Executive Summary Report (PIM-TRP)

"Test methodology investigations and parameters influencing Passive Intermodulation (PIM) interference (4000126012/18/NL/HK)"

I. INTRODUCTION

In the past decades passive intermodulation (PIM) has become a subject of utmost importance in the area of satellite communication systems.

The generation of intermodulation signal occurs in a signal path with non-linear transfer characteristics when two or more signals are passing through. Typically, active components such as solid state amplifiers generate intermodulation signals having frequency components adjacent to the signal frequency itself. Even passive components produce intermodulation at high power applications because of the non-linear behaviour of the transmission lines.

Due to very long transmission paths, such as the distance of approximately 36000 km between the earth and the Geostationary Earth Orbit (GEO) which share uplink and downlink signals, a high dynamic range is needed between transmit and receive units to guarantee signal integrity and speed of communication channels with low bit error rate (BER). PIM manifests itself in the form of increased noise levels in communication channels, which has a detrimental effect on the goal of achieving a high dynamic range and consequently a good signal to noise ratio. Typically, PIM products for sensitive payload components in communication satellites must not exceed levels of about -190 dBc. Therefore, the mitigation of PIM is of great importance. Moreover, the dynamic range must be kept stable over a temperature range from about -130° C to +180° C. For all transmission line connections, such as bolted waveguide flange connections, this temperature variation is a very demanding requirement.

Passive intermodulation has various sources. Its predictability can be exacerbated with multi-physic like behaviour of PIM sources interacting simultaneously. Many satellite manufacturers, operators and agencies have undertaken efforts to figure out the parameters related to non-linearity sources for PIM generation. The spectrum of PIM investigations has been excessive, from material science to the sophisticated spacecraft system performance.

Former studies indicated potential PIM source areas such as waveguide connections as well as illuminated structures encompassing surfaces with different materials exposed on high power transmission. Causes of PIM generators at waveguide connections were contaminations at connections, micro-cracks on surfaces, metal-insulator(oxide)-metal junctions, insufficient interface contact pressure and non-linear material properties (e.g. ferroelectrics). The nonlinear characteristic of PIM prone parameters was the root-cause for PIM generation.

II. TRP activities and outcomes

Research fields of PIM investigation were collected through a comprehensive survey of publications on conferences and theses as well as patents in the field of passive intermodulation. The largest part of PIM characterisation was performed using PIM tests alongside the analytical approach to understand the PIM mechanisms.

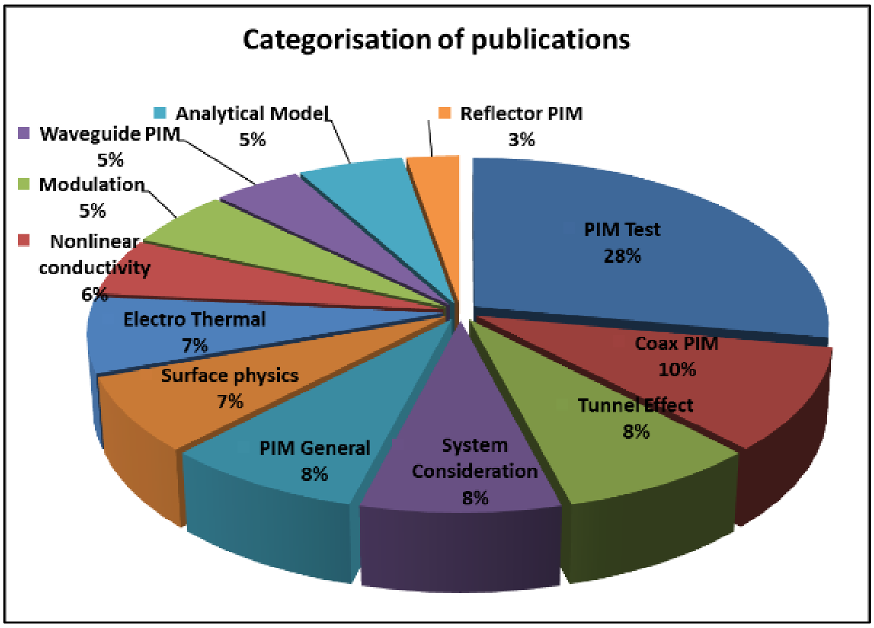

Figure 1: Categorisation of publications

Figure 2 shows the survey results about test capabilities with respect to the frequency band. The PIM test capability is currently focused on Ka and Ku band which enlightens the current demand on these frequency bands in the high-power satellite communication market. The Q-band test capability is growing in accordance with market need. However, the capability for analysing PIM has been considered as an area for development.

