CARMA Memorandum Series #55

Bandpass Calibration and Stability

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ABSTRACT

In this memo we analyze the bandpass calibration from observations of compact sources over periods of 1 hour, 1 day, and 2 months. For these 500 MHz bandwidth observations, the bandpass is not significantly flatter after applying the noise calibration. The bandpass is stable over a period of 1 day. No significant change was seen in the astronomical bandpass between pointings in a mosaic over 0.7 hours at the 0.4 to 1% level for the 15 Carma antennas. Similar residuals were also obtained by applying the bandpass from the previous day. However, over a period of 2 months, the bandpass does change at the 1 - 4 % level. If the bandpass is sufficiently stable, a recent observation for a bandpass calibration can be re-used until it goes stale. This will improve the scheduling and efficiency for many observations.

Change Record

Revision	Date	Author	Sections/Pages Affected
	Remarks		
1.1	2009-June-25	MCHW	1-14
	Draft memo		
1.2	2009-July-14	MCHW	1-24
	edits, add plots		
1.3	2009-July-24	MCHW	1-18
	edit text and figures		

1. INTRODUCTION

Accurate measurements of the instrumental bandpass are required for many astronomical observations. For high signal to noise observations, errors in the bandpass can be larger than the thermal noise and limit the accuracy of the data. At millimeter wavelengths, bandpass errors affect spectral dynamic range, comparisons of spectral line features in different molecular transitions, isotopic ratios, and MFS observations. Measurements of the bandpass phase are critical when phase referencing to a spectral line feature, such as in measuring the positions of, or w.r.t. SiO masers. Bandpass calibration for CARMA is discussed in BIMA memo 85 and CARMA memo 45. Bandpass calibration may require time consuming and complex observational and data reduction procedures to achieve the required accuracy (see CARMA memo 45), so it advantagous to re-use the bandbass calibration if it is sufficiently stable. In this memo we analyze the bandpass obtained during hex7 mosaic observations of 3C273 which were used to determine the aperture efficiency, pointing, and primary beam of the CARMA antennas (CARMA memo 52).

1.1. Bandpass, IF and RF frequency response

The complex gain of the array is a function of time and frequency. Most of the gain (amplitude and phase) is associated with the signal path for each antenna, so that the gain can be written as a product of the voltage gains for each antenna pair. In this case, the calibration can be antenna based resulting in a higher signal to noise (SNR), and enhanced imaging performance resulting from self calibration procedures. Any residual baseline based calibration, such as closure errors in the correlator can be minimized and eliminated if possible. E.g. by using orthogonal switching patterns in the antennas and correlator.

Ideally, the time and frequency dependence can be separated as the product of time dependent gains and frequency dependent bandpass measurements. In practice the bandpass may be a slow function of time and require periodic measurements, and the time dependent gains may be a function of frequency. The poor SNR of an astronomical measurement of narrow bandwidth IF characteristics in the bandpass requires an auxiliary measurement with a noise source or using total power autocorrelations. The RF bandpass is smoother and in a stable temperature controlled receiver environment, and can be determined from periodic measurements of an astronomical source. Traditionally this calibration has been the responsibility of the observer, but in practice the calibration is done at a system level to an accuracy of a few percent, and improving on this takes a large amount of observing time. The typical user's bandpass calibration may actually introduce systematic errors into the visibility data. For example, the correlator may have phase offsets between the wideband settings used for reference quasar measurements and the narrow band setting used for spectral line source observations requiring a wide-narrow-wide calibration sequence of the correlator.

A desirable goal is to provide a bandpass calibration which will suffice for 80-90% of the users, leaving the few observers who need a more accurate bandpass to request and schedule time to do so. If the bandpass is sufficiently stable, a recent observation for a bandpass calibration can be re-used until it goes stale. This will improve the scheduling and efficiency for many observations. In this memo we analyze the multichannel data from mosaic observation to determine the stability of the instrumental bandpass.

2. OBSERVATIONS AND DATA REDUCTION

Observations were obtained using a standard hexagonal 7-pointing mosaic of a strong compact source at the nominal pointing center and half power points for the 10m antennas. The data are self-calibrated to determine the antenna voltage gains. We used the MIRIAD task **mfcal** to determine the antenna-based gains versus time and bandpass. The bandpass is determined w.r.t. the antenna gains. i.e.

$$G_{ij}\ (t,f) = g_i\ (t,f) \times g_j^*\ (t,f)$$

$$g_i\ (t,f) = g_i\ (t) \times b_i\ (f)$$

• Solve for antenna gains, $g_i(t)$ as a function of time, and solve for bandpass, $b_i\ (f)$, as a function of frequency.

In addition to the astronomical observations, a noise source injected at baseband can be used to calibrate the bandpass. This is especially useful for narrow bandwidth observations where the signal-to-noise on an astronomical source is poor. The noise source is phase switched to appear as a lower sideband signal from the sky. For the noise source at baseband, the bandpass in the upper sideband is the complex conjugate of the lower sideband response, whereas for an astronomical source, the bandpass has different RF bandpass responses in the upper and lower sideband of LO1. The noise source can be used to correct astronomical observations for the baseband response, but does not include the signal path which preceeds the noise source injection. The correlator response to the strong correlation from the noise source also differs from the low correlation from astronomical sources. In the following we compare the bandpass obtained on the noise source with that obtained on an astronomical source at different epochs.

