Efficient Microstrip Filter for IF band in DTH Downlink

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This paper presents an efficient microstrip trisection bandpass filter consisting of cross-coupled open-loop resonators for IF band filtering in Ku band Direct to Home (DTH) applications. The proposed filter has been designed and investigated using Advanced Design System (ADS) software. The filter provides fractional Bandwidth (FBW) of 13.84% at the centre frequency, which is much higher than most of the cascaded trisection filter designs previously reported in literature. The fabricated filter has been experimentally tested on aKu band DTH downlink and the effect of the filter on the received signal has been analysed.

Keywords: Microstrip Filter, Cascaded Trisection, Open Loop Resonator (OLR), Coupled Resonator, Direct to Home (DTH), IF-filtering

1 Introduction

Rapid development in wireless communication systems has lead to the need for high quality microwave components. Frequency allocations and spectrum of operations for some systems (like DTH) require high selectivity filters with asymmetric responses, wherein high rejection is necessary on one side of the passband but a moderate requirement on the other side. DTH broadcast services have become an essentiality to any modern day family. DTH also known as Direct Broadcast Service (DBS) utilizes Ku band (12~18 GHz) for the downlink access to the customer premises. The received signal is then down converted to IF frequency ranges (0.9 ~ 2.2 GHz) by the Low Noise Block Convertor (LNBC) which is present at the DTH reception dish, for amplification and down conversion. A coaxial cable running to a tune of few 10's of metres connects the LNBC to the set-top box. It has been envisaged that a filter at the input of the set-top box would improve the signal characteristics and reduce the effect of noise and interference. This paper reports a Cascaded Trisection (CT) filter design[1,2] that provides miniaturization, low insertion loss and asymmetric response. The filter is designed in ADS software and has been further fabricated. The developed filter has been incorporated into the DTH downlink setup to analyse the effect of the filter and to validate its performance.

2 Materials and Methods

2.1 DTH IF band classification

The IF band realised at the output of the LNBC can be broadly classified into two major types namely Low-band IF and High-band IF, as indicated in Table 1. This classification is done on the basis of the output frequencies of the LNBC and the Local Oscillator (LO) frequency used for conversion from Ku band to IF frequency ranges.

The filter considered in this paper was designed to cater to High-band IF as well as Low-band IF. The specifications of the filter were drawn based on GSAT-15 frequency allocation for various channels. Details about the frequency channels based on which the filter specifications were drawn from are presented in Table 2.

As an example, the following filter specifications are drawn to catch the needs of a typical customer - Centre Frequency - 1.95 GHz, Bandwidth - 270 MHz, Fractional Bandwidth - 13.84 %, Rejection > 10 dB for frequencies in passband

2.2 Cascaded trisection filter

The lowpass prototype of the filter alongside the filter equivalent circuit is depicted as in Fig. 1

Table 1 — DTH IF band classification

	LO frequency (GHz)	LNBC input frequency (GHz)	LNBC output frequency (GHz)
Low-band IF	9.75	10.7 to 11.7	0.95 to 1.95
High-band IF	10.6	11.7 to 12.75	1.1 to 2.150

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Table 2 — Details of GSAT-15 satellite channel specifications

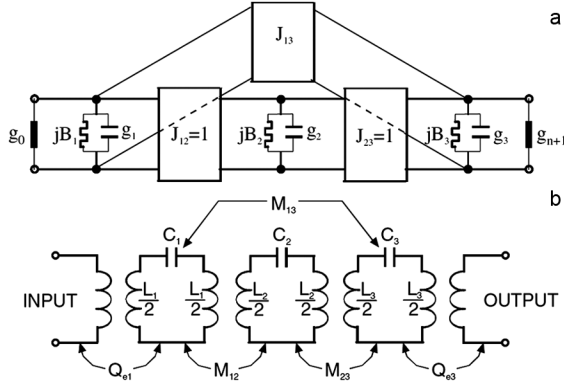| Frequency/ Polarization	Channel	Symbol Rate (MS/sec)	Forward error correction	Free/ Scrambled	Beam
11090 / V	DD National, DD News, DD sports	29.5	3/4	Free	India Beam
11170 / V	DD Rajasthan, DD Oriya, DD Podhigai	29.5	3/4	Free	India Beam
11470 / V	Manoranjan, News nation	29.5	3/4	Free	India Beam
11510 / V	Sanskar	29.5	3/4	Free	India Beam
11590 / V	MHRD 1, MHRD2, MHRD 3	29.5	3/4	Free	India Beam

