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Hybrid of SA and CG Methods for Designing the Ka-Band Group-Delay Equalized Filter

Ka-대역 군지연-등화 여파기용 SA 기법과 CG 기법의 하이브리드 설계 기법

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Abstract

This paper describes the realization of the Ka-band group-delay equalized filter designed with the help of a new hybrid method of Simulated Annealing(SA) and Conjugate Gradient(CG), to be employed by the multi-channel Input Multiplexer for a satellite use, each channel of which comprises a channel filter and a group-delay equalizer. The SA and CG find circuit parameters of an 8th order elliptic function filter and a 2-pole equalizer, respectively. Measurement results demonstrate that the performances of the designed component meet the specifications, and validate the design methods.

요 약

본 논문은, 각 채널이 여파기와 군지연 등화기로 구성되는, 위성용 다중채널 입력 멀티플렉서에서 사용되는 군지연-등화되는 여파기의, Simulated Annealing(SA) 기법과 Conjugate Gradient(CG) 기법의 새로운 결합형 설계 방식에 의한 구현을 기술한다. SA 기법은 8차 타원적분형 여파기, CG 기법은 2극 등화기 각각의 회로 설계변수들의 값을 찾아내는데 이용된다. 측정결과는 설계된 부품의 spec.에 대하여 성능이 만족함과 설계기법의 타당성을 나타낸다.

Key words : Hybrid of Simulated Annealing and Conjugate Gradient, Elliptic Function Filter, Group-Delay Equalizer, Ka-Band Passive Components

Ⅰ. Introduction

In a satellite payload system, the Input Multiplexer branches received signals into channels. A limited range of frequency is divided through channel filters as many as the channels. These filters are designed to have high selectivity and less mass and volume. Thus, elliptic function and higher order filters are adopted. However, this entails larger variation in the group-delay response. The group-delay equalizer follows the filter to reduce the variation within the band.

This paper presents the realization of the Ka-band Input Multiplexer composed of in-line type 8th order dual-mode channel filters, and 2-pole reflection-type group-delay equalizers for the Ka-band Input Multiplexer. The coupling matrix of the filter has the larger number(N_{Filter}) of elements as unknowns and can be found through numerical optimization. The error function is very simply obtained by summing the errors of coefficients of the rational function of the unknowns' coupling matrix and the transfer function. Then the SA stochastically moves along the error function of N_{Filter} dimensions, up and down to spot the global optimum point without being affected by the choice of the initial

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value. On the contrary, the coupling coefficients of the equalizer can be obtained by the CG, since it has the lower number of unknowns($N_{Equalizer}$) and an even smaller number of local minima.

Ⅱ. Design

2-1 Configuration and Specifications

The Input Multiplexer has three channels as seen in Fig. 1.

In each channel, the signal enters the input port, passes the circulator and arrives at the channel filter followed by the group-delay equalizer. If the signal is out of the channel band, it is returned and goes to next channel via the circulator. The specified requirements of the Input Multiplexer are given in Table 1 Bandwidth Δf is 100 MHz common to all the channels.

2-2 Channel Filter

The amplitude of the specified frequency response necessitates a filter like an 8th order dual-mode elliptic function type of coupling. Similar to [1]~[6], its filter transfer function is expressed and circuit parameters including coupling coefficients are obtained by the SA optimization, since SA is well-known as a global stochastic searcher where the result is far less sensitive to the initial values. The error function of the SA for the filter design is efficiently formed with the sum of the errors between the coefficients of the desired transfer function and that of the tried coupling coefficient matrix. This is the first attempt to solve a filter synthesis to the author's knowledge. The error function is a nonlinear N_{Filter} dimensional function, and SA stochastically moves both up and downhill and focuses on the area where the global optimum point possibly exists As an example, the filter is designed to have the center frequency at 21 GHz, 100 MHz of bandwidth and −20 dB of transmission S-parameter at 60 MHz-offset as rejection. The two important input parameters of the SA temperature T_{SA} and falling rate of temperature RT_{SA} are just linearly related.

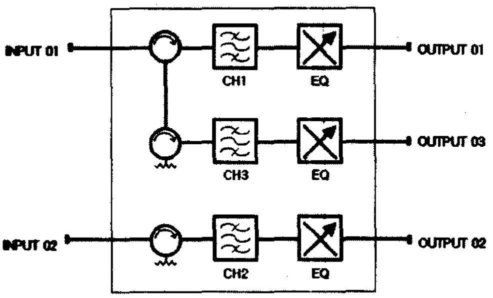


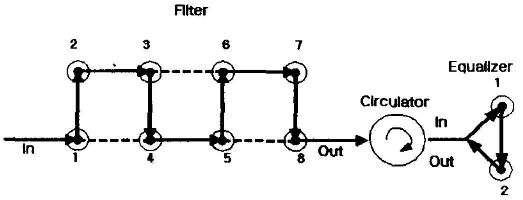
Fig. 1. An three-channel case of input multiplexer.

