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Characterization of the maximal frequency of operation of a SFQ digital cell in presence of a magnetic field

R. Collot, P. Febvre, J. Kunert, H.-G. Meyer, R. Stolz, J. Issler

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INTRODUCTION

→ We determine the maximal frequency of operation of a Toggle Flip Flop (TFF) cell, designed by the FLUXONICS foundry [1-2], for two values of the Mc-Cumber parameter β_c , using the technique presented in [3].

→ Magnetic fields can be created locally on-chip by the currents that bias RSFQ circuits [4-7] and due to external sources. Some techniques have to be used to minimize its impact on the operation of RSFQ circuits [8-9]. Such an impact on a basic SFQ digital cell have been already studied [10] and a method to take into account an external magnetic field with the JSIM simulator [11] was proposed [12]. We characterize here an on-chip magnetic shielding technique only based on the use of Nb metallic layers M_1 and M_2 of the FLUXONICS process.

DETERMINATION OF THE MAXIMAL FREQUENCY OF OPERATION OF A TOGGLE FLIP-FLOP CELL

The test circuit is composed of :

→ an overbiased shunted Josephson junction ($I_c=250 \mu A$) acts like a Voltage Controlled Oscillator (VCO). The frequency of the SFQ emitted pulses can be linked with the mean of the applied voltage $\langle V_{in} \rangle$ by the Josephson relation corresponding to 484 GHz/mV.

→ two Josephson Transmission Lines (JTLs) drive the SFQ pulses to the TFF. The BUFFERJTL cell acts like a switch, enabling pulses to be only transmitted from the right to the left of the test circuit. This ensures a proper measurement of the output mean voltage $\langle V_{out} \rangle$.

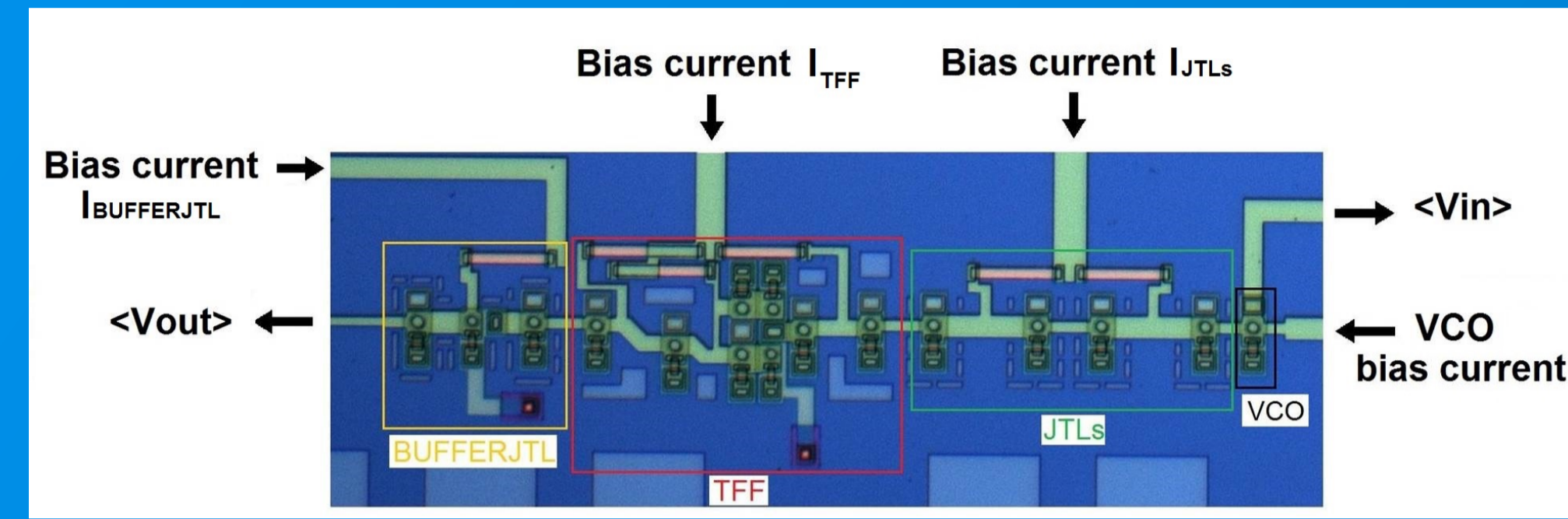


Fig. 1. The Nb/Al-AIOx/Nb test circuit designed by the FLUXONICS foundry.

