# The Impact of Radio Frequency Interference (RFI) on VLBI2010

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## Abstract

*A significant motivation for the development of a next generation system for geodetic VLBI is to address growing problems related to RFI, especially at S-band. In this regard, the broadband 2-14 GHz frequency range proposed for VLBI2010 has advantages and disadvantages. It has the advantage of flexible allocation of bands anywhere in the full range of 2-14 GHz. This provides the ability to place bands away from the worst RFI. It has the disadvantage that the receiver LNA is vulnerable to saturation from RFI anywhere in the full broadband range. A number of RFI examples are considered to better understand their impacts on the VLBI2010 system, along with a discussion of strategies to reduce those impacts*.


## 1. RFI and VLBI

*RFI is composed of man-mad radio emissions inadvertently added to the signal of interest. It can originate from land, marine, aeronautical, or space-based transmitters and for purposes ranging from commercial broadcast to scientific and amateur. The entire VLBI2010 spectrum from 2-14 GHz is allocated for a myriad of applications through international, national, and regional agreements, e.g. Fig. 1.1. Only a tiny portion is set aside for radio astronomy.*

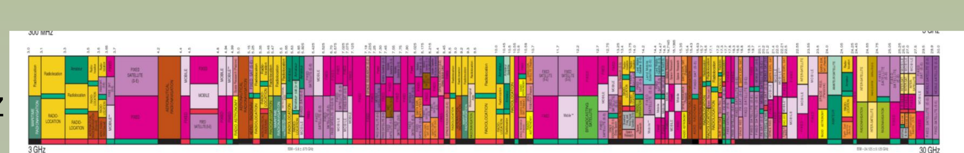
3 GHz  30 GHz

**Fig 1.1** U.S. frequency allocations for 3-30 GHz

*Fortunately, since VLBI is an interferometric technique, it is comparatively robust against RFI. This is particularly true since its antennas are widely separated. As a result, sources of RFI in the network are generally uncorrelated. Even when the RFI is correlated, as in the case of geostationary satellites, it appears in the cross-correlation function at a delay and fringe rate different from that of the geodetic signal.*

## 2. RFI and VLBI2010

*RFI has a significant impact at two points of the VLBI2010 signal path, those being at the LNA in the front-end, and at the sampler and digital back end (DBE) immediately before the data recorder. See Fig. 2.1.*