Table 1. Major requirements on each path of the Ka-band input multiplexer.

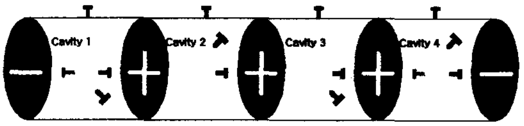
Parameter	Frequency	Requirements
Center freq	f_0 of Ch's [GHz]	20.87, 21.00, 21.13
Amplitude variation	F_0± 30 MHz	0.15(dBp-p)
	F_0± 38 MHz	0.25(dBp-p)
	F_0± 45 MHz	0.50(dBp-p)
	F_0± 50 MHz	1.50(dBp-p)
Group delay variation	F_0± 20 MHz	1.8(ns)
	F_0± 30 MHz	2.2(ns)
	F_0± 40 MHz	6.3(ns)
	F_0± 50 MHz	22.5(ns)
Near-band rejection	F_0± 60 MHz	−12(dB)
	F_0± 80 MHz	−49(dB)
Return loss	Within band	> 20(dB)
Insertion loss	Within band	< 4(dB)

Fig. 2 shows the filter and equalizer in one path of the Ka-band Input Multiplexer.

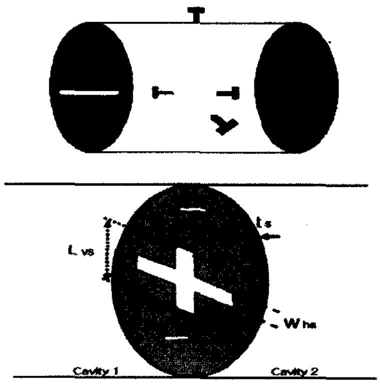
After the SA error-minimization, the circuit parameters of the filter in Fig. 2(a) are converted to the initial physical sizes of the slots as is done in [7], for the real structure in Fig. 2(b). TE$_{113}$ is chosen for cavity resonance mode. At the input and output ports, waveguides of WR51 are used for connection. For convenience, 0.7 mm chosen for W_S and 0.4 mm for t_s are common to all the irises with Fig. 2(b). The sizes are computed and verified by the measurement method in [5].



(a) Group-delay equalizer followed by a filter via a circulator



(b) Physical structure of a waveguide filter



(c) 1-cavity reflection-type group-delay equalizer and the unit iris for dual-mode coupling

Fig. 2. The filter, group-delay equalizer and the unit iris.

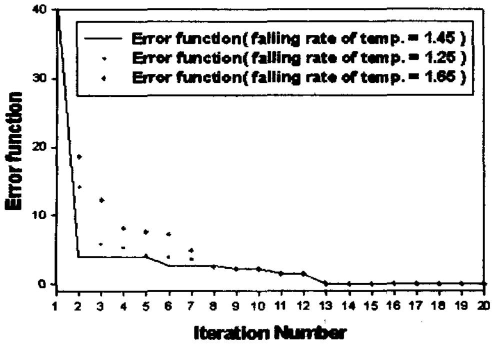
2-3 Group-Delay Equalizer

As in Fig. 2(a), the two parameters of the equalizer are obtained by the CG, since it has $N_{Equalizer}$ unknowns and gradient-based search simply finds the minimum error point. The group-delay equalizer design chooses reflection-type and one cavity with one end shorted end. This has already been given in Fig. 2(c). The equalizer cavity has the same radius and resonance mode as the channel filter. Referring to [8], the equalizer is designed for equalizing the amplitude and group-delay variation. And then, using the similar procedures, the sizes are found and tuning is done.

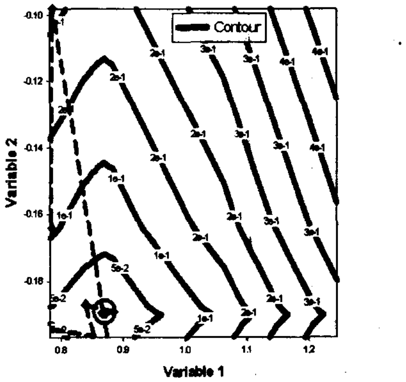
Ⅲ. Implementation and Experimental Results

