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** See annex of F. Romanelli et al, "Overview of JET Results",*
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ABSTRACT.
A Sub-Harmonic Arc Detection (SHAD) system has been installed on the transmission lines feeding the JET ICRF ITER-like-Antenna (ILA). Along with the commissioning of SHAD, extensive measurements of the RF field in the transmission lines were carried-out using fast sampling (125 Mb/s) oscilloscopes. The system is described, and the SHAD ability to detect arcs during ILA operation (in particular on ELMy H modes) is discussed. Overall, SHAD proved to be efficient, and in some conditions it can offer extra protection in complement to other arc detection systems.

1. SHAD DESCRIPTION

New arc detection systems need to be developed for ICRF ELM resilient systems, as conventional detection of high Voltage Standing Wave Ratio (VSWR) in the transmission lines feeding the antenna cannot distinguish between ELMs and arcs. Also problematic is the detection of arcs that could develop at low voltage points [1] that cannot be detected by standard arc detection systems. In this respect, the ILA [2] T-junctions needed extra protection, using the Scattering Matrix Arc Detection (SMAD [3]) and the Sub-Harmonic Arc Detection (SHAD) systems. This paper describes the operation of the SHAD system, which principle was described in [4].

The key features of the system, developed on CEA Tore-Supra (TS) [5] and adapted to the JET-ILA, are described below (see Fig.1). The signal from the measurement coupler is first filtered with a 5-20MHz band pass filter. Because of the low RF signal level (80dB couplers vs 60dB on TS), an extra RF amplification and filtering stage was added in the course of the commissioning to improve sensitivity. It uses 33dB gain amplifiers with a noise figure of 2.9, and the same 5-20MHz band pass filters as in the filter module. The net gain (13dB to 23dB) is tuned by adjusting the attenuator pad at the output of the RF amplifier. Sub-harmonic events are detected if the signal in the detection band at the input of amplification and detection module is above −50 Bm. The response time of the system to detect sub harmonics and report it to the Amplifier Trip Module and JET data acquisition system is typically 2µs. Fast digitizers with sampling rate of 200kS/s are used to record, in the JET acquisition system, SHAD events, SMAD events, generator trip events, and various RF measurements. This allows fine analysis of the sequence leading to generator trips (see Fig.4 and Fig.6 for example). In order to perform spectrum analysis on SHAD signals (as is done in [6] for example) sampling oscilloscopes are used (samples length of 128 ms typically); RF signals are sampled at the SHAD input, and at the input of the amplification and detection module. An acquisition rate of 125MS/s, allows spectral analysis on the signal up to the Nyquist frequency of 62.5MHz. All four transmission lines feeding the antenna are equipped with SHAD and associated RF measurements. A layout with SHAD measurement points is shown on Fig.2. During most of the commissioning tests, RF measurements were taken from dedicated 80dB directional couplers, measuring the reflected voltage in the Antenna Pressurized Transmission Line (APTL) section, and located approximately 80 meters from the SHAD system. To allow extensive testing without disturbing the ILA operation, the SHAD system was not plugged into the amplifier trip modules.

2. SYSTEM OPERATION

Pulse No: 78134 is taken as an example to illustrate the operation of the SHAD system (see Fig. 3). This pulse is an ELMy H-mode plasma, in which only the upper row of the antenna was used at 42MHz. The impedance at the T junctions was set to 3 . The gain of the SHAD RF amplification stage was 19dB. Eight different events labeled in Fig.3 are now described: Events 1-4 correspond to mismatch trips on ELMs. More details on event 5, which is not triggered by an ELM, are found in Fig.4 and Fig.5: This arc develops on strap 2 feeder (V2 drop synchronous with SHAD and VSWR signals increase at t = 21.81649s), and the arc is detected by SHAD and by the VSWR system which trips the generators. A spectrogram (sliding FFT over 2Js time slices) of the RF signal seen by the SHAD detection is shown on Fig. 5. The arc is detected by SHAD 20 Js before the system is tripped, and sub-harmonics are observed in the detection band with a peak at 7MHz. A zoom on event 6 is shown on Fig.6: This arc on strap 2 at t = 22.1048s (sudden drop in V2) is detected by SHAD, while it is not detected by SMAD (presumably not in the SMAD region) nor directly detected by the VSWR protection. The amplifiers are tripped by a VSWR event 1.4 ms after the arc developed, because the antenna is running out of match in these conditions. Event 7 and 8 are SHAD events in RDL56, triggered by ELMs, and not correlated with other protection systems. These could be (short) ELM triggered arcs outside the SMAD region and that are invisible for VSWR protection, as also observed on the A2 antennas [7], or spurious sub-harmonic emission detected by SHAD.

