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) (1.6/52) = 1.54×10^{-2}. Coding must be used in order to achieve bit error rates below the 5×10^{-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 information 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 reception 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:

$$P_b = 0.5\,(R_b T_2 - k + 1)/[R_b(T_1 + T_2)]$$

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 perfect 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, $k = 7$, $T_1 = 50.4$ ms, and $T_2 = 1.6$ ms. A graph of P_b as a function of R_b is shown in Fig. 2. This represents the best possible performance 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 described in Ref. 1. Five scenarios were simulated. For each scenario (except the second) two data rates were considered: 10.8 and 19.2 kbps. These data rates are representative of those that can be expected at Voyager's future planetary 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 *concatenated coding*, is an option for Voyager. 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 magnitude of losses that occur in the other scenarios.

(2) *Normal VLA.* This scenario represents the VLA as described in the introduction. The gaps are assumed to be periods of time in which the channel E_b/N_0 is arbitrarily 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 attenuation 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 attenuated 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 simulations, 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 solution 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

1. Deutsch, L. J., "The Performance of VLA as a Telemetry Receiver for Voyager Planetary Encounters," *TDA Progress Report 42-71*, Jet Propulsion Laboratory, Pasadena, Calif., Nov. 15, 1982.
2. Escoffier, R. P., "Module L8 Digital Divider," VLA Technical Report No. 12, National Radio Astronomy Observatory, Socorro, N. M., June 1976.
3. Butman, S. A., Deutsch, L. J., and Miller, R. L., *On the Error Statistics of Viterbi Decoding and the Performance of Concatenated Codes*, Publication 81-9, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1, 1981.
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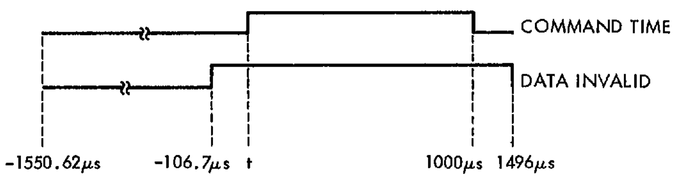

Fig. 1. Some important timing signals in the VLA. One cycle of operation is shown. The value t can be one of 0 μs, 3.133 μs, or 6.267 μs depending on the particular cycle

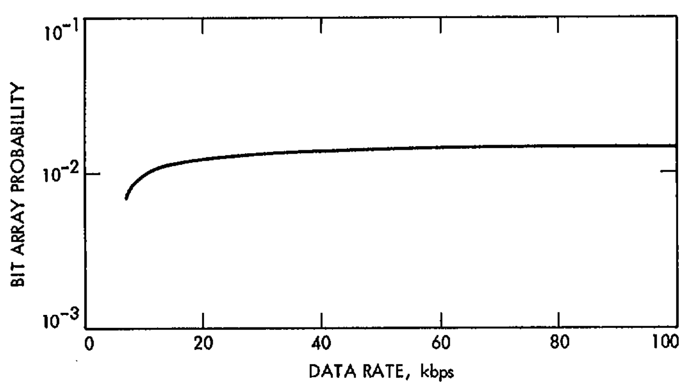

Fig. 2. Performance of VLA in the limit as SNR becomes infinite with Viterbi-decoded (7, 1/2) code (cycle = 50.4 ms infinite SNR followed by 1.6 ms of noise only)

