W. Tattam

EXHIBIT No. 3

HIRST RESEARCH CENTRE

COMMERCIAL IN CONFIDENCE

SURFACE ACOUSTIC WAVE FILTERS FOR ESA/SCCG QUALIFICATION APPROVAL PROCESS IDENTIFICATION DOCUMENT

QDA–PD–190 ISSUE: d Apr 90

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Section 1

HIRST RESEARCH CENTRE

COMMERCIAL IN CONFIDENCE

SURFACE ACOUSTIC WAVE FILTERS
FOR ESA/SCCG QUALIFICATION APPROVAL
PROCESS IDENTIFICATION DOCUMENT

ISSUE: Draft d Apr 1990

A J Dyer..Date............................

R A E QSA...Date............................

F S McClemont...Date............................

T A Elson...Date............................

Approved By:	.... (Manufacturer)	.... (Qualifying Space Agency)
Date:		

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AMENDMENT RECORD

Date	Details	C/N	Approved By: (Project Quality and Project Manager)

SURFACE ACOUSTIC WAVE FILTERS FOR ESA/SCCG QUALIFICATION APPROVAL PROCESS IDENTIFICATION DOCUMENT

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Section 3 - Manufacture and Testing

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Section 2

MANUFACTURING ORGANISATION

ORGANISATION AND MANAGEMENT

An organisational diagram for GEC is shown in Figure 1.

The GEC Hirst Research Centre

This is a central research facility for the main group of GEC companies, with direct responsibility to the General Electric Company plc. The Hirst Research Centre has contracts with the UK Ministry of Defence as well as communications systems companies and international authorities such as the European Space Agency. Collaborative research in the UK and in Europe is playing an increasing role in our activities and we are a major partner in JOERS and ALVEY in the UK, and ESPRIT, RACE and BRITE in the EEC.

Current activities include research on aspects of silicon integrated circuits, gallium arsenide microwave integrated circuits, infra-red and optical devices, and high temperature superconductors.

Materials Science Laboratory provides under-pinning to all programmes, as well as providing a wide range of analytical techniques of service throughout the Company. In particular, strategic materials are grown such as Very High Purity Quartz, which will be used in this programme.

An organisational diagram for the GEC Hirst Research Centre is shown in Figure 2.

The Device Applications Laboratory

The Device Applications Laboratory undertakes fundamental research and development of piezoelectric devices for high precision frequency control and signal processing applications in the space and defence markets. The main areas of work are:

Bulk Wave Research

Advanced studies of both the theory and technology of precision piezoelectric resonators are being undertaken to develop components for use in the next generation of communication systems. Current activities include the development of miniature low-power oscillators, and resonators for use in ionising radiation environments.

Surface acoustic wave (SAW) filters

A comprehensive capability is maintained for the design and fabrication of high performance SAW bandpass filters. Research work is concentrated on advanced device modelling and computer aided design techniques which have been used with proven success in recent high precision applications.

Piezoelectric materials

Fundamental studies on existing and new piezoelectric materials are being carried out. These include the investigation of radiation effects in quartz and the evaluation of lithium tetraborate for wide-band filter applications.

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Electron beam micro-fabrication (EBMF) unit

The EBMF unit offers an electron-beam lithography service for the fabrication of photomasks with fine linewidths down to 0.4μm. Highly accurate reticles for projection alignment systems are also made. There is a direct-write-on-wafer capability for certain specialised tasks, for example, the definition of sub-micron gates in microwave FETs and MMICs.

An organisational diagram for the Device Applications Laboratory is given in Figure 3.

Quality Assurance

The organisation of HRC's Quality Assurance Department is described in the Quality Manual ref QAM-01. Our approach to quality assurance is designed to satisfy AQAP1, NATO requirements for an Industrial Quality Control System.

An organisational diagram for HRC's Quality Assurance Department is given in Figure 4.

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Figure 1 ORGANISATIONAL DIAGRAM OF THE GEC

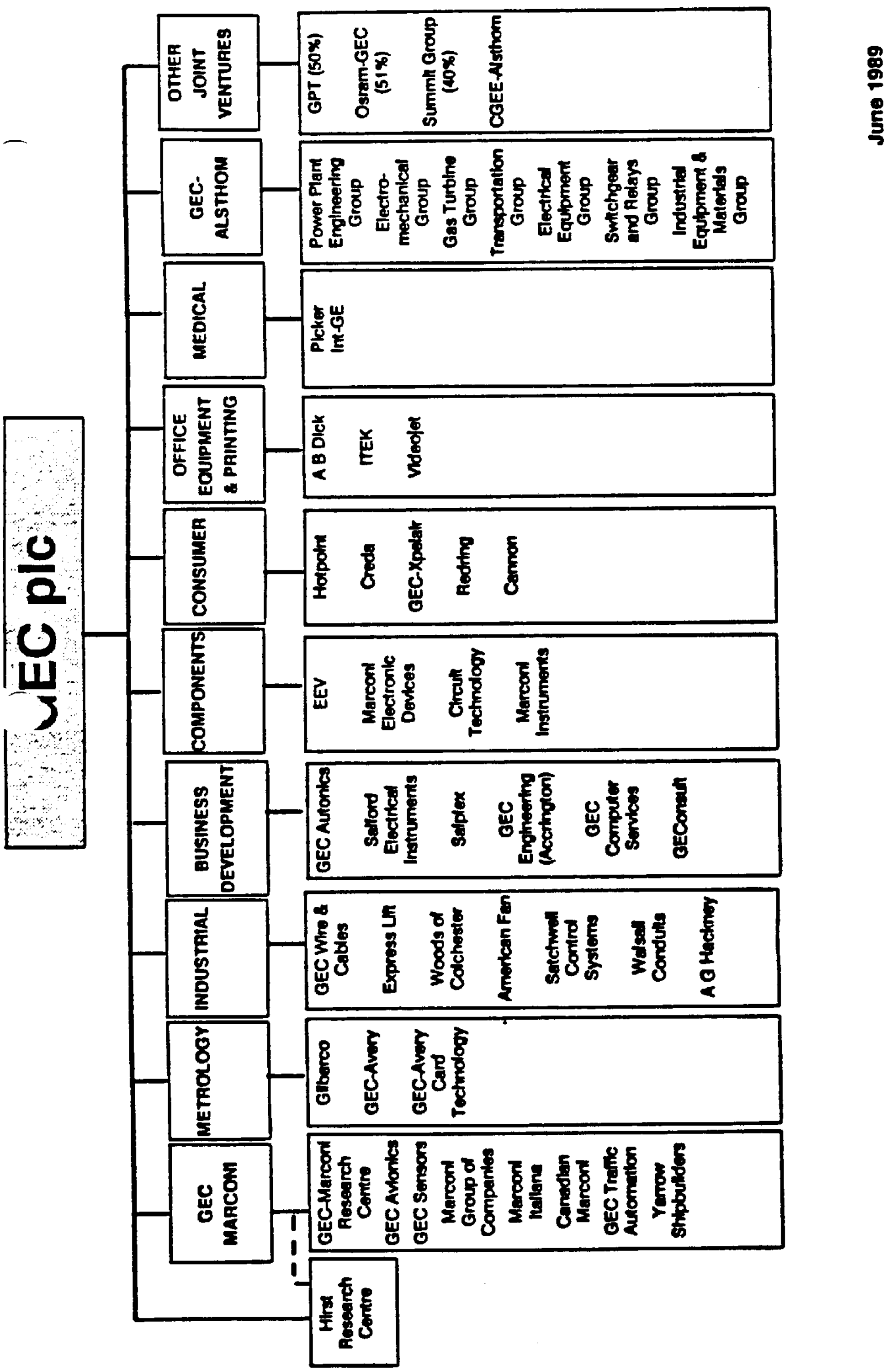

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Figure 2 ORGANISATIONAL DIAGRAM OF THE GEC HIRST RESEARCH CENTRE

