International Journal of Information Technology and Knowledge Management
July-December 2012, Volume 5, No. 2, pp. 409-412

ARCHITECTURE AND SYSTEM DESIGN ASPECTS OF RF FRONT-END BLOCKS FOR AN ADVANCED CATV STB CONVERTER

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Abstract: This paper proposes a suitable RF Front-end architecture for a Cable TV set top box application having video, audio and data support and features. The system design aspects are covered to meet the input signal's broad frequency range and signal flatness. The architecture supports both downstream and upstream signal interface for a partial bi-directional functionality. System Gain and Noise Figure analysis is carried out while finalizing the type of RF architecture. Simulation and measurement has been performed to support the design analysis. A system front-end noise figure of 3dB and unity-gain requirement is met as per target performance requirement.

***Keywords*:** CATV, QAM, STB, Tuner, RF Front-end, DOCSIS.

1. INTRODUCTION

In the contemporary scenario, the modern day television viewers are having the luxury of watching the Television (TV) program in a variety of multimedia devices ranging from a traditional TV set to a smart-phone device using 3G data connectivity. While the TV services have gone through a tremendous amount of evolutions in terms of their content and delivery mechanisms [1-2], the end device also has gone through a similar kind of upgradations to support the kind of media being delivered to the end user. When it comes to TV program broadcasting, there are three different types of distribution mechanisms which are in place as on today, namely, over the air (OTA) terrestrial method, direct to home (DTH) satellite method, Operator-specific Cable Television (CATV) method. In all of these methods, the end device is either an analog or a digital TV set which captures the media and displays the video and audio content. Also, in the DTH and CATV type of services, there are additional type of set top boxes which are required to decode the incoming signal and feeding it to the TV set. This is generally known as a Set top Box (STB). Commonly available STB's have also gone through lot of enhancement in terms of their feature addition and hardware functionality. To add to this, over the last few years, lot of momentum is happening around the world for the digital TV transition [3-4], which again puts the STB's to undergo another level of change in its functionality. This is particularly applicable for CATV domain. A common architecture for a generic CATV STB is as shown in figure 1.

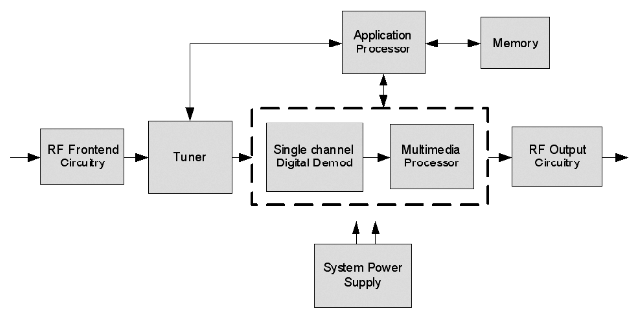

Figure 1: Generic CATV STB Architecture

A fair amount of research work has been published on the development of different types of STB's [5-9]. However, the key limitation of all these devices are in the flexibility of the architecture and the hardware limitations which is not suitable for handing a broad range of RF input frequency range and also in terms of handling the multi-QAM digital video and audio content.

To cater to this need, our present work illustrates the system level challenging requirements and supports the same with advanced type of front-end architecture arrangement. The suggested system blocks are also analyzed in terms of their gain and noise figure performance using simulation and some key parameters are also verified in actual test environment which are described as part of this paper.

2. RF FRONT-END DESIGN FOR CATV STB

Modern CATV STB's come with various types of advanced features. To support these features at the hardware level, the RF front-end should be designed to cater to key the specifications such as the input signal level, gain, noise figure, flatness, etc. Following sections illustrate in more detail some of these system level design requirements and their implementation related aspects.

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2.1 Specification Requirements

The current CATV STB shall support multimedia such as digital video and audio, analog video and audio, and bi-directional data for both upstream and downstream paths. In this regard, several standard documents specify the RF input interface requirements [10-11]. Following are the key requirements for the STB RF Front-end as listed in Table 1.

Table 1
RF Front-end Requirements

Multimedia Type	*RF Parameters*	*Specification*	*Units*
Analog Video/ Audio	Sensitivity	0 ~ 15	dBmV
	Frequency Range	55 ~ 550	MHz
	Channel Bandwidth	6	MHz
Digital Video/	Sensitivity	–6 ~ 9	dBmV
	Frequency Range	550 ~ 860	MHz
	Channel Bandwidth	6	MHz
Out-of-Band Signaling (DOCSIS)	Frequency	5-42	MHz
	Channel Spacing	1.0/2.0	MHz
	RF Transmission Rate	1.544/3.088	Mbps

As seen from these requirements, it is evident that the analog and digital video RF parameters have to be maintained over a broad frequency range. Also, the input signal level has to be maintained respectively for the respective signals.

