RF compatibility of VLBI with DORIS and SLR at GGOS stations: An experimental methodology to validate the models

Christopher Beaudoin[1] Brian Corey[1] Lawrence Hilliard[2] Bill Petrachenko[3]
[1]MIT Haystack Observatory [2]NASA-GSFC [3]Natural Resources Canada

Abstract: A continuing thrust in the space geodetic community is to deploy instruments using different techniques at common sites. While the close proximity (of order 100 meters) of the instruments to each other affords improved inter-comparison tests, it also increases the potential for interference between instruments. Of present concern to VLBI are DORIS beacons and the aircraft surveillance radars used in conjunction with satellite laser ranging (SLR). Initial numerical studies[1] were conducted to obtain rough estimates of the degree to which the VLBI SNR is degraded for various levels of DORIS and SLR radar interference. Numerical studies are only as good as the models upon which they are based, however, and there is sufficient uncertainty regarding their accuracy that field and laboratory validation is warranted. In this contribution, we present a measurement methodology designed to resolve the major uncertainties in the models. We also summarize the experimental results to date.

Field Measurement of GGOS transmitters at GGAO

Location	Measured Power	Calculated Power	Distance	Clear LOS?	LOS Blockage
DORIS Pad	-1 dBm	-1.3 dBm	6.4 m	YES	0
Field	-43.7 dBm	-28.6 dBm	148.5 m	NO	15 dB
Observatory Pad	-27.6 dBm	-29.5 dBm	163.7 m	YES	0
MV3 Post	-44.3 dBm	-30.8 dBm	191.7 m	NO	13 dB

Table 1: Field Measurements and expected DORIS power levels. Expected levels assume clear line-of-sight from DORIS to the field receiver

	Mob7		NGSLR	
	Expectation	Measured	Expectation	Measured
GODEW	[-3.0 1.0] dBm	-0.8 dBm	No Line-of-Sight	
Loc#2	[-6.1 -2.1]	-4.9 dBm	[-4.9 -1.0] dBm	-3.6 dBm

Table 2: Field measurements of SLR aircraft tracking radar power levels and corresponding expectation. Uncertainty in expectation is due to ambiguity in radar antenna pattern (see reference 2). The results reported here are those from [2] for which the radars were stripped of their operational provisions (e.g. radome, fall-protection railings). These provisions influence the radar's transmitting characteristics as shown in [2].

Purpose
In order to quantify the power levels received at the VLBI antenna, the characteristics of the transmitting systems must be understood. Tables 1 and 2 demonstrate this level of understanding through comparison of measured and expected power levels. The measured power levels are those received through a standard gain horn antenna, the gain characteristics of which are well-understood. The expected power levels are computed from the Friis transmission formula and are based on the power transmitted by the particular antenna, the frequency, the gain of the transmit and receive antennas, and displacement between the two antennas.

