

Innovative Phased Arrays for Radio Astronomy Applications

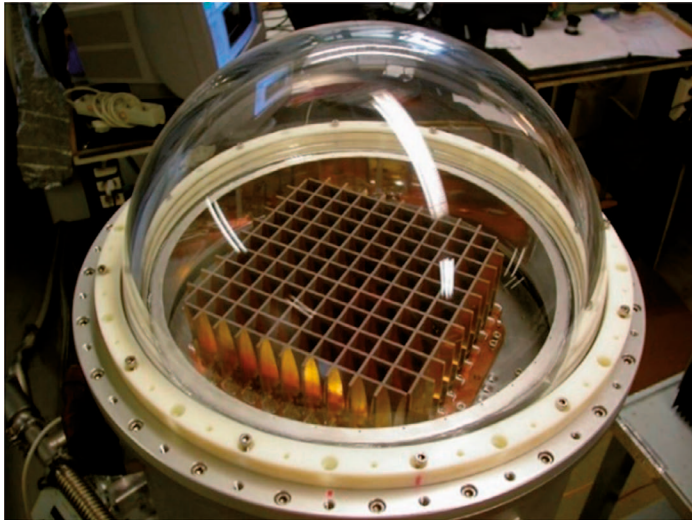


Figure 1: PHAROS 2 focal plane array and dome-shaped vacuum window attached to the cryostat

High-sensitivity, large-scale surveys are an essential tool for new discoveries in radio astronomy.

INAF designers were challenged to develop, fabricate, and test a room temperature, multi-channel heterodyne receiver operating across the 2.3...8.2 GHz RF band for radio astronomy applications. A phased-array feed (PAF) placed at the focal plane of an antenna can increase the field of view and mapping efficiency by fully sampling the sky. A phased array for reflector observing systems (PHAROS) is a cryogenically cooled PAF demonstrator with analog beamformer based on an array of dual polarization 10 x 11 Vivaldi antennas (Figure 1) designed for radio astronomy observations. The new upgraded version, PHAROS 2, utilizes new components to reduce the system noise temperature, enhance the aperture efficiency, and digitize the signals from a sub-array of 24 single-polarization PAF antenna elements that synthesize four independent single polarization beams.

The receiver performs signal filtering by using a switched-filter bank, signal conditioning, and single-frequency down-conversion of a section of the 2.3...8.2 GHz RF band down to the 375...650 MHz interme-

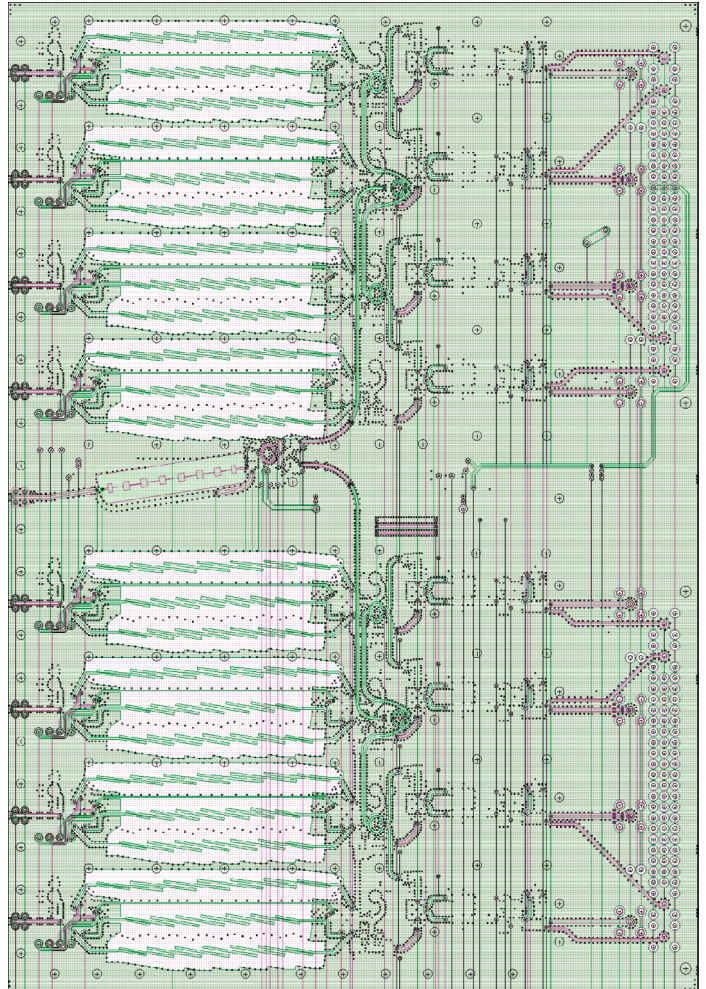


Figure 2: Microwave Office schematic of the receiver chain, including the distributed PCB-based passive networks of filters, splitters, and SMT components