2.2 Proposed Architecture

To support the bidirectional flow of signals, the RF front-end architecture and its key parameters should be aligned accordingly. In the current architecture arrangement, a front-end block such a Cable Modem (CM) facilitates this feature. The cable modem used is a Data Over Cable Service Interface Specification (DOCSIS) compliant block. While the CM takes care of the bi-directional data transfer, the uni-directional path of the RF frontend section is constituted with the combination of the following: A low noise amplifier, impedance matching sections, and a signal-distributing block. Further, the signal distributing block is realized with the help of a splitter circuit which again re-distributes the signal into three separate paths, namely, (*i*) Pass-thru section for both analog and digital TV's, (*ii*) Down-conversion path for analog TV's, and (*iii*) Band-split section supporting digital-only TV's.

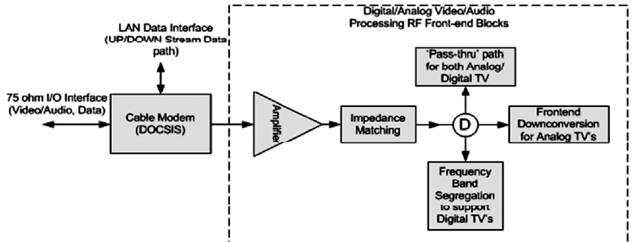


Figure 2: RF Front-end Blocks of CATV Digital STB

As shown above, the RF Front-end blocks have different target requirements to be met as listed in table 1. While the Out of band signaling requirements have to be met by the cable modem, the analog and digital video and audio requirements are mainly for the RF Front-end input blocks and the three distributed paths as shown in figure 2.

3. SYSTEM ANALYSIS AND DESIGN TRADE-OFF

The system design requirements for each of the front-end sections should be to maintain the signal quality of the input QAM signal in terms of noise figure, gain, signal flatness, etc. In addition to the high-level block arrangement of the front-end as shown in figure 2, there are additional RF blocks which are also incorporated as part of the respective sections to meet these system level requirements. These are captured in table 2 and table 3 in terms of their specification parameters.

3.1 System Gain Budget Calculation

The system gain budget is carried out for the circuit elements to ensure the 'zero-gain' requirements of the front-end and also for each of the paths except for the high pass section. For the high-pass section, there is 'non-zero-gain' is aimed to ensure the signal level requirements in line with the RF output section having up-converter sections as per [12].

The system gain analysis is calculated based on the following basic calculation:

$$G\_t = G_1 + G_2 + \ldots . Gn \quad (1)$$

Where, G_1, G_2, etc. are the individual gain (or, loss) of the respective circuit elements in the cascade arrangement. G_t is the total gain (or, loss) of the section; also called as path-gain.

Table 2
Gain Budgeting for Input Section and Tuner Section

Input Section		*Tuner (Down-conversion) section*	
Circuit Elements	*Insertion-Gain (dB)*	*Circuit Elements*	*Insertion-Gain (dB)*
RF Protection device	–1	Cable Modem (loop-through path)	–2
Input Amplifier-1	15	Input Amplifier-2	21.66
3-way splitter (75 ohm)	–6.27	Attenuation pad-1	–10
Downstream filter	–1	Input Amplifier-2	21.66
3-way splitter (75 ohm)	–6.27	Attenuation pad-2	–6
–	–	Matching pad (50-75 ohm)	–5.9
–	–	3-way splitter (75 ohm)	–6.27
–	–	Attenuation pad-3	–7
–	–	3-way splitter (75 ohm)	–6.27
Path Gain	**0.46**	**Path Gain**	**–0.12**

The pass-thru path has to meet the broadband RF requirements for both the analog and digital video and audio parameters. This path has to be a 'unity-gain' chain while maintaining the signal quality like the input and tuner section. However, for the high-pass section, the gain is budgeted so as to comply with the upconverter section of the STB.

Table 3
Gain Budgeting for Pass-thru Section and Band-splitting Section

Pass-Thru section		*High Pass Filter (Band-splitter) Section*	
Circuit Elements	*Insertion-Gain (dB)*	*Circuit Elements*	*Insertion-Gain (dB)*
Cable Modem	–2	Cable Modem	–2
Input Amplifier-2	21.66	Input Amplifier-2	21.66
Input Amplifier-2	21.66	Input Amplifier-2	21.66
Attenuation pad-1	–10	Attenuation pad-1	–10
Attenuation pad-2	–6	Attenuation pad-2	–6
Matching pad (50-75 ohm)	–5.9	Matching pad (50-75 ohm)	–5.9
3-way splitter (75 ohm)	–6.27	3-way splitter (75 ohm)	–6.27
RF Switch	–0.7	Matching pad (50-75 ohm)	–5.9
Attenuation pad-4	–13	Attenuation pad-3	–14
–	–	HPF	–3
–	–	8-way combiner	–10
–	–	Attenuation pad-4	–13
–	–	Input Amplifier-2	21.66
–	–	Input Amplifier-2	21.66
–	–	Attenuation pad-4	–13
–	–	Matching pad (50-75 ohm)	–5.9
Path Gain	**-0.55**	**Path Gain**	**–8.33**

