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Calibration of RISAT-1 Fine Resolution (FRS-1) Mode Data processed before implementation of DP software update Version- 1.3.00

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9. Abstract	This report brings out the results of radiometric calibration of RISAT-1 FRS beam mode data using point target response before DP update (version 1.3.00) was carried out during June 2014. Calibration constant has been computed by deploying corner reflectors and studying its Impulse response for 17 (seventeen) dates for CH, CV, HH and VV polarisation image. Data quality parameters have also been computed using the point target IRF. 10 (ten) corner reflectors responses have been studied for HH polarisation, 3 (three) corner reflectors responses have been studied for VV polarisation and 27 (twenty seven) corner reflectors responses have been studied for transmit circular polarisation and receive horizontal polarisation (CH) and transmit circular polarisation and receive vertical polarisation (CV).
10. Key words	Corner reflector, Corner reflector Deployment, Impulse Response Function, Calibration Constant, Backscattering Coefficient
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Content

1.0 Introduction

A large number of SAR sensors are operational resulting in greater use of the same in scientific community for various applications. In order to utilise data arising from SAR sensors from different missions or acquired from the same platform over a period of time, it is necessary to calibrate the SAR data. Calibration of SAR data has proven its necessity in order to do a quantitative analysis and reach to a meaningful conclusion [1,2]. Thus, one is able to extend results of studies carried out using one sensor to other [3-5]. This cumulative knowledge base leads to possibilities of developing robust parameter retrieval models for a variety of applications [6-14]. Radiometric calibration of a polarimetric SAR sensor helps in studying polarimetric information content in different frequencies [15]. Polarimetric calibration calls for amplitude as well as phases between different polarisation channels to be calibrated. For a given SAR image, the digital number (DN) 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]. Thus, with radiometric calibration, backscattering coefficients values can be compared from different SAR sensors and quantitative information can be obtained.

RISAT-1 is India's first space borne SAR sensor operating at C band. 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 [21, 22]. Thus, apart from calibrating the amplitude, polarimetric calibration of the RISAT-1 is also required to be carried out. While calibration of the amplitude will lead to meaningful utilisation of the RISAT-1 system for a large number of applications, calibrated circular hybrid polarimetric data will offer user community to explore potentials of polarimetric SAR data over large geographical areas. SAR calibration can be carried out by analysing standard targets response as well as reference distributed targets analysis [23, 24]. Firstly, standard targets like corner reflectors have been deployed to derive radiometric parameters of the data and computing necessary calibration parameters. Along with the exercise of deploying standard targets, reference distributed target can continuously be monitored and any deviation in the radiometry can be analysed to trace out the reason. In case of any deviation in radiometry for the reference distributed target, a rigorous campaign of standard target deployment is essential to be carried out to adjust the calibration parameters. This document reports details of radiometric calibration of RISAT-1 SAR FRS beam mode data which are processed before implementation of updated Risat-1 Data Processor (version 1.3.00) at NRSC during June 2014.

2.0 RISAT-1 SAR

RISAT-1 is India's first space borne SAR sensor operating at C-band at various beam modes having a number of combinations of linear polarisation modes as well as circular polarisation modes, incidence angle, swath and resolution. **Fig.1** shows schematic diagram of RISAT-1 SAR beam modes. . Specifications of RISAT-1 SAR beam modes are given in **Table-1**.

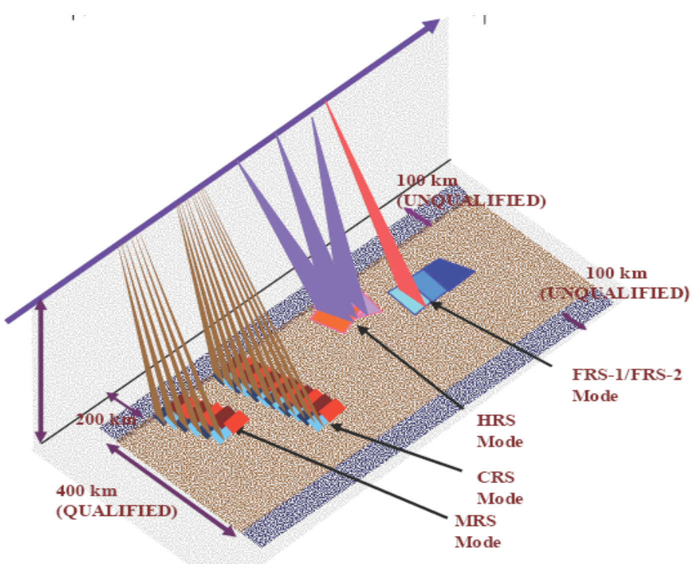

Fig.1: Schematic Diagram showing different beam modes of RISAT-1 SAR

Table-1: 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	20^0-49^0 (200-600 Km)				
	Total	10^0-54^0 (100 –700 Km)				
Swath/ Spot Km	*Defined*	10x10	30	30	120	240
	Experimental	100x10	---	---	---	---
Applicable Polarisation combinations		Single/ Dual (co+ cross)/ (CH&CV*	Single / Dual (co + cross) / (CH & CV)*	Quad / (CH&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				

3.0 Study area and data set

Corner reflectors deployment was carried out over grounds of Nirma University and M G Science Institute for Ahmedabad site whereas for Bhachau and Roorkee and Zinzuwada site corner reflectors were deployed in open grounds as described in [25]. A total of 17 (seventeen) date data sets of RISAT-1 covering 12 (twelve) beam modes of RISAT-1 FRS-1 mode SAR were acquired for the purpose of calibration. There are 12 (twelve) acquisition with hybrid polarimetric mode (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 14 (fourteen) dates of RISAT-1 SAR acquisition over Ahmedabad study area, for one date over Bhachau, one date over Roorkee and one date over Zinzuwada, as mentioned according to beams in **Table-2.**

Table 2: Details of point target deployment for different beam modes

Sr No	Date	Site	Beam number	Imagi-ng Mode	Incidence Angle	Orbit	Polaris--ation	# of Deplo-yed reflec-tors
1	22Jul12	Ahmedabad	10	FRS	21.80	1314	CH, CV	3
2	02Mar13	Roorkee	14	FRS	25.37	4684	CH, CV	2
3	04Jul12	Ahmedabad	19	FRS	29.64	1050	CH,CV	2
4	01Oct13	Ahmedabad	40	FRS	44.7	7889	CH, CV	3
5	15Dec13	Ahmedabad	41	FRS	45.2	9020	HH,HV	4
6	23Feb13	Bhachau	71	FRS	19.04	4579	CH, CV	1
7	29Jun12	Ahmedabad	73	FRS	20.98	967	CH, CV	1
8	16Jun13	Zinzuwada	74	FRS	21.9	6283	HH, HV	3

9	12Sep13	Ahmedabad	74	FRS	21.8	7610	CH, CV	1
10	13Jul12	Ahmedabad	94	FRS	38.20	1186	CH, CV	2
11	26Sep12	Ahmedabad	95	FRS	38.90	2317	CH, CV	4
12	28Jun13	Ahmedabad	95	FRS	38.8	6464	CH, CV	4
13	11Sep13	Ahmedabad	95	FRS	38.8	7595	CH, CV	2
14	01Jul12	Ahmedabad	114	FRS	50.38	997	HH	1
15	06Aug12	Ahmedabad	115	FRS	50.94	1548	HH	2
16	22Feb13	Ahmedabad	115	FRS	50.90	4564	CH, CV	2
17	02Jun13	Ahmedabad	115	FRS	50.91	6072	VV	3

4.0 Methodology

In order to carry out radiometric calibration of SAR, it is required to deploy standard point targets with known radar cross section accurately pointing towards the SAR sensor over a low clutter region [26, 27]. Once the point targets are imaged, integrated power from two dimensional impulse responses function (IRF) of the point target is to be analyzed for radiometry after removing clutter noise for the standard target response [18-20]. From point target impulse response, apart from deriving calibration constants, range and azimuth spatial resolution, range and azimuth peak side lobe ratio (PSLR), and background-to-peak ratio (BPR) can be computed [12]. Revised calibration constant has been documented in this report, rest of the data quality parameters can be accessed from [30].

Calibration constant can be derived by using the radar equation [28, 29]. Detail to derive a calibration constant is given in [30]. After deriving the calibration constant, backscattering coefficient σ^o can be derived as

$$\sigma^{o}(dB) = 10\log_{10}(\mathrm{P_u}) - 10\log_{10}(\mathrm{C}ii) + 10\log_{10}(\sin(\theta_i)) - 10\log_{10}(\sin(\theta_{center})) \quad (1)$$

Where C_{ii} is the calibration constant, which can be arrived at using the following equation

$$C_{\mathrm{ii}} = \frac{P_{\mathrm{ii}}\delta_r\delta_a}{\sin(\alpha)\, f_{\mathrm{int}}^2 \sigma_c \sin(\theta_{center})} \quad (2)$$

Once the calibration constant is arrived using equation (2), SAR DN values can be converted to the backscattering coefficient for that SAR processor using equation (1).

5.0 Results and Discussion

Corner reflectors [26, 27] have been used to carry out calibration of multi-polarised RISAT-1 SAR intensity data using 17 (seventeen) scenes consisting of 4 (four) HH, 1 (one) VV polarized and 12 (twelve) circular transmit linear receive RISAT-1 SAR scenes. Calibration has been carried out by analysing standard targets response.

Fig.2: Corner reflector mobilization & deployment

Firstly, standard targets like corner reflectors have been deployed. **Fig. 2** shows the mobilization and deployment of corner reflectors to research sites. Reflector responses in RISAT-1 SAR images were analysed to derive radiometric parameters of the data and computing the necessary calibration parameters.

5.1 Calibration Constant Using Point Target Impulse Response

Calibration campaign involving deployment of corner reflector was carried out by calculating the azimuth and elevation angle and pointing to the centre of the beam. Details of number of point targets deployed for each of the eleven dates are given in **Table-1**. As described in the methodology section, 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 the point target. Thus, for all the reflectors, interpolated Impulse Response Function was derived. Hence, there were in all 27 (twenty seven) Impulse Response Function (IRF) available for CH polarisation and 27 (twenty seven) IRF for CV polarisation. For HH polarisation, 10 (ten) IRF were studied and for VV polarisation 3 (three) IRF were studied. **Fig.3** shows the reflectors captured in the RISAT-1 SAR image.