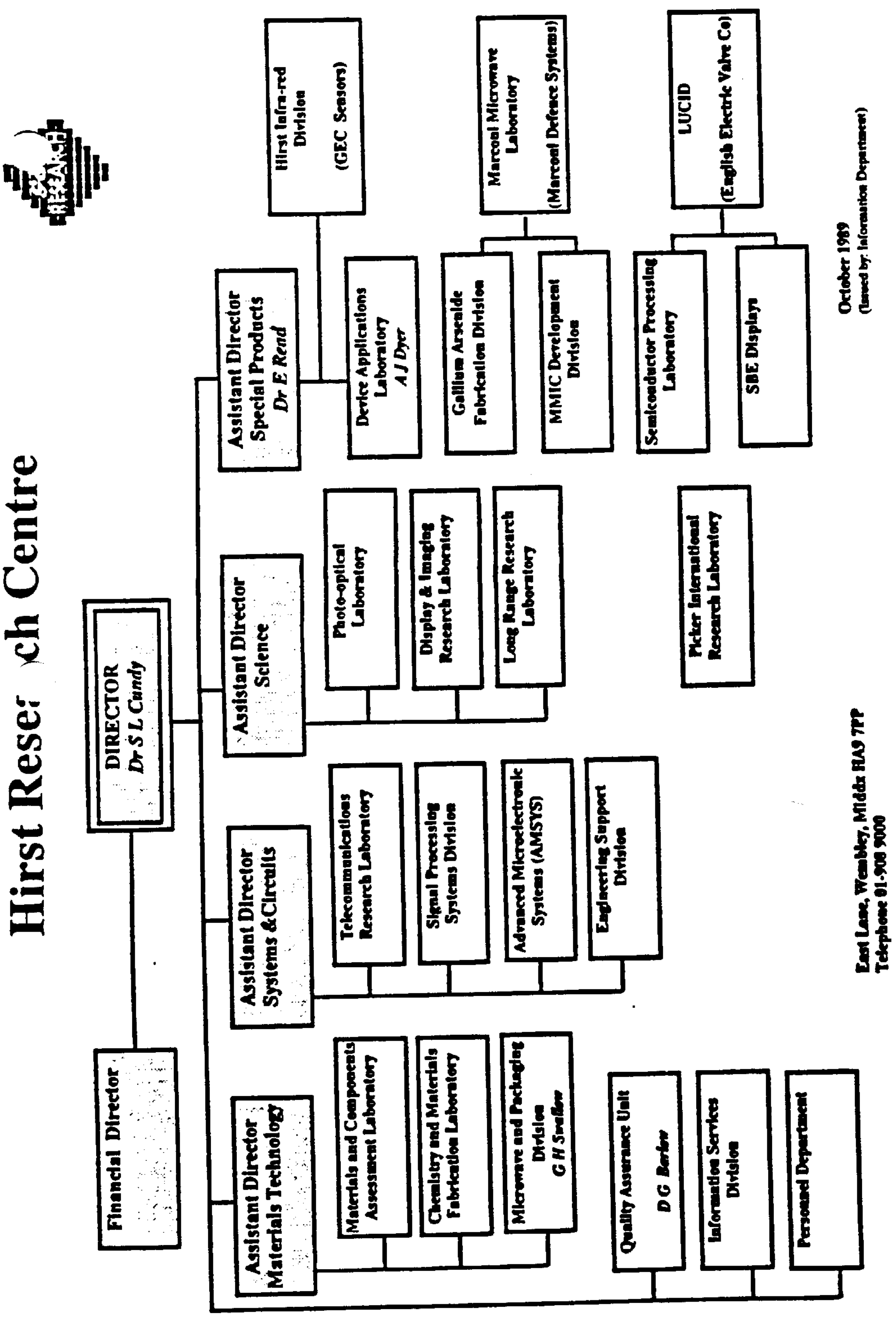

Figure 3 ORGANISATIONAL DIAGRAM OF THE DEVICE APPLICATIONS LABORATORY

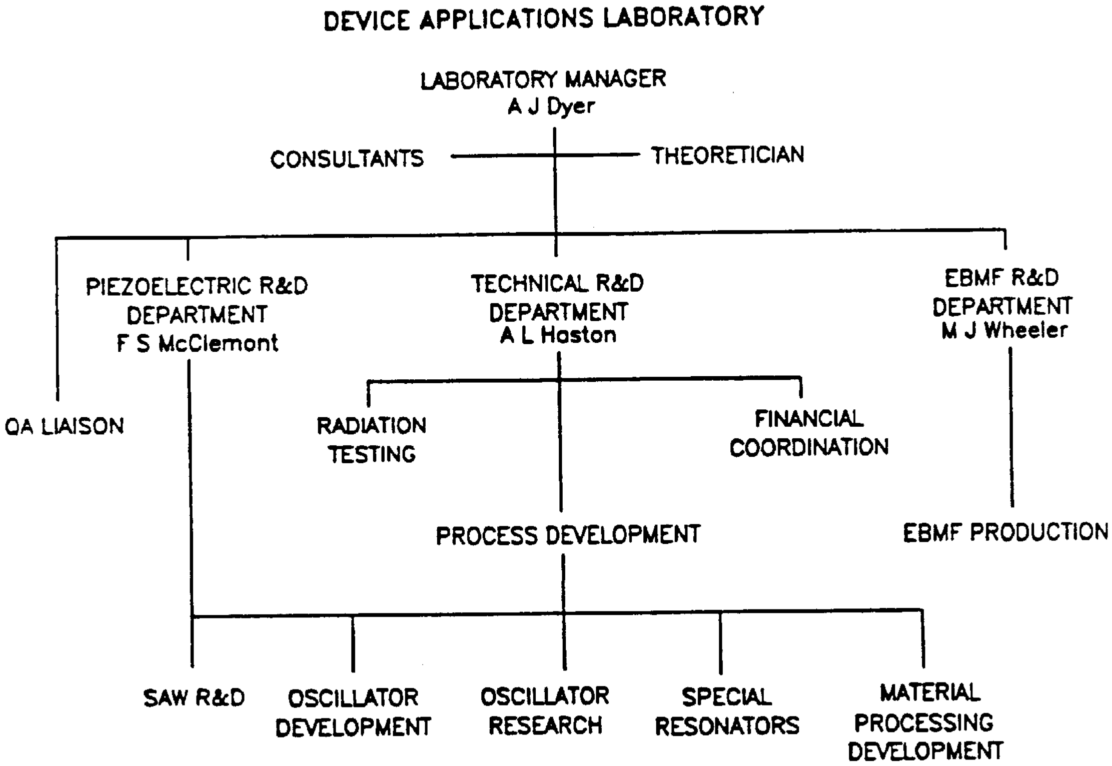

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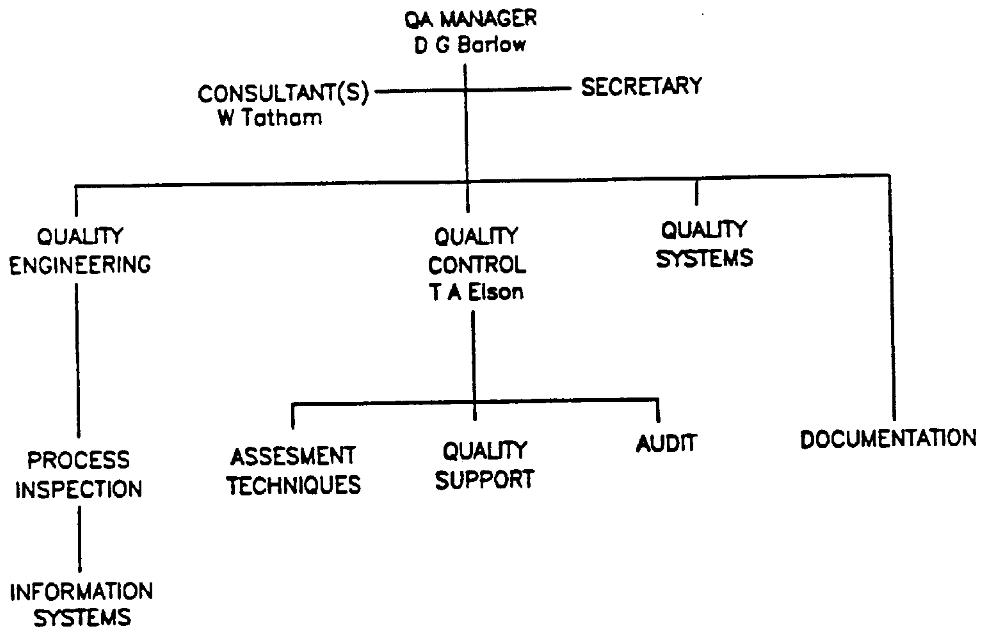
Figure 4 ORGANISATIONAL DIAGRAM OF HRC's QUALITY ASSURANCE UNIT

