# Radio Frequency Interference by Earth Orbiting Satellites: Deep Space Interference Prediction Program

D. L. Cain
Tracking Systems and Applications Section

P. E. Beyer
Control Center Operations

*The sensitivity requirements of the DSN Flight Projects make them quite susceptible to radio frequency interference. Efforts to predict this interference from earth orbiting satellites have been ongoing for approximately five years. Software development in the areas of trajectory computations and telecommunications analysis are discussed in this article.*

## I. Background

Development of the Deep Space Interference Program (DSIP) software began in 1976. Simplified engineering models and trajectory formulae were used. As a result, operational predicts did not meet the accuracy requirements of the DSN. Previous articles (Refs. 1 and 2) have defined the response of a ground receiver that is tracking a spacecraft telemetry signal to interference by a close (in frequency) sine wave, or spectral spike signal. A software model was developed to incorporate the receiver response; interface between the standard JPL navigation trajectory program, DPTRAJ, was incorporated in the second level, DSIP2. Hence, DSIP2 has been constructed to compute the times and amount of such interference, given the necessary descriptions of the spacecraft and satellite signals and ephemerides.

## II. Problem Statement

Given the definition of what constitutes a state of interference (roughly speaking, this consists of a satellite output spike being near enough to a received spike – either the carrier signal or a telemetry subcarrier or harmonic), and also given the spacecraft and satellite orbital information compute common view periods, compute signal strengths and doppler shifts and then finally construct a table of predicted interference indicating spacecraft, satellite, station, bit rate mode and type of interference.

## III. Input Required

The interfering signal must be defined. This consists of a list of discrete (spike) frequencies and corresponding output powers. Currently CW is the only type of interfering signal we have a model for (a model for spreadspectrum or pulse data is expected to be available in the future). In addition, to compute doppler shifts, orbital data for each satellite must be provided.

The above data is derived from orbital elements or initial conditions typically furnished by outside agencies. Further-more, the orbital elements sometimes need conversion (for example, mean elements often provided must be converted to oscillating elements, i.e., initial conditions required for subsequent integration; this is done by a computational algorithm supplied by the external agency). The resulting orbital elements or cartesian position and velocity are propagated forward in time in the form of a stored-file ephemeris. In the past, this ephemeris was provided by DPTRAJ. As part of ongoing program development, an alternate program, SATRAP, was built to reduce costs (described below in Section IV).

Next the spacecraft signal is characterized. The transmitter power, modulation index, and subcarrier frequencies are specified, and corresponding bit rates and coding schemes defined. These are treated also as sets of spikes of average power. (When these spikes are approached by the satellite spikes, degradation may occur.) Since the spacecraft-received carrier frequency depends upon the transmitted uplink frequency in the two-way mode, provision is made via a best-lock algorithm to predict what the uplink frequency will be.

For the trajectory data needed for the computations of view periods and doppler shifts, a standard DPTRAJ "P" file is provided by the respective project.

## IV. Program Logic

```
Read in the names of the Deep Space Stations (DSSs) of the run.

Do for each satellite of the run:

    Read in the satellite data.

    Compute view periods.

Enddo

Do for each spacecraft of the run:

    Read in the input spacecraft data.

    Compute view periods for the spacecraft.

    Construct a spacecraft pass transmitter frequency table.

    Do for each DSS of the run:

        Do for each satellite of the run

            Do for each spacecraft pass.

                Compute the spacecraft/satellite view period overlap intervals.

                Do for each view period overlap interval:

                    Look for RFI.

                Enddo

                If any RFI occurred during this pass print the spacecraft pass interference tables.

                Endif
            Enddo
        Enddo
    Enddo
Enddo
Stop
```

## V. Program RFI Definitions

Four types of RFI are distinguished by the program.

### A. Receiver Drop Lock

The receiver is predicted to drop lock (via phase lock jump phenomenon, Ref. 2) whenever either (a) the interfering signal is inside the phase lock loop (PLL) band and stronger than the carrier, or (b) the interfering signal is outside the PLL bandwidth and if the ratio of the interfering power to the carrier power is greater than the ratio $\Delta f/B$ where $\Delta f$, $B$ are the frequency separation and loop-bandwidth, respectively.