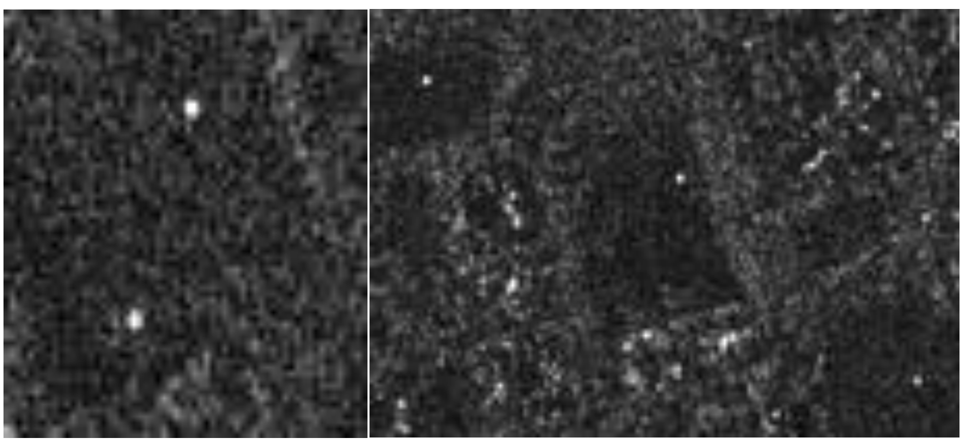

Fig. 3 Corner reflectors observed in the RISAT-1 image

Integrated power from two dimensional impulse responses has been analysed for radiometry after removing clutter noise for the standard target. From point target impulse response, apart from deriving calibration constants, range and azimuth spatial resolution, range and azimuth peak side lobe ratio (PSLR) have been computed. From the interpolated response of the point target, firstly, calibration constant was derived and then the data quality parameters were obtained as given below. **Fig 4, Fig 5, Fig 6** and **Fig 7** show the impulse response for point targets in CH, CV, HH and VV polarisation respectively.

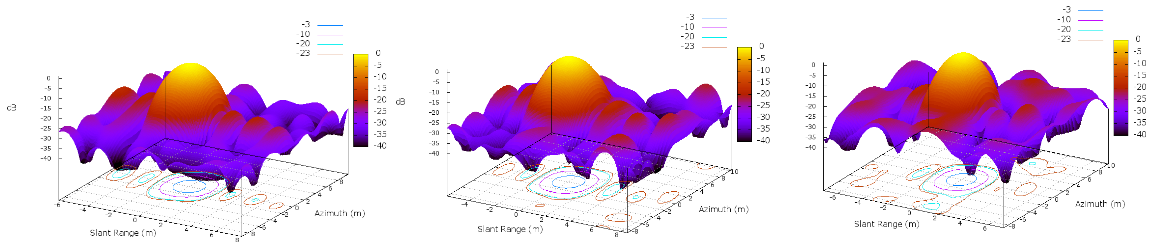

Fig. 4: Point target Impulse response Function for CH polarisation for point target 1, 2 and 3 (01Oct2013)

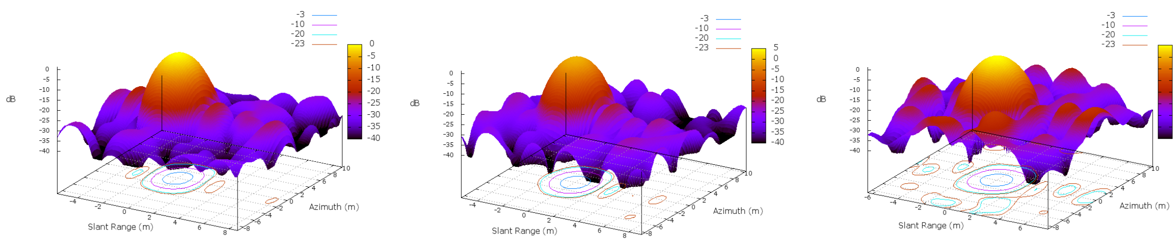

Fig. 5: Point target Impulse response Function for CV polarisation for point target 1, 2 and 3 (01Oct2013)

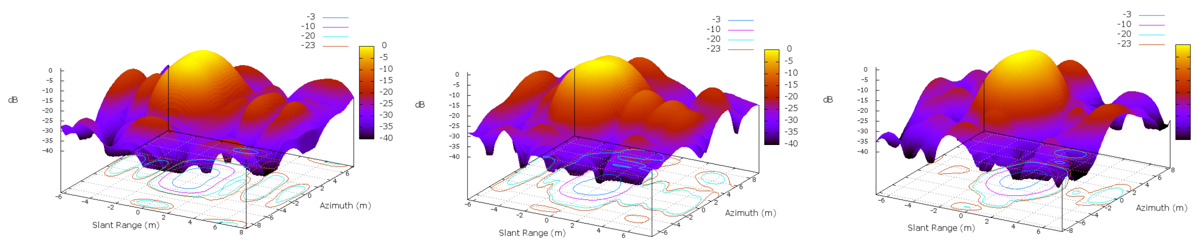

Fig. 6: Point target Impulse response Function for HH polarisation for point target 1, 2, and 3 (15Dec2013)

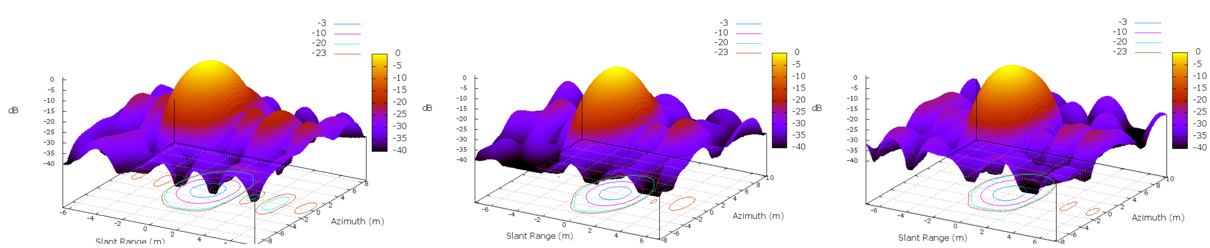

Fig. 7: Point target Impulse response Function for VV polarisation for point target 1, 2, 3 and 4 (02Jun2013)

After removing clutter noise, the point target impulse response has been used to derive the calibration constant using equation (2). The calibration constants derived for RISAT-1 SAR CH, CV, HH and VV polarisation for each of the point targets are given in **Table-3.1** through **Table3.17** and **Fig.8** through **Fig.36**.

Table 3.1: Calibration 22-Jul-12constant		
Beam No-10 Incidence Angle-21.81		
Point target	CH	CV
1	76.25	73.16
2	75.07	72.14
3	74.72	71.59
Average	75.34	72.297
DP Const	63.94	60.06

Table 3.2: Calibration constant 2-Mar-13		
Beam No-14 Incidence Angle-25.378		
Point target	CH	CV
1	74.61	70.22
2	74.56	71.17
Average	74.585	70.695
DP Const	70.62	67.14

Table 3.3: Calibration constant 4-Jul-12		
Beam No-19 Incidence Angle-29.64		
Point target	CH	CV
1	72.08	69.84
2	72.98	70.09
Average	72.53	69.965
DP Const	64.28	60.84

Table 3.4: Calibration Constant 1-Oct-13		
Beam No-40, Incidence Angle-44.6		
Point target	CH	CV
1	72.86	69.62
2	73.98	69.11
3	73.73	66.2
Average	73.52	68.31
DP Const	70.06	66.85

Table 3.5: Calibration Constant 15-Dec-13	
Beam No-41, Incidence Angle-45.2	
Point target	HH
1	78.18
2	78.12
3	79.28
4	78.79
Average	78.59
DP Const	74.27

Table 3.6: Calibration constant 23-Feb-13		
Beam No-71 Incidence Angle-19.044		
Point target	CH	CV
1	72.37	66.43
Average	72.37	66.43
DP Const	68.31	64.26

Table 3.7: Calibration constant 29-Jun-12		
Beam No-73 Incidence Angle-20.986		
Point target	CH	CV
1	75.91	72.14
Average	75.91	72.14
DP Const	68.09	64.14

Table 3.8 Calibration Constant 16-Jun-13	
Beam No-74, Incidence Angle-21.9	
Point target	HH
1	79.73
2	79.76
3	80.39
Average	79.96
DP Const	70.98

Table 3.9: Calibration Constant 12-Sep-13		
Beam No-74, Incidence Angle-21.8		
Point target	CH	CV
1	76.9	72.44
Average	76.9	72.44
DP Const	66.73	62.81

Table 3.10: Calibration constant 13-Jul-12		
Beam No-94 Incidence Angle-38.201		
Point target	CH	CV
1	73.74	70.53
2	74.01	70.6
Average	73.875	70.565
DP Const	70.21	67.05

Table 3.11: Calibration constant 26-Sep-12		
Beam No-95 Incidence Angle-38.90		
Point target	CH	CV
1	74.55	71.16
2	75.16	72.10
3	75.01	71.39
4	75.26	71.16
Average	74.90	71.55
DP Const	70.03	66.9

Table 3.12: Calibration Constant 28-Jun-13		
Beam No-95, Incidence Angle-38.8		
Point target	CH	CV
1	73.42	70.87
2	73.09	70.44
3	73.22	70.28
4	73.71	70.49
Average	73.36	70.52
DP Const	68.85	65.72

Table 3.13: Calibration Constant 11-Sep-13		
Beam No-95, Incidence Angle-38.8		
Point target	CH	CV
1	72.79	70.84
2	72.86	71.03
Average	72.825	70.935
DP Const	68.84	65.71

Table 3.14: Calibration constant 01-Jul-12	
Beam No-114 Incidence Angle-50.38	
Point target	HH
1	77.61
Average	77.61
DP Const	70.19

Table 3.15: Calibration constant 6-Aug-12	
Beam No-115 Incidence Angle-50.95	
Point target	HH
1	75.9
2	75.38
Average	75.64
DP Const	73.65

Table 3.16: Calibration constant 22-Feb-13		
Beam No-115 Incidence Angle-50.91		
Point target	CH	CV
1	71.82	67.28
2	71.06	67.66
Average	71.44	67.47
DP Const	70.62	67.14

Table 3.17: Calibration constant 02-Jun-13	
Beam No-115 Incidence Angle-50.916	
Point target	VV
1	75.87
2	75.17
3	75.7
Average	75.58
DP Const	71.44

