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"VLBI2010 Frequency Considerations"

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V2C Memo: VLBI2010 Frequency Considerations

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1. Introduction.

In the IVS WG3 final report [1], an initial recommendation for VLBI2010 frequencies was made, i.e. continuous coverage from 1 to 14 GHz. In light of new opportunities and a better understanding of feed and RFI issues, the purpose of this memo is to list all potential frequency allocations for VLBI2010 commenting on the motivation for each of them and limitations for their implementation. It is not anticipated that all frequency ranges can be supported simultaneously.

2. Broadband (2-14 GHz)

This is the most important frequency range for VLBI2010. The wide continuous 2-14 GHz range enables the use of the broadband delay technique to improve delay precision by roughly an order of magnitude.

Low frequency cut-off. Although theoretical studies of potential broadband frequency sequences [2] indicate that reducing the low frequency cut-off improves ability to resolve RF phase, experience with the NASA broadband proof-of-concept project indicates that low frequency RFI has the potential to saturate the broadband receiver, hence placing a low-frequency limit on the broadband range. There remains, however, a strong impetus to find solutions that allow the bottom of the frequency range to extend at least to 2.2 GHz to achieve compatibility with existing S/X systems.

High frequency cut-off. In the WG3 final report [1], an upper frequency limit of 14 GHz was recommended with frequencies as high as 18 GHz having been considered in the meantime. Although technological challenges impact the high frequency cut-off, there are benefits to making it as high as possible, including:

- Continued optimal phase resolution as RFI raises the low frequency cut-off
- Greater delay precision
- Observation of sources at higher frequencies where structure is generally less.

Linearly polarized feeds now exist that cover more than an order of magnitude of frequency range. Unfortunately, ohmic losses at the higher frequencies dictate that these feeds be cryogenically cooled for acceptable VLBI2010 performance. For optimal VLBI2010 performance, illumination of the antenna by the feed should be independent of frequency, isotropic about the antenna axis, and the physical location of the feed's phase centre should be independent of frequency. To date, the only known feed to have all of these properties is the so-called Eleven feed produced by Kildal et al. Although work continues, this feed has problems achieving the high frequency limit of 14 GHz. An option with the Kildal feed is to split the frequency range into one section below 11 GHz and another in the range 14-18 GHz. The example of the split ranges of 2-11 GHz and 14-18 GHz was analyzed theoretically [2] and shown to work quite well. Other potential uses of the additional high frequency range are discussed in sections 4 and 5.

3. S/X Band (2.3 and 8.5 GHz)

Current geodetic VLBI systems use a dual band receiver with S-band roughly in the 2.2-2.35 GHz range and X-band in the 8.2-8.95 GHz range. Although it is expected that existing antennas will eventually upgrade their feed/receiver systems to VLBI2010 specs, interoperability with existing S/X systems will be necessary during the period of transition to VLBI2010 operations, and since source positions are somewhat frequency dependent, it will be necessary for reasons of continuity to maintain a connection to the S/X CRF.

4. WVR (18-26 GHz)

The primary error source for geodetic VLBI is the wet atmosphere. One option for reducing its contribution is to measure it directly using water vapour radiometers (WVR). Unfortunately, although this approach has been under development for decades, to date it has shown no convincing improvement for geodetic results. This is at least partly due to the fact that current WVR's use a separate small broad-beam antenna that cannot observe at low elevation without picking up ground radiation and that observes a column of water vapour that is both offset and wider relative to the VLBI beam.

VLBI2010 has the potential to overcome both of these problems. As was mentioned in section 2, the Kildal feed (and perhaps others) can easily be combined with a second feed at a higher frequency. An option would be to assign the second feed to the 18-26 GHz range typical of WVR's resulting in a beam that is coaxial with (and roughly the same width as) the VLBI beam and also narrow enough to allow low elevation observations.

Solving these problems will not, in themselves, open the door to success application of WVR's to geodetic VLBI. WVR's have additional problems, e.g. they do not produce useful results when it is raining, and lack of detailed knowledge of the water vapour and temperature profiles along the line of site make it difficult to interpret WVR brightness temperatures as accurate signal delays. The latter effect may be a significant limitation for geodetic VLBI where schedules switch rapidly between sources in significantly different directions where the profiles can be quite different.