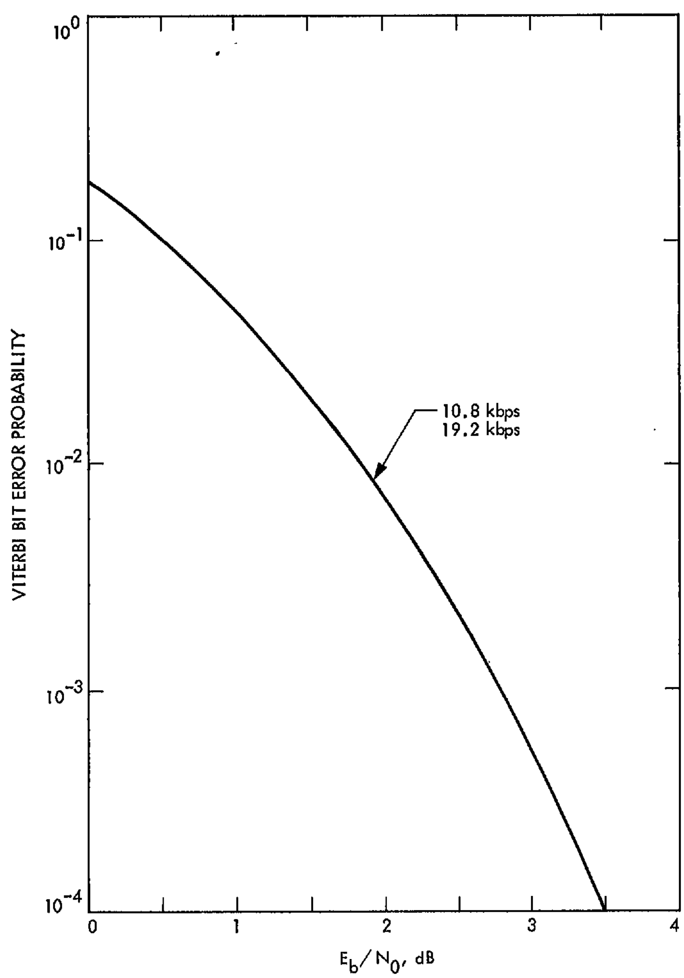

Fig. 3. Simulated performance of an ungapped receiving system, convolutional (Scenario 1). (7, 1/2) coding only

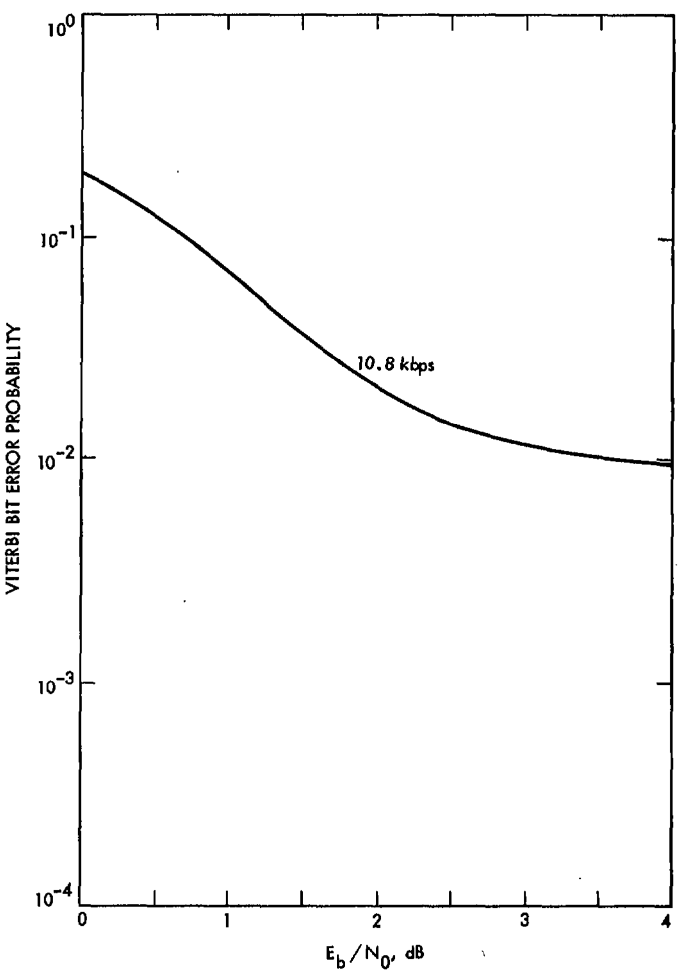

Fig. 4. Simulated performance of VLA with 1.6-ms gaps with no signal (Scenario 2). Convolutional (7, 1/2) coding only

