Communications Research Centre

SEMICONDUCTOR PROCUREMENT FOR SPACE APPLICATIONS

by

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CRC TECHNICAL NOTE NO. 681

Department of Communications
Ministère des Communications

OTTAWA, OCTOBER 1976

COMMUNICATIONS RESEARCH CENTRE

DEPARTMENT OF COMMUNICATIONS
CANADA

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October 1976
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Standard Press — Wallaceburg, Ontario, Canada
Contract No. 660KX — 5 — 0001/1

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ABSTRACT

The results achieved on the CTS parts-procurement program with respect to semiconductor reliability indicate in large measure the realization of the aims. The cost of high reliability on this parts-procurement program is estimated at just over 1.2% of the CTS project cost. Recommendations are made on the adoption of a high reliability approach to future Canadian space projects parts-procurement and suggestions are made to maximize cost effectiveness.

1. BACKGROUND

The purpose of this Note is to review the experience on the CTS parts-procurement program and propose an effective technical approach to the procurement of semiconductor devices for space applications.

At the outset of the CTS Project, it was decided that in an attempt to achieve high reliability (Reference 1) in the flight model spacecraft, all active semiconductor devices would be specified and procured by CRC for issue as Government Furnished Equipment (GFE) to subsystem contractors. The benefits of this approach was seen to be as follows:

- Ensure adequacy and uniformity of specifications against which devices would be purchased, screened, "burned-in" and judged as to their acceptability:

- Select the suppliers of devices who had the capability to supply the parts in accordance with the specifications:

- Minimize project costs by minimizing device-type requirements (from subsystem contractors) while maximizing orders for individual parts:

- Maintain visibility and control throughout the procurement phase in order to gain confidence in the reliability of final deliveries and reduce probabilities of rejection, during and after screening and "burn-in":

- Expedite the procurement cycle so that scheduled deliveries would be maintained without compromising the reliability requirements.

Four classes of active devices were procured for CTS; namely, diodes, transistors, integrated circuits and hybrid microcircuits. Table I lists the general requirements laid down in the specifications for these four classes. These represent the ideal.

TABLE I

	REQUIREMENT	DIODES	TRANSISTORS	ICs	HYBRIDS
1.	Wafer selection/traceability	√	√	√	√ [1]
2.	Wafer qualification		√ [2]	√ [2]	
3.	Structural analysis		√	√	
4.	Pre-cap visual examination	√	√	√	√
5.	Bond strength		√	√	√
6.	Serialization	√	√	√	√
7.	Screening and "burn-in"	√ [3]	√ [4]	√ [3]	√ [3]
8.	Read and record data	√	√	√	√
9.	X-ray examination	√	√	√	√
10.	Identification of all failures	√	√	√	√
11.	Lot qualification				√

NOTES: [1] *All active devices in Hybrids to meet the individual requirements listed as for Transistors. All passive elements to be in accordance with the appropriate NASA MFSC specifications.*

[2] *Includes SEM examination.*

[3] *240 hrs burn-in at 125°C.*

[4] *168 hrs burn-in at 125°C.*

2. PROCUREMENT PROGRAM

Much effort was put into selection of vendors and many audits were carried out to evaluate capabilities of potential suppliers. These included their production processes and controls, their willingness to accept CTS specifications and their ability to meet CTS schedules. This activity was spread out over a period of 12 months and 6 scientists/engineers carried out the surveys on a part-time basis.

From these surveys and with assistance from device experts at NASA MSFC, RADC, JPL and other U.S. space program contractors, the preferred suppliers were identified. The majority of preferred suppliers ultimately signed contracts and became the sources of CTS semiconductors, for example:

- National Semi-Conductor Corporation for TTL 54L Series integrated circuits.
- RCA for C-MOS integrated circuits.
- Texas Instruments and Circuit Technology Incorporated for custom hybrid microcircuits.
- Harris for operation amplifiers.
- Fairchild for numerous transistors from controlled lines.
- TRW for high power transistors.
- Hewlett Packard for special purpose diodes.
- Crystalonics Inc. for analog to digital convertors.

The importance of vendor selection was appreciated from the outset of the parts-procurement program, first from the standpoint of design adequancy and secondly from the knowledge of past performance and current process standards and quality controls. To ensure the maintenance of (high-reliability) standards, the need was also recognized for continued monitoring of suppliers' in-house activities after contract negotiation. The value of monitoring was found to be particularly effective when a single-point contact at the technical level was established between customer and supplier.

