50 WATT/CW DIODE TUNED UHF FILTER

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ABSTRACT

A novel diode tunable filter is described using quarter wavelength tapped stub resonator sections and digital microprocessor control. Fine resolution electronic tuning in 25KHz steps of a 2MHz-3dB transmission bandwidth from 270-400MHz was achieved with 50 watts CW RF power, 10dB average insertion loss and 42dB minimum rejection skirts, 6MHz from the center frequency.

INTRODUCTION

Highly selective tunable band-pass filters often referred to as "tracking filters", are being used to suppress unwanted radio emissions from high-power transmitters. One particular design has been implemented to provide a 3dB bandwidth greater than 2MHz and a skirt rejection of 42dB 6MHz from a carrier frequency which is tunable over the range 270MHz to 400MHz. In contrast with designs which embody phase-lock-loops and tunable amplifiers, the design shown in Figure 1 uses open loop PIN and varactor diode tuning with frequency electronically controlled by means of a local microprocessor and driver subsystem. The

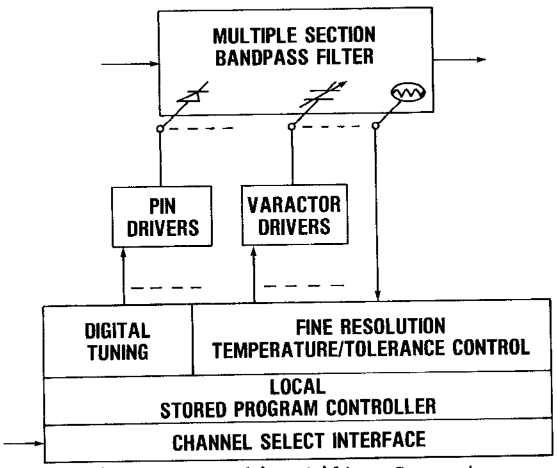

Figure 1 Tracking Filter Concept

significant performance criteria met by the design include a peak power handling capability of 50 watts at the input port, provision for temperature compensation, and a response time to channel assignments of less than 400 microseconds (350 microseconds for the processing, 50 microseconds for transient decay). Filter insertion loss at the carrier is 13.7dB max and less than 11dB for 76% of the tunable frequency range. The design incorporates PIN diodes to provide coarse tuning, varactor diodes for fine tuning and a local stored-program controller which uses look-up or "personality" tables to compensate for production tolerances and environmental temperature.

In the general case such a tracking function can be implemented using filter sections interconnected directly with passive elements or through unilateral networks such as amplifiers or isolators. This paper focuses upon one realization of a tracking filter section and its extension to a multisection design with passive interconnection networks.

DESIGN APPROACH

Figure 2 summarizes the design parameters of the filter. A four-section Chebyshev topology

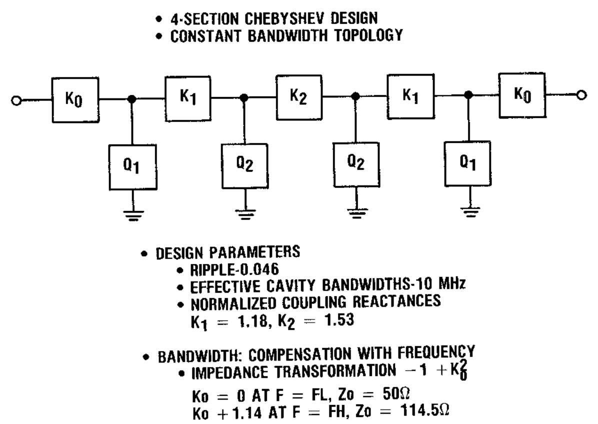

Figure 2 Tracking Filter Design Parameters

was selected to meet the skirt rejection criteria. Standard tables were used to generate the values for each of the four cavities, Q_1 and Q_2, and the coupling elements, K_1 and K_2. For a fixed frequency application, this process is straightforward. For a frequency tracking application, however, proper cavity bandwidths and coupling impedances must be maintained over a broad range of operating frequencies. To accomplish this, each of the coupling networks embody several reactive elements. Additionally, two K_0 transformer sections have been added at the source and load ports to provide the frequency-sensitive impedance transformations that are necessary to maintain constant bandwidth with tuning. These modifications to a standard Chebyshev design made it possible to achieve the selectivity requirements with minimum loss and bandwidth variation over the tuning range. The specific choice for the ripple parameter enabled an equalization and minimization of the voltage stresses on the diodes of the first two filter sections.

