A Study of DSN Traveling Wave Maser System Reliability

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This article reports on past and present reliability and availability characteristics of the DSN Traveling Wave Maser (TWM) Assemblies. For the years 1981 through 1983, the characteristics determined are: Mean Time Between Failures (MTBF) – 1200 hours; Mean Time to Restore Service (MTTRS) – 2.5 hours; and Availability – 99.83%. The TWM MTBF currently is very good relative to other DSN subsystems and assemblies; however, it has been significantly better in the past – in the late 1970s it was 3000 hours. The TWM MTTRS is currently about three times as long as the average of other DSN subsystems.

The dominant cause of TWM failures is contamination of the helium gas in the closed cycle refrigerators. Station configurations that do not provide TWM redundancy are subject to having reception outages for long periods of time.

A number of recommendations are made to improve the TWM Assembly availability characteristics for future mission support operations. Many of the recommendations result from a network-wide workshop of TWM experts that was recently conducted at the Canberra Complex.

I. Introduction and Summary

A. Introduction

The Traveling Wave Maser (TWM) Assemblies used on the large DSN antennas are truly remarkable devices. Their technical performance in the field is essentially equivalent to the best attainable in a laboratory environment.

The unique and critical attribute of the TWMs for deep space communications is the very small noise they introduce – the latest models add no more noise than the cosmic background (3K). That has enabled total system temperatures of 13 to 20K, increasing the reception capability of the DSN's large antennas by about a factor of two relative to that currently obtainable with any other amplifier approach. Other important attributes of the TWMs are: 40-45 dB gain over the S- and X-band frequencies assigned for deep space reception, excellent phase and amplitude stability, large dynamic range (greater than 100 dB), and immunity from damage by any reasonable input overload.

However, achieving a high availability of the TWM Assemblies is a very demanding task. And high availability is essential, because a TWM outage results in loss of DSN reception capability until the function is restored. In recent years, the availability of the TWM Assemblies apparently has been degrading. This study was done to assess the situation.

B. Summary of Study Findings

The current Mean Time Between Failures (MTBF) of the TWM Assemblies is very good relative to other DSN station equipment. The MTBF has been, and can be, significantly better than it is now. The dominant cause of TWM Assembly failure is gas contamination in the helium refrigerator.

The Mean Time to Restore Service (MTTRS) of the TWM Assemblies is about three times longer than the average of other station subsystems. The TWMs are the dominant cause of very long outages of station reception capability. Unreliable single point of failure mechanisms must be reduced at the stations to improve the service restoration characteristics of the TWM Assemblies.

The Availability[1] of the TWM Assemblies is approximately 99.8%. The TWMs account for about 20% of the total outage time of the Telemetry Data System, and almost one-half of its outages that are longer than six hours. It is practical to improve this performance significantly in the future.

A DSN Maser Reliability Workshop was conducted. Maser experts from all of the complexes and from JPL participated. The Workshop report gives a prioritized set of recommendations to provide improved TWM Assembly maintenance and repair capability at the complexes. The report also gives recommendations for engineering development effort to provide improved TWM Assembly availability characteristics.

C. Summary of Recommendations

The recommendations from the study are, in order of priority:

1. Implement the First Priority items as recommended in the Workshop report.

The items pertain to use of best available field maintenance and repair techniques and to providing needed instrumentation and logistic support at the complexes. Implementation will lead to significantly improved TWM MTBF. It will also minimize the risk of failures from maintenance or repair processes that have unperceived faults. Such faults can result in concurrent failures of both prime and back-up TWM Assemblies.

2. Provide on-line back-up configurations at supporting stations for all periods of critical S/C activity support.

This will greatly improve the service restoration characteristics of those Front End Areas (FEAs) currently lacking redundant TWM Assembly configurations. Specifically, that includes redundant X-band TWMs for FEAs 12 and 42 by early 1985, and for FEAs 15, 45, and 65 by 1988.

3. Emphasize the care lavished on TWM Assemblies at FEAs that will be used for critical support but that will lack redundancy.

This will maximize the MTBF of the non-redundant TWMs, and thus will decrease the likelihood of long reception outages. Specifically, that applies to FEAs 15 and 45 at X-band for Voyager at Uranus. It also applies to FEAs 14, 43, and 63 at S-band for International Cometary Explorer (ICE) critical telemetry and for Galileo critical radio science – both require simultaneous use of the prime and the back-up TWMs.