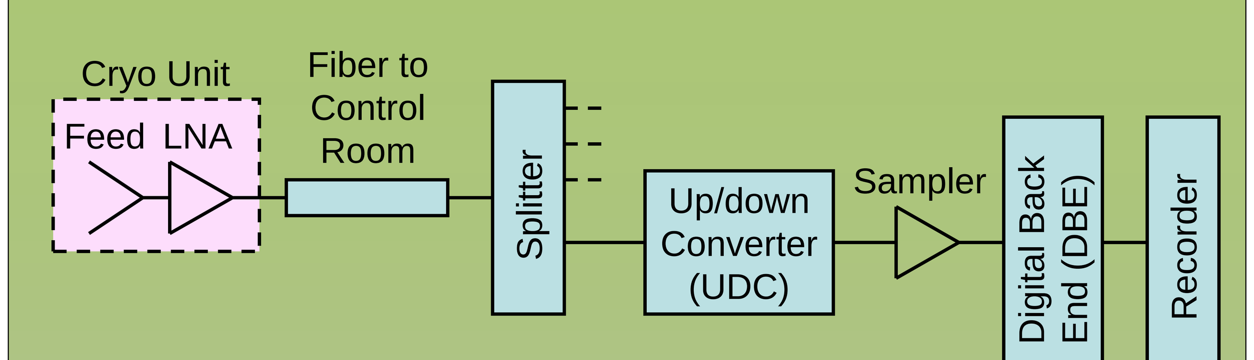



**Fig. 2.1** VLBI2010 Signal Path

### 2.1 Impact of RFI on the VLBI2010 LNA

*For moderate RFI, the main degradation is a reduction of SNR in the frequency range of the RFI. However, when the RFI begins to saturate the front end LNA, the degradation becomes much more serious. The left panel of Fig. 2.2 is a simulation of the non-saturation case. A narrow band RFI signal of amplitude five is added to a noise signal of rms amplitude one. The saturation level is 10. As expected, no saturation occurs. In the right panel, the RFI level is increased by a factor of 3 and saturation is clearly evident. During the periods of clipping, the astronomical signal disappears completely, which reduces signal level across the entire spectrum. More importantly though, the astronomical signal is now amplitude modulated and hence translated in frequency. At this level of modulation the full band is rendered useless for VLBI.*

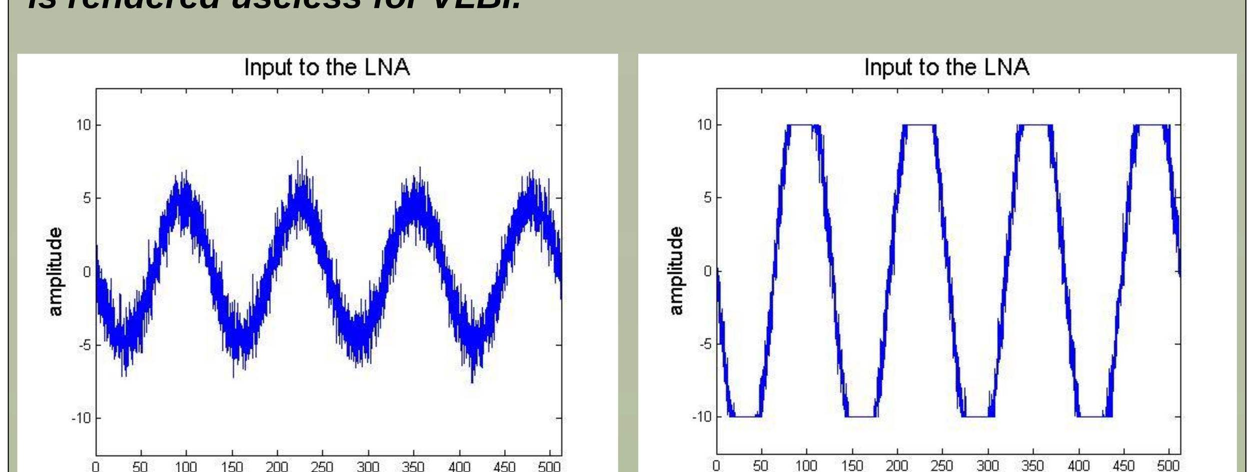



**Fig. 2.2** Simulation of the case of narrow band added RFI. In the left panel there is no saturation and in the right panel there is.

*If risk of significant front end saturation is anticipated at a location, remedial action must be taken. One solution, if available, is to use a higher dynamic range LNA. Otherwise, if space is available, a cryogenically cooled notch filter tuned to the RFI can be inserted between the feed and LNA.*

*Fortunately, the fact that the VLBI2010 frequency range is very broad helps mitigate against LNA saturation. VLBI LNA's will operate linearly with input signals 30 dB or more above the integrated LNA noise. What needs to be remembered here is that it is the integrated noise power across the band that is of concern. Hence, an RFI source that has spectral density 60 dB above the noise floor over a 10 MHz frequency range is only 30 dB above the integrated noise for an LNA with bandwidth 10 GHz.*

*Another mitigating factor is the directionality of the parabolic antennas used in VLBI. The power of RFI received through antenna sidelobes and backlobes is significantly attenuated over the strength of the signal of interest seen along the axis of the antenna.*

## 2.2 Sampler and Digital Back End (DBE)

*The input to the DBE is another place where saturation is a significant issue. However, in the case of the DBE, it is saturation of the sampler that needs to be consider. As with the front end LNA, saturation of the DBE input sampler has high impact since it affects the whole band and not just the spectral region where RFI occurs.*

