POWER OVER FIBRE SYSTEMS FOR THE ITALIAN SKA-LOW DEMONSTRATORS

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Abstract

The Power over Fibre technique allows to power remote electronics without using copper cables. Avoiding any interaction between the antenna and its power/signal cable is attractive in the case of testing systems where the evaluation of antenna and/or array performance are crucial parameters under investigation. This is the case of the Sardina Array Demonstrator, an Italian SKA testing platform. In this work is evaluated the applicability of this technology in order to power the electronics of the antennas which will form SAD. The results of an extensive measurement campaign, with respect to both temperature and fibre length, of commercial PoF receivers, is here presented.

Introduction

The Square Kilometre Array (SKA) represents one of the most challenging new-generation radio-telescopes due to its huge collective area and, consequently, its extreme performance [1]. Among the various technologies, a sparse aperture array operating between 50 and 350MHz (SKA-low) is the system that will be installed in Western Australia from 2016. Nowadays, several prototypes of reduced size, called demonstrators, have been designed, installed and operated in several countries to gain experience on scientific and technological aspects may be applied on such large low frequency aperture array. Italy, through the Institute of Radioastronomy, part of the National Institute for Astrophysics, is a member of the SKA project with a leading role in the receiver design work package and with a significant contribution to the antenna and digital signal processing work packages [2]. In this context, in collaboration with the Astronomical Observatory of Cagliari, part of INAF, and the Department of Electrical, Electronic and Information Engineering (DEI) of the University of Bologna, two demonstrators have been conceived in Italy. A 9 antennas array so called Medicina Array Demonstrator (MAD)[3] and the future larger Sardinia Array Demonstator (SAD)[4], which aims to install 128 Vivaldi antennas distributed between a core and few remote stations close to the Sardinia Radio Telescope (SRT). Both systems aim to perform tests on antenna array calibration and beam-forming. In particular, SAD will be devoted to test in a real environment SKA-low technology as the critical devices RFoF (RF over Fibre) to remote the signal received by the antennas.

Both demonstrators offer test platforms in particular to measure antenna and array performance in order to validate their models obtained by software simulations. To make the comparison more reliable, a metallic cabling deployed above the ground in the array region should be avoided. In fact, the interaction between antennas and metallic cables introduces distortions in the antenna patterns and worsens the antenna mutual coupling. Further, these effects are difficult to be simulated and to take into account.

Regarding MAD, the problem was overtaken using batteries inside the antennas to power both a low noise amplifier (LNA) and a RFoF Transmitter (TX) which transmits the RF signals over a full dielectric fibre optic (FO) cable to a receiver located 400m far away. This solution is adequate for short test duration (few hours) and acceptable considering the test were performed using an artificial source mounted on a flying drone. Instead, for SAD, which is an astronomical facility, continuous operation has to be guaranteed.

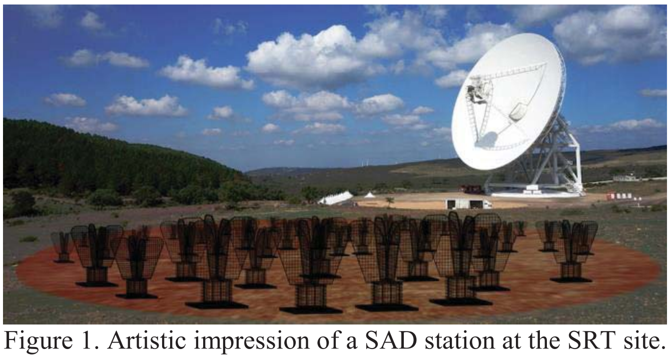

Figure 1. Artistic impression of a SAD station at the SRT site.

