Space Evaluation Testing on SAW Filter Based on POI Technology

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ABSTRACT

During the past ten years, a significant number of innovations have been developed to enhance the capability of passive acoustic-electric devices to answer the imperative demands of filter characteristic improvement. Piezo-On-Insulator wafers have been developed to consider the use of such a device for satellite communications.

This work presents the results of the evaluation testing activities conducted by ALTER TECHNOLOGY on existing surface acoustic wave (SAW) filters, particularly L-band GPS filters, based on POI substrate developed by SOITEC. Extensive testing was performed on L-band GPS SAW filters assembled in a 3.8SQ hermetic package within the framework of the HOMEMADE project. The primary objective of these tests was to assess the suitability of these filters for space applications and other markets with demanding environmental requirements, while simultaneously gathering critical data to support advanced filters development throughout the project.

The evaluation process included rigorous stress testing to determine the operational limits of temperature and power, as well as life testing, thermal cycling, and humidity assessments. Additionally, a comprehensive constructional analysis was carried out to gain detailed insights into the device's structural integrity. The findings indicate that the device effectively meets the stringent requirements of harsh environments, with only minor manufacturing adjustments needed.

A. Introduction:

The space industry must solve a key challenge with 5G direct satellite connectivity which is balancing the need for low-frequency L/S band operation with keeping the satellite's size and weight minimal. The objective to L/S band RF passive components integration while keeping the performance at a reasonable price can only be achieved with acoustic technologies SAW. Transducing electromagnetic signal to acoustic wave allows a strong wavelength compression while keeping quality factor high. Besides compared to existing technologies, POI-based SAW filters enable higher integration, thermal stability, better heat management, lower insertion loss and high rejection capability at various bandwidths.

The Homemade project is built around the main goal of supplying the European Space Industry with low-cost, high-performance, and highly integrated Surface Acoustic Wave (SAW) filters developed by SOITEC. These innovative acoustic filters, based on Piezo-On-Insulator technology, will contribute to the development of a competitive 5G direct connectivity satellite constellation by reducing overall mass and volume.

To ensure the reliability of the POI-based SAW filter, the first step is to evaluate the technology. The evaluation is aimed at studying the construction and limitations of the technology in terms of device reliability and robustness against harsh environments. Considering that, this paper presents the evaluation testing activities as the previous step before qualification on an existing L-band GPS SAW filter using SCAW topologies developed by SOITEC assembled in 3.8SQ hermetic package. The evaluation test flow is based on ESCC 2263502 “EVALUATION TEST PROGRAMME FOR SURFACE ACOUSTIC WAVE (SAW) DEVICES” and the ESCC generic specification No. 3502 “SURFACE ACOUSTIC WAVE (SAW) FILTERS, HERMETICALLY SEALED”.

B. Device information:

As SAW filters are based on the excitation of acoustic waves on the free surface of a piezoelectric substrate (POI: Piezo on Insulator), the package plays an important role in the filter performance. The device to be tested following this document was selected to be an L-band GPS filter, assembled on 3.8SQ package, standard solution for SAW filter in space environment. Figure 1 depict the drawing of the package.