*The input sampler is a physical device with both high resolution and high bandwidth. These characteristics allow maximum fidelity and dynamic range to be maintained for the signal processing in the DBE. Once the input signal has been separated into channels, the signals can be re-quantized to 2-bits for efficient data transmission to the correlator (see Fig. 2.3). After channelization, only the channels that contain RFI are impacted by the coarse 2-bit digitization and not the entire band.*

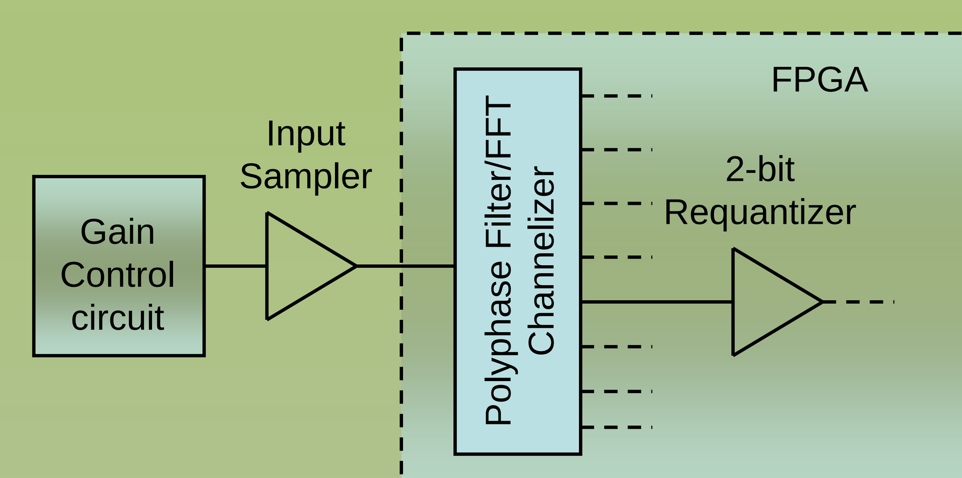



**Fig. 2.3** DBE signal processing

*Fortunately there is very little correlation loss if the astronomical signal is comparatively small within the sampler. In Fig. 2.4, it can be seen that the correlation loss is only 0.5% if the rms of the astronomical signals (at both stations) falls at 4 units within the sampler; the loss is 2% if the signal falls at 2 units within the sampler. This leaves the majority of the sampler range to handle RFI.*

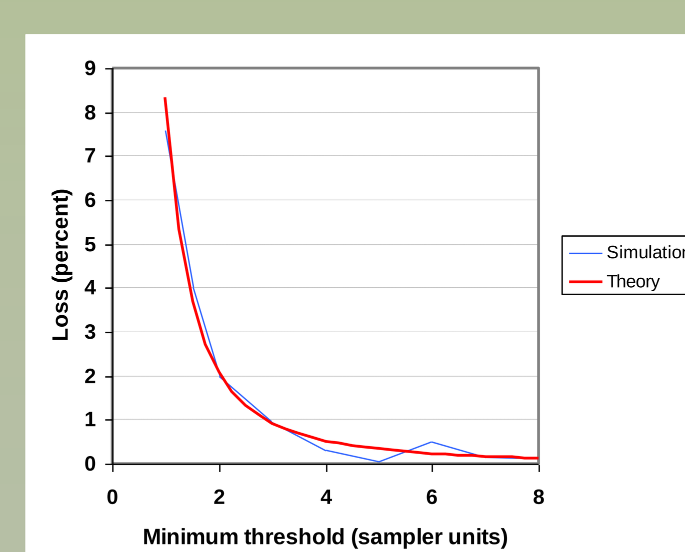



**Fig. 2.4** This is the correlation loss assuming both stations have set the astronomical signal at the same level within the sampler. The noisier blue curve is based on a Monte Carlo simulation while the red curve is based on a simple theoretical model. Both agree quite well in the region of interest.