QUALITY ASSURANCE UNIT



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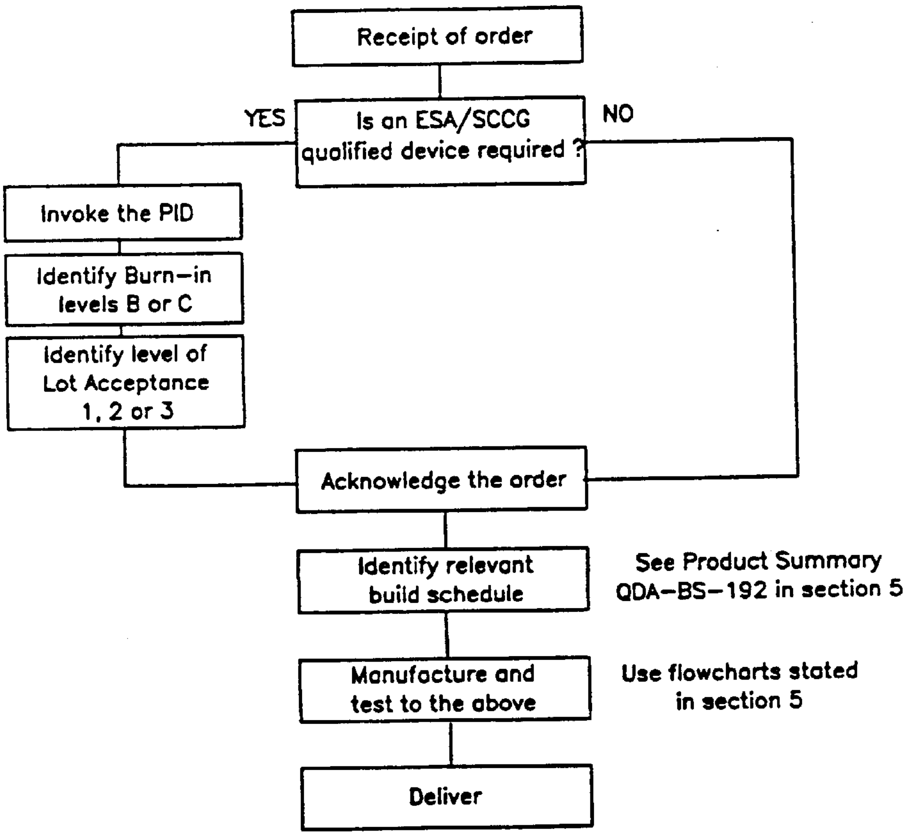
Section 3

MANUFACTURE AND TESTING



Related Procedures; QPM–01–17 Contract Negotiation and Orders
QPM–02–25 Project Management
QPM–09–36 Control of Fabrication

PROCESSING AREAS

1. Quartz Growth

The Chemistry and Materials Fabrication Laboratory at HRC maintains a facility for the growth of high purity synthetic quartz, which is radiation hard and is used for high quality SAW filter applications. The material is grown hydrothermally in highly specialised pressure vessels under extremely carefully controlled conditions in Laboratory C8.

2. Materials Processing Development

This area which is currently based in building 72 and occupies an area of 10,000 sq ft, provides a specialist service working to achieve optical tolerances on single crystals, glass, semiconductors and ceramics. Facilities include an X-ray goniometer to allow crystal orientation to be measured, auto-collimation for checking angular tolerances and parallelism, and interferometry for flatness measurement, as well as sawing, drilling, grinding, lapping and polishing machines to handle a wide range of materials and sizes. The area is under the direct management of the Device Applications Laboratory and is used extensively for the fabrication of quartz crystal blanks and SAW substrates.

3. B13 Clean Room

This area which is under the direct control of the Device Applications Laboratory is a class 100 clean room of approximate area 1000 sq ft and is the main facility for the processing/assembly of quartz resonators and SAW filters. Facilities in the cleanroom include chemical work stations for wet chemical operations, eg cleaning of crystals and substrates; deposition of metallisation by electron beam evaporation; assembly, adjustment and encapsulation of quartz resonators; photolithography, assembly and testing of SAW filters.

The clean room has recently been refurbished to implement extensive measures for protection against electro-static discharge, including conducting floor and bench surfaces, wrist straps etc.

4. Electron Beam Microfabrication Unit

The EBMF Unit, which is under the direct control of the Device Applications Laboratory, is housed in HRC Laboratory D11. The core of the facility is the Cambridge Instruments EBMF 6.5 electron beam microfabricator, which offers an e-beam lithography service for fabrication of photomasks with linewidths down to 0.4μm, and a direct-write-on-wafer capability. The EBMF 6.5 is housed in a small custom built clean room, and is supported by an ancillary clean area for processing by wet chemicals (dry etching available), and optical inspection.

5. B63 Laboratory

This is the general assembly/test/measurement area for quartz crystals, oscillators, and SAW filters within the Device Applications Laboratory, with an area of about 2500 sq ft the laboratory includes extensive modern r.f. measurement apparatus, including network, spectrum and noise analysis; frequency sources, including a primary reference standard; monitoring of frequency stability (short and long term). These measurements can be coupled together with environmental testing such as temperature cycling, vibration, shock etc. Almost all measurements are under computer control and a local area network has recently been installed to provide sharing of resources between equipments, and a central data storage facility. The laboratory is linked to HRC's central computing facility, but some powerful programs, eg a thermal modelling package are available on desk top computers.

There is a dedicated, environmentally controlled measurements room including ESD protection measures.

6. Thin Film Unit

The Special Techniques Division of the HRC operates a unit for the design and manufacture of thin film hybrid circuits. Facilities include circuit layout /design, semi clean work area, chemical workstations, photolithography, packaging, assembly, inspection and test areas. The thin film unit is based in Laboratory A8.

7. Quality Assurance

The QA area of HRC is based in laboratory B61 and includes a specialised area for the inspection and measurement of incoming goods, part of which is protected against damage to ESD sensitive devices.

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Section 4

COMPONENT DESCRIPTION

General

Surface Acoustic Waves

In a solid material elastic waves can propagate, with the displacement parallel or perpendicular to the direction of propagation. If a boundary is introduced parallel to the direction of propagation, modes other than bulk waves become possible. Surface Acoustic Waves (SAW) devices make use of the Rayleigh wave, which travels along the free surface of the material. The wave amplitude is a maximum at the surface and decays rapidly with depth into the material; almost all the energy is confined to a region extending about one wavelength into the bulk. As the velocity of the surface wave is around 3000 m/s, the wavelength is less than the free space electromagnetic wavelength by a factor of 10^5.

The surface motion is rather like that associated with waves on the sea. The only transverse displacement in isotropic materials is normal to the surface, and the longitudinal displacement is in phase quadrature with the vertical one. A particle of the material being subject to a SAW wave will therefore trace out an ellipse. Of the two most popular materials for SAW devices, YZ lithium niobate has only sagittal plane (i.e. vertical and longitudinal plane) displacement, whereas X directed waves on ST cut quartz have all three components of displacement. If the material is piezoelectric, the travelling acoustic wave will be accompanied by an electric wave, and by the same token electric fields may be used to excite surface acoustic waves.

Transducers

An interdigital transducer consists of two interleaved sets of parallel metal electrodes, connected to the two electrical terminals. The electric field gradient can be considered to be the driving force for the surface waves, so a wavelet is generated at every electrode edge where the field gradient is highest. The contributions of these wavelets add up to give a wave travelling in each direction.

A SAW device is naturally a tapped delay line, so the impulse response of a transducer is a stream of impulses; one for each finger edge, separated in time by d/v where d is the gap finger width and v is the SAW velocity. The response can be tailored by weighting the transducer, i.e by making some finger pairs emit more strongly than others.

As it is impracticable to apply different voltages across different finger pairs, weighting is normally achieved by adjusting the overlap length, a technique called 'apodisation'. Dummy electrodes are used to ensure uniform mass loading of the surface, reducing diffraction or focusing effects.

SAW filters

SAW phenomena are ideally suited to the manufacture of transversal filters where the output is the weighted sum of delayed versions of the input. Unlike L-C ladder networks, transversal filters are non minimum phase structures: this means that the amplitude and phase responses are capable of being independently specified. SAW bandpass filters can have very nearly linear phase shift (constant group delay) across the passband. On the other hand, SAW dispersive delay lines in which the finger pitch is varied can be used to generate FM chirp pulses and to compress the received pulses in pulse compression radar systems .

For over fifteen years GEC have been involved in the development of high quality SAW devices, resulting in a comprehensive computer aided design facility, and manufacturing techniques specialising in processing of quartz and lithium niobate. Filters may be designed within the following limits of performance:

Frequency range	10 MHz - 1 GHz
Fractional bandwidth	0.3% - 50%
Transitional bandwidth	>50 KHz
Stopband rejection	Up to 70 dB
Insertion loss	6 to 30 dB
Phase ripple	<1 deg p-p
Amplitude ripple	0.05 dB p-p
Temperature performance (25°C)	
$LiNbO_3$	90 ppm/C
$LiTaO_3$	35 ppm/C
Quartz	parabolic <4x10-8/°C

It should be noted that the above are limits, and due to conflicting design goals, are not all attainable in a single device. When considering variants of standard devices, all parameters detailed need to be specified to allow design trade-offs to be made. Careful consideration should be given to systems tolerances to avoid over specification of desired rather than required performance.