As a result of the policy of supplying GFE, all semiconductors (Reference 2) for spacecraft flight model equipment, for flight spare individually mounted units (IMUs) and for certain custom built hybrids for the engineering model IMUs, the following procurements were made:

- Diodes - 5,080 devices (61 device types)
- Transistors - 2,227 devices (46 device types)
- Integrated Circuits - 4,251 devices (58 device types)
- Hybrid Microcircuits - 673 devices (12 device types)

Two unforeseen factors affected the implementation of the GFE parts procurement program; namely, the delays in finalizing designs which held up the preparation of parts specifications, and the unexpected change from a buyers' to a sellers' market in the electronic components industry. Attempts to maintain the overall spacecraft schedule in the face of suppliers' quoted lead-times inevitably led to compromises with respect to specifications. A secondary effect was the lack of time in which to pursue rationalization of the requirements for multiple device types submitted by subsystem contractors.

Where promised deliveries exceeded schedule requirements, alternative procurement paths had to be found. These could require some relaxation in specifications, for example, the deletion of requirements with respect to wafer traceability and pre-cap visual inspection. The common denominator within these alternative procurement paths was the employment of an independent screening house to carry out screening and "burn-up" in accordance with specifications. Device purchase took a number of different forms ranging from buying of overages from other space programs (for example, HA2-2700 operational amplifiers from Philco Ford), to permitting the screening house to buy from existing stocks.

With respect to device types, the more stringent or complex the requirement, the greater was the reluctance to accept alternative procurement paths. With the limited resources available, the emphasis placed on hybrids, integrated circuits and certain power transistors made the acceptance of alternative procurement paths for diodes and simple transistors almost inevitable. Table II lists the percentages of the device types procured in accordance with full specification requirements and those obtained using the alternative procurement paths.

TABLE II

DEVICE TYPE	DIRECT PROCUREMENT	ALTERNATIVE PROCUREMENT
DIODES		
General		100%
Special (IMPATT, VARACTOR)	50%	50%
TRANSISTORS		
Low Power	50%	50%
Medium Power	50%	50%
High Power	50%	50%
High Power	50%	50%
Special (Field Effect)	30%	70%
INTEGRATED CIRCUITS		
54L Series	100%	
C-MOS	100% *	
Linear	60%	40%
HYBRID		
Microcircuits	100%	

* *Additional screen carried out by NASA (Goddard Space Flight Center).*

3. DEVICE SCREENING AND BURN-IN

Regardless of the procurement path followed, all devices were screened and burned-in in accordance with the relevant specifications. No difference in standard of screening and burn-in was detectable between part vendor's in-house commitment and the separate screening house commitment with one exception. In the case of C-MOS devices, a series of tests, supplementary to that deemed necessary by, and conducted at RCA, was carried out on behalf of CTS by NASA GSFC.

There were a few cases of inadequacy in the specifications with respect to screening, in part due to the lack of complete knowledge of circuit application at the time of procurement. Four cases were of particular significance:

- *High Power Transistors.* Due to a lack of appreciation of the proximity of operating range to safe limits at both high current/low voltage and high voltage/low current drive levels only one screen was selected. Subsequent device failures illustrated the inadequacy of margins in the untested region. A retrofit program had to be initiated to replace these devices (Kertron KP 3500's) throughout the spacecraft.

- *Harris HA2-2700 Operational Amplifiers.* Two specific production problem areas came to light, neither of which were detectable by the screens called up in the specifications (missing or partially-missing resistors and thin oxide capacitors). Post-purchase additional screens had to be initiated to re-examine these devices.

- *NSC 54L Series ICs.* Due to screening and burn-in stress levels being lower than the transient peaks experienced in applications, the existence of thin oxide pinholes under the metallization was not detected until testing of assembled units.

- *C-MOS Devices.* The advisability of additional functional testing to check for latent failure-modes was realized prior to placing of orders. Because such tests were not specifically carried out by the vendor, arrangements were made with NASA GSFC, which had the necessary automatic test equipment, to subject all C MOS devices to these additional tests.

The identification of these deficiencies in screening requirements resulted from either failure analysis carried out on defective parts discovered during tests on both engineering-model and protoflight-model equipment, or from GIDEP Alerts. In all cases however, it was as a result of failure analysis that sound recommendations could be formulated with respect to the need for additional screens, or for extended functional testing, or for outright replacement by a different device.