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Observation Log:

1) 09APR17:04:06:49.0  File: ct007.1C_1003C273.1.miriad
7-pointing mosaic at 95/100 GHz with  500 MHz BW.  Total observing time 0.73 hours

2) 09APR18:03:23:44.0   File: ct007.1C_1003C273.2.miriad
7-pointing mosaic at 95/100 GHz with  500 MHz BW.  Total observing time 0.89 hours

3) 09JUN24:23:22:35.5   File: ct007.1E_1003C273.1.mir
7-pointing mosaic at 95/100 GHz with  500 MHz BW.  Total observing time 0.70 hours
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3. RESULTS

3.1. Noise source and Astronomical bandpass shapes

Figures 1 & 2 show the bandpass amplitude and phase measured on the NOISE source on 09APR17.

Figures 3 & 4 show the bandpass amplitude and phase measured on 3C273 on 09APR17. The bandpass on the NOISE source is not the same shape as the bandpass on an astronomical source.

Figures 5 & 6 show the residual bandpass on 09APR17 for the3C273 central pointing after applying bandpass correction from the NOISE source. For these 500 MHz bandwidth observations, the bandpass is not significantly flatter after applying the noise calibration. Similar results were obtained for the 09APR18 and 09JUN24 observations.

3.2. Bandpass Stability

Figure 7 shows the residual bandpass amplitude for 3C273 on 09APR17 for an offset pointing after applying the bandpass correction derived from the central pointing position in the hexagonal mosaic. The astronomical bandpass changes slowly with time. No significant change was seen in the astronomical bandpass between pointings in a mosaic over 0.7 hours. The RMS residual across the bandpass is 0.004 to 0.011 (normalized to 1) for the 15 Carma antennas. Similar residuals were also obtained by applying the bandpass from the APR 17 observations of 3C273 to the APR 18 data. Figure 8 & 9 show the amplitude and phase residuals on the central pointing.

However, over a period of 2 months, the bandpass does change from APR 17 to JUN 24 (RMS residual 0.01 to 0.04) after applying bandpass. Figure 10 shows the amplitude residuals on the central pointing.

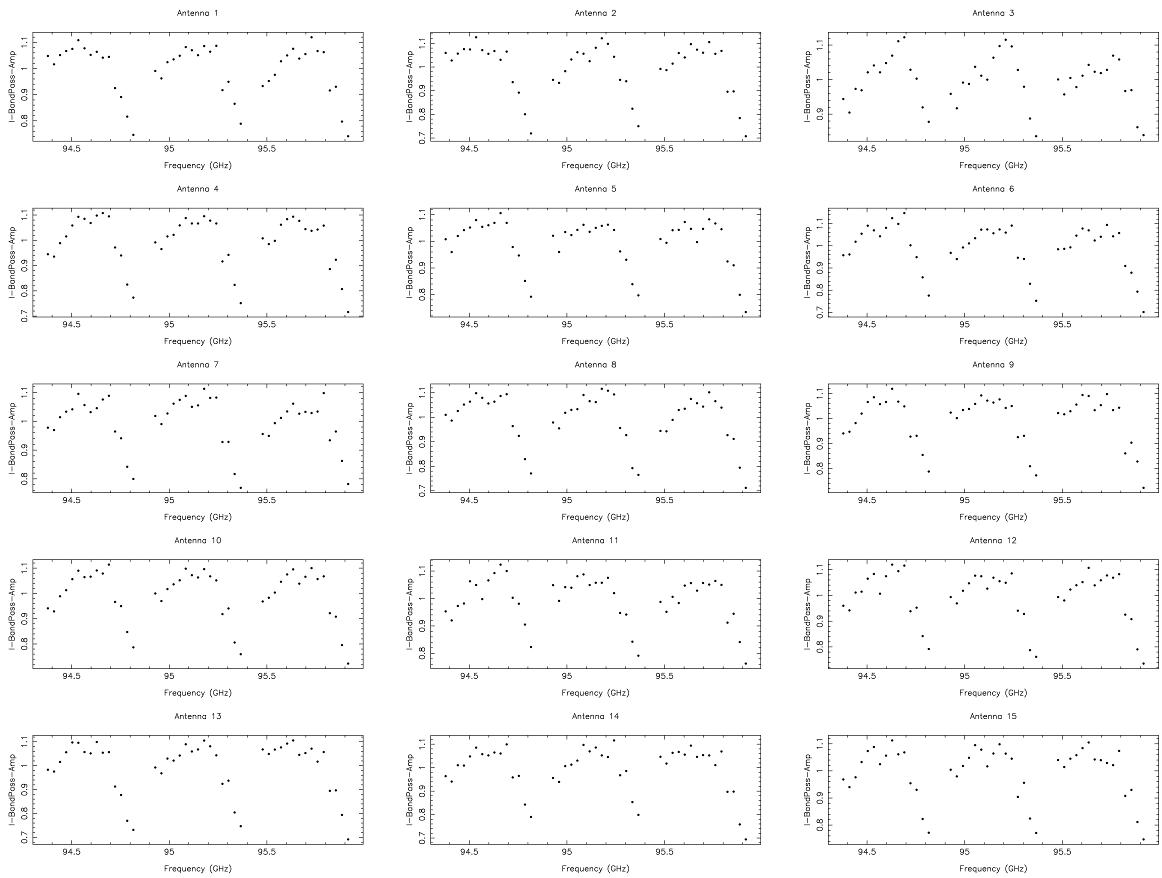

Fig. 1.— BandPass-Amplitude on NOISE source on 09APR17. Lower sideband at 93 GHz.

