VGOS Phase-Cal Performance at High Frequencies

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9th International VLBI Technology Workshop

MIT Haystack Observatory October 23, 2024





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Wir geben Orientierung.





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VGOS Phase-Cal Performance at High Frequencies



Max-Planck-Institut für Radioastronomie

Testing Alternative VGOS Frequency Setups

Background:

Since 2019, VGOS observations have been carried out with the same frequency setup.

Motivation for testing alternative setups:

- Optimization of observables (delay resolution function)
- Avoidance of disturbing signals (RFI)
- Political reason: We have to demonstrate that we make use of the allocated frequency range.

EU-VGOS Frequency Sequence Tests (EFSEQ)

Tested Frequency Setups



Network of VGOS Telescopes Employed for EFSEQ



Onsala Twin Telescopes



Ny Ålesund Twin Telescopes



Santa Maria



Yebes



Wettzell South

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Scheduling

- The sessions are 3 hours long.
- The exact same schedule (e.g. sequence of scans) is repeated 5 times (5 days), 2024 April 08-12, 09:00 UTC.
- In the first hour, we observed 10 sources ~3 times each for 60 seconds to ensure that we get good SNR.
- In the remaining two hours, we added 34 additional sources ~3 times, each using 30 second long integration times.
- The sources were selected based on experience with VGOS-OPS sessions (high success rate and low RMSE).

Scheduling by Matthias Schartner using VieSched++

Current Status of EFSEQ Processing

- Data of all EFSEQ sessions have been correlated at MPIfR in Bonn.
- Calibration of data could not be completed due to multiple issues.

Data of EFSEQ1-4 contain recordings of phase-cal signals at previously unexplored VGOS frequencies.



How does the phase-cal signal look at these high frequencies?
Is the signal still usable for the calibration of data?

Phase-Cal



Phase-Calibration signal injected right after the feed-horn.

Frequency spacing for VGOS: 5 MHz (Oe, Ow, Ws) 10 MHz (Sa, Yj)

Figure 2 in Nothnagel et al. (2018, SSRv, 214, 66)

Investigation of the Raw Data Power Spectra



Raw Data Power Spectra



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PCAL files contain one complex number

→ per tone,

DiFX-derived pulse cal data
File version = 1
Start MJD = 60412

- → per accumulation period,
- → per **polarization** (called X and Y).
- Given in real and imaginary.

$$a+\mathrm{i}b=r\cosarphi+\mathrm{i}r\sinarphi,\ r=\sqrt{a^2+b^2},\ arphi=\mathrm{atan2}(b,a)$$

• We analyze the phases φ .

