Improved Downlink Frequency Calculations for Voyager 2

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Voyager 2 and her sister ship Voyager 1 were launched, respectively, in August and September 1977. The object of these spacecraft was to conduct exploratory investigations of the Jupiter and Saturn planetary systems and the interplanetary medium between Earth and Saturn. In April 1978 the Voyager 2 redundant receiver and the loop capacitor in the prime spacecraft receiver failed, leaving the Voyager Project with a major problem: how to communicate with the spacecraft and get the data back.

I. Introduction

When Voyager 2 was launched on its modified Grand Tour of our Solar System, no one expected a spacecraft receiver failure in the phase locked loop (PLL) loop capacitor. A procedure to protect the loop capacitor on Voyager 1 has been developed and is working extremely well.

With Voyager 2's reduced receiver bandwidth (±100 Hz) special procedures were developed to communicate with the spacecraft. At about the same time a procedure with limitations was developed to calculate the closed-loop voltage controlled oscillator (VCO) frequencies for the receivers of the Deep Space Stations. The method had an uncertainty term of ±30 Hz due to uncertainties in the uplink.

Having been involved with both the Jupiter and Saturn Encounters, it seemed strange to personnel at DSS 43 that closed-loop receiver frequencies could not be calculated more accurately.

Prior to Voyager 2 Saturn Encounter a simple program was produced to calculate receiver ramps to maintain the receiver static phase error at zero in the closed-loop receivers. The ramps were maintained throughout the entire occultation of the planet and allowed the receivers to be locked up quickly at exit occultation of the planet.

After Saturn Encounter serious thought was given to the possibility of improving the downlink lockup calculation accuracy.

II. Normal Operation

The system now in operation has no uncertainty terms as had the previous method, the only uncertainty now being the accuracy of the doppler predicts.

First, consider a spacecraft with a good loop capacitor (see Fig. 1). At the start of the uplink, and subsequent two-way downlink, the uplink is tuned to gain lock on the spacecraft receiver. It is then tuned to what is known as the track synthesizer frequency (TSF), where the exciter remains for the duration of the pass. One round-trip light time (RTLT) later the

DSS receivers drop lock. The signal is reacquired in a coherent mode (two-way) using two-way doppler (D2).

The basic equation for a two-way S-band signal is

$$Frs = 240/221\,(48 \times TSF) \pm (D2 - 1 \times 10^6)$$

III. Voyager 2

Now look at Voyager 2. As a result of the receiver problem it is necessary to continuously tune the uplink to cancel out the doppler on the uplink, thus maintaining lock on the spacecraft receiver. With no apparent doppler in the uplink and the spacecraft appearing to see a constant frequency, we are left with a downlink that appears to have one-way characteristics. Take a snapshot at any point in time, at the uplink, follow it from the DSS to the spacecraft and back to Earth and it is not the case at all (see Fig. 2).

IV. Two-Way Acquisition

Consider a practical example. At 052506Z on day 246 the exciter is at a frequency of 44029327.082 Hz. This frequency is multiplied up to an S-band frequency to be radiated to the spacecraft. On the way it is frequency shifted by doppler. Upon reaching the spacecraft it is upconverted by the ratio 240/221 and retransmitted by the spacecraft as a coherent signal. After doppler shifting on the return, it reaches an Earth station as a two-way signal. Therefore, to calculate a correct DSS receiver frequency for two-way acquisition we need the following:

Exciter frequency one RTLT earlier = $XA0$

Two-way doppler from predicts = $D2$

Therefore the S-band equation is

$$Frs = 240/221\,(48 \times XA0) \pm (D2 - 1 \times 10^6)$$

This gives the exact frequency for calculating VCO values for the DSS receivers.

V. Three-Way Acquisition

Next came the consideration of three-way acquisitions, and could the exciter ramp predicts as generated at JPL be extended back in time beyond the upcoming stations' rise times to a point one RTLT earlier. Jim Hodder and Steve Wissler of the Network Analysis Team at JPL carried out tests and determined that this method was not valid.

The next alternative was to have the three-way station ramp and doppler predicts sent to the upcoming station. The doppler predicts were of no value. However, using the three-way doppler from the upcoming station doppler predicts and the three-way station ramps, and converting the ramps to the local station theoretical ramps, accurate receiver lock frequencies were calculated. To achieve this required the following (see Fig. 3):

Three-way station $TSF = TSF3$

Local stations $TSF = TSF1$

Three-way station ramp predicts back one RTLT = $XA3$

Three-way doppler from predicts = $D3$

The equation is

$$Frs = 240/221\,(48 \times [(TSF1 - TSF3) + XA3)] \pm (D3 - 1 \times 10^6)$$

A calculator program suitable for use on Hewlett-Packard HP-9810A calculators has been produced which converts the ramp predicts to their two- or three-way times. The calculator output spaces the results on 10-minute centers. Times in between are simply interpolated.

VI. Conclusion

The method descriped is not as important at a 64-meter station, with a Spectral Signal Indicator, as it is at a 34-meter station. Since there is no Spectral Signal Indicator, there is no signal visibility. As we move deeper into space and a Uranus Encounter with lower signal levels it will allow speedier lock of receivers and greater data gathering during near encounter phases.

