with a multipurpose, modular IF strip. The IF signals are produced at 70 MHz, and are coupled to a receive only, wideband FDM signal distribution system in which the SAW Filter Module is located.

The Surface Acousti,c Wave Filter Module provides four (4) key filtering functions ...

- Narrowband Signal Conversion (Bandwidth: 35 kHz): Used for processing low data rate information...such as voice communications, AM single-sideband, and narrowband FM. The special JTIDS LINK 11 communications waveform is fielded by this channel, which must also interface with existing military MANPAK hardware.

- The communications serviced by this channel originate predominantly in the HF range, and are designed to service JTIDS ship-to-ship and ship-to-shore communications requirements.

- Data Communications Channel (Bandwidth: 70 kHz): Used for higher data rate communications; such as the LINK 4 waveform, an FSK signal with a ±20 kHz information bandwidth.

  The communications here originate in the 225-400 band, and account for much of the air-to-ship information transfer.

- TACAN (Bandwidth: 350 kHz): Utilized for transmitting tactical airborne navigation information.

- Wideband Communications (Bandwidth: 7.0 MHz): Used to handle the IFF, GPS (Global Positioning System) and JTIDS waveforms. The bandwidth represents a compromise between the JTIDS requirements (@ 5 MHz), the IFF requirement (@ 8 MHz) and the future needs of GPS (@ 10 MHz).

The satisfaction of these various filter requirements necessitated the utilization of a variety of bandpass filters operating at a common (MODEM) IF frequency of 70 MHz. Choice of the proper filtering technique is dependent upon the bandwidth desired at the frequency of interest. This is illustrated in Figure 1. Although the system designer has multiple choices between lumped constant, bulk crystal, helical resonators and surface-wave devices, use of a common SAW approach for the multiple bandwidth module offers significant advantages in economy, size and reliability.

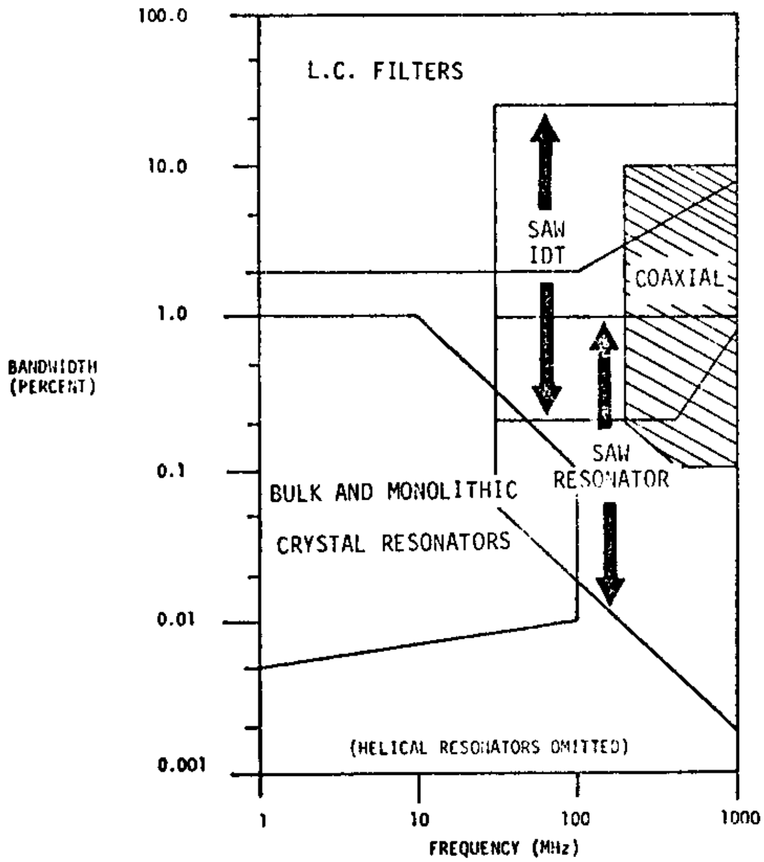


Figure 1. Surface acoustic wave filters and resonators are candidates for a wide variety of bandpass filters in the VHF-UHF range.

