

Absolute Radiometric Calibration of FRS-1 and MRS mode of RISAT-1 Synthetic Aperture Radar (SAR) data using Corner Reflectors

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Abstract— It's been more than two years since the launch of RISAT-1, India's first indigenous satellite SAR mission. Prior to radiometric calibration of any SAR data, no comparison can be made with any other data. Calibration procedure provides a reference mechanism to SAR DN values. With radiometric calibration digital numbers of SAR data are converted to backscattering coefficients which can be compared with backscattering coefficients of other SAR sensors.

An experiment for absolute radiometric calibration of 13 (thirteen) beams of RISAT-1 FRS-1 mode data and 1 (one) beam of RISAT-1 MRS mode data has been carried out using standard point targets. In this experiment, triangular trihedral corner reflectors were used as standard point targets and deployed prior to satellite overpass with precise azimuth and elevation angles in various selected research sites in India. For FRS-1 mode total 42 (forty two) triangular trihedral corner reflectors were deployed during 2012 – 2014 for 19 (nineteen) dates. 11 (eleven) beams for RH-RV, 4 (four) beams for HH and 1 (one) beam for VV polarisation RISAT -1 data was acquired. For MRS mode during 2013 – 2014 for (six) dates, a total of 14 (fourteen) reflectors were deployed for 1 (one) beam 87-97. These deployed corner reflectors were then located on SAR image and impulse response function for reflectors were derived using box integral method. The derived IRF were used to calculate calibration constant for each of the reflector.

Keywords— Calibration constant, Corner reflector, FRS-1, Impulse Response Function, MRS, RISAT-1.

I. INTRODUCTION

During eighties of twentieth century with launch of SeaSAT spaceborne synthetic aperture radar (SAR) lots of analysis was performed on qualitative basis. However with later spaceborne SAR satellite missions e.g ERS-1/2, Envisat, RADARSAT-1/2, ALOS-PALSAR-1, RISAT-1 data availability has also increased to research community. This increased amount of data has helped building up number of hypothesis and lots of them converted to established theories [1-3]. Thus it is very important to be assured that any SAR data being used for a research study should provide accurate backscatter value. This assurance is derived by a procedure called calibration and data undergone the procedure is referred as calibrated data. Calibration provides a reference mechanism to SAR DN (Digital Number) value so that they represent correct properties of the area illuminated by the sensor. After calibration of SAR data results from obtained from it, can be compared to data from other sensors [4-6]. This assurance also leads to development of parameter retrieval models for various applications [7-15]. For a given SAR image, its DN value is proportional to the received voltage [16]. Therefore, the image intensity I , is proportional to the received power P_r . The process to retrieve SAR backscattering coefficient from the observed SAR image intensity is known as radiometric calibration. [17]. Calibration establishes a relationship between the SAR sensor output and Radar Cross Section (RCS) of a known standard target or distributed target of known RCS [18-20].

Calibration procedure on SAR data can be applied by analysing standard targets response as well as reference distributed targets analysis [21 - 23]. In this study an experiment has been attempted for absolute calibration of

RISAT-1 data by deploying standard targets (triangular trihedral corner reflectors) in various research sites in India.

II. RISAT-1

Radar Imaging SATellite (RISAT-1) is India’s first indigenously developed spaceborne SAR sensor. This C-band active antenna based, multimode SAR payload was launched on 26th April 2012 by PSLV-C19 flight. After positioning at 536 km sun-synchronous dawn-dusk circular orbit it was operated on May 1, 2012. RISAT-1 mission is designed to provide SAR images with a repetivity period of 24 days. Its orbit design takes the space craft crossing the equator in its descending path (north to south) at 6 AM and crosses the equator in its ascending path (south to north) at 6 PM. RISAT-1 SAR sensor transmits a series of electromagnetic pulses of radiation in C band using an active array antenna of 576 transmit receive modules mounted in panel of ~6m X 2m. The electromagnetic pulses strike the earth surface and the backscattered signal is received by the receive modules mounted in the antenna and by time correlated processing of this signal, information about the earth surface is deciphered. RISAT-1 is not only capable of acquiring data in multi polarisation mode, including quad linear polarisation, but it is also first of its kind to operate in hybrid circular polarimetric mode for earth observation [24, 25]. Fig.1 shows a diagram of RISAT-1 SAR beam modes. Specifications of RISAT-1 SAR beam modes are given in Table-I.

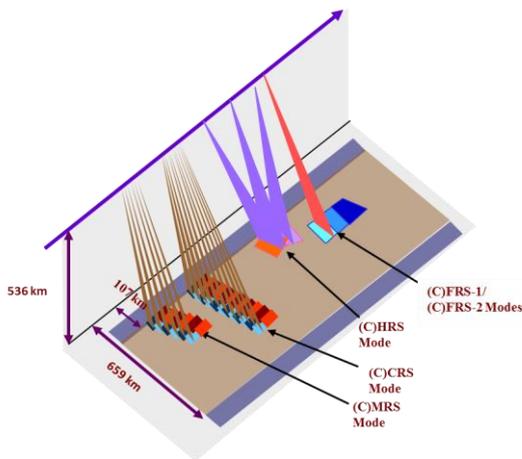


Fig.1: Different beam modes of RISAT-1 SAR

These RISAT-1 beam modes are elaborated in Fig. 2, showing how these beam modes form swath of RISAT-1.

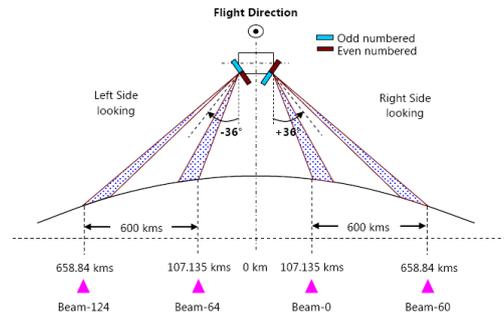


Fig.2 Multiple beams forming various swaths

TABLE I

Specifications of RISAT SAR Beam modes						
Altitude	536 Km					
Frequency	5.35 GHz					
Imaging Modes	HRS/ C- HRS	FRS- 1/ C- FRS- 1	FRS-2/ C- FRS-2	MRS/ C- MRS	CRS/ C-CRS	
Swath Coverage	Selectable within 100 – 700 KM off-nadir distance on either side (200 – 600 KM region is qualified, the rest is unqualified)					
Inc angle coverage	Qualified	200-490 (200-600 Km)				
	Total	100-540 (100 –700 Km)				
Swath/ Spot Km	Defi ned	10x10	30	30	120	240
	Expe rime ntal	100x10	---	---	---	---
Applicable Polarisation combinations	Single / Dual (co+ cross)/ (CH& CV)*	Single / Dual (co + cross) / (CH & CV)*	Quad / (C H&CV)*	Single / Dual (co + cross) / (CH & CV)*	Single / Dual (co + cross) / (CH & CV)*	
Resolution (Az x slant range)	1m x 0.7m	3m x 2m	9m x 4m	21- 23m x 8m	41- 55m x 8m	
Minimum sigma naught (dB) (Qualified Region)	-16.3	-17	-18	-18	-18	
Total no. of beams	64 on each side of the flight track: total 128					
Azimuth and Range ambiguity	< -20 dB					

