LINEAR PHASE VERSUS EXTERNALLY EQUALIZED LONGITUDINAL DUAL-MODE FILTERS FOR SPACE APPLICATION

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ABSTRACT

Theoretical and experimental study of linear phase and externally equalized longitudinal dual-mode filters was conducted for ANIK-C input multiplexers. This paper describes the results and tradeoffs for the two competing designs for typical satellite requirements.

Introduction

This paper presents the results of a comprehensive study, theoretical and experimental, for the input multiplexing requirements of the proposed Telesat Canada's ANIK-C satellite - dedicated to the 14/12 GHz frequency band. These requirements are typical of the upcoming satellite systems (SBS, ANIK-C and others) and represent an advance in the state-of-the-art.

This study takes cognizance of the recent advances in the filter technology at 12 GHz[1,2,3]. Longitudinal dual-mode self-equalized linear phase filters operating in dominant or higher order modes are examined and methods developed to optimize their performance. This provides an alternative design to the externally equalized filters using allpass networks. Filter tradeoffs are provided for typical satellite requirements.

The two competing optimized designs for ANIK-C requirements are realized in the dual-mode configuration with TE_{103} as the mode of propagation. Measured results agree closely with the predicted response.

Design Considerations

Based on typical performance, realiability and weight requirements for space application, following assumptions were made for the tradeoff calculations:

- Longitudinal dual-mode structure was chosen for the realization of filters and allpass networks.
- TE_{103} or TE_{113} is chosen as the preferred mode of propagation to realize a minimum unloaded Q of 9,000 at 12 GHz.
- For externally equalized filter, both the non equi-ripple quasi-elliptic response[4] having two pairs of transmission zeros as well as the response with maximum possible equi-ripple peaks and a single pair of transmission zeros[2,5] were examined. Analysis shows little difference in performance whereas realization with single

Table 1 - Input Multiplexer Filter Tradeoffs for ANIK-C Satellite

Critical Performance Requirements*

Frequency Band	:	11.7 to 12.2 GHz
Usable Channel Bandwidth	:	fo ±27 MHz
Insertion Loss Variation	:	<1.4 dB over fo ±27 MHz
Isolation	:	≥25 dB at fo ±36 MHz
		≥45 dB at fo ±50 and beyond
Amplitude Slope	:	≤.01 dB/MHz over fo ±13 MHz
Group Delay	:	≤2 nsec at fo ±18 MHz
		≤5 nsec at fo ±21 MHz
		<1.5 nsec ripple

Filter Configuration	Isolation at fo ±36 dB	Loss Variation over fo ±27 dB	Gain-Slope over fo ±13 dB/MHz	Group Delay-nanoseconds fo ±18	fo ±21	Ripple
10-pole linear phase filter with two pairs of real-axis zeros.	15 20 25	0.8 1.0 1.7	.007 .009 .016	1 1 1.8	3 4.0 5.5	.5 1.0 1.0
10-pole linear phase filter with one pair of transmission zeros and one pair of real-axis zeros.	20 25 30	.95 1.25 1.5	.013 .02 .02	3.5 7 7	8 11 12.5	0 0 0
8-pole filter with one pair of transmission zeros and 2-pole allpass equalizer.	25	0.9	.004	.7	3	.5

* These requirements are for the whole transponder prior to the TWTAs.

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transmission zero is simpler. Consequently, it was chosen as the preferred response shape.
An allowance of ±1 MHz for the equivalent linear frequency drift is incorporated in the tradeoff calculations. This is to take care of operating temperature range and manufacturing and alignment tolerances.

Tradeoffs and Optimization of Filter Response

For equi-ripple passband response with maximum possible number of peaks, it is most convenient to utilize Bennett's transformation[6,7]

$$Z = \sqrt{1 + \frac{1}{s^2}}$$

to determine the characteristic polynomial containing attenuation zeros for a given location of attenuation poles or real-axis zeros or both. Real-axis zeros tend to linearize the phase response. This transformation is used to generate the unified design charts[8] (UDCs) described in figures 1 and 2, for the two alternative response functions. UDCs for linear phase filters are generated in a parametric form with the available zero locations as the parameters. By inspection of these design charts, one can choose the near optimal values of zero-locations to achieve lowest group delay for a given isolation response. If necessary, further refinement can be obtained by computing the filter response with minor variations of these zero locations. This procedure, though less elegant than a formal optimization program, is significantly simpler and is best suited to generate performance tradeoffs. Rhodes[9,10] has described closed-form expressions for some other types of microwave linear phase filters. Group delay response of the minimum phase filter with single transmission zero is optimized using allpass networks as described in reference 11.

Table 1 describes the filter tradeoffs with respect to ANIK-C requirements.

Experimental Results Versus Computed Response

For a given set of critical frequencies, dual-mode realization is accomplished using a procedure similar to that of Atia[12] et al. Optimized critical frequencies of the prototype network for the two designs with respect to ANIK-C requirements are as follows:

	Linear Phase Filter	Externally Equalized Filter
Attenuation Zeros	.1373	.2138
	.4088	.5955
	.6629	.8599
	.8681	.9851
	.9847	
Attenuation Poles	-	1.30
Real-Axis Zeros	1.0	-
	1.2	
Zero Location of Microwave Allpass Network (D-Section)	-	225 ± 125

The computed and measured response for the two designs, realized in longitudinal dual-mode configuration with TE_{103} as the mode of propagation is described in figures 3 and 4. There is close correlation between the predicted response and measured results. Figures 5 and 6 are the photographs of the prototype units.