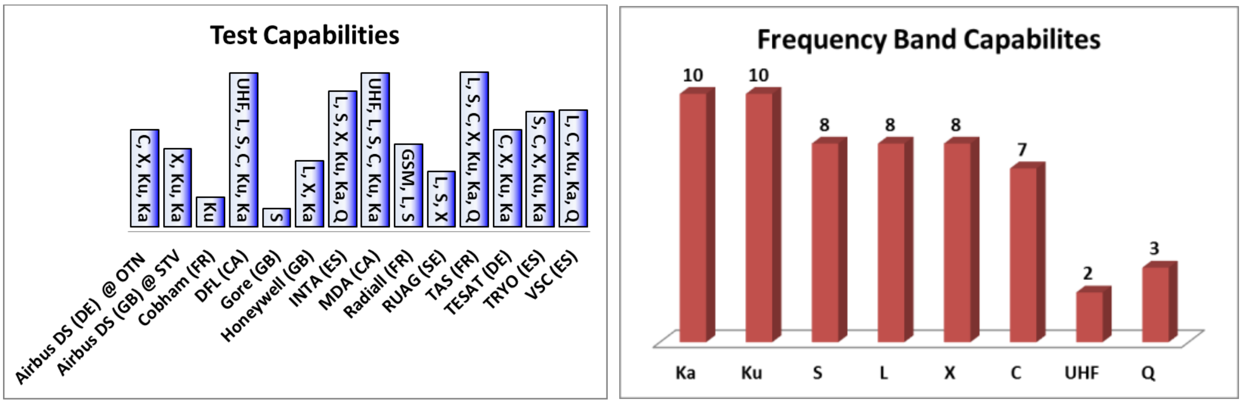

Figure 2: Test facilities and capabilities within ESA member states

The most relevant parameters for PIM behaviour characterisation were defined in the frame of this TRP. The main investigation scenarios were related to the topics such as RF carrier power variation, PIM level difference between orders, temperature influence, surface contact material difference, surface contact pressure influence, signal frequency and spacing as well as phase variation, multi-carrier operation and modulation scheme difference of carrier signals.

Extensive studies and tests were carried out in C-, X- and Ku-Band frequency bands using waveguide test samples with different materials and coaxial test samples with TNC as well as SMA connectors. Figure 3 shows the test samples in waveguide and coaxial technology.

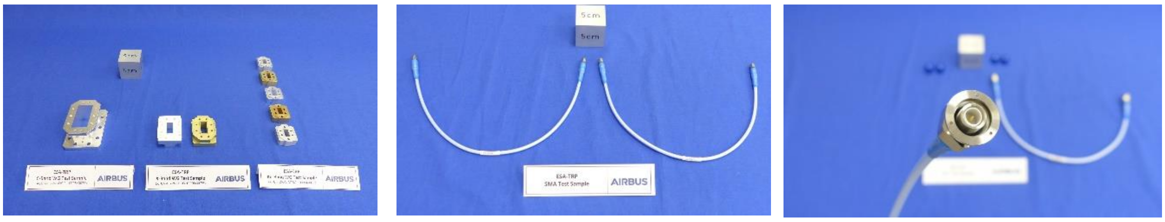

Figure 3: Test samples (waveguide samples for C-/X-/Ku-Band and coaxial samples)

The investigations show that the most important parameter for PIM behaviour is contact pressure, since all other factors were strongly related to this fundamental parameter. Based on a specific contact pressure, other PIM behaviours were examined, such as carrier power variation, temperature influence, material dependency, carrier signal characteristics etc. Especially the influence of temperature, causing an expansion or contraction of the contact material, can be explained as a result of contact pressure variation.

PIM amplitude variation induced by the carrier RF power variation proves to be an important characterisation method for the PIM behaviour. The variation of PIM level over the RF carrier power, which gives a slope value for the specific PIM source, enables the prediction of PIM level amplitude at an arbitrary carrier power level. Obtaining the slope values for a specific contact pressure and material provides a useful metric for the prediction of other power cases. Thus, PIM level tests using RF power ramp-up/down scenarios are an essential method for predicting PIM behaviour.