III. STUDY AREA AND DATA SET

To initiate the experiment of absolute radiometric calibration of RISAT-1 SAR data, first step was to select experimental sites in India for standard point target deployment. Keeping in mind site selection criteria to deploy standard targets [26], for FRS-1 beam mode 2 (two) sites in Ahmedabad, Gujarat, 3 (three) sites in Surendranagar, Gujarat, 1 (one) site in Bhachau, Gujarat and 1 (one) site in Roorkee, Uttarakhand was selected. For MRS beam mode 2 (two) sites in Ahmedabad, Gujarat, 3 (three) sites in Desalpar, Gujarat, and 1 (one) site in Jodhpur, Rajasthan was selected. Triangular trihedral corner reflectors were used as standard point target. Fig.3 and Fig.4 show spatial distribution of selected experimental sites in India, for deployment of corner reflectors in FRS-1 and MRS mode respectively. Corner reflectors were deployed in grounds of Nirma University and Space Applications Centre (SAC/ISRO) Bopal in Ahmedabad, Gujarat whereas for Bhachau, Roorkee, Surendranagar, Jodhpur and Desalpar corner reflectors were deployed in open grounds as shown in Fig.5 and Fig.6 Google Earth image. Triangular trihedral corner reflectors mobilization and deployment is shown in Fig.7. Further detailed description on study area can be found in [27]. A total of 17 (seventeen) FRS-1 data sets & 6 (six) MRS data sets of RISAT-1 were acquired for the purpose of absolute calibration.

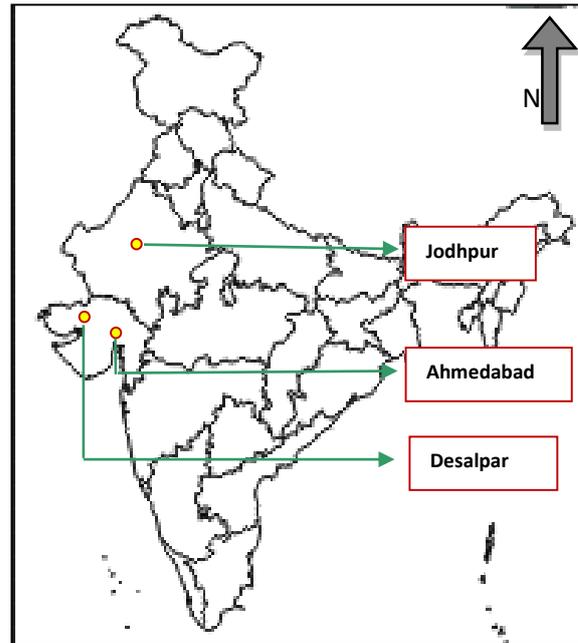


Fig. 4: Spatial distribution of corner reflectors in India for MRS mode (Map not to scale)

For FRS-1 there are 14 (fourteen) acquisition with hybrid polarimetric mode (RH/RV; Right circular transmit and receive in H as well as V polarisation), 1 (one) scene of linear (VV) polarisation mode and 4 (four) scene of linear (HH) polarisation mode. Corner reflectors were deployed for 16 (sixteen) dates of RISAT-1 SAR acquisition over Ahmedabad study area, for one date over Bhachau, one date over Roorkee and one date over Surendranagar as detailed in Table-II. For MRS there are 6 (six) acquisitions in HH polarisation. 1 (one) scene for Jodhpur, 1 (one) scene for Desalpar and 3 (three) scenes for Ahmedabad were acquired as detailed in Table III.

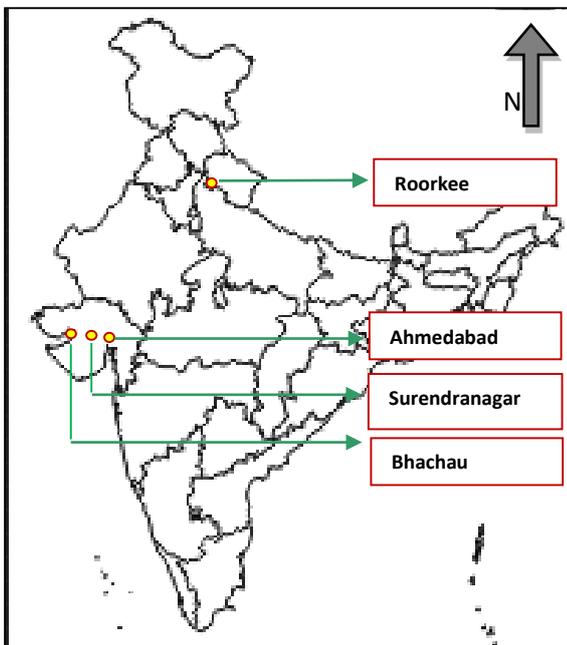


Fig. 3: Spatial distribution of corner reflectors in India for FRS-1 mode (Map not to scale)

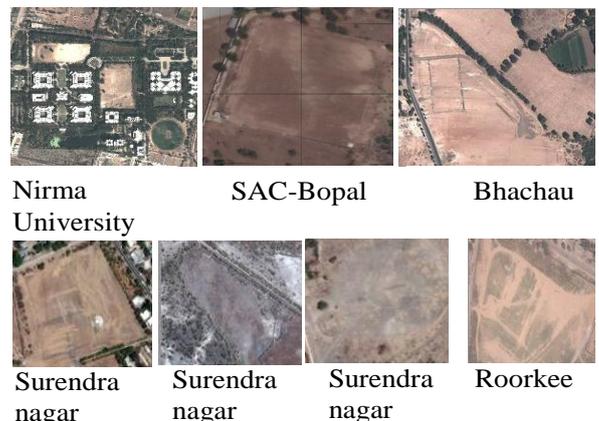


Fig.5: Corner reflector deployment sites in India for FRS-1

TABLE II

Details of corner reflector deployment for different beam modes of RISAT-1 FRS-1						
Sr No	Date	Experiment Site	Beam	Inci Angle	Polarisation	#of reflectors
1	21Jun2012	Ahmedabad	08	19.96	RH, RV	1
2	22Jul2012	Ahmedabad	10	21.8	RH, RV	3
3	02Mar2013	Roorkee	14	25.37	RH, RV	2
4	04Jul2012	Ahmedabad	19	29.64	RH, RV	2
5	01Oct2013	Ahmedabad	40	44.7	RH, RV	3
6	15Dec2013	Ahmedabad	41	45.2	HH, HV	4
7	23Feb2013	Bhachau	71	19.04	RH, RV	1
8	29Jun2012	Ahmedabad	73	20.98	RH, RV	1
9	16Jun2013	Surendranagar	74	21.9	HH, HV	3
10	12Sep2013	Ahmedabad	74	21.8	RH, RV	1
11	30Jun2012	Ahmedabad	94	38.18	RH, RV	1
12	13Jul2012	Ahmedabad	94	38.20	RH, RV	2
13	26Sep2012	Ahmedabad	95	38.90	RH, RV	4
14	28Jun2013	Ahmedabad	95	38.8	RH, RV	4
15	11Sep2013	Ahmedabad	95	38.8	RH, RV	2
16	01Jul2012	Ahmedabad	114	50.38	HH	1
17	06Aug2012	Ahmedabad	115	50.94	HH	2
18	22Feb2013	Ahmedabad	115	50.90	RH, RV	2
19	02Jun2013	Ahmedabad	115	50.91	VV	3