Power over Fibre Technology overview

The Power over Fibre principle of operation is shown in Figure 2. A high power laser source launches up to few watts on a single mode (SMF) or a multimode fibre (MMF). At the receiving end, an integrated photovoltaic module converts back the optical power into electrical power. This technology allows to provide power and to remote all the electronics inside the antennas without suffer of the interaction between copper cables and antennas by using totally dielectric fibre optic

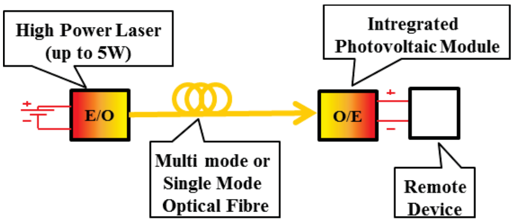

Figure 2. PoF basic principle.

cables (MMF for PoF and SMF for RFoF). Other advantages of PoF solution are complete galvanic isolation with the remote electronics, immunity to crosstalk, Electro Magnetic Interference (EMI), Radiofrequency Interference (RFI), electric and magnetic fields and lightening. The main drawbacks are high cost and low overall electrical to electrical efficiency (~15%).

For SAD project, the antenna electronics consists of the cascade of a LNA, a RF gain stage and a RFoF TX. All the circuitries work with ultra-stable 3.3V_{DC}, thanks to Low dropout (LDO) regulators, which need a voltage between 3.4V and 6V for proper operation. The current requirement is 185mA (worst case), for each antenna polarisation, and the maximum distance between antennas and power supplies is around 200m. Considering these requirements, SAD can be considered a good test bench to verify the applicability of PoF technology.

Market research and PoF devices under test

Through a market research, several companies (JDSU, L2W Energy, Laser Motive and RLH Industries) produce PoF components. Among them, JDSU and L2W can provide single laser diode and/or complete laser source driver and miniaturised integrated photovoltaic receiver as single components. JDSU provided a complete laser driver module called PPM (Photonic Power Module) [5] and a receiver (Photonic Power Converter) PPC-4E [6]. From L2W Energy we had only an optical receiver OPI-4G (Optical Power Isolator) since they do not have an own laser source [7]. Both integrated photovoltaic modules work at a nominal voltage of about 4V, meeting the SAD bias voltage specifications.

To characterise the PPM laser source and to obtain the relationship between PPM setting voltage control and emitted optical power, a Coherent PM30V1 High Peak Power Thermopile Sensors was used (see Figure 4). The maximum emitted optical power is a bit less than 2W with an estimated efficiency of about η = 0.72W/A compatible with the value reported in the laser datasheet [8].

Figure 3. L2W optical reveivers (OPI) with FC connectors.

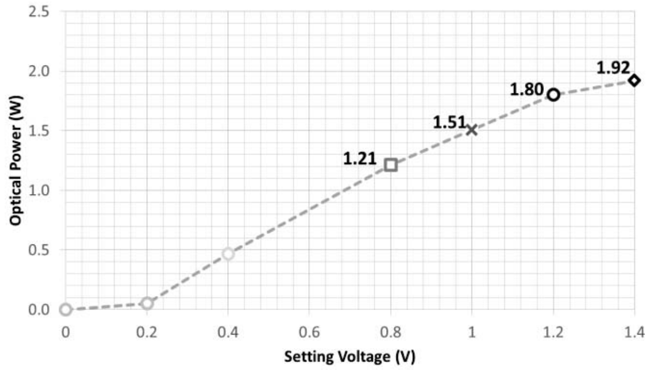

Figure 4. JDSU-PPM L-I curve at 27°C with 50m OM1 fibre.

Note that to properly operate with the integrated photovoltaic modules, a minimum length of 10m (better 50m) of OM1 fibre it is necessary to be installed in order to scramble the modes and better distribute the optical power on theirs surfaces to reduce the risks of back reflections.

To characterise the integrated photovoltaic modules, a semi-automatic measurement bench was set up (see Figure 5). Three power supplies are needed in order to supply, enable and control the PPM. A datalogger collects voltage and current at the optical receiver output and monitor the pin of the PPM which provides a voltage proportional to the laser bias current. Finally, it logs three temperatures: PPM case, optical receiver case and laboratory/thermal chamber. To exploit the entire I-V curve a variable resistor (0÷100Ohm/25W) has been provided.