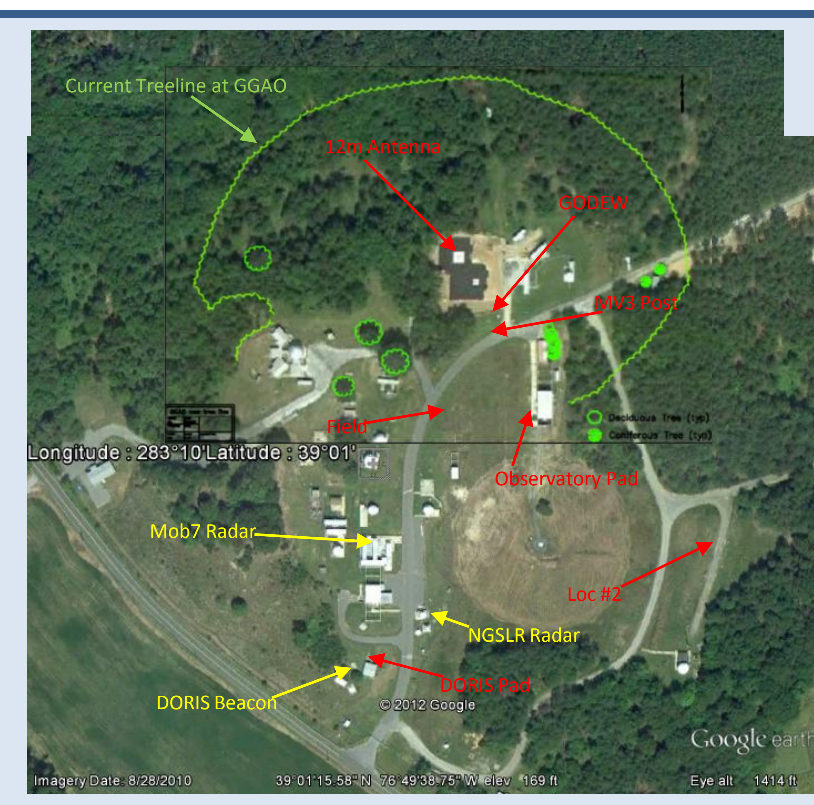


Figure 1: Map of GGAO identifying location of DORIS and SLR-radar transmitters(yellow) and locations at which power level measurements were collected (red)

Test of GGAO 12m sidelobe model

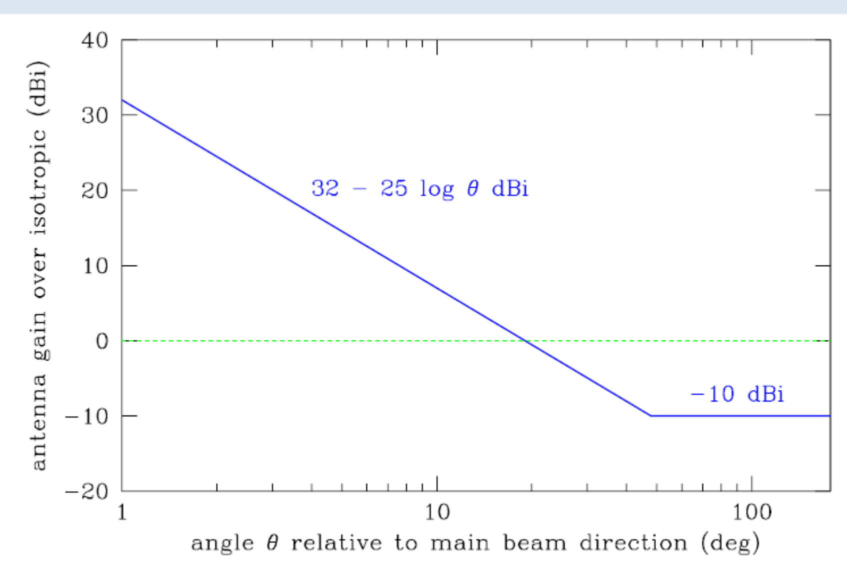


Figure 1: ITU-R SA.509 antenna sidelobe envelope model incorporated in numerical RFI-compatibility studies.

Purpose
The sidelobe envelope presented in Figure 1, is assumed to provide a worst-case 12m antenna gain vs. pointing-to-RFI-source. This assumption should be validated experimentally to provide assurance of the 12m antennas gain characteristic which in-turn (combined with other information) will provide confidence in the received DORIS/radar power levels will not exceed the worst-case expectation.

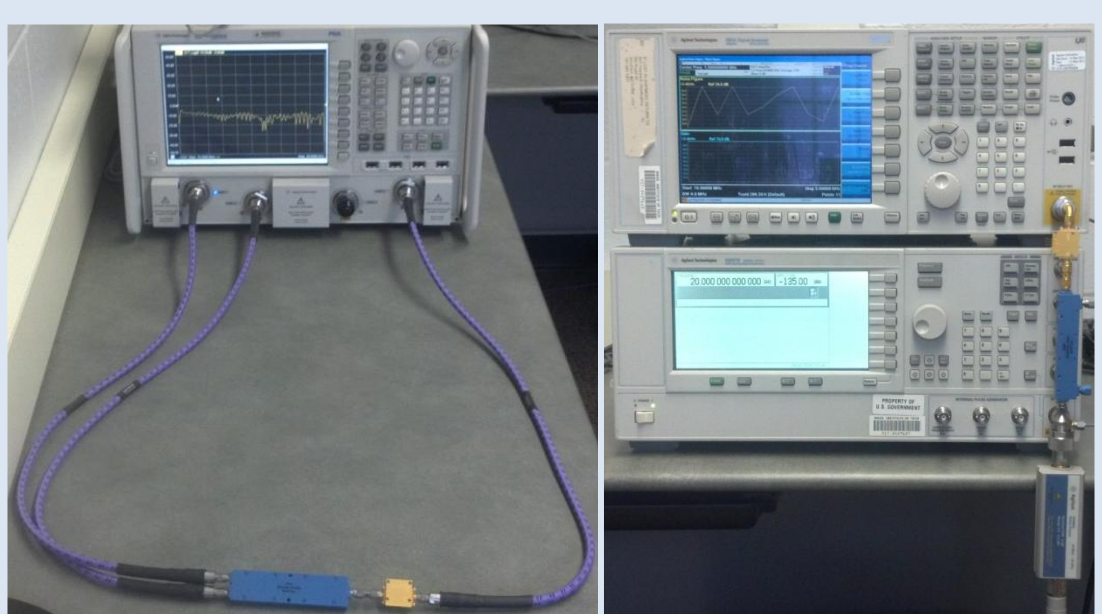
Planned Experimentation
To validate the sidelobe model, a separate field test of the 12m sidelobe envelope is planned. The field test will be carried out with a mobile beacon that is capable of transmitting at the DORIS and aircraft tracking radar frequencies, 2.036 and 9.4 GHz respectively.