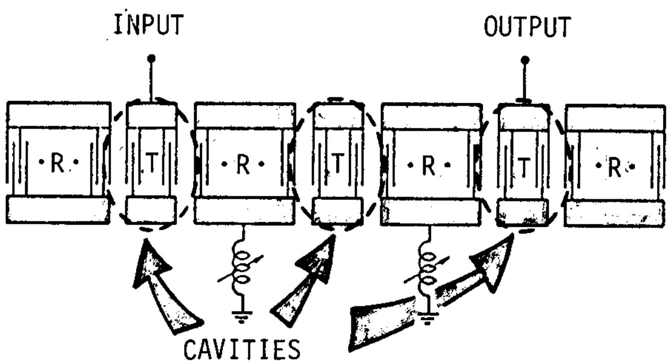
SAW Resonators Realize Ultranarrow Band Filters. Implementation of the Narrowband Signal Conversion and Data Communications channels represented the most difficult requirement ...with their respective bandwidths of 35 and 70 kHz. The requirements set forth by these lower data rates necessitated the use of a special technology. The surface acoustic wave monolithic resonator is such a technology.

The SAW resonator is a relatively new device. The concept was introduced by E. Ash in 1970,[1] with the first efficient devices discussed by E.J. Staples in 1974.[2] The recent advances in resonator design described below have made the narrowband filtering requirements of JTIDS a reality.

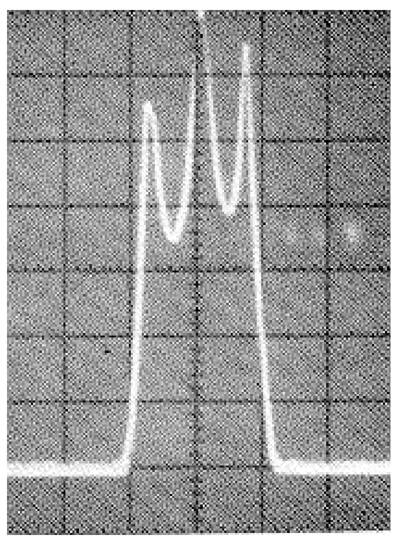
SAW resonators consist of periodic reflectors aligned so as to form the acoustic equivalent of a Fabry-Perot cavity. The fundamental elements are the distributed, reflective electrode arrays. When two such arrays are defined along the same axis, they form a cavity or, in this application, one pole of a resonator filter. In operation, reflections from the individual electrodes of the reflectors add in phase when the array periodicity is equal to one-half a wavelength. These coherent reflections will be maximized over a very narrow frequency band determined by the periodicity of the electrode array.

The basic approach selected for realizing the JTIDS ultranarrow band filters was the three-pole SAW resonator-filter shown in Figure 2a. In the three-pole, two-port approach, three such Fabry-Perot cavities are arrayed with two interdigital transducers (IDT's), one each for the input and output of the filter.

In the absence of any tuning elements, either across the reflectors or at the input/output transducers, we observe the response of Figure 2b.



a. The three-pole SAW resonator-filter consists of a linear array of three Fabry-Perot cavities... formed by periodic grating reflectors (R). Energy is introduced (coupled) into, and extracted from, the device by means of interdigital transducers (T).

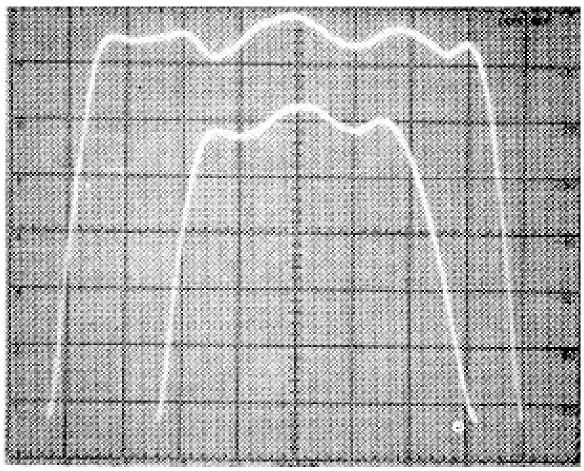


b. The unmatched three-pole filter exhibits a distinct three-mode response. These modes may be manipulated by tuning the distributed reflectors which form the respective cavities.
Vert: 10 dB/Div.
Horiz: 50 kHz/Div.