The PIM level difference, the so-called roll-off between different PIM orders, is dependent on the material and contact pressure. Thus, giving a general statement on the roll-off number between PIM orders from the investigations as part of this TRP is not feasible. The roll-off value, however, can be obtained through the power ramp-up/down PIM test results for a specific material and contact pressure.

The impact of temperature variations shows increasing and decreasing PIM levels during the cold, respectively the hot temperature cycles for waveguide samples as well as for coaxial samples. Improper contact pressure produces a progressively instable behaviour along the temperature cycles.

A defined contact pressure for PIM mitigation is essential. According to the TRP results the waveguide contact pressure shall be greater than 50 MPa as a minimum for waveguides. For coaxial connectors the torque values are advised to be kept below the recommended values by the supplier, dependent on the connector types. The tested SMA connector shows better PIM behaviour than the TNC connectors, which could be caused by the differences in TNC connectors from different suppliers.

This TRP delivers valuable information on the impact of different materials / surface coatings and contact pressure on PIM. Aluminium based material with Alocrom and Surtec650 surface passivation shows higher PIM levels in comparison to the bare Aluminium, silver- and gold-plated samples. In the case of a contact pressure higher than 50 MPa, the PIM level reduced to -140 dBm, regardless of the frequency band (C-, X- and Ku-Band.).

The test results obtained for the waveguide samples provide useful information about the PIM behaviour with respect to the variation of carrier signal frequencies, spacing and phases. No significant variation of the PIM level was observed for the CW signal characteristics in different frequency bands (C-, X- and Ku-Band).

The opportunity for multicarrier PIM characterisation tests was challenging, since only a few test facilities in the ESA member states have the facilities, equipment and capabilities to perform multicarrier PIM tests. The tests for multicarrier PIM scenarios were carried out at ESA-VSC. The results of the multicarrier PIM tests provide valuable information on the PIM behaviour with changing number of carriers. The PIM level increased concurrently to the number of carriers. Based on the relation between PIM level and number of carriers, the simplification of multicarrier PIM investigation using two-tone PIM test data is available.

Another important information about PIM level fluctuation has been obtained. When the number of carriers was larger than the number of PIM order, the PIM level fluctuation was higher. The reason is, that more than one orders are existing at the same PIM test frequency. These co-existing different PIM orders result in a fluctuation of PIM level due to constructive or destructive overlapping.

Figure 4 depicts test configurations in an exemplary way.