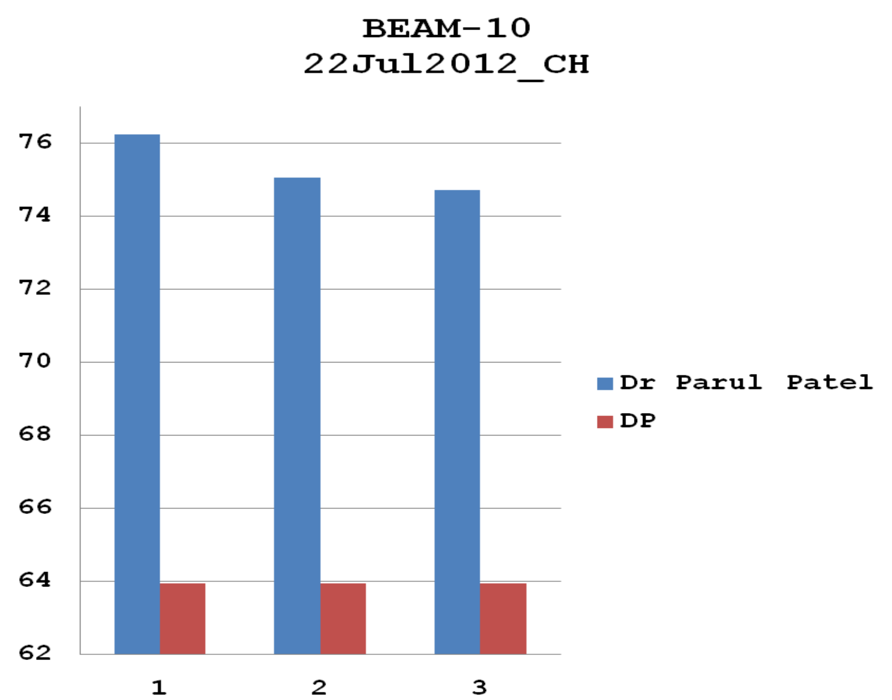

Fig. 8: Calibration Constant using point target impulse response along with that of DP (22Jul2012-CH, Ahmedabad)

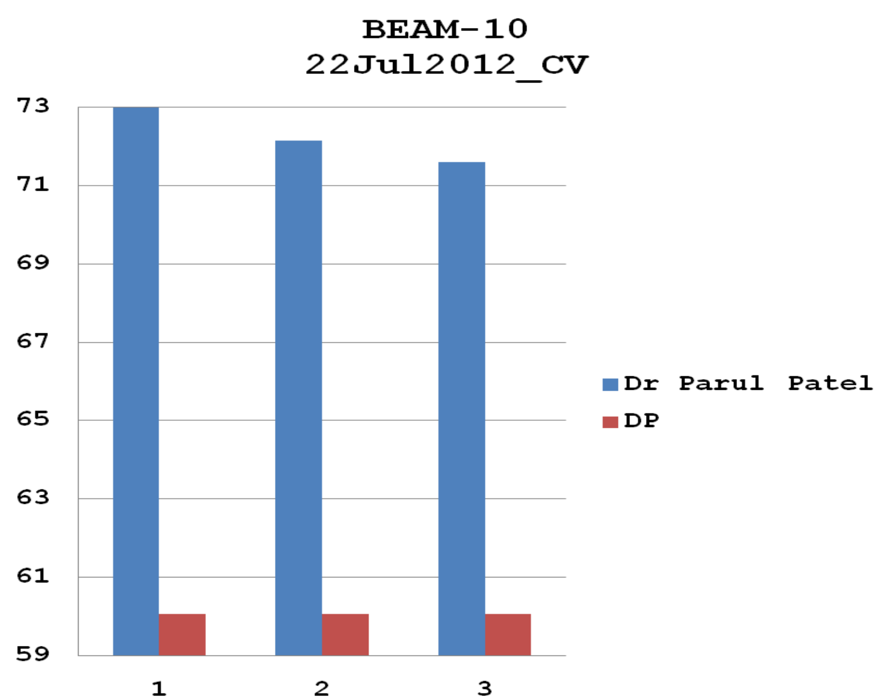

Fig. 9: Calibration Constant using point target impulse response along with that of DP (22Jul2012-CV, Ahmedabad)

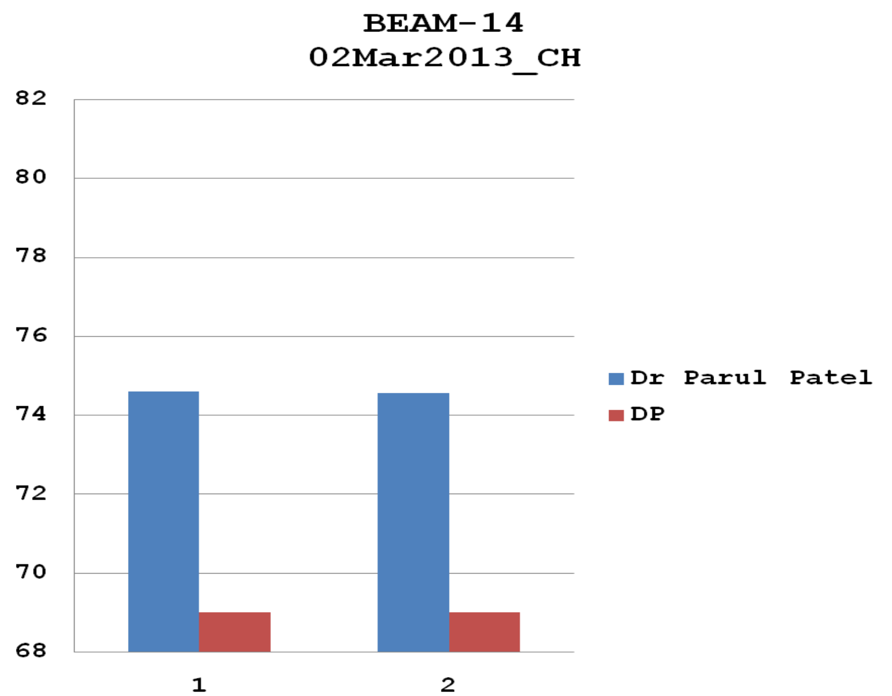

Fig. 10: Calibration Constant using point target impulse response along with that of DP (02Mar2013-CH, Roorkee)

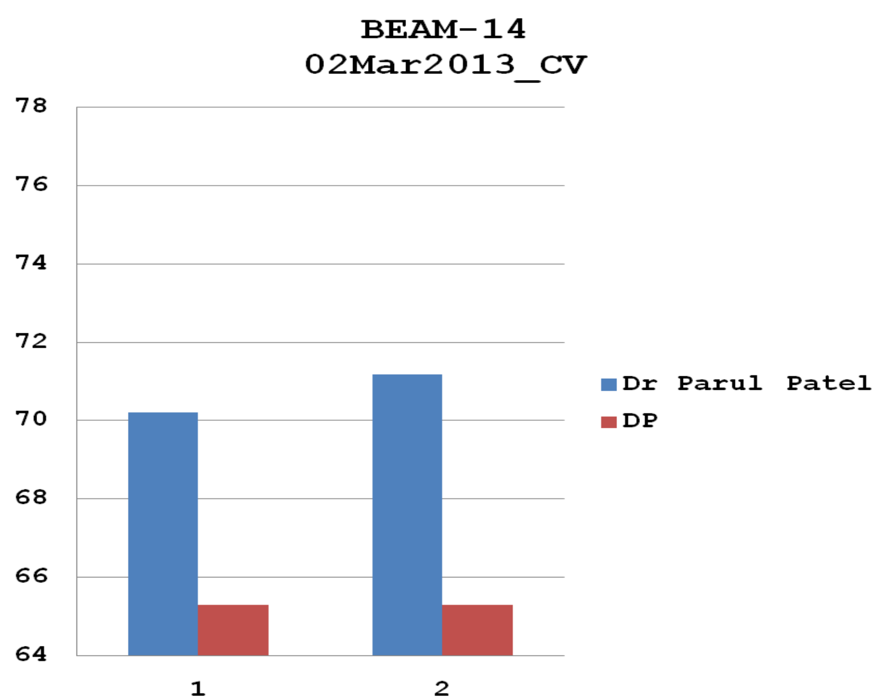

Fig. 11: Calibration Constant using point target impulse response along with that of DP (02Mar2013-CV, Roorkee)

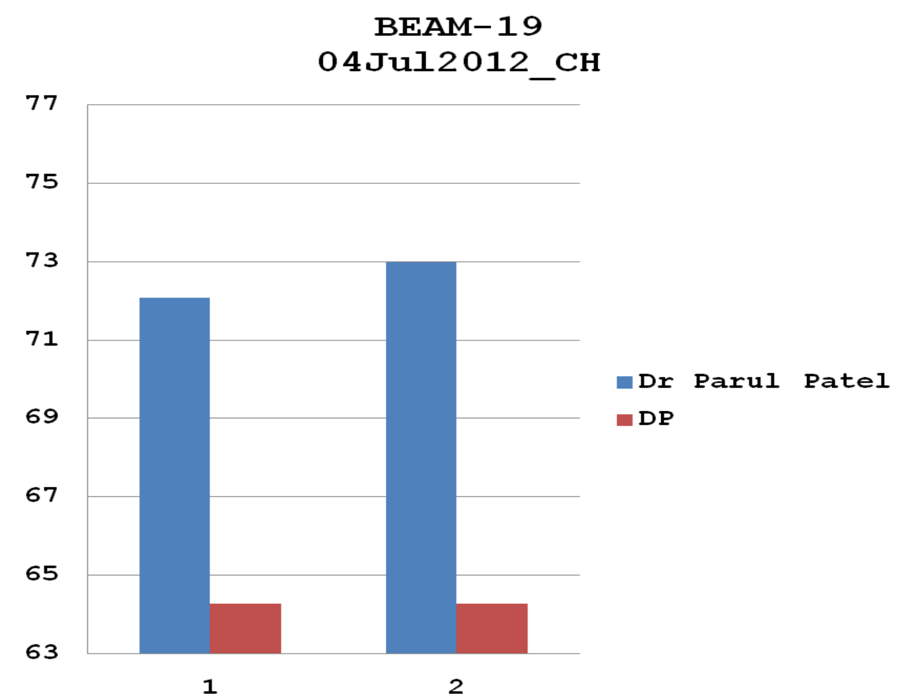

Fig. 12: Calibration Constant using point target impulse response along with that of DP (04Jul2012-CH, Ahmedabad)