3.2 System Noise Figure Estimation

The system noise-figure analysis is estimated using the following Friis' noise equation:

$$F\_t = F1 + [F2-1]/G1] + [(F3-1)/G2G2] + \\ ...[((Fn-1)-1)/G1G2Gn-1] \qquad (2)$$

Where, $G1$, $G2$, etc. are the individual gain (or, loss) of the respective circuit elements in the cascade arrangement. $F1$, $F2$, etc. are the individual noise-factor of the respective circuit elements in the cascade arrangement. F_t is the total noise factor of the cascades stages.

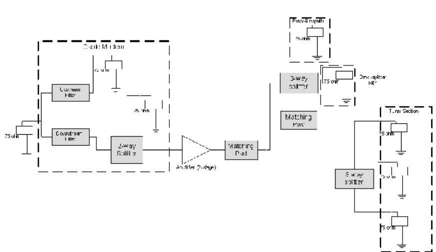


Figure 3: Basic Circuit Elements of RF Front-end for Simulation

Figure 3 shows a basic representation of the RF front-end section. The cable modem block has been approximated into simplified blocks consisting of the upstream and downstream filters alongwith power splitter and terminations. Some of the specifications of these blocks are derived from the requirements as listed in table 1. Additionally, the parameters of other circuit elements have been taken from the data sheet values as listed in table 2 and table 3.

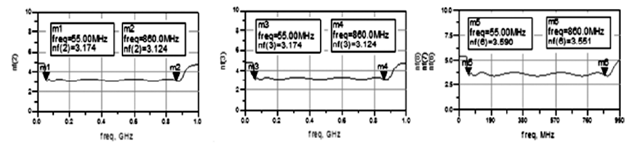


Figure 4: Cascade Noise Figure Estimation for RF Front-end

A system level s-parameter simulation is carried out to estimate the noise figure of the front-end section. The simulation results are shown in figure 4. As shown in simulation results, the noise figure for the pass-thru path is 3.15 dB. At the same time, the noise figure for the high pass path and tuner path is 3.15 dB and 3.57 dB respectively.

3.2.1 *Band-Split section*

This section uses a synthesized high pass filter block which has been simulated. The high pass filter performance is shown in figure 5. An elliptic filter topology with seventh order has been used for realising this high pass filter. This filter has been simulated with *s*-parameter data.

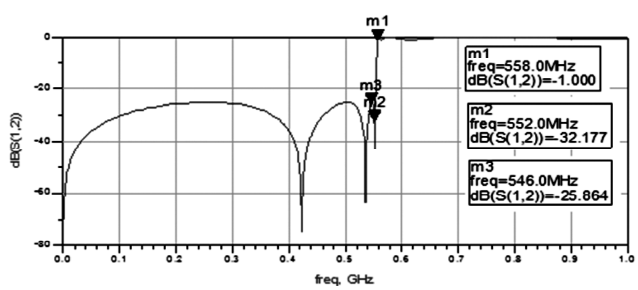


Figure 5: System Simulation for the High Pass Path

The result shows that the pass-band of HPF is from 558MHz to 1000MHz, whereas good rejection is achieved at the lower band between 10MHz to 552MHz. Insertion loss is less than 1.5dB in the pass-band of 558MHz to 1000MHz. The Attenuation is 32dB and 25dB respectively at the stop-band spot frequencies of 552MHz and 546MHz.

4. TEST SET-UP AND MEASURED RESULTS

A basic test setup is shown in fig. 6 for evaluation of the tuner section, which is a key frontend block. An 8-channel 64-QAM Modulated signal is fed to the tuner section through RF Connector and adapter assembly. Bias resistors for the frontend amplifier stages are selectively removed to feed the bias voltage for the devices from external DC power supply. Impedance matching pad is used between the tuner and instruments to take care of the impedance transitioning.

