EVLA Memo 193: Optimizing science on the VLA by eliminating the hybrid configurations

Claire J. Chandler
NM Operations
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Summary

In this memo we summarize the programmatic issues associated with offering the VLA hybrid configurations, and show that eliminating the hybrids and moving the associated observing time to the principal (A, B, C, D) configurations result in a better use of VLA resources, at the same time as improving the scheduling opportunities for those projects which might otherwise have requested the hybrids. We show that the surface brightness sensitivity of the hybrid configurations for very southern sources can be reproduced by a combination of principal configurations, for science goals requiring the imaging of extended structure. A general rule-of-thumb is that requesting the same amount of time as would have been requested for the hybrid, but in the next larger principal configuration, plus an additional 40% in the adjacent compact configuration, will give the same sensitivity to emission on the same spatial scales as the hybrid. Alternatively, double the integration time in the next larger configuration can reproduce the surface brightness sensitivity of the hybrid for a slightly more limited range of spatial scales. We note that while this may impact some types of observation and/or increase the complexity of the data reduction the resultant benefits outweigh the negatives.

1. The VLA hybrid configurations

Over the past 30 years the VLA has used its hybrid configurations, in which the antennas on the north arm are placed at the locations normally used in the next largest principal configuration, in order to produce more circular point spread functions for very southern targets (and very northern targets, although not often requested). However, as noted by Clark (2014), the hybrid configurations result in poor use of the VLA, for a number of reasons.

The VLA spends around 17 days (two weeks plus a weekend) in each hybrid configuration (DnC, CnB, BnA) per configuration cycle. The hybrids occur between their adjacent principal configurations, in January, May, and September. Given array maintenance and testing activities the availability of observing time in the hybrids is highly skewed to nighttime LSTs. Requests for the hybrid configurations have typically been dominated by Galactic Center LSTs; only the hybrid in May is therefore a reasonable match to the typical proposal pressure, and even then, the time away from the Galactic Center is often under-subscribed (Figure 1). The Time Allocation Committee typically tries to fill the hybrid time with projects requesting the principal or "Any" configurations, which does improve the mean science ranking of the projects observed (Figure 2), but for the configuration cycle shown in Figure 1 the hybrids were still under-subscribed at the level of ~150 hours. Furthermore, the projects moved to the hybrids do not obtain data in their preferred configuration.

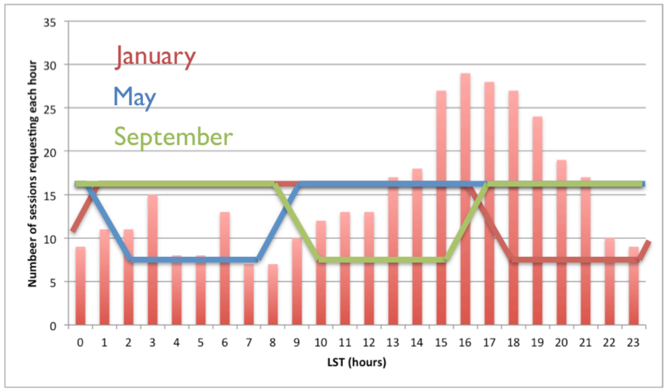
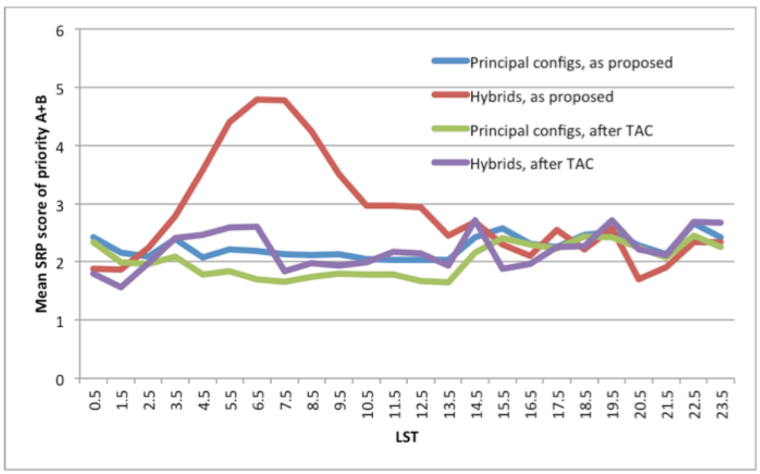


Figure 1: Median requested observing time in the three hybrids from semesters 15A through 16A (histogram). The solid colored lines show the time available in each of the hybrids occurring in January (red), May (blue), and September (green).



