Assessment of 20-kW S-Band Transmitter

R. Dickinson and H. Hansen
Radio Frequency and Microwave Subsystems Section

The recent performance history of the 20-kW S-band transmitter, installed at three 64-meter antennas and six 26-meter antennas in the DSN, is reviewed. An increasing number of failures and Discrepancy Reports are characteristic of the wearout phase of a failure curve. The type of failures are reviewed and four options toward reducing the number and cost of failures are reviewed. These are existing (no change), refurbish (replace worn components), redesign (extensive improvement) and replacement (with completely new transmitter).

The options are compared on a ten-year life cycle cost basis using FY77 expenditures for existing equipment as a base. It is found that benefits, in terms of reduction of outage time, increase with an increase of expenditure toward improvement. The choice of option to be exercised is dependent upon the amount of outage which is acceptable and, of course, upon funds available.

I. Introduction

The 20-kW S-band transmitter subsystem is installed at each of three 64-m antennas and at each of six 26-m antennas in the DSN, making a total of nine transmitters. The installations were completed in 1966. Recent performance has been characterized by an increase in both minutes of outage and number of Discrepancy Reports (DR) on the subsystem. Figure 1 shows a sharp rise in outage and DR's for the years 1977 and 1978. This record was the reason for initiating a study of the transmitter to determine what optimum remedy would reduce this trend in failures. The object of the study is to evaluate the record of recent failure reports and to assess methods of improving performance.

II. Recent Failure Trend

An explanation advanced for the recent rise in failures is increased emphasis on Discrepancy Reporting. This may be a partial cause. However, the reports do cite increased outage time as a result of failures. Further, many failures have resulted from worn bearings, pitted relay contacts, and leaking seals. These troubles suggest that some components are in an "end-of-life" period wherein a more frequent failure pattern is typical. This situation requires attention immediately to prevent reaching a point where failure rate soars prohibitively high. Another reason for searching for options for improvement is that numerous components are becoming obsolete and difficulty has been experienced in locating replacement parts, especially when needed immediately.

For the years 1976 through 1978, the outage time illustrated in Fig. 1 was divided among power amplifier (25%), power supply (25%), heat exchanger (25%), miscellaneous (20%) and procedural (5%) sources. Table 1, which describes the reports for 1977, is representative of the failure pattern and shows many of the large outages which were the reason for the sharp rise in 1977.

Note that total outage due to fan failure, cooling system leaks, arc detector tripping, and insulation faults is 3862 minutes, about 90% of the total.

Some of the outage charged to the power amplifier was described as due to waveguide mismatch. Actually, the transmitter subsystem arc detector is operating as designed and the source of trouble may be in the waveguide, possibly leakage or other problems causing arcing or high voltage standing wave ratio (VSWR). The waveguide is subject to mechanical vibration and probably needs preventive maintenance applied.

The largest source of power supply problems is fan failure due to bearing wearout. Reference 1 considers reliability of blowers to be composed of an electrical component, constant with time, and a mechanical "wearout" component which increases with time. It appears that mechanical components such as the fans may be at the end of life period where the failure rate is increasing rapidly.

Other causes of power supply failures are in relay tripping and insulation breakdown. These, also, suggest aging problems such as contact pitting and insulation deterioration.

Heat exchanger outage shows much time lost due to leaks at seals and fittings. Again, this suggests aging from hardening of packing and gaskets, vibration, bearing wear, etc.

The 926 minutes, under miscellaneous, described as high noise are difficult to explain. A major portion of this outage is ascribed to waveguide arcing which is not a fault within the transmitter.

III. Definition of Options

Possible approaches toward the recent failure history range from "doing nothing" to replacement of the transmitter with a complete new design. "Doing nothing" implies acceptance of probable increased repair cost in future years plus acceptance of greater risk of outage during a scheduled operation when lost data might be irrecoverable. Increased maintenance cost is undesirable at any time. Losing irrecoverable data after having made minimum effort to reduce the likelihood of failure would be inexcusable. Therefore, "doing nothing" is considered a first option but essentially as a starting point in searching for the most advisable plan of action.

A review of Table 1, (plus the details of the associated Discrepancy Reports), suggests that replacement of components subject to wear and/or deterioration would offer a low cost approach to reducing failure rate. For instance, Table 1 shows outage of 479 minutes from fan and air-flow switch failure, 735 minutes from seal and fitting leaks, and 426 minutes due to low flow, fan bearings, etc., in the coolant system. These three areas total 1640 minutes and comprise 38% of a total 4285 minutes outage.