Background:

Divisions of the National Institute for Astro Physics of the Institute of Radio Astronomy (INAF-IRA) in Bologna, Italy and the Cagliari Astronomical Observatory (INAF-OACa) in Cagliari, Italy conduct research into the physics of radio sources such as active galactic nucleus (AGN) and galaxies, clusters of galaxies, the galaxy stars and star formation, and cosmology. INAF scientists and staff are involved in the development and management of the radio telescopes distributed in the national territory and operate three radio telescope facilities for use by the scientific community. The Institute was extensively involved in the design, construction, and testing of the Sardinia radio telescope (SRT), a new 64-meter antenna that is part of the very long baseline interferometry (VLBI) global network.

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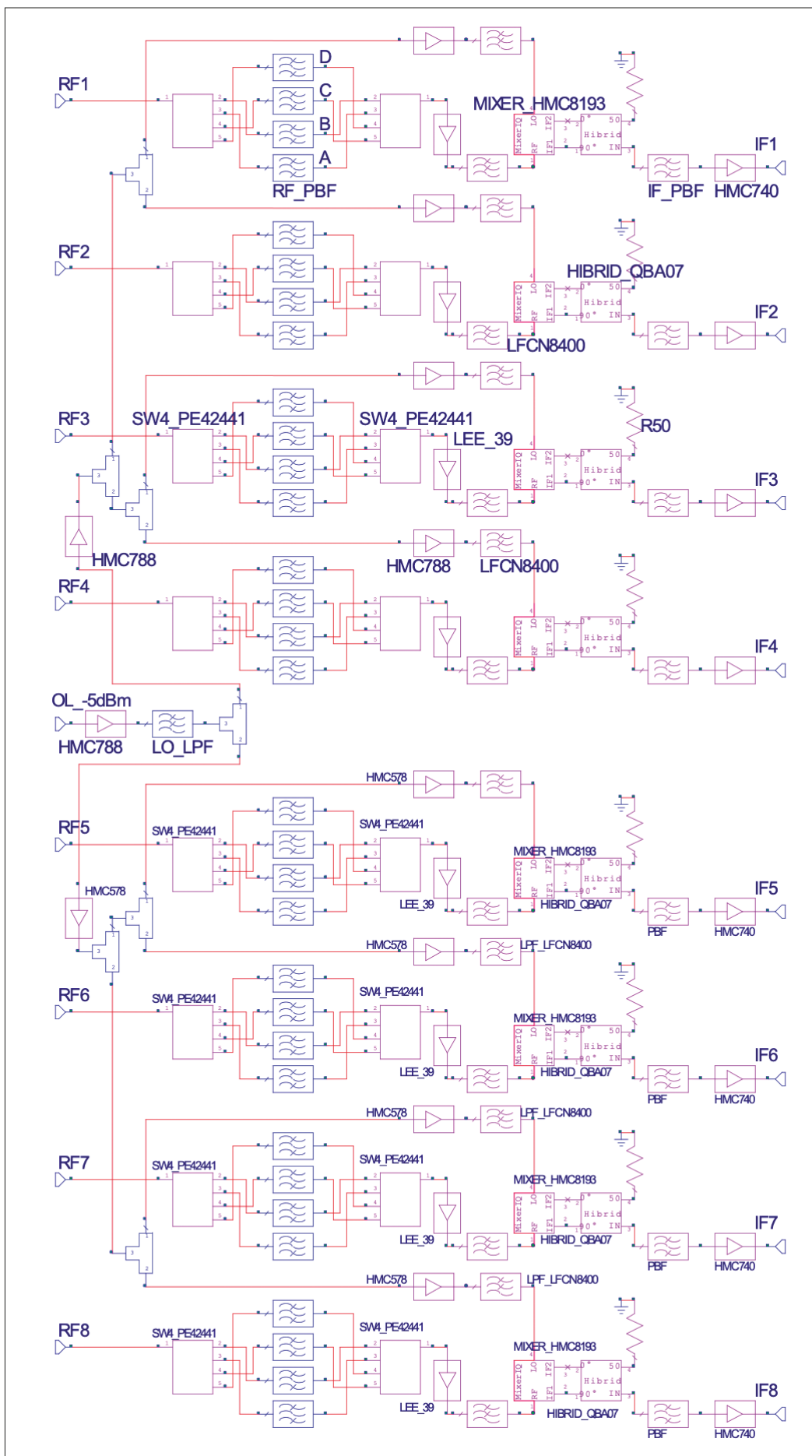