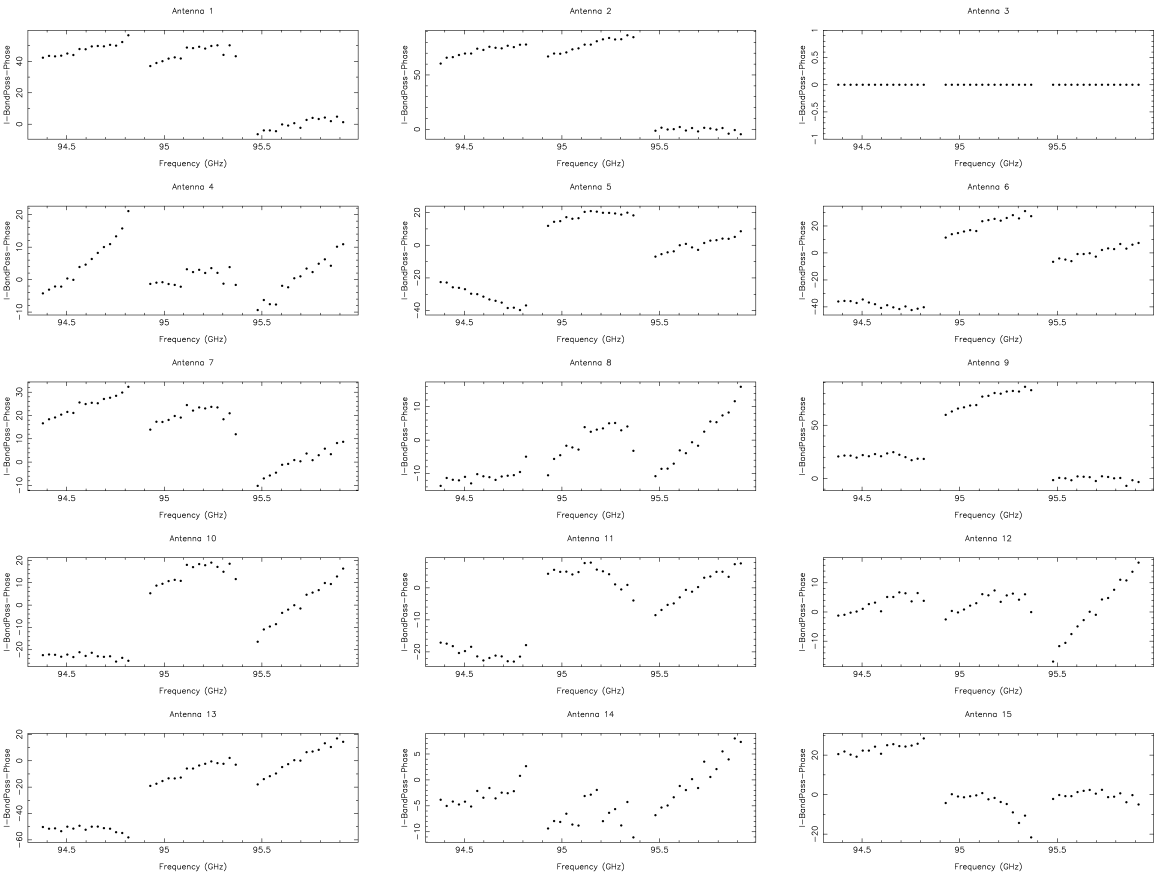

Fig. 2.— BandPass-Phase on NOISE source on 09APR17. Lower sideband at 93 GHz.