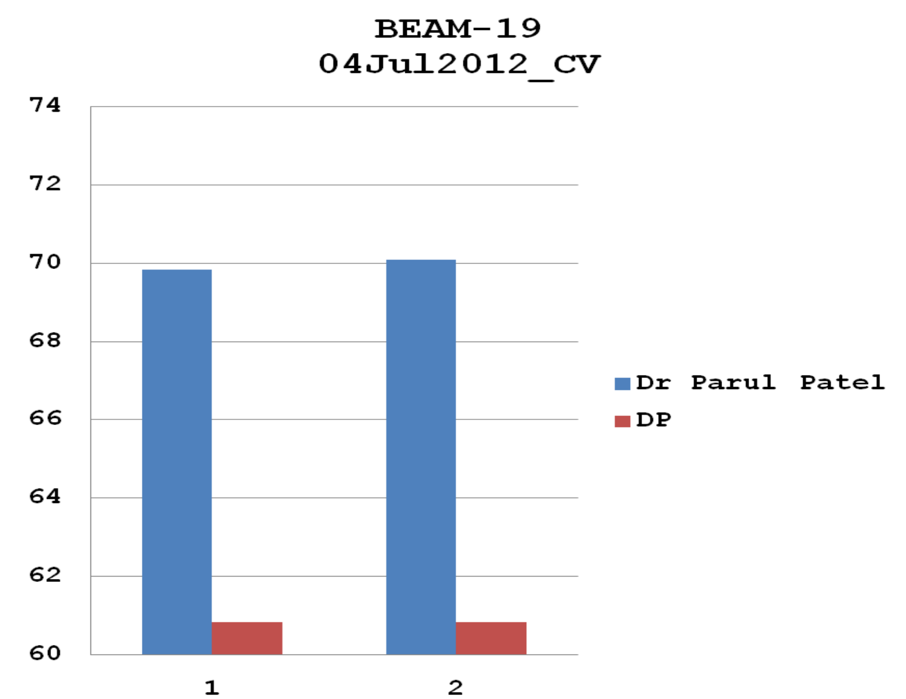

Fig. 13: Calibration Constant using point target impulse response along with that of DP (04Jul2012-CV, Ahmedabad)

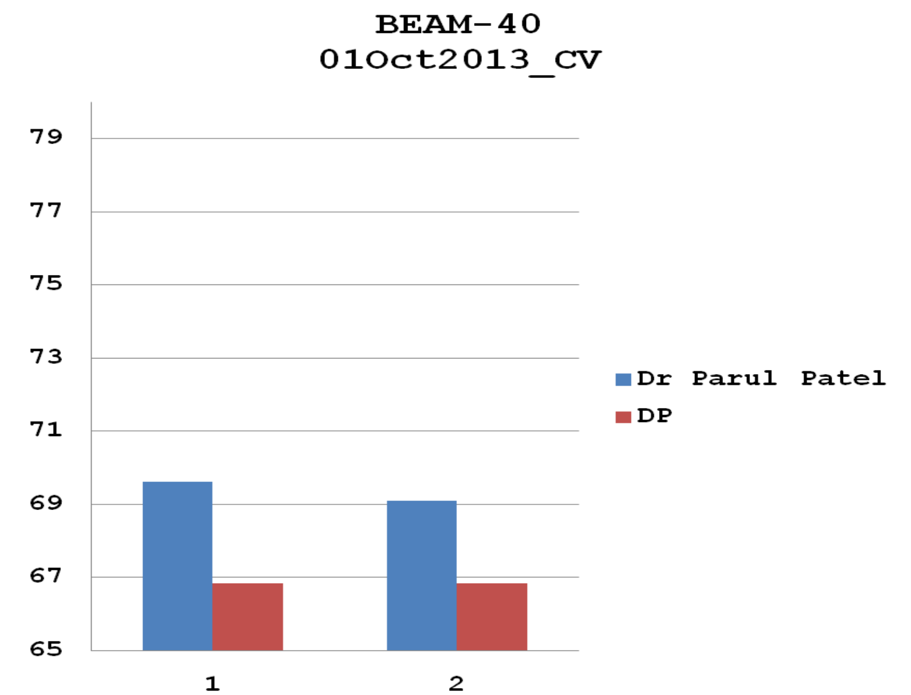

Fig. 14: Calibration Constant using point target impulse response along with that of DP (01Oct2013-CH, Ahmedabad)

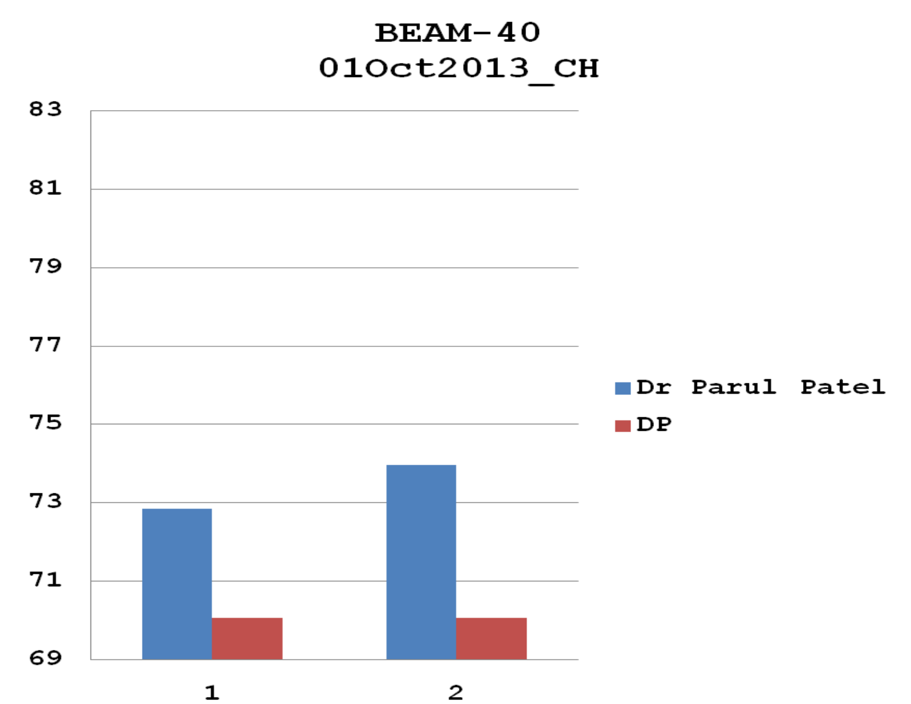

Fig. 15: Calibration Constant using point target impulse response along with that of DP (01Oct2013-CV, Ahmedabad)

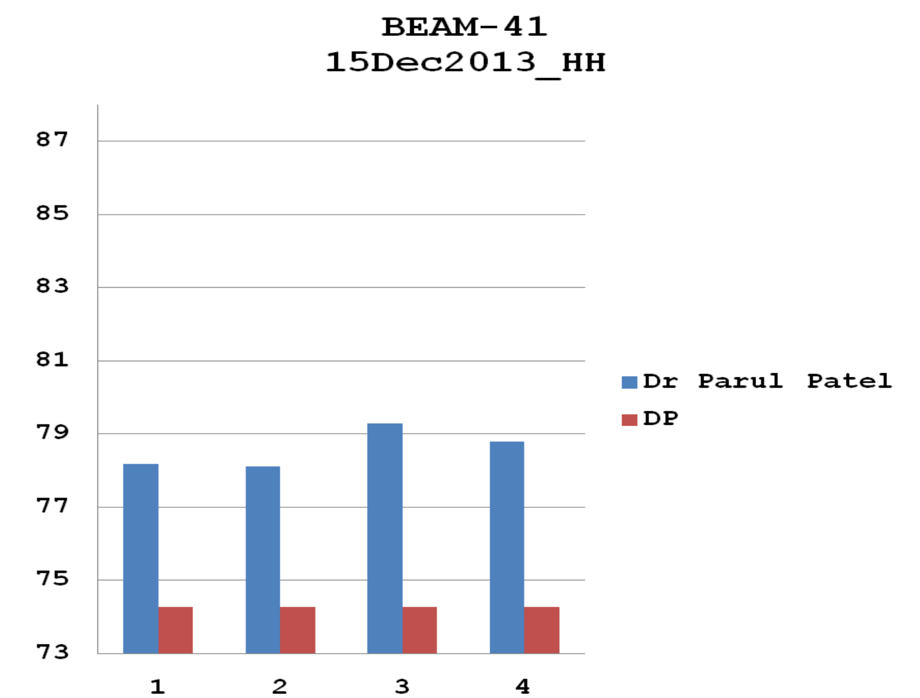

Fig. 16: Calibration Constant using point target impulse response along with that of DP (15Dec2013-HH, Ahmedabad)

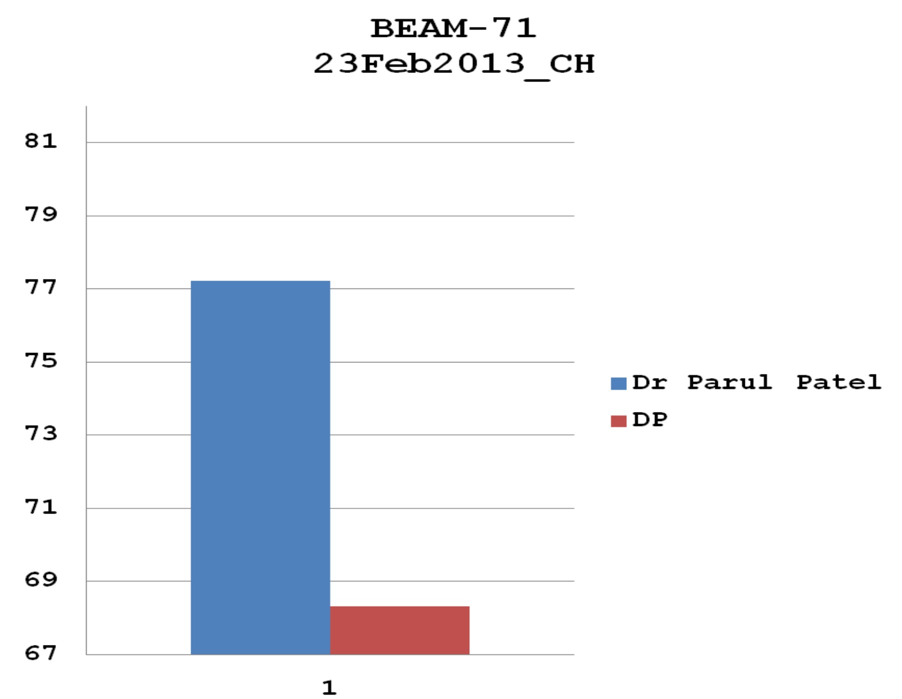

Fig. 17: Calibration Constant using point target impulse response along with that of DP (23Feb2013-CH, Bhachau)