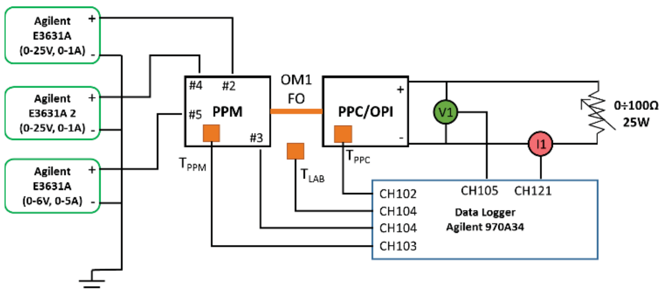

Figure 5. Measurement bench system.

The I-V curves for both PPC-4E and OPI-4G are reported, respectively, in Figure 6 and 8. As shown, the behaviour is the same of a typical solar panel. Open circuit voltage (Voc) and Short circuit current (Isc) are, respectively, the points were the I-V curve intersects the x and y axes.

The maximum conversion efficiency from optical power to electrical power (i.e. the product of current and voltage at the PPC/OPI output) is obtained operating the device close to the knee (see Figure 7 and 9).

Even if JDSU module exhibits a higher margin in terms of operating voltage (Voc is always greater than 4V), the efficiency appears to be smaller than the L2W one (~35% against ~47%). So the maximum current is possible to sink from JDSU module, with an optical input power in the 1.2÷1.9W range, is always lower than the L2W module.

In order to verify the applicability of those COTS components for the SAD project, an investigation of the performances of

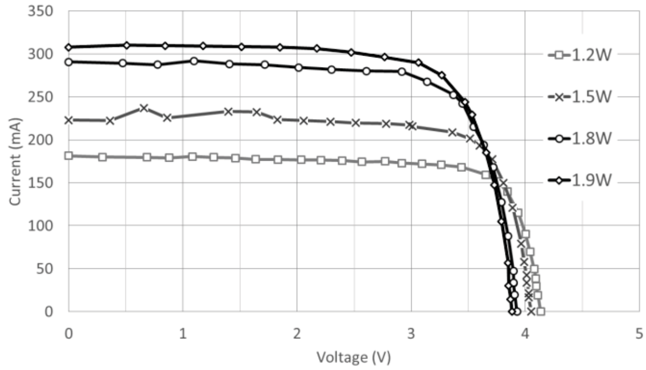

Figure 6. L2W OPI-4G I-V curves vs optical power.

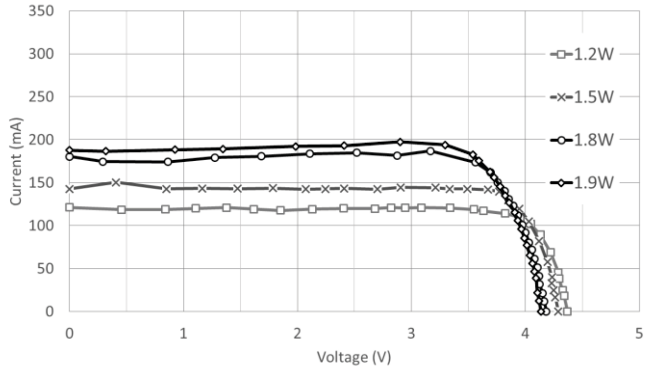

Figure 8. JDSU PPC-4E I-V curves vs optical power.

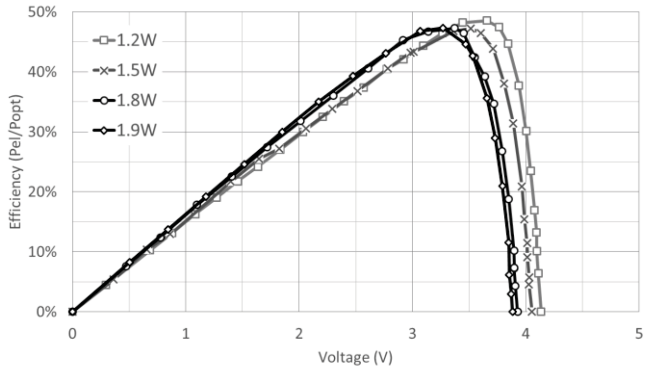

Figure 7. L2W OPI-4G conversion efficiency vs optical power.