TABLE III

Details of corner reflector deployment for beam 87-97 RISAT-1 MRS						
Sr No	Date	Experiment Site	Beam	Inci Angle	Polarisation	# of reflectors
1	22Feb 2013	Jodhpur	87-97	36.85	HH, HV	1
2	06Mar2013	Desalpar	87-97	36.59	HH, HV	4
3	12Nov2013	Ahmedabad	87-97	36.84	HH, HV	3
4	07Dec 2013	Ahmedabad	87-97	36.84	HH, HV	2
5	01Jan 2014	Ahmedabad	87-97	36.84	HH, HV	2
6	26Jan 2014	Ahmedabad	87-97	36.85	HH, HV	2

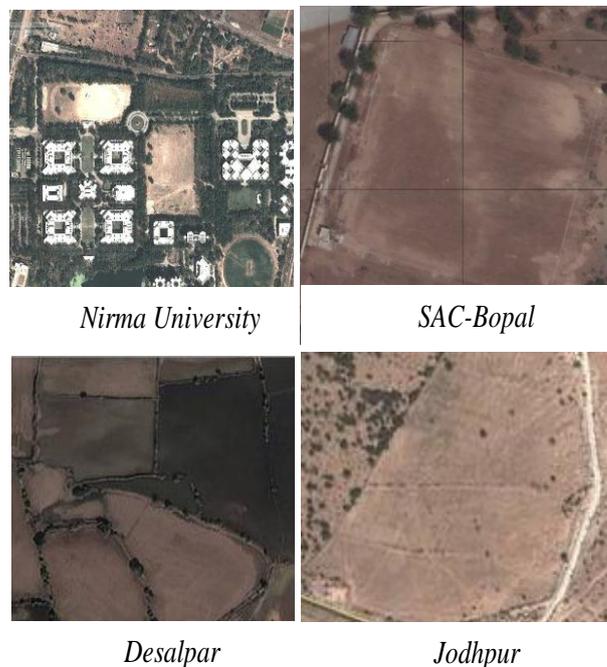


Fig.6: Corner reflector deployment sites in India for MRS



Fig.7: Corner reflectors deployment & mobilization

IV. METHODOLOGY

For absolute radiometric calibration of SAR data it is required to deploy standard point targets with known radar cross section (RCS) accurately pointing towards the SAR sensor over a low clutter region [26, 28, 29] with accurate azimuth and elevation angle couple of hours prior to satellite pass. These angles have to be calculated prior to satellite pass. For this experiment triangular trihedral corner reflectors [27, 28] were used. Deployed standard targets were then located in respective RISAT-1 SAR images. Once the point targets were accurately located in SAR image, integrated power from two dimensional Impulse Response Function (IRF) of the point target was analysed for radiometry, after removing clutter noise for the standard target response.

A. Calibration constant

Calibration constant can be derived by using radar equation [19-20, 30]. A detailed methodology is presented in [29] using integral box method [26] to derive calibration constant, as shown in equation (1):

$$C_{ii} = \frac{P_{ii} \delta_r \delta_a}{\sigma_c f_{int}^2 \sin \theta_{center}} \tag{1}$$

Using this equation once the calibration constant is arrived, equation (2) can be used to convert SAR DN values to backscattering coefficient for that SAR processor:

$$\sigma_i^o = 10 \log_{10} (DN_i^2) - C_{ii} + 10 \log_{10} \sin \theta_i - 10 \log_{10} (\sin \theta_{center}) \tag{2}$$

Where

P_{ii} = Integrated interpolated power for the target

$\delta_r \delta_a$ = Range and azimuth resolution

σ_c = Radar cross section

f_{int} = Interpolation factor used to arrive at P_{ii}

θ_{center} = Central incidence angle

DN = Digital Number

θ_i = local incidence angle at pixel i

V. RESULTS AND DISCUSSION

Triangular trihedral corner reflectors have been used to carry out calibration of multi-polarised RISAT-1 SAR intensity data using 19 (nineteen) scenes of FRS-1 consisting of 4 (four) HH, 1 (one) VV polarized and 14 (fourteen) circular transmit linear receive. For MRS 6 (six) HH polarised scenes were used. Calibration has been carried out by analysing standard targets' IRF.

A. Calibration Constant Using Point Target Impulse Response

As detailed in [30] RISAT-1 SLC data were taken to frequency domain using FFT and were interpolated in frequency domain with an interpolation factor of 16 in range and 16 in azimuth direction. An inverse FFT resulted in 16x interpolated IRF for point targets [31]. Thus, for all the reflectors, interpolated Impulse Response Function (IRF) was derived. Hence, for FRS-1 there were in all 29 (twenty nine) IRF were available for RH polarisation and 29 (twenty nine) IRF for RV polarisation. For HH polarisation, 10 (ten) IRF were studied and for VV polarisation 3 (three) IRF were studied. For MRS mode 14 (fourteen) IRF for HH polarisation were studied. Integrated power from two dimensional impulse responses has been analysed for radiometry after removing clutter noise for the standard target. Fig. 8 shows corner reflector in FRS-1 RISAT-1 SAR image and impulse response for a point target in RH polarisation. Fig. 9 shows corner reflector in MRS RISAT-1 SAR image and impulse response for a point target in HH polarisation.

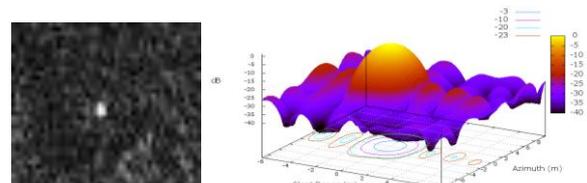


Fig. 8: A) Point target as observed in FRS-1 image
B) Impulse Response Function for RH

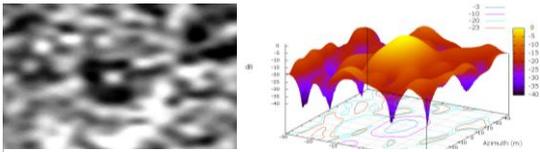


Fig. 9: A) Point target as observed in MRS image
B) Impulse response Function for HH

After removing clutter noise, point target impulse response has been used to derive calibration constant using equation (2). Calibration constants derived for RISAT-1 SAR FRS-1 mode RH, RV, HH and VV polarisation for each of the point targets are plotted in Fig.10 through Fig.42. Calibration constants derived for RISAT-1 SAR MRS mode HH polarisation for each of the point targets are plotted in Fig.43 through Fig.48.