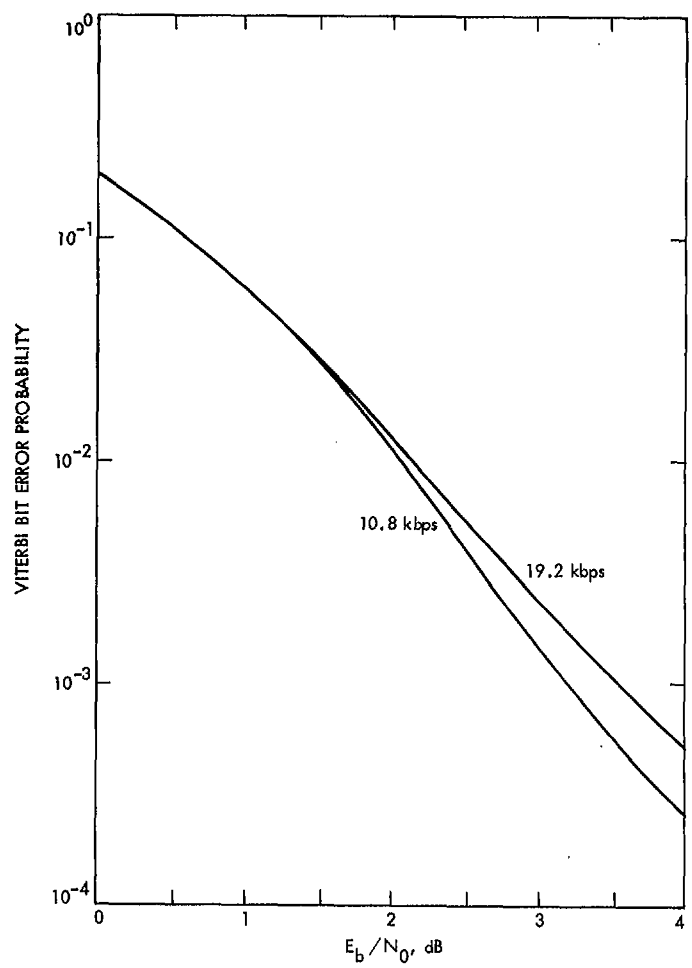

Fig. 5. Simulated performance of VLA with 1.6-ms gaps attenuated by 3 dB (Scenario 3). (7, 1/2) convolutional coding only

