An Update on the Use of the VLA for Telemetry Reception

L. J. Deutsch
Communications Systems Research Section

This article modifies a previous analysis to incorporate the actual structure of the command signal system of the Very Large Array (VLA). In particular, in addition to the 1-ms command signal of the previous article, there is a “data invalid” signal that is generated. The command signals are transmitted to the antennas during the period in which the “data invalid” signal is on. This means that the gaps in the received data are really 1.6 ms long rather than 1 ms long. Simulation results with this taken into account show that the VLA will not support (7, 1/2) convolutionally encoded telemetry at acceptable error rates at any of the Voyager telemetry data rates. VLA will support Voyager encounters provided that either concatenated coding is implemented, VLA is arrayed with another receiving site (such as Goldstone), or VLA is reconfigured so that the gaps are rotated.

I. Introduction

The performance of the Very Large Array (VLA) as a receiver for Voyager 2 coded telemetry data was recently determined (Ref. 1). Since that time, however, more information concerning the operation of the VLA has come to light. This additional knowledge does affect the previous results. In fact, new simulations and modeling show that the VLA will not be capable of supporting convolutional coded Voyager data at any of the data rates that are being considered for Uranus or Neptune encounters.

The VLA is a phased array consisting of 27 independently pointable parabolic dishes in the New Mexico desert. Each dish measures 25 meters in diameter. The array is configured in three linear arrays of nine antennas each that radiate from a common centerpoint. The antennas may be moved along these lines by means of railroad-type tracks. Communication between the antennas is by means of a connecting network of waveguides. The total aperture of the VLA is about twice that of a DSN array consisting of a 64-m antenna and three 34-m antennas. The VLA was designed for use as a radio astronomy observatory. Some additional equipment will be needed in order for the VLA to receive the X-band Voyager telemetry transmissions.

The main problem with using the VLA as a telemetry receiver is that signals are not transmitted continuously from the antennas to the processing facility. Instead, the VLA operates in a duty cycle mode. Every so often, at regular intervals, communications from the antennas are suspended momentarily so that calibration signals may be sent to the antennas. In Ref. 1 it was stated that the VLA collects data for 51 ms, followed by a 1-ms calibration period. This turns out to be only partially true (Ref. 2). There is indeed a 1-ms calibration signal. However, data is only collected for 50.4 ms of the 52-ms cycle. The relevant signals are illustrated in Fig. 1. The 1-ms calibration signal is transmitted during the time that the “data invalid” signal is on. This means that for the purposes of this study, the VLA must be treated as a system that collects data for 50.4 ms followed by a 1.6-ms gap.
If uncoded telemetry data were received by the VLA then, for data rates over a few thousand bits per second, the best
possible error rate would be \( (1/2)(16/52) = 1.54 \times 10^{-2} \).
Coding must be used in order to achieve bit error rates below the
5 \times 10^{-3} level required for good image quality. In Ref. 1 it
was stated that VLA could support Voyager 2 convolutionally
encoded transmissions at a data rate of 10.8 kbps at both
Uranus and Neptune encounters. In light of the new infor-
mation mentioned above, this is no longer the case. In order to
achieve good quality imaging data from either encounter at the
VLA, additional coding must be used or the VLA must be
reconfigured to at least partially resolve the gap problem.

II. Best Possible Performance of VLA with
Convolutional Coding Only

In this section, the performance of the VLA for the recep-
tion of convolutionally encoded data is derived in the case of
infinite bit SNR. This represents the best possible performance
of the system. The formula that was derived in Ref. 1 is still
valid:

\[
P_b = 0.5 \frac{(R_b T_2 - k + 1)}{(R_b T_1 + T_2)}
\]

As before, \( k \) is the constraint length of the convolutional
code, \( R_b \) is the data rate in bits per second, \( T_1 \) is the time in
seconds spent in that portion of the cycle representing a per-
fected channel, and \( T_2 \) is the time in seconds spent in each gap.
It is assumed that \( R_b \) is large enough so that the gaps are at
least \( k \) bits long. In the case of interest in this report, \( k = 7, 
T_1 = 50.4 \text{ ms}, \) and \( T_2 = 1.6 \text{ ms}. \) A graph of \( P_b \) as a function of
\( R_b \) is shown in Fig. 2. This represents the best possible per-
formance of the VLA with \( (7, 1/2) \) convolutional coding. It is
evident from the figure that in this scenario, the VLA will not
support any of the planned Voyager data rates at either
encounter.

