SQUID Flux Modulation

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HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

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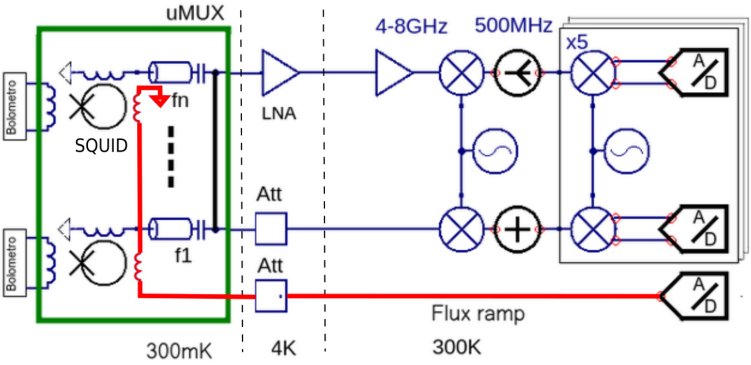
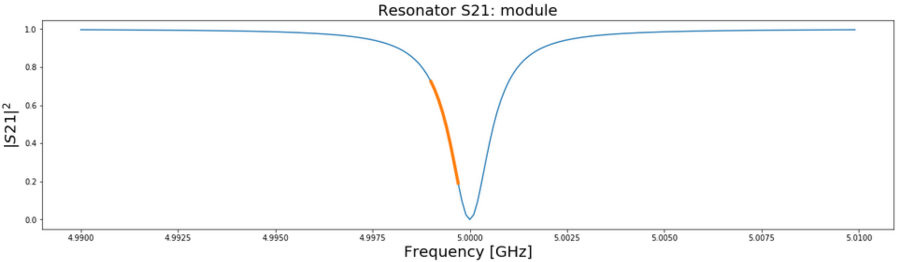
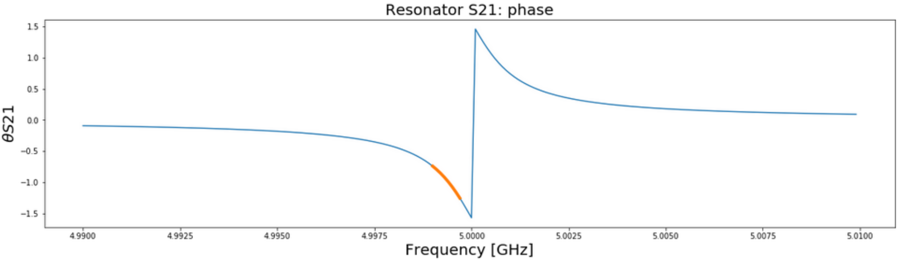
Read-out System



Read-out System





Modulation-Demodulation

Flux Ramp Modulation

$$I_{ramp} = I \cdot f_{ramp} \cdot t$$

$$\Phi_c = I \cdot M_m \cdot f_{ramp} \cdot t = n_{\Phi_o} \cdot f_{ramp} \cdot t$$

Input Signal

$$\Phi_i = I_i M_i$$

SQUID

$$\left.\begin{array}{l} I = I_c sin(\phi) \\ L = L_J \cdot sec(\phi) \\ \phi = \frac{2\pi\Phi}{\Phi_o} = \frac{2\pi(\Phi_c+\Phi_i)}{\Phi_o} \end{array}\right\} I = I_c sin(\frac{2\pi m_{ramp} t}{\Phi_o} + \frac{2\pi\Phi_i}{\Phi_o}), L(t)$$

Modulation-Demodulation

Microwave Tone

$$InputTone = A_s e^{j\theta_s} = A_s cos(\theta_s) + jA_s sin(\theta_s)$$

Periodic Variation

$$OutputTone = [A_s cos(\theta_s) + jA_s sin(\theta_s)] * s_{21}(t, \phi_i)$$

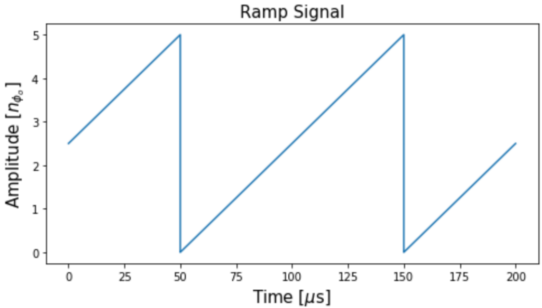
$$OutputTone = I(t, \phi_i) + jQ(t, \phi_i)$$