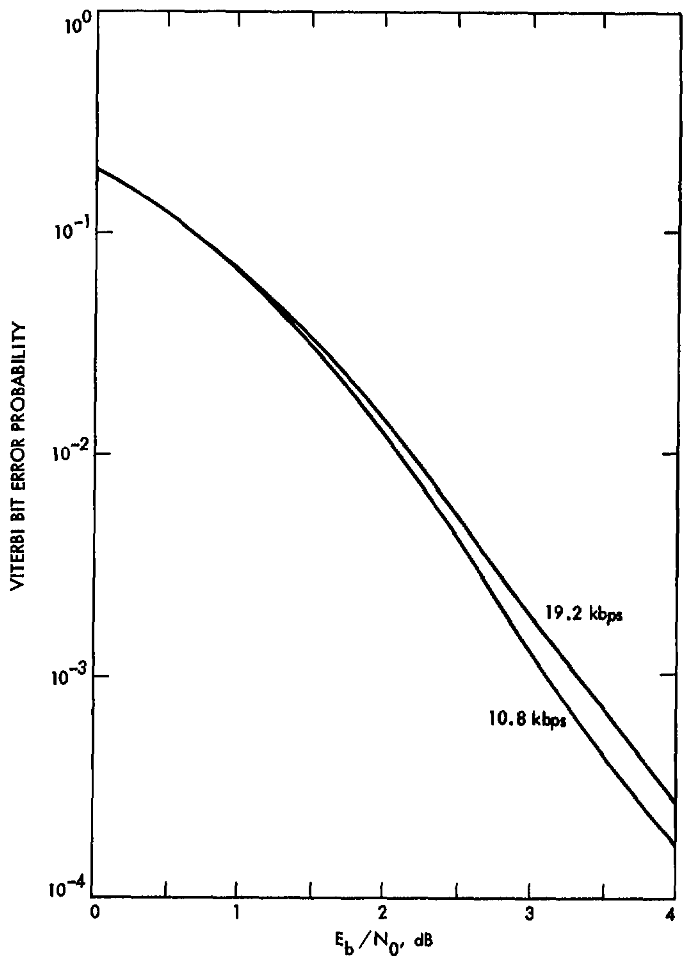

Fig. 6. Simulated performance of VLA with equally spaced rotated gaps (Scenario 4). (7, 1/2) convolutional coding only

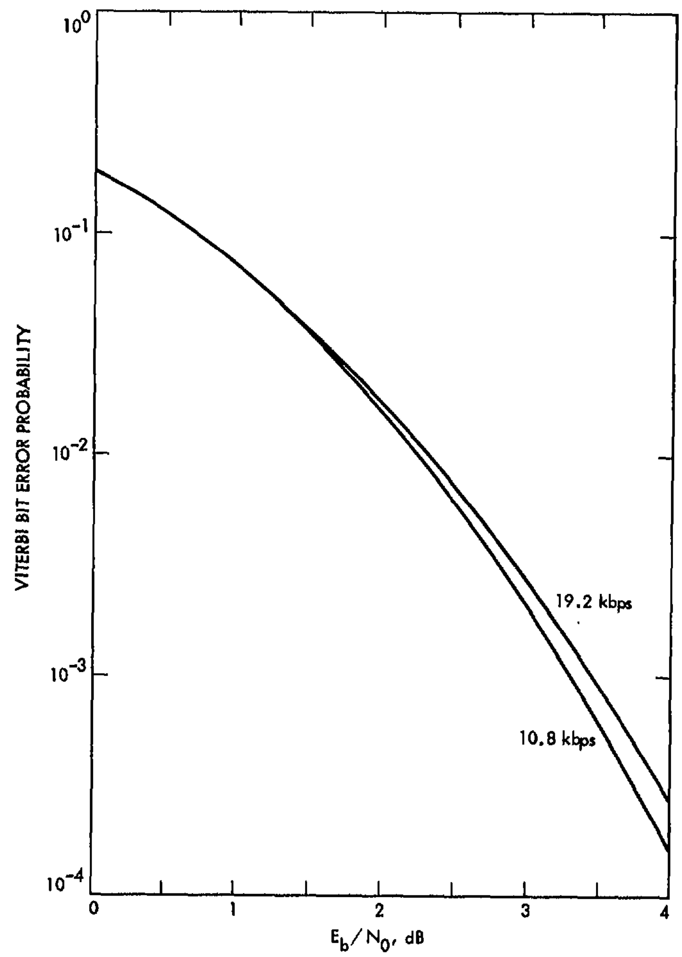

Fig. 7. Simulated performance of VLA with clumped rotated gaps (Scenario 5). (7, 1/2) convolutional coding only