4. Implement the distributed ground fault protection in the TWM AC input power circuits at FEAs 14 and 12.

Currently at the Goldstone Complex, AC input power ground fault protection circuitry is common to all individual TWM Assemblies. Thus, a single ground fault can cause all TWMs, primes and backups, to fail. Implementation of distributed protection will lower the risk of long outages at Goldstone.

5. Undertake the High Priority Engineering Development Tasks, and implement the Second Priority Maintenance and Sustaining items cited in the Workshop report.

This will further improve MTBF and MTTRS and will reduce the effort required at the complexes to maintain a very high level of TWM Assembly performance.

II. Study Background

The basic objectives of this study are: (1) to understand the availability characteristics, past and present, of the DSN TWM Assemblies, and (2) to identify actions that would improve their availability characteristics for future mission support. The study was started in June 1983. This report covers the complete study.

[1] Availability = MTBF/(MTBF+MTTRS)

III. Availability Characteristics of TWM Assemblies

The term, "Availability Characteristics," as used in this article, includes the MTBF; the service restoration properties, including the MTTRS; and the formal Availability that was previously defined.

A. MTBF History

Analysis of failure and DSN Discrepancy Report (DR) data gave the MTBF history shown in Table 1.

Approximately 1.8 million TWM operating hours are represented in the table.

B. Availability of the TWM Assembly vs Other Station Equipment

An analysis was done of the DSN Telemetry Data System outages for 1981 through 1983 (Ref. 1). The outage data were obtained from the DSN DR System reports. The Telemetry Data System includes the TWM Assembly as well as other major assemblies and subsystems. By tabulating the specific causes of the System outages, a comparison of the availability characteristics of the TWMs vs other major System elements was obtained.

The analysis of the Telemetry Data System outages gave the results shown in Table 2.

Approximately 107,000 hours of scheduled Telemetry Data System support are represented in the table.

The MTBF of the TWMs is relatively very good. However, the MTTRS of the TWMs is relatively very poor. Also, the data showed that the TWMs caused almost half of the Telemetry Data System outages that were longer than six hours.

C. Causes of TWM Assembly Failures

Analysis of the 1981-1983 DSN DRs to identify causes of TWM Assembly failures gave the results shown in Table 3.

The DR data show that refrigerator contamination is the dominant cause of TWM Assembly failure. That is supported by analysis of failure data samples collected from the stations during the past ten years: Of a total of 376 failures, 218, or 58%, were attributed to refrigerator contamination.

IV. Maser Reliability Workshop

A. Workshop Background

A Maser Reliability Workshop was conducted in December 1983, hosted by the Australian Complex. An agenda was prepared in advance by the JPL Cognizant Operations Engineer (COE) and the JPL Cognizant Development Engineer (CDE) with input and review by personnel from all of the complexes. A preliminary maser reliability improvement engineering program plan was prepared by the JPL Section 333 Microwave Electronics Group, including the CDE, and supplied to the Workshop participants for assessment. Maser experts from all complexes and maintenance facilities and the JPL COE and CDE participated in the Workshop.

B. Workshop Results

A formal report of the Workshop activities was issued. The report gives recommendations in three categories:

I. First Priority Implement FY84

II. Second Priority Implement FY85

III. High Priority Development Tasks

The Workshop attendees recommended that the Category I items be implemented prior to the Voyager encounter at Uranus. The Category I items abstracted from the Workshop report are:

1. Implement new and upgraded maser operation and maintenance procedures (developed at the Workshop);

2. Supply to each complex the necessary support equipment identified by the Workshop as required to perform Workshop recommended procedures;

3. Establish a special training course at each Complex Maintenance Facility for maser operation, maintenance, and repair personnel. The course should embody the latest and best engineering and operating knowledge of the DSN TWM Assemblies;

4. Implement the computer-based TWM-CCR monitoring and analysis system proposed in the preliminary reliability improvement engineering plan, previously noted, and include additional monitoring points as recommended by the Workshop; and

5. There are several engineering changes to the TWM Assemblies currently proposed. The following Engineering Change Orders (ECOs) are recommended by the Workshop as being top priority:

a. Provide new extended range flow meters for proper instrumentation of the Joule-Thompson valve return flow.

b. Provide for constant flow through the storage tank of the helium compressor, and add a pressure relief valve to the helium storage tank.

c. Provide a second stage oil injection line filter in the helium compressor.

There are thirteen Category II (Second Priority Implementation) items. They are considered by the Workshop attendees as being straightforward, of lower priority than Category I items, and they should be implemented as soon as practical after the Voyager Uranus encounter operations. The top four items on the list are:

1. Provide a mechanism to bypass in-service flow meters so that they may be calibrated or replaced without interrupting service.

