

## System Verification Report SYS # 224

SYSE-88.00.00.00-0028-A-REP

2013-04-16

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**Change Record**

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# 1 Summary

This is the System Verification test report for SYS #224 in the System Technical Requirements..

## 1.1 Requirement

Optics: ON-axis instrumental polarization:

- a) for the Antenna plus Front End the instrumental polarization shall be  $< -20$  dB (in power) before calibration, and
- b)  $< -40$  dB (in power) after calibration
- c) this applies over 30 degrees of antenna motion in azimuth or elevation and with a calibration interval of 4 hours.

The items (a) and (b) are equivalent to the conditions that **the D-term (in voltage) level is less than 10% before calibration and less than 1% after calibration**, respectively.

## 1.2 Applicable Documents

The following documents contain information and are applicable to this document.

Appl.	Document Title	ALMA Doc. Number
[AD01]	ALMA System Technical Requirements	<a href="#">ALMA-80.04.00.00-005-C-SPE</a>

## 1.3 Reference Documents

The following documents contain additional information and are referenced in this document.

Ref	Document Title	Doc. Number
[RD01]	Revised ALMA System Technical Requirements - Polarization	<a href="#">ALMA-80.04.00.00-0038-A-SPE</a>

## 1.4 Acronyms and Abbreviations






For a complete set of acronyms and abbreviations used in the ALMA project, please go to <http://aivwiki.alma.cl/index.php/Acronyms>.



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## 2 Compliance Matrix

Test Name	Pass 	Fail 	Comments
<b>Band 1</b>			
#xxx -:			Not Installed
<b>Band 2</b>			
#xxx -			Not Installed
<b>Band 3</b>			
#224 -: ON-axis instrumental polarization: a) for the Antenna plus Front End the instrumental polarization shall be < -20 dB (in power) before calibration, and b) < -40 dB (in power) after calibration c) this applies over 30 degrees of antenna motion in azimuth or elevation and with a calibration interval of 4 hours.			Tested on 12m antennas including at least one of DV, DA, and PM antennas for a) and b). No PM antenna participated to the test c).
<b>Band 4</b>			
#xxx -			Not Installed
<b>Band 5</b>			
#xxx -:			Not Installed
<b>Band 6</b>			
#224 -: ON-axis cross polarization: a) for the Antenna plus Front End the cross-polarization shall be < -20 dB (in power) before calibration, and b) < -40 dB (in power) after calibration c) this applies over 30 degrees of antenna motion in azimuth or elevation and with a calibration interval of 4 hours.			Tested on 12m antennas including at least one of DV and DA antennas. No PM antennas participated to this observation. The frequency coverage is limited to 217.9-246.5. The test for the rest of frequency range should be reported later.
<b>Band 7</b>			
#224 -: ON-axis cross polarization: a) for the Antenna plus Front End the cross-polarization shall be < -20 dB (in power) before calibration, and b) < -40 dB (in power) after calibration			Tested on 12m antennas including at least one of DV, DA, and PM antennas. The frequency coverage is limited to 332.5-356.0GHz. The test for the rest of frequency range and stability test should be reported later.
<b>Band 8</b>			
#xxx -:			Not Installed
<b>Band 9</b>			
#xxx -			
<b>Band 10</b>			



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Test Name	Pass 	Fail 	Comments
#xxx -:			Not Installed



### 3 Procedure

The verification of this System Technical Requirement was achieved with the following Verification Method:

**a) for the Antenna plus Front End the instrumental polarization shall be < -20 dB in power before calibration (D-term level < 10%)**

As given by [RD01], the D-terms can be determined by observing unresolved polarized calibrator at several different parallactic angles. The bright quasar 1924-292 was observed at band 3 and band 7 and 3C 279 at band 6. The band 6 data is the same one used for the analysis of c) (see below). The spectral setting was TDM mode. We made these observations in two frequency tunings for each band and each frequency tuning contains 4 spectral windows (spws). Therefore, we obtained 8 spws per one frequency band in total. Six different parallactic angles were obtained for each frequency tuning. The integration time per one parallactic angle sampling is 2-3 min, depending on the frequency band. The observation was done by switching two frequency tunings alternatively so that we can obtain similar parallactic angle coverage for both tunings. The detailed frequency setup is listed in Table 1. The upper sideband of the first tuning is overlapped with the lower sideband of the second tuning, allowing a direct comparison of the D-term results.

	Band 3 Frequency [GHz]	Band 6 Frequency [GHz]	Band 7 Frequency [GHz]
Spw 0	86134.335	217884.335	332484.375
Spw 1	87692.875	219692.875	333984.375
Spw 2	96557.125	230307.125	342515.625
Spw 3	98115.665	232115.665	344015.625
Spw 4	96534.335	230284.335	342484.375
Spw 5	980092.875	232092.875	343984.375
Spw 6	108957.125	244707.125	354515.625
Spw 7	110515.665	246515.665	356015.625

Table 1: Observation frequency.

The procedure for the calibration is as follows.

- 1) delay offset in parallel-hand correlations
- 2) bandpass characteristics of parallel-hand correlations
- 3) complex gain of parallel-hand correlations
- 4) delay offset in cross-hand correlations
- 5) phase offset in cross-hand correlations (X-Y phase) and solve the source polarization
- 6) fix the Q/U sign ambiguity of the source polarization model obtained in the step 5)
- 7) revise the complex gain obtained in the step 3) using the source polarization model 6)
- 8) D-terms

If the delay offset is stable enough during the observation, we skip the step 1) and implicitly calibrate this at the step 2). The detailed data reduction script is attached in the appendix.

**b) < -40 dB in power after calibration (residual D-term level < 1%)**



The requirement for the instrumental polarization of < -40dB (in power) after calibration turns out the residual D-terms of -20dB (1%). From [RD01], the residual D-terms ( $\sigma_D$ ) can be estimated from the following equation.

$$\sigma_Q / I \approx \sigma_U / I \approx \sigma_D,$$

where  $\sigma_Q$  is the rms error on the Stokes Q image,  $\sigma_U$  is the rms error on the Stokes U image, and  $I$  is the Stokes I intensity of the source. Assuming that the D-terms are all independent and same level among different baselines, the residual D-term for each baseline ( $\bar{\sigma}_D$ ) can be estimated as

$$\bar{\sigma}_D = \sigma_D / \sqrt{N(N-1)},$$

where N is the number of antennas. Thus, the residual D-term after the calibration appears on the Q and U images and can be estimated from the rms on these images. We used same datasets as used for the analysis a). After all calibrations described above applied, the rms on the Q and U images was estimated by using the CASA task 'imstat'.

**c) this applies over 30 degrees of antenna motion in azimuth or elevation and with a calibration interval of 4 hours.**

To test the stability of D-terms, we observed two quasars (3C279 and 0854+201) separated by ~4 hours in hour angle (Figure 1). The stability was evaluated by comparing two D-term solutions where one of them was determined from 3c279 and the other one was determined from 0854+201. During the observation of 3c279, the azimuth and elevation angles ranged from 50 to 5 degree and 66 to 73 degree, respectively. During the observation of 0854+201, the azimuth and elevation angles ranged from 20 to -40 degree and 38 to 47 degree, respectively. Therefore, the data were sampled at ~40 degree and ~70 degree in azimuth for 0854+201 and 3c279, respectively. The data analysis is the same manner described in a).

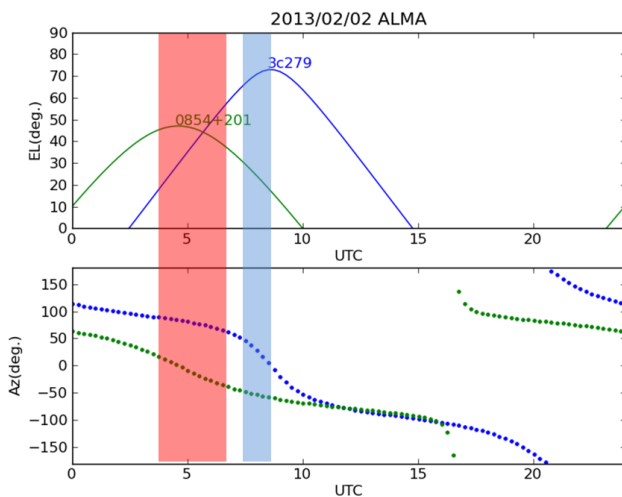


Figure 1: The azimuth and elevation plots of 0854+201 and 3c279. The red-shaded and blue-shaded regions indicate the range where the observation was carried out.

More in detail about the dataset used for all these analyses is summarized in Table 2.

	Band	date	Source	Uid name	CSV ticket
a)	Band 3	2012/Aug18	1924-292	uid__A002_X4a0772_X145 uid__A002_X4a0772_X197 uid__A002_X4a0772_X1e8 uid__A002_X4a0772_X77 uid__A002_X4a0772_Xa7	CSV-2146





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	Band 6	2013/Feb/2	3c279	uid__A002_X4a0772_Xf6 uid__A002_X5c26d9_X488 uid__A002_X5c26d9_X51a uid__A002_X5c26d9_X495 uid__A002_X5c26d9_X527 uid__A002_X5c26d9_X4df uid__A002_X5c26d9_X553 uid__A002_X5c26d9_X4ec uid__A002_X5c26d9_X560	CSV-2440
	Band 7	2012/Aug/19	1924-292	uid__A002_X4a2e2f_X2c2 uid__A002_X4a2e2f_X2e8 uid__A002_X4a2e2f_X30e uid__A002_X4a2e2f_X335 uid__A002_X4a2e2f_X35b uid__A002_X4a2e2f_X381	CSV-2146
b)	Band 3	2012/Aug18	1924-292	Same with a)	CSV-2146
	Band 6	2013/Feb/2	3c279	Same with a)	CSV-2440
	Band 7	2012/Aug/19	1924-292	Same with a)	
c)	Band 3	2013/Feb/2	3c279	uid__A002_X5c26d9_X488 uid__A002_X5c26d9_X51a uid__A002_X5c26d9_X495 uid__A002_X5c26d9_X527 uid__A002_X5c26d9_X4df uid__A002_X5c26d9_X553 uid__A002_X5c26d9_X4ec uid__A002_X5c26d9_X560	CSV-2440
			0854+201	uid__A002_X5c26d9_X2da uid__A002_X5c26d9_X386 uid__A002_X5c26d9_X2f4 uid__A002_X5c26d9_X393 uid__A002_X5c26d9_X313 uid__A002_X5c26d9_X3bf uid__A002_X5c26d9_X320 uid__A002_X5c26d9_X3cc uid__A002_X5c26d9_X34d uid__A002_X5c26d9_X3f8 uid__A002_X5c26d9_X35a uid__A002_X5c26d9_X405	CSV-2440
	Band 6	2013/Feb/2	3c279	Same with band 3	CSV-2440
			0854+201	Same with band 3	CSV-2440
	Band 7	N/A as of 2013/April/15			

Table 2: Summary of datasets used for the analysis.