Start seconds = 35624 # Telescope name = OE 0E 60412.4123196 0.0000095 0 8 7 3030 X -5.88876e-02 1.13935e-01 3025 X 8.57662e-02 -9.39092e-02 3020 X -1.06870e-01 6.82961e-02 3015 X 1.19797e-01 -3.95719e-02 3010 X -1.20023e-01 1.22131e-02 3005 X 8.48163e-02 1.15758e-02 -1 0 0 0 3095 X -9.80236e-02 9.01940e-02 3090 X 1.29785e-01 -7.68927e-02 3085 X -1.53427e-01 6.05534e-02 3080 X 1.65296e-01 -3.81118e-02 3075 X -1.70531e-01 9.76464e-03 3070 X 1.32623e-01 1.17128e-02 3065 X -4.41248e-02 -7.75872e-03 3160 X -2.61435e-03 2.81800e-02 3155 X 4.57008e-02 -1.24331e-01 3150 X -7.10687e-02 1.07234e-01 3145 X 9.28733e-02 -8.78964e-02 3140 X -1.07176e-01 5.45009e-02 3135 X 9.77571e-02 -1.95522e-02 3130 X -4.30131e-02 -2.51820e-03 3220 X -8.47666e-02 -1.25136e-01 3215 X 4.11828e-02 1.26746e-01 3210 X 1.16623e-03 -1.15742e-01 3205 X -3.70999e-02 1.08008e-01 3200 X 5.73483e-02 -7.56812e-02 3195 X -3.88803e-02 2.89420e-02 -1 0 0 0 3320 X 3.07691e-02 -1.28447e-02 3315 X -1.64090e-01 3.15858e-02 3310 X 1.66433e-01 2.69034e-03 3305 X -1.70383e-01 -3.72831e-02 3300 X 1.58587e-01 7 06096e-02 3295 X -1 18193e-01 -8 22718e-02 3290 X 4,25094e-02 4,47443e-02 3445 X -3.85246e-02 1.00061e-01 3440 X 6.59440e-02 -8.49013e-02 3435 X -8.72939e-02 5.87518e-02 3430 X 1.00709e-01 -3.03783e-02 3425 X -1.04980e-01 -2.14947e-03 3420 X 6.02693e-02 1.98133e-02 -1 0 0 0 3925 X -2.18726e-04 9.29889e-04 3920 X -3.45353e-03 -7.52020e-03 3915 X -1.98420e-03 1.60158e-02 3910 X 1.21827e-02 -2.65414e-02 3905 X -1.59339e-02 3.37121e-02 3900 X 1.79011e-02 -2.40726e-02 -1 0 0 0 3990 X -8.05772e-04 -2.31144e-03 3985 X 1.00167e-02 -3.39714e-03 3980 X -2.34604e-02 6.82644e-03 3975 X 4.25135e-02 -1.80071e-03 3970 X -5.11562e-02 2.39649e-03 3965 X 4.86014e-02 5.35531e-03 -1 0 0 0 0E 60412.4123196 0.0000095 1 8 7 3030 Y 1.63734e-01 -1.06482e-01 3025 Y -1.64022e-01 7.40871e-02 3020 Y 1.64909e-01 -4.81840e-02 3015 Y -1.62531e-01 1.98531e-02 3010 Y 1.46751e-01 -3.36508e-03 3005 Y -9.87022e-02 -1.29468e-02 -1 0 0 0 3095 Y 8.93617e-02 1.35842e-01 3090 Y -6.91667e-02 -1.62352e-01 3085 Y 4.91116e-02 1.85582e-01 3080 Y -2.87030e-02 -2.02396e-01 3075 Y 3.68481e-03 2.12782e-01 3070 Y 1.28478e-02 -1.75415e-01 3065 Y -3.39355e-03 5.20898e-02 3160 Y 5.60320e-03 3.65838e-02 3155 Y 1.09877e-02 -1.78885e-01 3150 Y -4.76571e-02 1.73579e-01 3145 Y 7.79298e-02 -1.68447e-01 3140 Y -1.07727e-01 1.46296e-01 3135 Y 1.14407e-01 -1.05546e-01 3130 Y -5.41082e-02 3.39223e-02 3220 Y 3.86486e-02 -1.66129e-01 3215 Y -7.34091e-02 1.47204e-01 3210 Y 9.69969e-02 -1.20322e-01 3205 Y -1.20420e-01 9.37445e-02 3200 Y 1.19110e-01 -5.37677e-02 3195 