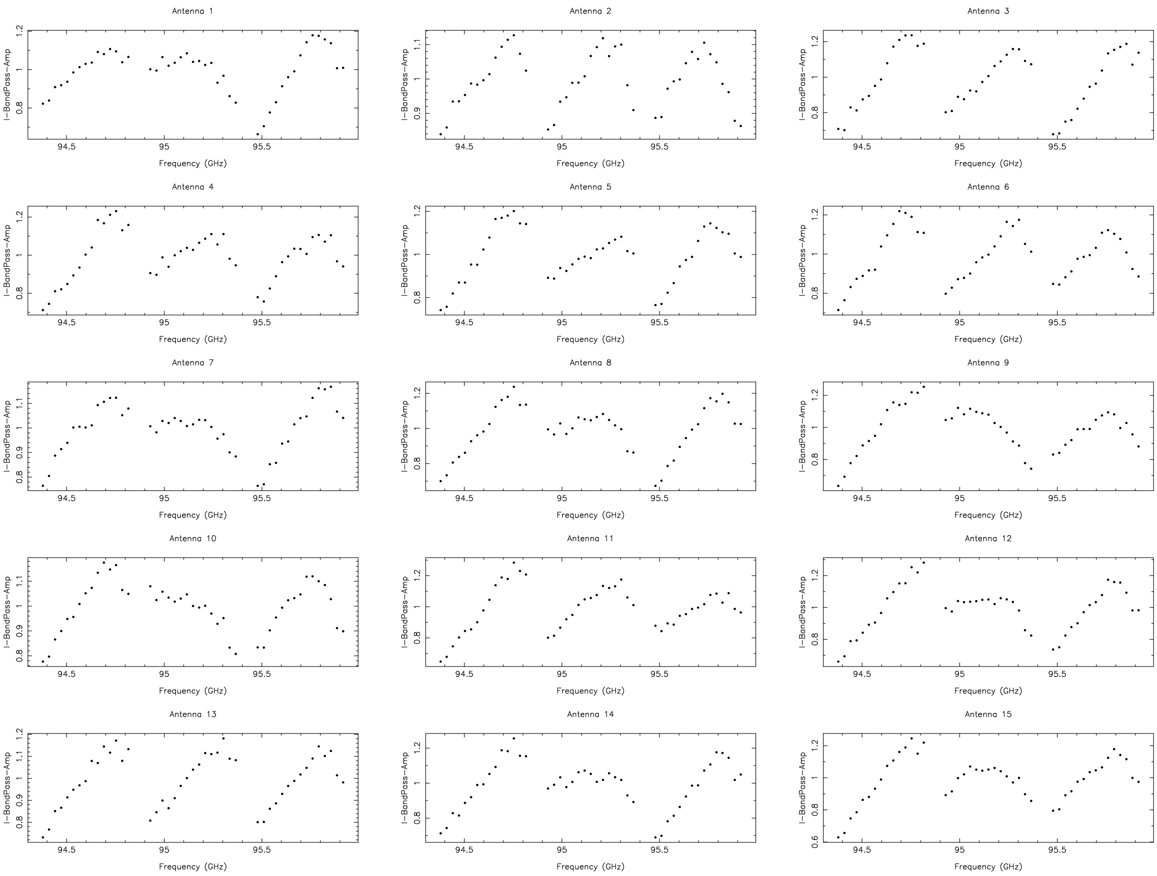

Fig. 3.— BandPass-Amplitude on 3C273 central pointing on 09APR17. Lower sideband at 93 GHz.

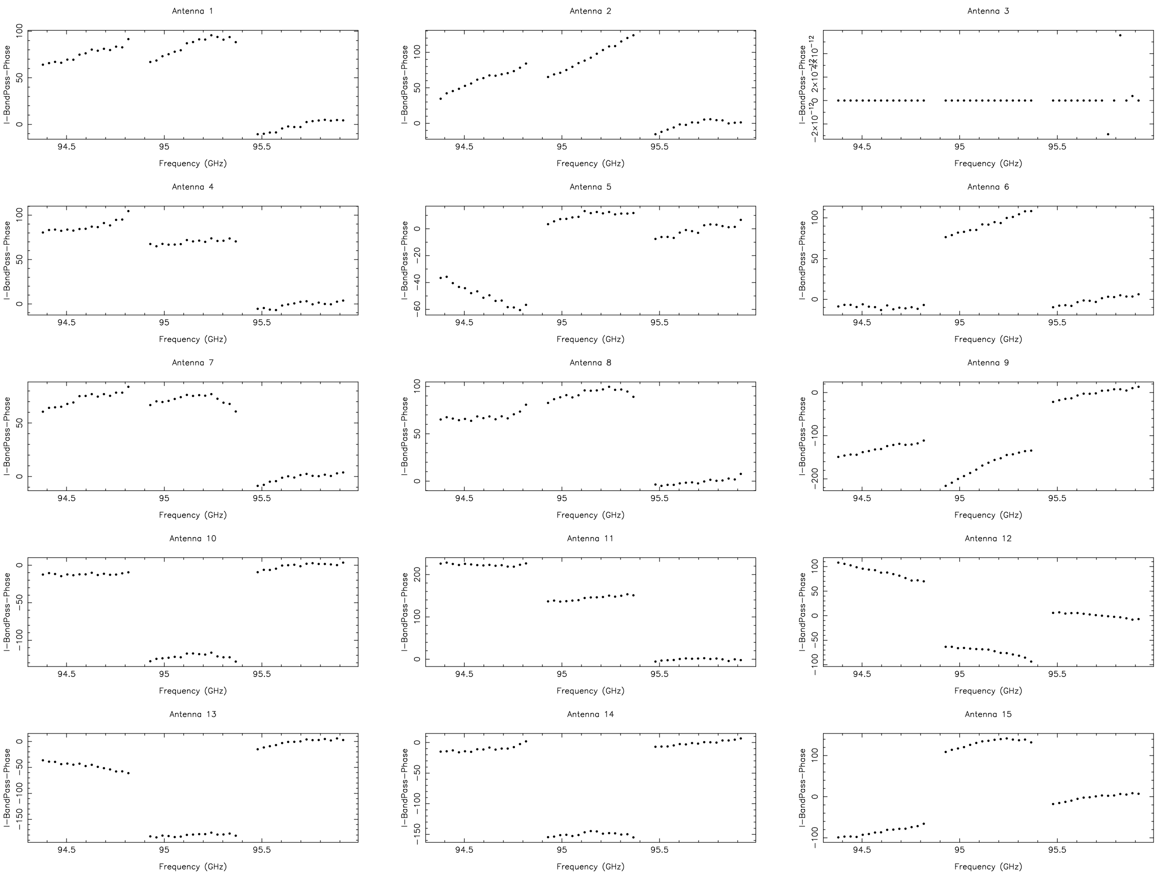

Fig. 4.— BandPass-Phase on 3C273 central pointing on 09APR17. Lower sideband at 93 GHz.