## 4 Results and Analysis

### 4.1 Measurement of D-terms

Figure 2, 3, and 4 show the D-terms as a function of frequency for DA42 at band 3, 6, and 7, respectively. We chose DV04 for the reference antenna at bands 3/7 and DV23 at band 6. The plots for all antennas are shown in the appendix. The D-term levels are relatively small, about 2%, 4%, 1% at band 3, 6, and 7 with variations over frequency that are generally less than 1%, 2%, and 0.5%, respectively. The difference of D-term level among different antennas is relatively large at band 6 (Figures 12 and 13 in Appendix). The D-terms become 10% at some channels for a few antennas in band 6 (Figure 5). Note that the requirement for the cross polarization of  $< -20\text{dB}$  turns out the D-terms of  $< -10\text{dB}$  (10%). Therefore, the measured D-term levels are mostly smaller than the required level. The D-term level at band 7 is relatively smaller than those at bands 3 and 6, and the frequency structure is also less significant. This might result from the difference of the polarization separation method, i.e., bands 3 and 6 adopt the OMT while band 7 adopts the wire grid. For the overlapping frequency coverage (spws=2,3,4,5), there is relatively good agreement in the D-terms. This implies that the polarization leakages are mostly from the frontends. There is a systematic difference between spws (2, 3) and (4, 5) at 0.1-0.3% level at bands 3/6/7. This difference could result from different electrical path (spws 2 and 3: upper sideband, spws 4 and 5: lower sideband) or different parallactic angle sampling. The study for the origin of this difference is beyond the scope of this report since the difference is very small.

Quasi-periodic frequency structure is evident in all bands. The cycle of the frequency structure is  $\sim 1\text{-}2$  GHz at band 3 and  $0.25\text{-}0.3$  GHz in bands 6 and 7. These cycles are corresponding to the reflection length of  $\sim 15\text{-}20$  cm at band 3 and  $\sim 50\text{-}60$  cm at band 7 if the frequency structures are caused by the reflections in the electrical path. This will give a hint for the origin of the D-terms.

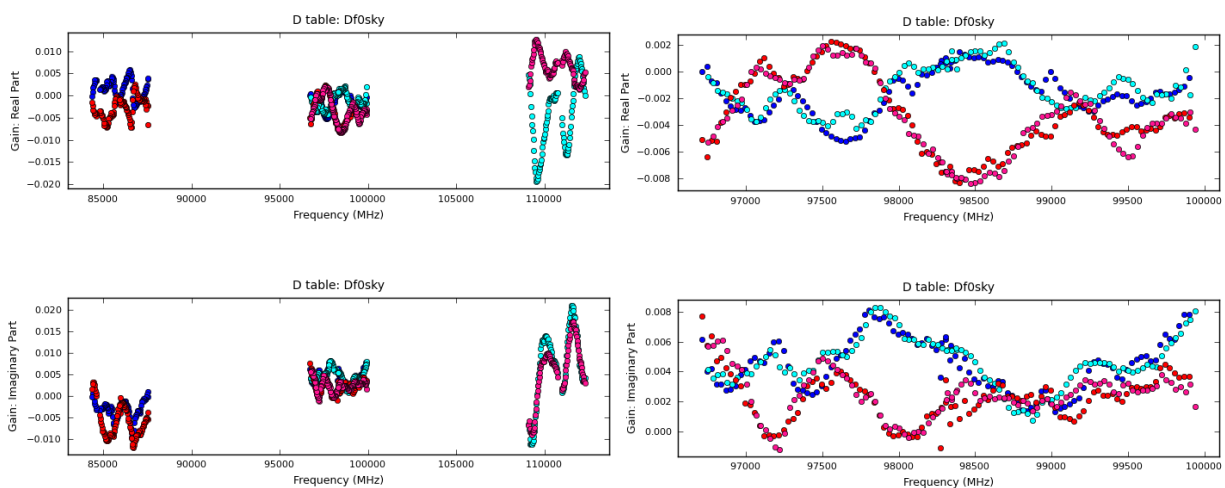


Figure 2--- Left: Real part (upper panel) and imaginary part (lower panel) of the D-terms as a function of frequency in band 3 (antenna=DA42). Blue (spw=0,1,2,3) and cyan (spw=4,5,6,7) show  $D_x$ , and red (spw=0,1,2,3) and pink (spw=4,5,6,7) show  $D_y$ . Right: Same plot with left, but only spws 2,3,4,5 are plotted. We chose DV04 as the reference antenna.



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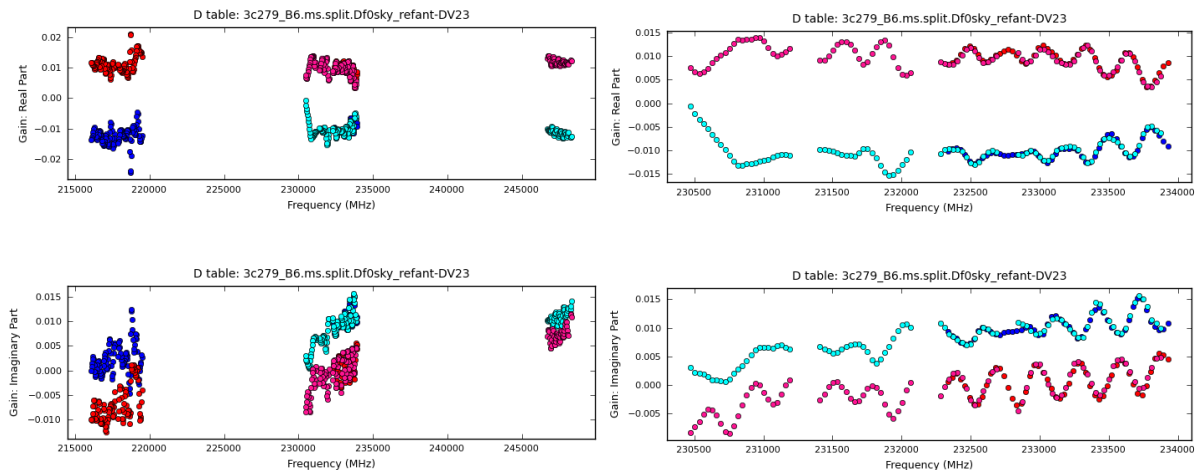


Figure 3--- Left: Real part (upper panel) and imaginary part (lower panel) of the D-terms as a function of frequency in band 6 (antenna=DA41). Blue (spw=0,1,3) and cyan (spw=4,5,7) show  $D_X$ , and red (spw=0,1,3) and pink (spw=4,5,7) show  $D_Y$ . Right: Same plot with left, but only spws 2,3,4,5 are plotted. The data for spws=2 and 6 were flagged due to the system problem reported in CSV-XXXX. We chose DV23 as the reference antenna.

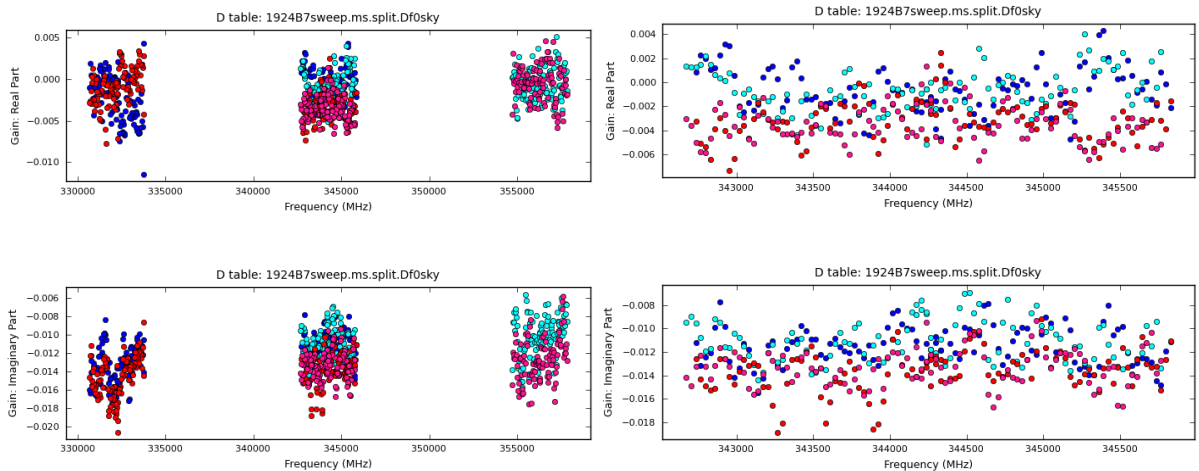


Figure 4--- Left: Real part (upper panel) and imaginary part (lower panel) of the D-terms as a function of frequency in band 7 (antenna=DA42). Blue (spw=0,1,2,3) and cyan (spw=4,5,6,7) show  $D_X$ , and red (spw=0,1,2,3) and pink (spw=4,5,6,7) show  $D_Y$ . Right: Same plot with left, but only spws 2,3,4,5 are plotted. We chose DV04 as the reference antenna.