Y -6.64355e-02 1.10212e-02 -1 0 0 0 3320 Y 9.79230e-03 4.20487e-02 3315 Y -9.36775e-03 -2.04311e-01 3310 Y -2.01102e-02 1.93598e-01 3305 Y 5.18871e-02 -1.86240e-01 3300 Y -8.00192e-02 1.65814e-01 3295 Y 9.06318e-02 -1.25374e-01 3290 Y -4.44879e-02 4.39268e-02 3445 Y 1.31451e-01 -1.39470e-02 3440 Y -1.32782e-01 -7.81589e-03 3435 Y 1.27930e-01 3.34942e-02 3430 Y -1.18235e-01 -5.27661e-02 3425 Y 1.01145e-01 7.30623e-02 3420 Y -5.13867e-02 -5.46360e-02 -1 0 0 0 3925 Y -1.18664e-02 -4.00647e-02 3920 Y -6.76506e-03 4.86855e-02 3915 Y 2.08986e-02 -5.84725e-02 3910 Y -2.82090e-02 6.56139e-02 3905 Y 4.71151e-02 -6.74472e-02 3900 Y -3.04235e-02 4.68933e-02 -1 0 0 0 3990 Y 4.28494e-02 -2.84092e-02 3985 Y -6.10468e-02 9.12391e-03 3980 Y 7.54632e-02 1.37249e-02 3975 Y -8.84350e-02 -2.25479e-02 3970 Y 8.44930e-02 4.78609e-02 3965 Y -6.30400e-02 -4.77128e-02 -1 0 0 0 0E 60412.4123196 0.0000095 2 8 7 5845 X -1.29148e-02 -1.35270e-02 5840 X 1.44378e-02 4.26452e-03 5835 X -1.27971e-02 3.39765e-03 5830 X 8.12274e-03 -7.48008e-03 5825 X -3.74895e-03 7.16951e-03 5820 X 2.27962e-03 -5.76465e-03 -1 0 0 0 5880 X 1.84938e-04 3.26000e-03 5875 X 6.24983e-03 -9.94286e-03 5870 X -6.04441e-03 1.05528e-02 5865 X 3.98701e-03 -8.85709e-03 5860 X -3.67191e-03 1.16121e-02 5855 X 1.21233e-03 -1.03499e-02 5850 X 2.13272e-03 4.61381e-03 5975 X -1.93826e-02 3.63591e-03 5970 X 1.86180e-02 -8.62392e-03 5965 X -1.59790e-02 1.35546e-02 5960 X 1.35483e-02 -1.84086e-02 5955 X -6.46795e-03 2.09870e-02 5950 X -1.34032e-03 -2.60360e-02 5945 X 1.20484e-03 6.91984e-03 6135 X 8.69458e-03 1.13549e-02 6130 X -9.91050e-03 -1.01827e-02 6125 X 1.18294e-02 1.08005e-02 6120 X -1.18005e-02 -8.85362e-03 6115 X 1.35668e-02 7.92316e-03 6110 X -1.27092e-02 -6.62366e-03 6105 X 4.14941e-03 2.18341e-03 6420 X -9.00788e-03 8.67541e-03 6415 X 7.38103e-03 -8.48100e-03 6410 X -7.31241e-03 8.61359e-03 6405 X 5.56512e-03 -1.02715e-02 6400 X -2.25946e-03 9.19956e-03 6395 X -5.24393e-04 -4.03511e-03 -1 0 0 0 6615 X -2.92063e-03 1.56382e-02 6610 X 3.94869e-03 -1.43750e-02 6605 X -4.66631e-03 1.53508e-02 6600 X 4.28328e-03 -1.41038e-02 6595 X -3.26726e-03 1.38011e-02 6590 X 3.72242e-03 -9.78251e-03 6585 X -5.83969e-04 3.34263e-03 6740 X 7.21605e-03 2.54230e-03 6735 X -8.95780e-03 -3.28240e-03 6730 X 8.51089e-03 4.48431e-03 6725 X -8.91794e-03 -5.31529e-03 6720 X 9.84512e-03 5.84245e-03 6715 X -5.63779e-03 -3.88966e-03 -1 0 0 0 6805 X -6.90028e-03 -3.23313e-03 6800 X 7.16858e-03 3.90782e-03 6795 X -5.81236e-03 -4.90914e-03 6790 X 4.00754e-03 5.70491e-03 6785 X -4.84162e-03 -7.15957e-03 6780 X 2.33307e-03 5.94005e-03 -1 0 0 0