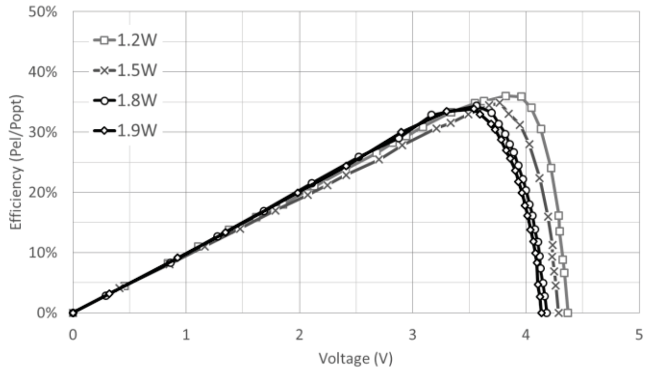

Figure 9. JDSU PPC-4E conversion efficiency vs optical power.

their behaviours respect to fibre length and optical receiver working temperature was done. Note that the effect of the temperature on the PPM module has not been investigated because we suppose the laser source will be installed in a thermo-controlled environment.

Figure 10 and 11 show the effect of the insertion of further 200m of OM1 fibre between laser source and the integrated photovoltaic modules with the PPM operating at 1.9W and all PoF elements (PPM and OPI/PPC) working at room temperature. As expected the fibre attenuation reduces the maximum power obtainable from both modules.

Instead, considering the temperature aspect, it is well know that the operating temperature of a photovoltaic module affects its performance. In particular, higher is its temperature, lower is Voc which might lead to a reduction in the voltage margin necessary for a correct LDO operation ($Vin_{LDO} \geq 3.4V$ as mentioned before). To investigate this effect, the L2W OPI-4G was put in a thermostatic chamber at 50°C, which is the maximum expected value which the electronics at the antenna level should experience. The measurements have been made with 250m OM1 optical fibre between laser source and optical receiver in order to reproduce at the same time the SAD worst-case scenario in terms of maximum distance and maximum receiver operating temperature. The resulting I-V curves is plotted in Figure 12. As can be noticed, the effect on OPI performance versus environmental temperature is negligible (small reduction of both Voc and Isc). When it operates without heat sink, as the cases considered here, its temperature

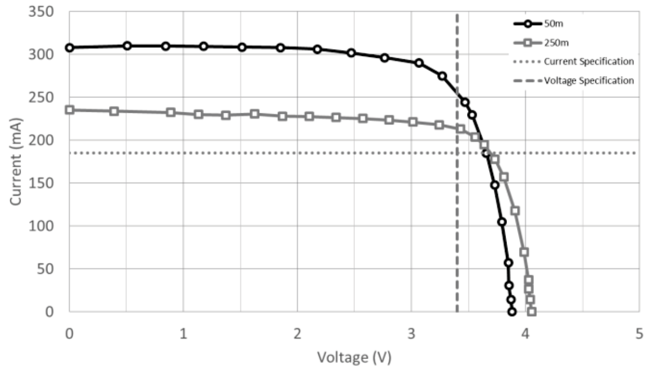

Figure 10. L2W OPI-4G I-V curve versus fibre length.