Figure 2

Tuning the reflectors has the effect of controlling the amount of interaction between the three modes ... thereby providing a means for adjusting the bandwidth, and the passband ripple. Tuning the input/output transducer structures will reduce the insertion loss (to approximately 5 dB), as well as contribute to a lower in-band ripple.

The key to utilizing one design for both ultranarrow band JTIDS filters is demonstrated in Figure 3. The combination of matching and reflector tuning demonstrates a 3 dB bandwidth variation of from 40 kHz to 70 kHz. Additional bandwidth flexibility can be achieved by tuning the outermost reflectors, as demonstrated by bandwidth variations between 18 kHz and 85 kHz.[3]



Vert: 2 dB/Div.
Horiz: 10 kHz/Div.

Figure 3. Control over each resonant cavity-mode makes it possible to achieve multiple filter bandwidths from a single device. Bandwidths range from 18 kHz to 80 kHz.

In the previous paragraph, we demonstrated that matching the input and output transducers would reduce the filter's insertion loss. However, at the same time, the close-in sidelobe rejection is also reduced; to approximately 20 dB. In order to increase the out-of-band rejection, it was necessary to analyze the transmission characteristics of in-line, multi-cavity devices .[4] The results indicated that the shape factor and rejection could be improved in direct relationship to the number of cavities utilized. The design approach yielded a cascaded triplet of three-pole resonators.

Figure 4 illustrates the resulting filter response achieved for the 70 kHz bandwidth filter. Input and output transducers are tuned only with a simple series inductor, as are the coupling transducers between each three-pole stage.

Using the center frequency/bandwidth tuning flexibility described previously, an identical device was constructed to satisfy the 35 kHz requirement (also Figure 4).

In Table 1, the overall level of performance achieved by the ultra-narrow band resonator filters is presented in detail.