As the number of SFQ pulses is directly linked to the mean voltages, the number of emitted pulses by the VCO is given by $\langle V_{in} \rangle$ and the number of pulses at the output of the TFF is given by $\langle V_{out} \rangle$. As long as the TFF cell is working correctly, the number of output pulses should be exactly half of the input one, i.e $\langle V_{in} \rangle = 2\langle V_{out} \rangle$.

The bias current of the VCO above which $\langle V_{in} \rangle$ differs from $2\langle V_{out} \rangle$ gives, thanks to the 484 GHz/mV relation, the maximal frequency of operation of the TFF.

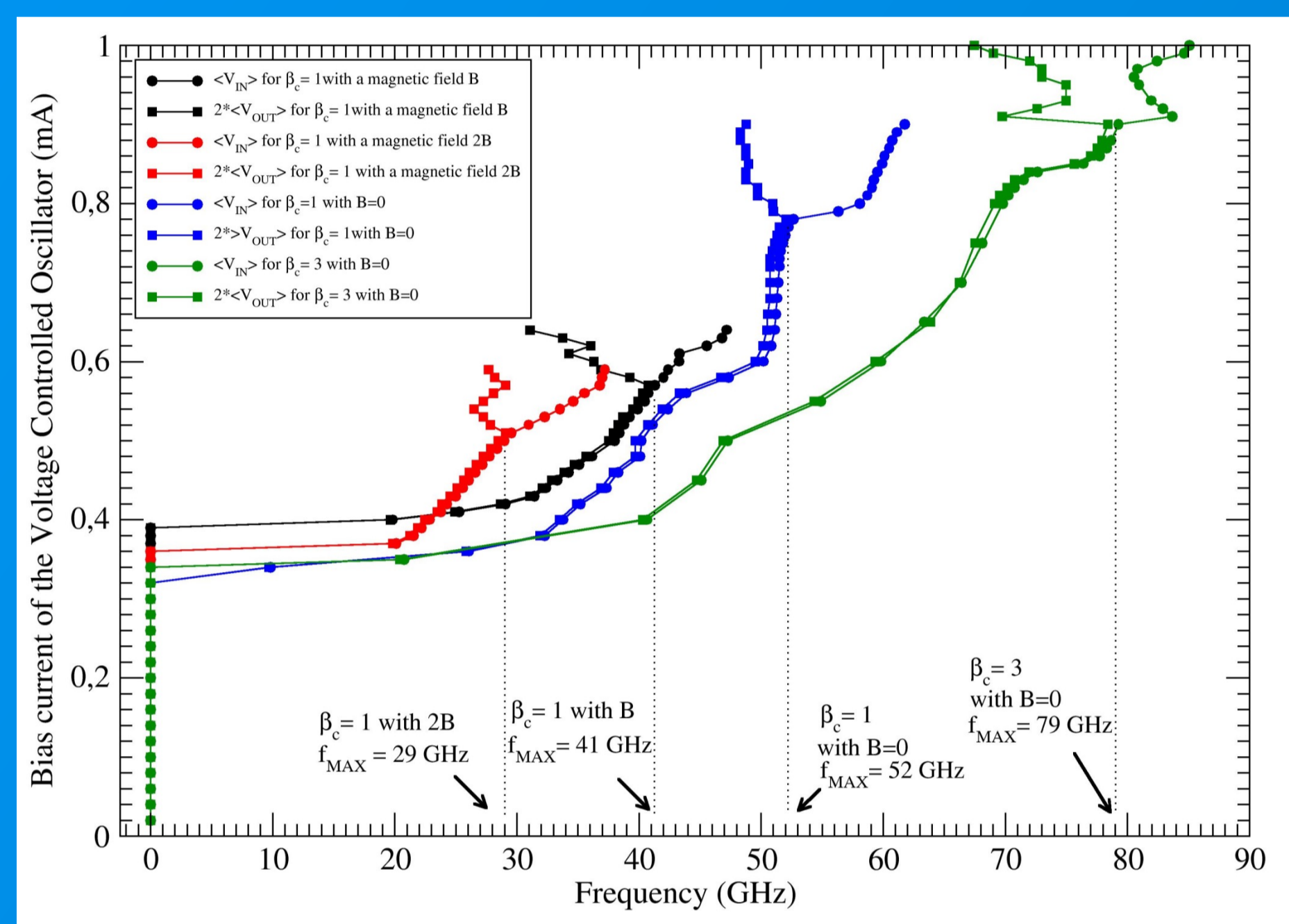


Fig. 2 : Simulation of the test circuit with the JSIM software for $\beta_c = 1$ and $\beta_c = 3$ with or without a simulated local magnetic field B. Nominal parameters are : $I_{JTLs} = 640 \mu A$, $I_{TFF} = 680 \mu A$ and $I_{BUFFERJTL} = 290 \mu A$. Curves with a local magnetic field were vertically shifted.