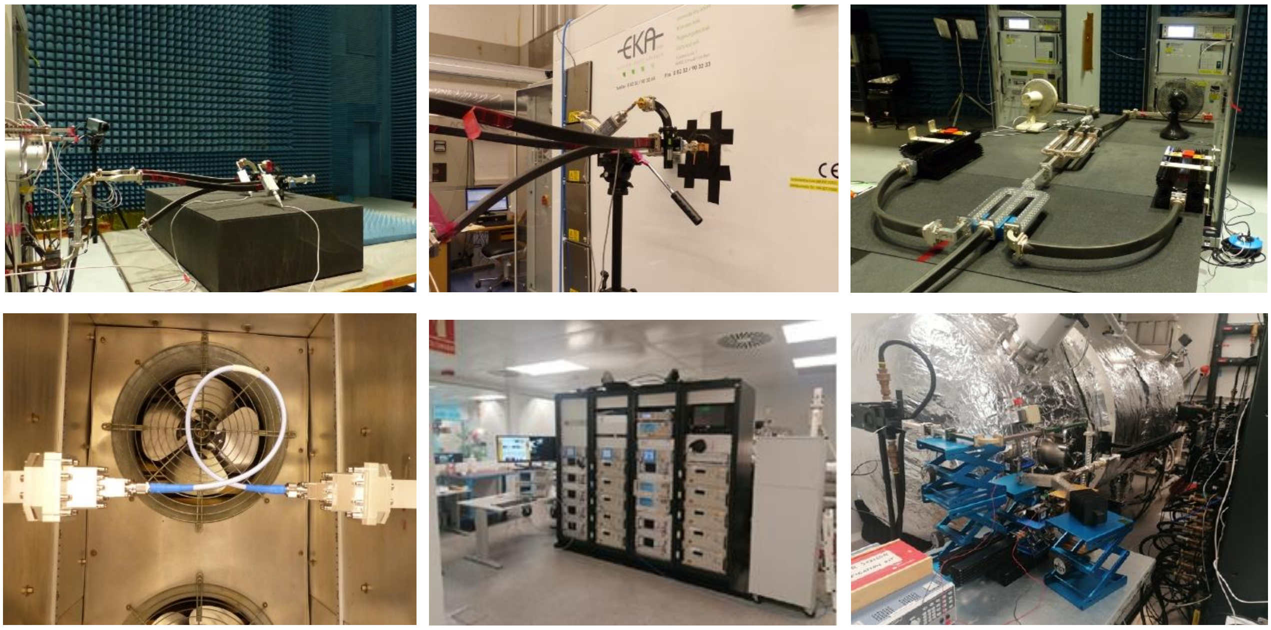

Figure 4: Test configurations at Airbus (DE) and at ESA-VSC (ES) - exemplary

PIM tests using different modulation schemes were carried out at ESA-VSC facility. The test results showed that the investigated digital modulation schemes such as QPSK, 8-PSK, QAM as well as 16-QAM had no significant impact on the PIM level. However, the modulation signal bandwidth revealed the direct relation to the PIM level of the modulated signal. The CW PIM signal energy remained equivalent to the spread PIM spectrum energy over the PIM spectrum bandwidth resulting from the PIM order and the modulation bandwidth of each carrier. The difference between CW PIM level and the modulated signal PIM level is equivalent to the bandwidth of the spreaded PIM spectrum. Thus the expected PIM level for the modulated signal can be evaluated from the two-tone CW PIM test level.

Finally, in the frame of the TRP, a software for passive intermodulation interference analysis - PIA (Passive Intermodulation analysis) - was developed. Based on the PIM test results, specific analysis models were obtained. Using PIA, other complex analysis cases can be performed.

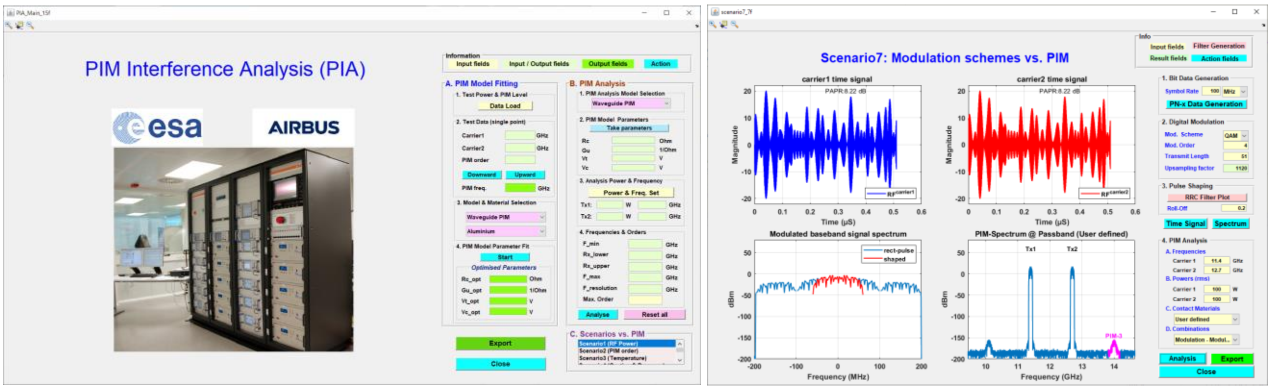

Figure 5: PIA software and modulated signal PIM analysis (exemplary)

III. Conclusion and outlook

The ESA-TRP "Test methodology investigations and parameters influencing Passive Inter Modulation (PIM) interference (4000126012/18/NL/HK)" was successfully performed. Valuable information for understanding PIM behaviour was acquired based on studies, tests and analyses using defined investigation scenarios.

With the knowledge obtained from the TRP, rule-of-thumb formulas can be derived, which allow PIM level predictions for various constellations, where PIM is relevant. PIM analysis models based on simple two-tone test data were obtained using the developed PIM analysis software PIA. PIA provides possibilities for further complex analysis cases.

The test results and the developed analysis tool is providing a valuable contribution to generate an ECSS standard in the discipline of "Passive Intermodulation Analysis and Test".

IV. Acknowledgment

Airbus thanks ESA-ESTEC for supporting this study to achieve a better understanding of PIM and to define common guidelines for PIM test investigations among the ESA member states.