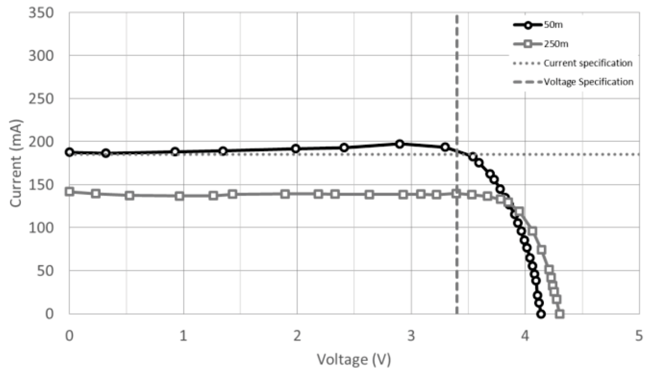

Figure 11. JDSU PPC-4E I-V curve versus fibre length.

reaches always values between 55°C and 65°C, higher and so independently from the environment temperature (23°C for the laboratory and 50°C in the thermal chamber). The OPI-4G equipped with a proper heat sink able to cool it down to 27°C verify our suppositions. From Figure 13 the Voc reduction effect is now more clear. Anyway, the SAD specifications can be met even without a proper OPI heat sink but further margin might be obtained realising a sort of heat sink at the antenna level.

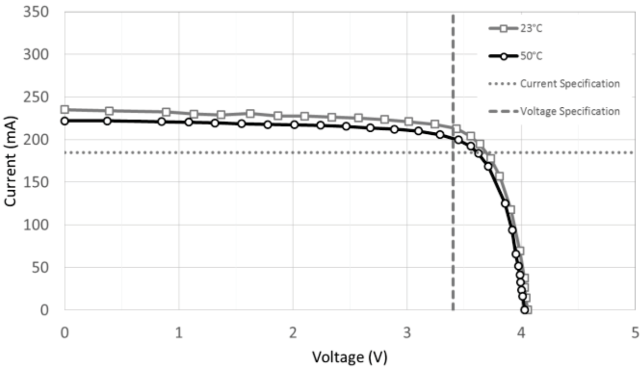

Fig. 12 L2W OPI-4G I-V curve versus (air) temperature (without heat sink).

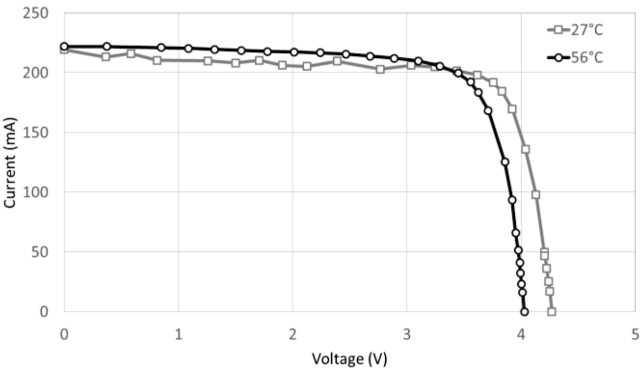

Fig. 13 L2W OPI-4G I-V curve versus its temperature (with and without heat sink).

Conclusions

A good knowledge on PoF technology has been gained thanks to the described work. A complete characterization of two COTS PoF modules (both from JDSU and L2W), with particular regards to optical receiver temperature and fibre length, has been performed.

A suitable PoF receiver (L2W OPI 4G) for the SAD project has been identified as possible solution to be installed. When it operates in conjunction with a 2W laser source, more than 0.63W (3.4V×0.185mA) of electrical power can be delivered up to 250m with OM1 fibre, exceeding the SAD electronics power requirements at the antenna end.

Further investigations about aging are necessary in order to verify the effect on the PoF system laser source and integrated photovoltaic module eithers. Unfortunately the applicability of this kind of technology is limited by costs (too expensive 1500÷2000€ for a single link pair and 300÷350€ for hundred pieces). In order to reduce the overall PoF module cost and also to increase the current margins respect to the SAD specifications, the design of a custom laser source with optical power greater than 2W (OPI 4G can accept up to 4.5W) might be taken into consideration. The implementation of a complete PoF system for one SAD tile (16 antennas/32 polarisations) could represent an intermediate step towards the extension to the overall SAD array and can be considered as a possibility to further investigate this technology.

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