Preliminary Telemetry Operations Experience With the Real-Time Combiner: 1 November 1978 to 1 November 1979

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A prototype version of a two station, real-time signal combiner was installed at Goldstone DSS 14/(12) and used to support the Voyager Mission at Jupiter and the Pioneer 11 Mission at Saturn. This article reports on early combined station operating experience with a Real-Time Combiner (RTC) in the loop.

I. Introduction

On September 21, 1974, the two 26-m antennas at DSSs 12 and 13 were arrayed with the 64-m antenna at DSS 14 to improve the telemetry data received during the Mariner 73 Mercury encounter (Ref. 1). The experimenters claimed an improvement in SNR of 0.7 dB over the operation of DSS 14 alone. The arraying was accomplished with a signal combiner that took baseband signals and phase correlated them to produce a single additive signal. The combined output signal was then input to a DSS 14 receiver and demodulator "for further processing." The experiment was a laboratory research effort meant for one time use during the MVM 73 encounter. It also demonstrated the value of arraying the antennas at a DSS complex. A reproduced graph of BER vs time from the September 21 encounter is shown in Fig. 1.

The current effort began in FY78. The objective was to develop a permanent Real-Time Combiner (RTC) installation for the 64-m/34-m net. A prototype unit became available in November 1978 and was successfully used for the Voyager 1 and 2 Jupiter encounters and for the Pioneer 11 Saturn encounter. It is the operation with the prototype unit that is the subject of this report.

The basic system block diagram for RTC operation is illustrated in Fig. 2. Baseband signals from a 64-m and 34-m station are fed into the combiner, phase locked, and sent through a standard telemetry string for normal processing. The SNR gain from combining over a 64-m station alone is dependent on the actual SNR spread between the two stations. For a nominal spread of 5-dB between the 64-m and 34-m antenna the RTC theoretical gain is 1.2 dB. This compares with 0.8 dB available from adding two 26-m stations to the 64-m signal.

II. Test Program

A. CTA 21

The prototype RTC unit was set up in CTA 21 and initial testing was conducted in November/December 1978.

Two methods of simulating a 2-station configuration at CTA 21 for testing RTC performance in an operational system environment were considered. Method 1: Receiver input terminations were isolated with a common modulated RF test signal fed to both receivers. Levels were adjusted by means of S-band attenuators in each line. Method 2: Separate RF signals modulated by a common data-modulated subcarrier from the Simulation Conversion Assembly (SCA) were fed to each Receiver.

In both cases the baseband outputs of each receiver were fed into separate RTC channels. Results indicated both methods to be acceptable. Method 2 was preferred for ease of configuration. The actual configuration used for CTA 21 is shown in Fig. 3.

With 10 dB difference between input signals the combiner provided a 0.4–0.5 dB SNR gain over that of the strong signal alone. This is in the correct range for what would be predicted by theory.

Although the initial test configuration tried was valid, several tests over a period of weeks were required to obtain the above result. This was because the following difficulties thwarted the experimenters during early tests:

(1) Laboratory power variations and noise interfered with the signal levels during the tests at CTA 21. It was found that the system appeared to be more stable after 5 p.m. Therefore, most testing was shifted from daytime to evenings and weekends.

(2) SNR values computed by the Telemetry Processor Assembly (TPA) fluctuated ±1.5 dB. In trying to measure a 0.5 dB gain, an SNR value good to ±0.1 dB is needed. It took some time before a technique was evolved to do this with any confidence in the results. The problem was exacerbated by the power variations noted above.

A Block IV receiver degradation problem also existed, and was eventually determined to be in the telemetry phase detector module. Several attempts were made to improve its performance, with none of them successful. So that testing could proceed, it was decided to use the Block III Receivers, and all successful testing at CTA 21 was performed with these receivers at S-band frequency.

Because of the variance in the telemetry processor estimated SNR outputs, a symbol error count was the more desirable criterion for measuring system performance. However, because of the delay through the combiner, a symbol error count at the higher data rates could not be made using the more desirable psuedo noise pattern. (The system has no provision for varying the delay in the symbol error line from the SCA to the Symbol Synchronizer Assembly (SSA)). Two alternatives remained: 1) use a less desirable square wave bit pattern or 2) lengthen test time and use the estimated SNR mean for performance measurements. Since combiner performance was measured by serially testing and comparing combined and uncombined performance, and with system stability uncertain, most of the testing at CTA 21 was performed with square-wave data using the symbol error count as the prime measurement data.