2. Provide a mechanism to replace in-service adsorbers without affecting maser operation.

3. Refrigerator stage temperature monitoring sensors should be made available as soon as possible and added to all CCRs during routine repair cycling.

4. A service loop should be put in the compressor plumbing between the first stage oil separator and the orifice block to overcome the vibration failure of this line.

There are thirteen Category III (High Priority Development) items that the Workshop attendees recommended should be investigated as soon as possible. The top three items on the list are:

1. Compressor upgrade to a 5hp motor. The compressors currently use a 3hp motor that is overloaded by the new TWMs.

2. Develop field techniques for measurement of gaseous impurities in helium.

3. Develop a thorough understanding of the behavior of the compressor oil at increased temperature.

V. Goldstone Power Distribution Study

A. TWM Assembly Outages Due to Power Failure

Analysis of the 1981 through 1983 DSN DR records for TWM outages due to AC power failure gave the results shown in Table 4.

Several of the outages at Goldstone were long. DSS 44 has been deactivated since the reported failures.

B. Study of Goldstone Power for TWMs

A consultant was engaged to assess the suitability of the power system that supplies the TWMs at Goldstone. The following is extracted from the consultant's report:

> Four of the (Goldstone) outages were caused by an accidental ground contact and eleven of the outages were caused by the undesired placement of ground fault protective equipment. The result was that a ground fault in any single compressor would cause loss of power to all other compressors served by the same "cryogenic" power panel. This condition has been recognized and ground fault protective equipment for the individual compressors was purchased and portions have been received. The study RECOMMENDED that installation of this equipment be given high priority.
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> . . . Other methods of improving reliability of electric service were studied which included by-passing busses and panels to reduce exposure to equipment failure and the addition of "clean" or dedicated circuits between the power source and the cryogenic panels. Costs ranged from $3,250 to $68,000 for the possible incremental improvements to a basically reliable system. NO additions were RECOMMENDED.
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> The study also examined the reliability of commercial power and the first level of redundancy which is the local station power. The advisability of installing a second level of redundancy consisting of emergency generation located adjacent to cryogenic power panels was also examined. Costs ranged from $85,000 at DSS 12 & 15 to $143,000 at DSS 14. It was determined that the multiplicity of local station generators and the good record of automatic transfer from commercial power to station generation during commercial power outages provide adequate reliability of power service to the maser compressors. NO RECOMMENDATIONS were made. The transfer process should be given periodic and realistic tests.

VI. TWM Assembly Redundancy and Spares

A. Planned Operational Configurations

The Mk IVA DSN will have TWMs configured as shown in Table 5.

The "2" TWM configurations provide redundancy for all conventional support operations. Some non-conventional support operations will be discussed in the next section. In summary, Table 5 shows that if current plans are implemented, there will be TWM redundancy at all FEAs except 15 and 45 by 1985; by 1988 there will be no exceptions.

B. Consideration of Support Operations When Redundancy is Not Available

When a TWM Assembly fails, it is almost sure to be out of service for 12 hours or more. Therefore, if there is not on-line redundancy available, a long reception outage is inevitable.

Here are three cases where on-line TWM redundancy is not available:

1. The FEA has a single TWM. An example is FEAs 15 and 45 used for X-Band support of Voyager at Uranus. All FEAs at the complexes will be simultaneously in use for Voyager support, so that functional back-up will not exist.

2. The mission support requires use of both prime and back-up TWMs. An example is support of ICE for a year beginning in March 1985 with a one-day critical encounter in September. ICE requires use of both prime and back-up S-Band TWMs to enable combining of two carrier channels. The support will be provided by FEAs 14, 43, and 63.

Another example is support of polarization measurement of the Galileo S-Band signal. That measurement requires use of both prime and back-up TWMs. FEAs 14, 43, and 63 will be used. The measurements are critical to Jupiter environment radio science experiment support. They will be made for about one week in August of 1988, and intermittently on a predefined schedule until April of 1990.

3. A common failure node brings down both prime and back-up TWMs. Recent examples of this are faulty charcoal filter stock unknowingly used in maintenance of multiple TWMs, and extended power outage to the TWMs.

Without TWM redundancy, lowering the risk of having an extended reception outage requires increasing the TWM MTBF. Although the TWM MTBF is good, it is believed that application of the use, maintenance, and repair practices recommended by the recent TWM Workshop will provide significant improvement. Also, healthy TWMs have the best chance of surviving AC power interruptions.