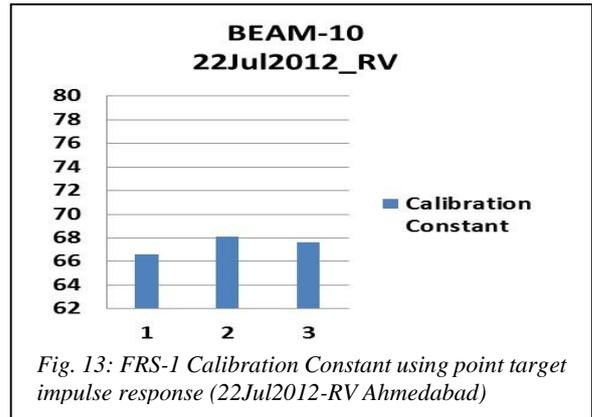


Fig. 13: FRS-1 Calibration Constant using point target impulse response (22Jul2012-RV Ahmedabad)

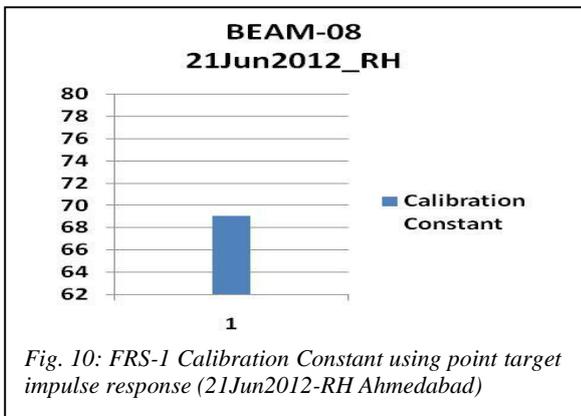


Fig. 10: FRS-1 Calibration Constant using point target impulse response (21Jun2012-RH Ahmedabad)

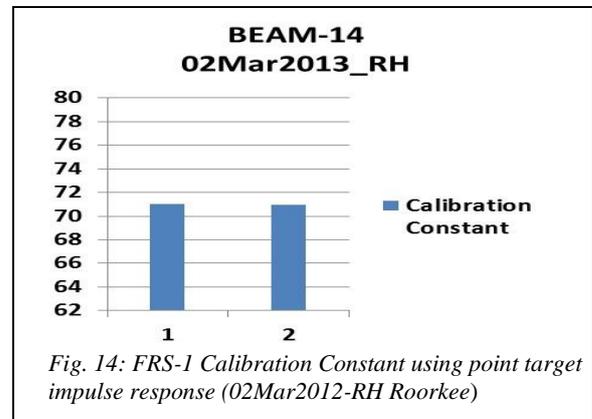


Fig. 14: FRS-1 Calibration Constant using point target impulse response (02Mar2012-RH Roorkee)

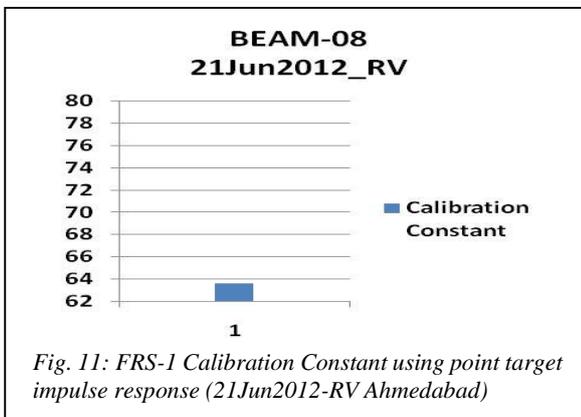


Fig. 11: FRS-1 Calibration Constant using point target impulse response (21Jun2012-RV Ahmedabad)

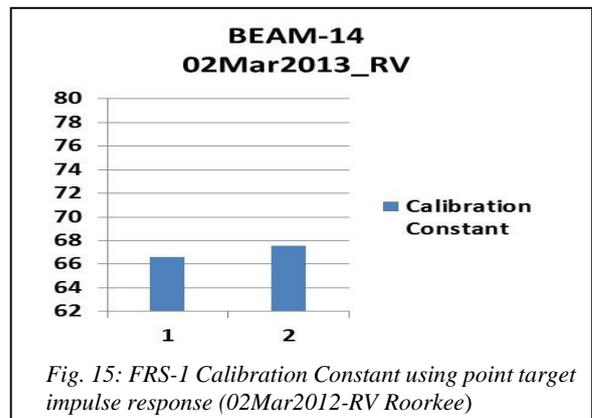


Fig. 15: FRS-1 Calibration Constant using point target impulse response (02Mar2012-RV Roorkee)

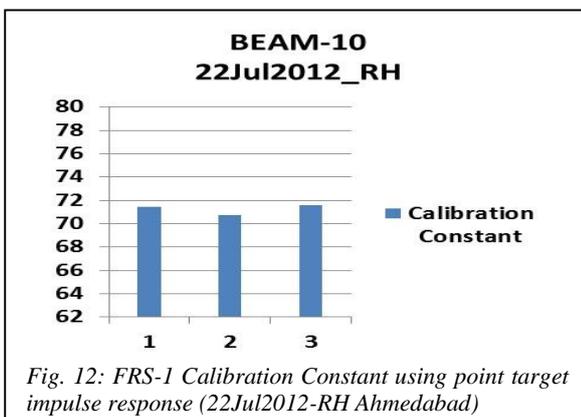


Fig. 12: FRS-1 Calibration Constant using point target impulse response (22Jul2012-RH Ahmedabad)

