Implementation of Waveguide Terminations with Low-Passive Intermodulation for Conducted Test Beds in Backward Configuration

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***Abstract*—This paper proposes a simple way to implement low-passive intermodulation (PIM) terminations in waveguide technology for test beds conceived to evaluate conducted backward PIM. By inserting a dedicated filter before the waveguide termination of the test bench, it is possible to diminish the PIM contribution from the load and consequently reduce the residual PIM noise floor of the test facility. To validate the practical application of this technique, a conducted backward low-PIM set-up working in K-band was assembled and tested. An improvement in terms of PIM performance has been obtained through the proposed solution.**

***Index Terms*—Intermodulation distorsion, passive circuits, microwave filters, low-pass filters, PIM mitigation.**

I. Introduction

CONDUCTED low-passive intermodulation (PIM) set-ups in backward configuration are typically employed for evaluating the PIM performance of conducted elements in terms of odd PIM orders [1]–[3].

Backward PIM test beds are normally more compact than forward ones since an output diplexer is not required. In addition, they are also suitable for measuring PIM of one-port devices. However, as it has been pointed out in [4], the PIM performance of the dummy termination at the end of the common RF path is critical for backward PIM test beds. The high-power carriers reach the load, so it can generate relevant levels of passive intermodulation. Due to its particular configuration, backward test beds are completely exposed to an eventual PIM signal generated by the dummy termination. As a consequence, such termination tends to be a limiting factor in the noise floor PIM level of the test bed.

For coaxial technology this issue is overcome by manufacturing dummy terminations with long rolled cables (having longitude of hundreds of meters or even more) terminated by a coaxial load. This solution allows to gradually dissipate the RF power by Joule effect along the rolled cable, so the residual RF power arriving at the coaxial load is so attenuated that it does not add a significant PIM contribution. In addition, since coaxial cables tend to be flexible, this solution does not load the set-up with excessive mechanical tension, thus avoiding further PIM contributions in the interconnections.

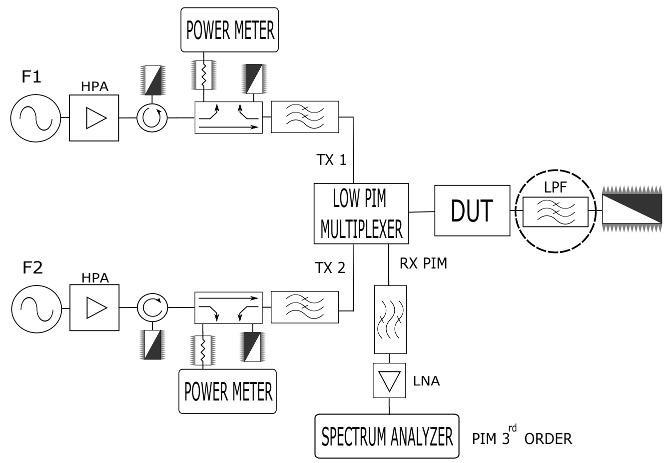

Fig. 1. Low-PIM test bench in backward configuration with the filter (circled block) placed before the waveguide dummy load.

In waveguide technology, however, this solution is not feasible for several reasons. First, long waveguide loads are very challenging (and expensive) to manufacture. Second, they would generate mechanical tensions to the set-up which could add residual PIM sources and even cause cracks in the structure, thus jeopardizing the integrity of the test facility.

In this paper, a solution to overwhelm this issue is proposed. It consists on inserting a suitable filter between the device under test (DUT) and the dummy termination, as shown in Fig. 1. This filter should allow the transmission carriers to go through, and at the same time reject the passive intermodulation coming from the waveguide termination, thus protecting the test bed against the PIM generated by the dummy load.

II. Filter Considerations

The filter to be inserted in the common RF path between the DUT and the dummy load must be designed not to affect the transmission carriers. Therefore, it must provide a passband expanding over the frequency region of the carriers. The return loss in such passband should be kept high (above $15-20$ dB) to avoid that a significant portion of the transmission carriers

Manuscript received Month Day, Year; revised Month Day, Year; accepted Month Day, Year. This work was supported in part by the European Space Agency through several research and development contracts, in part by the Ministerio de Economa y Competitividad (Spanish Government) under Project TEC2016-75934-C4-1-R, and in part by the ESA-VSC High Power RF Space Laboratory.

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could travel back again, and generate unwanted resonances or additional intermodulation terms.