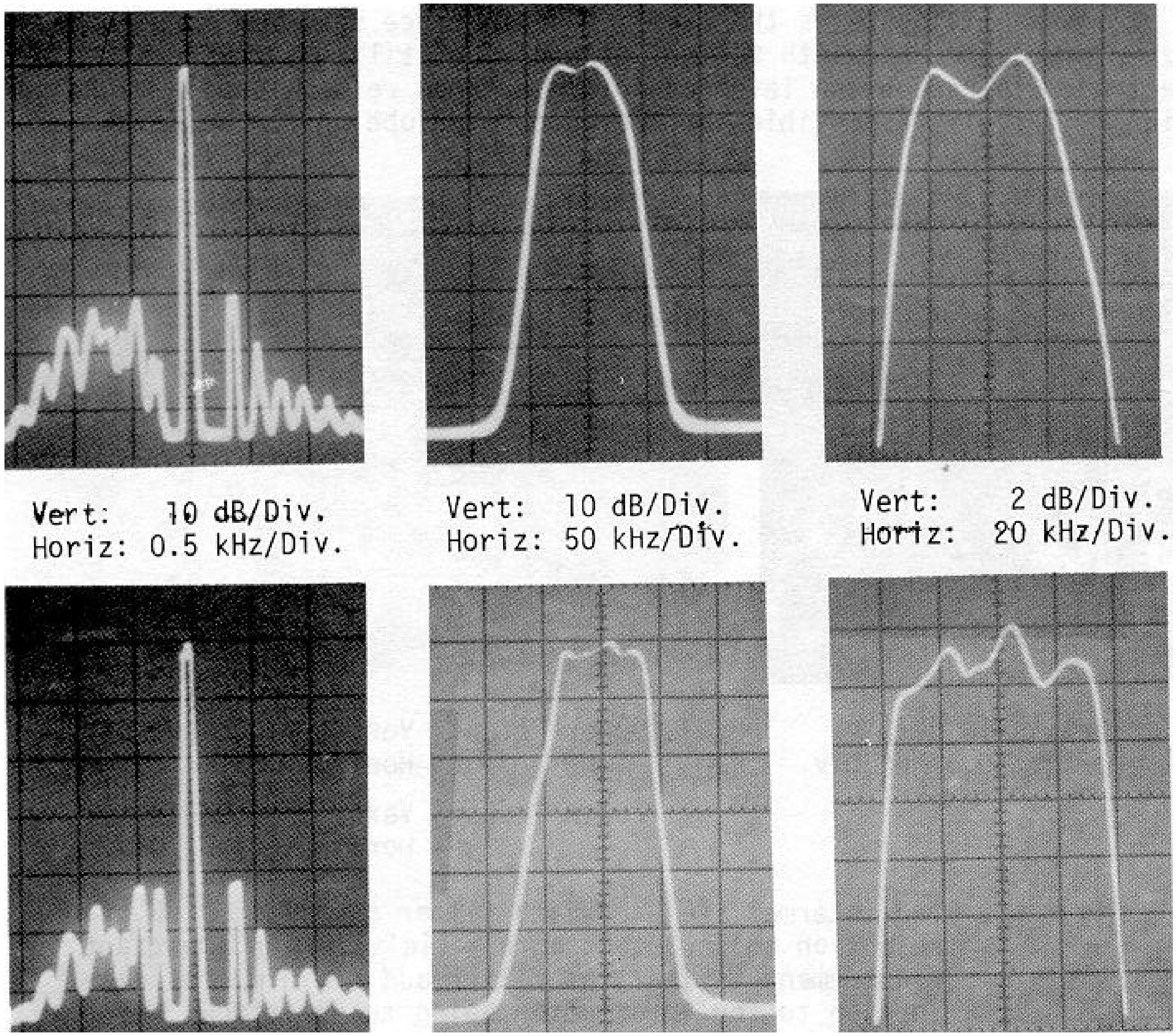


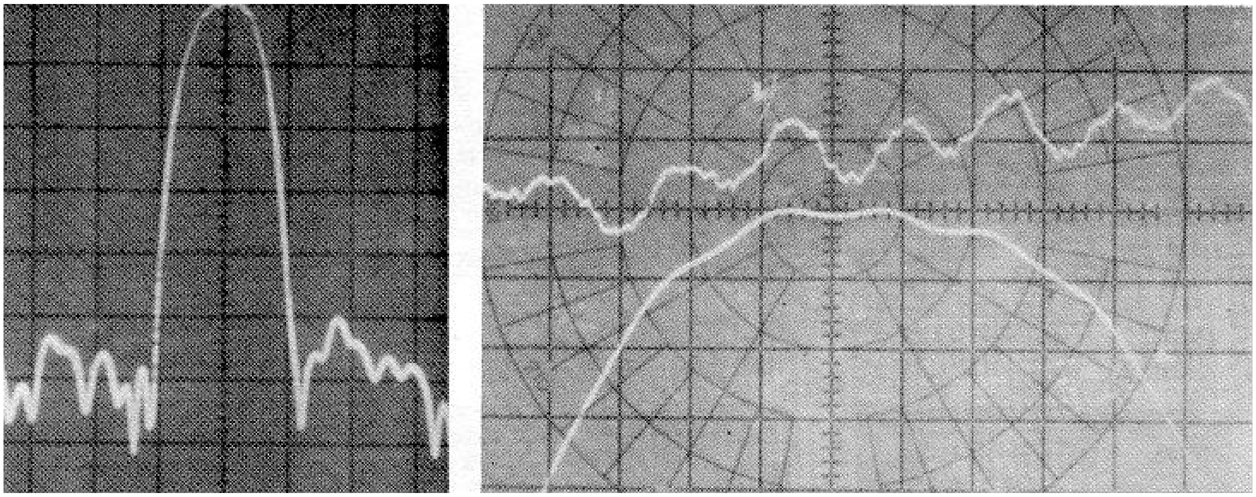
Figure 4. The 70 kHz (lower) and 35 kHz (upper) bandwidth filters both exhibit a minimum of 40 dB of out-of-band rejection (left). Providing a nominal 3:1 shape factor (middle), the ultra-narrow bandwidth filters have in band ripple (right) sufficient for low distortion data transmission.