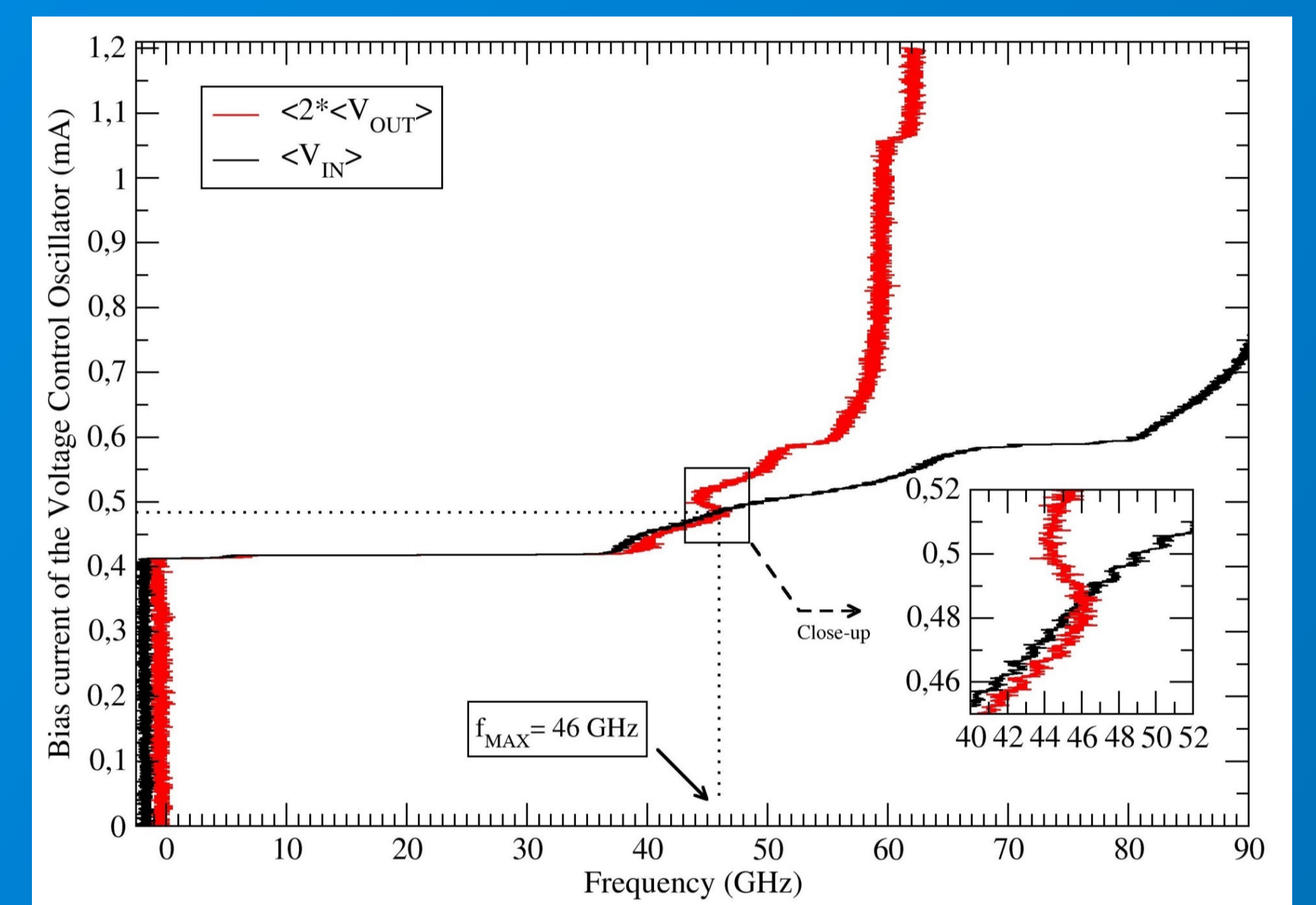


Fig. 3 : Measurement of the test circuit for $\beta_c = 1$. Nominal parameters are : $I_{JTLs} = 640 \mu A$, $I_{TFF} = 680 \mu A$ and $I_{BUFFERJTL} = 290 \mu A$. The experimental f_{MAX} is equal to 46 GHz.