CONCLUSIONS

SHAD has proven its capability to detect arcs on the JET ILA. In some instances, arcs were captured by SHAD and not by other arc detection systems, thus confirming that SHAD can offer extra protection. On H mode plasmas, ELM triggered SHAD events are observed, as on ASDEX [8], and the system sensitivity needed to be adjusted to the operating conditions, to find an acceptable (see Fig.3) compromise between protection and reducing trips. As these ELM triggered SHAD events could arise from multiple causes, including ELM triggered arcs, they represent a challenge for the protection of ICRF systems on ELMy plasmas, and deserve further studies.

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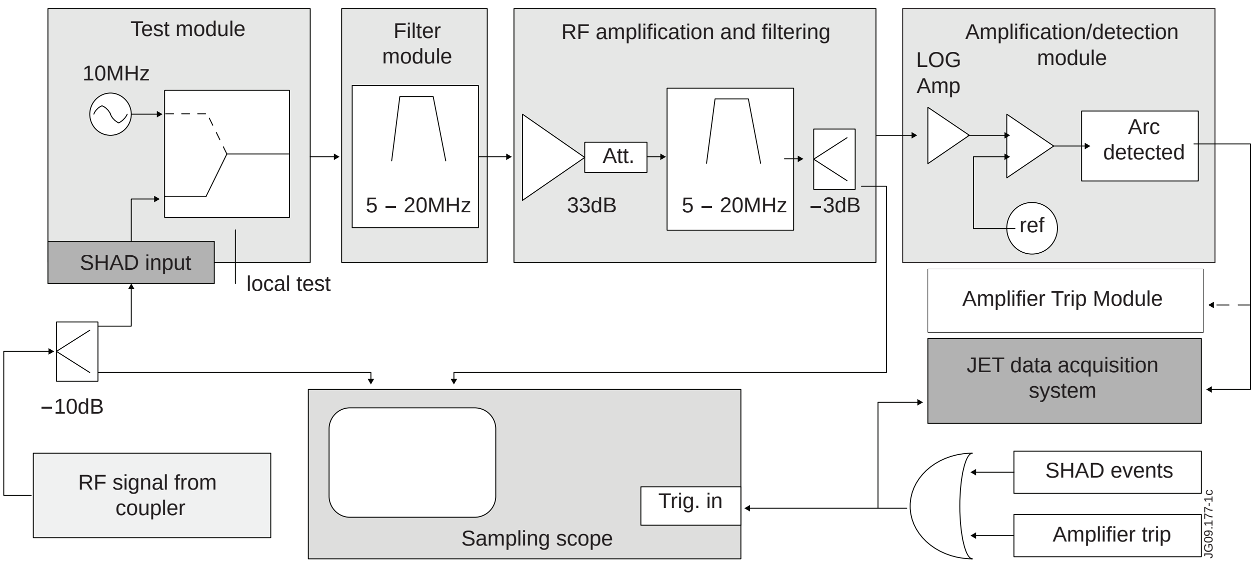

Figure 1: Block diagram of the SHAD system.