III. Software Simulations of VLA
Performance

The performance of the VLA under various scenarios was
determined by using the simulation software that was de-
scribed in Ref. 1. Five scenarios were simulated. For each
scenario (except the second) two data rates were consid-
ered: 10.8 and 19.2 kbps. These data rates are representa-
tive of those that can be expected at Voyager's future plan-
etary encounters. In addition, the performance of VLA was
determined both for \( (7, 1/2) \) convolutionally encoded data and
for \( (7, 1/2) \) coded data concatenated with a \( (255, 223) \)
Reed-Solomon code. This latter coding scheme, which will
be referred to as \textit{concatenated coding}, is an option for Voy-
ger. A detailed description of concatenated codes may be
found in Ref. 3. The scenarios that were considered are as
follows:

1. **Ideal performance.** In this scenario, it was assumed that
no gaps were present in the data. This represents a best
possible case and it can be used to measure the magni-
dude of losses that occur in the other scenarios.

2. **Normal VLA.** This scenario represents the VLA as de-
scribed in the introduction. The gaps are assumed to be
periodic in time in which the channel \( E_b/N_0 \) is arbi-
trarily small. Since it is already known from the
remarks in Section II that this scenario will not suffice
for Voyager encounters, only the 10.8-kbps data rate
was simulated. The results give an indication of just
how far off the mark the performance really is.

3. **VLA arrayed with an equal aperture.** The gaps in this
scenario are 3.0 dB lower in \( E_b/N_0 \) than the rest of
the data. This scenario can be interpreted as arraying half
of the VLA with the Goldstone DSN complex. The
combining is assumed to be perfect combined carrier
referencing (CCR). Two different methods of achieving
nearly ideal CCR performance are described in
Refs. 4 and 5.

4. **Equally spaced rotating gaps.** This is the first of two
scenarios that involve a reconfiguring of the VLA. In
this scenario, each of the three arms of the VLA
receives its 1.6-ms gaps at a different time. These times
are equally spaced so that the entire array has a duty
cycle of 52/3 ms with 1.6-ms periods of 1.7-dB attenu-
ation in the received data.

5. **Clumped rotating gaps.** In this scenario, as in 4, each
arm receives its 1.6 ms of control signals at a different
time. In this case, however, these individual arm gaps
are consecutive in time. This means that the VLA
would still have a duty cycle of 52 ms but there would
be a 3 \times 1.6 = 4.8 ms part of each cycle that is atten-
uated by 1.7 dB. It turns out that although one could
expect better performance from scenario 4, this
scenario is easier to implement in the present VLA
hardware.

For the purposes of displaying the results of the simula-
tions, the expression \( E_b/N_0 \) represents the bit SNR during the
good part of the VLA cycle at all times in the figures.

The results of the simulations for the convolutional-only
case are shown in Figs. 3-7. The performance of the VLA in
scenarios 2, 3, and 4 is slightly worse than that reported in
Ref. 1 due to the longer gap lengths. Also, one can clearly see
the slight advantage that scenario 4 has over scenario 5. This is
because the Viterbi decoder can handle several short gaps
better than a single long one.
The performance of the VLA with concatenated coding was calculated from these simulations using the formulas described in Ref. 1. These results are shown in Figs. 8-12. In the case of concatenated coding, a bit error rate of $10^{-5}$ is considered necessary for good image quality.