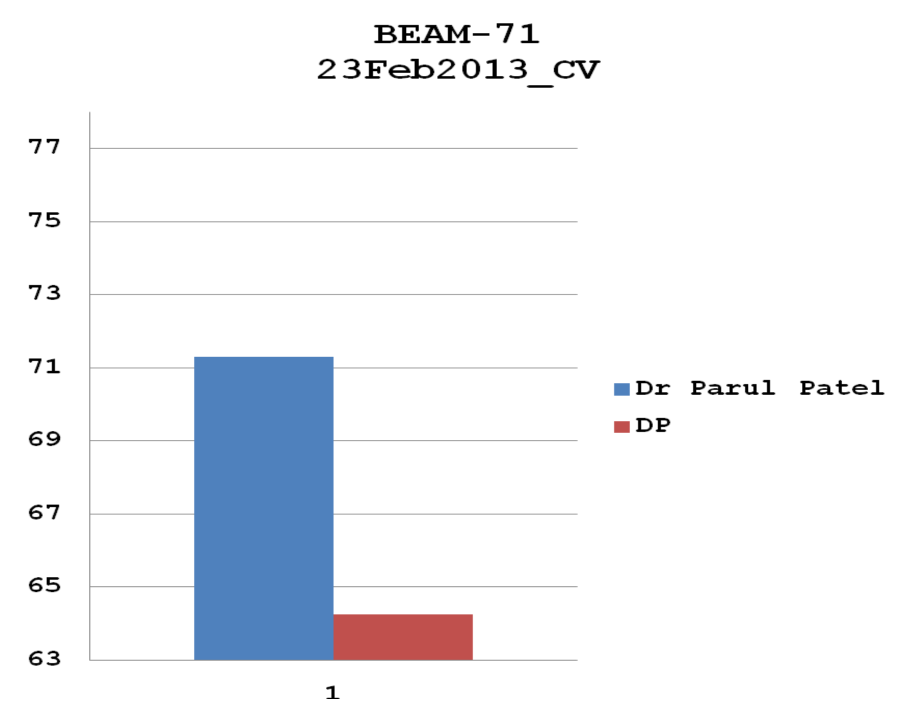

Fig. 18: Calibration Constant using point target impulse response along with that of DP (23Feb2013-CV, Bhachau)

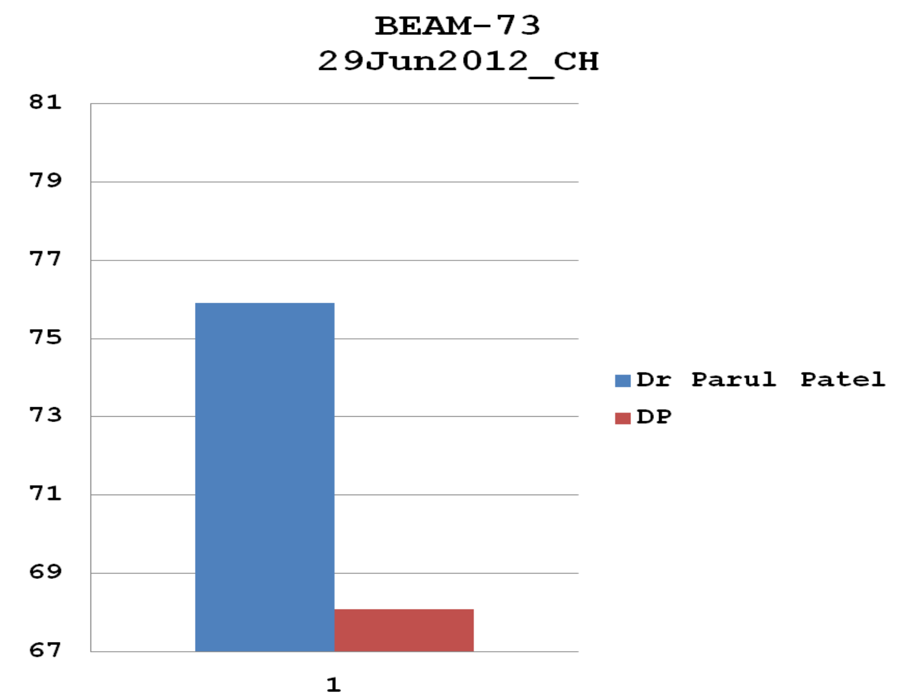

Fig. 19: Calibration Constant using point target impulse response along with that of DP (29Jun2012-CH, Ahmedabad)

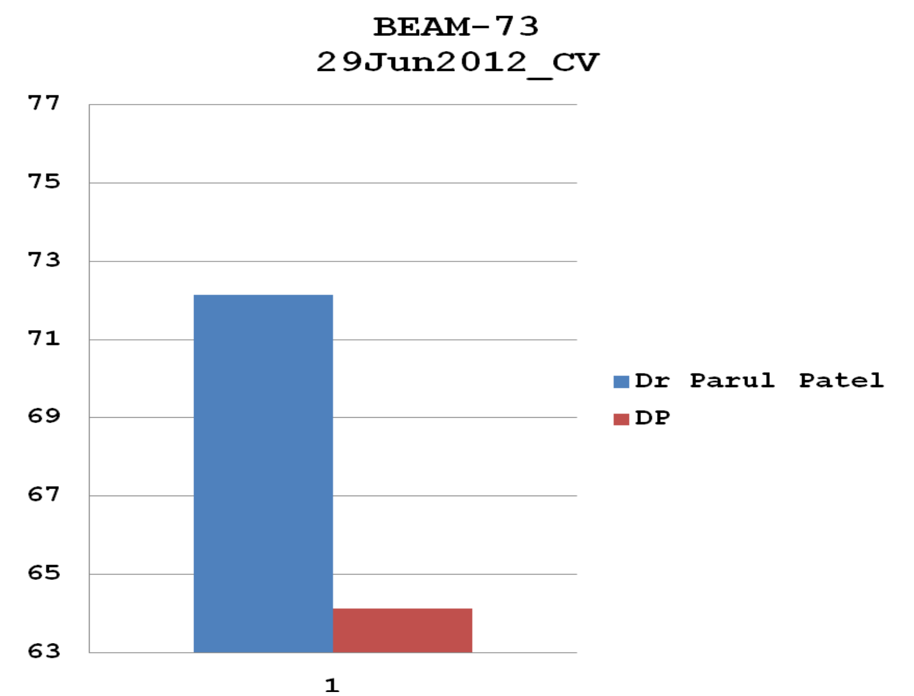

Fig. 20: Calibration Constant using point target impulse response along with that of DP (29Jun2012-CV, Ahmedabad)

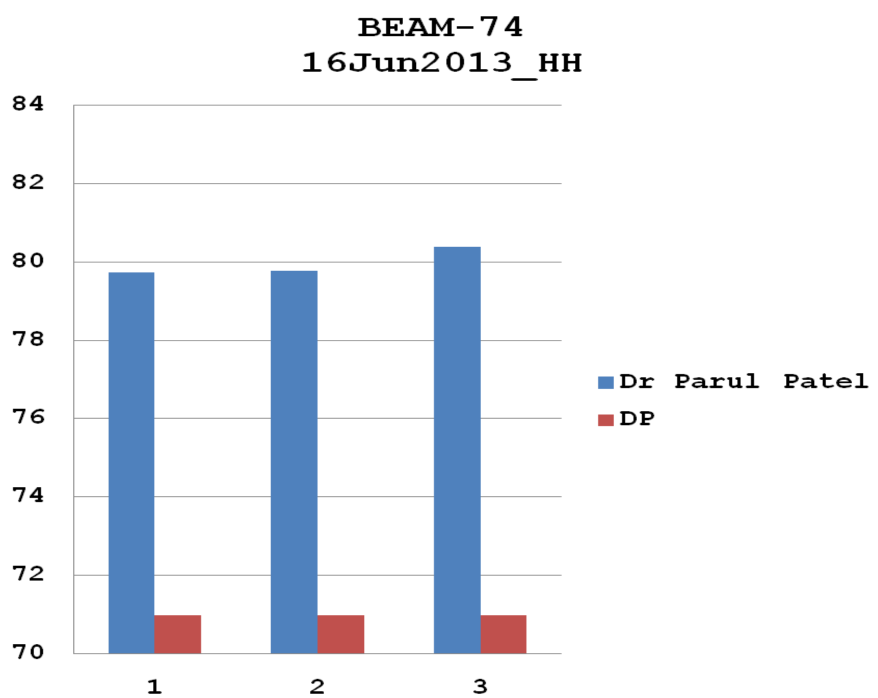

Fig. 21: Calibration Constant using point target impulse response along with that of DP (22Jul2012-CH, Ahmedabad)

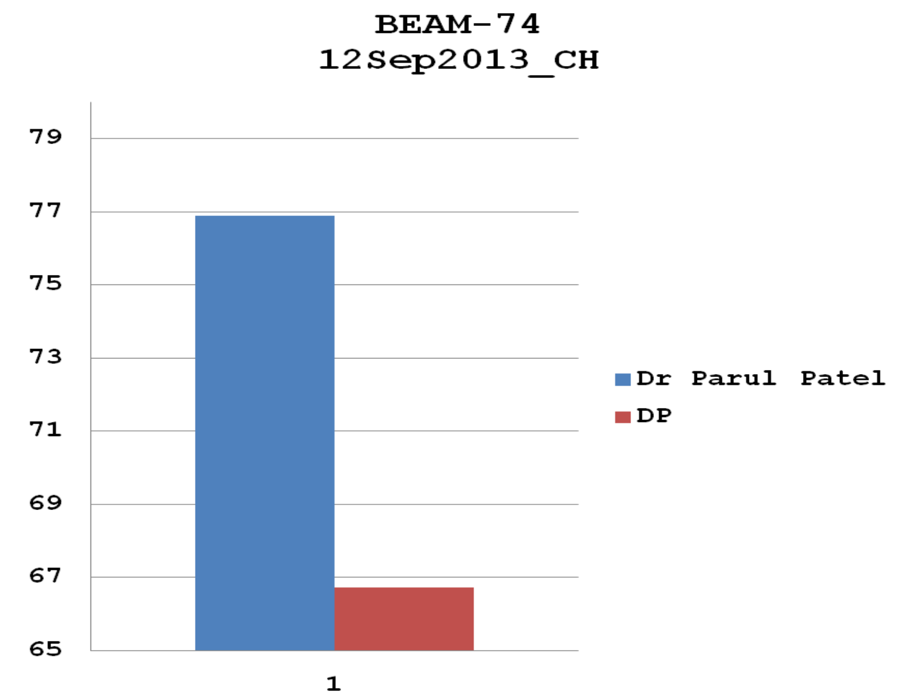

Fig. 22: Calibration Constant using point target impulse response along with that of DP (12Sep2013-CH, Ahmedabad)