TABLE I			
SPECIFICATION	PERFORMANCE		UNITS
	35 kHz	70 kHz	
• Center Frequency	70.000 ± .005	70.000 ± .005	MHz
• Bandwidth 1 dB	40	-	kHz
3 dB	52	70	kHz
50 dB	130	140	kHz
• Shape Factor (3-40)	2.5:1	2:1	-
• Insertion Loss	15	15	dB
• Passband Ripple	±.5	±1.0	dB
• Out-of-Band Rejection	40	40	dB
• Ultimate Spurious Attenuation	>60	>60	dB
• Input/Output Isolation	>75	>75	dB
• VSWR	2:1	2:1	-
• Temperature Range	-40 to +85		^{o}C
• Temperature Stability	.03 ppm/$^{o}C^2$		-

350 kHz Withdrawal Weighted Transducer Satisfies JTIDS TACAN Requirement. There are two basic approaches to SAW bandpass filter synthesis which will satisfy the moderately low shape factor filters required by the TACAN channel ... apodization (weighting) of the electrode overlap function and withdrawal[5] weighting. The withdrawal approach is ideal for filter bandwidths of less than 3% ... as such a transducer does not suffer diffraction loss, nor is its acoustic wavefront distorted by variations in the metalization pattern.

Figure 5 illustrates the level of performance realized for the 350 kHz intermediate bandwidth filter. The device utilizes grounded-dummy electrodes to reduce the level of interelectrode reflections; a technique which is largely responsible for the 50 dB sidelobe levels achieved.

Another key to achieving a designed-for level of out-of-band rejection is the suppression of unwanted bulk mode energy that exists in the volume of the SAW substrate. This is accomplished by “sandblasting” the bottom surface of the substrate, thereby inhibiting unwanted energy that could reflect to the top surface and interfere with filter performance. Table II summarizes the full range of performance achieved by the 350 kHz, intermediate bandwidth filter.



Vert: 10 dB/Div.
Horiz: 0.5 MHz/Div.

Upper Trace: Vert: 100 nsec/Div.
Horiz: 50 kHz/Div.

Lower Trace: Vert: 1 dB/Div.
Horiz: 50 kHz/Div.

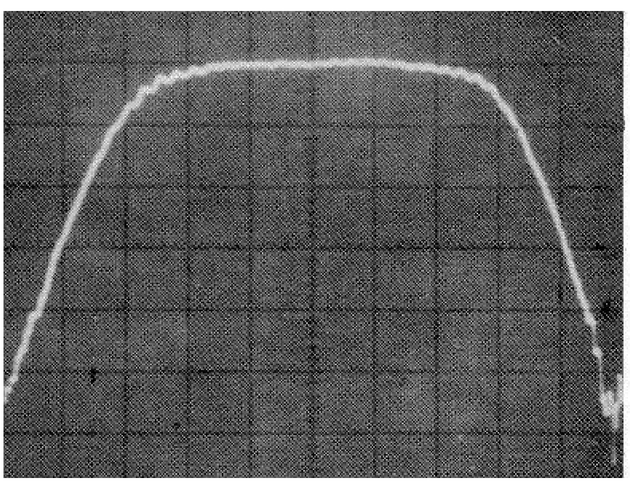
Figure 5. The intermediate bandwidth filter supplies 50 dB of rejection to unwanted signals (left). An important requirement is that the filter add a minimum of distortion to the information being transmitted...key to this quality performance are the group delay and amplitude ripple characteristics (right).