The SA searches global extreme points, trying the unknowns in the directions of both uphill and downhill stochastically, checking the rate of convergence. Also, the sensitivity to the choice of the initial guesses is very low in the SA application[9]. For the SA to optimize the filters, 1 and 1.45 will be used as temperature T_{SA}(a kind of the status-index related to convergence) and falling rate of RT_{SA} temperature(convergence rate index and size of next try in the unknown space), respectively. 1 is customarily given to T_{SA} in SA searching and preliminary numerical experiments are carried out for choosing RT_{SA}. Without a doubt, N_{Filter} is 8 for an 8th-order symmetric dual-mode filter. The variables to be sought are determined as $M_{12}(=M_{78})$, $M_{23}(=M_{67})$, $M_{34}(=M_{56})$, and M_{45} as sequential coupling and $M_{14}(=M_{58})$ and M_{36} as cross coupling. The error function of the SA is effectively formed with the sum of the errors between the coefficients of the desired transfer function and that of the tried coupling coefficient matrix[10] that never necessitates deciding the case-dependent sample points. Plus, the initial guesses for the unknown couplings are given as any values from -1.5 to 1.5 empirically and by examining the literature. Before SA is applied, convergence features need to be investigated with a number of the falling rates of temperature. In Fig. 3(a), the error function behavior of three different cases is presented with 1.25, 1.45 and 1.65, where the error function is formed by the summed difference between the specifications and the amplitude and group-delay variation specified at the frequency points in Table 1. The value 1.45 is found to be the best in convergence. And Fig. 3(b) provides the information on how the minimum point(the circle) in the contours(the green lines) of the error function is sought by the SA, and the trace of tried values(the diamonds and the dotted line of them). Fig. 3(b) describes the 2D space or 2-variable searching space(variable $1=M_{12}$ and variable $2=M_{14}$) with the other variables fixed.

In Fig. 3(b), the line between the two adjacent tried values(red diamonds) gets shorter and represents the step size is reduced, when the tried value approached



(a) Error behavior with falling temperature rates



(b) Error function contours(solid lines), minimum point(circle)-trace(dotted line)

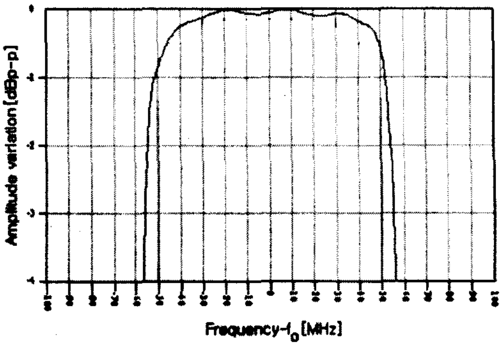
Fig. 3. Amplitude variation, and error function contours and minimum point-searching trace.

Table 2. The resultant sought variables of SA.

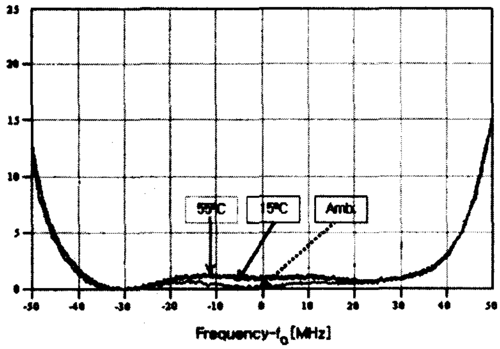
Sequential coupling		Cross coupling	
M_{12}(= M_{78})	0.807	M_{14}(= M_{58})	-0.193
M_{23}(= M_{67})	0.734		
M_{34}(= M_{56})	0.532	M_{36}	-0.00543
M_{45}	0.548		

the target value or minimum value. As the SA process is completed, the resultant sought variables can be obtained like Table 2.

The performances of channel filters and group-delay equalizers should be least influenced by thermal change, because they are designed for narrow bandwidths. To cope with this, Invar 36 is used for group-delay stability over 15℃ to 55℃ and silver-plated. On the contrary, the low-pass filters as a wider band circuit are made of



(a) Amplitude variation



(b) Group-delay variation

Fig. 4. Amplitude variation and group-delay variation of channel 3.

Aluminum, since it has wide-band characteristics. In order to demonstrate how well equalization is achieved, the results of amplitude and group-delay variation are investigated. Fig. 4(a) and (b) show the amplitude variation, and group-delay variation and stability of channel 3, respectively.

All satisfy the specifications and the resultant st-

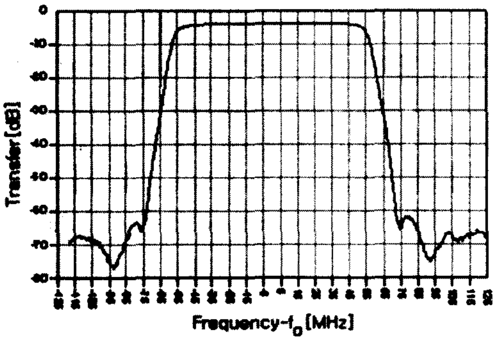


Fig. 5. Near-band transfer s-parameter S_{21}.

ability is less than 2.5 nsecs. In Fig. 5, transfer s-parameter S_{21} is presented and can be compared with near-band rejection specifications.

In comparison with Table 1, it shows enough margins in near-band rejection performance. Besides, the insertion loss at the center frequency is less than 4 dB and complies with the specification.

Ⅳ. Conclusion

A new numerical design of the group-delay equalized filter for the Ka-band Input Mulitiplexer has been highlighted. 8th-order channel filters and 2-pole group-delay equalizers are designed with the SA error minimization technique and the CG method for the circuit parameter solutions. Experimental results show that the amplitude variation and group-delay variation are much flattened, with good rejection, less insertion loss, good group-delay stability and desired bandwidths.

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