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October 23, 1990

Dr. J.W. Layland
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Dear Jim,

Enclosed is the NRAO report on the feasibility of using the VLA to receive data from the Galileo spacecraft in 1995. We see no technical reasons why this cannot be done. Installation of an optical fiber data transmission system plus modifications to the correlator delay modules and the correlator controller should provide a continuous signal with less than 20 usec interruption from any one antenna.

I would like to emphasize that the costs and time scales for this project are still approximate. We've not had the time to get competitive pricing or explore alternate sources for equipment; in many cases accurate costing is impossible until we get a more detailed design. Also, unforseen costs may appear as we get further into the project. Still, the overall figure roughly reflects the costs of modifying the VLA to support the Io encounter.

One result of the study is the realization that we must get started in early 1991 on detail design and prototyping if we are to be ready for Galileo in 1995. The hardware and software development for the correlator controller will take about two years. The details of the fiber optic system need a lot more thought. Any delays could shove the prototype system evaluation well into 1993. If we lose six months or more now, we may regret it in 1995.

I feel that with this report we've finished the limited feasibility study that we were asked to do for the VLA. I will submit to you shortly a few more budget details as indicated in the report. Please let me know if there are any items that need clarification. We've not addressed the questions of signal/noise ratio in the presence of Jupiter, large antenna versus array, or the optimal VLA configuration. I believe these items are being considered by your planning group. Please keep me informed of developments on these questions.

Sincerely,

R. Sramek

R. A. Sramek
Dep. Asst. Director
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enclosures

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National Radio Astronomy Observatory
New Mexico
October 31, 1990

To: J.W. Layland

From: R.A. Sramek R.S.

Subject: VLA Support of the Galileo Encounter with Jupiter, December, 1995

ABSTRACT

An NRAO study group reports that the VLA can be modified to deliver continuous analog-sum data in support of the Galileo encounter with Jupiter. Transients in the data from any individual antenna can be limited to 20 usec or less. This requires installing an alternate fiber optic data path from the VLA antennas to the control building plus some modifications at the VLA correlator. In order to have this system ready by May 1995, it is necessary that start-up funding be available in early 1991 for detailed design and prototyping.

I. INTRODUCTION

On December 7, 1995 the spacecraft Galileo will fly by the Jovian satellite Io. In response to a request from Larry Dumas, JPL (letter to Paul Vanden Bout, July 20, 1990), members of the NRAO staff have been investigating the electronic and software modifications needed to allow the VLA to receive the Galileo signal at the time of encounter. This report presents the result of that study.

The most significant problem identified involves the VLA data gap. During the encounter with Io the Galileo data rate will be 134 kb/s. The signal on the VLA data transmission waveguide suffers a 1.6 msec gap every 52 msec due to time multiplexing of the communications to and from the antennas. This gap introduces an unacceptably large error in the received Galileo data. The adopted goal was to reduce the gap to 25 to 50 usec.

Various ways of modifying the communication system to narrow the gap were discussed. A plan that was simple and which did not represent a major departure from the existing and rather reliable waveguide system was needed. In the end it was felt that we should simply tap the data stream before the transmit/receive switch and send the uninterrupted data from the antennas on a separate fiber optic data path. All of the existing timing, control, l.o. phase lock and path length measuring systems would remain unchanged and on the waveguide. This system could be installed without interrupting the on-going VLA operation and would be an important step in the upgrade of the VLA to wider bandwidth that we hope to accomplish in the next decade.

Even with a continuous data stream, there will be transients introduced in the received signal as the phase rotation and delay modules are periodically reset. These present significant but not unmanageable problems; solutions are discussed in Section III.

This study did not investigate the proper array configuration nor the signal/noise ratio of the phased array VLA in the presence of Jupiter. These questions are being addressed by JPL.