Other failures, such as wiring breakdown, offer additional potential for improvement by replacing components which show the effects of aging or high voltage deterioration.

Thus, refurbishment was chosen as one avenue for improvement which should offer substantial gains, possibly as much as 30% to 40% reduction in outage, and at low cost.

A third option would entail a more complete rebuilding/redesign of the existing transmitter. This would allow replacement of all worn components, replacement of deteriorated insulation with new wiring, and minor improvement in circuitry if deemed advisable from experience. A recommended addition would be expansion of the monitoring circuitry to a built-in test equipment system to aid in faster diagnosis of failures and, thereby, reduce outage time. The proposed redesign would be considerably higher in cost than the refurbishment, but would be limited by using most major components of the high voltage power supply, motor-generator set, heat exchanger, and the klystron.

The potential cost of a redesigned transmitter and the compromises inherent in redesigning any equipment suggest consideration of an entirely new transmitter to replace the existing equipment. The added design cost would be justified by improved performance, high reliability and extensive monitoring and self-test circuitry.

The result of the foregoing considerations was a plan to compare, on a life-cycle cost basis, four options to reduce the rise in failures, shown in Fig. 1:

Option 1. *Existing transmitter.* Continue use without action.

Option 2. *Refurbishment.* Replace worn and obsolete components with new, current items.

Option 3. *Redesign.* Replace additional components, such as obsolescent transistors. Redesign circuitry to remedy known problems, expand monitoring and self-test circuits, redesign cooling system to reduce leaks and vibration caused failures.

Option 4. *New transmitter.* Incorporate highest reliability components, current manufacture, extensive monitoring and self-test circuits. Design to current and anticipated future requirements. Centralized control would be a design objective, with an option for completely unattended operation. A pre-failure status file would be incorporated with the monitoring circuits to store pre-failure status information.

IV. Cost History

A cost model for the DSN was reported in Ref. 2. This study developed a cost model for the DSN giving maintenance, operations, sustaining, and support costs for each subsystem (see Table 2). For the transmitter subsystem, the 1977 costs were:

Category	Cost
Maintenance	$ 646,000
Operations	501,000
Sustaining	547,000
Support	462,000
Total	$2,156,000

These figures were used as a base for making a cost comparison of the four approaches toward improvement of the transmitter.

V. Estimating Cost to Upgrade Transmitter

A comparison of life cycle cost for each of the four options was desired for the 10 year period beginning in FY80. The subsystem cost figures for FY77 were adjusted to FY80 using an estimated inflation rate of six percent per year. A subsequent allowance for the combined effect of inflation and discount rates was made using a net discount factor of 0.98 per year, per Ref. 3.

The cost for each option was estimated by making an estimate of the cost of implementation. The effect of the changes made toward lowering maintenance, operations, sustaining, and support costs was estimated in terms of percent reduction in expense which might reasonably be expected. A similar estimate was made of the minimum percentage reduction in minutes outage which could be expected. The following assumptions were made for each option:

Option 1: There will be no cost of implementation since no improvement will be made. It is believed that the failure rate is increasing due to aging of mechanical and electrical components. The rate was estimated to increase at five percent per year and this figure was assumed to increase maintenance costs proportionately. While the more frequent failures would have some effect on other costs, it was assumed that operations, sustaining, and support costs would not be increased.

Option 2: A minimum program of refurbishment was assumed:

(a) Replacement of fans with an estimated reduction in fan failures to 25% of the FY77 level.

(b) A thorough rework of coolant lines and fittings will reduce coolant system failures to 25% of FY77 level.

(c) Increased efforts to keep the waveguide mechanically tight, pressurized, and free from impurities will reduce waveguide arcing and will give at least a 20% reduction in arc detector trip-outs.

(d) Efforts to relocate critical controls plus improvement in operating procedures will reduce procedural errors by 33%.

(e) While efforts to improve and replace wiring would be made, most wiring would be unchanged. Therefore, it was assumed that the number of wiring shorts, opens, etc., would be unchanged.