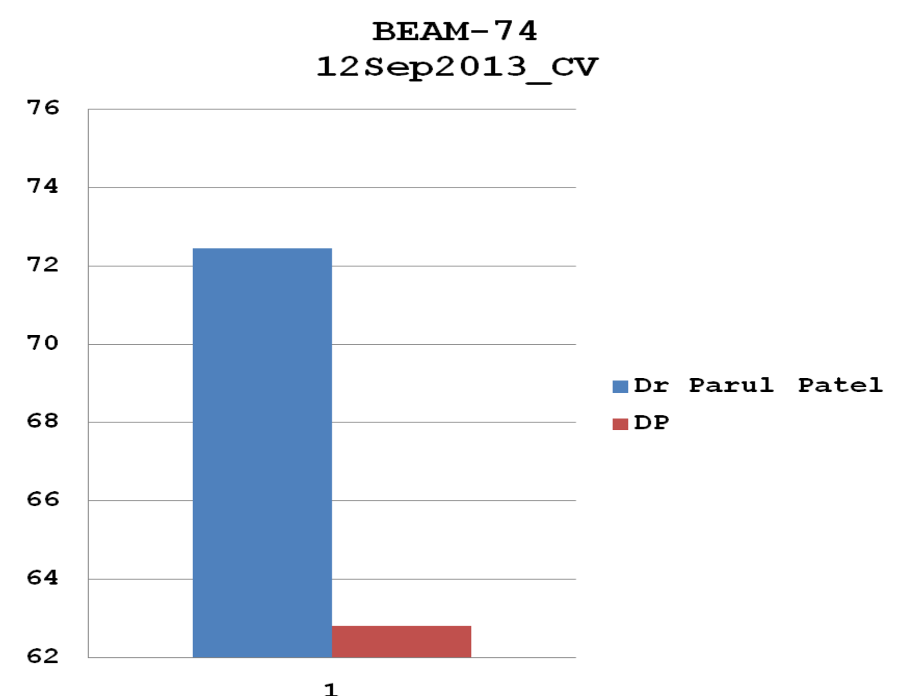

Fig. 23: Calibration Constant using point target impulse response along with that of DP (12Sep2013-CV, Ahmedabad)

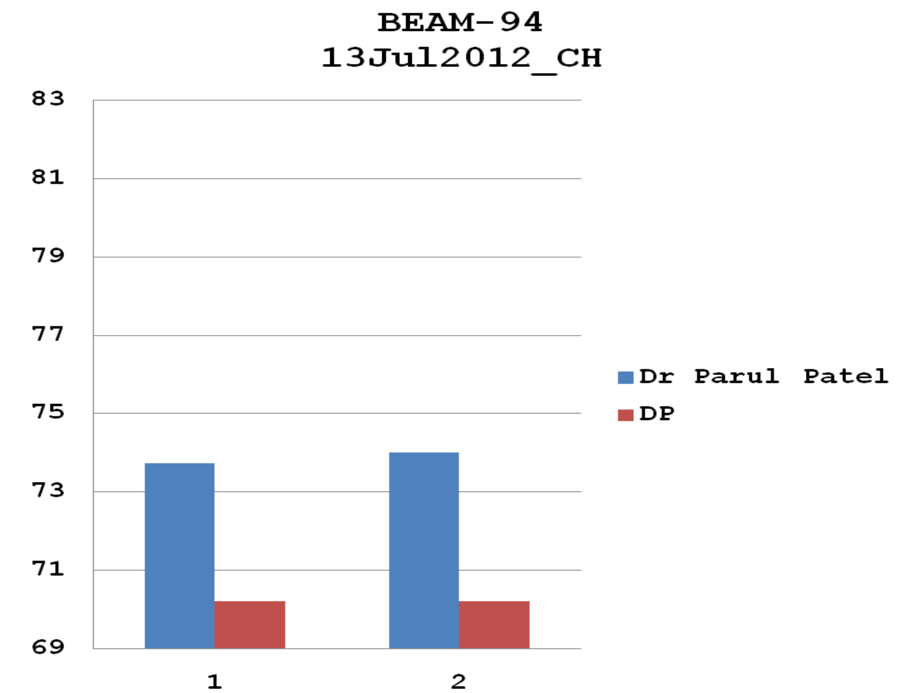

Fig. 24: Calibration Constant using point target impulse response along with that of DP (13Jul2012-CH, Ahmedabad)

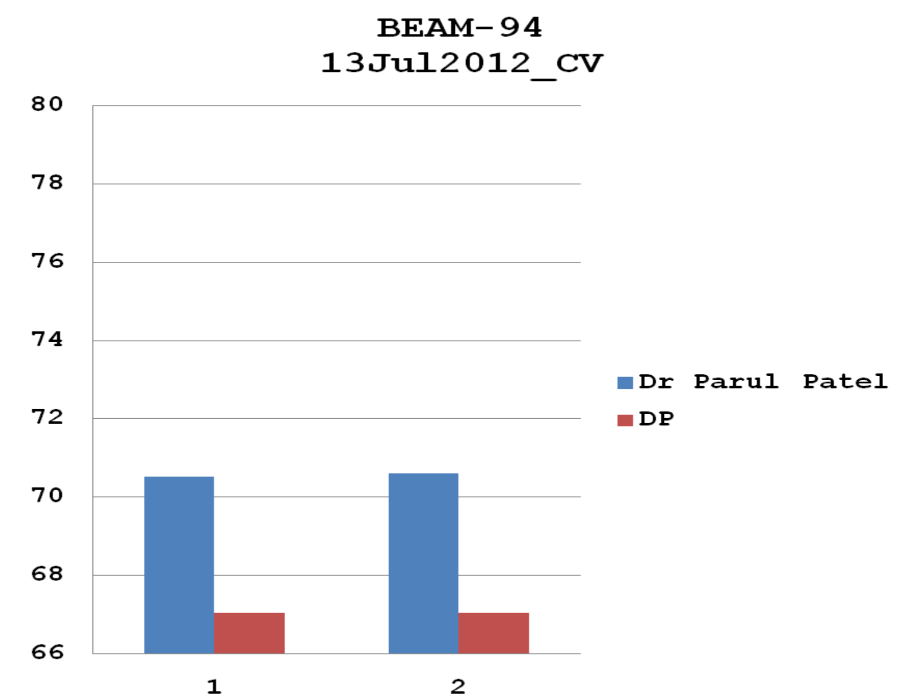

Fig. 25: Calibration Constant using point target impulse response along with that of DP (13Jul2012-CV, Ahmedabad)

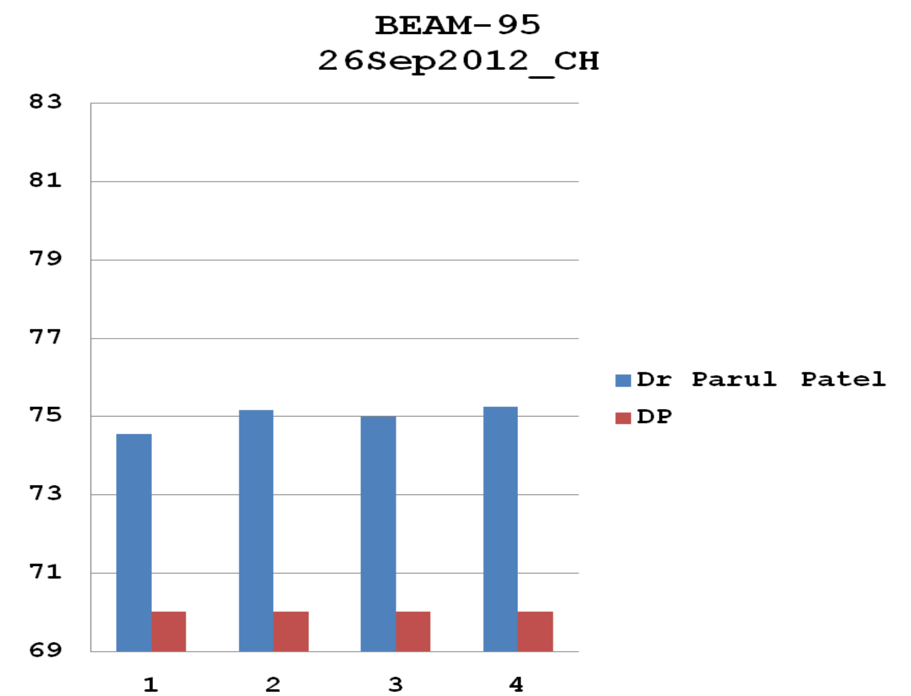

Fig. 26: Calibration Constant using point target impulse response along with that of DP (26Sep2012-CH, Ahmedabad)

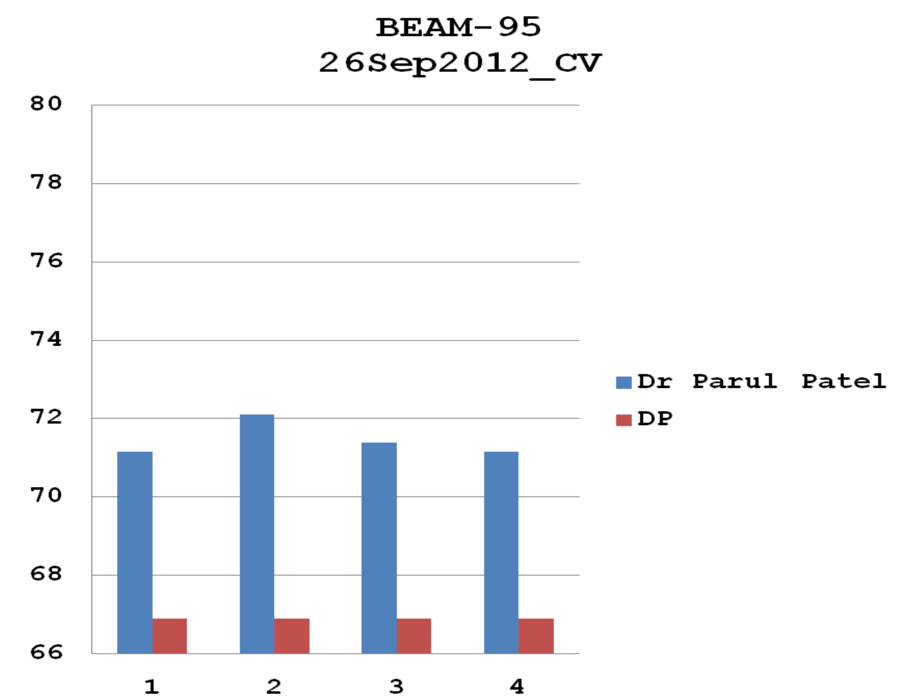

Fig. 27: Calibration Constant using point target impulse response along with that of DP (26Sep2012-CH, Ahmedabad)