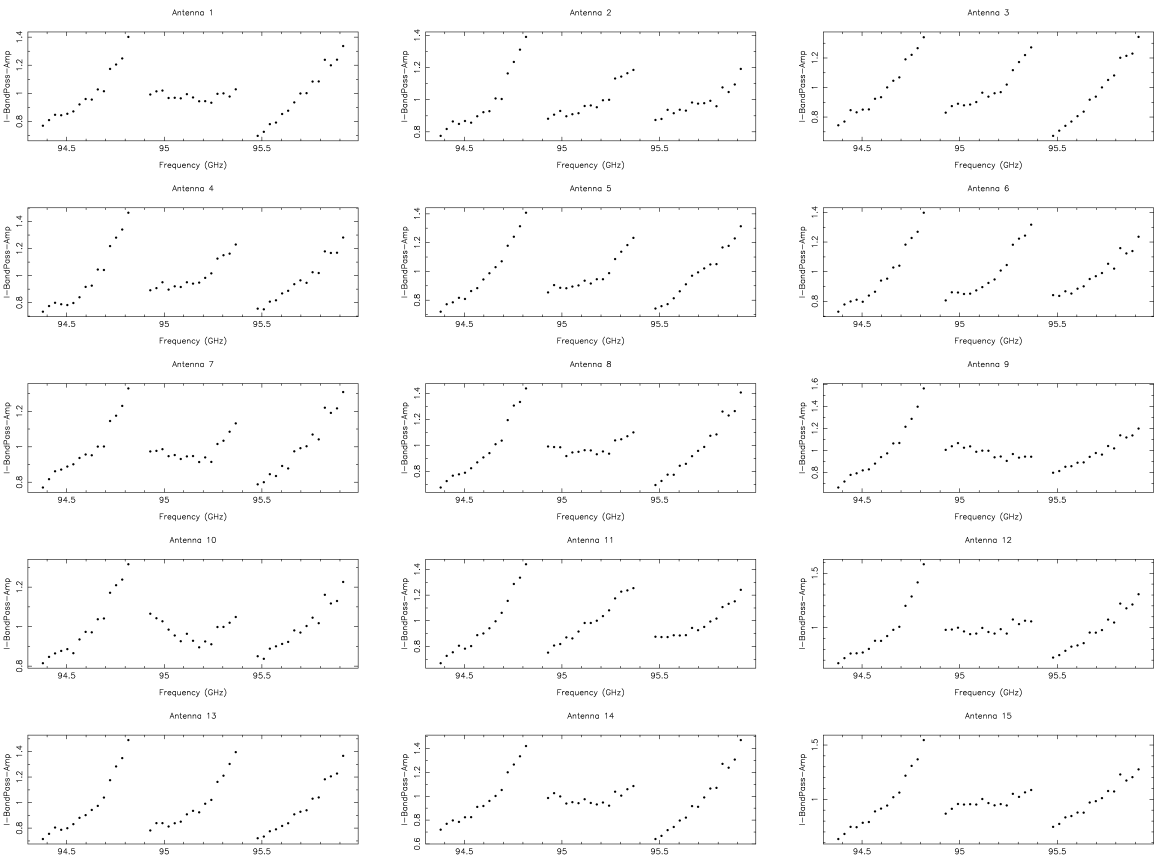

Fig. 5.— BandPass-Amplitude residual on 09APR17 on 3C273 central pointing after applying bandpass correction from NOISE source.