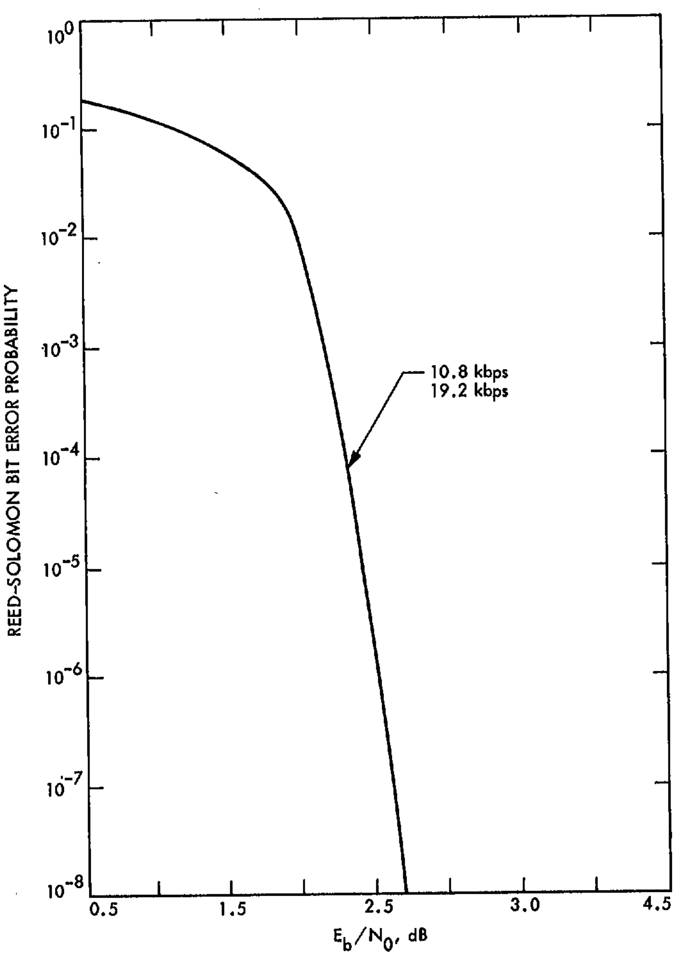

Fig. 8. Simulated performance of an ungapped receiving system (Scenario 1). Concatenated coding

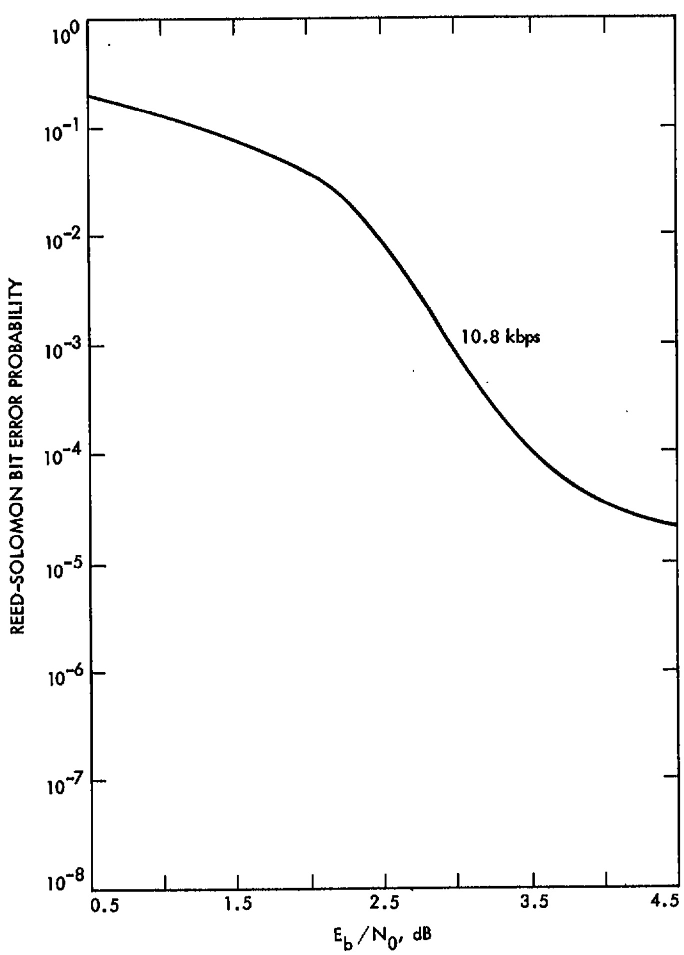

Fig. 9. Simulated performance of VLA with 1.6-ms gaps with no signal (Scenario 2). Concatenated coding