Note that the purpose of testing at CTA 21 was to measure performance of the RTC only; therefore, all measurements were relative (combined to uncombined), masking degradation of the remaining system components.

Of primary concern during this period was the source of the SNR fluctuations:

(1) Were the SNR fluctuations real?

   (a) How accurate was the estimator?

   (b) Was it averaged over sufficient time?

(2) Were there system problems causing the fluctuations?

   (a) If so which component in the telemetry string varied?

(3) Was the signal varying?

Solutions included,

(1) Running tests on swing or midshift.

(2) Switching hardware to improve the telemetry string.

(3) Running extensive BER (bit error rate) tests on the data to determine the appropriate data collection time and isolate causes of SNR variation.

It was found that approximately 10 minutes of data at or above 2 kb/s[1] was needed to obtain stable SNR results. BER

[1]More specifically: @1 dB ± 0.1 dB = SNR

$$\text{SER} = 0.056 \pm 0.0025$$

$$n = \frac{\text{SER}(1 - \text{SER})}{\sigma^2}$$

$$= \frac{(0.056)\,(0.944)}{(0.00125)^2}$$

$$n = 350{,}000 \text{ bits}$$

$$t = \frac{3500 \text{ bits}}{2000 \text{ bps}} = 17.5 \text{ s } (@2 \text{ kb/s})$$

Therefore at 2 kb/s it should only take approximately 18 s to establish the SNR to within 0.1 dB. But with all the uncertainties of telemetry string operation, a 10 minute test is recommended to assure system stability and to validate proper operation of the string.

tests using controlled data verified that SNR data from the TPA was accurate and stable over this time period. It is essential that all equipment in the telemetry string be calibrated and in specification, to obtain reliable data.

B. Goldstone

The RTC was then moved to Goldstone and installed for a first test with live spacecraft data on December 19, 1978. The first two tests were inconclusive. A test was run on February 21, 1979 that showed a combined signal gain of from 0.4 to 1.0 dB. This was still inconclusive proof of combiner performance since the expected value was a steady 1.2 dB gain. However, there were several hours of combiner operation with positive gain registered. This was a step in the right direction. Because station availability was extremely limited it was necessary to perform almost all testing at Goldstone during regularly scheduled Voyager passes on a noninterference basis. This was highly undesirable in that there was no control over data rates or signal level and available configurations were limited. This, coupled with several unknowns (such as proper telemetry receiver phasing requirements, antenna gain at DSS 12, CONSCAN stability, etc.) and uncertainties (such as best procedures for configuring an array system, total delay between stations, Block IV receiver performance, etc.) was probably the greatest contributing factor to the long time period required to uncover many of the arraying problems, the most significant of which are discussed below.

(1) If DSS 12 dropped lock, the only evidence at DSS 14 was that the RTC went from 1 dB gain to 1 dB net loss. This relates to how visible the performance of the RTC "system" is to station operators during arraying operations. The subject is being studied by a working group.

(2) The micro-wave system could invert the signal from DSS 12. This simply required a procedural change.

(3) The baseband module in the Block IV receiver cost 1 dB in SNR over that observed in the Block III receiver. The baseband module problem is the subject of an approved design change which will be completed in the 64 Meter Network on 1 June 1980. As an interim solution the Block IV 1F was cabled through the Block III baseband modules as shown in Fig. 4.

(4) The antenna spread between DSS 12 and 14 was 5 to 6 dB at X-band instead of the 4.2 dB expected, due to lower than expected antenna gain at DSS 12. DSS 12 gain was out of specification when the antenna was measured and post encounter adjustments have not improved it.

(5) The receiver signal level at DSS 12 would vary ±1.5 dB in a gusty wind (20 knots gusting to 35 knots). The Automatic Gain Control (AGC) variation during gusty winds probably was resolved by antenna servo modifications made to reduce jitter. Certainly AGC from both antennas needs to be monitored to track arrayed system performance. CONSCAN at DSS 12 was first suspected when this condition occurred. Investigation proved otherwise. However, CONSCAN does have some glitches with the current software and this is planned to be corrected.

(6) No means existed to stop and restart the combiner without complete re-initialization. Initialization of the combiner required a minimum of eight operator inputs and is time consuming. The production version of the combiner will allow restart with one input and configuration change without restart. Configuration and prepass calibration procedures required two hours which was seldom available with the prototype system. The Saturn configuration should require no more than 30 minutes if string selection can be eliminated. (See discussion, Section VI.)