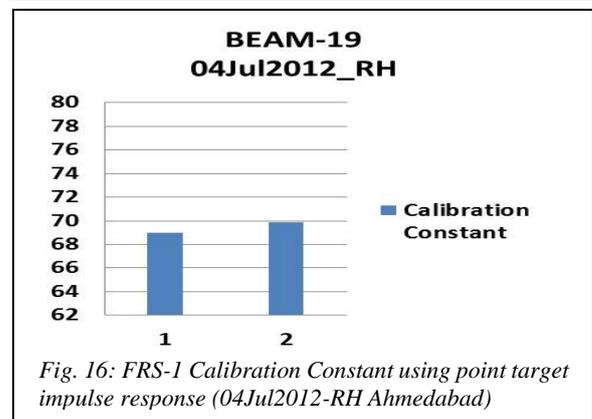
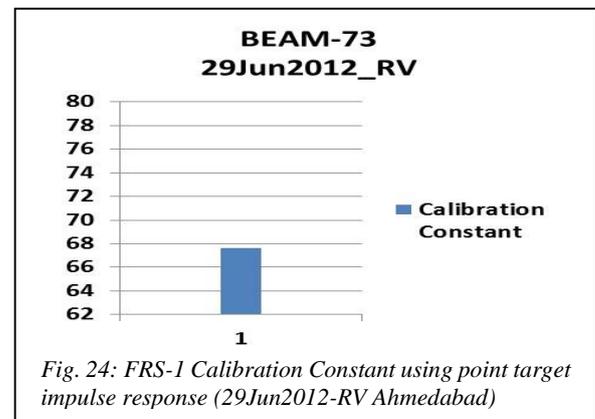
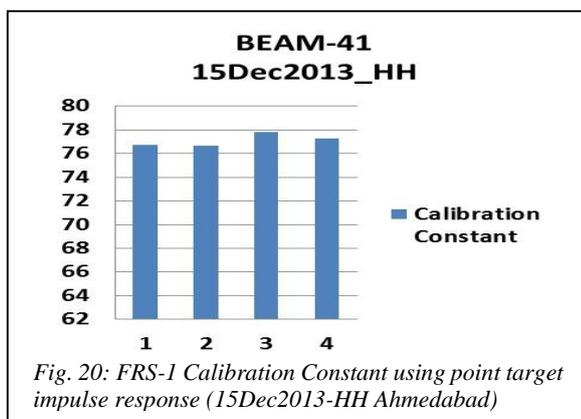
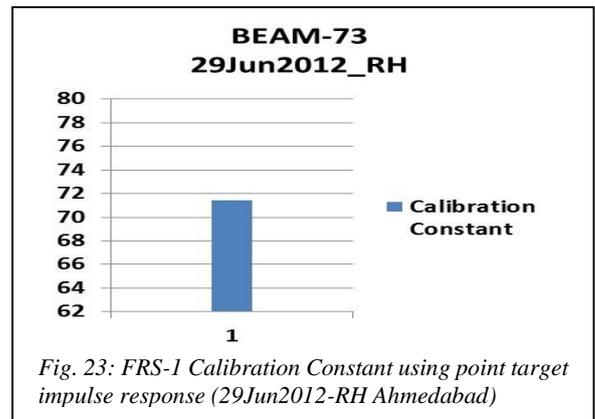
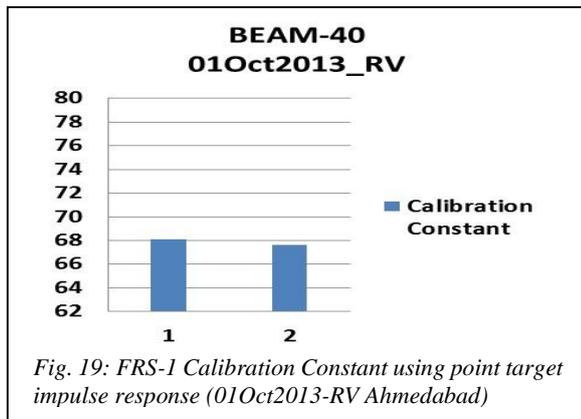
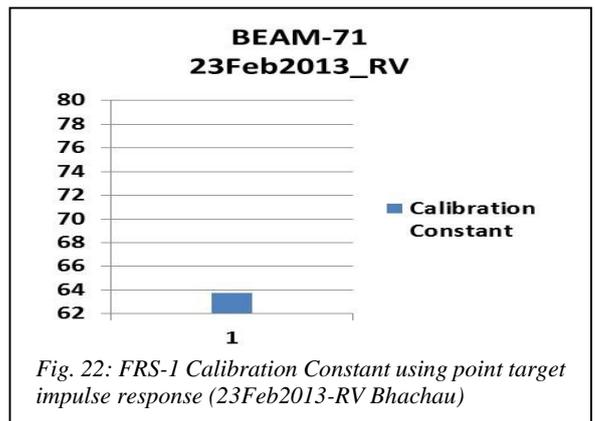
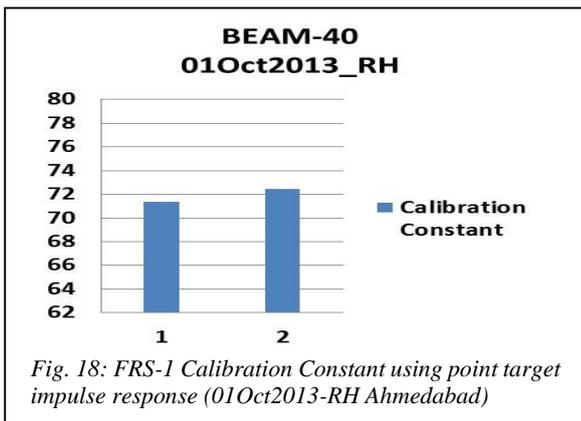
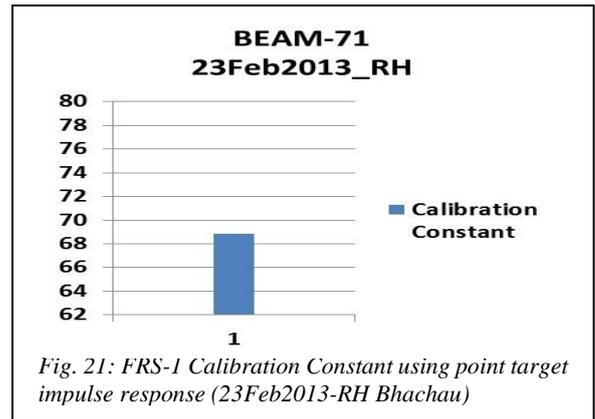
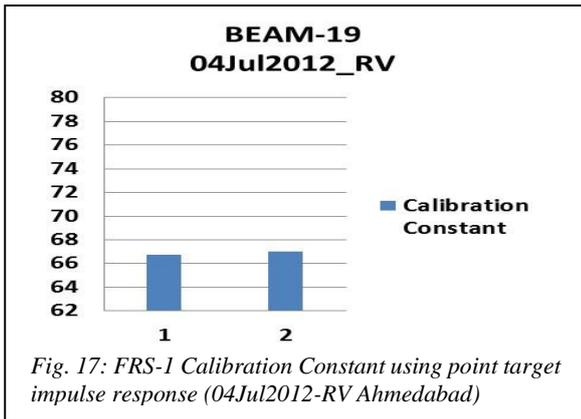
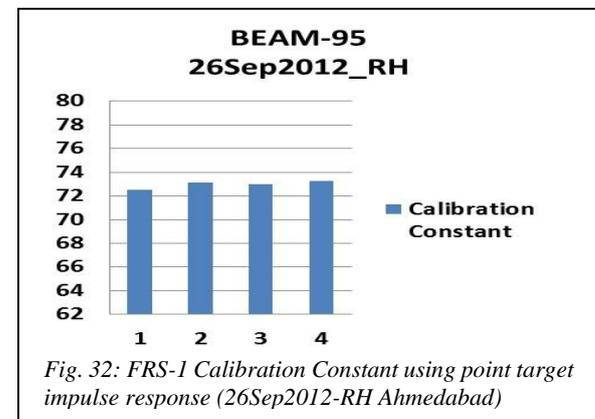
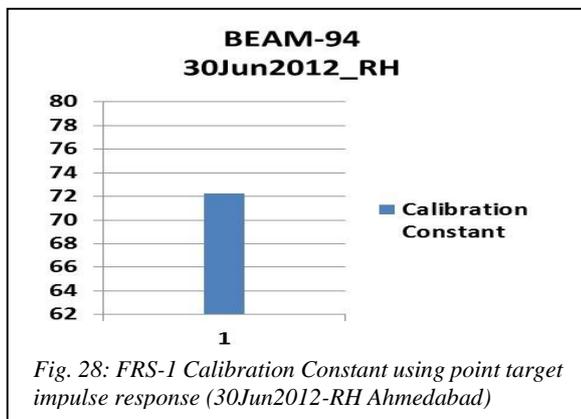