Figure 3: RF/IF board design with view of two different PCB layers: metallization layer n. 2 and 3, showing the BPF-B, BPF-C, BPF-D and LPFLO filter

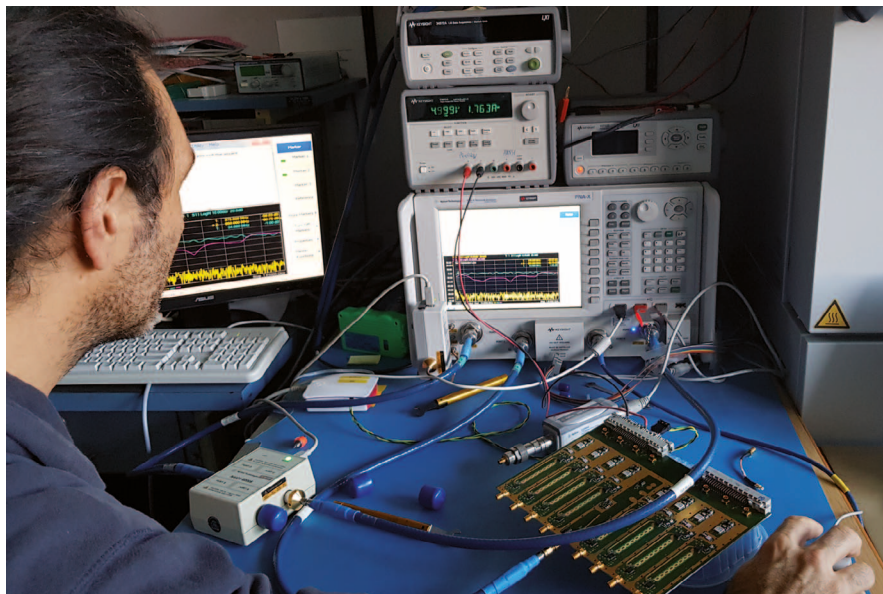
diate-frequency (IF) band (275 MHz instantaneous bandwidth). A switched-filter bank on the receiver input section is used to mitigate the effects of the radio-frequency interference (RFI) signals across the RF band that could otherwise saturate the receiver chain and the optical links. The switched-filter bank is cascaded with an RF amplification stage followed by a sideband separating (2SB) mixer operated in single down-conversion lower-sideband (LSB) mode.

The wide bandwidth and high-performance receiver requirements call for precise electrical modeling of the individual components and RF characterization of the multi-layer printed-circuit board (PCB) substrate in order to achieve the accurate simulation results necessary for successful design.

Solution

INAF IRA designers used the Microwave Office circuit simulator within the NI AWR Design Environment platform to design the PCB circuitry of the receiver chains (Figure 2). The AXIEM 3D EM planar simulator was used to simulate the electromagnetic (EM) response of all interconnecting transmission lines and distributed BPFs. Microwave Office software was employed to optimize the overall performance of the entire receiver chain of a PCB populated with surface-mount technology (SMT) components, as shown in Figure 3.

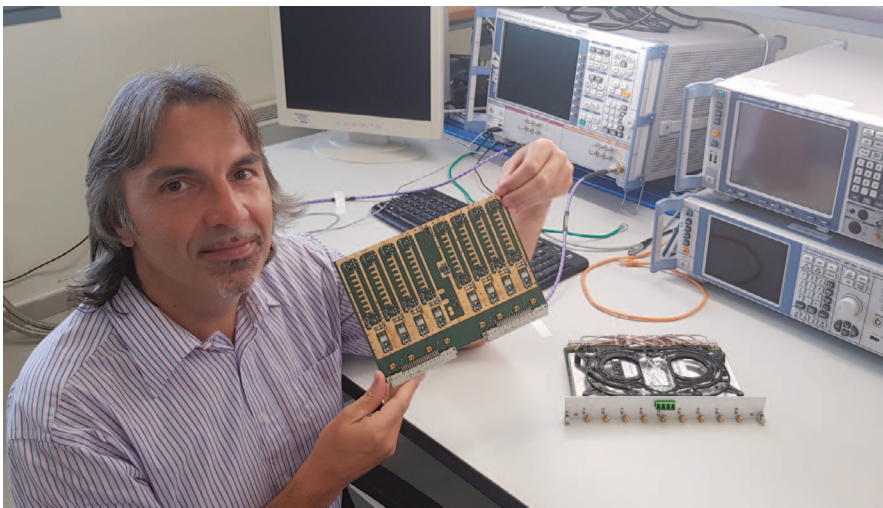
The designers imported the S-parameters of the SMT components from the manufacturer's website into the circuit schematic for network analysis, directly incorporating the results of the AXIEM EM co-simulation and optimization of the interconnecting transmission lines and matching circuitries. They also took advantage of the Micro-