Filter Configuration to be Qualified

Design Techniques

The two transducers of the SAW filter are designed using a custom, proprietary suite of programs described in the relevant flowchart, and installed on HRC's mainframe computer system. The first, simple transducer can be designed using empirical design rules, or if necessary by a modified version of the optimisation technique used for the second transducer. The second transducer is synthesised by subtracting the frequency response of the first transducer from the overall desired frequency response, which gives the ideal response of the second transducer. This is Fourier transformed to give the ideal impulse response of the second transducer, which unfortunately is infinite and cannot be implemented in the real world. This impulse response must be truncated to a duration (transducer length) which can be physically tolerated. The truncation introduces certain distortions back into the corresponding frequency response; using this condition as the starting point, the frequency response of the second transducer is optimised by a linear programming technique.

This 'ideal' response must then be analysed for the main second order effects such as diffraction and circuit loading (connecting one transducers to actual electrical impedances). Corrections for these effects can be introduced by pre-distorting the design at the synthesis stage, or (diffraction only), by an iterative procedure, in which the tap weights of the second transducer are adjusted so as to give the correct (ideal) SAW signal as seen from the first transducer.

Once the final geometry of the device has been finalised, the design is turned into pattern data in a format compatible with the electron beam machine which will be used to direct-write the devices, using custom software.

Materials and Manufacturing Methods

The SAW filters to be qualified utilise a CST - cut quartz substrate. These substrates are derived from synthetic quartz, which is grown in-house. HRC's High Purity Quartz, which is radiation hard, is grown hydrothermally in large autoclaves by a proprietary process. The resulting quartz stones are qualified to stringent standards, using x-ray topography to find crystal defects, and infra-red spectroscopy to measure impurities.
Stones are processed into precision - oriented, optically polished wafers by specialised sawing, grinding, lapping, polishing and x-ray crystallography techniques.

Wafers are cleaned and metallised in clear conditions using standard wet chemical processes followed by electron-beam evaporation/deposition of a film of aluminium. The launching and detecting transducers of the filter (IDT's) are formed using a specially developed direct-write-on-wafer electron beam lithography technique, using a Cambridge Instruments EBMF 6.5 Microfabricator, which provides a sub-micron linewidth capability. Wafers are diced into substrates by standard techniques, and the resulting 'chips' are subject to rigorous visual inspection procedures.

Substrates are mounted in bought-in custom solid sidewall metal packages designed for seam sealing.

The mounting adhesive, and SAW end absorber, is a thin film of one-part silicone rubber compound, which provides the necessary compliance over a wide temperature range. Connection of the transducers to the relevant package pins is by gold thermocompression tape bonding.

Some devices, for operation with reduced insertion loss, require additional, integral tuning components in the form of thin film spiral inductors. These are designed using custom software, which generates its own artwork. The inductors are formed on fused silica substrates which are machined in-house, and processed in HRC's Thin Film Unit. The inductors are mounted and connected in a similar manner to the SAW substrate.

The saw filters are electrically tested using custom test fixtures and automatic network analyser techniques using error correction software, both before and after encapsulation, which is by a standard seam sealing process.

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Figure 5 Typical SAW Filter.

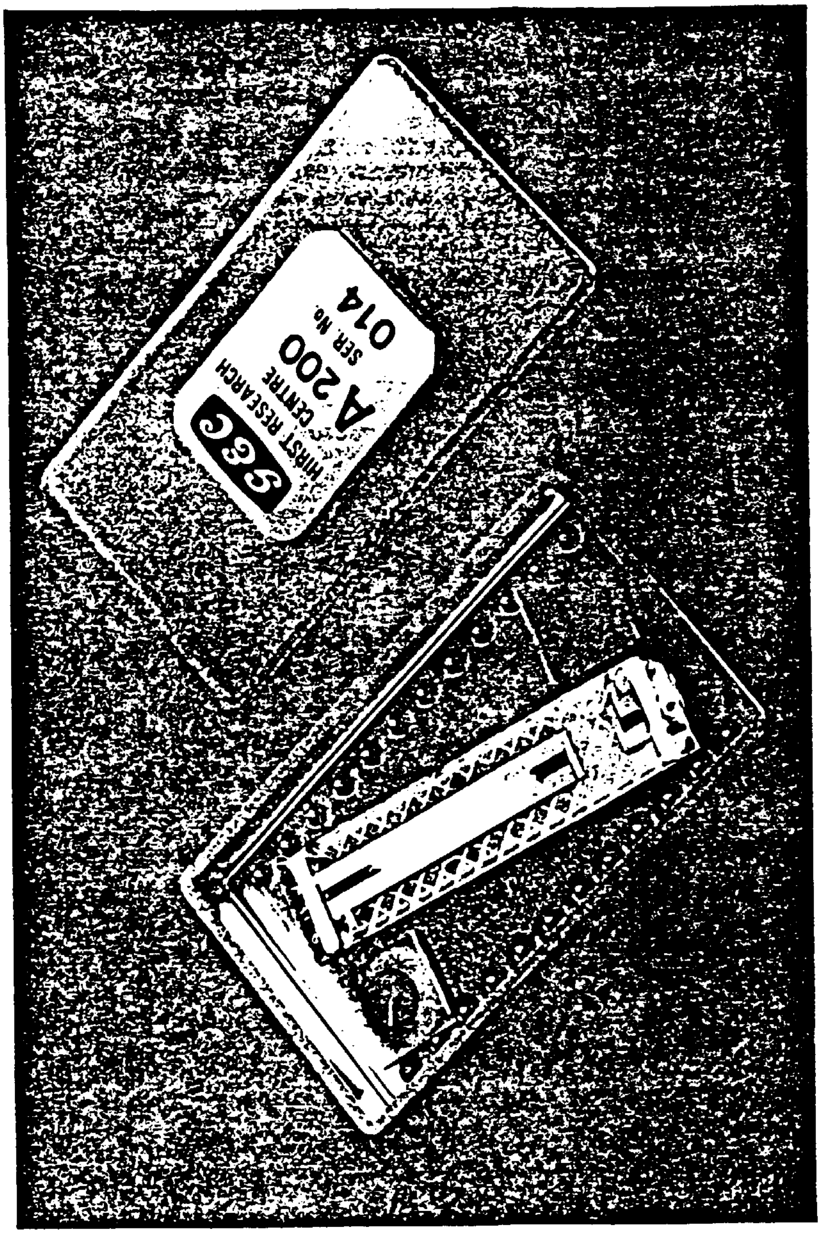

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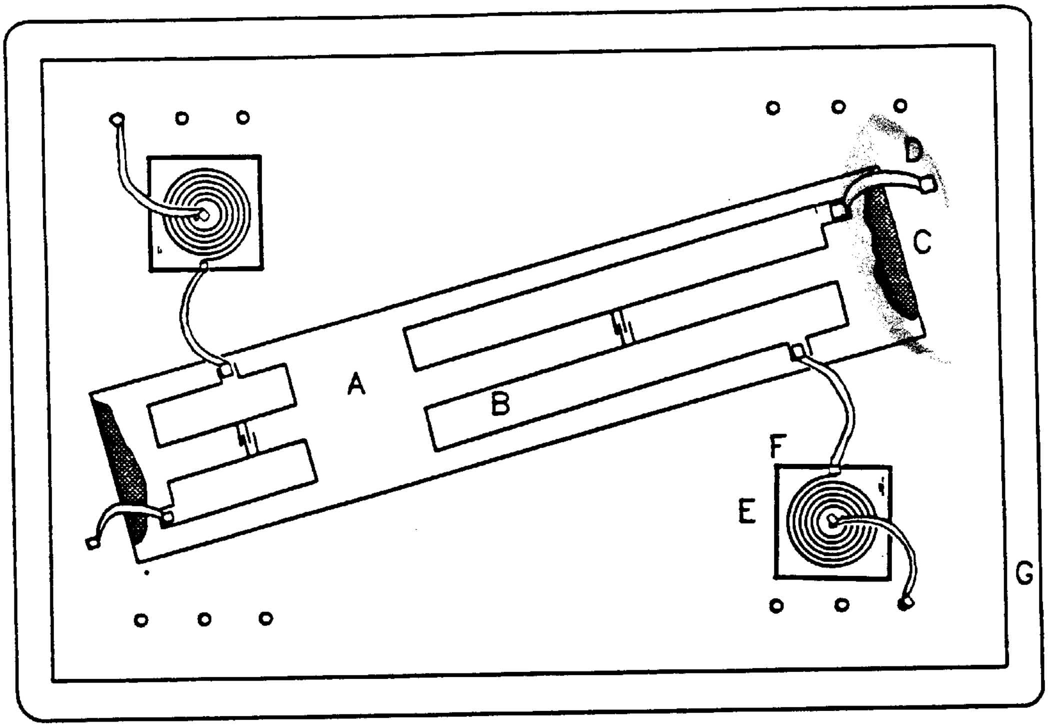
Figure 6 Schematic diagram of a typical SAW Filter.