5. Ka-band CRF and Deep Space Tracking (32 GHz)

Due to RFI problems at S-band, the DSN is making a transition from S/X band tracking to X/Ka band (8/32 GHz) tracking. This is supported by a new CRF at X/Ka band. Although the new CRF benefits from the fact that source structure is less at those frequencies, an important factor for improving geodetic results, these benefits are tempered by the fact that, at X/Ka band, antenna and receiver design is more difficult, source fluxes are weaker and atmosphere attenuation and instability can degrade to the point where observations may be impossible under some conditions. In a majority of cases, reflectors of existing IVS antennas have low efficiency at Ka band.

As was mentioned in sections 2 and 4, the Kildal feed (and perhaps others) can easily be combined with a second feed at a higher frequency. Another option for the high frequency range would be to assign it to Ka band (~32 GHz). Although some antennas would be ineligible due to inadequate surfaces and some observations would be dropped due to bad weather, supporting this frequency option would make it possible to take advantage of the more stable Ka band CRF and allow IVS to contribute to the new DSN tracking mode.

6. GNSS (1.1 – 1.6 GHz)

There are two motives for observing GNSS satellites with a VLBI antenna. One is to improve GNSS orbits by tracking them directly in the inertial frame defined by the ICRF, which could also serve as an additional mode for inter-comparing VLBI and GNSS. The second is to make differential measurements between the VLBI antenna and a small local directional GNSS antenna to establish gravitational and thermal models for the VLBI antenna and to define and monitor site ties. The intersection of axes of the small antenna would then represent the local VLBI reference point.

There are, however, problems associated with including GNSS frequencies directly into the VLBI broadband spectrum. GNSS signals, when in the antenna beam, are strong enough to saturate the broadband receiver. In addition, RFI sources in the GNSS spectral region may be strong enough to cause saturation problems of their own.

The most prevalent concept for observing GNSS satellites is to detect them outside of the VLBI spectrum where they are attenuated by the natural selectivity of the feed, LNA, etc. However, in these regions, the phase, delay and amplitude of the GNSS signal will not be well controlled and will probably depend strongly on environmental conditions such as temperature, thus degrading their potential for state-of-the-art geodesy. Also, the illumination of the antenna may be quite different for the GNSS frequencies (compared to the VLBI frequencies) so that average deformations may differ between the two illuminated patterns resulting in an apparent offset of the reference point of the antenna.

Another approach might be to have an electrically separate part of the feed (with separate outputs) that is sensitive only to GNSS frequencies. The benefits of this option would be a well-controlled design having stable phase, delay and amplitude and an illumination pattern similar to that of the VLBI feed. The main drawback would be a doubling of the linear dimension of the feed. All aspects of the antenna optics, including size of the sub-reflector, need to be designed to handle the lower frequencies.

7. Summary and Conclusions

- The lower edge of the broadband spectrum will likely be limited by problems with RFI.
- A means must be found to observe at least down to 2.2 GHz to maintain compatibility with existing S/X systems.
- The upper edge of the broadband spectrum may be limited by technology to below 14 GHz, at least initially.
- A second higher broadband spectral region may be feasible, which could be used to either:
    - Enhance the initial broadband region
    - Implement a line-of-site WVR
    - Develop a Ka band CRF capability

- For state-of-the-art measurements, a separate but spatially aligned GNSS feed may have advantages over observing GNSS beyond the edge of the VLBI2010 broadband response.

References

1. Niell, Arthur et al., “VLBI2010 Current and Future Requirements for Geodetic VLBI Systems”, IVS memo 2006-008v01, http://ivscc.gsfc.nasa.gov/publications/memos/index.html
2. Petrachenko, Bill, “Performance of Broadband Delay (BBD) Sequences”, IVS memo 2008-005v01, http://ivscc.gsfc.nasa.gov/publications/memos/index.html