THE DIODE TUNED RESONATOR

The quarter-wavelength tapped resonator of Figure 3 provides the designer with the option of choosing the location of the stub/mainline junction as well as the electrical length and characteristic admittance of the stub. This stub

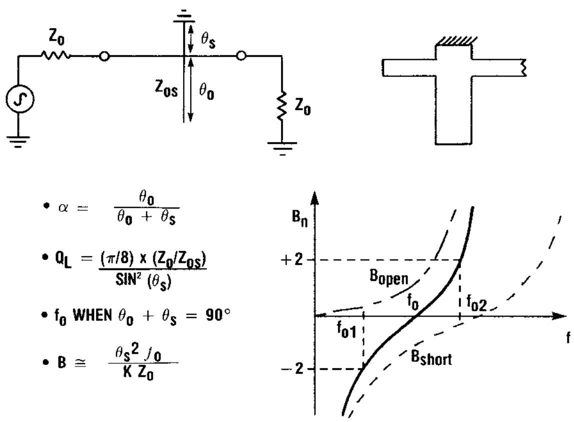

Figure 3 Properties of Tapped Stub Resonator

geometry will always resonate when its electrical length is a quarter wavelength or an odd multiple thereof--regardless of the junction location (tapping ratio, α) and stub admittance, Y_{OS}. The choice of the tapped stub as the resonating element derives, at least in part, from its direct physical connection via the shorted stub to the ground plane. This connection provides robust means to implement an efficient RF ground, control vibration, remove heat, and, where necessary, return bias current. Electrically, it provides two convenient design variables, tapping ratio and stub admittance, to control inherent loss and bandwidth. For this application the tapped resonator permits the designer to achieve the required selectivity with a stub admittance that minimizes loss at a chosen maximum voltage stress on the diodes which load it. It has, however, asymmetric band-pass properties which bear close attention by the designer. Figure 4 illustrates the approach used to tune the resonator with a simple series combination of a single PIN diode (represented by the shunt

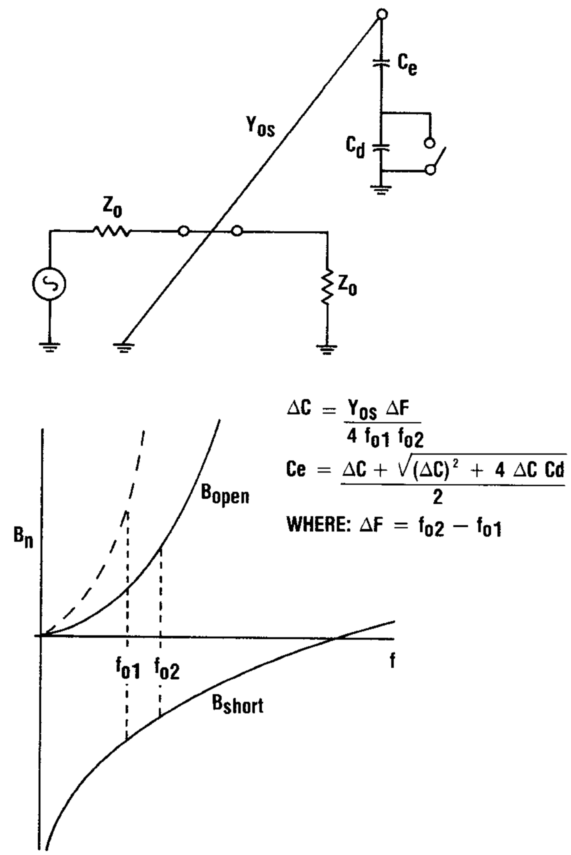

Figure 4 Cavity Tuned By Single Diode Switch

switched capacitor, C_D) and an external capacitor, C_E. When the diode is forward biased, the capacitance loading the stub is maximum and resonance occurs at F_{o1}. Conversely when the diode is reverse biased, the capacitance loading the stub is minimum and resonance occurs at F_{o2}. The magnitude of the frequency shift relates directly to the change in capacitance effected by the switching.

To achieve the necessary tuning range as a first approximation, the values of the external capacitors can be chosen so that the increments form a binary sequence, the smallest of which provides for the smallest frequency shift. Correspondingly, the largest external capacitor provides for the largest frequency shift. The design challenge is to ensure enough overlap so as to minimize any possibility of a gap in the tuning range. For this design, eight discrete PIN diode bits effect coarse tuning (approximate resolution of 1MHz) and a varactor diode effects fine tuning over a range of 2-6MHz. A consequence of this tuning approach is that the insertion loss of a given bit varies almost directly with the magnitude of the frequency shift it contributes. To offset this loss, two PIN diodes are used to implement the largest bit. Consequently, nine PIN diodes are used for each resonator to implement the 8-bit binary-related capacitance control.