Scalambra Alessandro testing the PHAROS 2 board

wave Office PCB import wizard to streamline the exchange of design information from the PCB layout tool into the simulator, which was required for the EM verification of the entire layout, including the integrated distributed filters and power splitters.

One of the four BPF filters, BPF-A, was specified to cover the broad 2.3...8.2 GHz RF frequency band, while the other three filters, BPF-B, C, and D, had 275 MHz “narrowband” features. The BPF-A was based on an inductor/capacitor (L-C) cell high-pass filter cascaded with a microstrip eight-pole Chebyshev low-pass filter (LPF), while BPF-B, BPF-C, and BPF-D were based on six-pole Chebyshev BPFs fully implemented on microstrip. Figure 4 shows the simulated RF transmissions that were obtained by selecting the four BPFs. It can be seen that simulated response of the filters closely matches the specified ones in terms of pass-band (bandwidth at half-power points), insertion loss, return loss, in-band ripple, stop-band attenuations, and size.



Navarrini Alessandro displaying the PHAROS 2 board

Conclusion

The test results confirmed that the two WS 32-channel receivers, one of which will be used for PHAROS 2, performed well and according to specification. The designers attributed the success of the design in part to the ease of use, simulation speed, integration of EM analysis, and availability of component models in NI AWR software, as well as the excellent technical support. The paper describing the application in this success story, “The Room Temperature Multi-Channel Heterodyne Receiver Section of the PHAROS2 Phased-Array Feed,” can be found at mdpi.com/2079-9292/8/6/666/pdf-vor.

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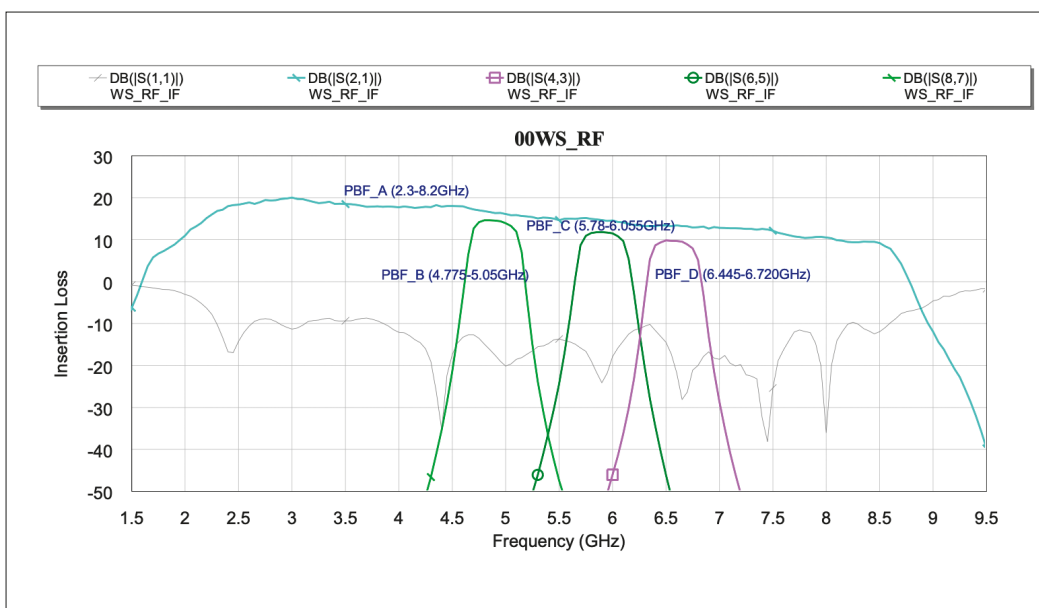


Figure 4: AXIEM EM simulation of the S21 transmissions of one RF/IF board receiver chain from SMA board input to mixer, including the RF low-noise amplifier (LNA), BPF, and mixer conversion loss, obtained by selecting the four BPFs