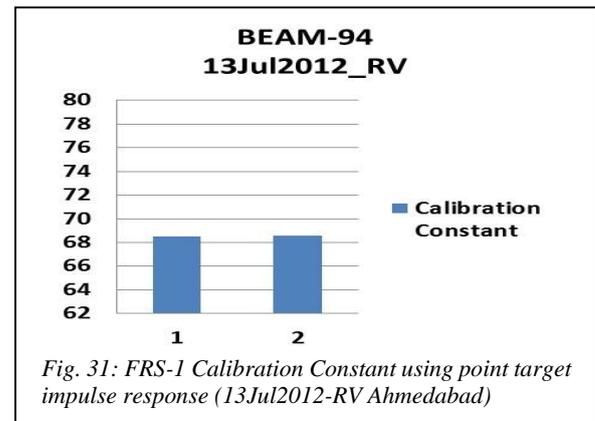
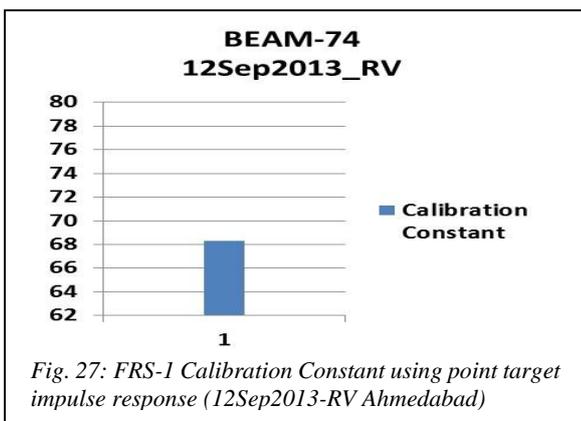
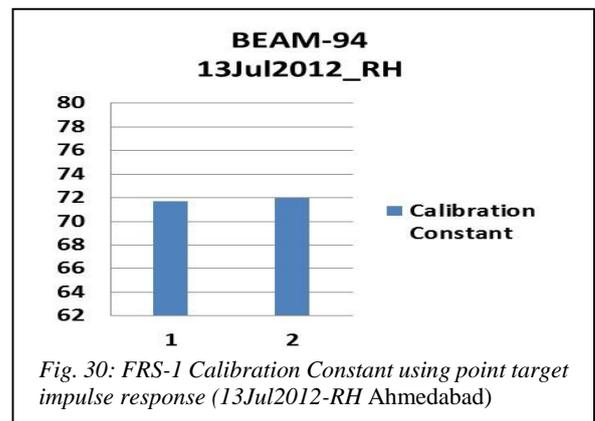
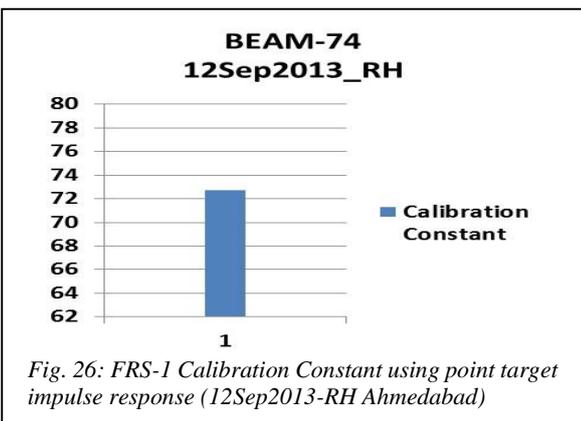
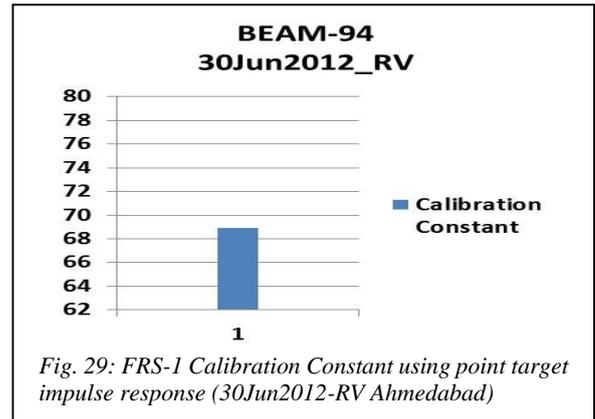
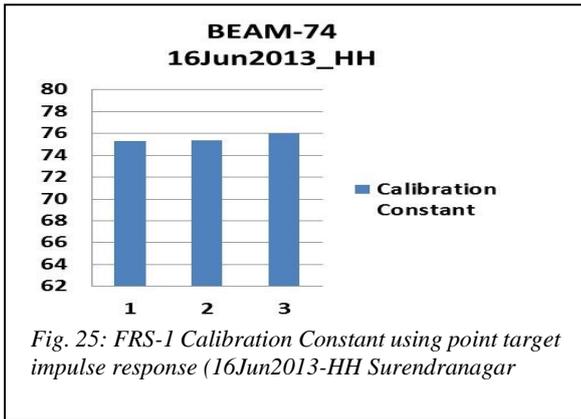
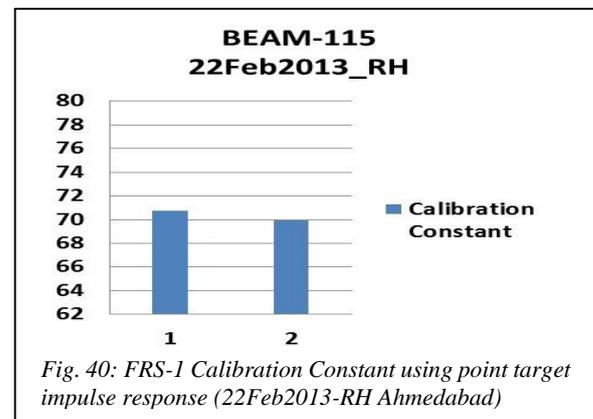
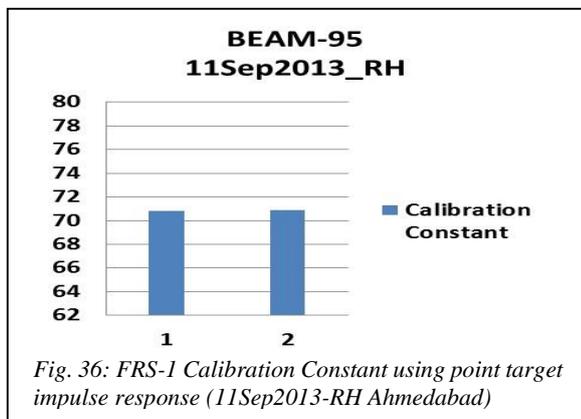
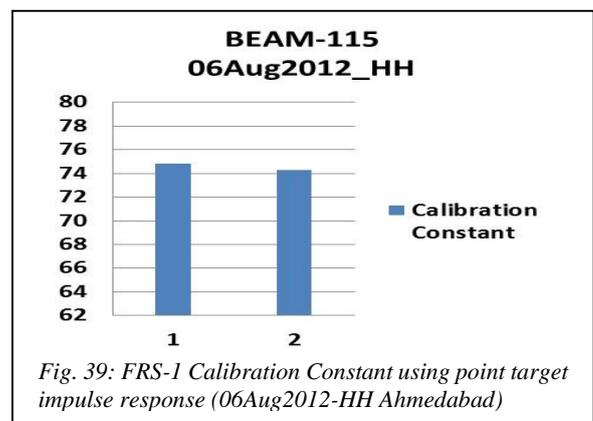
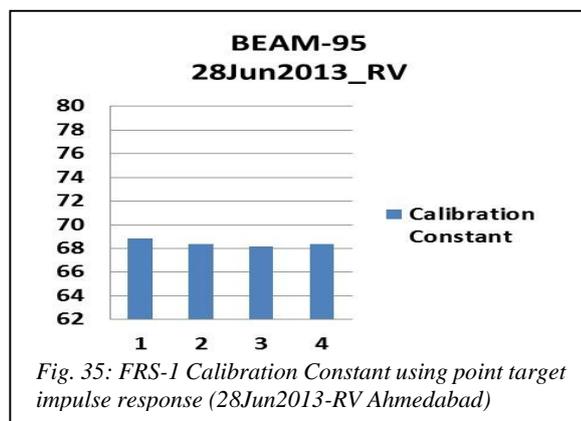
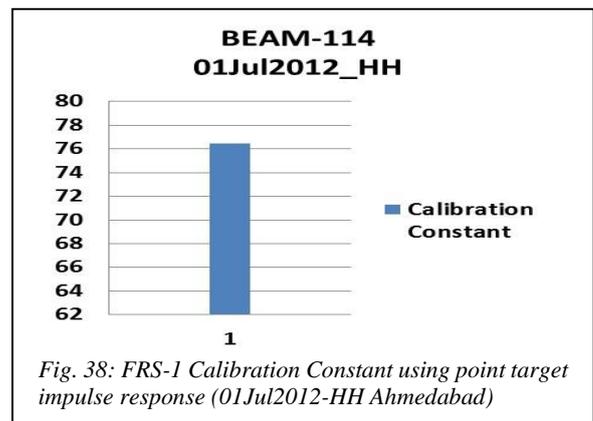