At the same time, the filter must have enough rejection at the frequency band where PIM signals are detected to prevent that the PIM generated by the dummy load could mask the one measured. Let be PIM^T (dBm) the target PIM level that should be detected using the test bed (i.e, if the PIM level generated by a component must be certified to be below -120 dBm, the target $PIM^T = -120$ dBm). After assembling the PIM set-up with the dummy termination, a measurement of the residual PIM level of the set-up (without DUT or using a PIM-free DUT) must be carried out. Let be PIM^L (dBm) the PIM noise floor measured for the test bed. The rejection the filter must provide in the PIM frequency band must satisfy:

$$Rej.\,(\mathrm{dB}) \geq PIM^L\,(\mathrm{dBm}) - PIM^T\,(\mathrm{dBm}) + M\,(\mathrm{dB}) \quad (1)$$

where M is the design margin, which is recommended to be above 20 dB (to guarantee that the PIM generated by the load will always be negligible over a PIM signal of a level similar to the threshold PIM^T (dBm) to be detected).

The nature of the filter to be employed depends on the frequency position of the transmission carrier band and the PIM band for the set-up. Two options are possible. For test benches where the PIM frequency band is above the transmission carriers, a low-pass filter is normally the best choice in terms of return loss, compactness and rejection. On the other hand, a high pass filter will be issued for those test benches where the PIM band is below the transmission carriers (although a combination of a band-pass filter and a high-pass filter is also possible, as shown in section III.B. of [4], if a more compact solution is sought to reduce mechanical stress). In both cases, the filter must have outstanding PIM performance. Tuning elements must therefore not be used. The filter must also be manufactured in clam-shell configuration with symmetrical width, to avoid cutting currents in the assembly [4].

It is important to mention that there can be other sources of residual PIM in the test bed. Therefore, after the insertion of the filter, the residual PIM level of the test facility could still be higher than the target one (although it will not be due to the PIM generated by the dummy termination itself).

III. Results

The PIM mitigation technique proposed in this paper has been verified by means of a backward low-PIM set-up in K-band, on which the PIM frequency is above the transmission carriers. The key element of the set-up is a multiplexer with a transmission band between 17.89 and 20.67 GHz and a reception band (for PIM signals) expanding from 22.7 to 24.1 GHz. The transmission band is splitted into five channels of 420 MHz bandwidth (and guard-bands of 170 MHz) implemented with low-loss high-power bandpass filters [5], [6].

Only 3rd PIM order was evaluated, using two continuous wave (CW) high-power input carriers of 30 W each. A first set of PIM measurements with only the dummy load in place was conducted. The frequencies used for each transmission carrier, as well as the frequency and level of the PIM signal measured, are compiled in Table I.

TABLE I
CONDUCTED BACKWARD PIM AT K-BAND WITH ONLY DUMMY LOAD IN PLACE, TEST SCENARIO.

Tx1 30 W CW Freq. (GHz)	Tx 2 30 W CW Freq. (GHz)	3rd PIM Freq. (GHz)	3rd PIM Level (dBm)
17.96	20.34	22.72	-106
	20.36	22.76	-106
	20.38	22.80	-106
	20.40	22.84	-106
	20.42	22.88	-104
	20.44	22.92	-104
	20.46	22.96	-104
	20.48	23.00	-102
	20.50	23.04	-102
17.92	20.50	23.08	-102

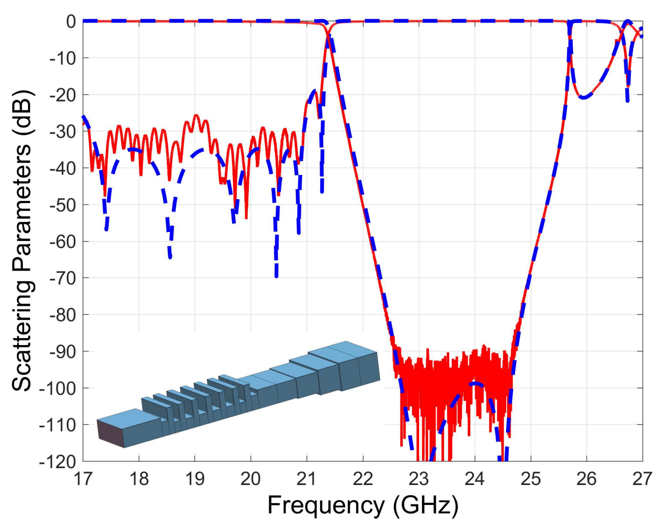

Fig. 2. Comparison between measured (continuous lines) and simulated response with FEST3D (dashed lines) of the low-pass filter used to mitigate the PIM of the dummy load in the K-band test bed.

It can be observed that the set-up was employed for several combinations of carrier frequencies, resulting in different frequencies for the PIM signal. This was done in order to check the effective PIM contribution of the test facility, getting rid of uncertainties associated to sum and destruction of several PIM contributions which could appear in backward PIM test beds (as it has been reported for the coaxial case in [7], [8]). In our case, the residual PIM level was kept approximately constant over the whole PIM frequency band of the test scenario. This result is consistent with a dominant reflected PIM source, since sum or cancellation with other PIM sources are not observed [7]. Under normal operating and assembly conditions, the load termination should be the dominant PIM source of a PIM test bed in backward configuration.

