Interference in VLBI Observations

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Abstract

This lecture addresses the effects of interfering signals on the specific observational technique known as Very Long Baseline Interferometry, VLBI. Sections 1 and 2 present some background on interferometry in general, and on VLBI, which will be essential to an understanding of the impact of interference in these techniques. The purported "immunity" of VLBI observations to interference, an essential point that applies in both practical and regulatory senses, is then discussed in Section 3. The special regulatory status that has been assigned to VLBI as a result is considered in Section 4. The lecture concludes in Section 5 by describing the impact of interference on some of the auxiliary measurements essential for calibration of VLBI results.

1. Interferometry

Operating in the long-wavelength region of the electromagnetic spectrum, radio astronomy has been driven since its inception by a quest for higher angular resolution. Practical limits on the size of single, filled-aperture telescopes led quickly to the development of interferometric observing systems, in which a large effective aperture is "synthesized" by combining signals from multiple smaller filled-aperture elements. This technique increases both the total collecting area of the instrument, and the angular resolution. The latter aspect led to the development of VLBI, and will be emphasized here. The angular resolution achieved by an interferometer system is inversely proportional to the maximum geometric extent of the array of individual elements.

An essential detail of an interferometer's operation is that signals from the individual elements must be shifted in delay and phase to re-align the wavefronts arriving from the desired direction, before the signals can be combined. This has the effect of dispersing and washing out interfering signals arriving from any other direction. Thus, the angular-resolution scale to which the interferometer is sensitive is also the range of directions about the observed source from which interference can have a direct impact.

Indeed, an interferometer can be said to be even less sensitive to interference than a filled-aperture telescope with the same synthesized beam. The reason is that the angular discrimination just described applies at *all* frequencies (albeit with varying effectiveness). Single-dish telescopes, in contrast, are also affected by interference received directly into their electronic signal channels. This interference can arrive from directions far outside their main antenna beam.

2. VLBI: Very Long Baseline Interferometry

VLBI is simply the extension of the interferometric technique to continental or global distance scales. This technique was developed in the 1970s. NRAO operates the world's only dedicated VLBI instrument, the Very Long Baseline Array, VLBA. Other VLBI arrays, both formally and informally organized, also exist on a part-time basis.

The large distances intrinsic to VLBI require two specialized implementation details. First, the distances and bandwidths are (currently) too great to transmit the observed signals to the central correlation site in real time. Instead, the signals must be recorded, with precise time tags; the recorded media are shipped in bulk to the correlation center, where the signals are later reproduced from the recordings. Further, and similarly, the distances are also too great to transmit the reference signal that allows all interferometer elements to observe precisely the same band of frequencies. Each antenna must have its own independent, precise frequency standard, which in current practice is typically an atomic clock such as a hydrogen maser.

Since the individual antennas operating as part of a VLBI array generally require a full complement of a typical radio observatory's infrastructure, they are usually referred to as "stations". This usage will be followed henceforth in this lecture.

3. Interference "Immunity" of VLBI

The fundamental consideration that makes VLBI observations unique with respect to interference also arises directly from the large distances separating the stations: interfering signals almost always are independent at the individual stations. This is true whether the interference arises from a local, ground-based source, from an aircraft, or even from a satellite. (A few exceptional cases are noted below.)

Such independent interference signals generally do not appear in the VLBI interferometer's output. One reason is shared with local or "connected-element" interferometers: signals arriving from directions offset from the observed radio source by more than an angular-resolution scale are dispersed or washed out in the interferometer instrumentation. But perhaps more fundamentally, the independent interference signals are not correlated with each other, unlike the signals that arrive at the different stations from the radio source.

The principal exception to this "immunity" occurs when the interference is sufficiently strong that the gain of the receiving system is compressed. In such a case, the VLBI output signal would be reduced without (in the absence of specialized measures) a corresponding increase in the calibration factors. It is also possible in principle, but unlikely, that simultaneous, coherent (i.e., non-independent) interfering signals could arise from certain satellite systems; one such event actually may have been observed.

4. Regulatory Status of VLBI

The fundamental ITU Recommendation on "Protection Criteria Used for Radioastronomical Measurements", the famous Rec. RA.769, recognizes that some interference immunity exists even for local, connected-element interferometers:

> ... compared to a single radio telescope, the interferometer has a degree of immunity to interference which, under reasonable assumptions increases with the array size expressed in wavelengths.

However, Rec. 769 recommends special treatment only for VLBI:

> The greatest immunity from interference occurs for interferometers and arrays in which the separation of the antennas is sufficiently great that the chance of occurrence of correlated interference is very small (e.g. for very long baseline interferometry (VLBI)).

and specifies an alternative level of protection:

> The tolerable interference level is determined by the requirement that the power level of the interfering signal should be no more than 1% of the receiver noise power.

These levels, specified in terms of SPFD, are 40-55 dB higher than for non-VLBI observations.

The few other ITU Recommendations that specifically mention VLBI only apply to very special cases, such as Space VLBI (observations using one – or in principle more – radio telescopes in space) or the Shielded Zone of the Moon.

A special regulatory concept of VLBI *observatories*, derived from the RA.769 category of VLBI *observations*, appears in some other ITU documents. These are observatories that perform *only* VLBI observations; so far, this class is limited to the ten stations of NRAO's VLBA instrument. (Some other VLBI-only stations do exist, but do not operate in any bands allocated to the Radio Astronomy Service.) This distinction is significant only with respect to the site-dependent protection agreements that are becoming increasingly common. In such agreements, VLBI observatories are entitled only to the protection levels specified for VLBI in RA.769.

5. Impact of Interference on VLBI Calibration

Several types of calibration and other auxiliary measurements must be performed by treating the stations of a VLBI array as individual antennas. Most important among these are measurements of antenna gain and pointing. To a large extent, such measurements can be – indeed, often must be – done in ways that mitigate any possible adverse effects of interference, by observing relatively strong sources and by observing at nearby frequencies free of interference.

An important exception is the "template method" of gain calibration sometimes used in observations of spectral lines. This approach monitors the strength of emission or absorption features in the total-power spectrum from each individual station. It is useful when the gain cannot be measured directly at all, for example when small antennas or low-sensitivity receivers must be used, or when only weak sources are available. Another common application is the case of unstable gain caused by pointing errors, typically at high frequencies where an antenna's performance becomes marginal. Successful application of the template method, however, requires that the total-power spectra be free of interference.

The template method was essential in the early days of VLBI, when many of the conditions mentioned above actually prevailed. Modern VLBI arrays have largely eliminated this necessity for routine observations, but the method remains useful in extreme cases, which typically occur at the forefronts of the VLBI technique.