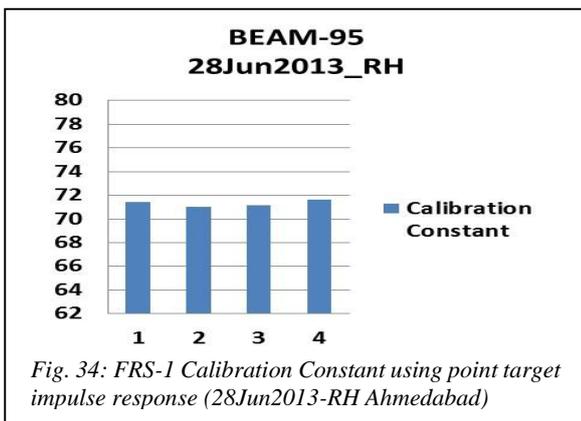
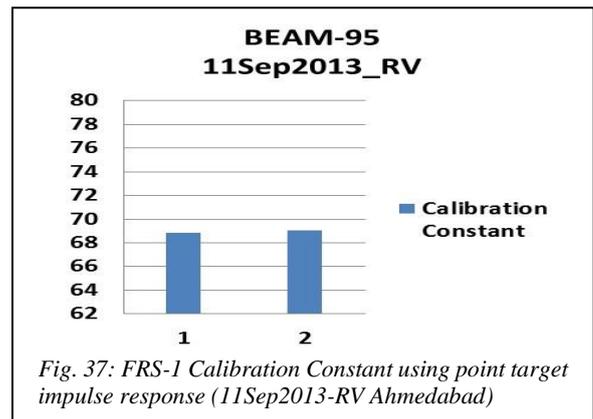
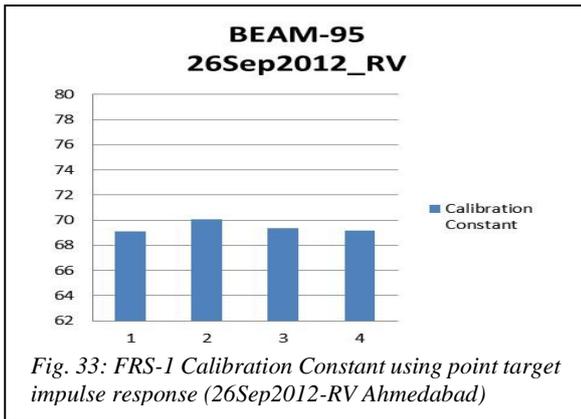
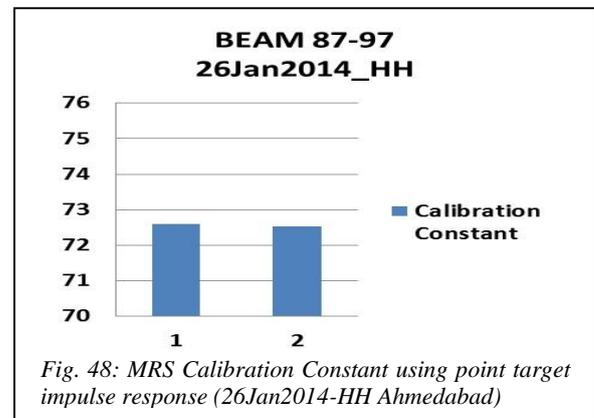
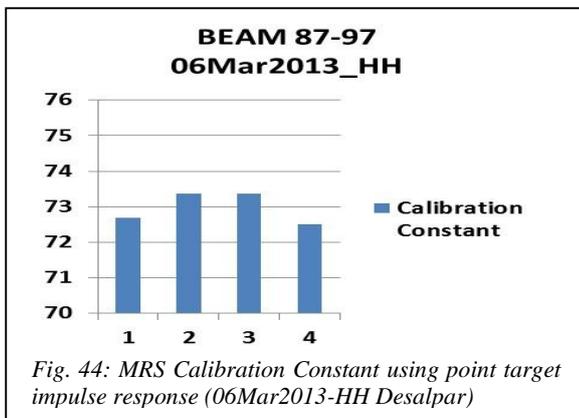
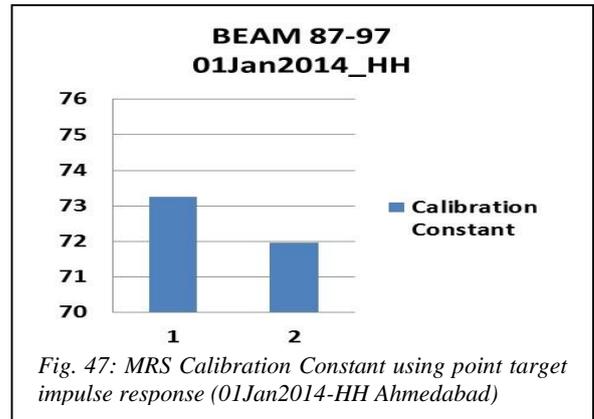
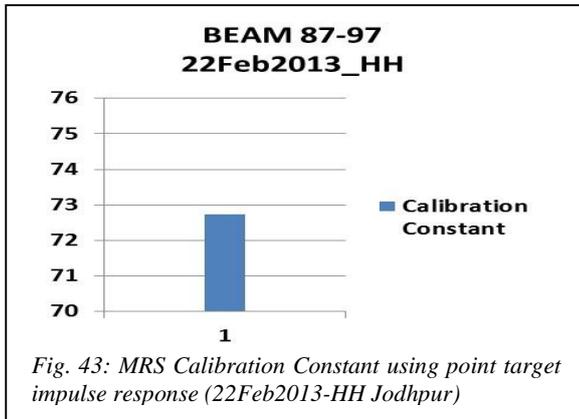
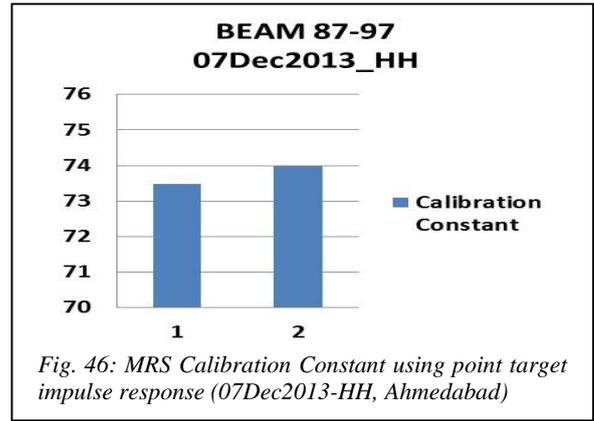
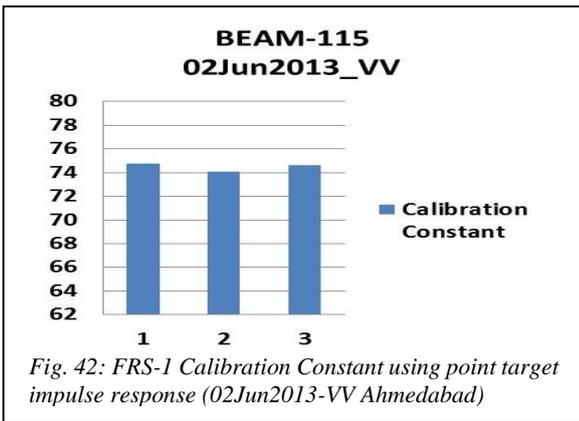
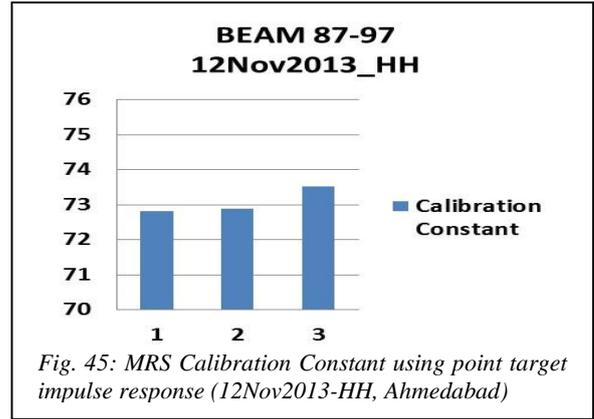
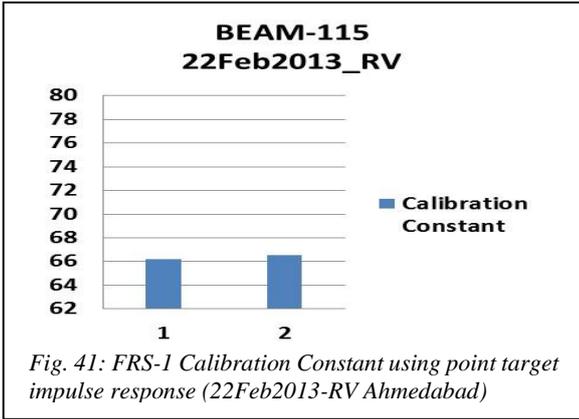