II. VLA GALILEO SUPPORT

The VLA support of the Voyager mission in 1989 serves as a good model for how we might handle the Galileo data. In fact much of the hardware and software integrated into the VLA for Voyager will be directly applicable to Galileo. Galileo will be simpler in that no arraying with Goldstone is planned at this time.

As with Voyager, the phased array VLA will track Galileo and the analog sum output will be sent to a recording system supplied by JPL. The i.f. signal will also go to the correlator since the VLA will need to phase up on the Galileo signal. The correlator will continue to operate with its 1.6 msec data-invalid gap as it does in normal operation. The existing 8.4 GHz receiver systems will be adequate for the Galileo encounter.

The backup on-line control computer and the power generating system provided for Voyager support will still be in place in December 1995.

III. VLA MODIFICATIONS

Changes needed at the VLA include adding the fiber optic data transmission system, reducing transients in the data, and increasing reliability. These are discussed below.

A. Install fiber optic system

Proposed changes to the VLA data transmission system are shown in Figure 1. The continuous i.f. data plus the l.o. signals to demodulate it are sent from each antenna along a fiber optic cable. Switches S1, S2, S3 allow switching between the waveguide i.f. and the fiber optic system. Modules L9 and L14 are reproductions of existing VLA modules. The analog fiber optic transmitters and receivers would be commercial products.

Since this system will be installed, tested, and used as part of regular VLA operations, we would run the fiber optic cable to all antenna stations.

B. Reduce transient events

In the normal VLA operation, many things happen during the 1.6 msec waveguide gap. With the correlator in a data-invalid state, system parameters are reset and the correlator performs a self test. Most of this can go on as normal, but we must look at module resets that occur in the signal path before the analog sum.

Four items concern us, 1) the delay compensation cards that feed the correlator and the analog sum are reset every 52 msec waveguide cycle, 2) the controller for the correlator transfers new values to the delay cards in a slow and inefficient manner, 3) the L7 local oscillator modules in the antennas that provide fringe rotation are updated every 1.25 sec, and 4) the 180 degree Walsh function phase switching introduced in the L7 and removed at the samplers can occur every 52 msec waveguide cycle. Whenever these systems are updated for an antenna, the correlated signal from that antenna will be reduced for some short period of time. Each of these systems are discussed below.

1. Delay module

The VLA digital delays are reset every waveguide cycle. During the 1.6 msec data-invalid period new delay values are fed to the delay cards and for 82 usec the digital bit stream at the output of the delay card can have a completely erroneous delay. At present commands are sent to all 27 antennas over a 200 to 300 usec period.

Another problem with the existing delay cards is that given the reduced speed of light in fiber optic cable compared to the waveguide, the range of programmable delay is inadequate to compensate for the geometrical delay over the VLA. This would result in regions of the sky that could not be observed using the fiber optic system.

The proposed solution is to redesign the VLA delay cards using FIFO's. With this design the resulting period of bad data should be reduced to a micro-second as new delay values are switched in. On the redesigned cards new values of delay would be stored on the cards and latched-in for all antennas in a few micro-seconds. These new delay cards should be plug-in compatible with the existing cards resulting in a minimum down time as this retrofit is done.

2. Correlator Controller

One consequence of upgrading the delay system is that changes must be made to the correlator system controller to support the new cards. This is complicated by the fact that there will be a period of time when both the new and old delay cards will need to be supported. Also, for Galileo we will have to remove the delay lines from the correlator self-test system. This too will require changes to the controller.

In addition, even when we have delay cards with very small reset times, the present correlator controller sends to these delay cards 20-bit commands whose various bytes are spread over 200 to 300 usec. As a result, the delays are scrambled and the array is incoherent for that period of time.

All of these problems mandate significant changes to the controller. However, the existing controller is a very inflexible and difficult to program device; any modification to it would be complicated, time consuming, and somewhat risky. A better path would be to replace the controller with a microprocessor based device with built in array processor and high speed link to the Modcomp BOSS. This would provide the fast control for the new delay cards plus great flexibility in developing new modes of processing the correlator output.

