The 352 MHz superconducting (SC) RF system of the SOLEIL storage ring consists in two cryomodules, each containing a pair of SC Nb/Cu cavities, cooled with LH2 at 4 K from a single 350 W cryogenic plant, in order to store 500 mA, a power of 575 kW and a voltage of 3.5 MV. The RF power is provided by 4 solid state amplifiers delivering up to 180 kW each. The original cavity input power couplers, which are LEP-type antennas, designed to handle up to 200 kW, were replaced by upgraded versions, able to transmit up to 300 kW CW. This opens the possibility to operate at full beam current with only one active cryomodule. The SC RF system operational experience over the past ten years as well as the different upgrades will be reported here.

**Cryomodule**

The SOLEIL cryomodule (CM) contains a pair of single-cell “HOM-free” SC cavities, equipped with input power couplers (antennas), capable to transmit up to 200 kW in their original version, and two types of HOM couplers (loops).

**Cryogenic Plant**

Both CM’s are supplied with LH2 at 4.5 K and LN2 from a single cryogenic plant, based on the HELIUS 2000 from Air Liquid. The cold box unit, a 2000 ltr LH2 storage, the cryogenic valve box distributing the LH2 and LN2 towards each CM are located in the accelerator building. The compressor plant is housed in a dedicated room of the utility’s building and nearby, outdoors, stand two 50 m3 LH2 buffers.

**Low Level RF System**

The analog low level RF (LLRF) system comprises three relatively slow loops which control the cavity resonant frequency and accelerating field, in amplitude and phase; besides a fast direct RF feedback copes with the Robinson instability at high beam current. It can achieve a voltage stability of ± 0.1 % in amplitude and 0.03 degree in phase.

**Description of the SOLEIL Cryomodule (CM)**

The SOLEIL CM consists in a crystallographic device that contains two 352 MHz single-cell cavities, made of copper with a Niobium layer and enclosed in their tank. Both cavities are immersed in a bath of 4.5 K. Each cell has its own frequency tuning, a mechanism driven by a stepping motor, which changes the cavity length. The tuning assembly, housed inside the CM, works under vacuum and in cryogenics environment. Four HOM couplers (loops), located on central tube, strongly damp the cavity parasitic HOM impedances; they have been upgraded and they are made of bulk Niobium and cooled with LH2 circulating through their coupling loop. Two input power couplers (antennas) are also located on the central tube; they have been upgraded and can now feed each cavity with up to 200 kW.

**SOLID Storage Ring RF system**

- **SOLEIL storage ring parameters:**
  - $E = 2.75$ GeV, $\Delta E = 0.2$ MeV, $I = 500$ mA
  - $P_{\text{FW}} = 575$ kW at $E = 3.4$ MeV @ 352 MHz
  - 4 x 352 MHz SC cavities, 4 x 180 kW amplifiers, 4 LLRF systems, 1 cryogenic plant

**Main upgrades of the SOLEIL RF systems**

- **Frequency tuner upgrade**
  - The main difficulty that was encountered with the RF system came after 2 years of operation from repetitive jams on the frequency tuning mechanism. Fortunately, the impact on the user runs remained quite marginal.

- **Upgrading of the input power coupler (IPC)**
  - The upgrade of the IPC was motivated by the problems of ceramic aging encountered at ESRF with a similar design and by the occurrences of discharges, especially on one of the SOLEIL IPC’s, at a rate of once a week, when operating above 120 kW. Furthermore the ability of feeding up to 300 kW per cavity opens the option to SOLEIL of storing more than 450 mA using a single CM (a redundancy).

- **SSPA refurbishment**
  - In 2011, a collaboration agreement was concluded with CERN & ESRF to develop a new 352 MHz SSPA, based on the LHC design and capable of handling up to 300 kW. The antenna of the new IPP’s is lengthened by 1 cm to double the coupling factor hence matching the new standard operating condition, $V_{\text{in}} = 3$ MV instead of 4.85 MV, which prevents from fast ion instabilities.

- **Upgrade of the waveguide network**
  - In parallel, the waveguide network is being modified for a fast and easy combining of 2 amplifiers into a single cavity. For this purpose, we have developed a new device that we called “Magic Switch”. It is a 4 ports (2 inputs & 2 outputs) waveguide component with a number of holes into which one can insert metallic posts. Depending on the post configuration, one can transfer either each input power to each output or their sum to one or the other output. Furthermore connecting two Magic Switches, one can power one or the other CM with 260 kW per cavity from our four amplifiers, combined by pairs, which allows storing 450 mA using a single CM.

**Conclusion**

The RF system of the SOLEIL SR is quite innovative and challenging with the use of SSPA’s and “HOM-free” SC cavities, both developed in house. However, after more than 10 years of operation, it has demonstrated outstanding availability, top performance and reliability. Two operation modes with open and closed injection are routinely delivered to the users: 450 mA multibunch in hybrid mode and 500 mA multibunch in uniform filling. The difficulties encountered with the CM frequency tuners had only minor impact on the user operation and were quickly overcome by improving the initial design. Cavity IPC’s of higher power capability, have been developed. They are now implemented on the four cavities and are working quite satisfactorily when applying a 1 kV DC bias voltage for curing recalcitrant multipactoring level. They are able to feeds more than 260 kW per cavity. Moreover the refurbishment of the SSPA’s and modifications of the waveguide network with the implementation of “Magic Switches” opens the option for SOLEIL of storing > 450 mA using a single CM or 2 CM’s with only 3 running amplifiers/cavities and consequently to take advantage of the resulting redundancy.

Upgrades of the cryogenic system for improving its autonomy are also under way.

A special effort is put on the success of the SSPA technology, which has demonstrated that it could advantageously replace the vacuum tubes in such an application. Further R&D, carried out by SOLEIL, allowed improving the original design in compactness, reliability and efficiency. SOLEIL was thus asked to share its experience through scientific collaborations and transfers technology. It is now being adopted by many other accelerator facilities.