Fig. 1 — (a) Lowpass filter prototype of the filter, and (b) equivalent circuit of cross-coupled bandpass filter[1].

The CT filter employs the idea of introducing finite transmission zeros to achieve high roll off in the filter response. The cross-coupling between the resonators 1 and 3 was due to their proximity with each other as indicated in Fig. 2 (a). This introduced a transmission zero in the filter transfer function, were-in S_{21} equates to zero, so as to achieve high roll-off[3,4,5,6,7,8]. As indicated in the Fig 1. (b), M_{12} and M_{23} are direct coupling coefficients and M_{13} is the cross-coupling coefficient, while Q_{e1} and Q_{e2} indicate the external quality factors for the input and output couplings.

Though CT filters offer asymmetric responses, they still exhibit structural symmetry about their physical axis. The asymmetry in the frequency response can be attributed to asymmetrically tuning the filter, wherein the centre frequencies of the resonator 1 and 3 happen to be the same while being lower than the centre frequency of the resonator 2. The centre frequency of the resonators can be given by the formula

$$1/\sqrt{L_i C_i} = \omega_{0i} = 2\pi f_i \qquad \qquad ... (1)$$

where, i varies from 1 to 3 for each of the resonators. J terms in the lowpass filter prototype of the filter represent ideal admittance inverter.

2.3 Filter design

The proposed filter has three open-loop resonators and it occurs to be the simplest of all the forms of CT
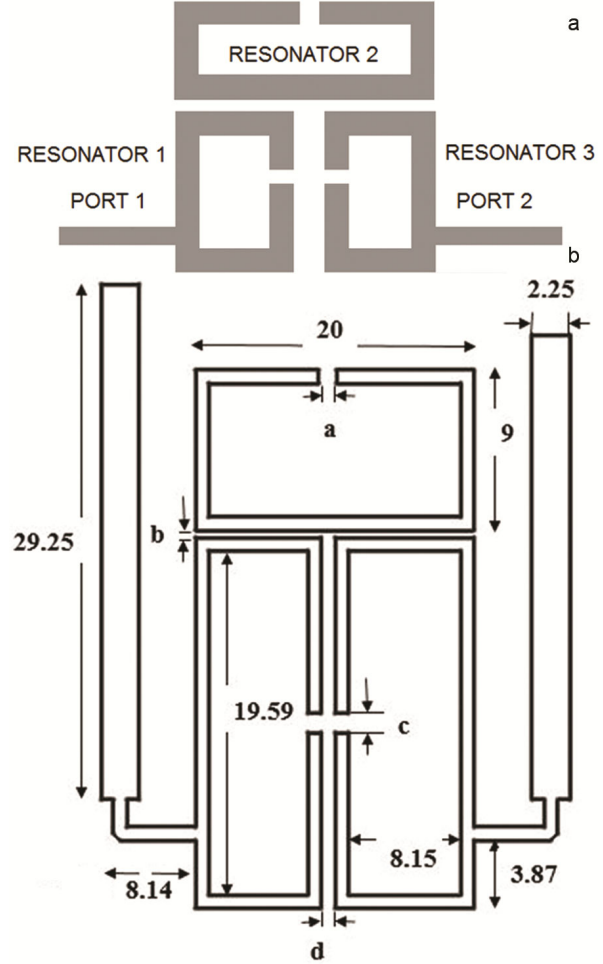

Fig. 2 — (a) Schematic of cross coupled trisection filter, and (b) filter dimensions in mm.