Component		Supplier
A.	Quartz Substrate	HRC
B.	Aluminium Metallisation	HRC
C.	Dow Corning 730 RTV acoustic absorber (2 places) This material is also used for mounting the substrate	Dow Corning
D.	Gold tape	Johnson Matthey
E.	Spiral inductor substrate	Heraeus
F.	Thin film spiral inductor	HRC
G.	Package and lid	Doloy

cf p42

Section 5

CONTROL DOCUMENTATION

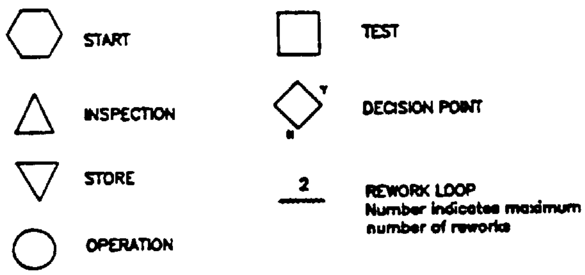
This section includes the design, manufacture and testing flowcharts for the Space Qualified SAW filter, in which the nominated processes cross refer to the Product Summary.

This section also includes a list of specifications for each process step, control inspection and test in the manufacturing and testing of Space Qualified SAW filters. The list defines the build standard of a particular device.

Finally, this section includes inspection and control specifications jointly agreed by HRC and the QSA to be part of the PID.

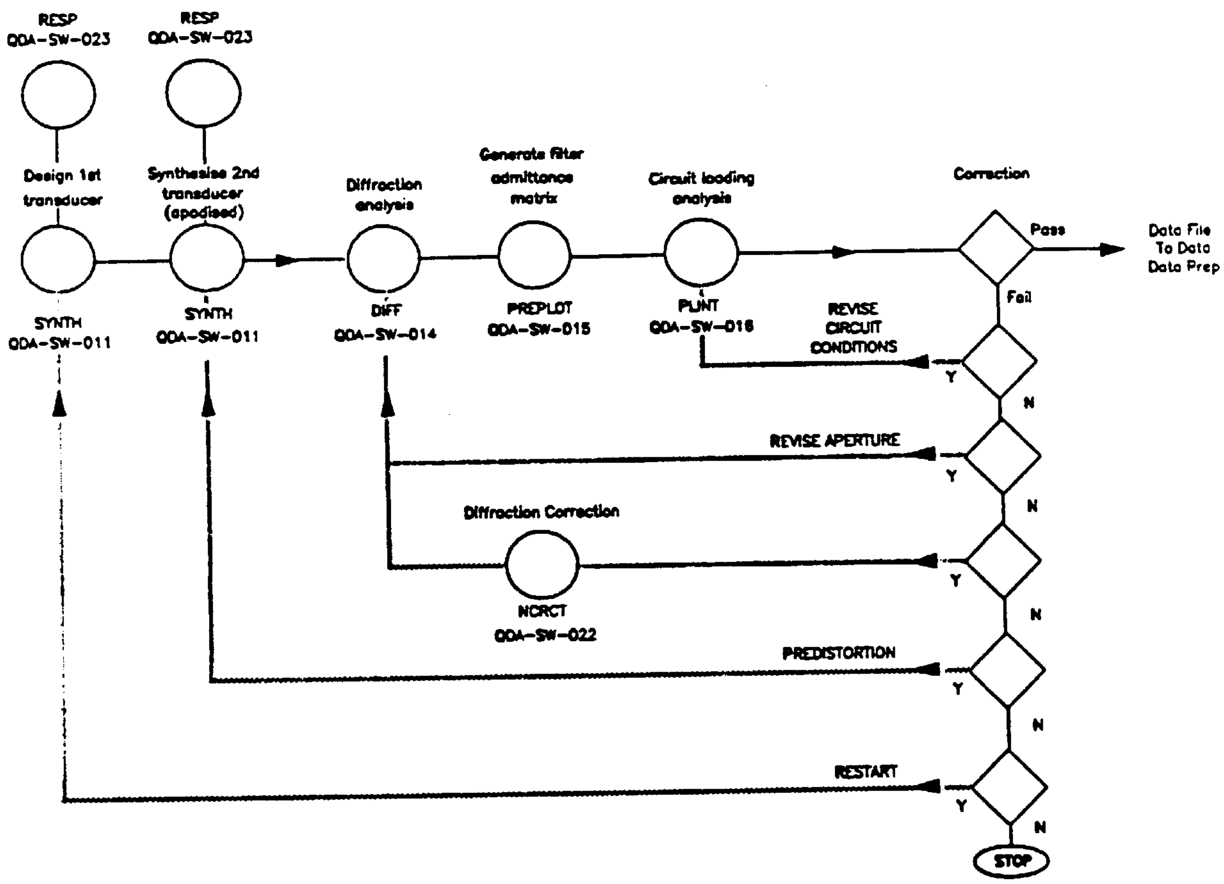
A list of the symbols used in the flowcharts is printed below:

FLOWCHART SYMBOLS



Design Flowchart for SAW filters (Please see next page for key)

SAW Filters
Flowchart A – Design (Quartz Substrate)



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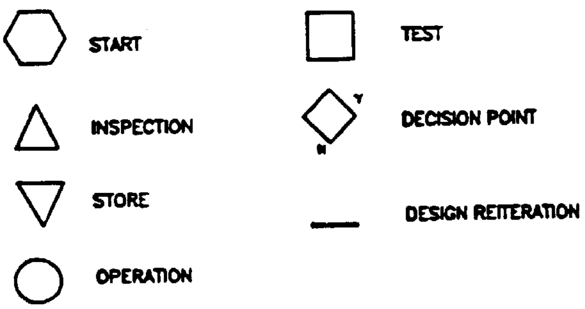

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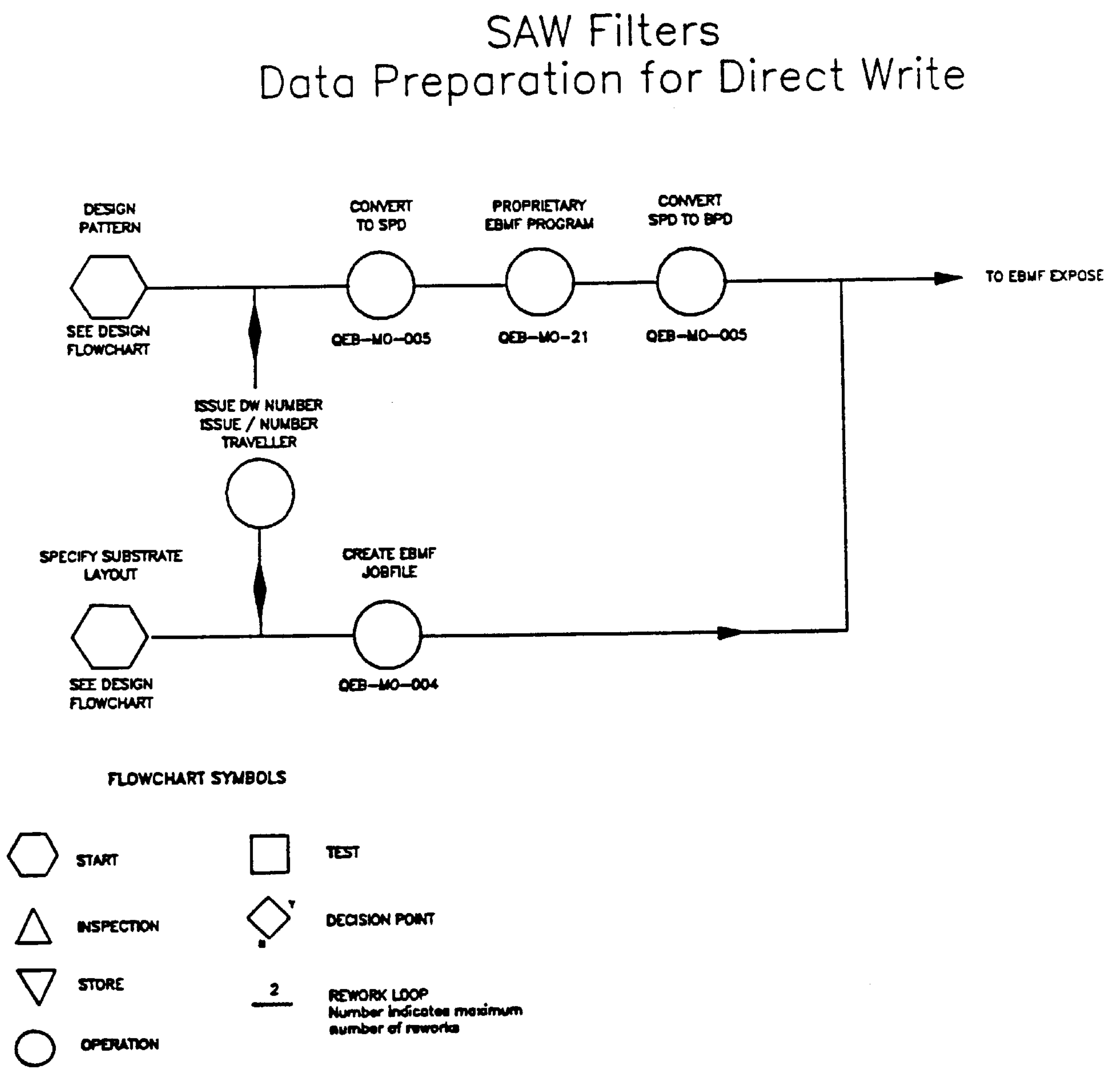
Key to Design Flowchart