A second type of drop-lock occurs when the maser loses enough gain to take the carrier below threshold.

### B. Receiver Interference

The receiver is adjudged as being interfered with whenever the interference is above threshold (−175 dBm) and within one kilohertz of the carrier.

### C. Telemetry Drop Lock

When conditions similar to Subsection A above occur to a subcarrier, it also suffers drop of lock. This of course is a function of the carrier strength, spacecraft output power, mod index, bit rate, and coding scheme.

### D. Signal-to-Noise Degradation

From theoretical and test data, P. Low (Ref. 1) developed a model for the decrease in signal-to-noise ratio in a telemetry stream due to an interfering spike near a carrier or subcarrier. That model [Eq. 6, p. 206 of Ref. 1] has been incorporated into DSIP2, except that the sin $(x)/x$ function has been replaced by a more conservative and easier to compute decreasing-magnitude $(1/n)$ square wave. When by that expression the signal-to-noise ratio drops by more than 0.5 dB, then degradation is predicted to occur.

## VI. New Developments

### A. DSIP2

The program DSIP2 has been converted to the Univac 1100/81. This involved changing the source code formerly SFTRAN (no longer available) to the newer language SF3. The program was modified to find and interpolate satellite coordinates from a SATRAP file, described next.

### B. SATRAP

This special purpose trajectory program was constructed to reduce the high costs of using DPTRAJ, the standard general purpose integrator in use at JPL.

A simple model of spacecraft motion is used (i.e., a nonspherical earth potential, a simplified drag model, radiation pressure, and the sun and moon are the perturbing forces). Only earth satellites can be accommodated. To facilitate the integration, the independent variable is eccentric anomaly rather than time. This change has the characteristic that uniform steps in this variable give smaller steps in time close to earth and longer steps in time farther from earth-desirable in that it is near the earth that the perturbing functions act strongest. Thus, SATRAP uses about twice the step size relative to a time integration (DPTRAJ).

The form of the output file is that of a random access, distributed index file. The concept of volumes, chapters, and verses (a coarse index followed by a finer index, and then one even finer) is used. Thus, with a few file accesses, first inquiring what "volume", then what "chapter," and finally what "verse" is involved (the final one giving the times desired), one can find records bracketing any given requested time. Another analogy would be a hypothetical congressional record, first bound in volumes by year, then a chapter for each month, and then verses for daily proceedings. Such considerations are important since one satellite can be involved in a hundred orbits in a week.

## VII. Future Developments

(1) There is a need to develop improved interference models for spread-spectrum signals.

(2) The same is true for pulsed signals.

(3) Still further development is needed in trajectory computation and/or program organization to reduce costs and increase ease of use.

(4) The advent of the new Support System computer and its planned teletype interface will result in a more rapid, more automated operation.

## VIII. Accuracy of Performance

(1) Of the nine instances of Voyager I telemetry drop-lock attributable to the Cosmos satellite (from January 1 to October 15, 1981), all were predicted by DSIP2.

(2) Of the fifteen instances of Pioneer 10 telemetry drop-lock or receiver drop-lock in 1980, eleven were predicted. The other four occurred shortly after launch, hence not enough was known of this particular Cosmos spectrum, since that data must be acquired by observation.

In summary, the whole effort appears successful and with the oncoming increase in the number of S- and X-band satellites and with the high-earth orbiters requiring DSN support (as well as becoming themselves potential interferers) the effort to predict and avoid RFI will continue.

## References


1. Low, P. W., "Radio Frequency Interference Effects of Continuous Wave Signals on Telemetry Data: Part II", *The Deep Space Network Progress Report 42-51*, Jet Propulsion Laboratory, Pasadena, California, March and April 1979. See also *ibid*, 42-40, May and June 1977 for first part.

2. Kliger, I. E., and Olenberger, C. F., "Phase-Lock Loop Jump Phenomenon in the Presence of Two Signals", *IEEE Trans. on Aerospace and Electronic Systems*, Vol. AES-12, No. 1, January 1976, pp. 55-63.