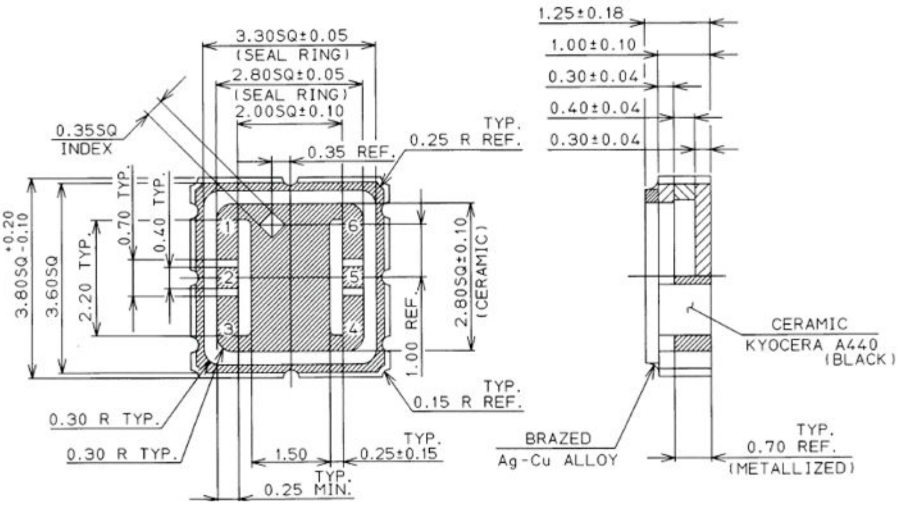

Figure 1. *The 3.8SQ package drawing*

To carry out all the electrical tests, samples were soldered onto dedicated test boards designed for the testing purpose. The test board is made of RO4350B with a 20mil thickness, featuring a 50-ohm grounded coplanar waveguide and SMA connectors operating up to 18 GHz Figure 2. Prior to soldering the samples, a specific conditioning step was performed by baking the samples at 125ºC for 24 hours. Reflow process was then performed as specified in IPC/JEDEC J-STD-020E with a peak temperature of 235ºC corresponding to SnPb soldering profile, using the last cycle to solder the samples, see Figure 2.

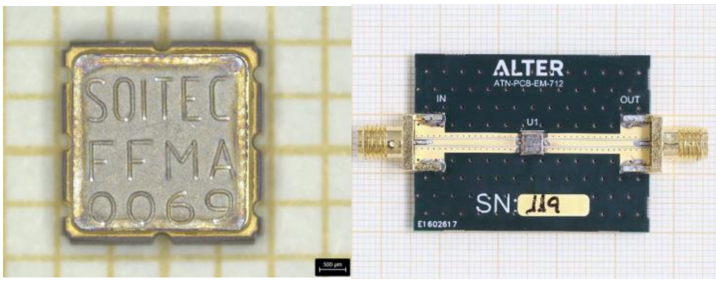

Figure 2. *GPS filter - PCBs used including a soldered sample*

C. Test flow description:

Twenty-two samples of 3.8SQ L-GPS filter have been submitted for a complete test sequence presented in Figure 3, to evaluate the sensitivity of the device to harsh environments. Based on the ESCC 2263502 "EVALUATION TEST PROGRAMME FOR SURFACE ACOUSTIC WAVE (SAW) DEVICES", testing sequence started with temperature stress tests followed by a power stress test to evaluate operational limits of the devices. After that, a steady state accelerated life test, a low temperature life test and a complete constructional analysis were performed.

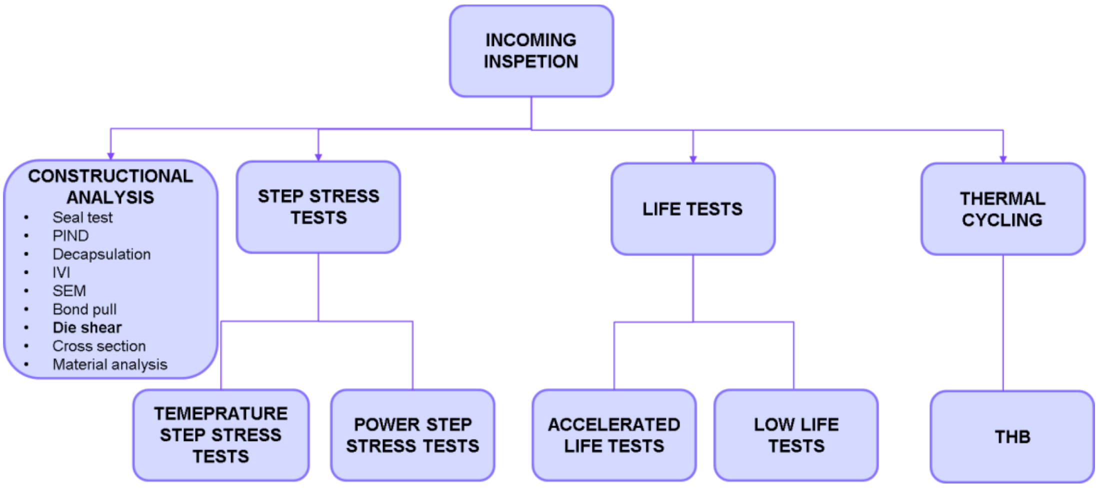

Figure 3. *Testing sequence of 3.8SQ GPS Filters*

D. Results and Interpretations:

All received samples underwent an initial non-destructive inspection, consisting of an External Visual Inspection, during which no anomalies were detected.

a. Constructional analysis

Evaluation activities began with a constructional analysis of five samples, all of which show no external anomalies. All external surfaces appear free of damage (cracks, voids, separation, etc.) or contamination (corrosion, foreign material, discoloration, etc.), see Figure 4.