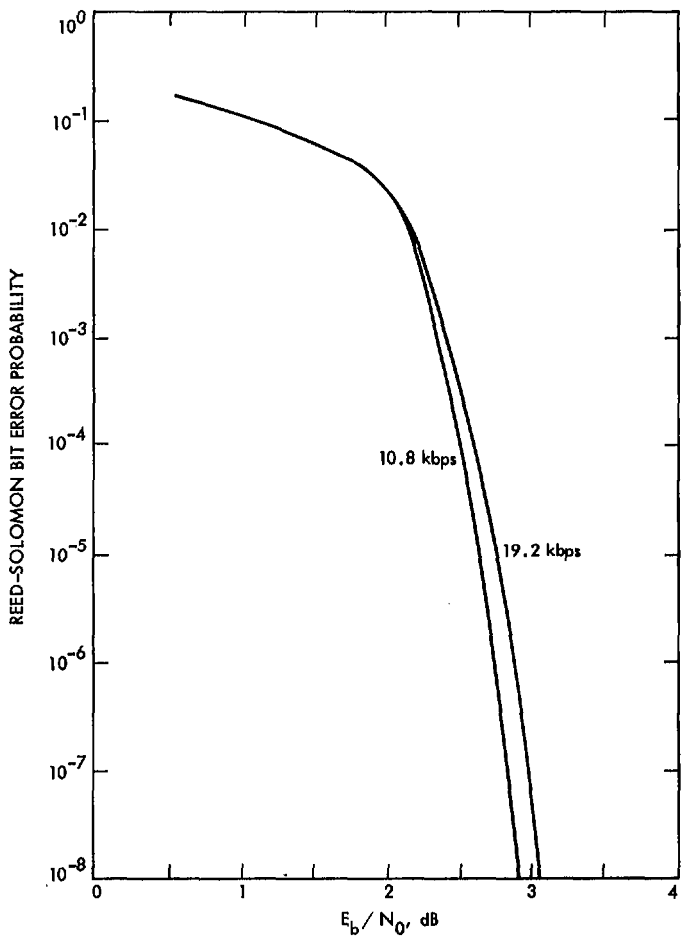

Fig. 10. Simulated performance of VLA with 1.6-ms gaps attenuated by 3 dB (Scenario 3). Concatenated coding