*Once the gain control circuit has been set (see Fig. 2.3), added RFI will not degrade performance until the signal level enters saturation. For noise-like RFI to just enter saturation, the rms signal level is about a factor of four below the full sampler range. The RFI dynamic range for a number of different conditions of sampler sizes and signal thresholds is summarized in Table 1.*

| Sampler size (bits) | Signal threshold (sampler units) | Dynamic Range for RFI (dB) |
|---|---|---|
| 8 | 4 | 18 |
| | 2 | 24 |
| 9 | 4 | 24 |
| | 2 | 30 |
| 10 | 4 | 30 |
| | 2 | 36 |

**Table 1** Dynamic Range for handling RFI for different values of sampler size and signal threshold

*A high resolution input sampler ensures that the signal will enter the DBE with minimum distortion. For effective RFI mitigation, it is also necessary that the channels in the DBE be well isolated. Very efficient digital algorithms have been developed to implement filter banks based on a combination of poly-phase filter and FFT. Practical implementations can achieve stop-band performance approaching 60 dB or better. Examples are depicted in Fig. 2.5.*

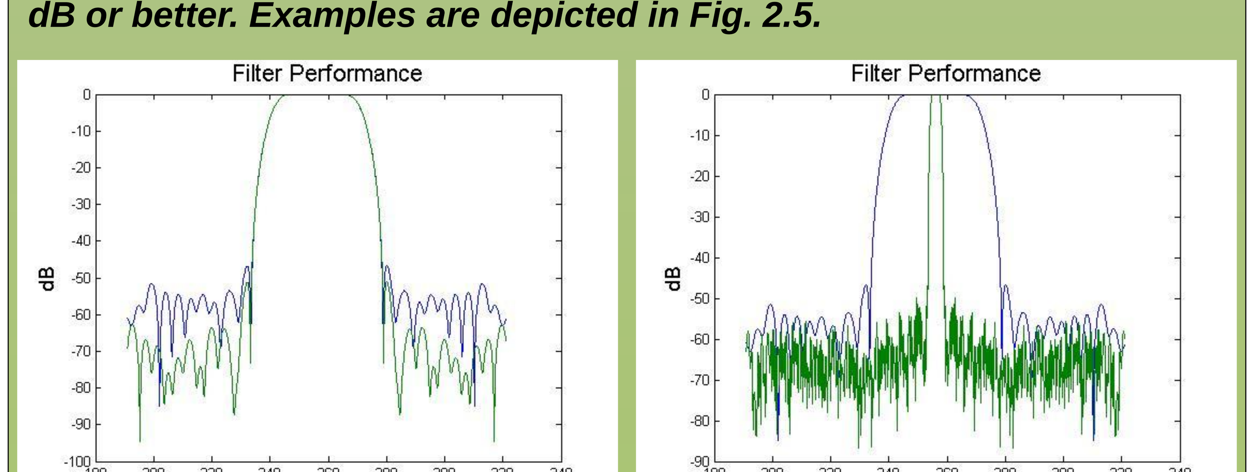



**Fig. 2.5** In the left-hand panel, the performance for two filters is displayed. In both cases the poly-phase filter is 8 times the length of the FFT but for the blue trace, the tap weights are represented by 8-bit numbers and for the green trace, they were represented by 10-bit numbers. In the right-hand panel, a 4 MHz filter is compared with a 32 MHz filter. In both cases the poly-phase filter is 8 times the length of the FFT and the tap weights are represented by 8-bit numbers.