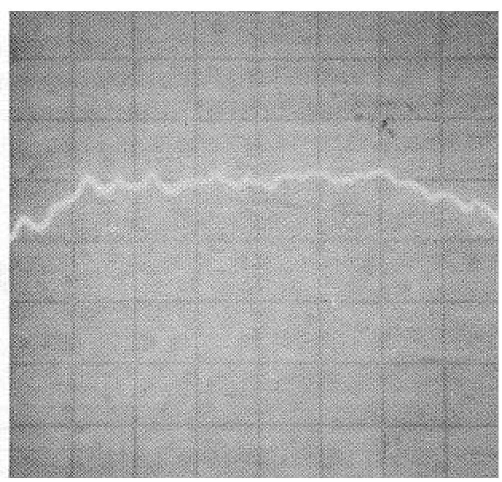
7 MHz Wideband Communications Channel Filter. Due to its relatively wide fractional bandwidth (~10%), this particular filter was designed utilizing overlap apodization. Apodization, however, has design pitfalls which must be properly resolved. For example, the extremely small acoustic apertures near the points of phase reversal will cause off-axis radiation (diffraction). This diffraction will cause improper convolution of the acoustic signal at the output transducer... producing an inaccurate in-band response, and a higher than desired sidelobe level. In order to compensate for this, a minimum weighting technique is utilized. This technique controls the smallest aperture allowed, replacing the smaller aperture electrodes with floating electrodes.

In the final design approach to the 7 MHz bandwidth filter, a three transducer approach has been utilized to provide additional control over the in-band amplitude ripple, while providing nearly a 3 dB improvement in insertion loss.

TABLE II		
SPECIFICATION	PERFORMANCE	UNITS
• Center Frequency	70.000 ± .025	MHz
• Bandwidth 3 dB 50 dB	350 1.050	kHz MHz
• Shape Factor (3-50)	3:1	-
• Insertion Loss	12	dB
• Passband Ripple	±.4	dB
• Out-of-Band Rejection	50	dB
• Ultimate Spurious Attenuation	>60	dB
• Phase Linearity	±3	degrees
• Insertion Delay	5.0	μsec
• Triple-Transit Suppression	45	dB
• Input/Output Isolation	75	dB
• VSWR	2:1	-
• Temperature Range	-40 to +85	°C
• Temperature Sensitivity	.03 ppm/°C²	-

The wideband frequency response for this filter is illustrated in Figure 6, as is its detailed response, which demonstrates the device's 3:1 shape factor.





Vert: 10 dB/Div.
Horiz: 2 MHz/Div.

Vert: 2 dB/Div.
Horiz: 1 MHz/Div.

Figure 6. The wide bandwidth filter provides better than a 3:1 shape factor (left) in conjunction with a low amplitude ripple, 7 MHz, 1 dB bandwidth (right). Flat, low ripple group delay is provided over its full bandwidth for relatively distortion free performance.

TABLE III		
SPECIFICATION	PERFORMANCE	UNITS
• Center Frequency	70.000 ± .100	MHz
• Bandwidth 1 dB	7.0	MHz
3 dB	9.0	MHz
40 dB	17.5	MHz
• Shape Factor	2.5:1	-
• Insertion Loss	12	dB
• Passband Ripple	±.4	dB
• Out-of-Band Rejection	40	dB
• Ultimate Spurious Attenuation	>60	dB
• Phase Linearity	± 3	degrees
• Insertion Delay	1.0	µsec
• Triple-Transit Suppression	45	dB
• Input/Output Isolation	75	dB
• VSWR	2:1	-
• Temperature Range	-40 to +85	°C
• Temperature Sensitivity	6 kHz/°C	-

Bandwidth Selectivity. One of the keys to the performance of the Switchable Filter Module is its ability to provide the user with bandwidth selectivity. The functional schematic of the bandwidth selection scheme is illustrated in Figure 7. There are two switch groups involved, one at the input and one at the output ... each of which contains four selectable channels (one for each filter bandwidth).