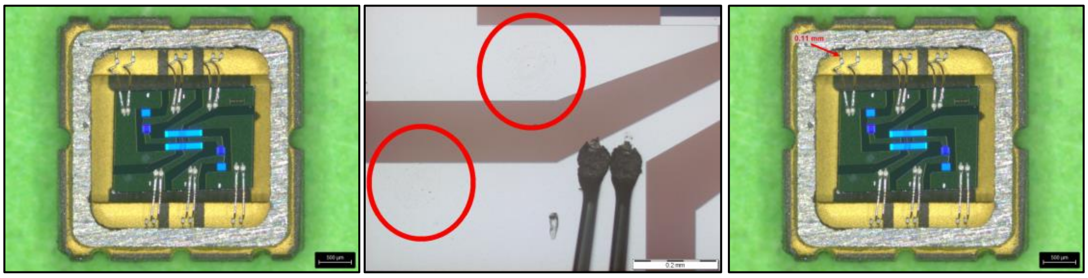

Figure 4*. General and detailed internal views*

Seal and **PIND** tests confirmed acceptable leak values, no loose particles, and no bubbles were observed during the Gross Leak test. The samples, consisting of a silicon die with aluminum metallization in a hermetic ceramic package (LCC-6), were subjected to **SEM** inspections Figure 5, same features which are already checked during the Internal Visual Inspection, plus die surface, metallizations layer and bond junctions, were inspected with satisfactory results and they were within ESCC 2045010 limits.

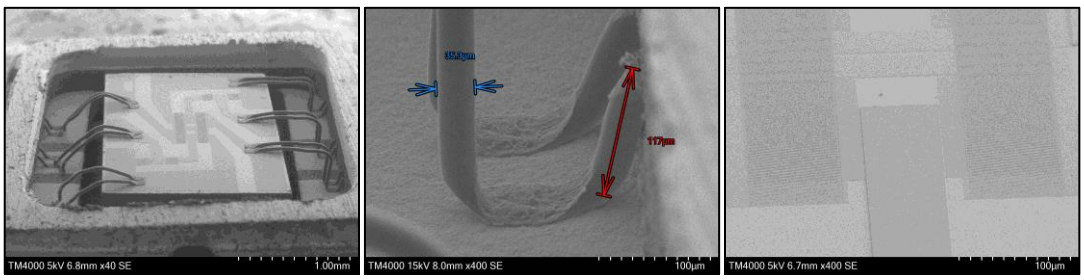

Figure 5. *Detailed SEM views*

The **bond pull** test yielded satisfactory results, with all wires exceeding the required strength. However, the **die shear** test revealed failures in three samples per MIL-STD-883-2, indicating potential die attachment issues. **Cross-section** analysis showed slight wedge bond separations without applicable rejection criteria. Finaly **material analysis** of internal metal surfaces confirmed the absence of prohibited materials such as sulfur, chlorine, pure tin, or zinc, with all internal materials aligning with plastic package manufacturing standards.

While most tests were successful, the failures in the die shear test indicate that the tested parts are not fully compliant with the requirements and guidelines defined in the MIL-STD-883 and ESCC systems, with the main deviation related to die shear failure and not attributed to the technology itself , but to the assembly process, highlighting the need to reassess and optimize the die attach process to ensure full adherence to applicable standards.

b. Temperature step-stress tests

The goal of this test is to determine the maximum operating temperature of the filters by operating the devices (power = -10 dBm, frequency= 2 GHz) for 16 hours at different temperatures that are increased in steps between 45ºC and 105ºC. After operation at each temperature, test chamber needs to be cooled down to room temperature, sample removed and stored for one hour at room temperature, and finally performance tested by performing an electrical measurement at room temperature (EMRT). The procedure is graphically described in Figure 6.