Lock-in Detection

$$\theta(t, \phi_i) = arctan(\frac{Q(t, \phi_i)}{I(t, \phi_i)})$$

$$\phi_i = arctan(-\frac{\theta(t, \phi_i) \cdot sin(w_c t)}{\theta(t, \phi_i) \cdot cos(w_c t)})$$

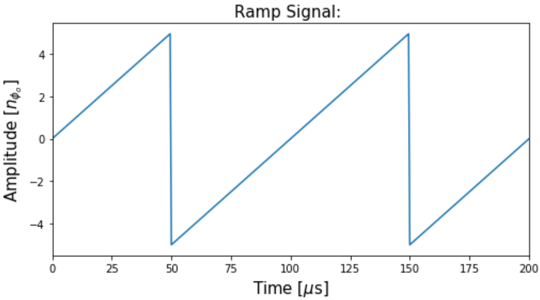
Flux Ramp Parameters

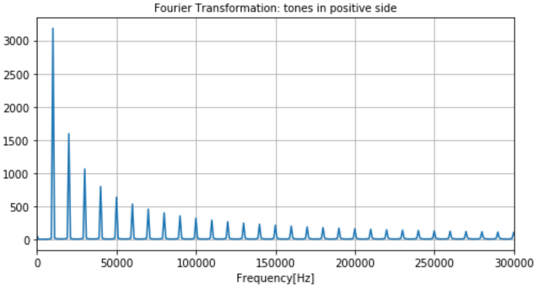


Considerations:

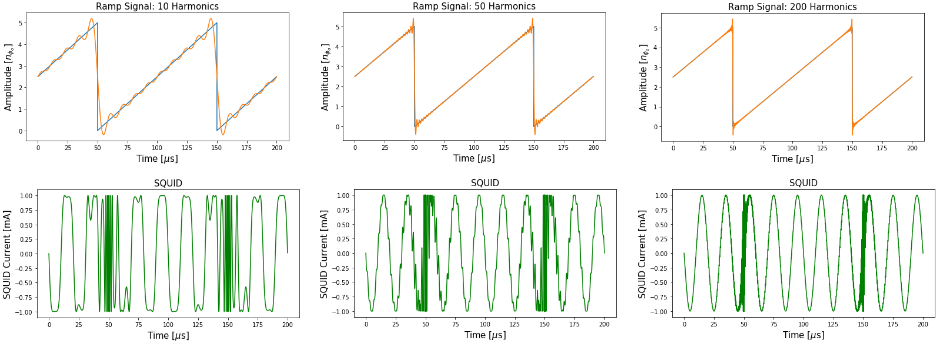
- $\Delta f_{BW} = 2 f_{ramp} \cdot n_{\Phi_o}$
- $f_{ramp} \downarrow$ and $n_{\Phi_o} \uparrow$: less noise and reflection problems.
- $f_{ramp} \uparrow$ and $n_{\Phi_o} \downarrow$: improve distortion factor and power dissipation in path.

Ramp Signal

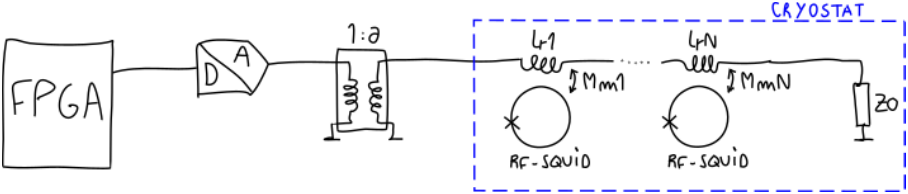

Ramp Signal:
Amplitude [n_{ϕ_o}]
4
2
0
−2
−4
0
25
50
75
100
125
150
175
200
Time [μs]