REALIZATION CONSIDERATIONS

The concept described above has been implemented using identical 3-pF PIN diodes binned to reverse bias capacitance tolerances of ±0.05pF. This was a choice based upon modeling and production conveniences. All of the diodes are placed at the end of the stub to accommodate requirements related to thermal design, assembly and production testing.

The extension of the concept illustrated in Figure 4 to a fully loaded, eight-diode resonator including bias networks and parasitics is shown in Figure 5. The complexity of the loaded

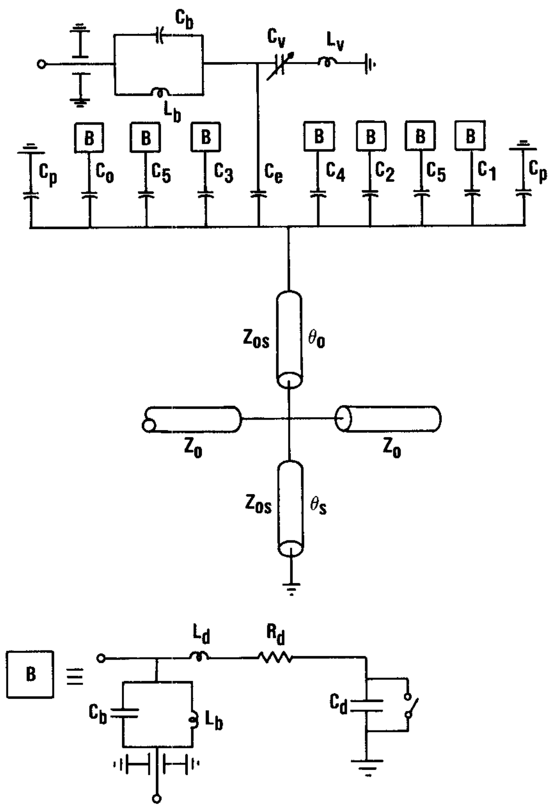

Figure 5 Six-bit Diode-tuned Cavity

resonator and the fact that four such resonators are used in the design established the need to rely upon both conventional and specially developed computer aids to synthesize the complete filter.

A fully configured single-cavity filter, an internal view of which is pictured in Figure 6,

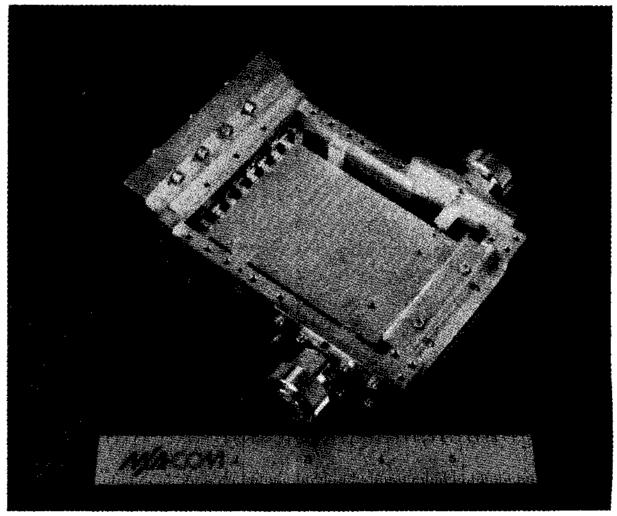

Figure 6 Prototype Cavity

was designed and implemented to provide an early concept and modeling verification. It used seven PIN diodes to provide digital tuning and one varactor diode to provide fine tuning and compensation of component tolerances. If tuning for such a cavity were carried out simply by varying the stub open-circuit length, the expression for Q in Figure 3 would imply a bandwidth variation as the cube of the resonant frequency. In practice, the exponent is closer to two, with significant variations as the diode-capacitor configuration goes through major changes. Compensation for the overall bandwidth variation can be achieved with multi-element passive transformation networks that change the input/output and internal impedance levels accordingly. The coupling elements used in the full-bandwidth design are shown in Figure 8 along

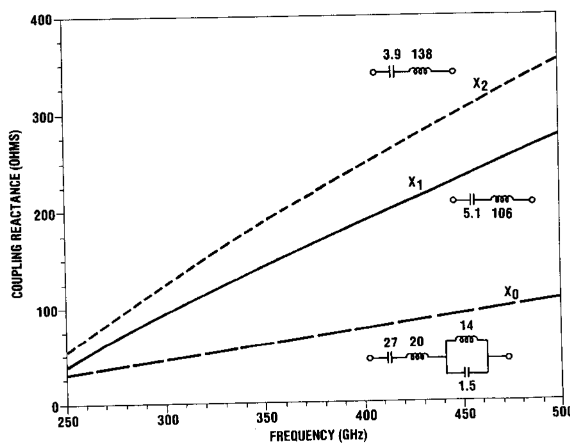

Figure 7 Cavity Coupling Elements

with their reactance characteristics. These networks each have a zero close to the transmission band and thus require careful consideration of their influence upon skirt rejection.