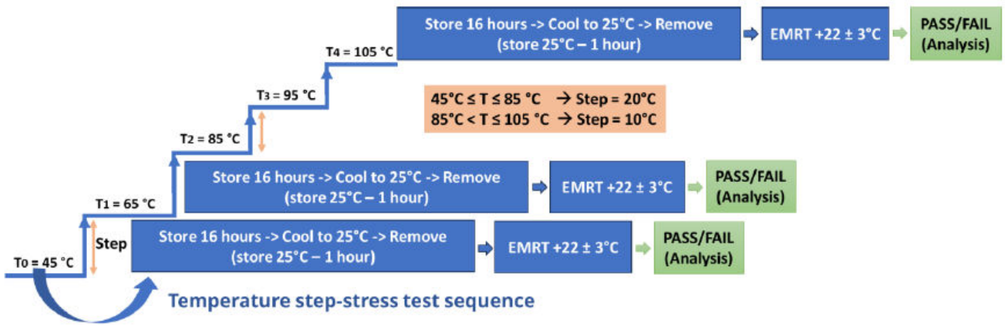

***Figure 6**. Temperature step-stress test sequence*

Figure 7, shows the S-parameter measurements of the samples corresponding to the initial step and final post process 105ºC. These graphs demonstrate that no deviation has been observed in the performance of the samples tested, hence, confirming the samples can operate up to maximum temperature applied.

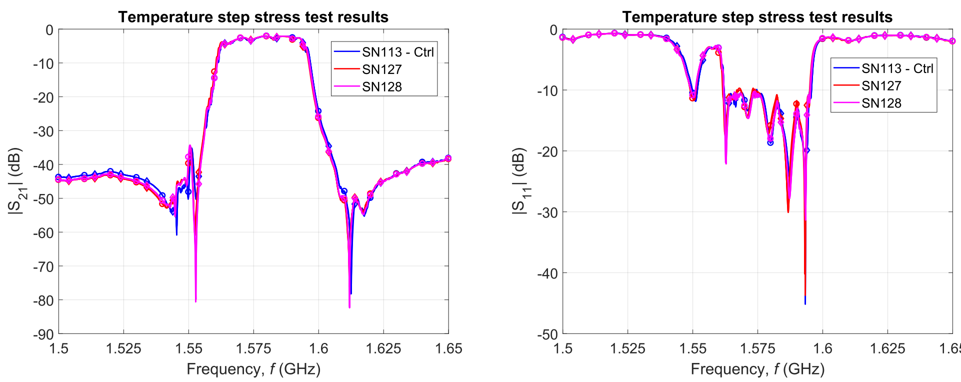

***Figure 7**. Electrical performance results for temperature step-stress tests corresponding to the initial step (circle) and final post 105ºC (diamond)*

c. Power step-stress tests

The goal of these tests is to determine the maximum power handling capacity of the filters by operating the devices at maximum operating temperature as determined by temperature stress test, while increasing the applied power level in steps. Power levels range between -20dBm and +10dBm following the procedure described in Figure 8.

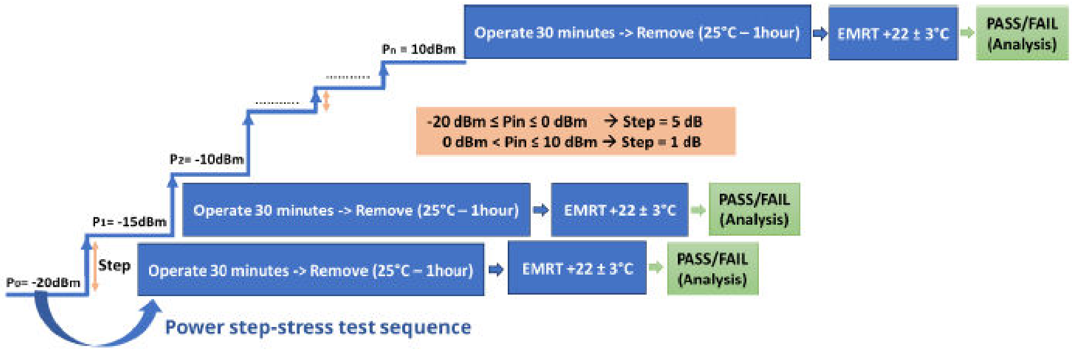

Figure 8. *Power step stress test sequence*

Following the defined test procedure, electrical measurements at room temperature have been performed after each power step level. Figure 9, shows that there is no deviation in the performance of the samples. Additionally, the results of the internal visual inspection after Power step stress test confirmed that the IDTs remained intact.