The PIM noise floor of the test bed can be assumed to be $PIM^L = -102$ dBm (worst case) due to the dummy load. Assuming that the weakest PIM signal to be detected is $PIM^T = -130$ dBm, from (1), the rejection to be provided by the filter in the PIM band should be above 50 dB.

A suitable stub-based low-pass filter (LPF) band has been chosen, since the PIM band is placed at higher frequencies than the transmission band. It has a measured rejection above 90 dB in the PIM band, and it is transparent to the carriers with

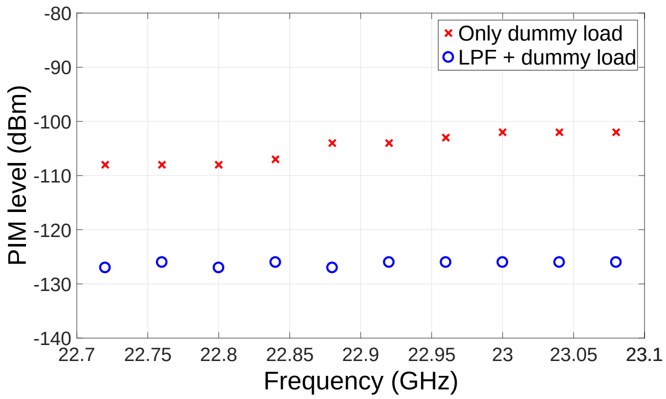

Fig. 3. PIM measurements with and without LPF before the dummy load.

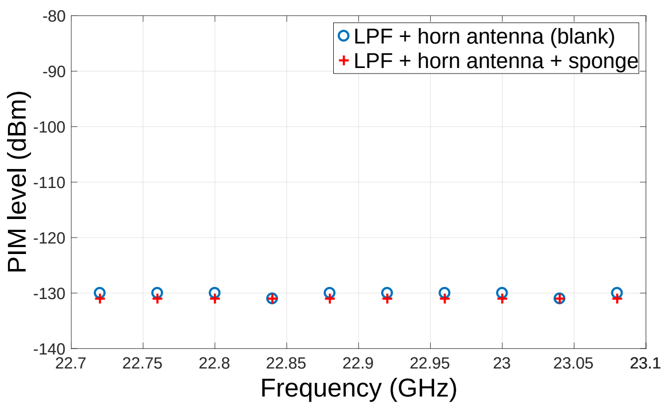

Fig. 4. PIM measurements with LPF and horn as dummy load: comparison with and without metallic sponge as PIM source.

a return loss better than 25 dB (see Fig. 2). The filter has an input WR42 port (since the multiplexer common port is ended in WR42), whereas the output port is WR51 (the usual one for the transmission band). The ripple measured in the return loss was due to the additional input taper that was required to perform the measurements with a network analyzer.

The low-pass filter was inserted into the test facility just before the dummy load. Figure 3 shows a comparison between the measurements conducted, with and without the LPF in place. The same frequency sets shown in Table I has been considered. As it can be observed, the insertion of the LPF provides a substantial residual PIM mitigation of the test facility, in the range between $20-25$ dB. As a result, the main PIM source of the test bed turned out to be the dummy termination, which can be blocked by the proposed low-pass filter. It must be pointed out that with the LPF in place, the PIM level is also constant over the whole frequency band. This is due to a "weaker" PIM source present in the common RF path (probably the 4-holes standard UBR220 flange used for connecting the filter input to the test bed, whose PIM performance can be improved if required by using a higher number of holes or a wider flange, according to the rule described in [9]).

In order to check the effectiveness of the 90 dB rejection filter to improve the PIM performance of the set-up, a second set of PIM measurements took place as follows. First, the dummy load was replaced by a horn antenna and the whole set-up was moved into an anechoic chamber. Next, a first set of measurements was conducted with the LPF connected to a horn antenna radiating towards the anechoic chamber (blank scenario). Then a metallic sponge (a typical strong PIM source) was placed at 30 cm from the horn antenna and a second PIM campaign took place. The results are provided in Fig. 4. The set-up showed essentially the same PIM level in both situations, thus demonstrating that the insertion of a high rejection low-pass filter blocks the PIM generated by the sponge. It is therefore a valid solution to protect a PIM test bed in backward configuration with respect to dummy loads having poor PIM performance.

IV. Conclusion

This paper proposes a simple technique to reduce the residual PIM level of test benches in waveguide technology conceived to evaluate backward PIM. With the insertion of a dedicated filter before the dummy load, it is possible to reduce the residual PIM level of the test set-up related to the termination. Details for the choice of a suitable filter for this application have also been given. Several sets of measurements with a PIM set-up in K-band has been carried out to show the validity and practical use of this solution.

Acknowledgment

The authors are indebted with Mr. Uwe Rosenberg, from Mician Global Engineering GbR, for practical discussions related to this topic.

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