For ease of fabrication, the basic design uses identical cavities in each position, except that the short-circuit lengths get adjusted slightly differently after characterization. This results from the effective absorption of the shunt elements in the coupling networks. The small length correction is a compromise since it does not represent a fixed inductance any more than the coupling elements do. The coupling reactances vary significantly faster with frequency than those of pure inductors in order to maintain the proper bandwidth along with the designed ripple characteristic. Figure 8

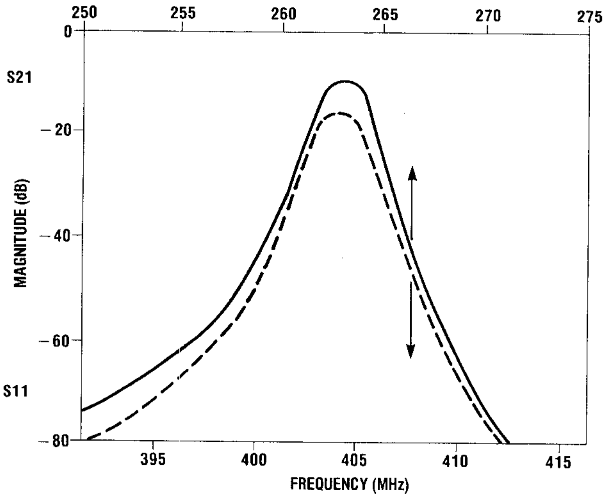

Figure 8 Predicted Four-Cavity Performance

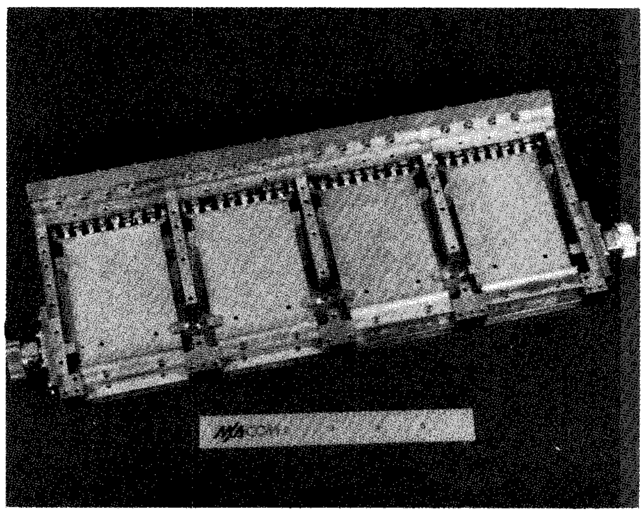

Figure 9 Four-Cavity Prototype

overlays the predicted transmission pass-band of the four-section filter at the extremes and mid-section of the tuning range (270MHz to 400Mhz). The results of the synthesis procedure indicate that the constant bandwidth objective for such a design is not only practical but capable of providing for a minimum of loss variation as well. Figure 9 shows the internal structure of the four-section prototype which was designed to cover half of the tuning range. Here the largest bits had not been incorporated as yet. Representative characteristics for the final design are depicted in Figure 10 and represent a gratifying confirmation of the design principles, showing the achievement of almost constant shape factor and loss with frequency. The results of this work have been used to synthesize tracking filter configurations which can tune over considerably greater frequency ranges such as

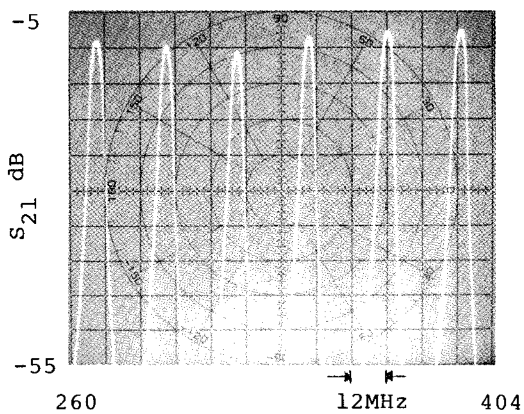

Figure 10 Measured Transmission Characteristics

200-400MHz. As the tuning range requirements increase, the minimum insertion loss of the filter elements increase. Design options to offset this loss increase with large frequency shifts include:

- o tailoring switching diodes to bit sizes to reduce excess capacitance.
- o multiple PIN diodes for the large bits
- o the use of 2 or more (if necessary) filter structures in a split or multiple band configuration.

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