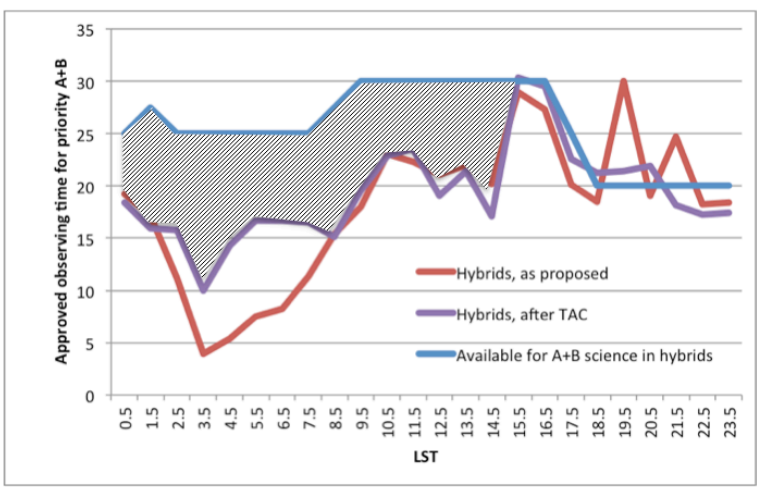


Figure 2: Top, mean SRP score of priority A and B proposals requesting the hybrids and principal configurations, before and after the TAC meeting. Bottom, the grey shaded area shows the number of hours remaining unscheduled in the hybrids, even after including projects that requested the principal configurations.

In addition to the above considerations, the short duration and timing of the hybrids mean that projects requiring night time observations in a particular hybrid match the available LST hours only once every 4 years, and high frequency observations are highly subject to the foibles of local weather patterns. There would be considerably more scheduling opportunities if very low/high declination science goals could be met through time in the principal configurations.

The demand for Virgo LSTs in the principal configurations is high, but these LSTs are under-subscribed in the hybrids. It follows that some of the best science in Virgo is currently not being carried out because the VLA spends time in the hybrids, or that highly ranked science is not being awarded time in the configuration requested. Conversely, there is generally a lower over-subscription rate at Galactic Center LSTs in the principal configurations that could easily support imaging projects requiring additional surface brightness sensitivity if the hybrids are eliminated. The transfer of time from hybrids to the principal configurations therefore serves to increase the overall science return from the VLA, a conclusion supported by the TAC and the NRAO Users Committee.

2. Use of principal vs. hybrid configurations

Point sources

For projects aiming to investigate point sources the time needed in a principal configuration would be the same as that in the hybrid to achieve the same point-source sensitivity, and indeed, there are potentially additional benefits from improvements in the spatial filtering properties of the more extended principal configuration compared with the hybrid, if extended emission is present.

Extended structure

For projects aiming to image extended structure one needs to be able to reproduce the surface brightness sensitivity of the hybrid using the principal configurations. The rest of this section concerns how best to do this.

Consider the density of visibilities, N_{vis}, as a function of uv-distance, as a measure of the sensitivity to different spatial scales: the sensitivity (rms noise) will be proportional to $\sqrt{N_{vis}}$. The goal of matching the surface brightness sensitivity of a particular hybrid configuration is therefore one of matching the visibility density as a function of uv-distance through a combination of integration time in one or more principal configurations. An example is given in Figures 3 and 4, which show the uv-coverage of a single integration (snapshot) observation in the BnA hybrid (yellow) at ν=3GHz for a declination δ=−25deg compared with that of the A and B configurations. Figure 3 demonstrates that the density of points in the inner uv-plane for the principal configuration is about half that of the hybrid, while Figure 4 shows that a combination of adjacent principal configurations matches the uv-coverage of the hybrid well.