At the time of the Voyager mission the correlator controller was identified as a possible single point of failure that could completely shut down the VLA. Building a new controller plus a spare was considered then, but there was insufficient time for construction and testing. It is advisable to build this new controller for Galileo.

3. Local Oscillator modifications

In order to produce fringes with zero frequency, the phase locked local oscillator at each antenna is given a phase offset and phase rate in the L7 module. These values are updated for all antennas during the same data-invalid period once every 24 waveguide cycles (1.25 sec). At 8.4 GHZ observing frequency, the phase update will cause the l.o. to change by about 5 degrees in the worst case; it will make this transition in 10 to 20 usec. However, during this period the l.o. phase may wander significantly and the data from that antenna will lose coherence with the rest of the array. (We will make a laboratory simulation to determine how far the phase will wander.)

The command to update the L7 leaves the control building simultaneously for all antennas. However it arrives at the antennas spread out by up to 70 usec owing to the light travel time along the array arms. The update then produces 10 to 20 usec of incoherent signal which is further spread out by the delay compensation system. As seen at the analog sum input, these short periods of incoherence for each of the 27 antennas may be spread over about 150 usec. Several antennas will have reduced coherence at the same time.

If the loss of coherence per antenna is significant, and if Galileo requires that no more than two antennas be out of coherence at any time, we will investigate having the antennas perform their L7 update during different waveguide cycles. This is the only modification that we see at this time for the l.o. system.

4. Phase switching

A 180 degree phase shift is periodically introduced in the L7 of each antenna and then digitally removed in the sampler module. This cancels d.c. offsets in the sampler and cancels the effects of common signals (cross talk) from different antennas which will show up as d.c. offsets in the correlator visibilities. If not removed, these visibility offsets would lead to closure errors in the antenna complex gain solutions while observing in continuum mode.

The phase switching occurs during the 1.6 msec data-invalid period. In principle the L7 and sampler switching occur simultaneously. In practice owing to the 70 usec travel time and timing errors, there will be a period of time (several tens of micro-seconds) during which an antenna is phase reversed with respect to the rest of the array. Rather than try to get the timing straightened out it seems feasible to simply turn off the phase switching for the Galileo encounter.

The correlator would operate in spectral line mode where the zero-frequency correlation products would all be in the first spectral channel and can be excised from the antenna gain solution. This has been tested by phasing up the VLA in spectral line mode; there was no significant difference between the phase solutions or the convergence with the phase switching on and off.

With phase switching turned off the cross products and the self products of the sampler offsets will appear in the analog sum output. This should not harm the Galileo signal unless the offsets are sufficiently time variable so as to introduce an additional noise source in the analog sum output.

This problem should be investigated further. Other than disabling phase switching during the Io encounter, we are not planning at present any modifications to the phase switching system.

C. Reliability

Much effort went into increasing the reliability of the VLA for the Voyager encounter. Special attention was given to single points of failure which could bring down the entire array. Action taken included recabling the power distribution system, the purchase of a backup on-line control computer, and building a power generating station that allowed us to disconnect from the commercial lines.

All of this will remain in place for Galileo. Barring new developments, the only upgrades anticipated to increase reliability are recabling the power distribution system to the end of B-configuration (or A-configuration if needed by Galileo) and overhauling the engine generators at some time prior to the 1995 encounter.

IV. BUDGET and TIME-LINE

A budget for the project is given in Table I and a time-line is shown in Figure 2. Both the cost and the time scales are very approximate. We will continue to refine the plan and will provide a five-year distribution of funding plus more detail on the activities in 1991 and 1992. These items will be issued as an addendum to this report within four weeks.

The budget is shown in 1990 dollars. The cost of the f.o. cable is based on $1.25/ft for eight fiber cable. The cost of the f.o. transmitter/receiver pairs is taken as $18k. Quantity purchases and improvements in technology may bring these costs down ten to thirty percent. Since these are such major items in the budget, they will need to be carefully studied before selection.