Fig. 16: FRS-1 Calibration Constant using point target impulse response (04Jul2012-RH Ahmedabad)









A study of Fig.10 through Fig.42 which gives calibration constants of FRS-1 mode, using corner reflector IRF response reveals that RISAT-1 RH calibration constant is having maximum standard deviation (0.9 dB) in Beam-95 and minimum standard deviation (0.03 dB) in Beam-14. RV calibration constant is having maximum standard deviation (0.7 dB) in Beam-10 and minimum standard deviation (0.17 dB) in Beam-19. HH calibration constant is having maximum standard deviation (0.55 dB) in Beam-41 and minimum standard deviation (0.36 dB) in Beam-115. A study of Fig.43 through Fig.48 reveals that RISAT-1 MRS calibration constants are ranging from 71.9 dB to 73.9 dB with an average of 72.91 dB and standard deviation of 0.53 dB.

VI. CONCLUSION

This paper brings out results of an experiment performed for absolute radiometric calibration of FRS-1 and MRS beam mode RISAT-1 data. Triangular trihedral corner reflectors were used as standard point targets for this experiment. Corner reflectors were deployed for FRS-1 beams during June 2012 to December 2013 and for MRS systematic coverage (beam 87 to beam 97) for one year during 2013 to 2014. RISAT-1 SAR data of experimentation dates for both FRS-1 and MRS beam modes have been analysed for this purpose. FRS-1 results are based on 19 (nineteen) date data comprising 11 (eleven) beams for RH, RV, 4 (four) beams for HH and 1 (One) beam for VV polarisation with a total of 42 (forty two) corner reflector IRFs. MRS results are based on 6 (six) date data of HH polarisation with a total of 14 (fourteen) corner reflector IRFs. Study of IRFs of deployed corner reflectors revealed that temporal and spatial variation of calibration constants within beam of FRS-1 and MRS systematic beam mode is very small. For FRS-1 minimum standard deviation is 0.03 dB and maximum standard deviation is 0.9 dB whereas for MRS-1 systematic coverage (beam 87-97) standard deviation is 0.53 dB. Thus, both FRS-1 and MRS beams have been observed to be radiometrically stable. Results show that integral box method can be used for absolute radiometric calibration of any operational or planned SAR mission to validate the accuracy of derived backscattering coefficients from the data.

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