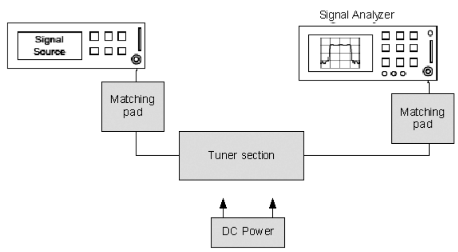
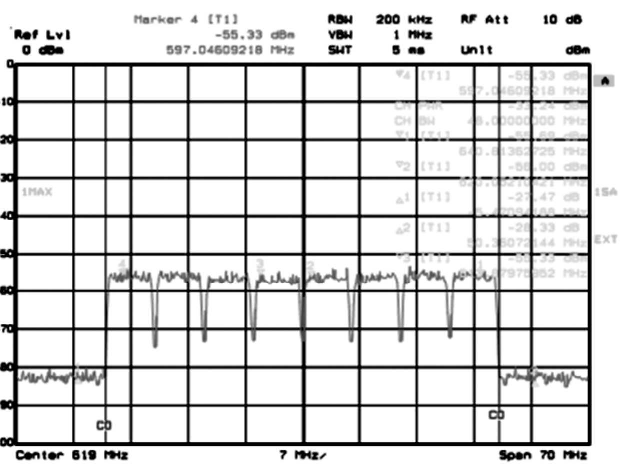
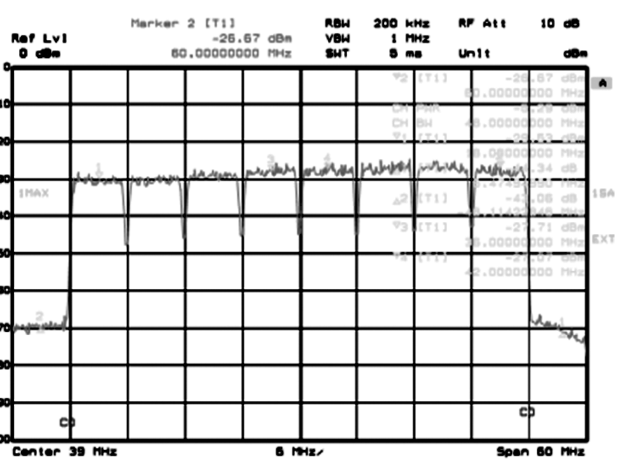


Figure 6: Test Setup for the Tuner Section Evaluation

The input signal has a bandwidth of 598MHz to 640MHz with a channel bandwidth of 6MHz each. As seen in figure 7(*a*) and 7(*b*), an RF signal level flatness of less than 3dB is maintained for the QAM signal over the 48MHz bandwidth for each tuner. The combination of three tuners covers a 150MHz signal bandwidth.



(*a*) **64-QAM Signal Input to Tuner**



(*b*) **64-QAM Signal at Tuner Output**

Figure 7: Tuner Path RF Performance for 64-QAM Signal Stimulus

5. CONCLUSION

In the present work, system architecture has been proposed for the RF front-end for an advanced STB application. Supporting system level design analysis has been performed for gain and noise figure followed by simulation results. Experimental results show good agreement with the frequency range requirements and signal level flatness. Our future work will include detail circuit level analysis and results for the RF Front-end sections of the STB.

REFERENCES

[1] Lennard G. Kruger, “Digital Television: An Overview”, *CRS Report for Congress*, January 2008.

[2] A.K. Sekhar, “An Introduction to Digital Cable TV”, *Part II, Satellite and Cable TV*, January, 2001.

[3] Melissa Chee, “The Global Analog-to-Digital TV Transition Heats Up”, *Global Semiconductor Alliance (GS)*, **15(2)**, June 2008.

[4] “Analog Switch-off: Learning from Experiences in Europe”, *DigiTAG-2008*, ver.1.0.

[5] Yin-Hwa Huang, “Design of an MPEG-Based Set-Top Box for Video on Demand Services”, *IEEE*, 1995, pp. 2655-58.

[6] Lionel J. D’Luna, “A Single-Chip Universal Cable Set-Top Box/Modem Transceiver”, *IEEE Journal of Solid-State Circuits*, **34(11)**, pp. 1647-1660, NOVEMBER 1999.

[7] Mukta L. Kar, et. al., “Retail Set-Top-Box Architecture for Digital Cable Network”, pp. 148-49, IEEE 2000.

[8] “NXP Set-top Box System Solution STB220 for Terrestrial, Cable and Satellite Applications”, *Application Information, NXP Semiconductor*, September 2006.

[9] Chengchen Ge, et. al., “The Intelligent STB-Implementation of Next Generation of Residential Gateway in Digital Home”, IEEE 2007.

[10] “SCTE 40: Digital Cable Network Interface Standard”, 2011.

[11] “ANSI/SCTE 55-2: Digital Broadband Delivery System: Out of Band Transport Part2: Mode B”, 2008.

[12] Rabindra K. Mishra, Ajit K. Panda, Saroj K. Patro, “A Suitable Upconverter Architecture and Design Considerations for Digital Set Top Box for CATV Applications”, *IEEE AEMC’09*, Kolkata, India, Dec’2009.