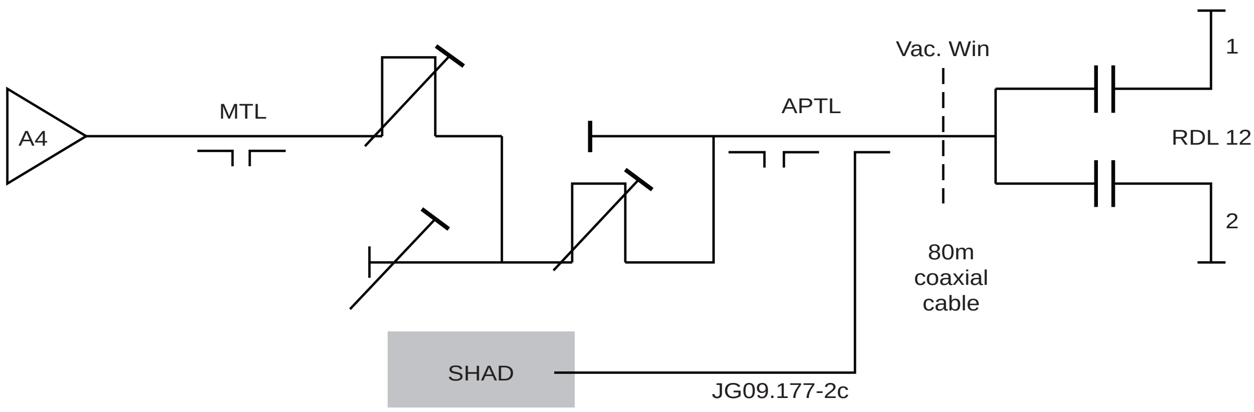

Figure 2: Measurement points in the ILA system, shown for RDL12 only. MTL stands for Main Transmission Line.

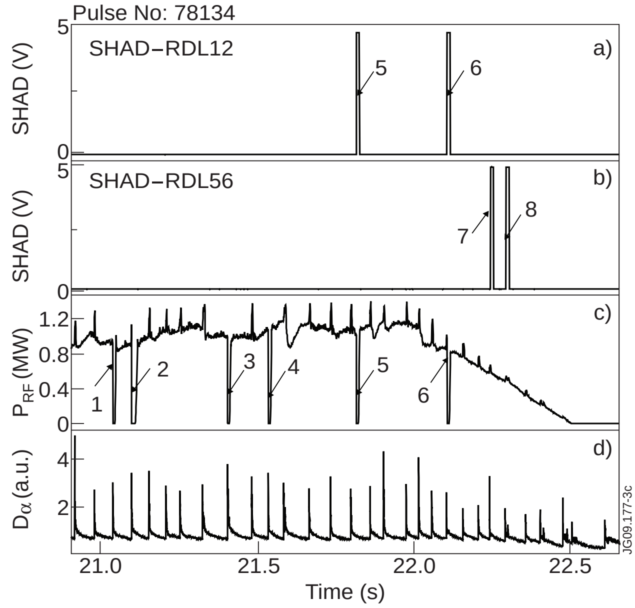

Figure 3: SHAD operation on ELMy plasma, JET Pulse No: 78134. (a) SHAD-out RDL12, (b) SHAD-out RDL56, (c) ILA launched power, (d) D_α signal.

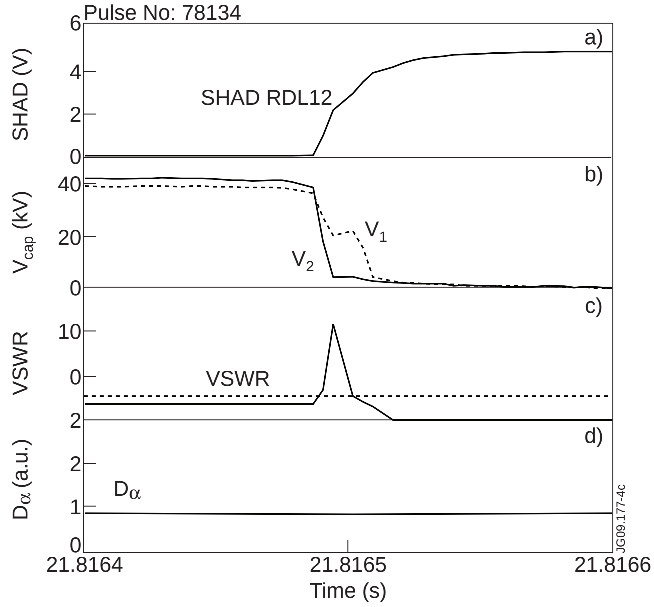

Figure 4: Zoom on event 5 of Fig.3: (a) SHADRDL12, (b) Capacitor voltage straps 1 and 2, (c) MTL VSWR (dotted line, trip threshold), (d) D_α signal.