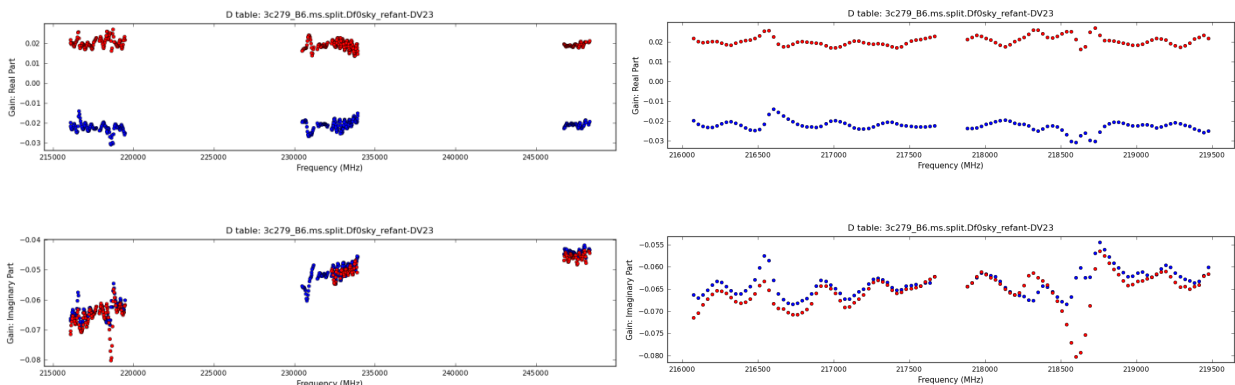


Figure 5--- An example of the worst D-term antenna (DV04). The level of D-terms is  $\sim 2\%$  for real part and  $7\%$  for imaginary part between 216 GHz and 217.5 GHz. At 218.6 GHz, the magnitude of  $D_Y$  ( $=\sqrt{D_{Yreal}^2 + D_{Yimag}^2}$ ) reaches  $\sim 10\%$ . Left: Real part (upper panel) and imaginary part (lower panel) of the D-terms as a function of frequency at band 6. Blue (spw=0,1,3) and cyan (spw=4,5,7) show  $D_X$ , and red (spw=0,1,2,3) and pink (spw=4,5,7) show  $D_Y$ . Right:

Same plot with left, but only spws 0 and 1 are plotted. The data for spws=2 and 6 were flagged due to the system problem reported in CSV-XXXX. We chose DV04 as the reference antenna.

## 4.2 Residual D-terms

In Figure 6, we show a typical example of the polarization image with and without D-term calibration applied. By applying the D-term solution, the image noise rms improves by a factor of  $\sim 10$ . While the calibrated image shows the point-like emission, the uncalibrated one shows the emission with a slight elongation in Stokes U image. There are significant fake emissions in the Stokes U image, which are indicated by the yellow ellipse in Figure 6. These distortions are also improved by applying the D-term solution.

We list  $\sigma_Q, \sigma_U, \sigma_D$  at band center (spw=3) and edges (spws=0,7) in Table 3. Note that the error other than the residual D-terms, such as thermal noise, deconvolution error, and so on, can be included in  $\sigma_Q$  and  $\sigma_U$ . Therefore,  $\bar{\sigma}_D$  is regarded as the upper limit of the residual D-term. All the residual D-terms for each baseline ( $\sigma_D$ ) listed in Table 3 are smaller than the required level (1%). Note that the error on Stokes Q and U images is typically an order of  $10^{-4}$ . This demonstrates that ALMA has a potential capability to detect the polarized emission better than 0.1%.

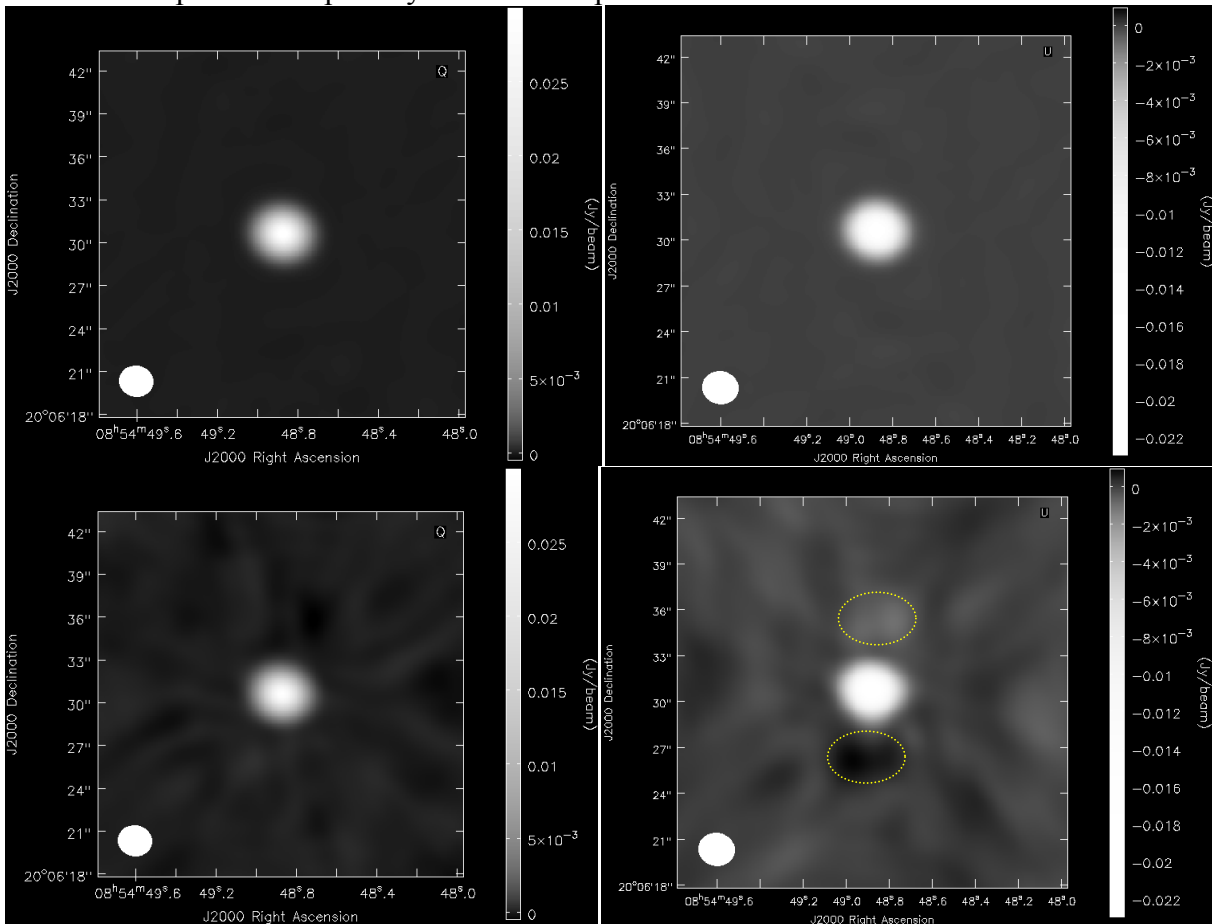


Figure 6--- Example of Stokes Q and U images with and without D-term calibration applied. Upper left: Stokes Q image with D-term calibration, Upper right: Stokes U image with D-term calibration, Lower left: Stokes Q image without D-term calibration, Lower right: Stokes U image without D-term calibration. Fake emissions, which result from the D-term, are shown in yellow ellipse in the lower right image.

Band/spw	Frq. [GHz]	$\sigma_Q$	$\sigma_U$	$\bar{\sigma}_D^{(1)}$
Band 3 / spw 0	86.1 GHz	8.45E-05	1.20E-04	1.65E-03,



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				2.34E-03
Band 3 / spw 3	98.1 GHz	1.34E-04	2.01E-04	2.61E-03, 3.92E-03
Band 3 / spw 7	110. 5 GHz	1.58E-04	2.38E-04	3.07E-03, 4.64E-03
Band 6 / spw 0	217.9 GHz	1.09E-05	9.37E-06	2.89E-04 2.48E-04
Band 6 / spw 3	232.1 GHz	1.30E-05	1.15E-05	3.44E-04 3.05E-04
Band 6 / spw 7	246.5 GHz	2.56E-05	1.80E-05	6.78E-04 4.77E-04
Band 7 / spw 0	332. 5 GHz	1.18E-04	1.30E-04	2.65E-03, 2.91E-03
Band 7 / spw 3	344. 0 GHz	1.93E-04	2.39E-04	4.34E-03, 5.39E-03
Band 7 / spw 7	356. 0 GHz	2.62E-04	2.48E-04	5.90E-03, 5.59E-03

Table 3: The rms on Q and U images ( $\sigma_Q, \sigma_U$ ) and the resultant residual D-terms ( $\bar{\sigma}_D$ ). Note: (1) Two values are denoted in each frequency, and the upper one indicates  $\bar{\sigma}_D$  calculated from  $\sigma_Q$  and lower one indicates  $\bar{\sigma}_D$  calculated from  $\sigma_U$ .

### 4.3 Stability

Figure 7 and 8 show the comparison of D-terms derived from 0854+201 and 3c279 at band 3 and band 6, respectively. These plots are for DA41 at spws=0 and 1, but other antennas and other spws show similar properties. The two solutions show a very good agreement in terms of both the level and frequency structure. The difference is typically less than 0.3% at band 3 and 0.5% at band 6. The difference at band 6 is relatively large, but required level ( $D < 10\%$ ) is still fulfilled. Intriguingly, the worst D-term antenna (DV04) also shows a remarkable agreement between two solutions (Figure 9). This indicates that the level of time variation does not depend on the magnitude of D-terms. All evidences suggest that the D-terms are stable over typical calibration time and over a typical angle between target and D-term calibrator.

The residual D-terms derived from both 3c279 and 0854+201 are not much different from those listed in Table 3, so we do not repeat them here.

See also an independent analysis reported by Ed Fomalont in CSV-2440.