Barrier Efficacy

Purpose
Based on the numerical study[1], the VLBI technique will loose significant sky coverage if the transmitting techniques are placed within 100m of the VLBI antenna. For this reason, a comprehensive electromagnetics analysis of physical barriers/blockages has been undertaken to mitigate the offending signal levels and provide the VLBI technique satisfactory sky coverage at GGOS stations. The barrier is expected to have little impact on the SLR radar performance, however, considerations in the barrier design are being made to ensure that a DORIS barrier does not introduce significant multipath which is a source of position error to the DORIS technique.

Planned Experimentation
Once the computational barrier analysis have been completed, they will be verified experimentally. The barriers are planned to be tested first with mock-transmitters. This will be minimally instrusive to DORIS/SLR operations and will provide sufficient flexibility to carefully study the results of these experiments. Assuming the results obtained using the mock-transmitters are satisfactory (i.e. barrier provides sufficient shielding), the respective barriers will be deployed to the SLR and DORIS techniques, where the testing process will be repeated. Upon successful installation of the DORIS barrier (as far as VLBI is concerned), the IDS will undergo a one-month trial observation with the new barrier to evaluate its impact on the DORIS observations.

Receiver Saturation Characterization


(a) (b)
Figure 2: (a) Intermodulation distortion measurement setup used for characterizing LNA saturation power levels (b) Experimental setup for measuring LNA noise figure degradation due to LNA saturation.