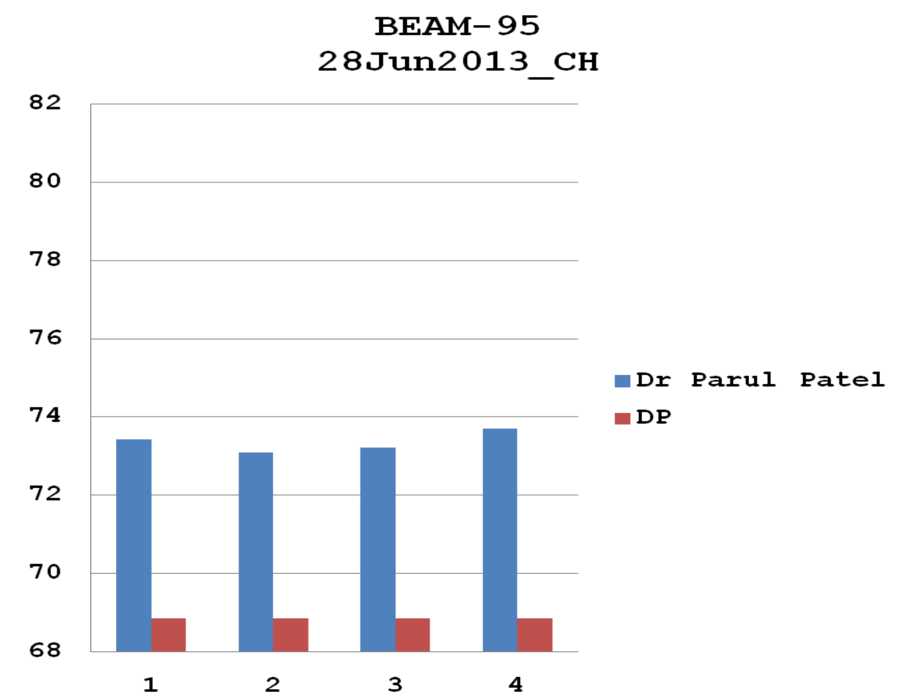

Fig. 28: Calibration Constant using point target impulse response along with that of DP (28Jun2013-CH, Ahmedabad)

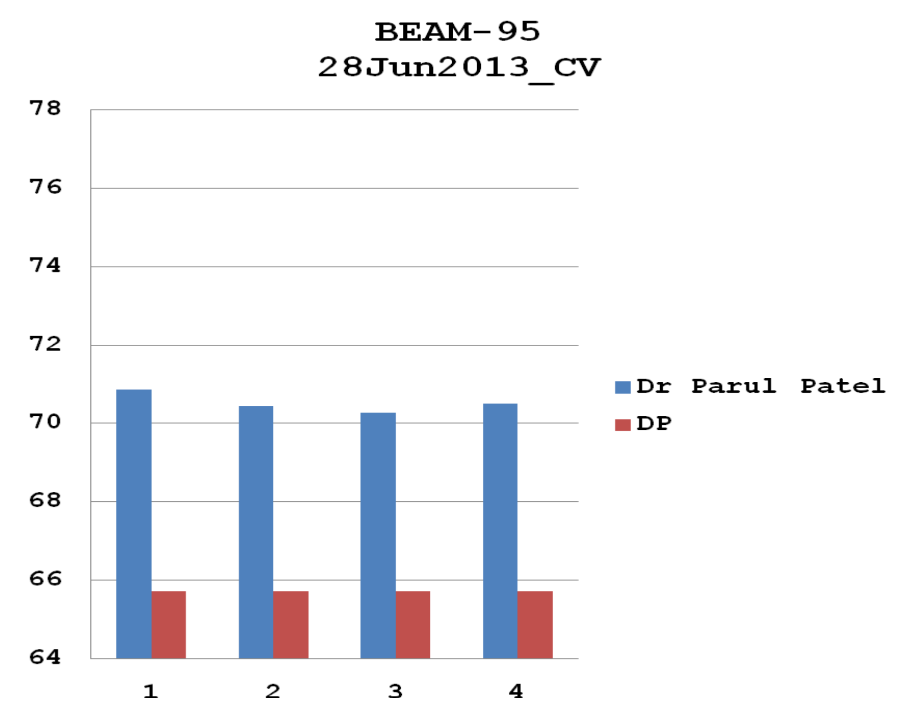

Fig. 29: Calibration Constant using point target impulse response along with that of DP (28Jun2013-CH, Ahmedabad)

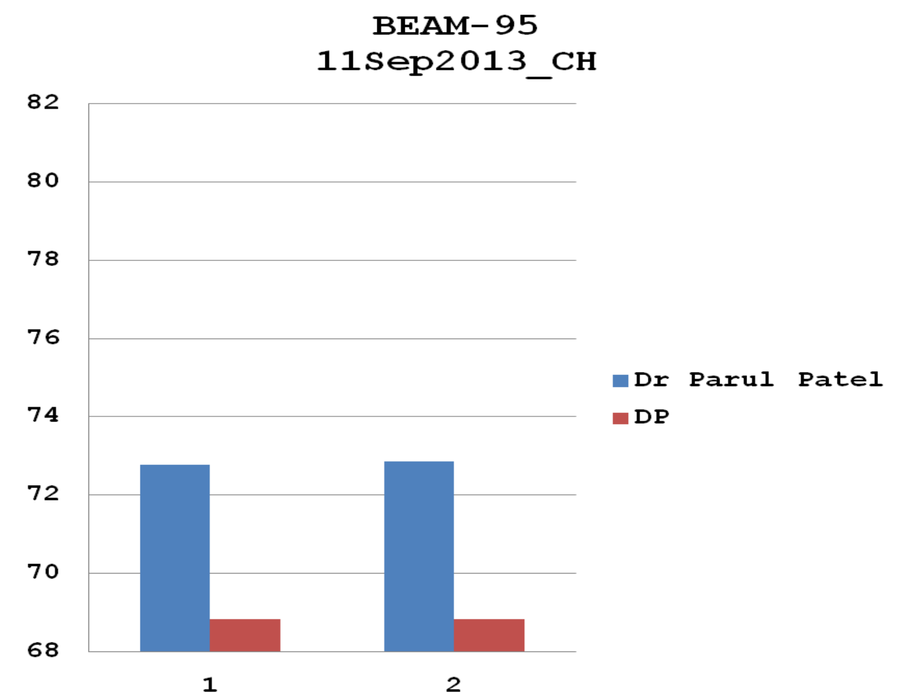

Fig. 30: Calibration Constant using point target impulse response along with that of DP (11Sep2013-CH, Ahmedabad)

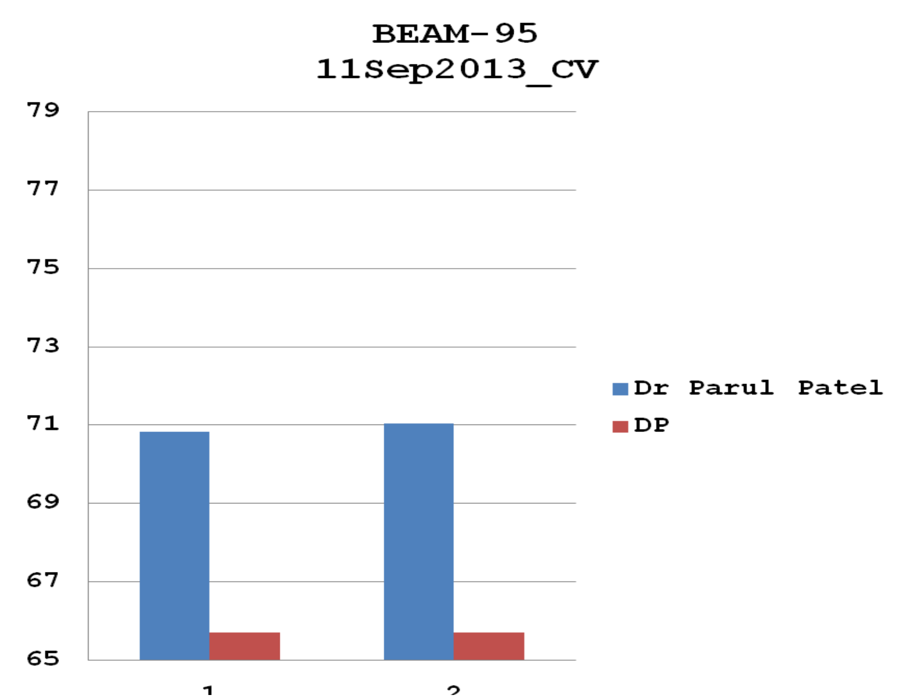

Fig. 31: Calibration Constant using point target impulse response along with that of DP (11Sep2013-CV, Ahmedabad)

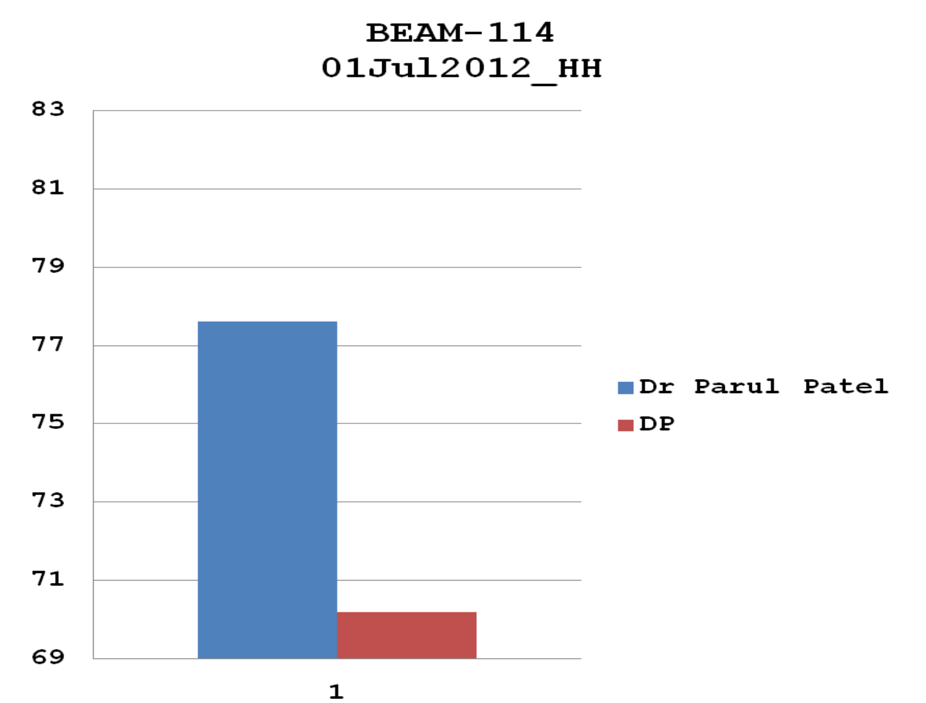

Fig. 32: Calibration Constant using point target impulse response along with that of DP (01Jul2012-HH, Ahmedabad)