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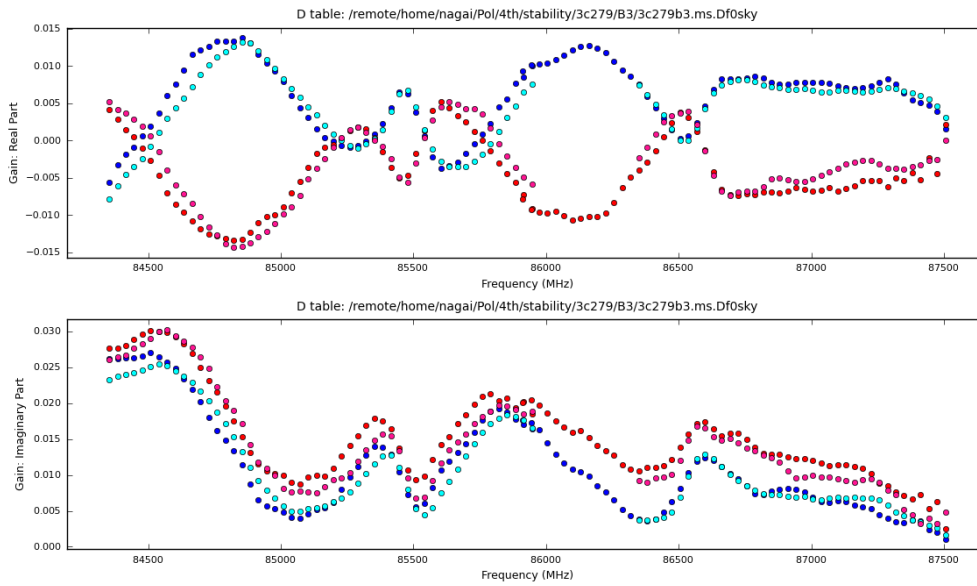


Figure 7: Comparison of D-term solutions between 3c279 and 0854+201 at band 3 for DA41. Upper and lower panels show the real and imaginary part of D-terms. Blue ( $D_x$ ) and red ( $D_y$ ) symbols indicate the solution from 0854+201, and cyan ( $D_x$ ) and pink ( $D_y$ ) symbols indicate the solution from 3c279. We chose DV23 as the reference antenna.

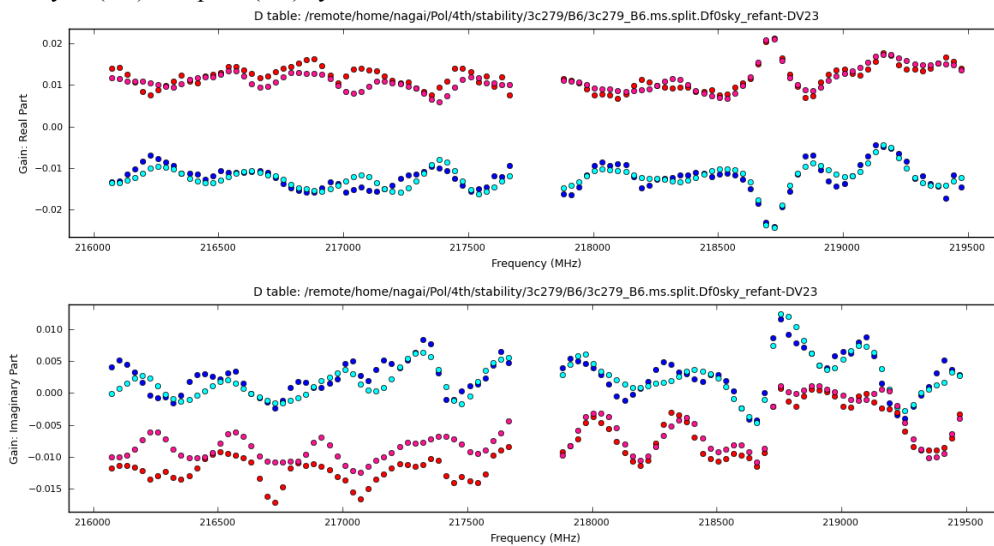


Figure 8: Comparison of D-term solutions between 3c279 and 0854+201 at band 6 for DA41. Upper and lower panels show the real and imaginary part of D-terms. Blue ( $D_x$ ) and red ( $D_y$ ) symbols indicate the solution from 0854+201, and cyan ( $D_x$ ) and pink ( $D_y$ ) symbols indicate the solution from 3c279. We chose DV23 as the reference antenna.



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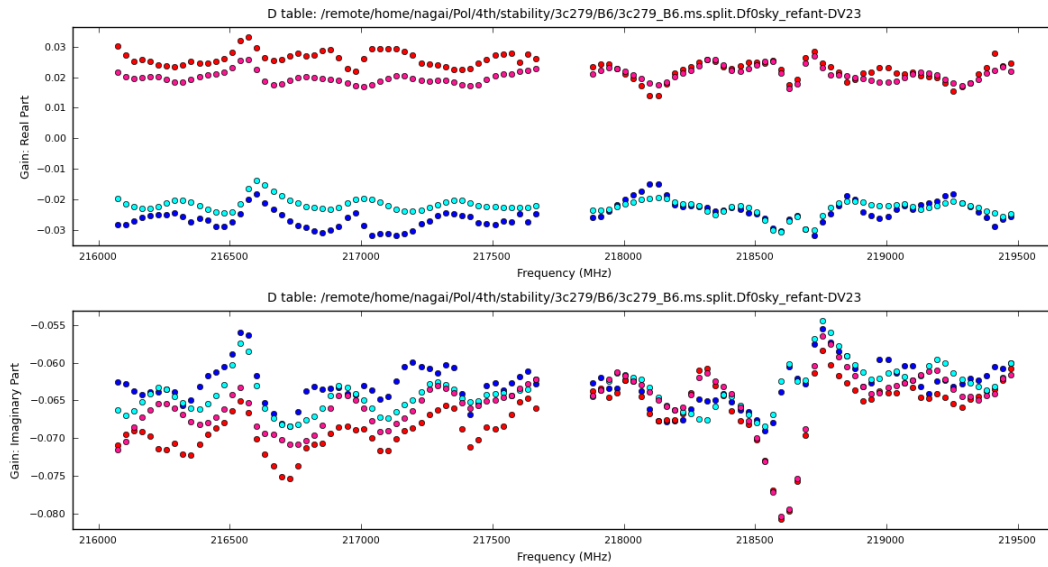


Figure 9: Comparison of D-term solutions between 3c279 and 0854+201 at band 6 for DV04. Upper and lower panels show the real and imaginary part of D-terms. Blue ( $D_X$ ) and red ( $D_Y$ ) symbols indicate the solution from 0854+201, and cyan ( $D_X$ ) and pink ( $D_Y$ ) symbols indicate the solution from 3c279. We chose DV23 as the reference antenna.



## 5 Conclusion

Although verified condition is limited, we confirmed that ALMA system meets the requirements

- (a) on-axis instrumental polarization is less than -20dB ( $D < 10\%$ ) before calibration,
- (b) less than -40dB ( $D < 1\%$ ) after calibration,
- (c) this applies over 30 degrees of antenna motion in azimuth or elevation and with a calibration interval of 4 hours.

The items (a) and (b) are verified at the frequencies between 217.9 and 246.5 GHz at band 6 and between 332.5-356.0 GHz at band 7. The item (c) are verified at the frequencies between 217.9 and 246.5 GHz at band 6 and no observation has been made at band 7 as of 2013/Apr/16. The data required for these remaining tasks are planned to be taken in CSV, and the results should be reported in near future.

## 6 Appendix

### 6.1 Data calibration scripts

#The script for the items (a) and (b) at band 3

**#Original data reduction script is developed by G. Moellenbrock (NRAO)**  
**#Modified by H. Nagai with the help by E. Fomalont and K. Nakanishi**

```
execfile('almapolhelpers.py')

#convert asdm to ms
importasdm(asdm='uid__A002_X4a0772_X145',vis='uid__A002_X4a0772_X145.ms')
importasdm(asdm='uid__A002_X4a0772_X197',vis='uid__A002_X4a0772_X197.ms')
importasdm(asdm='uid__A002_X4a0772_X1e8',vis='uid__A002_X4a0772_X1e8.ms')
importasdm(asdm='uid__A002_X4a0772_X77',vis='uid__A002_X4a0772_X77.ms')
importasdm(asdm='uid__A002_X4a0772_Xa7',vis='uid__A002_X4a0772_Xa7.ms')
importasdm(asdm='uid__A002_X4a0772_Xf6',vis='uid__A002_X4a0772_Xf6.ms')

#concatnating multiple datasets into one dataset
concat(vis=['uid__A002_X4a0772_X145.ms','uid__A002_X4a0772_X197.ms',\
           'uid__A002_X4a0772_X1e8.ms','uid__A002_X4a0772_X77.ms',\
           'uid__A002_X4a0772_Xa7.ms','uid__A002_X4a0772_Xf6.ms'],\
       concatvis='B3sweep.ms')

#split science spws
split(vis='B3sweep.ms',outputvis='B3sweep.ms.split',datacolumn='data',\
      spw='1,3,5,7,9,11,13,15')

msdata='1924_B3_AUG18.concat.ms.split'

#list obs. information
listobs(vis=msdata,listfile=msdata+'.listobs')

#flag edge channels
tflagdata(vis=msdata,spw='*:0~4,*:58~63')

#flag shadowed antennas
flagdata(vis=msdata,mode='shadow')

#flag bad data
tflagdata(vis=msdata,spw='7:5~14')
tflagdata(vis=msdata,spw='0:44~48')
tflagdata(vis=msdata,antenna='DV08',scan='2',spw='4:14~17')
```





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```
#feed position angle problem (CSV-2569)
tb.open('1924_B3_AUG18.concat.ms.split/FEED',nomodify=F)
ra=tb.getcol('RECEPTOR_ANGLE')
ra[:,:]=0.0
tb.putcol('RECEPTOR_ANGLE',ra)
tb.close()

refant='DV04'

# delay by scan
gaincal(vis=msdata,caltable=msdata+'.Kscan',
        selectdata=T,scan='',
        gaintype='K',
        solint='inf',
        refant=refant,smodel=[1,0,0,0])

# phase(t) cal. (relative to Kscan)
gaincal(vis=msdata,caltable=msdata+'.G0ph',
        gaintype='G',solint='int',calmode='p',
        refant=refant,smodel=[1,0,0,0],
        gaintable=msdata+'.Kscan',interp='nearest')

# scan-dep bandpass
bandpass(vis=msdata,caltable=msdata+'.Bscan',
        solint='inf',combine='',
        refant=refant,solnorm=T, # smodel=[1,0,0,0],
        gaintable=[msdata+'.Kscan',msdata+'.G0ph'],interp=['nearest','nearest'])

# Full G (solint=int) using K1,G0ph,Bscan
gaincal(vis=msdata,caltable=msdata+'.G1', \
        solint='int',refant=refant,smodel=[1,0,0,0], \
        gaintable=[msdata+'.Kscan',msdata+'.G0ph',msdata+'.Bscan'],interp=['nearest','nearest','nearest'])

qu=qufromgain(msdata+'.G1')

# cross-hand delay (scans 1,2,3,4 are strong source pol scans)
gaincal(vis=msdata,caltable=msdata+'.Kcrs',
        selectdata=T,antenna='',scan='1,2,3,4',
        gaintype='KCROSS',
        solint='inf',refant=refant, smodel=[1,0,1,0],
        gaintable=[msdata+'.Kscan',msdata+'.G0ph',msdata+'.Bscan',msdata+'.G1'],
        interp=['nearest','nearest','nearest','linear'])

# XY-phase and QU
# (output caltable called 'XY0amb' because it may contain ambiguities)
gaincal(vis=msdata,caltable=msdata+'.XY0amb',
        gaintype='XYF+QU',
        solint='inf',combine='scan',preavg=200, refant=refant,smodel=[1,0,1,0],
        gaintable=[msdata+'.Kscan',msdata+'.G0ph',msdata+'.Bscan',msdata+'.G1',msdata+'.Kcrs'],
        interp=['nearest','nearest','nearest','linear','nearest'])

# Revise gain w/ good source pol estimate
# (cross-hands not used here, so cross-hand cal tables not needed)
# (NB: we are using S from above in smodel; parang=T so p-hand model has pol variation)
gaincal(vis=msdata,caltable=msdata+'.G2',
        solint='int',refant=refant,smodel=S,
        gaintable=[msdata+'.Kscan',msdata+'.G0ph',msdata+'.Bscan'],interp=['nearest','nearest','nearest'],
        parang=T)

# verify by running qufromgain again:
qu2=qufromgain(msdata+'.G2')

# Now D, finally!
polcal(vis=msdata,caltable=msdata+'.Df0',
        solint='inf',combine='scan',preavg=60,
        poltype='Dfls',refant=refant,
        smodel=S,
        gaintable=[msdata+'.Kscan',msdata+'.G0ph',msdata+'.Bscan',msdata+'.G2',msdata+'.Kcrs',msdata+'.XY0'],
        interp=['nearest','nearest','nearest','linear','nearest','nearest'])

# Shift Df0 solution to sky frame
# (THIS IS ONLY FOR EXAMINATION PURPOSES, NOT FOR APPLYCAL!)
dxy(dtab=msdata+'.Df0',xtab=msdata+'.XY0',dout=msdata+'.Df0sky')

#apply everything
```



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```
applycal(vis=msdata,  
calwt=F,  
gaintable=[msdata+'.Kscan',msdata+'.G0ph',msdata+'.Bscan',msdata+'.G2',msdata+'.Kcrs',msdata+'.XY0',msdata+'.Df0'],  
interp=['nearest','nearest','nearest','linear','nearest','nearest'],  
parang=T)  
  
# end
```

The scripts for other bands and other items are basically same with the procedure shown above except for data flagging. Below I only show the data flagging part.

# data flagging part for the item (a) and (b) at band 6 -----

```
tflagdata(vis = msdata,  
mode = 'manual',  
spw = '*:0~6,*:59~63',  
flagbackup = F)  
tflagdata(vis=msdata, mode='shadow')  
tflagdata(vis=msdata, antenna='DV20,DV24,DV07,DA46')  
tflagdata(vis=msdata, scan='1')  
  
tflagdata(vis=msdata, timerange='2013/02/02/07:22:36~2013/02/02/07:22:38')  
tflagdata(vis=msdata, timerange='2013/02/02/07:37:50~2013/02/02/07:37:51')  
tflagdata(vis=msdata, timerange='2013/02/02/07:42:25~2013/02/02/07:42:26')  
tflagdata(vis=msdata, timerange='2013/02/02/08:21:13~2013/02/02/08:21:14')  
tflagdata(vis=msdata, timerange='2013/02/02/08:36:39~2013/02/02/08:36:40')  
tflagdata(vis=msdata, timerange='2013/02/02/09:09:43~2013/02/02/09:09:44')  
tflagdata(vis=msdata, timerange='2013/02/02/09:14:29~2013/02/02/09:14:30')  
tflagdata(vis=msdata, timerange='2013/02/02/09:29:34~2013/02/02/09:29:36')  
tflagdata(vis=msdata, timerange='2013/02/02/10:04:42~2013/02/02/10:04:44')  
tflagdata(vis=msdata, timerange='2013/02/02/10:19:44~2013/02/02/10:19:45')  
tflagdata(vis=msdata, timerange='2013/02/02/10:24:21~2013/02/02/10:24:22')  
tflagdata(vis=msdata, spw='4:29~34')  
tflagdata(vis=msdata, spw='2,6')  
tflagdata(vis=msdata, spw='7:52~55')
```

# data flagging part for the item (a) and (b) at band 7-----

```
tflagdata(vis = msdata,  
mode = 'manual',  
spw = '*:0~6,*:59~63',  
flagbackup = F)  
tflagdata(vis=msdata, mode='shadow')  
tflagdata(vis=msdata, antenna='DV08')
```

# data flagging part of the item (c) at band 3 -----

```
#for 3c279 data  
tflagdata(vis=msdata, spw='2,6')  
tflagdata(vis=msdata, spw='*:0~5;58~63')  
tflagdata(vis=msdata, antenna = 'DA45,DV20')  
tflagdata(vis=msdata, spw='1:44~63,7:0~9')  
tflagdata(vis=msdata, timerange='2013/02/02/07:27:21~2013/02/02/07:27:22')  
tflagdata(vis=msdata, timerange='2013/02/02/07:31:15~2013/02/02/07:31:16')  
tflagdata(vis=msdata, timerange='2013/02/02/07:50:38~2013/02/02/07:50:39')  
tflagdata(vis=msdata, timerange='2013/02/02/08:29:22~2013/02/02/08:29:23')  
tflagdata(vis=msdata, timerange='2013/02/02/07:46:57~2013/02/02/07:46:58')  
tflagdata(vis=msdata, timerange='2013/02/02/08:25:43~2013/02/02/08:25:44')
```

```
#for0854+201 data  
tflagdata(vis=msdata, spw='2,6')  
tflagdata(vis=msdata, spw='*:0~5;58~63', flagbackup = F)  
tflagdata(vis=msdata, timerange='2013/02/02/03:29:50~2013/02/02/03:29:55')  
tflagdata(vis=msdata, timerange='2013/02/02/03:46:28~2013/02/02/03:46:29')  
tflagdata(vis=msdata, timerange='2013/02/02/04:07:41~2013/02/02/04:07:42')  
tflagdata(vis=msdata, timerange='2013/02/02/04:18:55~2013/02/02/04:18:56')  
tflagdata(vis=msdata, timerange='2013/02/02/04:43:19~2013/02/02/04:43:20')  
tflagdata(vis=msdata, timerange='2013/02/02/04:54:28~2013/02/02/04:54:29')  
tflagdata(vis=msdata, timerange='2013/02/02/05:14:45~2013/02/02/05:14:46')  
tflagdata(vis=msdata, timerange='2013/02/02/05:26:42~2013/02/02/05:26:43')  
tflagdata(vis=msdata, timerange='2013/02/02/05:48:20~2013/02/02/05:48:21')
```



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tflagdata(vis=msdata,timerange='2013/02/02/05:59:45~2013/02/02/05:59:46')  
tflagdata(vis=msdata,timerange='2013/02/02/06:22:32~2013/02/02/06:22:33')  
tflagdata(vis=msdata,timerange='2013/02/02/06:34:29~2013/02/02/06:34:30')  
tflagdata(vis=msdata,timerange='2013/02/02/04:07:41~2013/02/02/04:07:42')  
tflagdata(vis=msdata,timerange='2013/02/02/05:46:43~2013/02/02/05:46:44')

# data flagging part of the item (c) at band 6 -----

#for 3c279 data

tflagdata(vis = msdata, spw = '\*:0~6,\*:59~63')  
tflagdata(vis=msdata, mode='shadow')  
tflagdata(vis=msdata, antenna='DV20,DV24,DV07,DA46')  
tflagdata(vis=msdata, scan='1')  
tflagdata(vis=msdata, timerange='2013/02/02/07:22:36~2013/02/02/07:22:38')  
tflagdata(vis=msdata, timerange='2013/02/02/07:37:50~2013/02/02/07:37:51')  
tflagdata(vis=msdata, timerange='2013/02/02/07:42:25~2013/02/02/07:42:26')  
tflagdata(vis=msdata, timerange='2013/02/02/08:21:13~2013/02/02/08:21:14')  
tflagdata(vis=msdata, timerange='2013/02/02/08:36:39~2013/02/02/08:36:40')  
tflagdata(vis=msdata, timerange='2013/02/02/09:09:43~2013/02/02/09:09:44')  
tflagdata(vis=msdata, timerange='2013/02/02/09:14:29~2013/02/02/09:14:30')  
tflagdata(vis=msdata, timerange='2013/02/02/09:29:34~2013/02/02/09:29:36')  
tflagdata(vis=msdata, timerange='2013/02/02/10:04:42~2013/02/02/10:04:44')  
tflagdata(vis=msdata, timerange='2013/02/02/10:19:44~2013/02/02/10:19:45')  
tflagdata(vis=msdata, timerange='2013/02/02/10:24:21~2013/02/02/10:24:22')  
tflagdata(vis=msdata, spw='4:29~34')  
tflagdata(vis=msdata, spw='2,6')  
tflagdata(vis=msdata, spw='7:52~55')

#for 0854+201 data

tflagdata(vis = msdata, spw = '\*:0~6,\*:59~63')  
tflagdata(vis=msdata, mode='shadow')  
tflagdata(vis=msdata, antenna='DV24')  
tflagdata(vis=msdata, antenna='DV15', scan='39')  
tflagdata(vis=msdata, timerange='2013/02/02/04:00:43~2013/02/02/04:00:44')  
tflagdata(vis=msdata, timerange='2013/02/02/04:03:29~2013/02/02/04:03:30')  
tflagdata(vis=msdata, timerange='2013/02/02/04:12:08~2013/02/02/04:12:09')  
tflagdata(vis=msdata, timerange='2013/02/02/04:14:44~2013/02/02/04:14:45')  
tflagdata(vis=msdata, timerange='2013/02/02/04:36:19~2013/02/02/04:36:20')  
tflagdata(vis=msdata, timerange='2013/02/02/04:39:08~2013/02/02/04:39:09')  
tflagdata(vis=msdata, timerange='2013/02/02/04:47:43~2013/02/02/04:47:44')  
tflagdata(vis=msdata, timerange='2013/02/02/04:52:11~2013/02/02/04:52:12')  
tflagdata(vis=msdata, timerange='2013/02/02/05:07:45~2013/02/02/05:07:46')  
tflagdata(vis=msdata, timerange='2013/02/02/05:22:31~2013/02/02/05:22:32')  
tflagdata(vis=msdata, timerange='2013/02/02/05:41:22~2013/02/02/05:41:24')  
tflagdata(vis=msdata, timerange='2013/02/02/06:15:34~2013/02/02/06:15:35')  
tflagdata(vis=msdata, timerange='2013/02/02/06:27:43~2013/02/02/06:27:44')  
tflagdata(vis=msdata, timerange='2013/02/02/05:52:57~2013/02/02/05:52:58')  
tflagdata(vis=msdata, timerange='2013/02/02/05:55:33~2013/02/02/05:55:34')  
tflagdata(vis=msdata, scan='9')  
tflagdata(vis=msdata, spw='2,6')  
tflagdata(vis=msdata, spw='4:29~35')  
tflagdata(vis=msdata, spw='7:52~55')



## 6.2 Plots

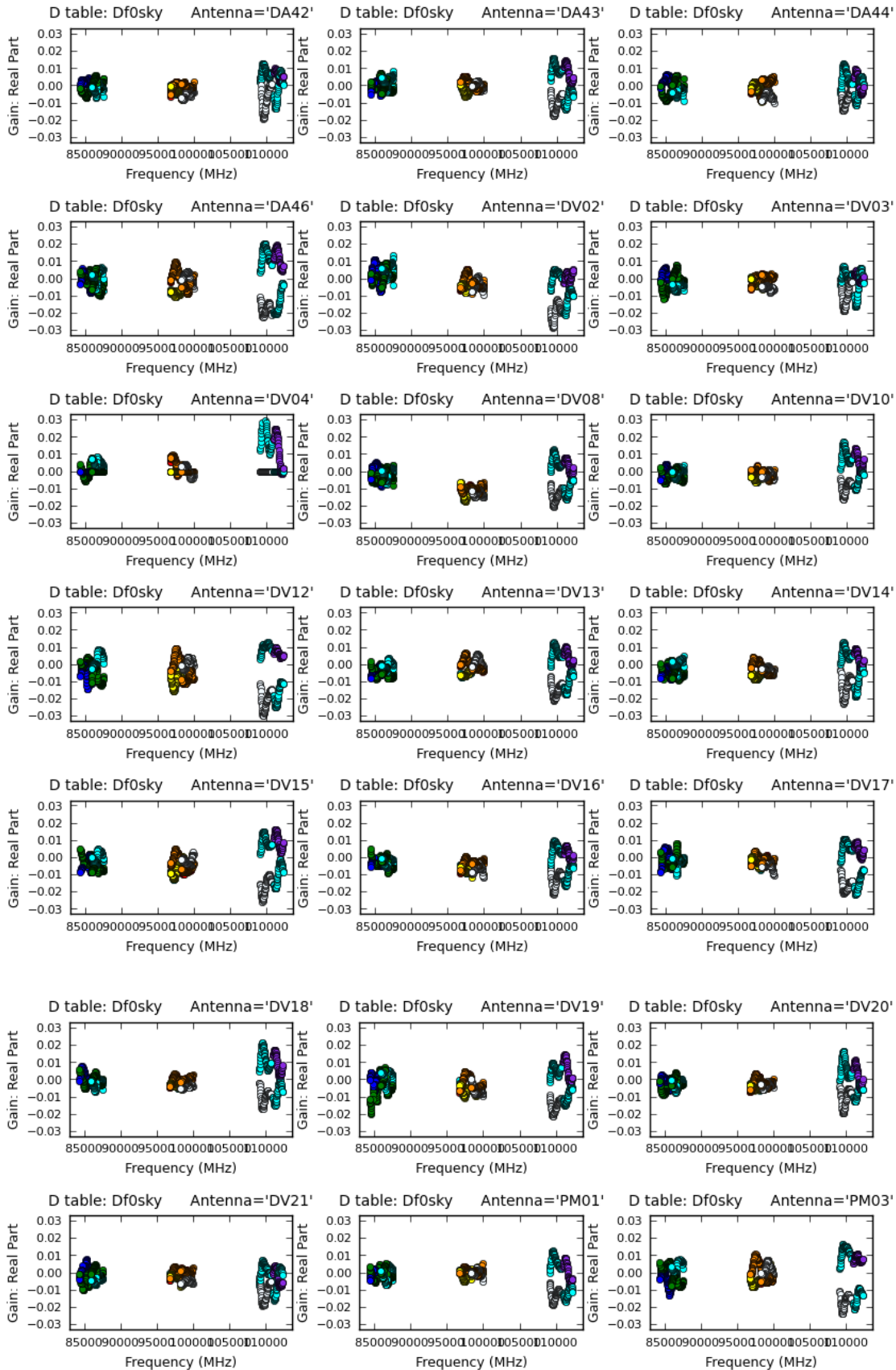


Figure 10: The real part of D-terms as a function of frequency at band 3 (colored by different spw and polarization).



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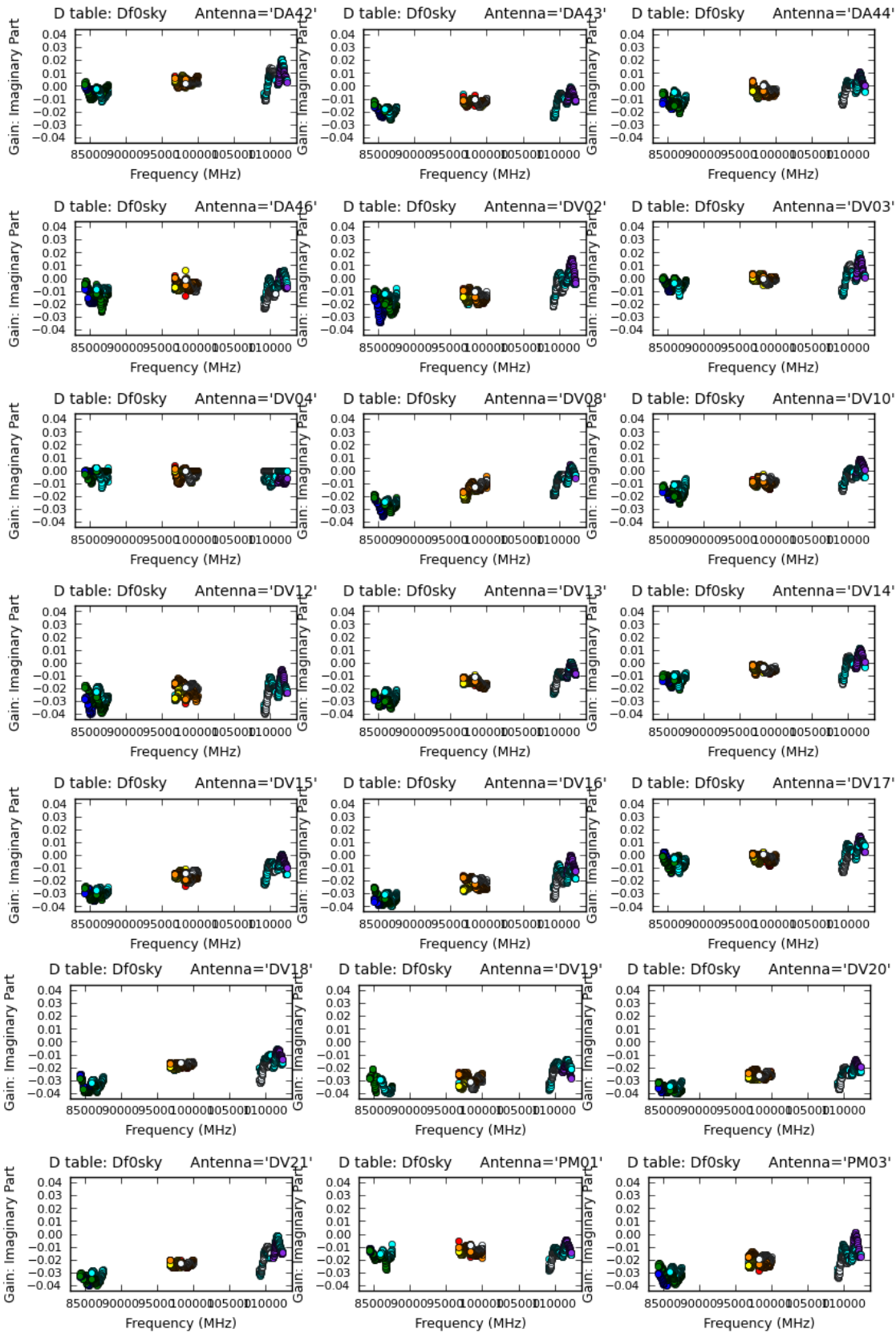


Figure 11: The imaginary part of D-terms as a function of frequency at band 3 (colored by different spw and polarization).



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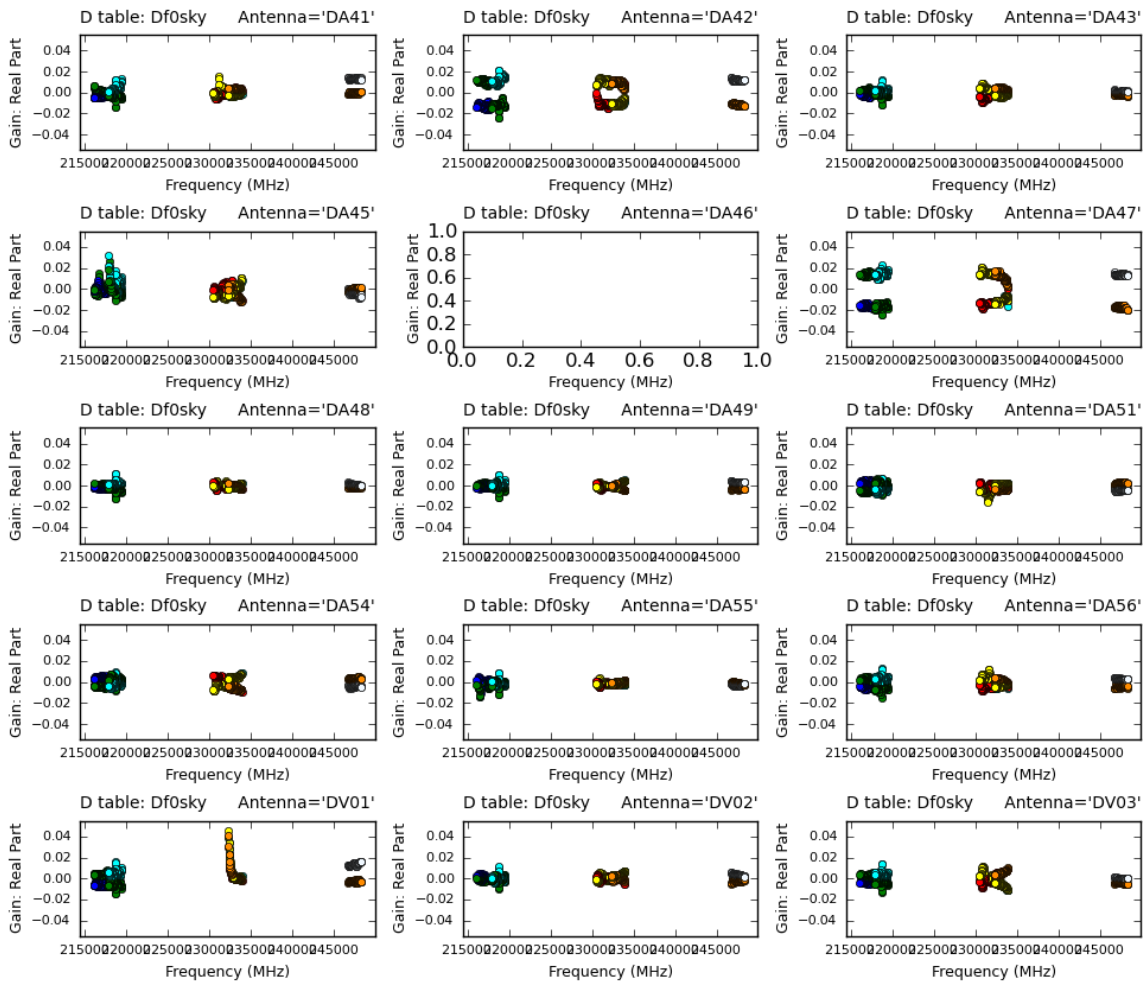


Figure 12: The real part of D-terms as a function of frequency at band 6 (colored by different spw and polarization).



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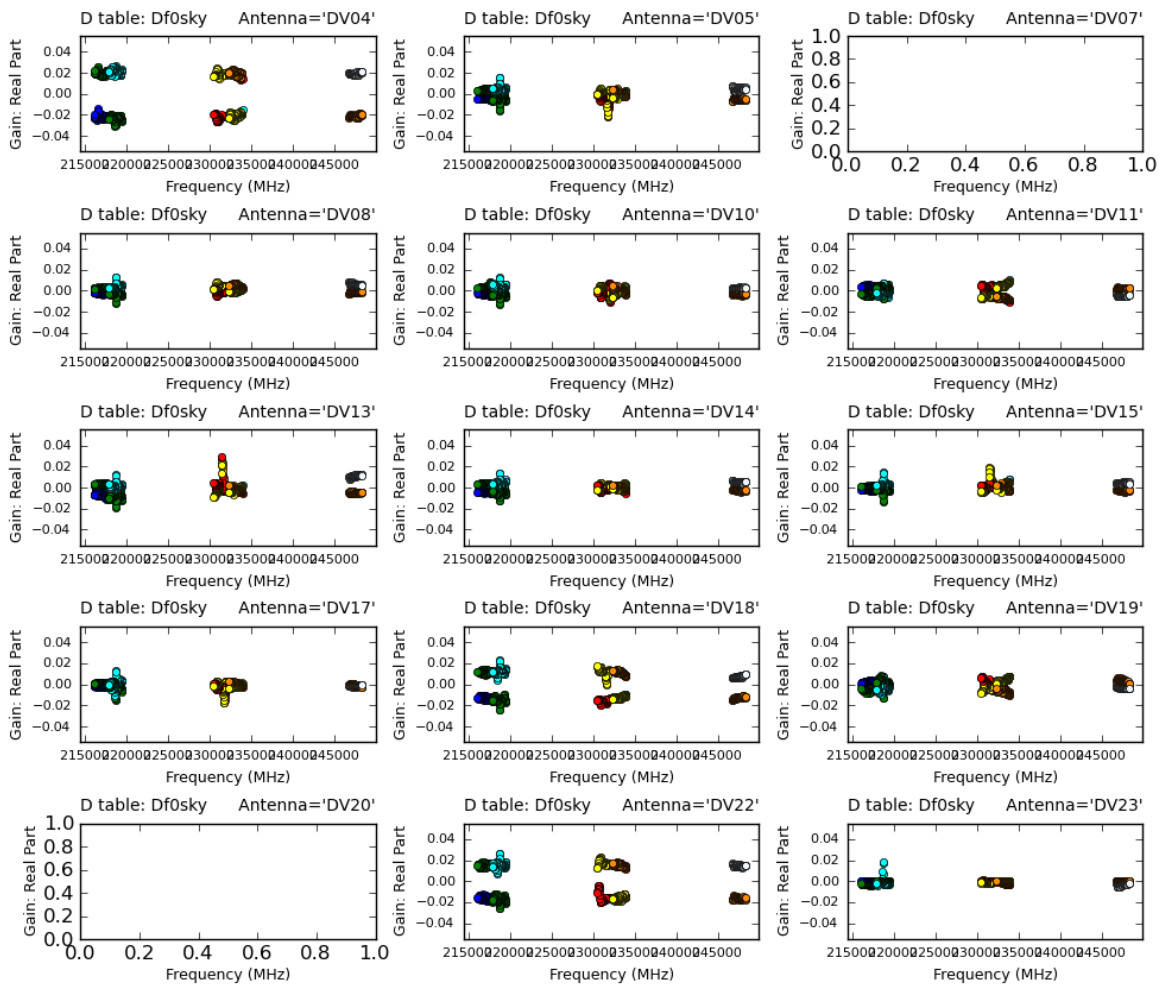


Figure 12: Continued



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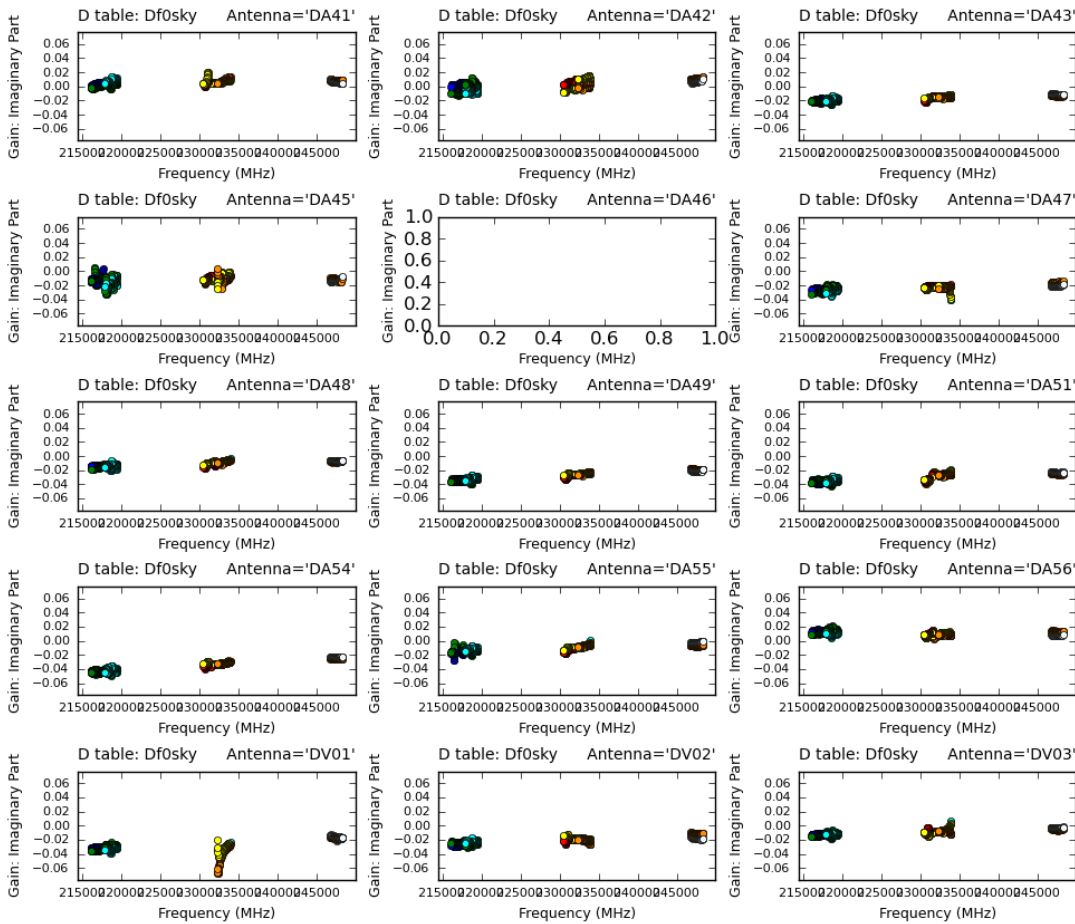


Figure 13: The imaginary part of D-terms as a function of frequency at band 6 (colored by different spw and polarization).