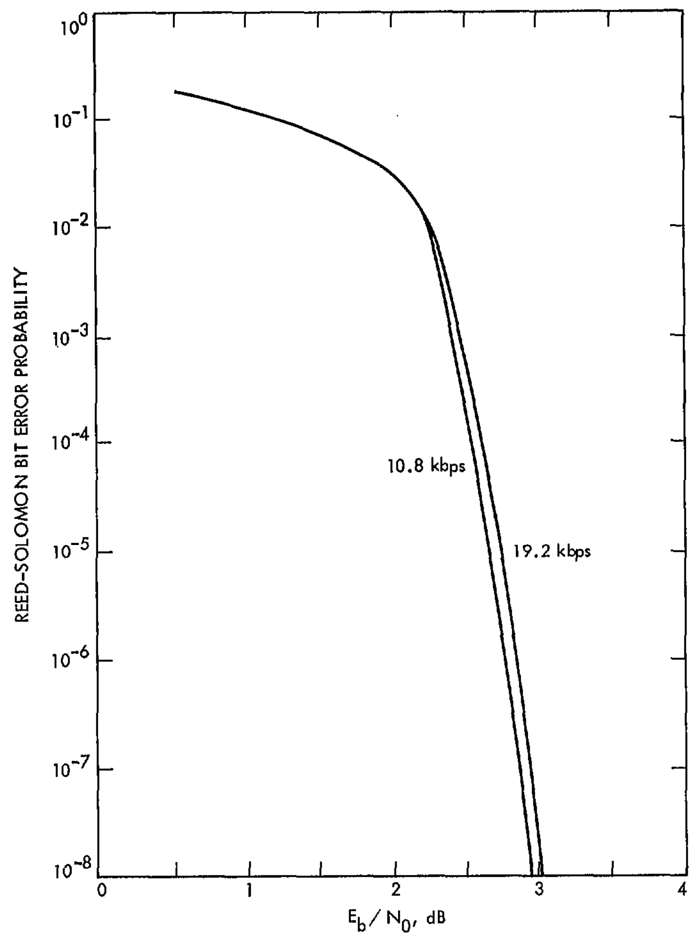

Fig. 11. Simulated performance of VLA with equally spaced rotated gaps (Scenario 4). Concatenated coding

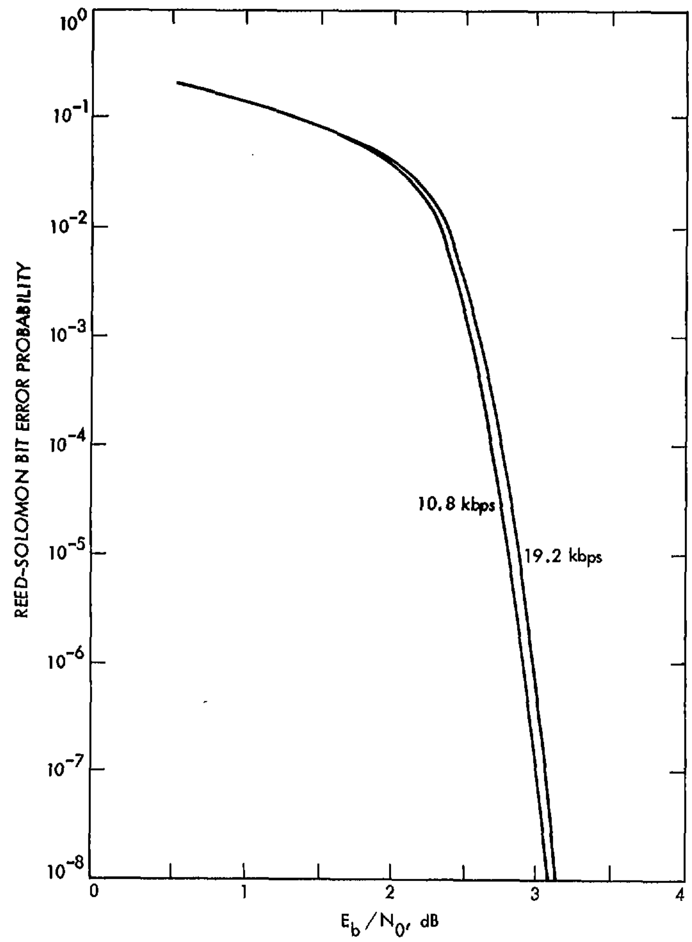

Fig. 12. Simulated performance of VLA with clumped rotated gaps (Scenario 5). Concatenated coding

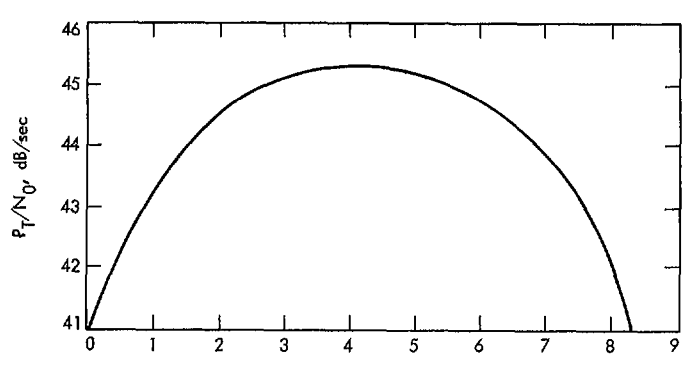

Fig. 13. Baseline performance of Goldstone array at Voyager 2 Uranus Encounter; array = 64 m + 34 m + 34 m; day 34, 1986, 90% weather