filters. For simplicity of the design procedure, some basic assumptions are made in the filter design process. Let $M_{12}=M_{23}$, $Q_{e1}=Q_{e3}$, $\omega_{01}=\omega_{03}$. Also, let $J_{12}=J_{23}=1$, $g_0=g_4=1$, $B_1=B_3$ and $g_1=g_3$. Furthermore, the elemental values of the lowpass filter prototype are determined using synthesis method equations specified in[1,5,6,7]. Based on the equations the strip dimensions were obtained and the dimensions are denoted diagrammatically as in Fig. 2 (b). Further, the parametric analysis has been performed to obtain the optimized split ring gap (Fig. 3 (a and b)) and the
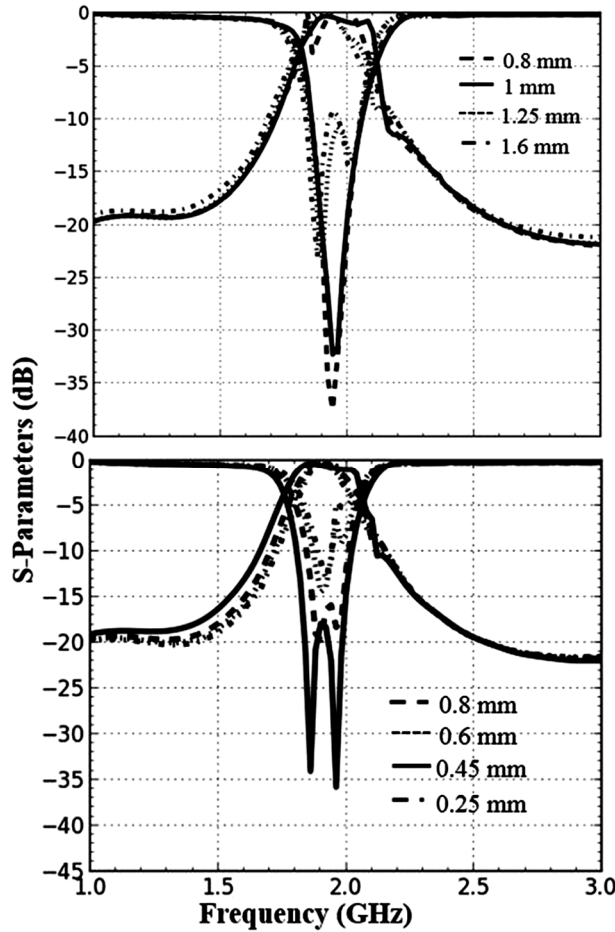
Fig. 3 — Effect of (a) split ring gap (a = 1 mm) of resonator 2, and (b) split ring gap (c=1 mm) of resonators 1, and 3.
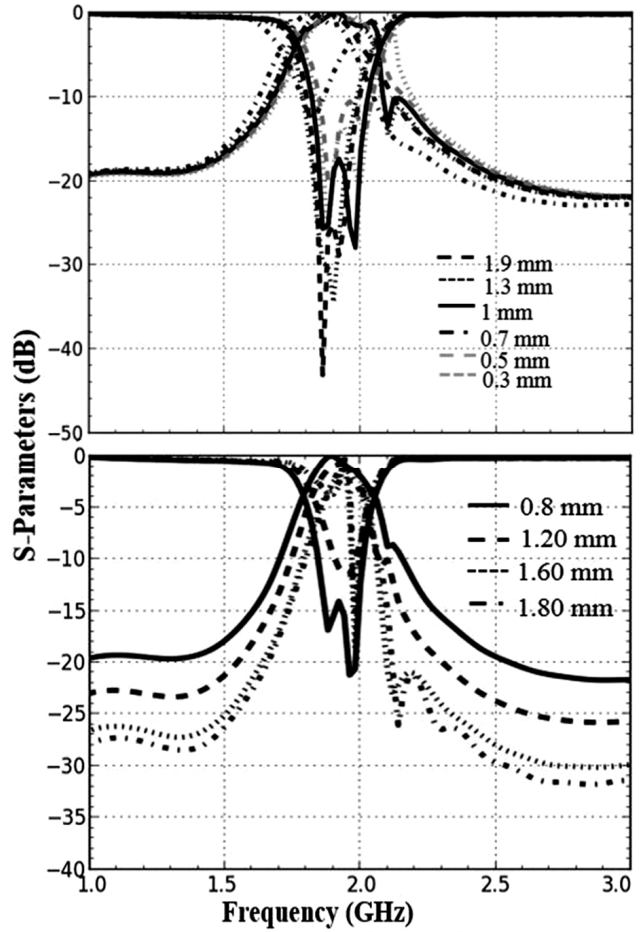