4. DEVICE YIELDS

It was impossible to determine the device yields that vendors achieved from a given wafer, because this was regarded as proprietory information. In a number of cases it was known, by virtue of vendor monitoring, that yields were high but there was insufficient data available to make any assessment of the effect of the stringent CTS requirements with respect to wafer selection and qualification, structural analysis, and pre-cap visual examination upon a vendor's yield from the normal commercial level. By limiting the objective however and considering only yields from quantities of devices presented for screening and burn-in, comparisons based on different procurement methods are possible.

In the case of transistors, roughly 50% of these devices were procured from and screened and burned-in by, the manufacturer. The other 50% were screened and burned-in by an independent screening house. In a number of cases, the total order for a single device type was divided between these two procurement methods. Excluding the Kertron transistors eliminated from the parts list (KP 3500's) as previously mentioned, the figures shown in Table III were derived.

TABLE III

PROCUREMENT METHOD	NUMBER OF DEVICE TYPES	NUMBER OF DEVICES	PERCENTAGE ACCEPTABLE
Direct from Manufacturer	20	1,060	89%
Through a Screening House	25	1,060	65%

While the figures shown in Table III against "Direct from Manufacturer" are a fair assessment of yield, those shown against "Through a Screening House" require some interpretation. First, in those cases in which the screening house was given unscreened devices, there was good visibility on rejection rates and yields because all devices belonged to CRC and the screening house was being paid a piece rate for their work. Where a contract was negotiated with the screening house to supply a given number of screened and burned-in devices i.e., device procurement by the screening house from whatever source they could find, yield figures could be somewhat different to those used in compiling Table III, as lot rejection and replacement was not disclosed to the customer.

Secondly, while the pedigree of many device types screened and burned-in by a screening house was known (e.g., overages purchased from other space programs) a few were totally without the manufacturer's data, being only of standard commercial quality. A larger quantity of such devices had to be processed to establish confidence in the final selection for issue as GFE. Taking these factors into account, the assessment of the yield "Through a Screening House" being about 70% of that "Direct from Manufacturer" is probably valid.

5. COSTS COMPARISON

Using transistors as an example, a comparison of unit costs was carried out on those device types in which the two methods of procurement were employed. On a sample of 10 device types, the "Direct from Manufacturer" devices cost three and a half times as much as those obtained "Through a Screening House" (some cost 10 times as much).

Relating costs to yield, which gives a more accurate comparison for useable devices, the cost differential can be taken as 70% of 3.5:1, i.e., 2.5:1. This ratio still does not take into account the cost of any destructive type testing necessary to categorize the quality of the device lots purchased without manufacturer's data. With such purchases on CTS, destructive analysis was carried out, in-house by the Failure Analysis Section of DOC, at no direct cost against device procurement.

A further consideration which should be taken into account in making cost comparisons is the resulting stock overages. At a lower expected yield level, uncertainty about its true value forces the procurement agency to over-buy to avoid shortfalls. The tendency existed to make greater initial purchases of those devices being supplied "Through a Screening House" than when ordering "Direct from Manufacturer". Even making allowances for all the above, it is concluded that devices obtained "Direct from Manufacturer" cost at least twice as much as those procured "Through a Screening House".

6. RESULTS

Whilst it is too early to define the difference in operational life between devices whose procurement rigorously followed the specification and those purchased with lesser knowledge of pedigree but subjected to full screening and burn-in, the experience is as follows:

1. Out of a total of 8,000 semiconductor parts supplied GFE to subsystem contractors after CRC inspection and selection (examination of read and record data and X-rays), there were 21 genuine failures prior to subsystem deliveries (Reference 3). Of these 21 failures, 13 concerned four device types on which systematic failure modes were identified. These were:

- *Four TI Hybrids with damaged beam lead chips;*

- *Two NSC TTL ICs with thin oxide in pinholes under metallization;*

- *Three Harris HA2-2700 Operational Amplifiers with missing or partially-missing resistors or capacitor oxide breakdowns;*

- *Four Kertron 2N 4239 Transistors with defective metallization over oxide steps.*

2. Out of the 21 genuine failures at least nine can be attributed to the inadequacy of the screening requirements. These did not address the detection of the particular shortcomings (TI Hybrids with damaged beam lead chips; NSC TTL ICs with thin oxide pinholes; and Harris op-amps with missing resistors. It may be postulated that the Kertron 2N 4239 Transistor failures should have been identified before delivery.

3. There were no semiconductor failures after delivery for subsystem phases. Activities in this period covered subsystem integration, compatibility and spacecraft environmental testing, pre-launch checkout and launch, in-orbit activation and operation for two months.