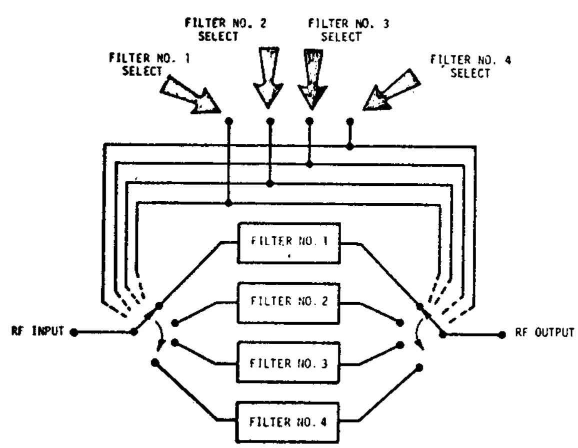


Figure 7. The "selectable filter" concept is designed around switches at both the input and output ports... in order to provide a maximum of interchannel isolation.

The design provides the following performance:

- Insertion Loss: Approximately 0.5 dB.
- On/Off Isolation: At 23 dB per diode ... two diodes per switch (four per channel) will provide an input/output isolation of nearly 80 dB.
- Crosstalk Isolation: More than 60 dB isolation between channels is achieved by compartmentally packaging each channel.
- Video Signal Isolation: Low-pass filtering is utilized to prevent undesired "video" signals, produced by the external circuitry responsible for filter/bandwidth selection, from interfering with performance.

The basic operation of the switchable module is quite simple: each bandwidth filter has an external pin through which the selection is made. For example, a "select" signal at PIN 1 would enable the 7 MHz bandwidth filter, while inhibiting all others. The operational information is summarized in the following table.

TABLE IV

Switchable Module Function	"ON" Logic Level	"OFF" Logic Level	"OFF" Current
Select Filter #1	+5 at 20 mA	Filter #2: -5V Filter #3: -5V Filter #4: -5V	3(-20 mA) = -60 mA
Select Filter #2	+5V at 20 mA	Filter #1: -5V Filter #3: -5V Filter #4: -5V	Same
Select Filter #3	+5V at 20 mA	Filter #1: -5V Filter #2: -5V Filter #4: -5V	Same
Select Filter #4	+5V at 20 mA	Filter #1: -5V Filter #2: -5V Filter #3: -5V	Samo

Mechanical Design. The proper packaging is an integral part of any product. And, the high levels of performance required by the Switchable Filter Module are no exception. The prototype package is illustrated in Figure 8. The key feature is that the acoustic components are electrically isolated from each other on one side of the package ... while the electrical components are isolated from each other on the opposite side. In other words, each bandwidth-filter has its own compartment. Such a cavity design will minimize electrical feedthrough and crosstalk. Matching networks, coupling elements and switches are all compartmentalized in order to achieve more than 80 dB of overall isolation.

SMA (female) connectors are connected to the input and output switches, as described previously. The switches are TTL compatible, and are controlled via the four input pins.

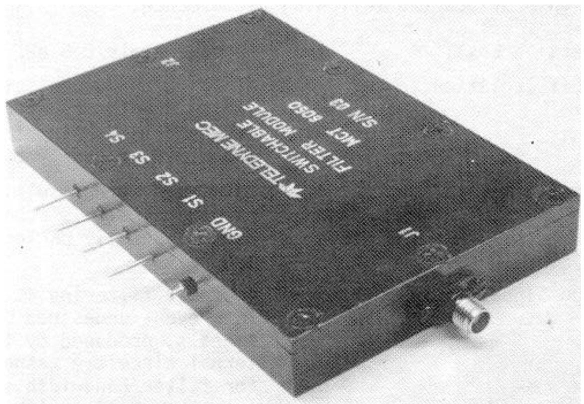


Figure 8. The Switchable Filter Module is constructed with its logic "selection" circuits physically isolated from its SAW devices...all housed in a 2 x 3 x .5 inch, hermetically sealed package.

CONCLUSION. The SAW Selectable Bandpass Filter Module presented here now achieves a level of performance which is in most respects superior to to other alternatives. Of particular note is the ability of the technology to produce the desired functions in such a relatively compact form... including bandwidth selection switches. In many respects, this unit embodies much of that which has been written about the potential of SAW devices ... and, perhaps, signals that, for the first time, surface acoustic wave bandpass filters are reaching the stage where the potential for expanded utilization is substantial.

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