The cost of implementation was estimated as the cost of new fans, coolant fittings, and other hardware to accomplish these improvements, plus the cost of associated labor. The estimated percent reduction in failures was applied to the outage time reported for 1977. The result indicated an approximate 30% reduction in outage time. This reduction was applied to maintenance costs beginning in the second year, assuming one year required for completion of the changes. A reduction of 30% in outage should aid in reducing costs of other functions and it was estimated that the cost of operations, sustaining, and support would be reduced by 10%, 5%, and 10%, respectively.

Option 3: A "best estimate" of the cost of redesign was made, for each subassembly in the transmitter subsystem, to find the cost of implementation.

The redesigned subassemblies would have new, current components and new wiring. Presumably, known problem areas would be eliminated. By this reasoning, it was concluded that improvement in outage would be considerably greater than the 30% reduction predicted in Option 2. Therefore, an estimate of 50% reduction in outage was made as a feasible design goal. This percentage was applied to maintenance to compute a ten year cost.

It was estimated that a 15% reduction in operations, sustaining, and support costs could be expected from less outage, from expanded self-test circuits, and from other refinements. This reduction was used to calculate a ten year cost for operations, sustaining, and support.

Option 4: Being in a conceptual stage, this option was the most difficult on which to make cost estimates. For cost of implementation, a "best guess" estimate was used for cost of design, fabrication and installation, of each assembly.

A major objective in the new transmitter is rapid fault diagnosis and quick repair of failures. For a conservative figure for reduction in outage time, 60% was estimated to be a minimum design goal. This percentage was used to compute maintenance cost.

The self-test circuit, pre-failure status file, and central control operation, should provide a substantial reduction in operations requirements and a 25% reduction was thought to be a realistic, minimum estimate. This figure was used in computing a ten-year cost of operations, sustaining and support.

The specification, design, and procurement of the new transmitter would require at least three years. Therefore, in computing total cost, allowance was made for maintenance cost of the existing transmitter during a three-year design and phase-in cycle.

The assumptions are listed in Table 2 and represent simply a single point selected estimate of the cost benefits which could be expected from each option. Further studies may set more definitive, reasonable goals for achievement.

VI. Results

The result of the estimates and computation of costs for the nine transmitters in the DSN are shown in Table 3 and Fig. 2. As noted above, the computations for Option 4 made allowance for costs of the old transmitter during a three-year design cycle. By way of interest, a computation was made for the new transmitter for FY83 through FY92, i.e., after completion of the design-phase in cycle. These figures, Table 3, make Option 4 especially attractive when charges for the change-over period are deleted.

VII. Conclusions

The reduction in relative outage increases proportionally to expenditure, as would be expected. The figures result from estimates considered to be conservative. The improvement from which reduction in outage was estimated is thought to be the minimum gain possible.

Option 2, refurbishment, gives a high benefit-to-cost ratio. Basically, Option 2 involves replacement of old and worn parts and this program would be the minimum to be initiated.

Additional improvements under Option 3, redesign, and Option 4, a new transmitter, are cost effective also. It appears that the choice of option is dependent upon, first, judgement as to the value of outage reduction in DSN operations, and, second, as to budget which is available for improvement purposes.

Ten years was chosen as the life cycle span to conform with current life cycle cost studies. It is thought that Options 2 and 3 would place the transmitter in condition to serve beyond ten years. A new transmitter per Option 4 should be useful for well beyond a ten-year life.

The figures for DSN expenditures for the S-band transmitter used as a base for costs were determined after a lengthy study (Ref. 2). The cost estimates for the four options were of a "best guess" type in accordance with the improvement to be made. Therefore, accuracy of the total cost is commensurate with the accuracy of the "best guess" estimate. The trend shown in Table 1 and Fig. 2 is valid, however. Basically, the results show that substantial improvement can be obtained for small costs. As more improvements are made, the benefit-to-cost ratio drops and the gain becomes more expensive.

Plans for additional refinement of the figures include contacting cognizant organizations for opinions and estimates on improvements which are required and the effect on outage and on costs if the changes are made. Also, current quotations for hardware requirements will be needed to arrive at more accurate cost figures.

References

1. MIL-HDBK-217B, 20 Sept. 1974, with Notice 1, 7 Sept. 1976, and Notice 2, 17 March 1978.

2. R. W. Burt and J. R. Lesh, "Maintenance and Operations Cost Model for DSN Subsystems," *DSN Progress Report 42-40*, May and June 1977, pp. 91-96.