4. Considering the spacecraft project as a whole, with a failure incidence with respect to semiconductors of 0.0026 (21 parts in 8,000) all of which were detected prior to spacecraft integration, it is concluded that the parts-procurement program followed on CTS did result in a very satisfactory standard of electronic device reliability.

7. CONCLUSIONS

With minor exceptions, the success of the CTS parts-procurement program can be attributed to:

Carefully Prepared Specifications. Whilst departures from specification were permitted with respect to diode and transistor purchase, there were, by and large, no deviations from the screening and burn-in requirements on any device type. The CTS requirements on hybrids and integrated circuits for traceability and manufacturing quality are now accepted as normal on (high-reliability) programs and as such have become standard on NASA MSFC specifications for such parts.

Vendor Selection. A knowledge of suppliers' methods, process controls and quality controls enabled risks to be minimized in the selection of the best source for individual device type purchases. Although a vendor's product may not remain consistent over a period of time, examination of past records plus confidence engendered by current practices, is still a good starting point in reliability forecasting. The complexity of the product and the difficulties of the processes are factors which, however, have to be taken into account in making decisions on the need for continued monitoring throughout the procurement orders.

Use of a Reputable Screening House. When scheduling requirements forced the decision to use a screening house for diodes and transistors, the integrity and capability of that screening house became a major factor in the CTS parts program. Although the experience on CTS in this respect was good, certain lessons were learned which may have future applicability, such as the undesirability of using the screening house as a purchasing agency. Besides the possibility of losing control on vendor selection, it is believed that this approach leaves the screening house prone to conflict of interest type situations in which reliability may be sacrificed in meeting schedules, or not incurring financial loss. It is to be noted that on CTS, there were occasions on which the screening house, acting as a purchasing agent, found itself "personna non grata" with the source of supply.

The Screening and Burn-in of Parts. With the exception of hybrids, little attention was paid to lot qualification. With small, one-time only orders for parts being filled from existing stocks and overages, the rejection of lot qualification as an essential step in the hi-rel procurement program was not a difficult decision to make. Other safeguards, such as quality sampling by destructive analysis on good specimens and failure analysis on rejected parts, were deemed to be a more cost effective method of gaining confidence in the standard of purchased parts. Major reliance was placed on the requirement for 100% screening and burn-in of parts.

The Slection of Parts for GFE Issue. Before issuing devices to subsystem contractors as GFE, careful scrutiny was carried out of both the devices themselves and the pertinent read and record data. Devices were examined for handling or transit damage. Read and record data were sifted to identify those devices whose parameter values lay closest to the limits and whose parameter drifts exhibited the greatest excursions. Any doubtful devices were rejected and final selection was made from the best available.

On the question of cost, it is difficult to apportion charges between reliability and schedule. On CTS, many trips had to be arranged to possible sources of supply in an endeavor to procure devices to meet subsystem requirement dates. All deliveries to CRC were arranged to be "hand carried" partly to meet urgent requirements but also to minimize the risk of transit damage or loss. To take CTS as representative of other space projects may or may not be realistic but on the data to hand, the cost of high reliability of semiconductors on the CTS project is assessed as follows:

1.	Cost of hi-rel in devices (at an actual cost of $900,000 covering all purchases, screening and burn-in and reducing this total in the ratio of 2:1 to bring it down to the cost of normal Mil.Std. devices, the remainder is taken as the cost of high reliability).	$450,000
2.	Cost of hi-rel specifications (assumed as 50% attributable to hi-rel requirements in the contract price negotiated with RCAL for specification preparation).	$100,000
3.	Cost of scientists/engineers employed in vendor surveys, production monitoring, quality sampling and failure analysis (taken as 4.5 manyears).	$180,000
4.	Cost of travel and living in the execution of the procurement program.	$ 25,000
	TOTAL	$755,000

Thus, in a $60,000,000 project embracing 8,000 flight semiconductors, this represents just over 1.2% of the total cost.

8. RECOMMENDATIONS

From the results achieved on the CTS Project, it is recommended that any future Canadian space project of a similar nature should adopt a hi-rel approach to parts procurement. This would achieve:

- A spacecraft or installation on which pre-launch performance can be demonstrated without ambiguity resulting from unreliability;

- an in-orbit life in which the reliability of parts is not the mission limiting factor.

8.1 BUDGETING

In pursuing a hi-rel approach on future space projects, budgeting should make allowance for:

1. Adequate preparation of parts specifications to ensure completeness of requirements with respect to applications and rationalization of device types to minimize parts lists. The need to specify and obtain critical components at the earliest possible time to confirm satisfactory operation in actual use, should be allowed for.

