In the last years, the progress on low temperature detector technologies has allowed to design large scale experiments aiming at pushing down the sensitivity on the neutrino mass below 1 eV. Even with outstanding performances in both energy (~ eV on keV) and time resolution (~ 1 microsecond ) on the single channel, a large number of detectors working in parallel is required to reach a sub-eV sensitivity. Microwave frequency domain read out is the best viable technique to read out large array of low temperature detectors, such as Transition Edge Sensors (TES) or Microwave Kinetic Inductance Detectors (MKIDs). This microwave multiplexing system will be used to read out the HOLMES detectors, an array of 1000 microcalorimeters based on TES sensors in which the 163Ho will be implanted. HOLMES is a new experiment for measuring the electron neutrino mass by means of the electron capture (EC) decay of 163Ho. We present here the microwave frequency multiplex which will be used in the HOLMES experiment and the microwave frequency multiplex used to read out the MKID detectors developed in Milan as well.

### Microwave multiplex read out for superconducting sensors

**Detectors:** Transition Edge Sensor (TES) with 163Ho implanted in Bi/Au absorbers

**Activity:**
- 6.5x10^{11} nuclei per detector to 300 dec/s

**Performance:**
- ΔE = 1 eV and τ = 1 μs

**16 channel demonstrator**

**Final configuration:**
- 1000 channel array
  - 6.5 x 10^{11} 163Ho nuclei
  - 3 x 10^{15} events in 3 y

**Detailed information on HOLMES:** see A. Nucciotti’s poster

**Detailed information on Ho implantation:** see G. Pizzigoni’s poster

**Test in progress @ Milano-Bicocca**
- μmux 33 channels (2/3 of resonators shorted)
  - + IF board with R_{nuc} + TES → all provided by NIST.
  - Available:
    - ‘naked’ resonators with input coil directly linked to external wires for simulating the TES response
    - resonators + TES with a 25 eV source
    - (activity of few Bq)
  - Homodyne set up developed in Milano-Bicocca

**Detailed information on TES:**
- Cryogenic particle detector that exploits the strongly temperature-dependent resistance of the superconducting phase transition
  - Excellent energy resolution
  - Low impedance
  - Large array and multiplexing (TDM; CDM; FDM, μmux)
  - Tunable critical temperature Tc exploiting the proximity effect

**Homodyne detection**
- Signal reconstructed by homodyne detection and demodulation
  - frequency shift Δf = carrier phase shift 6θ

**Homodyne set up developed in Milano-Bicocca**
- capable to readout 2 channels

**ROACH2 read out system**
- Xilinx FPGA based digital data processing
  - frequency comb generation (up to ~60 in 0-550 MHz)
  - GHz band up/down conversion (5-5.5 GHz)
  - Homodyne detection: IQ signal de-multiplexing and rf-SQUID signal de-modulation
  - real time signal processing
- → 140TB in 3 year

**Microwave multiplex read out with microwave multiplexing**
- DC biased TES
- SQUID coupled with TES and a resonator circuit
- microwave rf-SQUID read out with flux ramp demodulation (common flux line inductively coupled to all SQUIDs)

**Bandwidth Budget:**
- Effective sampling rate is set by the ramp - f_ramp
- Necessary resonator bandwidth per flux ramp: Δf ≈ 2n_0 f_ramp
- To avoid cross talk spacing between resonances f_{n+2} > f_{n+1} Δf (potentially reduced by a factor 2)
- To avoid distortions f_{n+1}/τ [potentially reduced by a factor 2]
- Available ADC bandwidth f_{ADC} with ROACH2 system 550 MHz
- Mux factor:
  - Number of flux per ramp n_0
    - currently 3, easily scalable to 2, feasible 1.1
  - τ_{T_{RAMP}} = 5 μs, n_{0mux} = 2 - n_{0} = 50

**Mixer**
- IQ signal de-multiplexing
- signal processing
- real time signal processing
- → 140TB in 3 year

**ROACH2-based Software Defined Radio**
- Xilinx FPGA based digital data processing
  - frequency comb generation
  - GHz band up/down conversion
  - homodyne detection: IQ signal de-multiplexing and rf-SQUID signal de-modulation
  - real time signal processing
  - → 140TB in 3 year