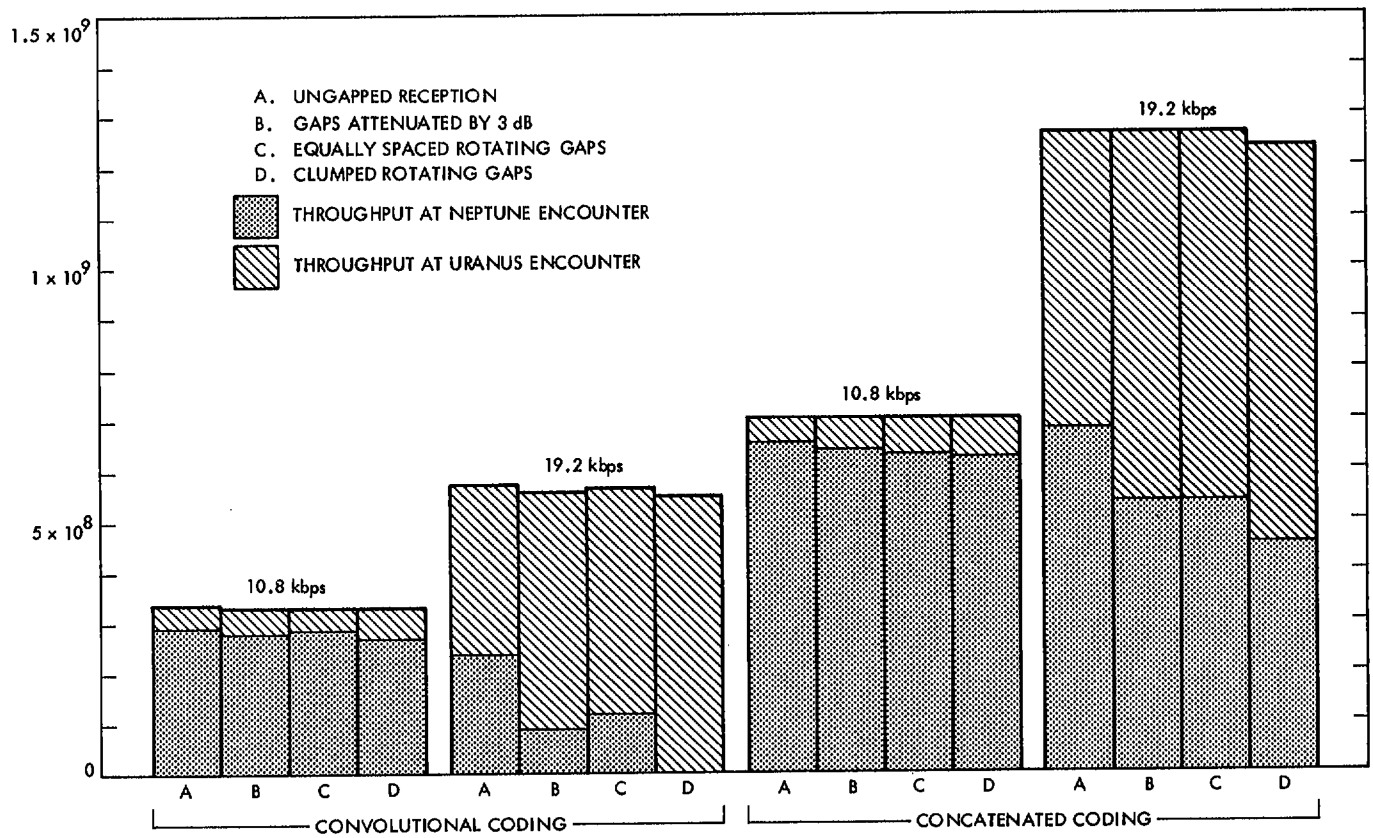

Fig. 14. VLA throughput at Voyager 2 Uranus and Neptune encounters