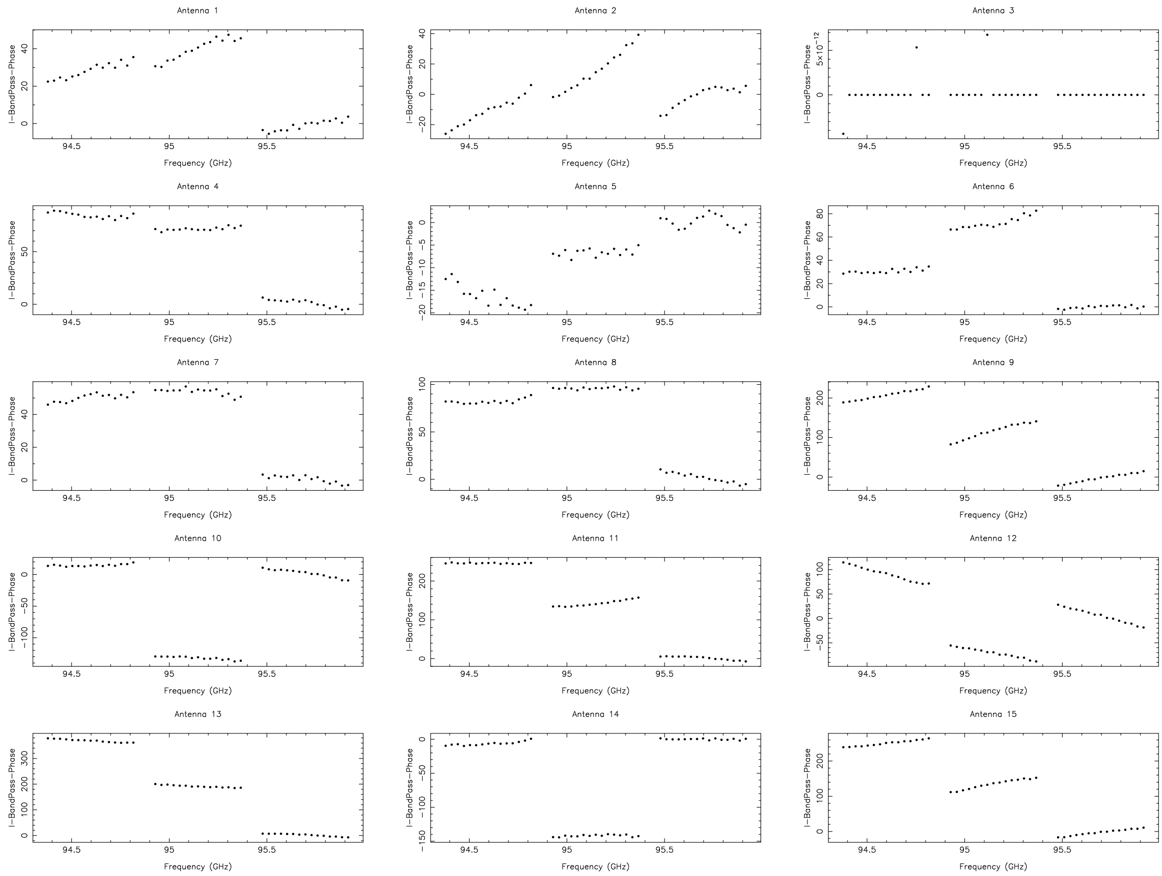

Fig. 6.— BandPass-Phase residual on 09APR17 on 3C273 central pointing after applying bandpass correction from NOISE source.

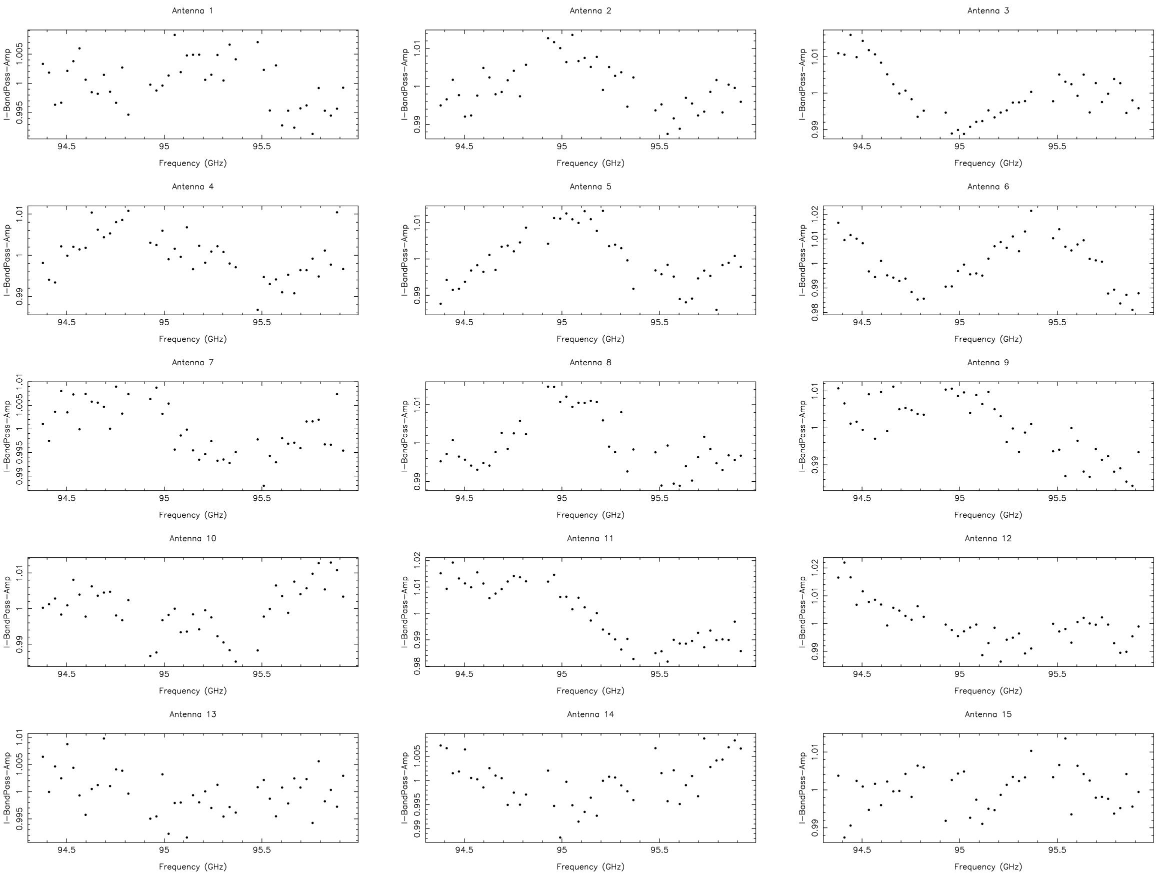

Fig. 7.— BandPass-Amplitude residual on 09APR17 offset pointing after applying bandpass correction from 3C273 on central pointing position in hexagonal mosaic.