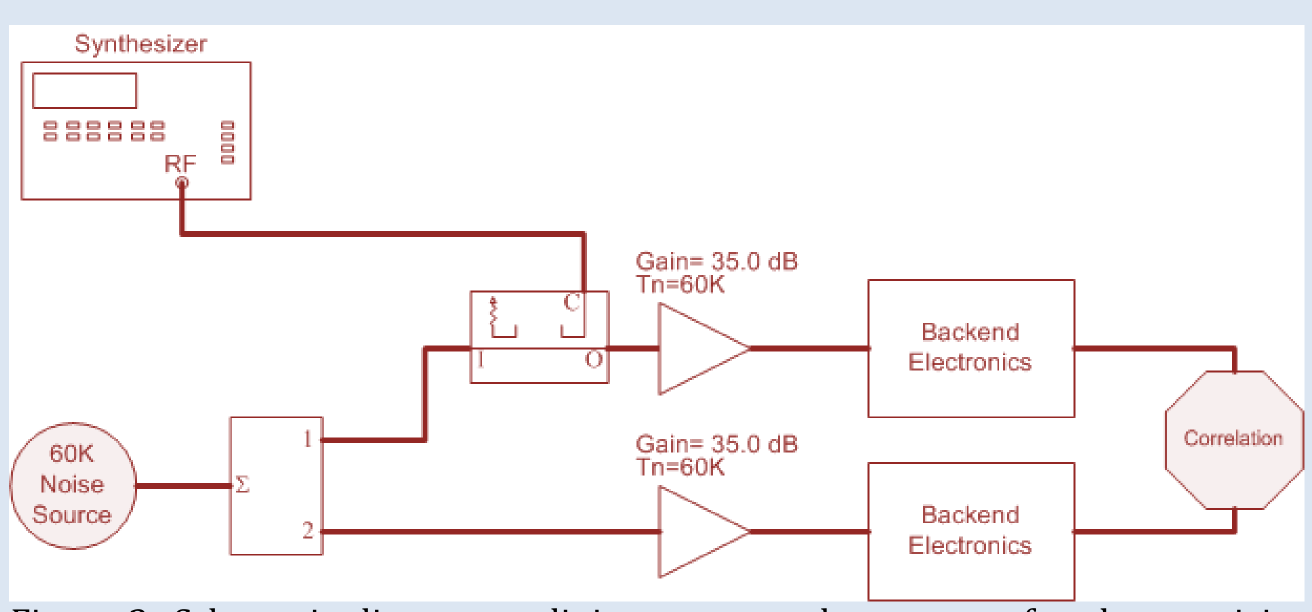


Figure 3: Schematic diagram outlining conceptual test setup for characterizing degradation in VLBI correlation observable as a function of LNA saturation. The synthesizer can produce either continuous or pulsed/continuous waveforms at both the DORIS and radar frequencies.

Purpose
The output 1 dB compression point of the CRYO1-12 LNA is nominally -5 dBm and the output third-order intercept point (OIP3) is ~+5 dBm. However, broadband measurements of this data are not available so the nominal compression point has been utilized for the numerical studies[1]. The degradation in the VLBI observable depends strongly on the saturation properties of the LNA, hence both the 1 dB compression point and OIP3 and characteristics should be measured.

Planned Experimentation
The Agilent N5222A will be used to measure the two-tone intercept point of the CRYO1-12 LNA in order to quantify the broadband saturation characteristics of the LNA (Figure 2a). The MXA N9020A with noise figure option (Figure 2b) will be used to characterize the room temperature noise figure of the LNA under varied levels of saturation. Lastly, the expected degradation of the VLBI observable will be characterized using the test setup outlined in Figure 3.

Acknowledgements
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References
[1] Beaudoin, C., Corey, B., and Petrachenko, B., "Radio frequency compatibility of VLBI, SLR, and DORIS at GGOS stations" poster presented at AGU 2010 fall meeting in San Francisco, CA, 2010.

[2] Beaudoin, C. and Cappallo, S., MOBLAS7 and NG SLR Radar Power Level Measurements Collected at GGAO, MIT Haystack Observatory VLBI Broad Band Memo Series, No. 37, 2011.

Conclusions
Preliminary power level specifications have been computed based on a numerical model[1] of the transmit/receive systems at GGOS stations. The experimental methodology presented here will be used to validate assumptions of the numerical model or be used to augment the aforementioned assumptions if they are grossly incorrect.

Comparison of field measurements and expectations regarding the DORIS and SLR-radar transmitters is outlined in Tables 1 and 2. The data reported in these tables show that the DORIS measurements are in agreement to within 2 dB of the expected power levels. The SLR radar results, when the radome/railings are removed from the radar, are also within 2 dB and nearly equdistant from either limit of sidelobe uncertainties in the expected results. Given this level of agreement, we conclude that the transmission properties of these systems are sufficiently well-understood for this RFI compatibility study. As shown in [2], these operational provisions do influence the transmitting characteristics of the radar. Since the Friis tranmission formula does not consider line-of-site scattering effects, a more detailed model of the complete radiation pattern (i.e. radar/radome/railings) is needed to fully-describe the transmission characteristics. This complete transmission characteristic should be well-understood to ensure the the radar power levels in the direction of the VLBI antenna are adequately mitigated.

Based on the numerical model[1], when placed 100m from the VLBI antenna, the radar signal levels must be attenuated by a factor of 36 dB so as not to exceed 5° of VLBI sky loss coverage in the direction of the radar(assuming the radar never points within 10° of the VLBI antenna). In the case of DORIS, the required attenuation is 25 dB for the same VLBI sky loss specification. Metallic barriers are currently being considered as a means to provide the necessary attenuation and these results are forthcoming.

Computation of the required signal attenuation is critically dependent upon the sidelobe envelope of the VLBI antenna, which is currently assumed to conform to the ITU-R SA.509 specification. If the true sidelobe envelope of the 12m antenna significantly exceeds this specification, then a redesign of the barrier may be necessary. Similarly, the required attenuation is dependent on the actual power levels that the LNA may tolerate before significant loss of signal-to-noise ratio in the VLBI observable. For this reason, it is also important to experimentally verify the LNA's broadband power handling capability.