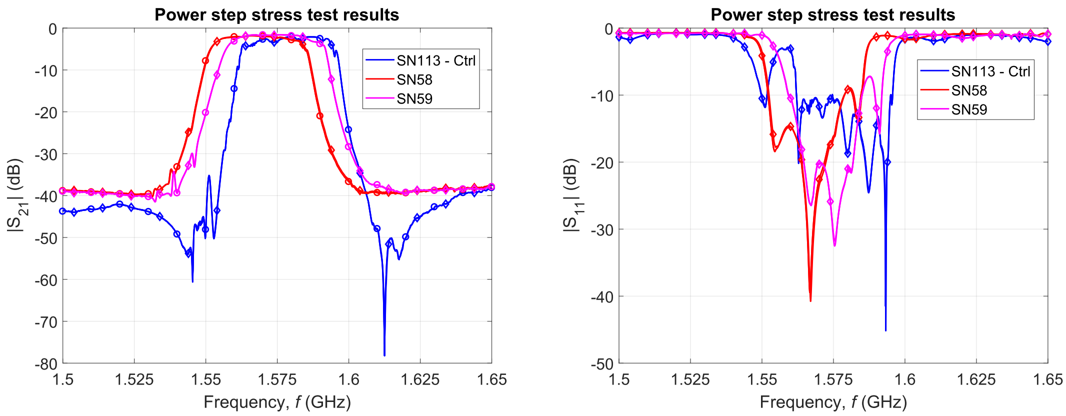

Figure 9. *Electrical performance results for power step-stress tests corresponding to initial step (circle) and final post +10dBm (diamond)*

To complete the electrical verification, an additional physical test was conducted on one sample that underwent a power step-stress test. The sample was opened for internal visual inspection and SEM analysis to confirm the integrity of the SAW filter IDTs. The results, shown in Figure 10, confirmed that the IDTs remained undamaged. Particles observed on the die surface resulted from the lid removal process using a scalpel.

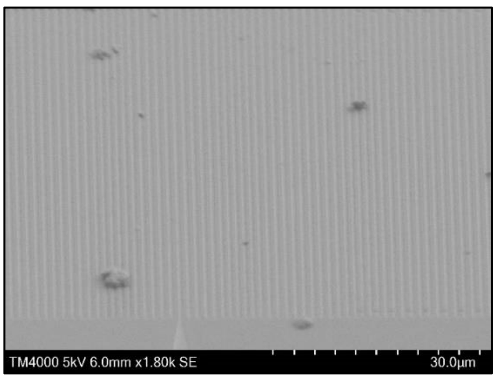

Figure 10. *SEM analysis of the IDT on sample SN59*

d. Steady state accelerated life test

Life tests have been performed after finishing both temperature and power step-stress tests to confirm maximum operating conditions. Life test conditions were the maximum operating temperature of 105ºC and a CW RF signal of - 10 dBm at filter's center frequency of 1.57 GHz.

Electrical measurements have been performed at room temperature after 200 (±24) hours, 400 (±24) hours, 700 (±24) hours, and 1000 (+24/-0) hours, to monitor the correct performance of the samples for each phase of the life test.

Electrical intermediate measurements at room temperature after 1000 hours prove that all the samples submitted to life test show a small shift of the pass band towards lower frequencies. The sample showing the maximum shift is SN131 with around 2 MHz deviation as can be seen in Figure 11.

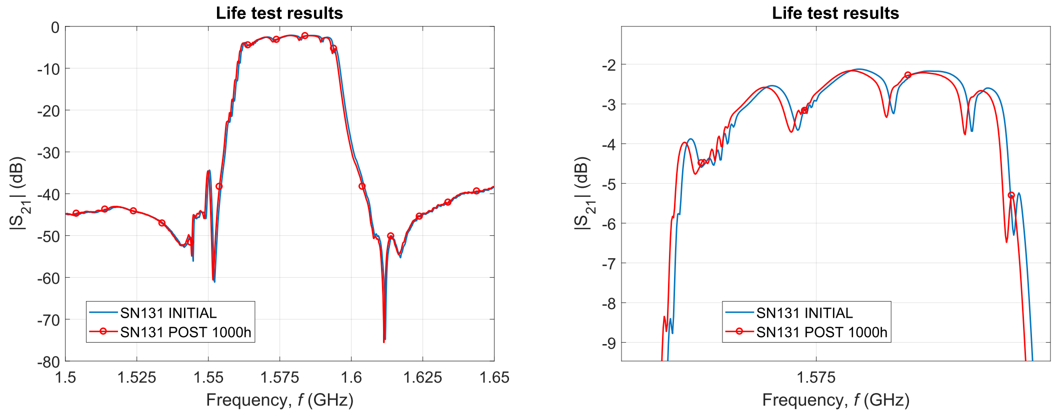

Figure 11. *Electrical performance results during a life test of sample SN131- A zoomed view of the filter pass band where the drift can be better observed*