Fig. 4 — Effect of (a) coupling gap (b = 0.45 mm) between resonators, and (b) coupling gap (d=0.8 mm) between the resonator 1, and 3.

coupling gap (Fig. 4 (a and b)) between the resonators. The optimum values of split ring gap (a), coupling gap (b) are found be 1mm, 0.45 mm respectively. Similarly, the dimensions of parameters (c) and (d) are determined as 1 mm and 0.8 mm. These values lead to maximum bandwidth for the filter. The solid dark line in each figure indicates the response under optimized dimension for a particular filter parameter.

In this design, the filter was developed for 75 Ohms impedance, which is the standard for television systems. However, an optimized transmission line segment was added for experimental verification using the available 50 ohm test set up. In real time implementation, this transmission line segment was not required. The design was carried out on an Arlon AD250 substrate, whose specifications are shown in Table 3.

3 Results and Discussion

The filter as per the specifications was designed in 3D EM solver and fabricated using printed circuit

Table 3 — Substrate specification

Property	Typical Value
Dielectric Constant	2.55
Relative Permeability	1
Thickness	30 mil
Loss Tangent	0.0018

board milling machine (LPKF protomat E34). It is the process of removing areas of copper from a sheet of printed circuit board material (Arlon AD250) to recreate the filter structure according to patterns from a digital circuit board plan known as layout file. For this fabrication 0.4 mil milling bit was utilized for curving the structure with the accuracy of about 30μm. Further SMA type connectors were added for measurements. The photograph of the fabricated filter is illustrated in Fig. 5.

The fabricated filter was tested using Rohde and Schwarz network analyzer (Model ZVH-8) and

measured S-parameter characteristics are depicted in Fig. 6 (a and b).The simulation and measured values of S_{11} and S_{21} are found to agree weell.

It is quite clear from the Fig. 6 (b), that the measured 10 dB bandwidth is about 270MHz which agrees well with the design intensions. All the more, the S_{11} characteristics also match with the design specifications of providing a return loss greater than
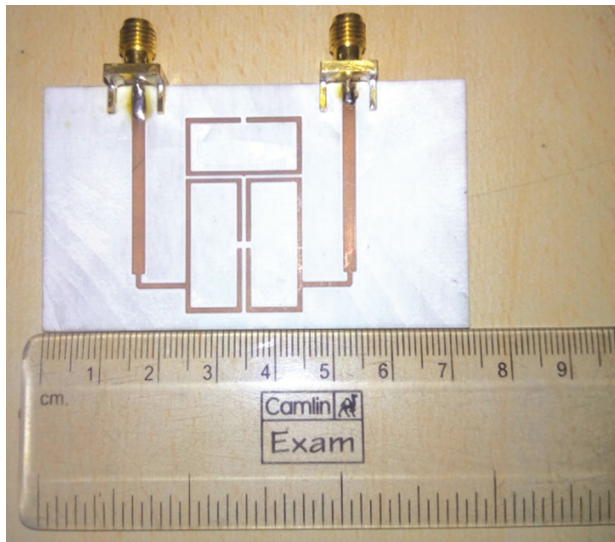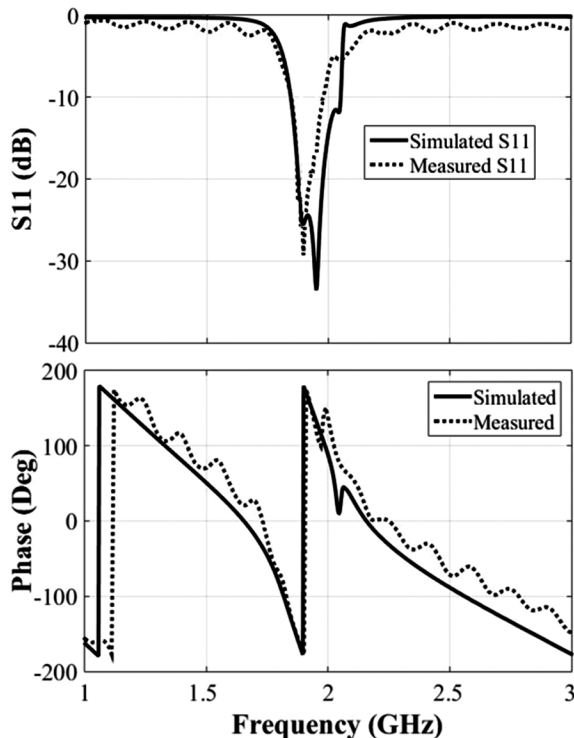