Fourier Transformation: tones in positive side
3000
2500
2000
1500
1000
500
0
0
50000
100000
150000
200000
250000
300000
Frequency[Hz]

Ramp Signal


Ramp Signal: 10 Harmonics
Ramp Signal: 50 Harmonics
Ramp Signal: 200 Harmonics
Amplitude [n_{ϕ_o}]
Time [μs]
SQUID
SQUID Current [mA]
Time [μs]

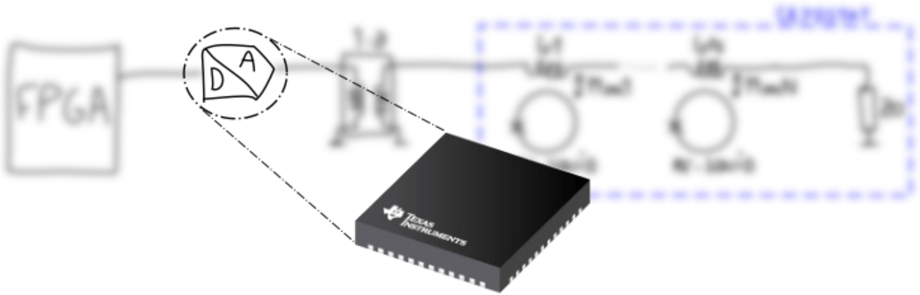
Flux Ramp Path



Adopting $f_{ramp} = 10KHz$, $n_{\Phi_o} = 5$

$I = \frac{n_{\Phi_o}}{M_m} = 200\mu A$, considering M_m as tens of pH

Flux Ramp Path



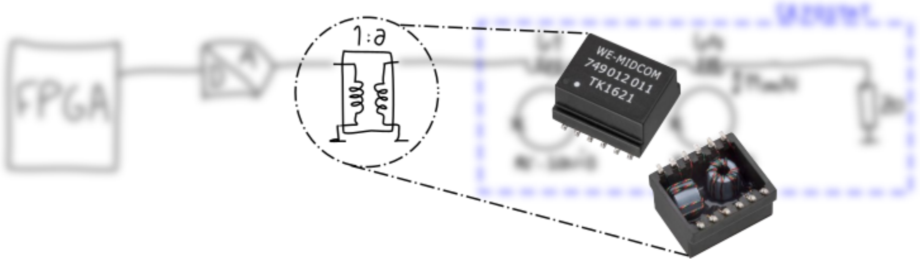
MDAC 7821

- fs = 20.4MHz
- 12 Nbits
- ±1 LSB INL, DNL
- Price = 6.54 USD

MDAC 8811

- fs = 25MHz
- 16 Nbits
- ±1 LSB INL, ±0.5 DNL
- Price = 15 USD

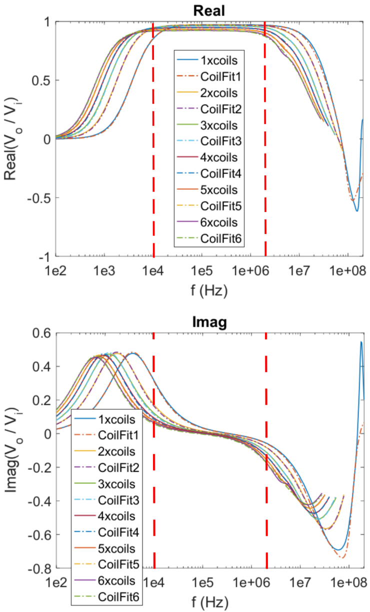
Flux Ramp Path



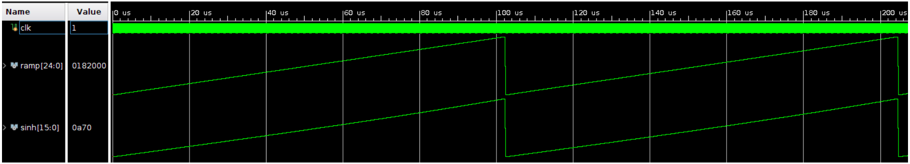
Wurth Elektronik 749012011

- 1:1 relation
- 2 transformer
- Price = 4 USD

Flux Ramp Path



VIVADO Generation



Future Work

- Make a complete analysis of the signal path:
  - Cables, connections
  - Attenuation inside the cryostat
  - Optimal amount of harmonics
  - SNR in all the chain
- Lab
  - Study different signal generation approach
  - Take into account another modulations signals
  - Build setup and measure