PROGRAM	DESCRIPTION	INPUT	OUTPUT
SYNTH	Master synthesis program using linear programming	Desired frequency response	Transducer tap weights
DIFF	Analysis of diffraction effects	Transducer geometry, substrate material data, frequency range	Input data for PREPLOT
PREPLOT	Plotting of diffraction effects	Frequency range	Frequency response with diffraction
PLINT	Circuit loading analysis	Admittance matrix of filter from PREPLOT	Frequency response with circuit loading
NCRCT	Diffraction correction	Uncorrected tap weights	Corrected tap wts.
RESP	Plotting for SYNTH	Transducer tap weights	Frequency response

Data preparation flowchart



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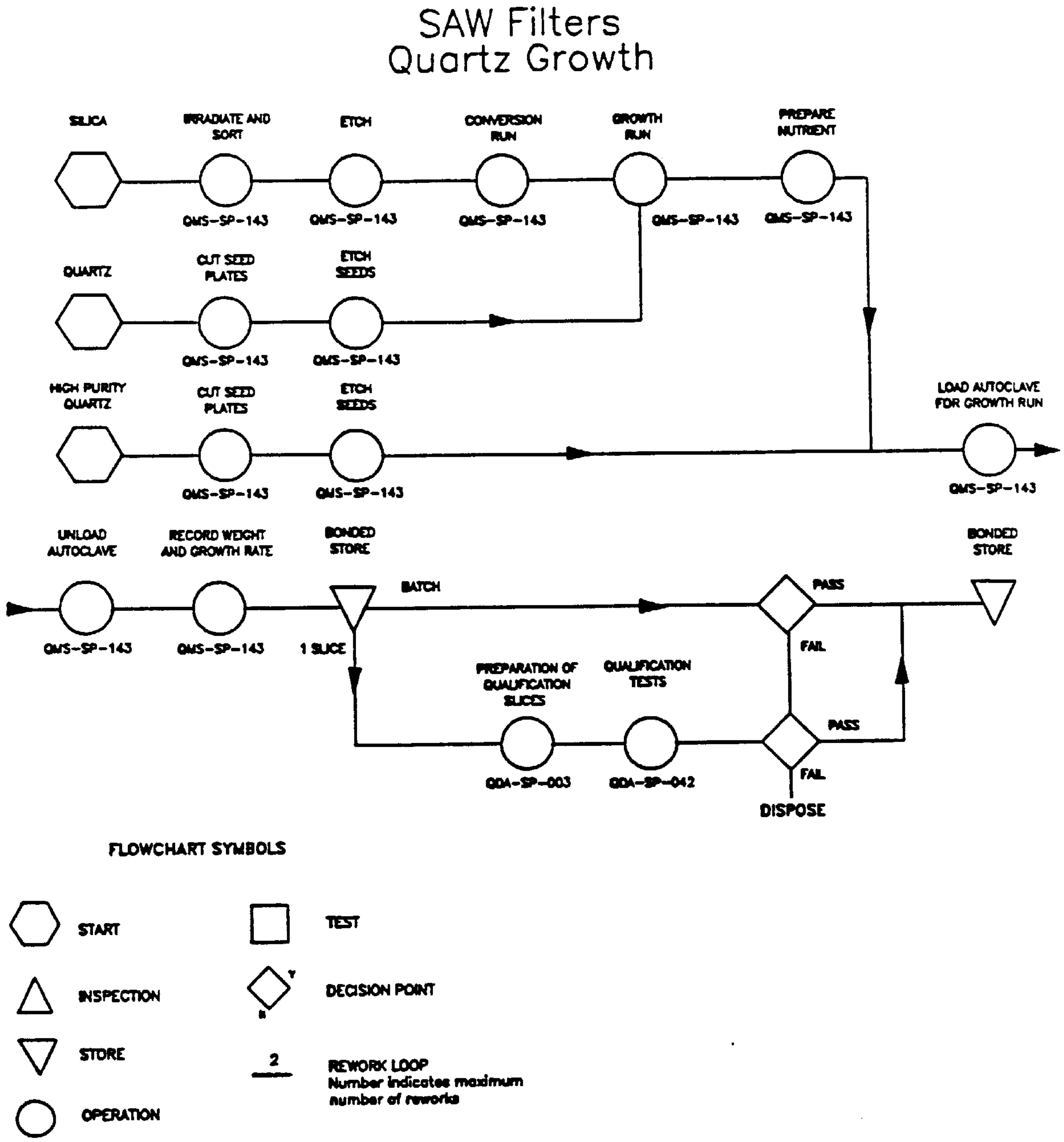
Manufacturing Flowchart - Quartz Growth



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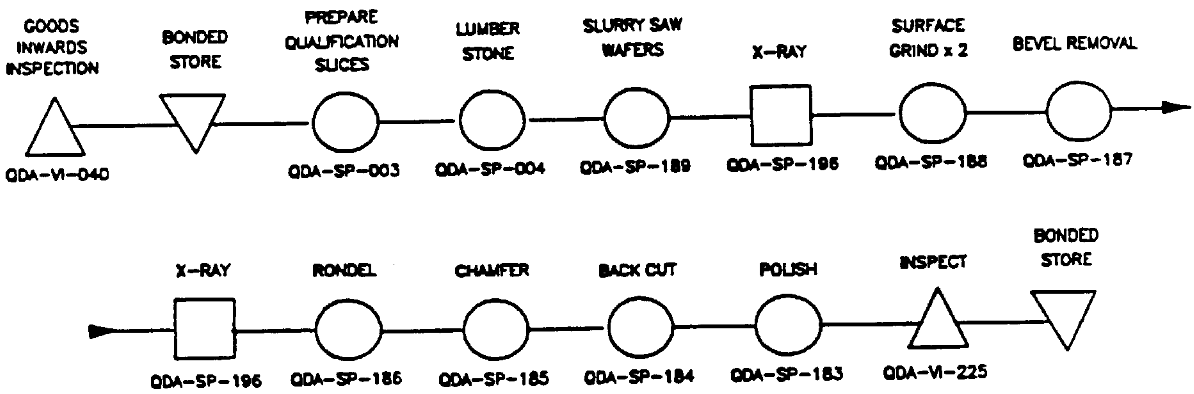
Manufacturing Flowchart - Stone to Wafer

SAW Filters
Stone to Wafer



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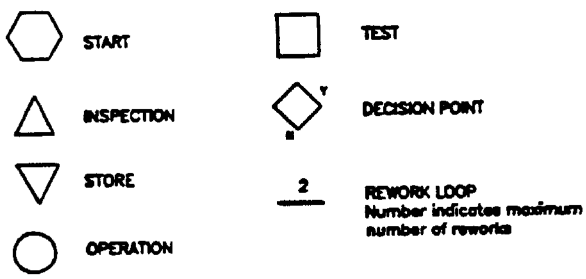