The senior technical personnel are called out in the budget as Full-Time-Equivalent (FTE) manpower. For unskilled labor and trades people only the cost estimates for labor are shown.

As part of our planning we will investigate establishing some milestone tests that will utilize all of the newly developed systems on a subset of the VLA antennas to receive the Galileo signal.

V. PROJECT START-UP

The schedule for the project is a concern. Working back from having the full system ready in early May 1995, we should already in late 1990 be specifying the system modifications in greater detail.

Starting in early 1991 we should begin designing and building prototype equipment. By early 1992 we should be evaluating a three antenna test array to demonstrate the feasibility of our approach.

Of particular concern is the correlator controller which will take at least two years for construction and software development. This means that the full evaluation of the prototype delay cards on the VLA correlator will be delayed into mid-1993. We would have preferred to be well into production by that time.

If we are to undertake supporting the Galileo mission it is important that we start prototyping equipment soon. Funding of $500k to $700k should be available to NRAO for prototyping in FY 1991 with a similar amount in FY 1992. Later in FY 1992 the bulk of the funds should be available for production in quantity.

Since most of our senior engineering staff are involved in VLBA construction and commissioning, in order to get a rapid start on the Galileo support project in early 1991, we may need fiber-optic engineering help from JPL as well as funding for the project.

VI. CONCLUSION

At this time we see no technical reason why the VLA can not produce continuous data from the analog sum output with switching transients lasting no more that 20 usec from any one antenna. The time distribution and magnitude of these transients needs more study. If needed, it would not be difficult to have all of the delay transients occur simultaneously and have the L7 transients occur at two antennas per waveguide cycle.

From a management point of view, the project is only feasible if JPL provides initial funding in early 1991 to begin detail design and prototyping.

A1. APPENDIX

NRAO Study Group Members:

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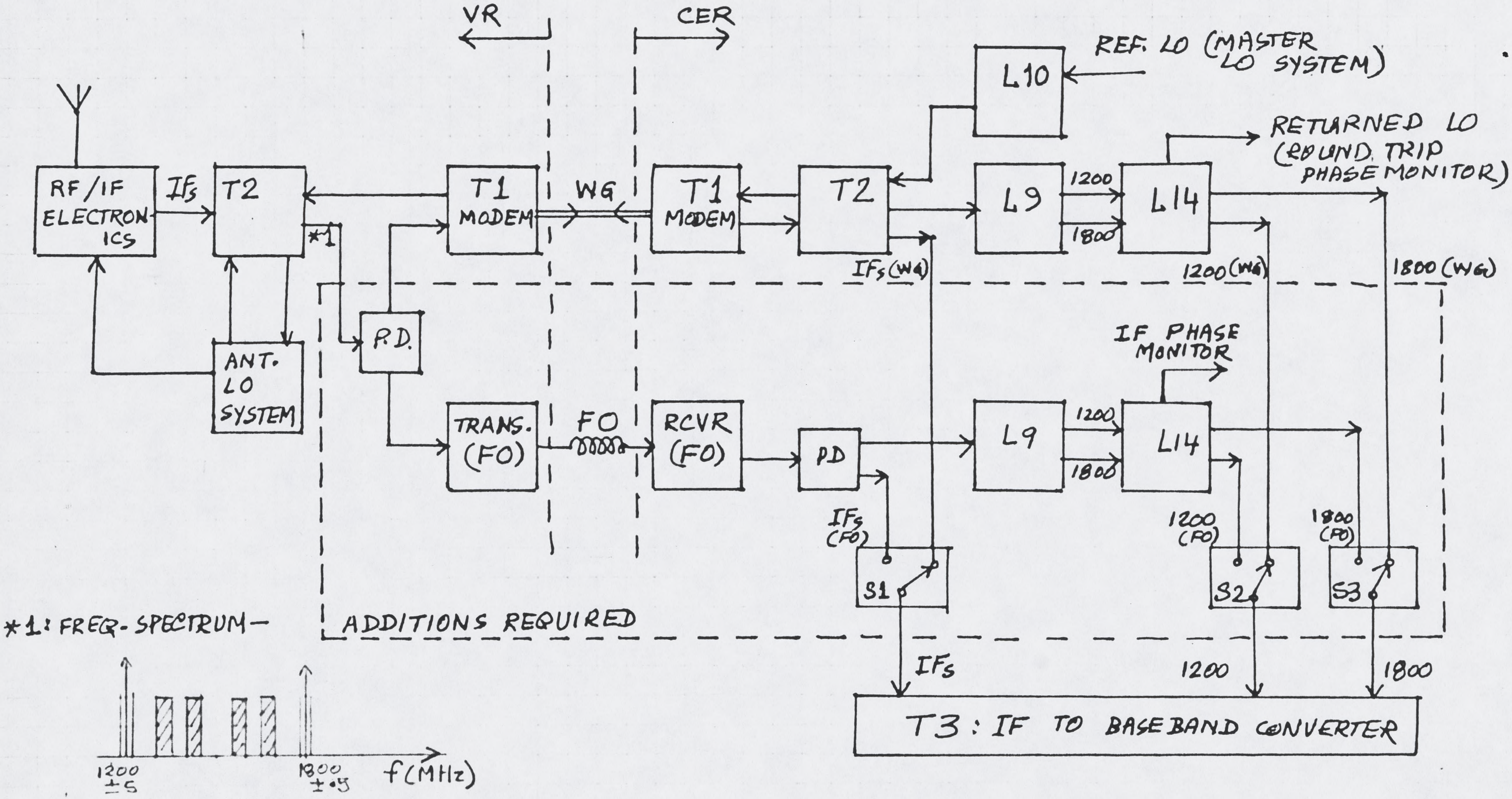
BUDGET ESTIMATE FOR JPL/GALILEO PROPOSAL 23-Oct

	ITEM	LABOR FTE	LABOR $k	M & S $k
1	DUAL FIBER OPTIC - WAVEGUIDE SYSTEM			
	FO cables and connectors			1000
	FO cable laying		155	220
	engineer	0.3	14	
	technician (splicing/testing)	1	25	
	FO xmtr/rcvr system			1050
	l.o. electronics			300
	engineer	2	90	
	technician	4	100	
	documentation	0.5	18	
2	CORRELATOR & CORR. CONTROLLER			
	controller			80
	Modcomp IPS-2			40
	engineer	1.5	68	
	technician	1	25	
	documentation	0.5	18	
3	DELAY CARD UPGRADE			
	delay cards with FIFO			250
	engineer	1	45	
	technician	2	50	
	documentation	0.4	14	
4	SOFTWARE DEVELOPEMENT			
	correlator controller	2.5	113	
	Modcomp	1	45	
	documentation	0.5	18	
5	POWER SYSTEM			
	recable to end of B config		20	155
	generator overhaul (2)			100
6	PROJECT MANAGEMENT			
	proj/sys engineer	5	225	
	test equipment			200
		23.2	1040	3395
	Overhead (123.4%)		1283	
	Benefits (28%)		291	
	Travel		77	
			2692	3395
	Contingency 15%			913
	TOTAL			7000



BLOCK DIAGRAM 1 : LO-IF TRANSMISSION SCHEME USING WAVEGUIDE AND FIBER OPTIC SYSTEM.

S1, S2, S3 To select operation using only waveguide *or* waveguide for LO and optical fiber for continuous IFs.

L9, L14 – MODULES FOR GENERATING 1200 & 1800 MHz SIGNALS phase locked to 1200 & 1800 SIGNALS COMING FROM ANTENNA.

T2 = IF-LO COMBINER / SPLITTER MODULE

ESTIMATED TIME SCALE: