A DIELECTRIC RESONATOR FILTER AS LOW LOSS DELAY ELEMENT FOR 14 GHz ON-BOARD 4Ø-DCPSK DEMODULATION

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ABSTRACT

A new implementation of a 16.7 ns delay element for on-board regenerative satellite repeaters is presented. The use of high Q dielectric resonator delay filters allows a significant insertion loss reduction with respect to known microstrip solutions, full compatibility with other microstrip circuitry being still maintained. The reduced loss permits some critical demodulator specifications to be substantially relaxed.

Introduction

Direct on-board demodulation of differentially coherent QPSK signals requires a one-symbol delay element with a very high phase stability over the operating temperature range. Known implementations in this field employ either a microstrip delay line[1] or a cascade of parallel coupled microstrip filters[2]. Both solutions meet the aim of providing the 16.7 ns delay with acceptable impairments in amplitude and phase over the operating bandwidth, but suffer from a very hygh insertion loss that is in any case in excess of 17 dB. This high loss on the delayed signal involves severe restrictions on the performance of the whole demodulator[3], limiting the level and range of the input signal and requiring for the RF ports of the phase detectors a high degree of isolation which is difficult to achieve in microstrip technique.

This paper presents a novel microstrip implementation for the delay filters that makes use of very stable high Q dielectric resonators. This allows a significant reduction of the attenuation of the delayed signal (about to 5 dB) maintaining a fairly good behaviour over the operating bandwidth.

Furthermore, the delay filter is still fully compatible with a microstrip implementation of the whole demodulator.

DESIGN

Direct demodulation of 120 Mbit/s DCQPSK signals calls for a 16.67 ns ideal delay element over a Nyquist bandwidth of 60 MHz. Accounting for a channel filter approximating a cosine roll-off ideal filter with a roll-off factor of about 0.5, the operating bandwidth of the delay filter is considered to be 90 MHz with a centre frequency of 14.125 GHz.

A major limitation to deal with in the choice of the type of filter to be implemented is the limited degree of external coupling achievable between a microstrip line and a dielectric resonator. Experimental assessment of the maximum obtainable external coupling at 14 GHz showed achievable a value of about 80, using a reflection test set with a 50Ω feeding line on alumina and a dielectric resonator with a square quartz stand-off in waveguide below cutoff. The same set-up was used to measure inter-resonator coupling factors.

The final choice for the delay filter was a cascade of three 5-pole 0.1 dB ripple Chebyshev filters with 202 MHz nominal bandwidth.

Each filter has a nominal 5.5 ns group delay at centre frequency and its group delay behaviour at near centre frequencies is better than a comparable Butterworth filter[4].

The filters were constructed using low-loss high stability disk resonators[5] of 4 mm diameter and 1.6 mm height, supported by square 2.5 x 2.5 x 0.5 mm fused quartz stand-offs and stuck to a 25 mils alumina substrate with low-loss silicon adhesive. The use of low-loss stand-offs allows both the unloaded Q of all the resonators and the external coupling of the input and output resonators[6] to be maximized.

EXPERIMENTAL RESULTS

Each filter was completed by sticking the alumina substrate to copper plated invar carrier 1.2 mm thick and adding a cover manufactured from the same invar sheet and copper plated[6]. This allowed separated pre--tuning of the filters, which were then assembled on a common invar carrier of the same thickness and directly interconnected by means of an indium soldered thin gold ribbon. A photograph of the whole assembly is shown in Fig. 1. Total length of the unit is 123 mm. The delay filter can be easily connected to other microstrip circuitry without any adapter.

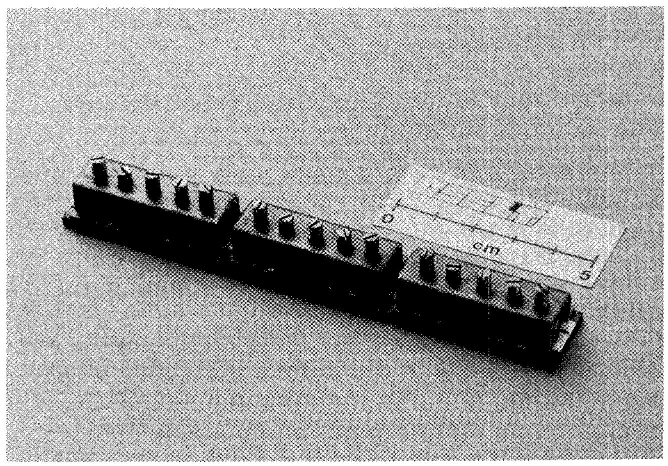

Fig. 1 - Dielectric resonator delay filter assembly

The amplitude and group delay performance of a single unit is shown in Fig. 2. Passband loss is less than 2 dB and compares favorably with computer simulations, assuming an unloaded Q of 3000 for inner resonators and 600 for input and output resonators as previously measured[6]. The remarkable unloaded Q reduction of the input and output resonators is likely due to the rather strong interaction of their fields with the feeding lines.

Furthermore the filter response is not exactly symmetrical with respect to the band centre. This feature is most evident observing the group delay. This led to design and tune each filter for a band centre slightly lower than the nominal carrier frequency

(14.125 GHz).

The whole delay filter required a light degree of tuning to achieve the final result, displayed in Fig. 3.