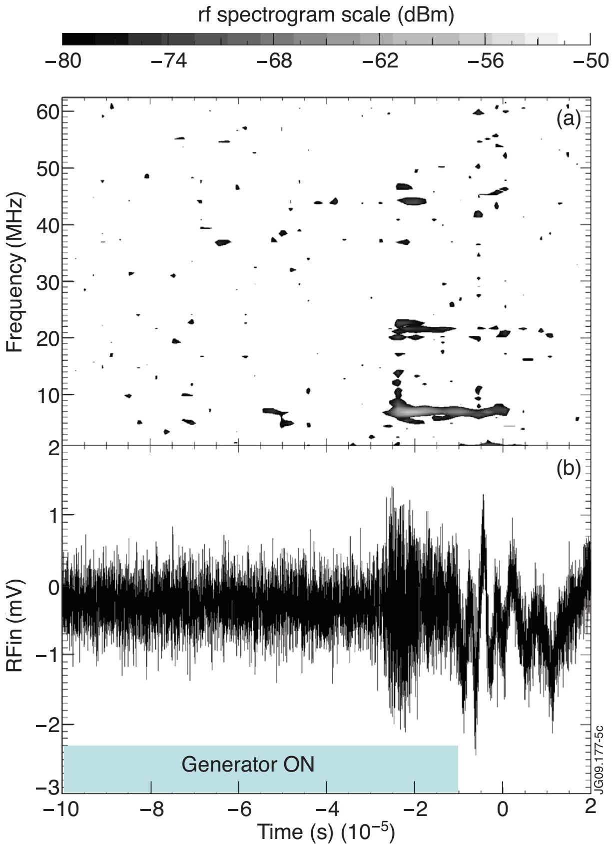

Figure 5: Event 5/JET Pulse No:78134, RDL12, analysis of SHAD signal: (a) spectrogram of the signal, and (b) corresponding rf signal. t=0 corresponds to 21.81652s in JET time base.

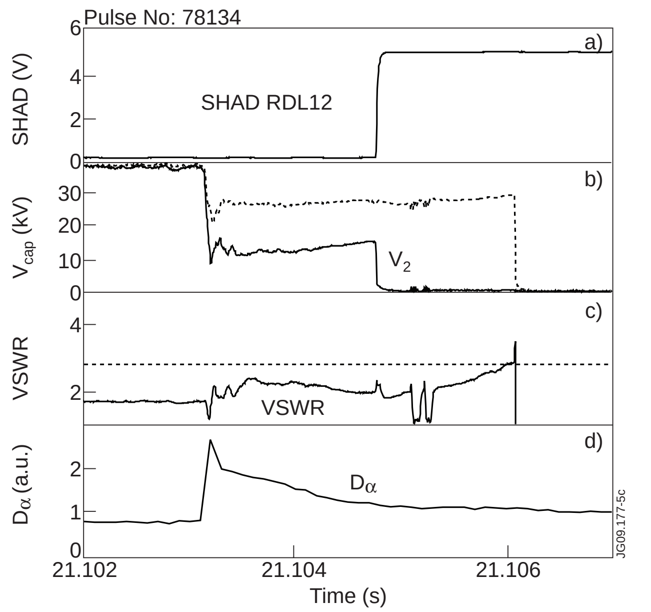

Figure 6: Event 6: (a) SHAD-RDL12, (b) Capacitor voltage straps 1 and 2, (c) MTL VSWR (dotted line, trip threshold), (d) D_α signal. rf spectrogram scale (dBm) Generator ON b) a)