References

- D.T. Becker et al. Working principle and demonstrator of microwave-multiplexing for the HOLMES experiment microcalorimeters (2020). https://doi.org/10.1088/1748-0221/14/10/P10035.
- J.A.B. Mates, K.D. Irwin, L.R. Vale, G.C. Hilton, J. Gao, K.W. Lehnert. Flux-Ramp Modulation for SQUID Multiplexing (2012). https://doi.org/10.1007/s10909-012-0518-6.
- P. Carniti et al. Transformer coupling and its modelling for the flux-ramp modulation of rf-SQUIDs (2018). https://doi.org/10.3390/instruments3010003.

Mein Aufenthalt in Deutschland

Courses

- Thin Film: Technology, Physics, Application - I. Karlsruher Institut für Technologie, Karlsruhe, Alemania.
- Single Photon Detectors.Karlsruher Institut für Technologie, Karlsruhe, Alemania.
- Radio Frequency Integrated Circuit and System. Karlsruher Institut für Technologie, Karlsruhe, Alemania.

Conferences

- Karlsruhe School of Elementary Particle and Astroparticle Physics: Science and Technology. Vierjahreszeiten Hotel, Durbach, Deutschland.
- Superconducting Kinetic Inductances. Physikzentrum, Bad Honnef, Deutschland. (POSTER)
- Kryo 2019. Hotelpark Königshof, Königslutter, Deutschland. (POSTER)
- Helmholtz International Research School for Astroparticle Physics. Achat Plaza, Karlsruhe, Deutschland. (TALK)

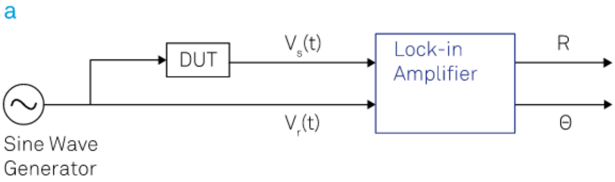
Mein Aufenthalt in Deutschland

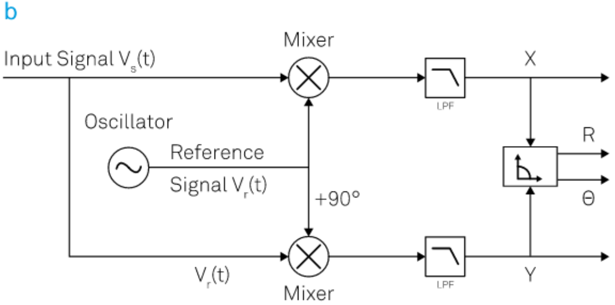
Lab

- Work in Campus South Low Temperature Lab.
- TWPA Amplifier Measurement.
- Cryostat Measurement Experience.

THANKS

Detector Lock-in





Other Modulation Signals

Sinusoidal

$$\phi = \frac{2\pi sin(w_c t)}{\Phi_o} + \frac{2\pi \phi_i}{\Phi_o}$$

$$I = I_c \cdot sin(\frac{2\pi sin(w_c t)}{\Phi_o} + \frac{2\pi \phi_i}{\Phi_o})$$

Exponential

$$\phi = \frac{2\pi e^{w_c t}}{\Phi_o} + \frac{2\pi \phi_i}{\Phi_o}$$

$$I = I_c \cdot sin(\frac{2\pi e^{w_c t}}{\Phi_o} + \frac{2\pi \phi_i}{\Phi_o})$$