Fig. 5 — Photograph of the fabricated filter.

Fig. 6 — Simulated and measured (a) S11, and (b) S_{21}.

10 dB in the desired band. It must be noted from Fig. 7(a) that the phase response of S_{21} is linear in the passband indicating that the group delay in the passband is to be constant in the same. This inference is further reinforced by Fig. 7(b) wherein the group delay response that was measured is plotted. The group delay that was measured in the pass band is constant around 3 ns which also agree well for practicality of the filter, as filters with non-linear phase response and variable group delay lead to distortions in the received signal. Furthermore, it could also be noted that the VSWR in the passband varies between 1 and 2 (corresponding levels are indicated in Fig. 7 (c)), which is recommended for any filter. It could be inferred from the Fig. 7(d) that depicts a smith chart that the impedance is close to 50 ohms at the centre frequency which indicates good matching. Table 4 provides the FBW obtained in this filter in comparison with relevant literature, as given below.

It is very clear from Table 4 that design with optimized parameters provide a high FBW of 13.84%, which is superior compared to these existing reports of similar designs.

3.1 Effect of filter on DTH link

The fabricated filter is included in the DTH downlink and its influence is analysed. The experimental setup of the DTH downlink is the same as that used in[12,13]. A photo of the same is depicted below in Fig. 8 (a).

The DTH satellite receiver dish is connected to the set-top box and the spectrum analyser by means of coaxial cable. The filter was attached to the coaxial cable by suitable means of connector type conversions and then onto the spectrum analyser (Agilent E4402B) to investigate the effect of the filter on the DTH link. Also, the spectrum analyser was interfaced to a computer (as shown in Fig. 8 (a)) to record the readings obtained in it. Moreover, a self-explanatory block diagram of the setup depicted above in Fig. 8 (a) is shown in Fig. 8 (b),

The effect of the filter on the DTH downlink spectrum for both IF bands, with and without the filter is depicted in Fig. 9 (a and b).

One of the primary motivations of the filter is to bring in improvement in the signal characteristics. From the measurement, it was observed that the signals in the pass band are less attenuated, whereas out of band signals are attenuated more than 10 dB, leading to better selection of channels.