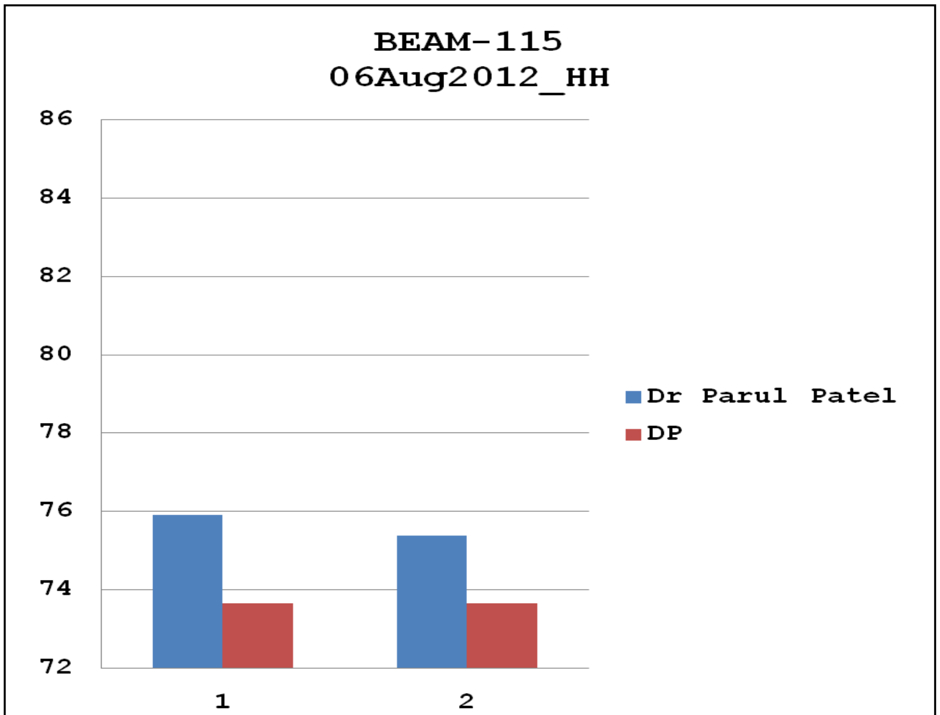

Fig. 33: Calibration Constant using point target impulse response along with that of DP (06Aug2012-HH, Ahmedabad)

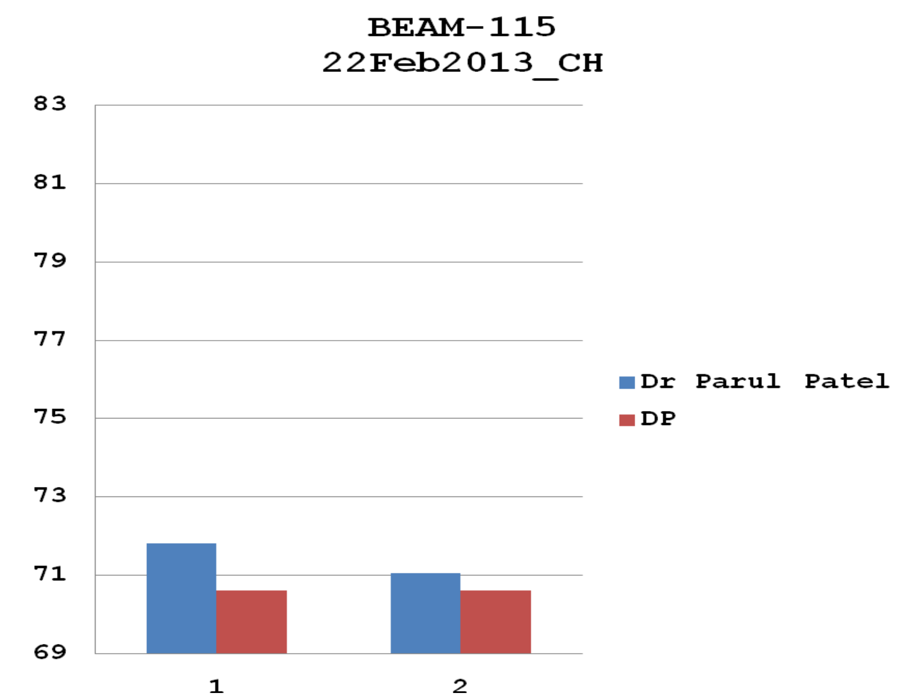

Fig. 34: Calibration Constant using point target impulse response along with that of DP (22Feb2013-CH, Ahmedabad)

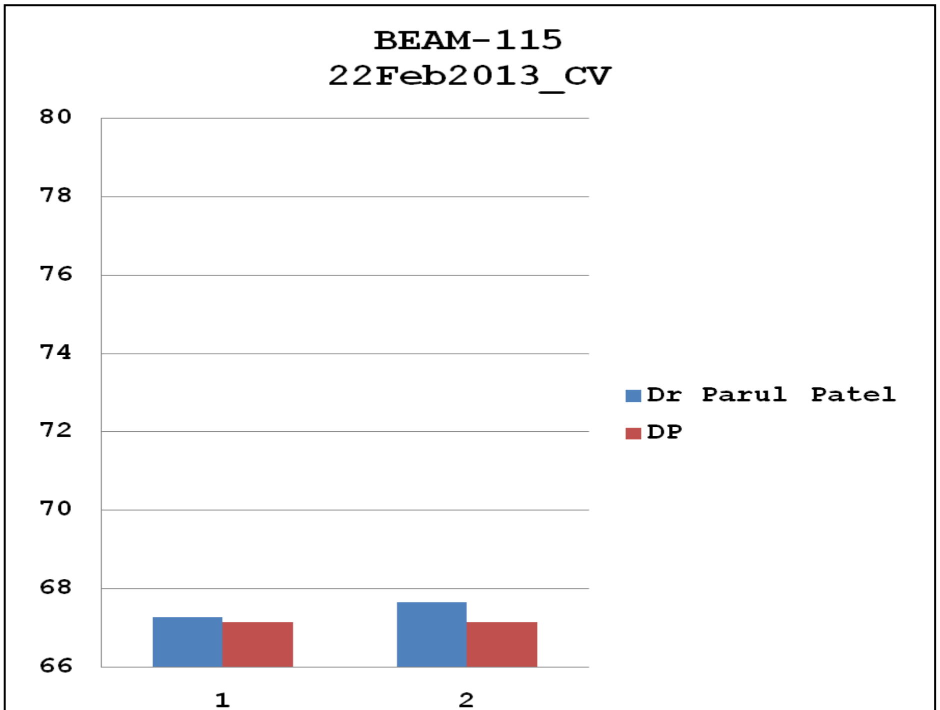

Fig. 35: Calibration Constant using point target impulse response along with that of DP (22Feb2013-CH, Ahmedabad)

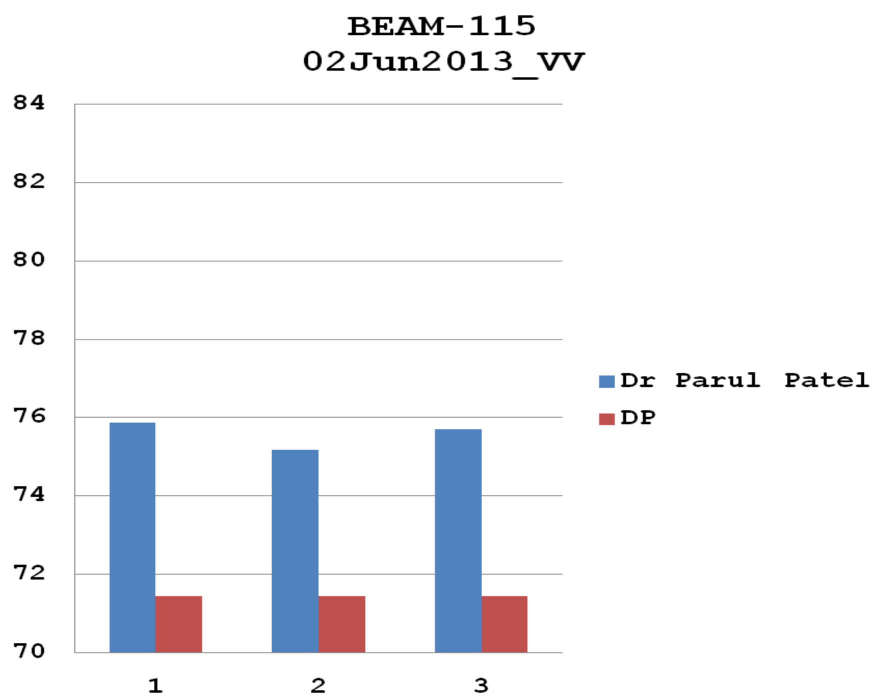

Fig. 36: Calibration Constant using point target impulse response along with that of DP (12Sep2013-CH, Ahmedabad)

A study of **Table-3.1** through **Table3.17** and **Fig.8** through **Fig.36** which gives calibration constants derived using point target response and that of DP reveals that the two differs significantly and the difference varies from beam to beam. The reflectors were deployed during June 2012 to December 2013. It can be observed that the Calibration constants derived using point target response and that of the DP provided calibration constant values in the header of the data differed by between 0.32 to 12.23 dB depending upon the beam and polarisation. Besides it can be observed from Fig.33 through **Fig.36** that for beam 115 CH, CV , HH and VV polarisations were studied. Strudy of this beam reveals that the difference in calibration constants derived using point target response and that of DP is dependent on polarisations and/or different date of acquisition when they were observed. This difference could be due to uncompensated antenna pattern in the data product.

6.0 Conclusion

This report brings out the results of independent calibration exercise carried out by the team on the FRS beam mode data which are processed before implementation of updated RISAT-1 Data Processor (version 1.3.00) at NRSC during June 2014. Point targets deployment carried for RISAT-1 FRS-1 beam mode SAR data during 2012 to 2014 has been analysed for the purpose. The results are based upon 17 (seventeen) date data comprising of 10 (ten) beams for CH, CV, 4 (four) beams for HH and 1 beam for VV polarisation with a total of 40 (forty) corner reflector responses. Calibration constant for converting SAR image digital number to backscattering coefficient is reported and compared to that of DP value of calibration constant provided in the header of the data. It is observed that DP provided calibration constant differs to that of calibration constant derived by independent calibration exercise of deploying corner reflectors and deriving calibration constant based upon their impulse response up to 10dB. The variation can be attributed to uncompensated antenna pattern.

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