3. I. Eisenberger and D. S. Remer, "The Role of Interest and Inflation Rates in Life-Cycle Cost Analysis," *DSN Progress Report 42-43*, November and December 1977, pp. 105-107.

Table 1. Discrepancy Report summary, 1977

Assembly	Outage	Description of failure
Power amplifier	351 min	Six arc detector trips, three due to suspected waveguide mismatch.
	405 min	One high reflected power indication, removed by turning on coolant flow to an isolator.
	355 min	RF power limited; required adjustment of attenuator coupler set screw.
	35 min	Beam overcurrent relay tripped.
Power supply	17 min	Arc in high voltage cable; cable replaced.
	479 min	Eight fan or air-flow switch failures required replacing six fans and two air-flow switches.
	21 min	Three relay malfunctions.
	168 min	HV cable insulation breakdown and one loose HV connector.
	165 min	Transmitter could not be turned on because of jammed emergency off switch on remote control console.
Heat exchanger	735 min	Nine leaks at seals, sight glass, fittings, etc.
	426 min	Nine failures due to low flow, lost pressure, fan bearings, etc.
Procedural error	132 min	Outage (3% of total).
Miscellaneous	424 min	High noise, due to waveguide arcing.
	502 min	High noise, cause undetermined, no recurrence.
	70 min	Other miscellaneous.

Table 2. Effect assumed on costs

Option	Maintenance	Operations	Sustaining	Support
1. No improvement	+5%/Year	N/C	N/C	N/C
2. Refurbishment	-30%	-10%	-5%	-10%
3. Redesign	-50%	-15%	-15%	-15%
4. New transmitter	-60%	-25%	-25%	-25

Table 3. Comparative cost of transmitter options (thousands)

Transmitter option	Total cost	Implementation	Maintenance	Operations sustaining support	Cost reduction	% Outage reduction
Existing	$25,220	No cost	$8,776	$16,444	--	0%
Refurbish	$20,599	$265	$5,241	$15,093	$4,621	30%
Redesign	$18,991	$891	$4,115	$13,985	$6,229	50%
New design	$22,583	$4,406	$4,522	$13,655	$2,637	60%
New design (FY83 FY92)[a]	$18,996	$4,406	$2,983	$11,607	$6,224	60%

[a]Ten year cost after phase-out of old transmitter

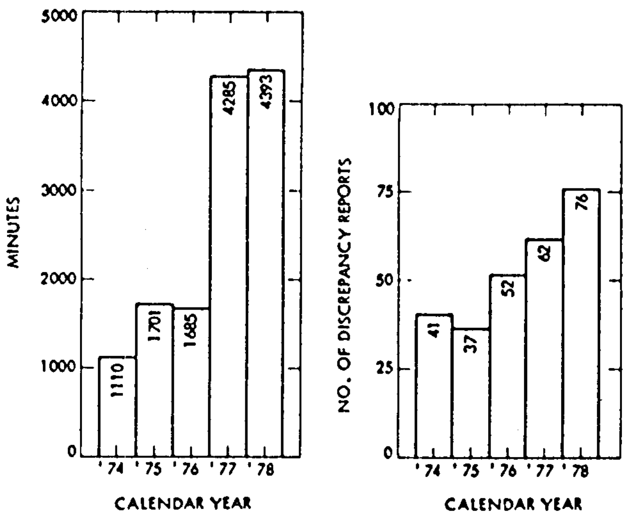

Fig. 1. 20-kW transmitter outage

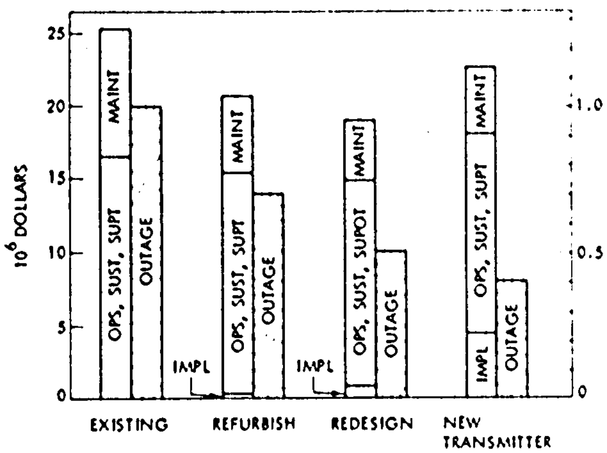

Fig. 2. Relative outage