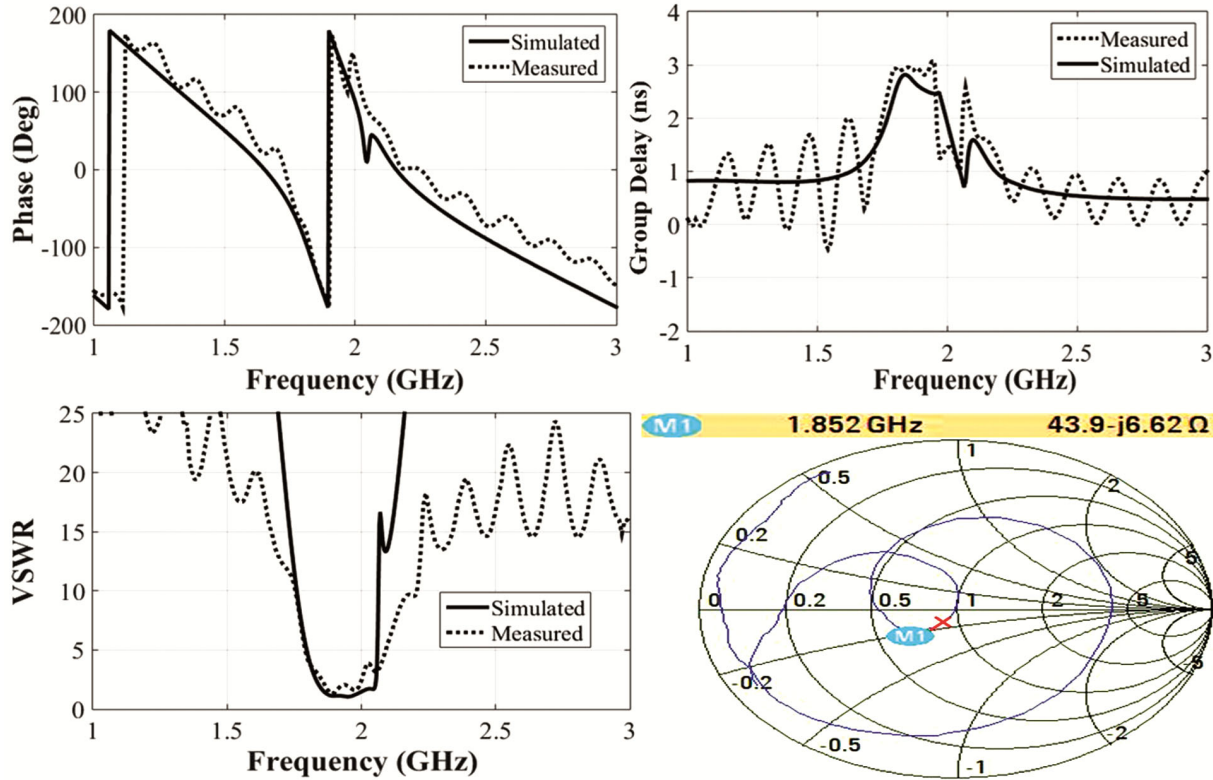The analysis of DTH signals pertaining to the RF section of cable TV is evaluated in terms of Carrier to

Fig. 7 — Measured (a) S21 phase response, (b) Group delay response, (c) VSWR, and (d) Impedance.

Table 4 — Comparison of the FBWs

Author	FBW (%)	Centre frequency (GHz)
Hossein Saghlatoon and Mohammad H. Neshati[9]	1.252	2.4
JS Hong and M.J.Lanchaster[1]	4.42	0.9
A Ismail, M S Razalli, M A Mahdi, R S A R Abdullah N K Noordin and M F A Rasid[10]	3	10
Chu-Cheng Yang, Chi-Yang Chang[2]	3.33	2.94
P Castillo-Araníbar, P Rodríguez-Postigo, A García-Lampérez, DSegovia-Vargas[11]	9.48	1.795
This Paper	13.84	1.95