2. Sufficient effort to carry out the necessary surveys of potential vendors of parts so that the selection of preferred suppliers will reflect the lowest risks to reliability.

3. Sustained effort on parts production monitoring to ensure compliance with specifications. Rationalization with respect to this recommendation must take into account such factors as device complexity, processing difficulties, custom design, application criticality, vendor proficiency, volume production, space qualification, etc.

4. 100% screening and burn-in of all flight parts.

5. Adequate support from failure-analysis facilities to sample finished products and categorize rejects and failures.

6. Selection processes to ensure best choice of flight parts from available populations of devices.

8.2 PLANNING

To maximize cost-effectiveness in a hi-rel parts-procurement program for a space project the following points should be carefully considered by the responsible establishment or agency:

1. Maximum use of Mil Std and NASA specifications wherever applicable to avoid duplication of effort.

2. Maximum use of NASA Alerts and GIDEP evaluations to avoid pitfalls.

3. Establishing single point contacts at the technical level between customer and supplier and between customer and advisors to prevent misunderstanding and confusion.

4. Scrutinizing parts lists, preferred supplier lists and NASA documentation, to ascertain which parts could be separately purchased, then screened by an independent screening house, to minimize costs without compromising overall reliability.

5. Maintaining individual part traceability from purchase to application and location, to avoid uncertainty in the event of the need for replacement or substitution.

6. Ensuring that handling plans are adequate so that the reliability of devices is not inadvertantly compromised through carelessness.

9. REFERENCES

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CRC DOCUMENT CONTROL DATA

1. **ORIGINATOR:** Department of Communications/Communications Research Centre

2. **DOCUMENT NO:** CRC Technical Note 681

3. **DOCUMENT DATE:** October 1976

4. **DOCUMENT TITLE:** Semiconductor Procurement for Space Applications

5. **AUTHOR(s):** A.B. Shearer and R.S. Sennett

6. **KEYWORDS:**
   (1) Semiconductor
   (2) Procurement
   (3) Space

7. **SUBJECT CATEGORY (FIELD & GROUP: COSATI)**

   22 Space Technology
   22 02 Spacecraft

8. **ABSTRACT:**

The results achieved on the CTS parts-procurement program with respect to semiconductor reliability indicate in large measure the realization of the aims. The cost of high reliability on this parts-procurement program is estimated at just over 1.2% of the CTS project cost. Recommendations are made on the adoption of a high reliability approach to future Canadian space projects parts-procurement and suggestions are made to maximize cost effectiveness.

9. **CITATION:**

EXECUTIVE SUMMARY

DOCUMENT NO: CRC Technical Note 681

TITLE: Semiconductor Procurement for Space Applications

AUTHOR(S): A.B. Shearer and R.S. Sennett

DATE: October 1976

This Technical Note was prepared as part of the documentation of the CTS Project to record the approach employed; the experience gained; results achieved; and the conclusions reached with respect to the CTS Parts Procurement Program. It is believed that the information will be of considerable use to those employed on future space application projects in which the requirement for high reliability has a high priority.

The significance of the results achieved on the CTS Project was the failure-free performance of semiconductors, procured under this CTS program from spacecraft integration to in-orbit operation. This document records this achievement and makes recommendations for future space-projects management.

SOMMAIRE À L'INTENTION DE LA DIRECTION

N° DU DOCUMENT: Note technique n° 681 du CRC

TITRE: Acquisition de semiconducteurs aux fins d'applications spatiales

AUTEUR(S): A.B. Shearer et R.S. Sennett

DATE: octobre 1976

La présente note technique a été préparée à titre documentaire dans le cadre du programme du STT afin d'indiquer la méthode qui a été utilisée, l'expérience acquise, les résultats obtenus et les conclusions tirées en ce qui concerne le Programme d'acquisition de pièces. On croit que ces renseignements seront extrêmement utiles aux employés qui s'occuperont des projets futurs en matière d'applications spatiales où il est nécessaire d'accorder une forte priorité à l'exigence de fiabilité élevée.

L'importance des résultats obtenus dans le cadre du programme du STT réside dans la performance parfaite des semiconducteurs utilisés, du début de la fabrication de l'engin spatial jusqu'à son utilisation sur orbite. Le document expose les résultats en question et présente des recommandations concernant la gestion future des programmes spatiaux.

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DATE DE RETOUR

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