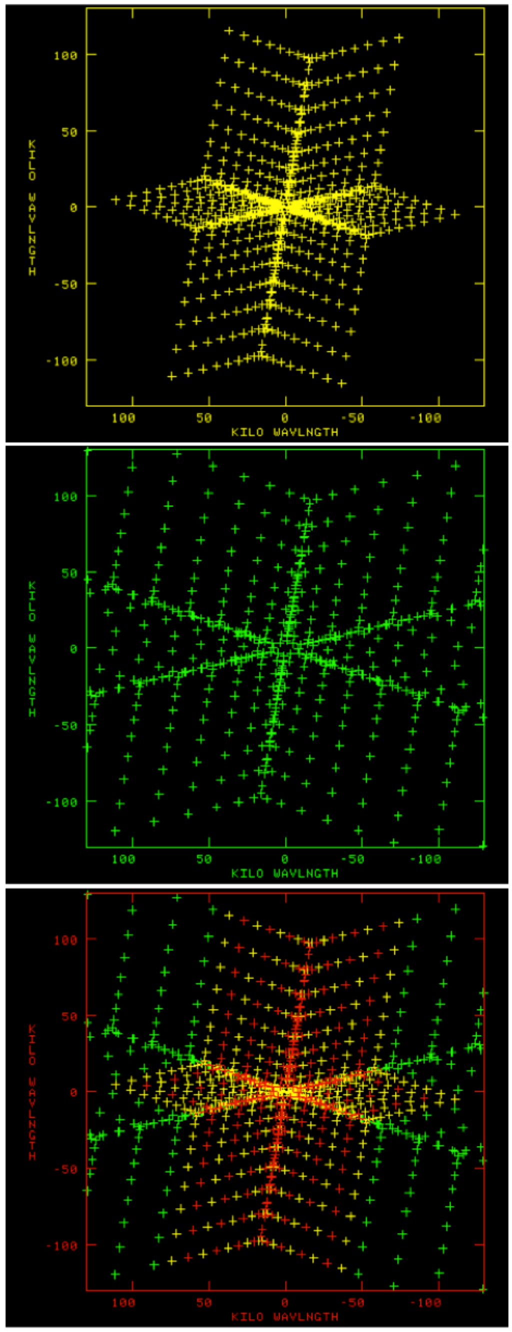


Figure 3: Snapshot uv-coverage for ν=3GHz and δ=−25deg in the BnA hybrid (top, yellow), the A configuration (center, green), and their points in common (bottom, red). The density of points in the inner uv-plane for the principal configuration is about half that of the hybrid.

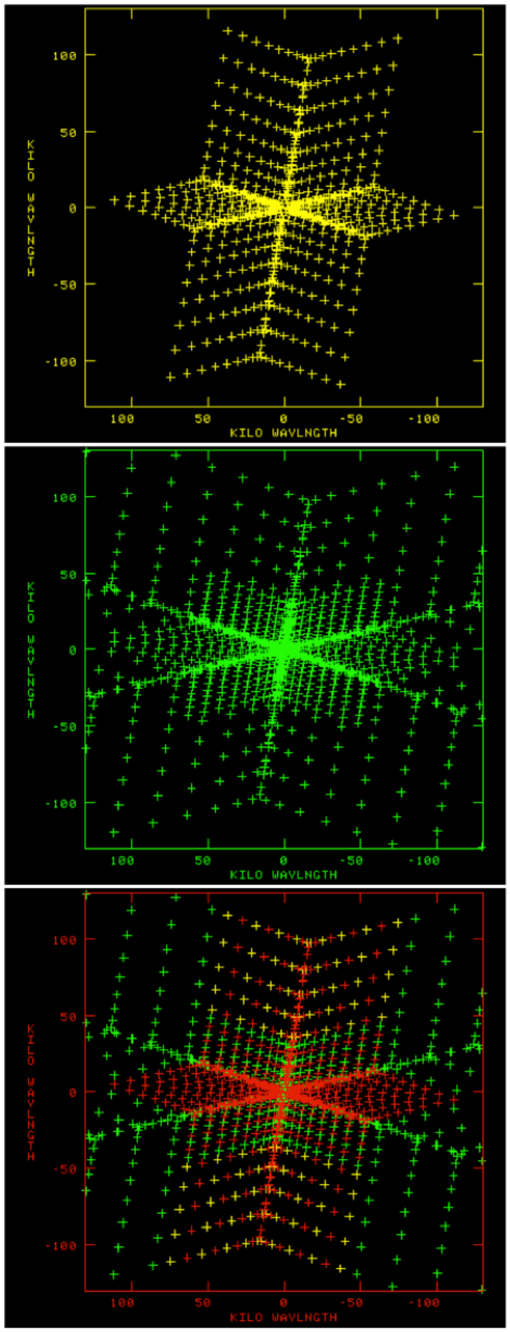


Figure 4: Snapshot uv-coverage for ν=3GHz and δ=−25deg in the BnA hybrid (top, yellow), a combination of A+B configurations (center, green), and their points in common (bottom, red). The combination of the adjacent principal configurations matches the uv-coverage of the hybrid well.