Noise Ratio (CNR). It could be observed from Fig. 9 (a), that the average noise floor level for the signal without the filter happens to be around - 50dBm while that with the filter occurs to be about -65dBm. Similar observations could be made from Fig. 9 (b) wherein the noise floor level with and without the filter are – 55dBm and -60dBm respectively. Meanwhile, analysis into the measurements relating to carrier power level and noise floor level along with associated CNR values helps us perceive the effect of the filter. Thereby, the influence of the filter on the signal characteristics is depicted in Tables 5 and 6, as follows.
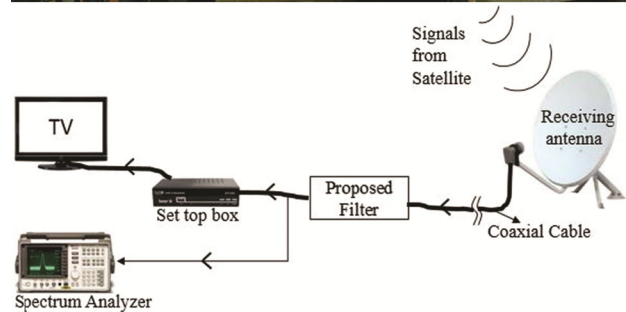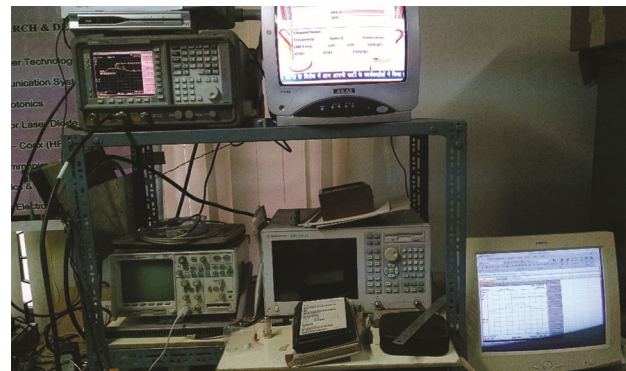

Fig. 8 — Experimental setup (a) photograph, and (b) schematic.

It is observed from Tables 5 and 6 that the addition of the filter in the downlink leads to reduction of the noise floor level throughout the whole range of DTH
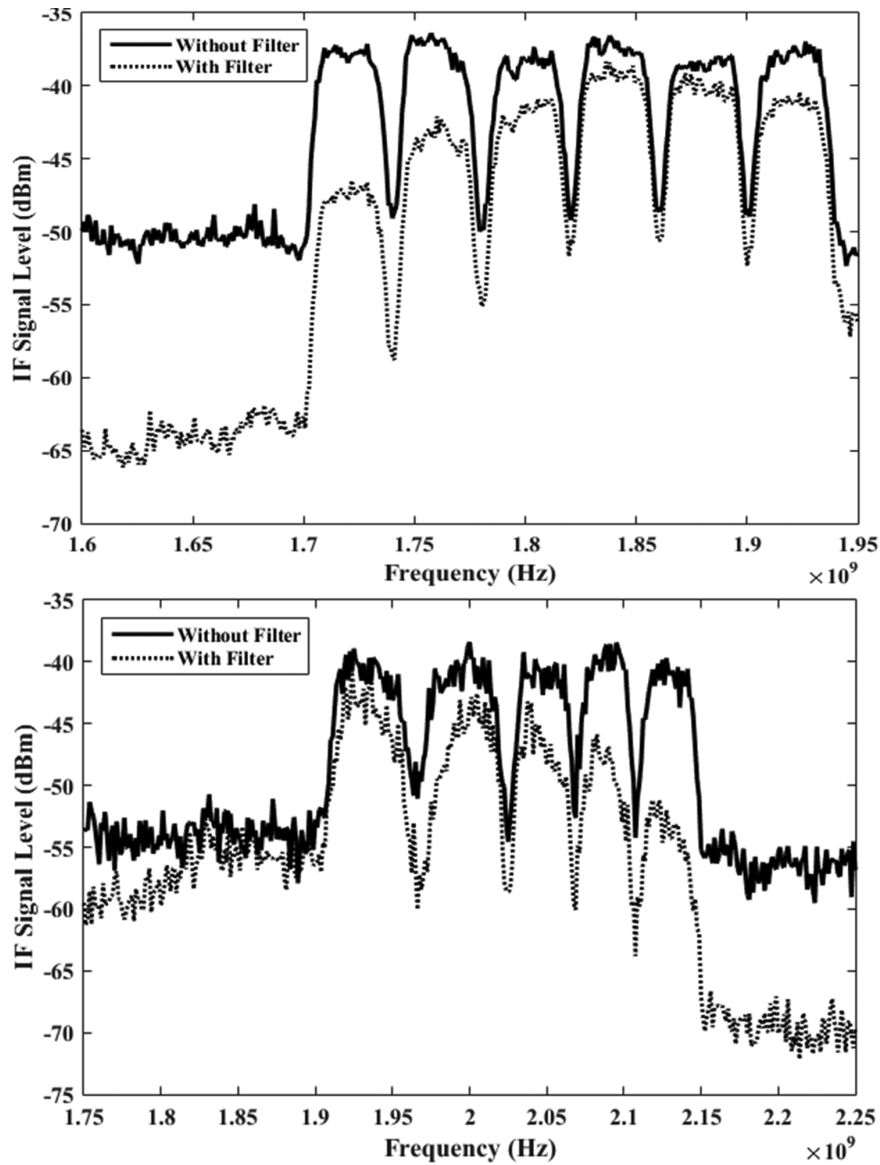
Fig. 9 — DTH Spectrum (a) Low-band IF specific to passband, and (b) High-band IF specific to passband.