III. Voyager/Jupiter Encounters

The final array configuration at Goldstone used for all encounters thus far is shown in Fig. 4. The prototype RTC was used for 10 days around 5 March 1979, for the Voyager I Jupiter encounter; and for 14 days around 2 July 1979, for the Voyager II Jupiter encounter. RTC gain was determined to be 0.8 to 1.0 dB and the combined telemetry data stream was used by the project for most of each track. Combiner up-time was >95 percent. The received carrier frequency was X-band and the SNR difference between DSS 14 and DSS 12 was approximately 5 dB.

IV. Pioneer 11/Saturn Encounter

A real bonus was achieved when the array system was used at Goldstone for 10 days around the Pioneer 11 encounter of Saturn on 1 September 1979. Signal levels (at S-band) were too low to use the RTC phase lock loop mode to combine the signals from DSS 12 and 14. DSS 14 is able to improve its gain by 3 dB at S-band by going into a "listen only" mode. DSS 12 does not have the listen only option so that its system noise temperature, SNT, remains relatively high[2]. For this reason and due to other equipment differences the station SNR difference goes from 5 dB at X-band to 9 dB at S-band. With this spread the theoretical combiner gain is only 0.5 dB.

[2]at DSS 14, SNT_{nom} = 16 K
at DSS 12, SNT_{nom} = 26 K

The RTC was operated in the "dead-reckoning" mode whereby the signals are phased by calculating the delay time between the two stations using the combiner minicomputer. Normally this calculation is made to bring the signals in range of the phase lock loop (PLL). In the dead-reckoning mode the PLL is bypassed.

RTC gain during the Pioneer-Saturn Encounter was 0.3–0.4 dB. This was sufficient to permit the project many more hours of 1024b/s data at Goldstone and substantially enhanced the imaging mission. With low RTC gain, system performance was difficult to measure in real time. The best potential measure of system performance with Pioneer telemetry is frame deletion rate of the sequential decoder. Unfortunately, this parameter was calculated based on a running average. It proved almost valueless in establishing short term performance of the telemetry string. The real measure of performance was Goldstone's ability to receive 1024 b/s data while the rest of the network functioned at 512 b/s.

V. Future Use of Arrayed Systems

Permanent RTC installations are to be made at the 64-m net in the first and second quarter of 1980. This will provide the capability to array 64-m/34-m stations at Goldstone, Madrid, and Canberra in time for the Saturn encounters by Voyager in November 1980 and August 1981. Some improvements in display capability will be implemented by that time to permit combined performance evaluation from a central location, either at the 64-m station or at JPL. Ninety days of continued RTC operation is currently being planned for the first encounter and 30 days for the second encounter.

The most striking operational system problem facing the test investigators at the start of Goldstone array operations was lack of visibility into the arrayed system performance. Voice communication provided the most useful means of station status monitoring and very often an investigator had to make trips from DSS 14 to DSS 12 and back to solve problems. No information on the microwave system or DSS 12 status was available at DSS 14 where the combiner was installed (see Fig. 4). This lack of visibility led to the formation of a combiner working group at JPL. This group is concentrating on improving combiner operational visibility for the Voyager/Saturn encounters.

The RTC produces a gain of approximately 1 dB when a 34-m signal is added to a 64-m signal in standard X-band configuration. In order to measure performance it is necessary to know the gain to, say, 0.1 dB. This says that the entire telemetry string must be known to ±0.1 dB. Furthermore, each component in that string must be calibrated and within spec to 0.1 dB in order to make combiner gain meaningful. During testing, investigators found several instances of 1 dB variations in other components of the telemetry string (refer to earlier discussion of high winds, the Blk IV baseband module, and DSS 12 antenna gain). The message is that a carefully calibrated, tuned, and stable DSS is a prerequisite to successful combiner operations. During the encounters, parallel telemetry strings were performance checked daily to determine optimum DSS configuration. This was time-consuming and would be unnecessary with proper calibration. SPTs run on telemetry strings bi-weekly should ensure good station calibration.