Example PCAL file

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VGOS Phase-Cal Performance at High Frequencies



VGOS Phase-Cal Performance at High Frequencies



VGOS Phase-Cal Performance at High Frequencies



VGOS Phase-Cal Performance at High Frequencies



VGOS Phase-Cal Performance at High Frequencies

No phase-cal



Multitone Phase-cal



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No phase-cal



VGOS Phase-Cal Performance at High Frequencies

Multitone Phase-cal

All Bands



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All Bands



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Only Band D (13-14 GHz)



Only Band D (13-14 GHz)



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VGOS Phase-Cal Performance at High Frequencies

Summary and Outlook

- 1. Alternative frequency setups have been tested with a network of European VGOS antennas.
- 2. The power of the phase-cal signal is greatly reduced towards high frequencies.
- 3. Extracted phase-cal signals appear stable, also at high frequencies.
- 4. Applying the phase-cal signal increases the signal-to-noise ratio of observations.
- 5. Similar studies should be performed with all international VGOS stations.

Extra Slides

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EU-VGOS Frequency Sequence Tests

Participating stations: Oe, Ow, (Nn,) Sa, Ws, Yj

Observations performed on:

2024-04-08efseq0 - VO setup2024-04-09efseq1 - mode_02024-04-10efseq2 - mode_12024-04-11efseq3 - mode_22024-04-12efseq4 - mode_3

Setup Sa, Ws, Yj: ↑ Setup Oe, Ow: ↓

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- From 100-0900 to 0957: 60 sec - From 100-0959 - 100-1158: 30 sec



Group A:

- often observed VGOS sources with good performance
- scheduled four times (except 0235+164)

Group B:

- additional often observed VGOS sources
- scheduled three times
- -> 44 sources in total (10 from group A, 34 from group B).

0059+581 0133+476 0202+319 0235+164 0322+222 0613+570 1751+288 1803+784 1846+322 2113+293

Source group A

0016+731 0019+058 0025+197 0109+224 0119+115 0307+380 0345+460 0415+398 0454+844 0529+483 0552+398 0602+673 0716+714 0800+618 1039+811 1053+704 1418+546 1636+473 1726+455 1746+470 1806+456 1849+670 1923+210 2000+472 2013+163 2144+092 2201+171 2214+241 2214+350 2215+150 2229+695 2309+454 2319+317 2325+093

Source group B

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VGOS Phase-Cal Performance at High Frequencies

Known Issues



Nn not operational for efseq1 - efseq4

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efseq1 - mode_0

band A				band B			band C			band D		
a	3000.4	3032.4	i	4204.4	4236.4	q	7600.4	7632.4	у	12984.4	13016.4	
ь	3032.4	3064.4	j	4236.4	4268.4	r	7632.4	7664.4	z	13016.4	13048.4	
с	3064.4	3096.4	k	4268.4	4300.4	s	7728.4	7760.4	Α	13112.4	13144.4	
d	3128.4	3160.4	Т	4364.4	4396.4	t	7888.4	7920.4	В	13272.4	13304.4	
e	3224.4	3256.4	m	5004.4	5036.4	u	8176.4	8208.4	С	13560.4	13592.4	
f	3288.4	3320.4	n	5100.4	5132.4	v	8368.4	8400.4	D	13752.4	13784.4	
g	3320.4	3352.4	ο	5132.4	5164.4	w	8496.4	8528.4	Е	13880.4	13912.4	
h	3352.4	3384.4	р	5164.4	5196.4	×	8560.4	8592.4	F	13944.4	13976.4	

VGOS Phase-Cal Performance at High Frequencies

T

- Oe No fringes in band B and channel F (Y-pol only)
- Oe X pol: low pcal in channels i, j, k, l, n, o, y, A, B, C, D, E, F
- Oe Y pol: low pcal in channels i, j, k, l, u, y, z, B, C, D, E, F
- Ow No fringes in band B and channel F
- Ow X pol: low pcal in channels i, j, k, l, m, n, o, p, y, z, A, B, C, D, E, F
- Ow Y pol: low pcal in channels i, j, k, l, q, y, z, A, B, C, D, E, F
- Sa No problems

Ws Polswap

- Ws No fringes in band A, B Y(X) pol
- Ws However, Y pol pcal available (sometimes low in h)
- Ws No signal in channel p
- Ws No fringes in channels E, F
- Ws X(Y) pol: low pcal in channels y, z, C, D, E, F
- Ws Y(X) pol: low pcal in channel F
- Ws RFI(?) in channel h
- Yj No signal in last 4 channels of band B (m, n, o, p)
- Yj No signal in last 4 channels of band C (u, v, w (pcal!), x)
- Yj No signal in last 4 channels of band D (C, D, E (pcal!), F)
- Yj Y pol: low pcal in channel t

Post-processing notes

- ffres2pcp finally worked for all stations
- fourphase did not work for Ws

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NOTE: low pcal -> amplitudes < 10





band A				band B			band C			band D		
a	4204.4	4236.4	i	7596.4	7628.4	q	9708.4	9740.4	у	12972.4	13004.4	
Ь	4236.4	4268.4	j	7628.4	7660.4	r	9740.4	9772.4	z	13004.4	13036.4	
с	4268.4	4300.4	k	7724.4	7756.4	S	9836.4	9868.4	Α	13100.4	13132.4	
d	4364.4	4396.4	Т	7884.4	7916.4	t	9996.4	10028.4	В	13260.4	13292.4	
e	5004.4	5036.4	m	8172.4	8204.4	u	10284.4	10316.4	С	13548.4	13580.4	
f	5100.4	5132.4	n	8364.4	8396.4	v	10476.4	10508.4	D	13740.4	13772.4	
9	5132.4	5164.4	ο	8492.4	8524.4	w	10604.4	10636.4	Е	13868.4	13900.4	
h	5164.4	5196.4	р	8556.4	8588.4	x	10668.4	10700.4	F	13932.4	13964.4	