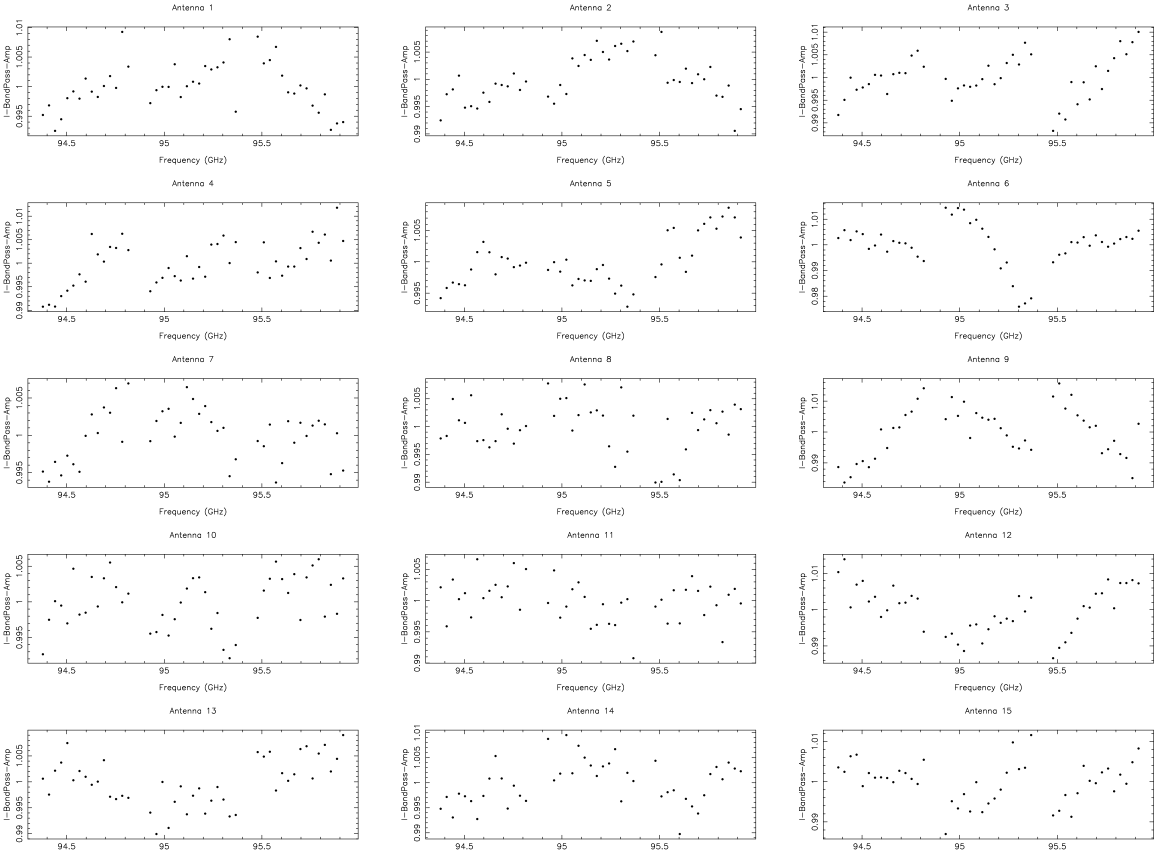

Fig. 8.— BandPass-Amplitude residual on 09APR18 after applying bandpass correction from 3C273 on previous day.