IV. VLA Throughput at Voyager Encounters

The most reasonable measure of performance for a telemetry receiving system such as the VLA is the amount of data throughput that it is capable of handling. The particular measure of throughput used in this study is the number of “good bits per day.” During each day of an encounter, Voyager will be “visible” from the VLA for some number of hours. Depending on the data rate and coding that are implemented, only a fraction of this viewing time may support reception at the required bit error rate or better. This is due to the fact that received power is a function of the elevation angle of the antennas.

The raw data in this section comes from design control tables for Voyager 2 Uranus encounter. The curve shown in Fig. 13 represents the total power-to-noise-spectral-density ratio ($P_T/N_0$) that is expected to be incident at the Goldstone complex on day 34 of 1986 (Uranus encounter). This curve includes a 90% weather confidence level and the effects of antenna elevation angle. Since the VLA is at approximately the same latitude as Goldstone, the values of $P_T/N_0$ for the VLA at Uranus encounter were derived from these by simply scaling them up by the ratio of the apertures involved. For Neptune encounter, 3.5 dB was subtracted to account for the additional space loss. It was assumed that the maximum viewing time is 8.3 hours.

The throughputs for the various scenarios and data rates were calculated according to the formulas that were derived in Ref. 1 and the data from the simulations of Section III. The results are shown in Fig. 14. A comparison with the corresponding figures in Ref. 1 shows the extra loss from the 0.6-ms additional gap length.

V. Conclusions

The main point of this study is that the VLA cannot be used as a telemetry receiver for Voyager 2 Uranus and Neptune encounters in its present configuration with only convolutional coding. There are three workable solutions to this problem. The first and easiest is to use concatenated coding. Voyager 2 does have this capability on board and there is already Reed-Solomon decoding hardware at JPL. The second is to array the VLA with another receiver that does not have this gapped behavior. The prime candidate for such an array would be the Goldstone complex due to its relatively close proximity. The third solution is to reconfigure the VLA so that the gaps occur at different times in the different apertures. Two such methods were described in Section III.

References


Fig. 1. Some important timing signals in the VLA. One cycle of operation is shown. The value $t$ can be one of 0 $\mu$s, 3.133 $\mu$s, or 6.267 $\mu$s depending on the particular cycle.

Fig. 2. Performance of VLA in the limit as SNR becomes infinite with Viterbi-decoded (7, 1/2) code (cycle $= 50.4$ ms, infinite SNR followed by 1.6 ms of noise only).

Fig. 3. Simulated performance of an ungapped receiving system, convolutional (Scenario 1), (7, 1/2) coding only.
Fig. 4. Simulated performance of VLA with 1.6-ms gaps with no signal (Scenario 2). Convolutional (7, 1/2) coding only

Fig. 5. Simulated performance of VLA with 1.6-ms gaps attenuated by 3 dB (Scenario 3). (7, 1/2) convolutional coding only
Fig. 6. Simulated performance of VLA with equally spaced rotated gaps (Scenario 4). (7, 1/2) convolutional coding only

Fig. 7. Simulated performance of VLA with clumped rotated gaps (Scenario 5). (7, 1/2) convolutional coding only
**Fig. 8.** Simulated performance of an ungapped receiving system (Scenario 1). Concatenated coding

**Fig. 9.** Simulated performance of VLA with 1.6-ms gaps with no signal (Scenario 2). Concatenated coding
Fig. 10. Simulated performance of VLA with 1.6-ms gaps attenuated by 3 dB (Scenario 3). Concatenated coding

Fig. 11. Simulated performance of VLA with equally spaced rotated gaps (Scenario 4). Concatenated coding
Fig. 12. Simulated performance of VLA with slumped rotated gaps (Scenario 5). Concatenated coding

Fig. 13. Baseline performance of Goldstone array at Voyager 2 Uranus Encounter; array = 84 m + 34 m + 34 m; day 34, 1986, 90% weather
Fig. 14. YLA throughput at Voyager 2 Uranus and Neptune encounters.