- Oe No fringes in band A
- Ow No fringes in band A
- Sa efseq3: first time GCoMo downconversion is used in IFE/IFF
- Sa last channel in Band D (bbc49 and 57): low pcal and high tsys
- Ws Polarisation swap
- Ws No fringes in band A, low pcal in X pol in band A
- Yj No pcal in channels e f g h k l m n p t u v x B C D F
- Yj No fringes in channels o q r s w E
- Yj Fringes in only 9 channels a b c d i j y z A

Post-processing notes

- ffres2pcp only worked for Ow and Yj (Sa ref)



band A				band B			band C			band D		
۵	5004.4	5036.4	i	7628.4	7660.4	q	9676.4	9708.4	у	12940.4	12972.4	
Ь	5036.4	5068.4	j	7660.4	7692.4	r	9708.4	9740.4	z	12972.4	13004.4	
с	5132.4	5164.4	k	7756.4	7788.4	s	9804.4	9836.4	A	13068.4	13100.4	
d	5260.4	5292.4	Т	7916.4	7948.4	t	9964.4	9996.4	В	13228.4	13260.4	
e	5516.4	5548.4	m	8204.4	8236.4	u	10252.4	10284.4	С	13516.4	13548.4	
f	5708.4	5740.4	n	8396.4	8428.4	v	10444.4	10476.4	D	13708.4	13740.4	
9	5836.4	5868.4	ο	8524.4	8556.4	w	10572.4	10604.4	E	13836.4	13868.4	
h	5868.4	5900.4	р	8588.4	8620.4	x	10636.4	10668.4	F	13900.4	13932.4	

- Oe No fringes in band A, however, pcal present
- Oe X pol: low pcal in channels a, b, c, e, f, g, h
- Oe Y pol: low pcal in band A
- Ow No fringes in band A, however, pcal okay (except f and h)
- Ow X pol: low pcal in band D
- Ow Y pol: low pcal inannels u, v, x, band D
- Sa RFI(?) in channels e, p
- Sa No fringes in channel r

Ws Polswap

- Ws No fringes in bands A, B Y(X) pol
- Ws However, Y(X) pol pcal available
- Ws Y(X) pol: no fringes in channel F
- Ws X(Y) pol: low pcal in channels q, r, u, v, w, x
- Yj No signal in last 4 channels of band A (e, f, g, h)
- Yj No signal in last 4 channels of band B (m, n, o (pcal!), p)
- Yj No signal in last 4 channels of band C (u, v, w (pcal!), x)
- Yj No signal in last 4 channels of band D (C, D, E (pcal!), F)

Post-processing notes

- ffres2pcp only worked for (Sa ref) Yj

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efseq4 - mode_3

	band A			band B			band C			band D		
a	3000.4	3032.4	i	5816.4	5848.4	q	9720.4	9752.4	у	12984.4	13016.4	
b	3064.4	3096.4	j	5848.4	5880.4	r	9752.4	9784.4	z	13016.4	13048.4	
с	3128.4	3160.4	k	5944.4	5976.4	S	9848.4	9880.4	Α	13112.4	13144.4	
d	3192.4	3224.4	Т	6104.4	6136.4	t	10008.4	10040.4	В	13272.4	13304.4	
e	3288.4	3320.4	m	6392.4	6424.4	u	10296.4	10328.4	С	13560.4	13592.4	
f	3416.4	3448.4	n	6584.4	6616.4	v	10488.4	10520.4	D	13752.4	13784.4	
9	3896.4	3928.4	o	6712.4	6744.4	w	10616.4	10648.4	Е	13880.4	13912.4	
h	3960.4	3992.4	р	6776.4	6808.4	×	10680.4	10712.4	F	13944.4	13976.4	



- Oe No fringes in channels g, h, F
- Oe No fringes in band B
- Oe X pol: low pcal in channels j, m, o, p
- Oe Y pol: low pcal in channels i, j, p
- Oe Low pcal in band D
- Ow No fringes in channels g, h, F
- Ow No fringes in band B, low pcal in channels o, p
- Ow Low pcal in band D
- Sa No fringes in channel F
- Sa RFI(?) in channels b, e, f, i, j, k, l, m
- Ws Polswap
- Ws No fringes in bands A, B Y(X) pol
- Ws However, Y(X) pol pcal available
- Ws No fringes in channel F
- Ws RFI(?) in channel i
- Yj No signal in last 5 channels of band A (d, e, f, g, h)
- Yj No signal in last 4 channels of band B (m, n, o (pcal!), p)
- Yj No signal in last 4 channels of band C (u, v, w (pcal!), x)
- Yj No signal in last 4 channels of band D (C, D, E (pcal!), F)

Post-processing notes

- ffresc2pcp worked for all stations
- fourphase did not work for Oe, Ws and Yj



- Oe No fringes in channels g, h, F
- Oe No fringes in band B
- Oe X pol: low pcal in channels j, m, o, p
- Oe Y pol: low pcal in channels i, j, p
- Oe Low pcal in band D
- Ow No fringes in channels g, h, F
- Ow No fringes in band B, low pcal in channels o, p
- Ow Low pcal in band D
- Sa No fringes in channel F
- Sa RFI(?) in channels b, e, f, i, j, k, l, m
- Ws Polswap
- Ws No fringes in bands A, B Y(X) pol
- Ws However, Y(X) pol pcal available
- Ws No fringes in channel F
- Ws RFI(?) in channel i
- Yj No signal in last 5 channels of band A (d, e, f, g, h)
- Yj No signal in last 4 channels of band B (m, n, o (pcal!), p)
- Yj No signal in last 4 channels of band C (u, v, w (pcal!), x)
- Yj No signal in last 4 channels of band D (C, D, E (pcal!), F)

Post-processing notes

- ffresc2pcp worked for all stations
- fourphase did not work for Oe, Ws and Yj





- Oe No fringes in channels g, h, F
- Oe No fringes in band B
- Oe X pol: low pcal in channels j, m, o, p
- Oe Y pol: low pcal in channels i, j, p
- Oe Low pcal in band D
- Ow No fringes in channels g, h, F
- Ow No fringes in band B, low pcal in channels o, p
- Ow Low pcal in band D
- Sa No fringes in channel F
- Sa RFI(?) in channels b, e, f, i, j, k, l, m
- Ws Polswap
- Ws No fringes in bands A, B Y(X) pol
- Ws However, Y(X) pol pcal available
- Ws No fringes in channel F
- Ws RFI(?) in channel i
- Yj No signal in last 5 channels of band A (d, e, f, g, h)
- Yj No signal in last 4 channels of band B (m, n, o (pcal!), p)
- Yj No signal in last 4 channels of band C (u, v, w (pcal!), x)
- Yj No signal in last 4 channels of band D (C, D, E (pcal!), F)

Post-processing notes

- ffresc2pcp worked for all stations
- fourphase did not work for Oe, Ws and Yj



VGOS Phase-Cal Performance at High Frequencies

Scheduling

Source Selection

Source Group A 0059+581 0133+476 0202+319 0235+164 0322+222 0613+570 1751+288 1803+784 1846+322 2113+293

- Often observed VGOS sources with good performance
- Scheduled four times (except for 0235+164)

Scan Duration / Integration Time

- From 09:00 to 09:57: 60 sec
- From 09:59 to 11:58: 30 sec

Source Group B

0016+731 0019+058 0025+197 0109+224 0119+115 0307+380 0345+460 0415+398 0454+844 0529+483 0552+398 0602+673 0716+714 0800+618 1039+811 1053+704 1418+546 1636+473 1726+455 1746+470 1806+456 1849+670 1923+210 2000+472 2013+163 2144+092 2201+171 2214+241 2214+350 2215+150 2229+695 2309+454 2319+317 2325+093

- Additional often observed VGOS sources
- Scheduled three times