Figure 5 shows a graphical visualization useful for quantifying N_{vis} vs. uv-distance, for an example using ν=3GHz, δ=−25deg, aiming to match the visibility density of the BnA hybrid for a snapshot observation. It demonstrates that to match the visibility density in the inner uv-plane of the BnA hybrid a combination of the same amount of integration time that would have been requested for the BnA hybrid ($t_{int}=t_{BnA}$) is needed in the A configuration, along with an additional 40% of the hybrid time ($t_{int}=0.4t_{BnA}$) in the B configuration (hereafter referred to as A+0.4B). Alternatively, double the integration time in the A configuration (t_{int}=2t_{BnA}, hereafter 2A) can match the BnA visibility density at short uv spacings. The situation is similar for the CnB configuration.

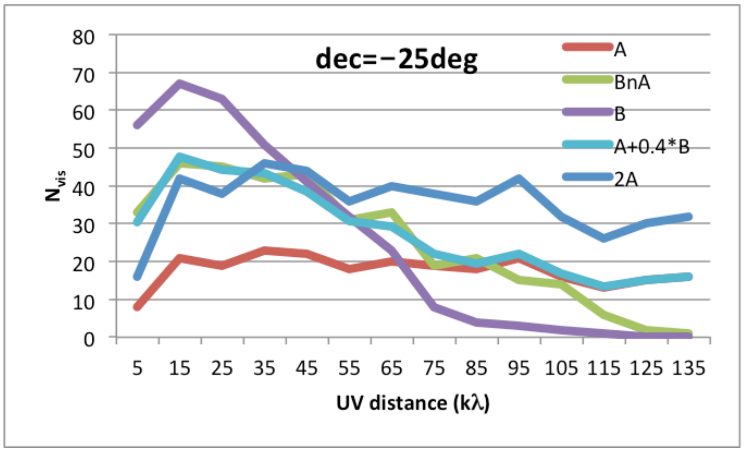


Figure 5: N_{vis} vs. uv-distance for a ν=3GHz snapshot at δ=−25deg in the A (red), BnA (green), and B (purple) configurations. The visibility density in BnA at short uv-spacings can be matched by A+0.4B (cyan) or 2A (blue).

Figure 6 shows how the additional time needed in the more compact configuration is a function of declination, and also the dependence on observation length. A long (e.g., 5 or 6-hour) earth rotation synthesis is able to fill the uv-plane more effectively due to the decreased antenna shadowing when the target is away from the meridian compared with a snapshot or even a 2-hour synthesis centered on the meridian. Nevertheless, for both BnA and CnB configurations, combining 100% of the more extended configuration with an additional 40% of time in the more compact configuration is a good rule of thumb for matching the hybrid visibility density. For reproducing the visibility density of the DnC hybrid the shadowing on short baselines in the D configuration for δ<−25deg is severe, and unless a long synthesis is possible it is more effective at these low declinations to double the hybrid time request and observe entirely in the C configuration.