spectrum irrespective of the frequency. Also, the reduction in the power level can be attributed to the insertion loss present in the filter. However, the carrier power levels are not drastically reduced. All the more, the reduction in the noise floor levels along with a minor reduction in carrier power levels implies that the CNR levels improve. Since the filter is followed by Automatic Gain Control (AGC) system in the set-top box, reduction in the carrier power level is of little or no consequence. A basic equation substantiating the direct correlation between the CNR and the SNR levels in a DTH system is as below,

$$E_b/N_0 = (C/N) * (B/R) \qquad \ldots (2)$$

Wherein, E_b/N_0 is the Energy per bit to noise density, C/N denotes CNR, B denotes Bandwidth and R denotes information in bits per sec. Hence, an improvement in CNR leading to better signal characteristics and an enhancement in DTH system performance is realised.

Besides, it could be also observed that for other frequency bands (outside the frequency band of interest), the filter provides high attenuation. This essentially means that the filter provides means to restrict and limit the channels of access to the subscriber. Apart from channel restriction it helps in avoiding abuse of the system rather than for the stated requisitions. Further, any set of channels could be

Table 5 — Low-band IF

Frequency (GHz)	LNBC Frequency (GHz)	Parameter	Without filtering	With filtering
		Noise Floor	-50dBm	-65dBm
11.550	9.750	Carrier Level	- 38.28dBm	-40.08dBm
		CNR	11.7dB	24.92 dB

Table 6 — High-band IF

Frequency (GHz)	LNBC Frequency (GHz)	Parameter	Without filtering	With filtering
		Noise Floor	-55dBm	-70dBm
12.600	10.600	Carrier Level	-40dBm	-42dBm
		CNR	15 dB	28 dB

received by just adjusting the parameters pertaining to the alternate polarisation in the DTH receiving dish.

4 Conclusion

An efficient microstrip trisection filter has been proposed for DTH-IF signal filtering. A microstrip trisection bandpass filters consisting of cross-coupled open-loop resonators was designed using ADS software package. The filter provides a bandwidth of 270 MHz and a centre frequency of 1.95GHz. The Fractional Bandwidth (FBW) of the filter which equates to about 13.84% presented herein has been much higher than most cascaded trisection filter designs present in literature. The filter serves to limit

the bands of reception which could prove to be useful for restricted access and also to maintain conformance to its stated requisition. Finally, the fabricated filter has been experimentally tested on DTH link to analyse the effect of the filter. In addition to reduction in the noise floor levels, it also leads to improvement in CNR, and thereby the RF signal characteristics of the DTH reception systems.

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