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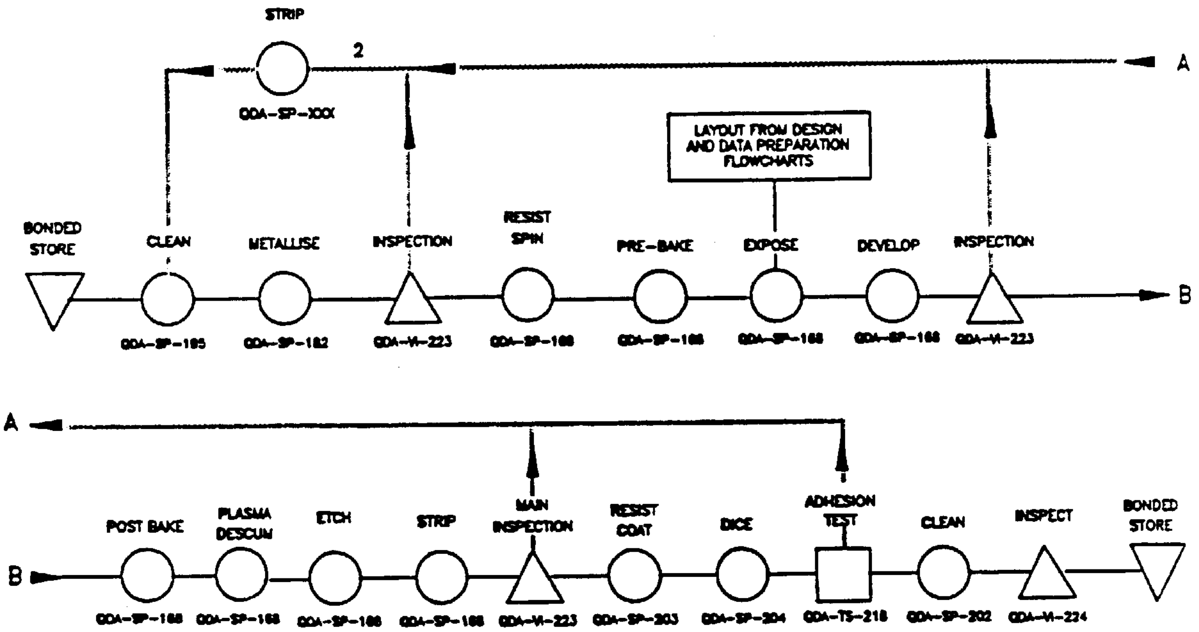
Manufacturing Flowchart - Wafer to Substrate by Direct Write

SAW Filters
Wafer to Substrate by Direct Write



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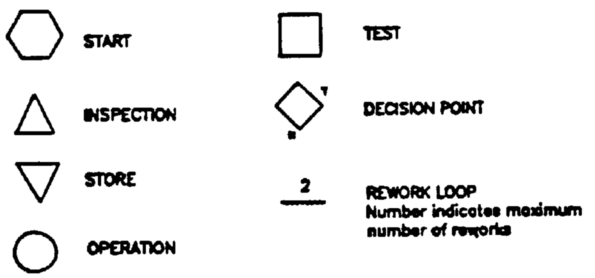

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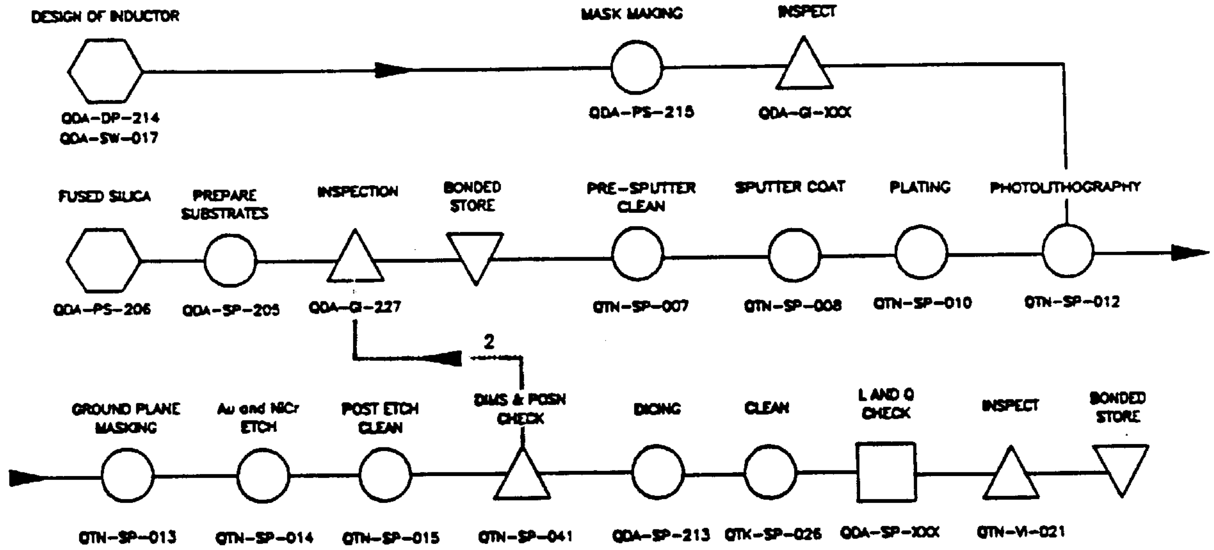
Manufacturing Flowchart - Design and Manufacture of Spiral Inductors

SAW Filters
Design and Manufacture
of Spiral Inductors to QTN-SC-056



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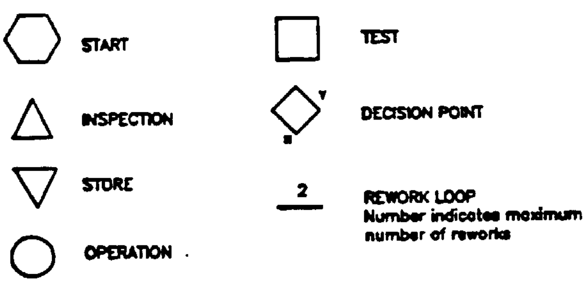

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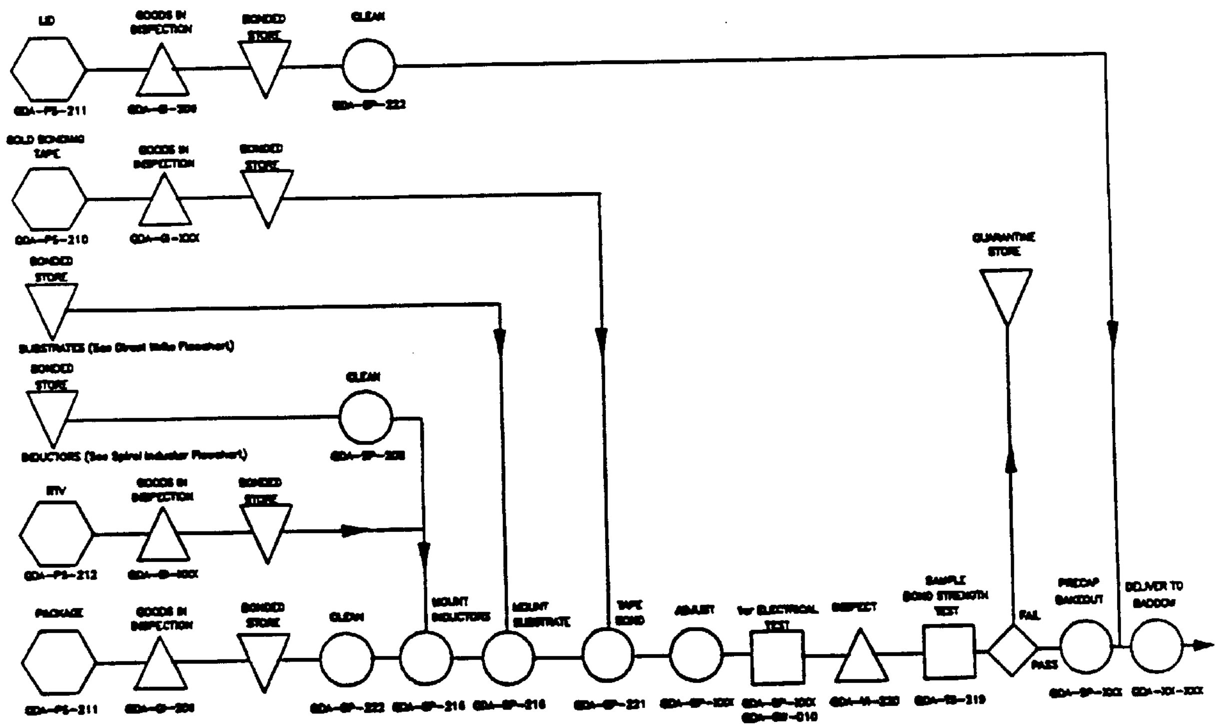
Manufacturing Flowchart - Final Assembly

SAW Filters
Final Assembly / Test



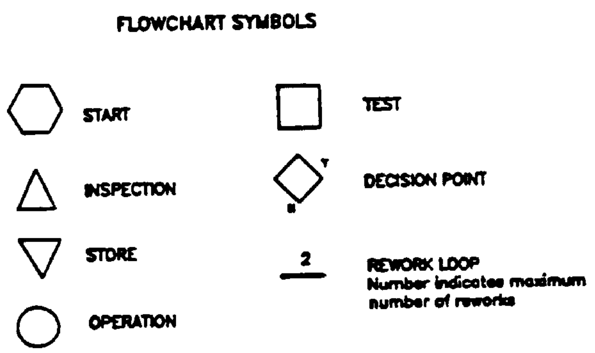


EXHIBIT No. 8 (CTD.)