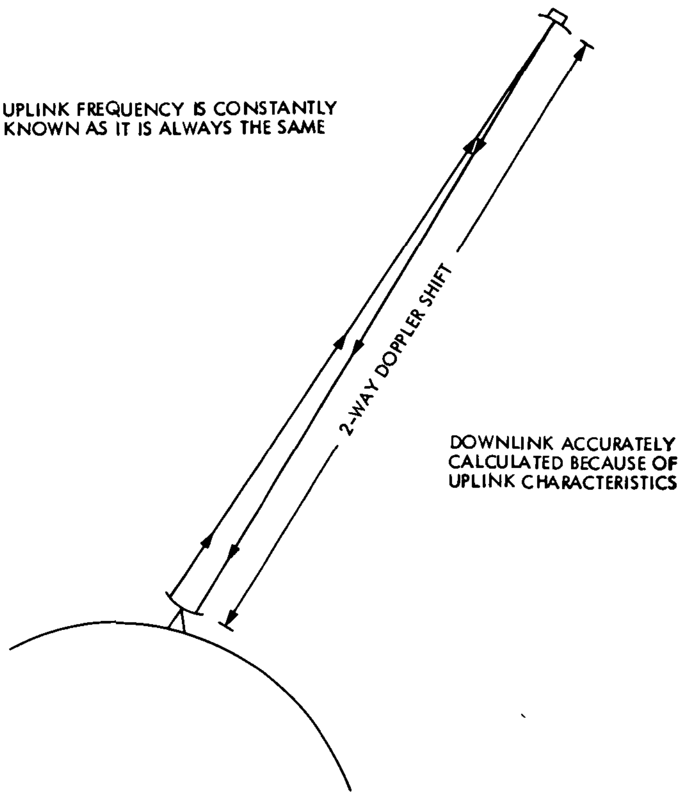

Fig. 1. Conventional spacecraft with good loop capacitor

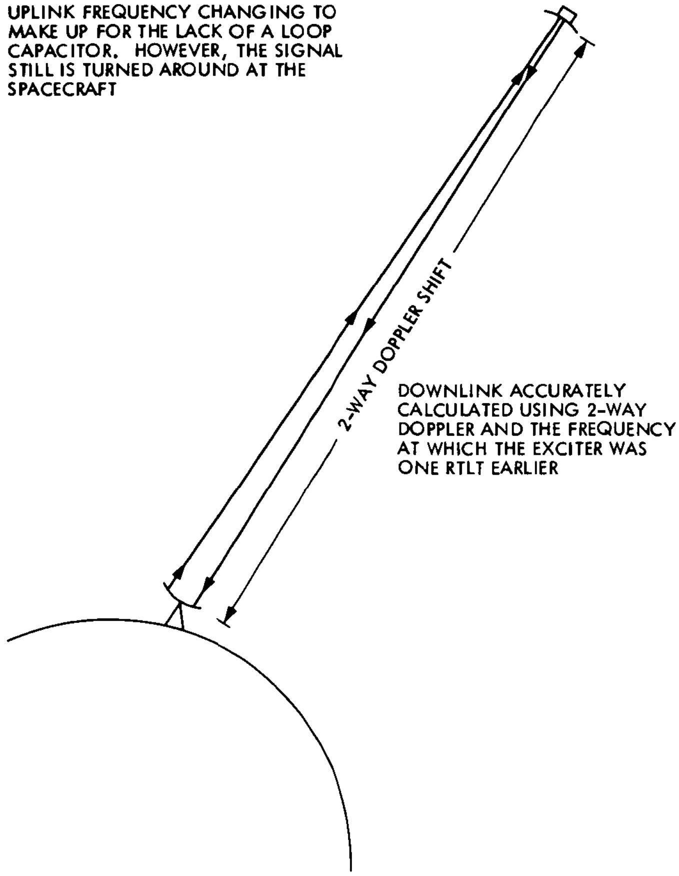

Fig. 2. Voyager 2 with no loop capacitor

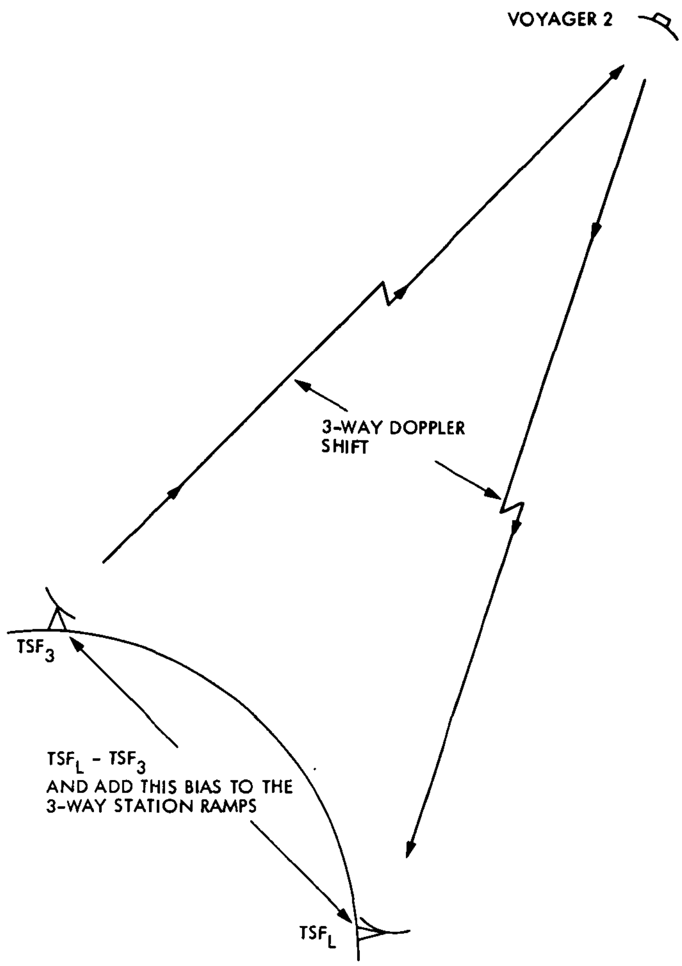

Fig. 3. Voyager 2 three-way acquisition