VI. Future System Design

The success of increasingly complex arraying operations envisioned in Network Consolidation will depend on sufficient automation in areas of system calibration, array configuration, string selection, and display formatting. In particular it would be desirable to have the combiner analyze and disconnect antenna receiver systems that did not meet performance specs. As was shown earlier, an out of lock receiver can provide a significant negative gain to combiner system performance. These future array systems will be sufficiently complex that operators will not be able to react in real time to system changes.

Acknowledgment

The combiner was developed by Larry D. Howard under the direction of R. Bruce Crow of Section 333. The authors were privileged, as members of DSN Operations Section 377, to become involved in combiner operations during development and early systems testing.

Reference

1. R. A. Winkelstein, "Analysis of the Signal Combiner for Multiple Antenna Arraying", *DSN Progress Report 42-26, January and February 1975*, pp. 102-118, 15 April 1975.

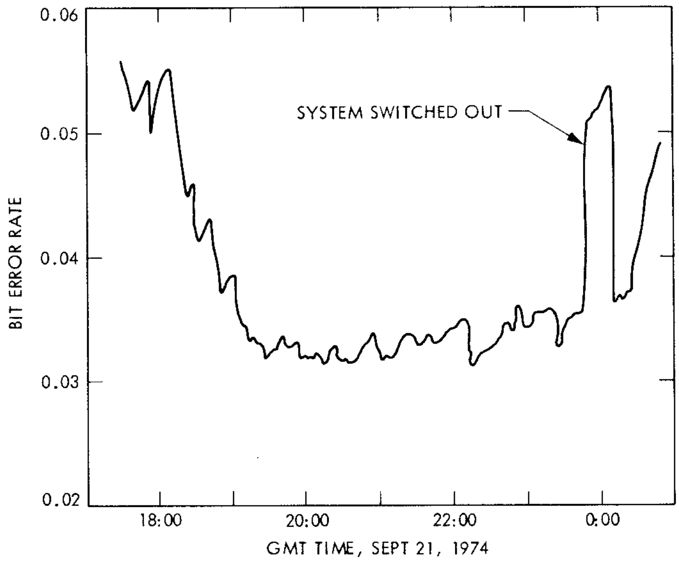

Fig. 1. Reproduction of the BER results of the MVM encounter

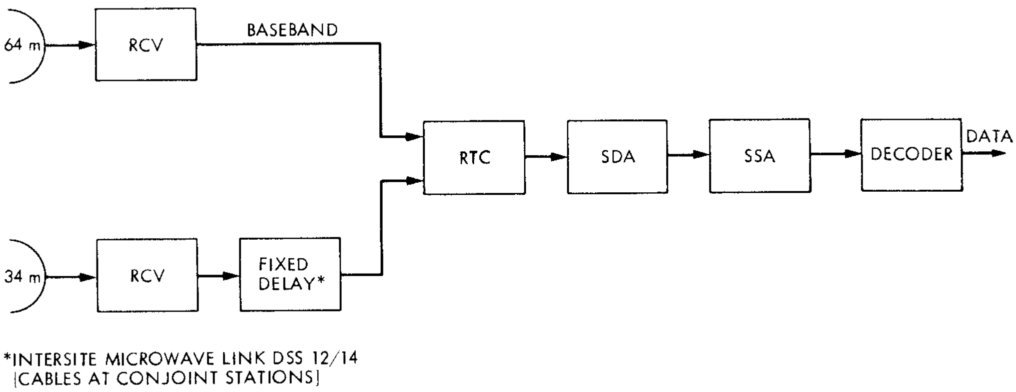

Fig. 2. Real-time array system block diagram

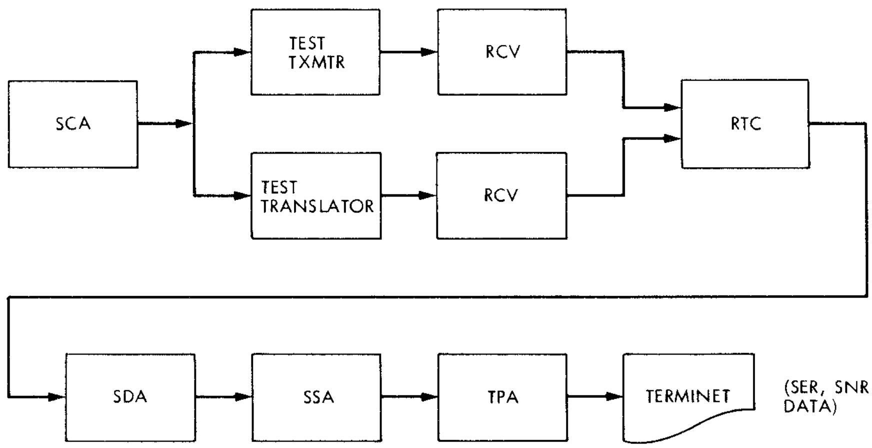

Fig. 3. CTA 21 test configuration

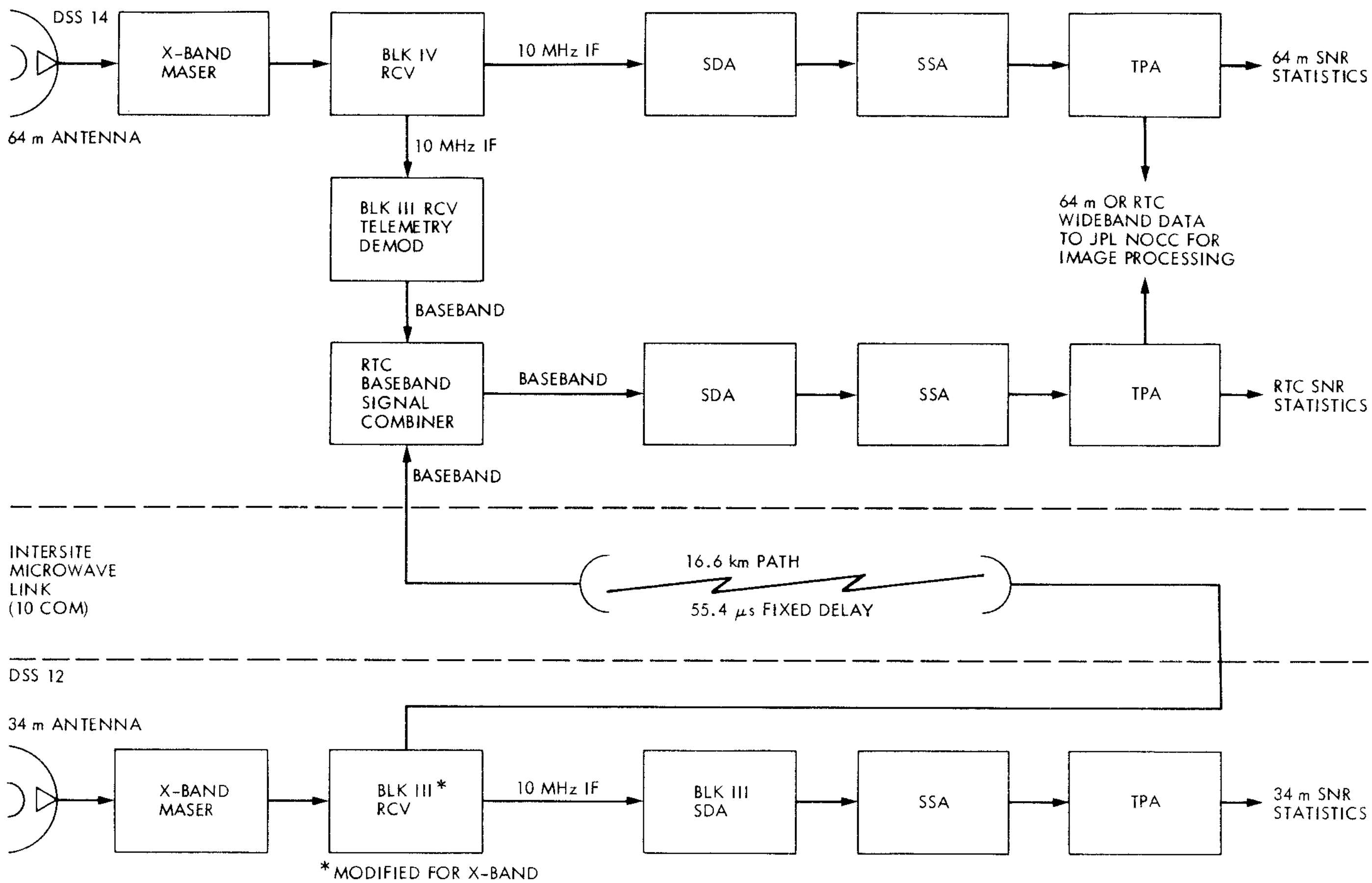

Fig. 4. Encounter configuration, real-time combining system block diagram