ACHIEVING THE MAXIMAL FREQUENCY OF OPERATION FOR COMPLEX DIGITAL CIRCUITS : CHARACTERIZATION OF AN ON-CHIP MAGNETIC SHIELDING TECHNIQUE

4 DC-SQUIDS, each composed of two unshunted Josephson junction, with a critical current of $250 \mu A$, have been designed by the FLUXONICS foundry, with different magnetic shielding configurations (see Fig.4).

An excitation line, with an independent ground plane, enables to generate a local magnetic field, near the test circuits, by injecting a DC-current along the line.

For each test configuration, we have plotted the interference pattern of the different SQUIDS. For each case, the effective area of the loop is equal to $95 \mu m^2$, which leads to a theoretical magnetic period ΔB_{th} for the interference pattern of $22 \mu T$. The line current needed to obtain a magnetic period for each configuration characterizes the efficiency of the shielding technique.

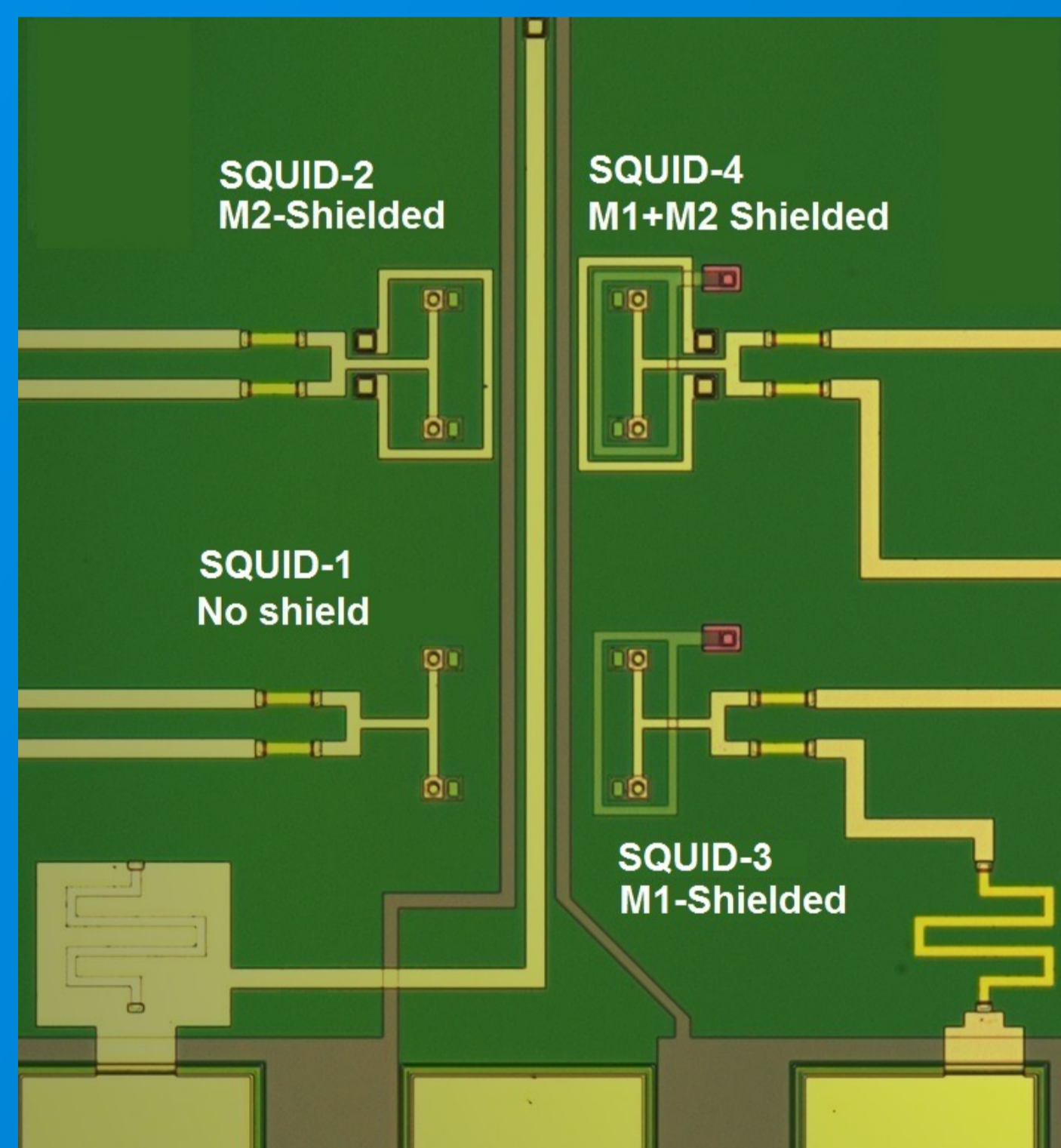


Fig. 4 The four different test circuits, based on DC-SQUIDS, designed by the FLUXONICS foundry