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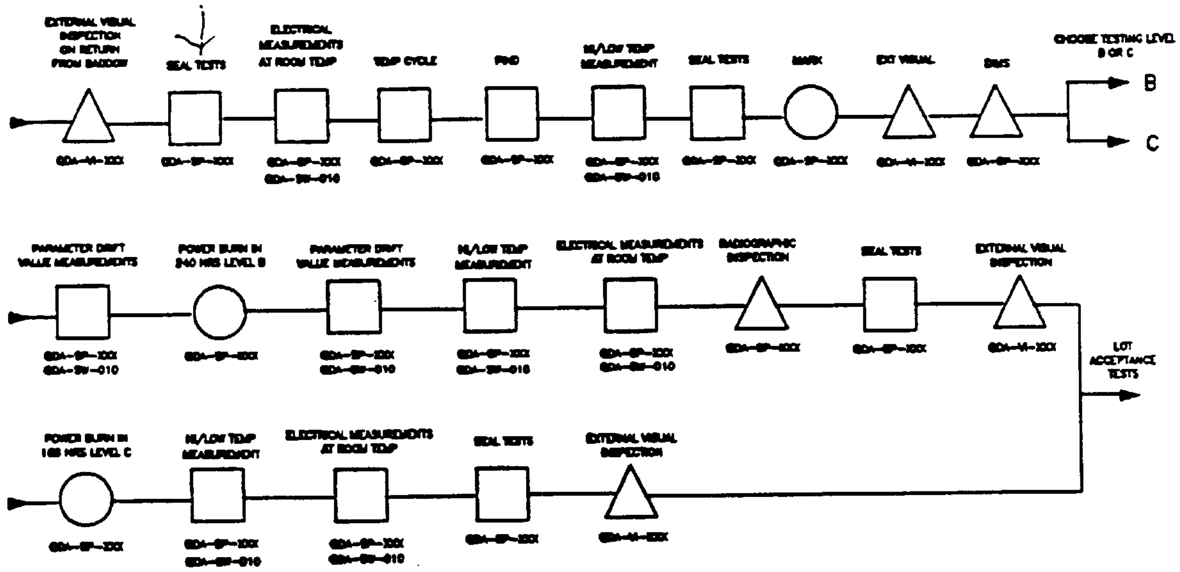
Manufacturing Flowchart - Final Test

SAW Filters
Final Test



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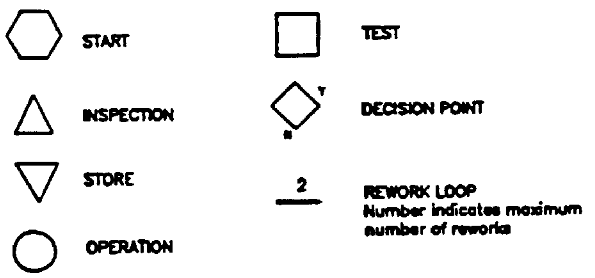

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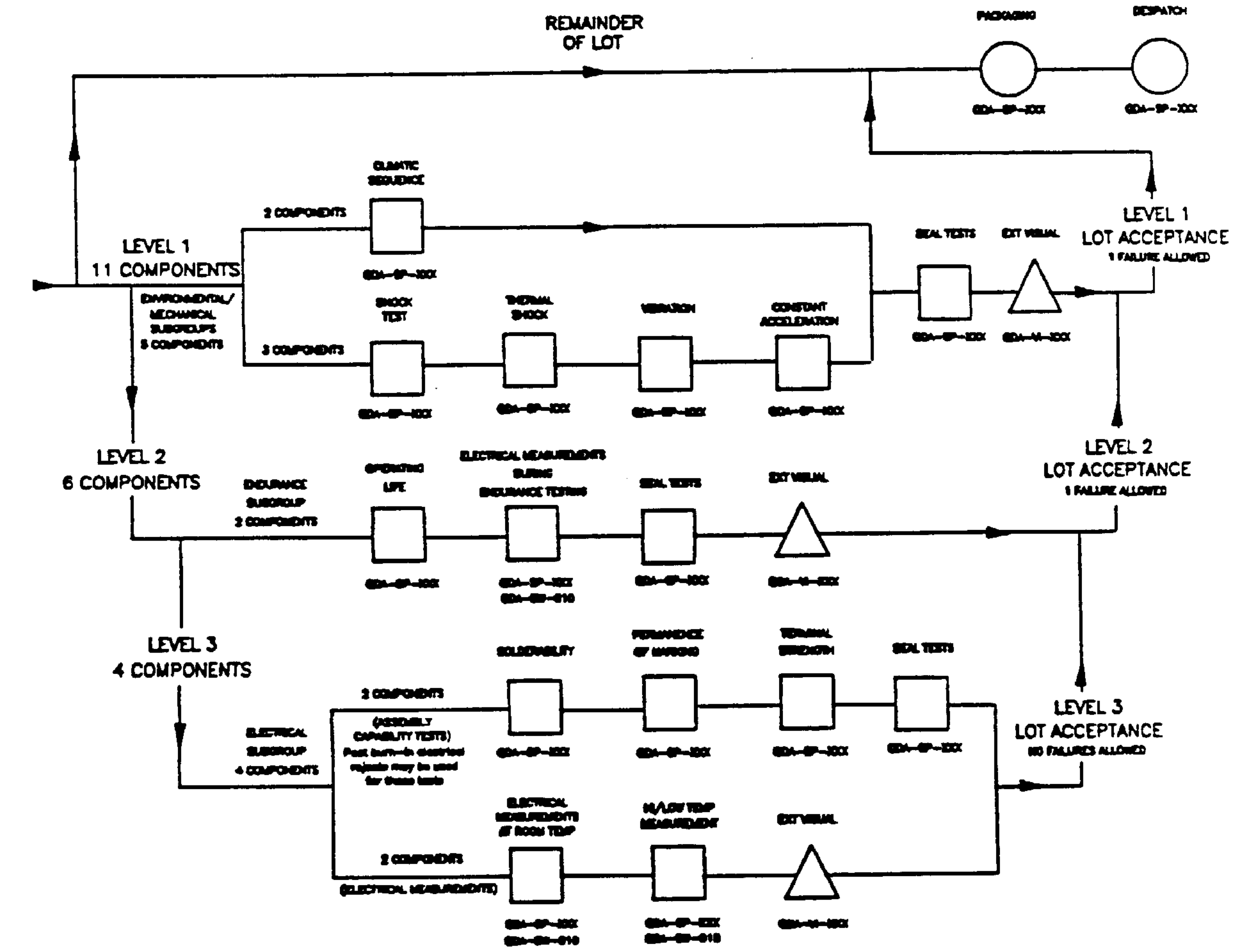
Manufacturing Flowchart - Lot Acceptance Tests

SAW Filters
Lot Acceptance Tests



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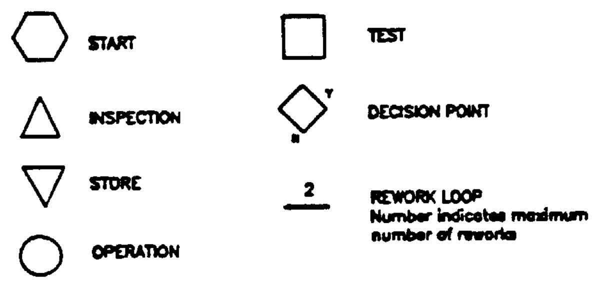

SURFACE ACOUSTIC WAVE FILTERS FOR ESA/SCCG QUALIFICATION APPROVAL PROCESS IDENTIFICATION DOCUMENT

PRODUCT SUMMARY

Documents

REF NO	TITLE	ISS	DATE	C/N	FROM
PS-002	Procurement Specification for High Purity Quartz	1	May 88	197	Feb 89
SP-003	Preparation of Quartz Qualification Slices	1	May 88	198	Feb 89
SP-004	Lumbering	A	Aug 87	004	Sep 87
SP-196	SAW filters for space	a	Sep 89	297	Sep 89
	qualification X-ray Orientation	A	Dec 89	343	Dec 89
GI-016	Deposition Metal Inspection	1	Dec 88	228	Feb 89
DC-036	Control System for QDA Documents	2	Dec 88	220	Feb 89
CR-038	Environmental Standards for B13 Clean Room	A	Aug 87	029	Feb 89
DC-039	Drawing Control	1	June 88	202	Sep 87
DC-158	Software Control	e	May 89	249	May 89
GI-040	Incoming Inspection for Quartz Stones	1	Jul 88	210	Feb 89
SP-042	Quartz Qualification Tests	1	May 88	187	Feb 89
MO-046	Syton Polisher	A	Aug 87	033	Sep 87
MO-047	Secasi X-ray Goniometer	A	Aug 87	034	Sep 87
MO-048	Meyer and Burger Slurry Saw	A	Aug 87	079	Sep 87
MO-052	Cylinder Grinder	A	Aug 87	039	Sep 87
MO-059	Hand Lap	A	Aug 87	060	Sep 87