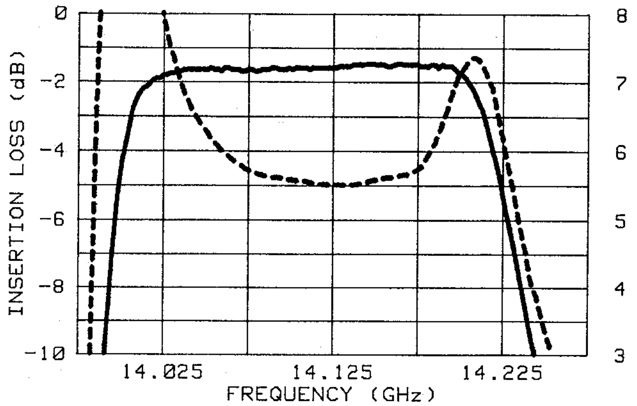

Fig.2 Amplitude and group delay response of a single filter

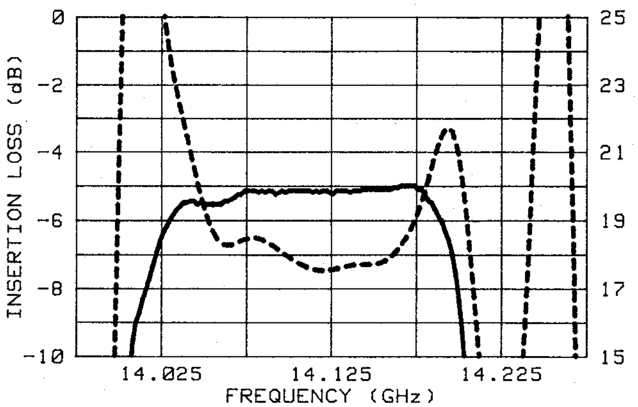

Fig.3 Amplitude and group delay response of the delay element

Insertion loss over the operating bandwidth is 5 dB, while the group delay response shows a delay increase at band centre, compared with the desired 16.7 ns. Actually, group delay at centre frequency is 17.6 ns. This is mainly due to two reasons. First, effective bandwidth of individual filters resulted to be slightly smaller than the design value and consequently the group delay was higher. Secondly the final overall tuning was mainly directed to flatten the amplitude response, and this likely caused some group delay mistuning among the single filters, obviously resulting in a group delay increase of the whole assembly.

Anyway, this increase was recovered without redesigning the filters as shown in the next section.

PHASE STABILITY

In order to maintain the BER degradation of the whole demodulator within acceptable limits, the delay element has to provide[3] a phase stability of ± 2 degrees over a temperature range of 30°C (25 $\pm$ 15).

Although the dielectric resonator material possesses a very high temperature stability, measurements carried out at 14 GHz using a bare resonator on quartz substrate which virtually contributes no temperature drift, showed a temperature coefficient of +1.9 ppm/°C, not sufficient to satisfy the previous phase specification. As a consequence, some kinds of temperature compensation must be devised.

Furthermore the interposition between actual resonators and supporting substrate of a quartz stand-off minimized the influence of the substrate drift on the resonators, making the choice of the substrate almost independent from temperature stability considerations. Since other demodulator circuitry is on alumina, also the delay filter has been constructed on the same substrate, to minimize discontinuities between microstrip circuits.

For the same purpose, it was decided to apply the temperature compensation not as a cascaded phase variation opposite in sign to that of the delay filter[1,3]. Since phase stability has to be maintained between the main and the delayed signal at phase detector ports, the compensation was applied as an increase of the main signal path such that its phase variation with temperature would equal that of the delay filter.

The temperature stability of the delay filter was carefully measured using the modified pi-point method[2] in reflection mode, and the results reported in Fig. 4, give a temperature coefficient of + 3.5 ppm/°C corresponding to 9.4 degrees of phase variation over a 30°C temperature range. The variation is inclusive of some 50 mm of microstrip lines interconnecting the filters.

Separate measurements on straight line resonators on alumina substrates, showed a temperature coefficient of alumina at 14 GHz of + 60 ppm/°C. Therefore the lenghtening of the main path in the demodulator necessary to compensate the delay filter phase variation, has to be 114 mm. This length of microstrip line on alumina contributes a 1.1 ns group delay at 14 GHz, that actually diminishes the delay provided by the filter to a value of about 16.5 ns.

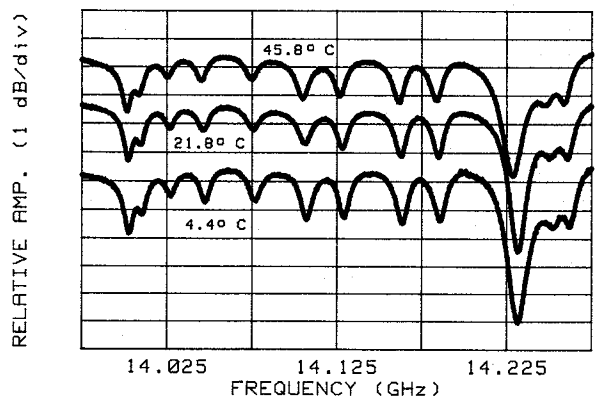

Fig.4 Temperature stability measurements

CONCLUDING REMARKS

The reduced loss of the dielectric resonator delay filter allows a substantial relaxation of some demodulator specifications that otherwise would be much severe[3]. In particular, the nominal input signal level is lowered, the input range compatible with good demodulator operation is much widened and the isolation required for the phase detector ports decreases from values hardly attainable with planar microstrip technique to acceptable values.

The C/N degradation introduced by non-ideal amplitude and group delay characteristics of the delay filter is very low. Simulations carried out using an in-house computer model[7] showed a degradation of the order of 0.1 dB at a bit error rate of 10^{-4}. Channel filter was modelled as an ideal cosine roll-off filter with a 0.5 roll-off factor.

The dielectric resonator filter has demonstrated an actractive implementation for a low-loss delay element for direct on-board DC-PSK demodulation. Phase stability is easily achieved using a stable resonator material and a simple compensation technique which minimizes substrate dishomogeneities. Finally the whole assembly is fully compatible with other microstrip circuitry.

ACKNOWLEDGEMENTS

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