*Some regions of the spectrum are very congested with RFI. In Fig. 2.6, the Medicina S-band spectrum from 2.0-2.8 GHz is displayed. Particularly heavy congestion is seen in the 2.1-2.5 GHz region.*

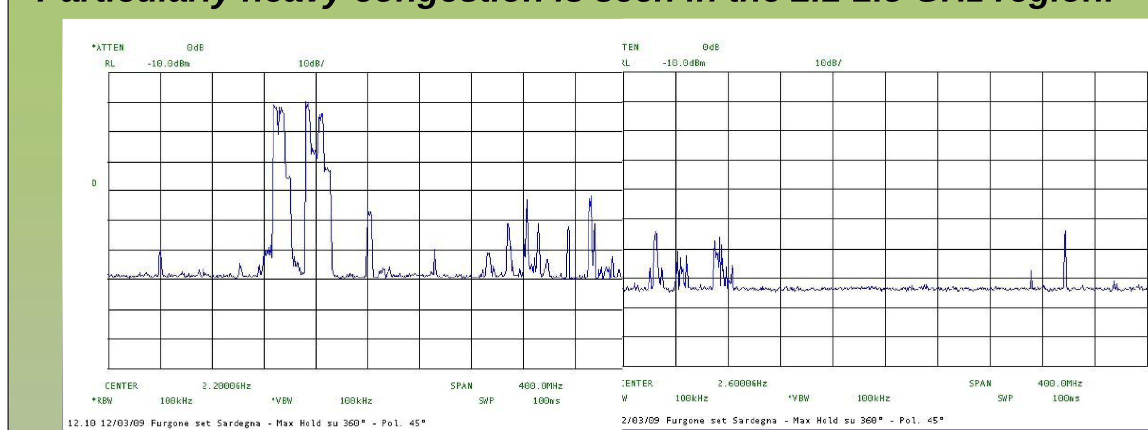


**Fig. 2.6** RFI spectrum taken near Medicina as presented by Roberto Ambrosini at the FRFF workshop in Wettzell, Germany, March 18-20. The frequency range for the plot is 2.0-2.8 GHz.

*When RFI is congested, narrower bandwidth DBE channels make it possible to acquire good data in the spaces between the RFI. For the 1 GHz section of the Medicina RFI spectrum from 2.0-3.0 GHz, the amount of the spectrum that is lost due to RFI is plotted as a function of DBE channel bandwidth in Fig. 2.7. In the figure, the amount of available spectrum increases by nearly a factor of two from just over 400 MHz to just under 800 MHz as the channel bandwidth decrease from 32 to 2 MHz.*

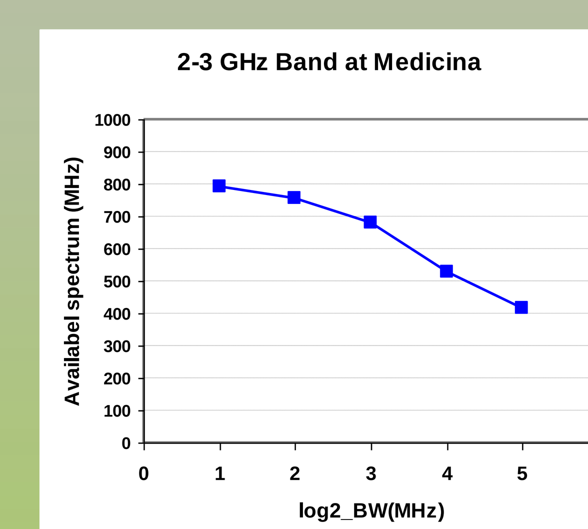



**Fig. 2.7** Loss of available S-band spectrum at Medicina as the channel bandwidth increases from 2 to 32 MHz

## 3. RFI in the 2-14 GHz range

*The entire radio spectrum from 2-14 GHz is allocated to one application or another. In the frequency range from 2.2-3.0 GHz, the US regulations show over 70 separate allocations. Due to the distribution and operating modes of emitters, the RFI environment varies significantly from location to location and from time to time.*