Conclusions and Discussions

This study shows that minimum phase filters with at least one pair of transmission zeros in conjunction with allpass networks provide superior performance as compared to a linear phase filter of equivalent order in a longitudinal dual-mode realization. However, dual-mode allpass equalizer requires a circulator, which for space application at 12 GHz represents a weight penalty of 0.15 lbs. Allpass network is nearly independent of the associated filter which simplifies the tuning of the overall assembly. On the other hand, linear phase structure is elegant, requires no circulator but moderately complex to design and tune. The two competing optimized designs for ANIK-C requirements were realized in a dual-mode structure with TE_{103} as the mode of propagation. Measured results agree closely with the predicted response.

Based on specifications of upcoming satellite systems (SBS, ANIK-C), it can be concluded that the externally equalized filter configuration is favoured over the linear phase filters at the present time.

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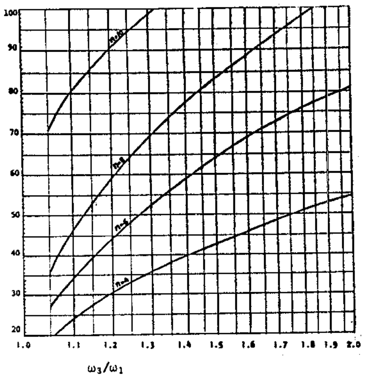

Fig. 1 - Unified design chart for filters with maximum possible equi-ripple peaks in passband and a single pair of transmission zeros.

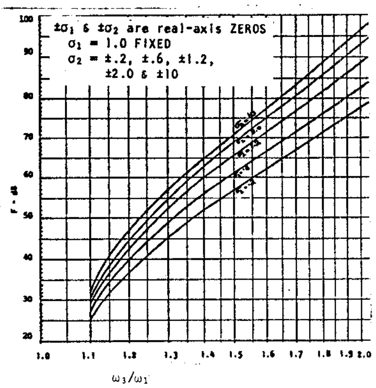

Fig. 2 - Unified design charts for a 10-pole filter with ten equi-ripple peaks in passband and two pairs of real-axis zeros

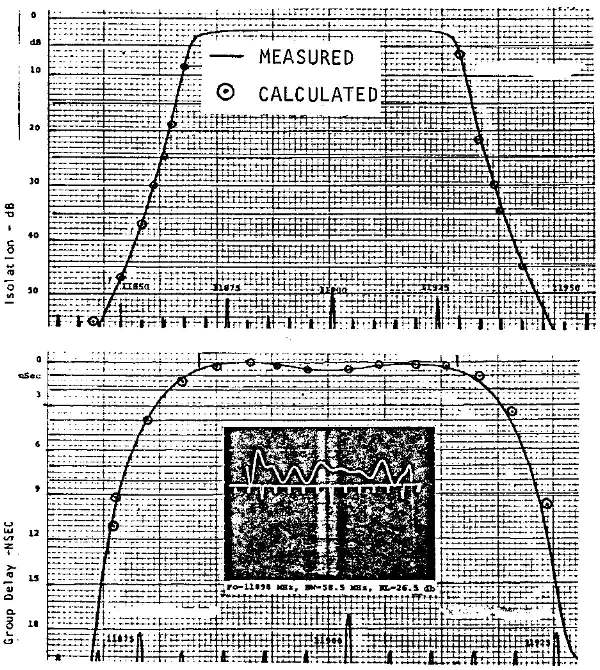

Fig. 3- Measured Response of Linear Phase Filter, (a) Amplitude response and (b) Group Delay response.

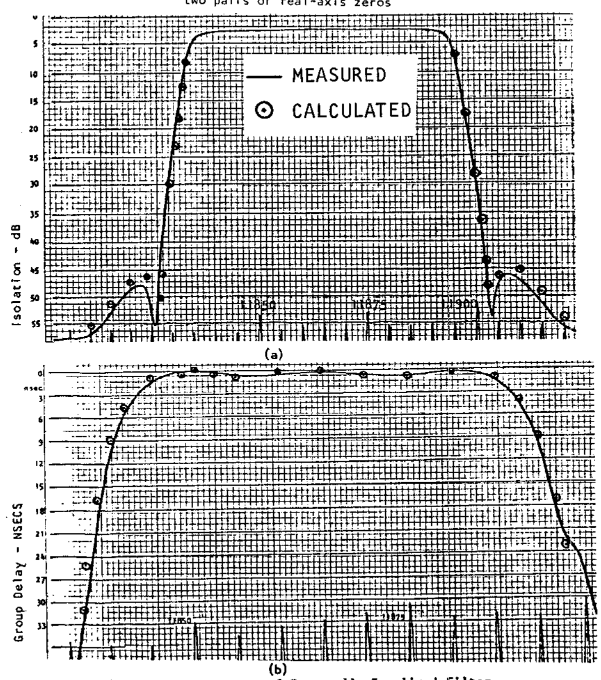

Fig. 4- Measured Response of Externally Equalized Filter, (a) Amplitude response and (b) Group Delay response.

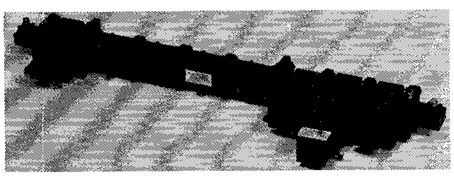

Fig. 6- Externally equalized Prototype Filter

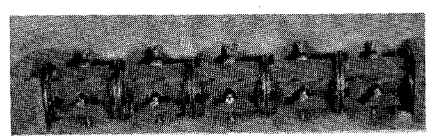

Fig. 5 - 10-pole Linear Phase dual-mode filter operating in TE_{103} mode.