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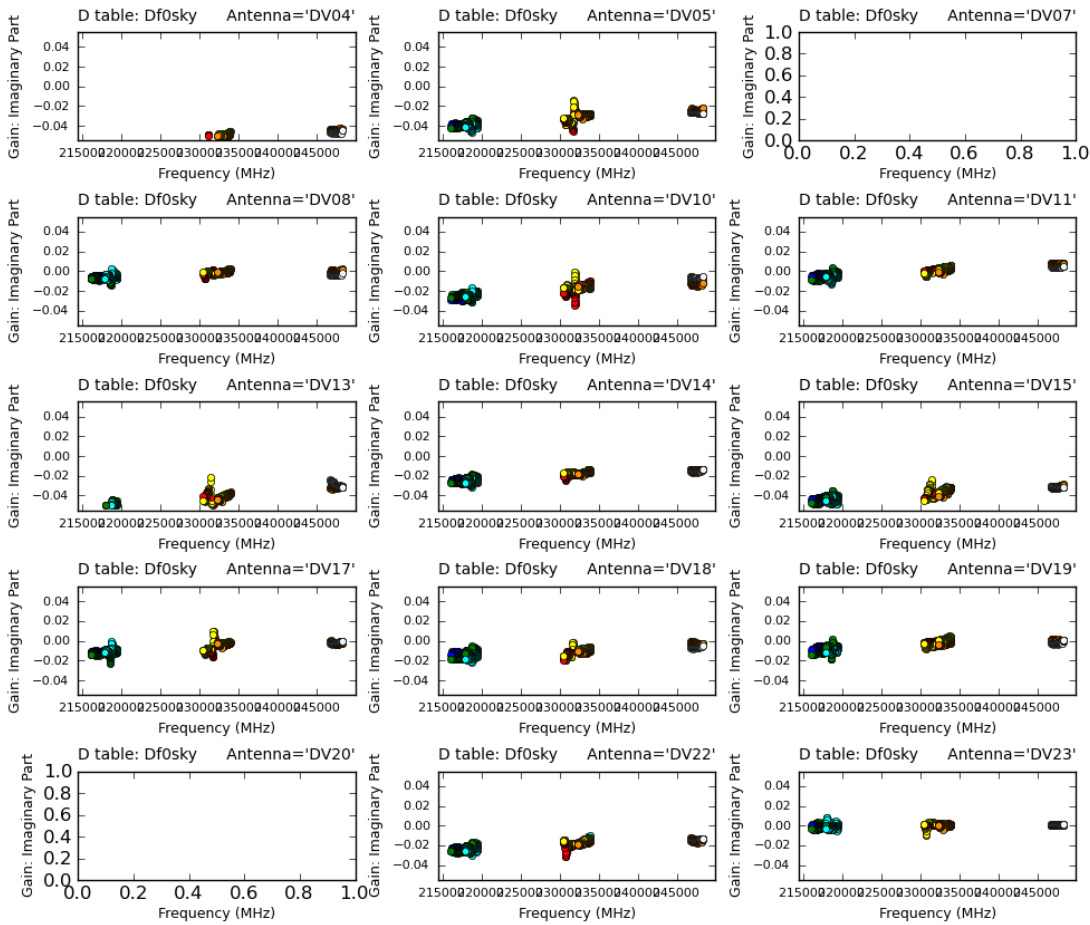


Figure 13: Continued.



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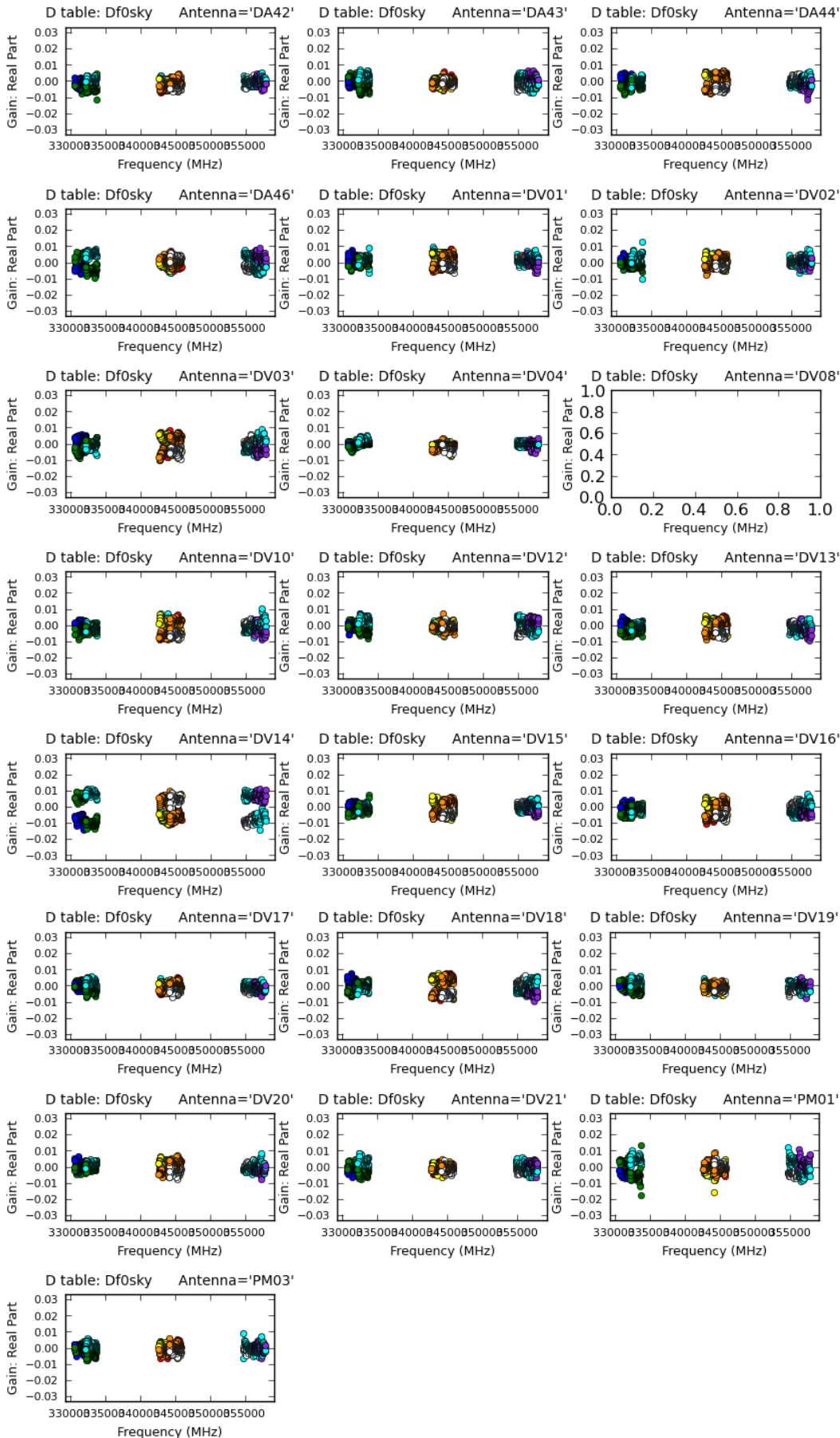


Figure 14: The real part of D-terms as a function of frequency at band 7 (colored by different spw and polarization).



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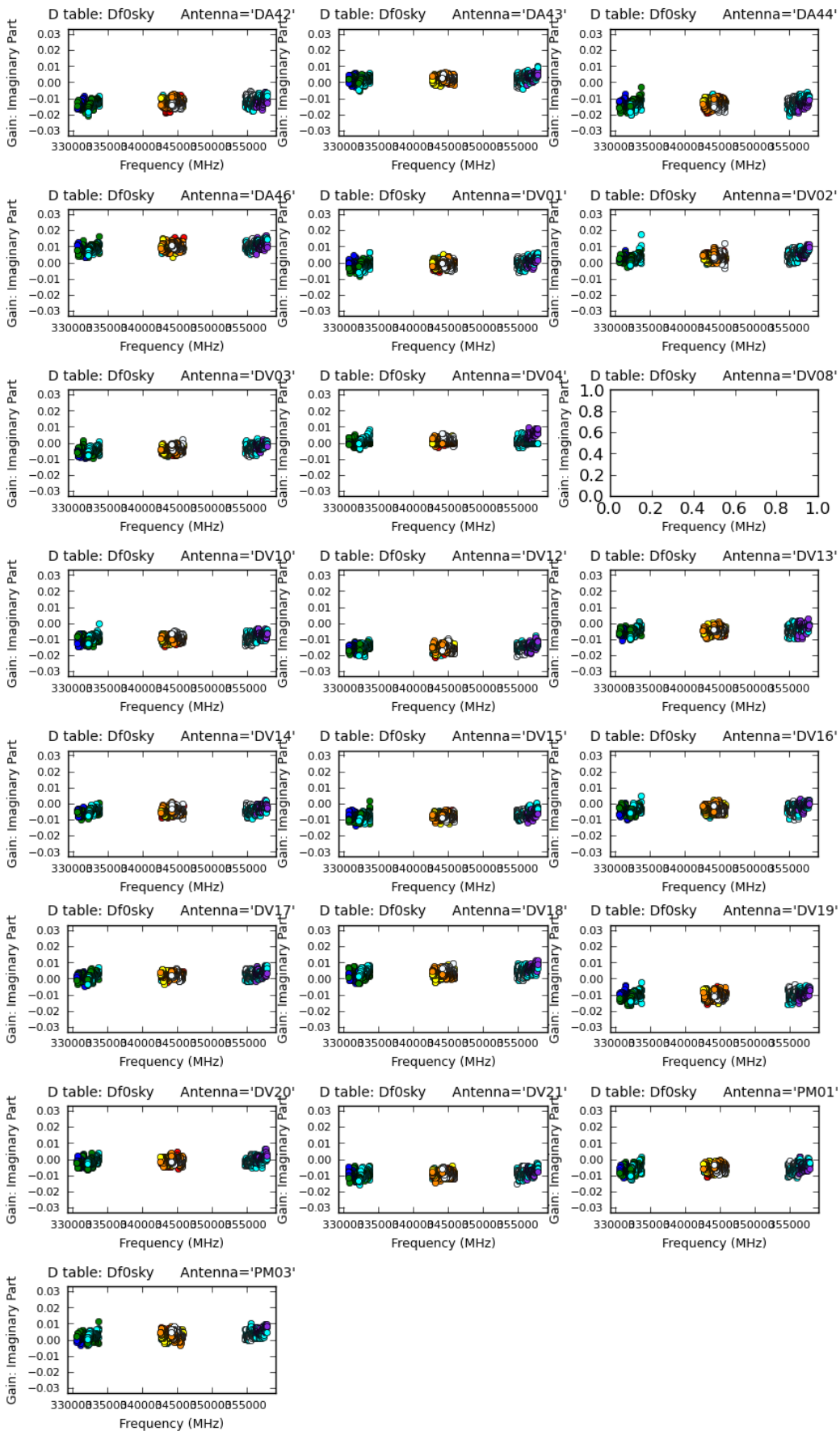


Figure 15: The imaginary part of D-terms as a function of frequency at band 7 (colored by different spw and polarization).