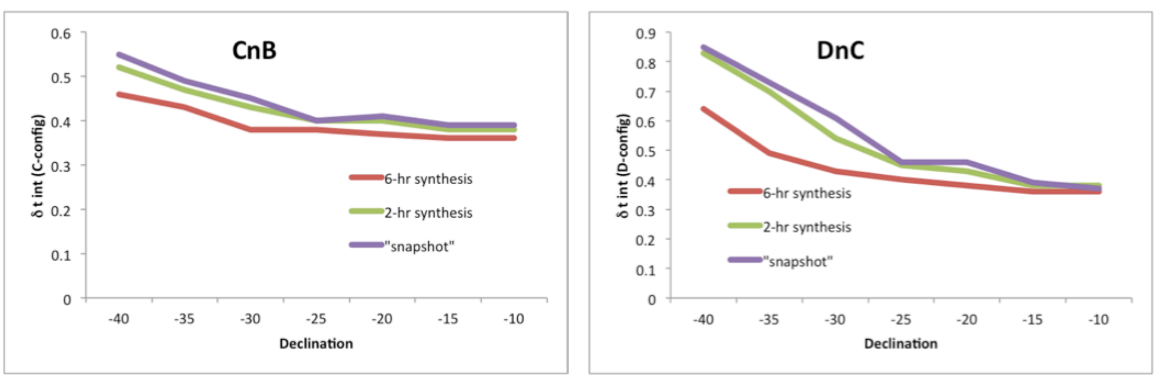


Figure 6: Additional time required in the more compact configuration to match the surface brightness sensitivity of the CnB and DnC hybrids, as a function of declination, for different length syntheses. The red curve corresponds to a 5-hr synthesis at δ=−40deg, and a 6-hr synthesis at all other declinations. The results for BnA are similar to CnB.

To verify that the 1D visibility densities vs. uv-distance shown in Figure 5 translate into the expected sensitivity as a function of spatial scale we created simulated measurement sets using the

CASA task *simobserve*, for ν=3GHz, δ=−25deg, snapshot observations in the BnA hybrid, A+0.4B, and 2A as defined above. The simulated data were then imaged with a variety of uv-tapers and natural weighting. The resulting RMS noise as a function of the geometric mean FWHM of the synthesized beam is displayed in Figure 7. This shows that A+0.4B matches well the surface brightness sensitivity of the hybrid on spatial scales of at least 10 times the untapered, naturally weighted BnA synthesized beam of 2-arcsec, while 2A matches the RMS noise of the hybrid for spatial scales out to ~5 times the untapered, naturally weighted BnA synthesized beam. Exactly which combination of principal configurations is appropriate may depend on the details of the science goal.

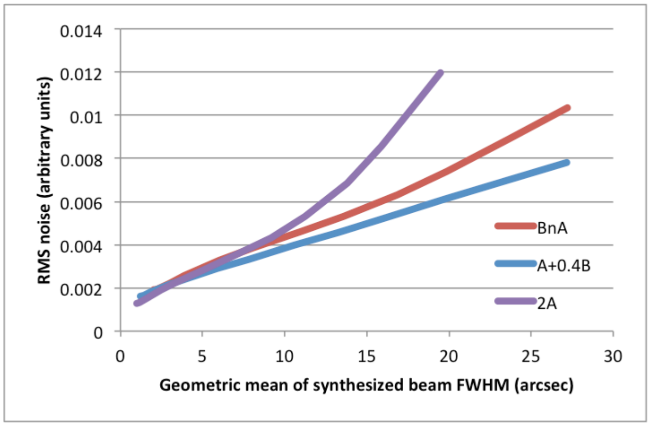


Figure 7: RMS noise as a function of the geometric mean of the synthesized beam for ν=3GHz, δ=−25deg, naturally weighted, tapered, snapshot images for BnA, A+0.4B, and 2A configurations.

3. Conclusions: pros and cons of eliminating the hybrids

As indicated above, there are three main arguments for eliminating the hybrid configurations and moving the time to the principal configurations:

1) Provides a better overall match to VLA proposal pressure vs. LST, eliminates under-subscribed time in the hybrids, and enables more high priority science requesting the principal configurations;
2) Provides improved overall quality (based on SRP score) of the programs executed on the VLA;
3) Provides improved scheduling opportunities, especially for high frequency, Galactic Center projects, that would otherwise have requested the hybrids.

While the arguments for NRAO discontinuing the hybrid configurations are strong, there is a price to pay. The cons of eliminating the hybrids for imaging extended emission from very southern or northern sources are as follows:

1) Additional integration time is needed in the principal configurations for imaging complex structures
2) Data from multiple configurations need to be combined, resulting in:
    a. More complex data reduction;
    b. Potential deconvolution problems if the field contains time variable sources. In the case where there is a known risk of sources varying between observations in adjacent principal configurations (i.e., variable on timescales of weeks) then the

equivalent surface brightness sensitivity on short baselines can be obtained by doubling the time request in a single (larger) principal configuration instead of combining data from adjacent configurations. If point sources are found to have unexpectedly varied then they can be modeled and subtracted from individual datasets prior to combining, as needed.

3) Time-variable weak sources (including solar system objects) may be particularly impacted, for which it may not be possible to observe over multiple epochs and/or configurations.

Additional tools (such as CASA's *simobserve*) can help users to evaluate which combination of principal configurations best match a given science goal.

References

Clark, B. 2014, EVLA Memo 180