Efforts to provide improvements should focus especially on preparations for critical S/C support events.

VII. Improved Instrumentation of TWM Refrigerator Operating Parameters

We believe that observation and analysis of the operating parameters of the TWM Closed Cycle Refrigerators (CCRs) can provide insight into CCR condition and can identify impending CCR failures before they occur.

A. Previous Work on Instrumentation

An early result of this study was the recommendation to develop and demonstrate a computer-based data collection and analysis system for the CCRs. The concept was endorsed by the TWM Workshop – it is Recommendation 4 of the Priority I list (see Section IV.B.) Work was started but has been temporarily set aside on the design of a prototype.

Meanwhile, attempts were made to analyze CCR parameter data previously collected by hand. The results could not validate the belief that reliable predictions of incipient failures could be obtained from the data. One problem with all of the past data available is that the critical measurement of the Joule-Thompson stage return flow is spoiled by a flowmeter that is saturated almost all of the time. That problem can be corrected for the future by the implementation of a planned ECO (refer to IVB, item 5a).

B. Current Work on Instrumentation

The TWM/CCRs at DSS 12 will be properly instrumented, and their operating parameter data will be systematically collected for a period of several months. The data will be manually collected and analyzed. Definition of the data collection regimen and the analyses of the data are under way.

If the effort is successful, as we believe it must be, the results will be used to guide the future development of a computer-based prototype system. Also, the results will provide techniques for manual data collection and analysis that can be used during the interim until the computer-based system is available to the network.

VIII. Concluding Observations

Reliable performance of the TWM Assemblies is essential, especially during support of critical S/C activities.

Both the MTBF and the MTTRS of the TWMs can be improved significantly by practical measures. The MTTRS probably needs the most attention, but when redundancy is lacking, improved MTBF is the only road to lowering the risk of long outage of reception capability.

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Reference

1. Stevens, R., Availability of the DSN Telemetry Data System and Its Major Elements, Including the TWM Assemblies. *The Telecommunications and Data Acquisition Progress Report 42-78*, Jet Propulsion Laboratory, Pasadena, California, August 15, 1984.

Table 1. MTBF history

Time Period	Approximate MTBF (hrs)
Late 1960s	1300
Late 1970s	3000
Early 1980s	1200

Table 2. Analysis of Telemetry Data System outages

Syst/SS/Assy	Total Outage (hrs)	MTBF (hrs)	MTTRS (hrs)	Availability (%)
Tele Data Syst	1044	90	0.9	99.03
Antenna+APS SSs	322	300	0.9	99.70
TWM Assy	186	1420	2.5	99.83
Receiver SS	165	560	0.9	99.85
Telemetry SS	113	720	0.8	99.89
Facility SS	43	1670	0.7	99.96

Table 3. Causes of TWM Assembly failures

Area of Failure	No. of Failures	% of Total No.
Helium Refrigerator	120	64
Contamination	(109)	(58)
Other (drive unit, etc.)	(11)	(6)
Helium Compressor	14	7
Miscellaneous (pump, MWV, electr.)	30	16
AC Input Power	19	10
Unidentified (DR not definitive)	6	3
Total	189	100

Table 4. TWM outages due to AC power failure

Complex–Station	No. of TWM Outages
Goldstone–DSS 12	3
Goldstone–DSS 14	12
Canberra–DSS 44	4
Total (refer to Table 3)	19

Table 5. TWMS configurations

Complex–FEA	X-Band	S-Band	Comments
Gold–12(34m)	1(2)[a]	2	(2) X by 1985 if 1 SPC-10 spare instld as B/U.
Gold–14(64m)	2	2	
Gold–15(34mHEF)	1(2)	-	(2) planned by 1988. S-Band FET.
Gold–10(spares)	2(1)	4	(1) X if spare instld as on-line B/U at FEA-12.
Aust–42(34m)	1(2)	2	(2) X by 1985 if 1 SPC-40 spare instld as B/U.
Aust–43(64m)	2	2	
Aust–45(34mHEF)	1(2)	-	(2) planned by 1988. S-Band FET.
Aust–40(spares)	2(1)	3	(1) X if spare instld as on-line B/U at FEA-42.
Spain–61(34m)	2	2	Spare X has been instld as on-line B/U.
Spain–63(64m)	2	2	
Spain–65(34mHEF)	(2)	(-)	FEA on-line 1988. Gets 2 X TWMs and S FET.
Spain–60(spares)	1	2	

[a]Numbers in parentheses are changes to present configurations.