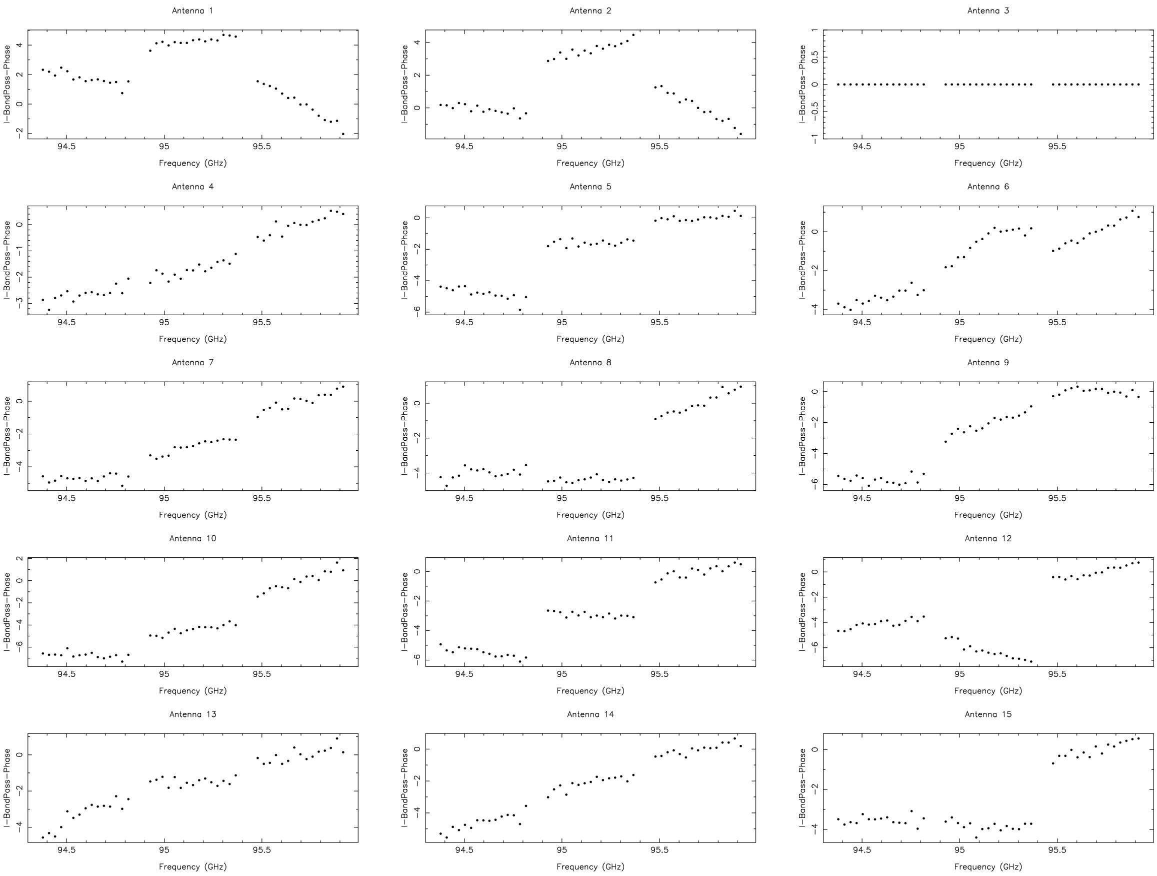

Fig. 9.— BandPass-Phase residual on 09APR18 after applying bandpass correction from 3C273 on previous day.

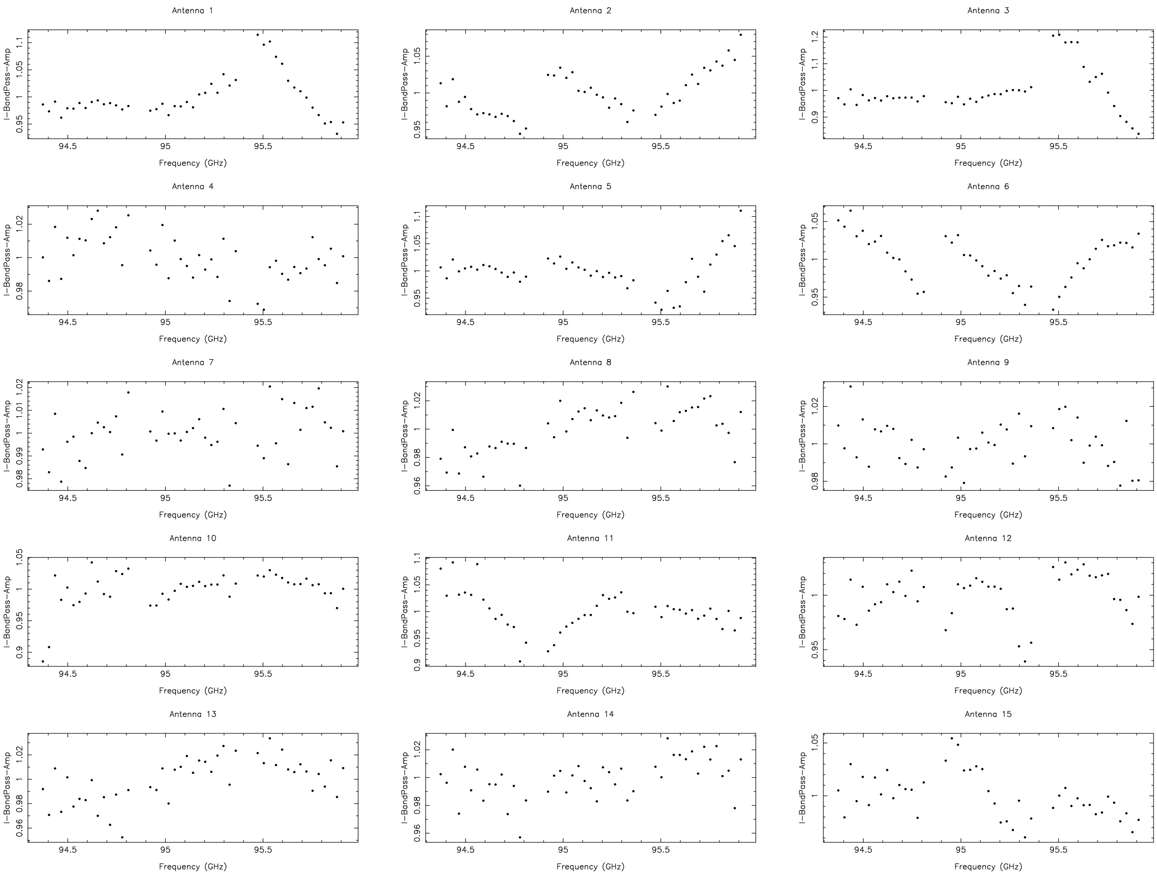

Fig. 10.— BandPass-Amplitude residual on 09JUN24 after applying bandpass from 3C273 on 09APR17

4. CONCLUSION

In this memo we analyze the bandpass calibration from observations of compact sources in an interferometer mosaic pattern over a period of 2 months. For these 500 MHz bandwidth observations, the bandpass is not significantly flatter after applying the noise calibration. The bandpass is stable over a period of 1 day. No significant change was seen in the astronomical bandpass between pointings in a mosaic over 0.7 hours at the 0.4 to 1% level for the 15 Carma antennas. Similar residuals were also obtained by applying the bandpass from the previous day. However, over a period of 2 months, the bandpass does change at the 1 - 4 % level. If the bandpass is sufficiently stable, a recent observation for a bandpass calibration can be re-used until it goes stale. This will improve the scheduling and efficiency for many observations.

5. References

Wei, L., Woody, D., Teuben, T., La Vigne, M., & Vogel, S. 2008, CARMA memo 45, *Bandpass Calibration for CARMA*

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