Analysis identified that the deviation was originated by skipping the post front-end annealing process, which is critical step that stabilizes Al-Cu electrodes through heating at 250ºC for three hours. Life test results on complementary samples confirmed that this process is essential for ensuring long-term electrical performance and reliability particularly in demanding space applications.

e. Low temperature life test

This test consists of a long storage process of the samples at low temperature followed by an internal visual inspection of the samples. In particular, the temperature applied during the test was -55ºC with a duration of 1000 hours. No bias was applied to the samples during the test.

No anomalies were detected during the whole test sequence. After decapsulation and during internal visual inspection Figure 12, a good internal structure was observed.

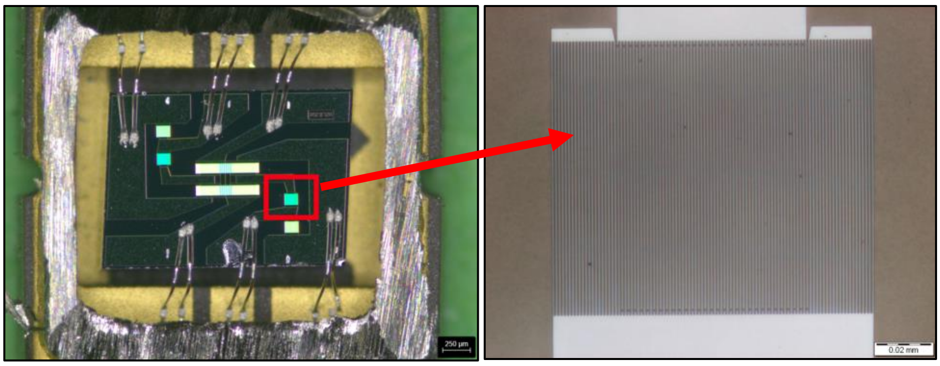

Figure 12. *General internal view of the component (left) and detailed image of one of the filter's IDT (right) after low life test*

f. Thermal cycling and moisture tests

During the thermal cycling no bias was applied to the samples. The temperature cycling test was performed between -55ºC and 125ºC for 100 cycles with a dwell time of 10 minutes at each temperature. After 100 cycles intermediate electrical measurements were conducted at room temperature, revealing no performance deviation in the samples. Subsequently a humidity test was performed on the same six samples at +85ºC and 85% relative humidity, without applying any bias during the THB tests.

The test flow is completed with another thermal cycling after humidity test, for the same temperature and dwell times, but for 10 cycles now. The final electrical measurement of the samples revealed no deviations in performance.

CONCLUSIONS

In this work, we defined and performed an in-depth evaluation of SAW GPS filters developed by SOITEC, based on POI substrates and SCAW topology. The evaluation demonstrated their robustness under harsh environmental conditions and confirmed their compliance with space application requirements. Although some deviations related to assembly techniques were observed, necessitating further adjustments to fully meet space quality standards, the insights gained from this study indicate that with minor manufacturing improvements, these filters have strong potential for successful space qualification and future project developments.

ACKNOWLEDGEMENTS

This work was carried out within the framework of the HOMEMADE project funded by the European Union (HORIZON EUROPE project No.101081785, Horizon-CL4-2021-SPACE-01). We sincerely thank all participants of the HOMEMADE project for their dedication and hard work. We would especially like to acknowledge the outstanding contributions of UCLuvain, INCIZE, and particularly SOITEC and Thales Alenia space teams for their work on parts and packaging. Their efforts have been essential to the success of this work. We truly appreciate their commitment and collaboration.

REFERENCES

[1] ESCC Basic Specification No. 2263502, “EVALUATION TEST PROGRAMME FOR SURFACE ACOUSTIC WAVE (SAW) DEVICES”.

[2] ESCC Generic Specification No. 3502 for SURFACE ACOUSTIC WAVE (SAW) FILTERS, HERMETICALLY SEALED.