*In many ways, urban areas, due to their greater population density, provide a more congested RFI environment. Rural areas have their own challenges. In these areas, the laying of cables for communication and broadcast purposes is less cost effective and is often replaced by the use of airwaves. In addition, transportation routes, whether they be by land, sea, or air, all suffer from RFI related to the need for long-range mobile communications, radio-navigation, radiolocation and weather surveillance. For the same reasons, airports, seaports, and military installations represent heavy concentrations of RFI emitters, both mobile and fixed.*

*It is recommended that site selection criterion for new VLBI2010 sites include a thorough RFI evaluation. It is further recommended that all VLBI sites make themselves, and their spectrum needs, known to local regulators so that appropriate considerations can be applied when applications for new emitters are processed.*

*There is one class of RFI emitters with nearly equal impact at all locations, those being space based emitters. Of particular concern are the emissions from geostationary Direct Broadcast Satellites (DBS) in the broad frequency ranges of 3.7-4.2 GHz (C-band) and 10.7-12.7 GHz (Ku-band). In the case of Ku-band, the DBS emissions are strong enough to be acquired by antennas well under 1-m in diameter. A quick internet search provided a list of 107 DBS's in the western hemisphere alone. Based on transmitter power, bandwidth, and antenna pattern, the noise per satellite is expected to be about 1K into an isotropic radiator. Strangely, little is mentioned of the DBS bands in most RFI surveys. One exception is an RFI survey done at the GBT. One panel from the survey is shown in Fig.3.1. This represents a full azimuth sweep at 20° elevation. The frequency range is 12.0-12.8 GHz. Clearly, no DBS RFI is detected to the north, but as the antenna sweeps to the south, a series of 9 satellites is picked up in the GBT sidelobes. Since the survey was not amplitude calibrated, it is difficult to determine the extent of the problem. All the same, if the Ku-band DBS frequency range of 10.7-12.7 GHz needs to be used by VLBI2010, scheduling software may be required to avoid observations close to DBS's.*

http://www.gb.nrao.edu/~tminter/rfi/ku-band-rfi.shtml

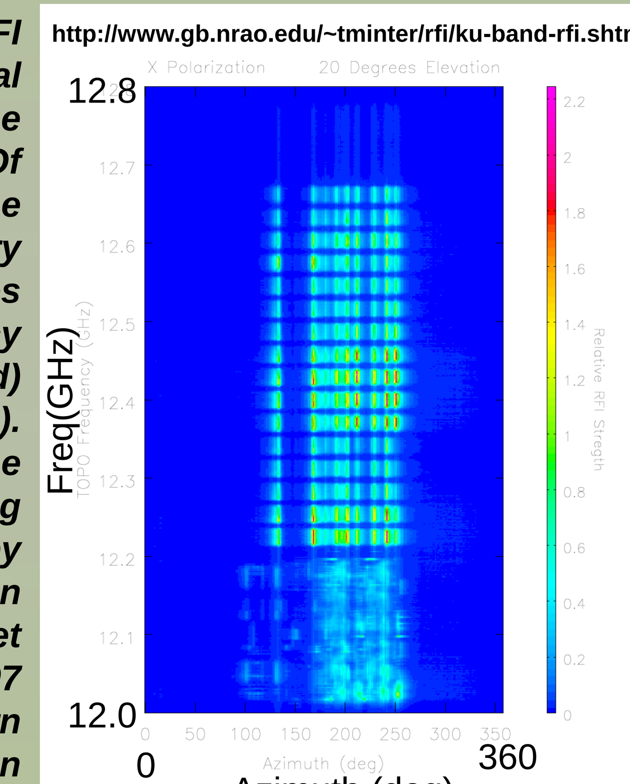



Fig. 3.1 GBT sweep from 0° to 360° azimuth at 20° elevation (from Toney Minter, NRAO ~web reference above).

*Two final important and unavoidable RFI sources are related to space geodesy site co-locations. They are the DORIS beacon and the SLR aircraft avoidance radar. Since both are powerful nearby emitters, it is strongly recommended that they be located out of the line of site of the VLBI antenna.*