TABLE I EXPERIMENTAL MAGNETIC PERIOD FOR EACH CONFIGURATION		
	Current line needed to obtain one magnetic period (mA)	Extrapolated corresponding magnetic field value (μT)
SQUID-1	48	22
SQUID-2	120	55
SQUID-3	-	-
SQUID-4	200	91.6

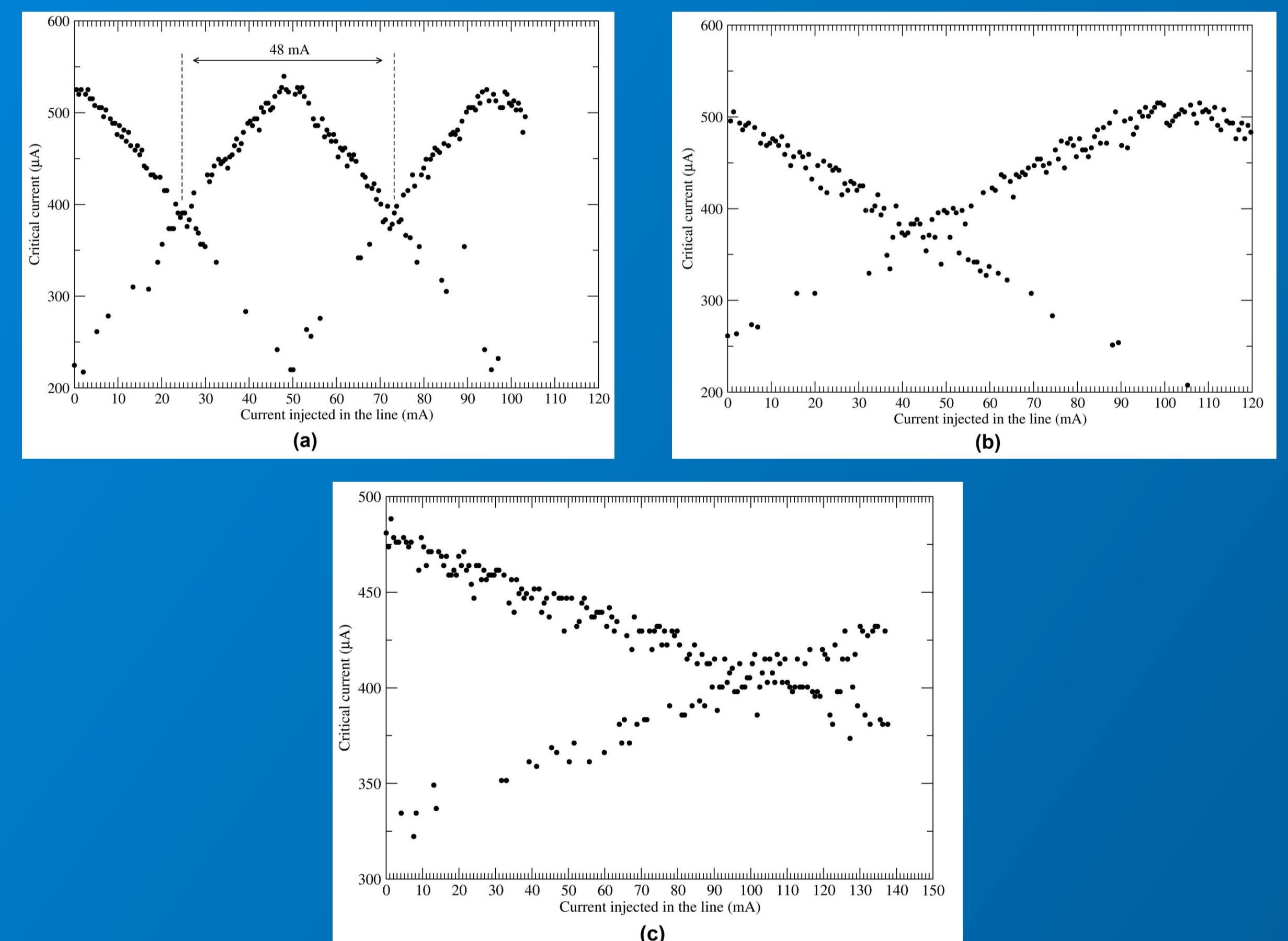


Fig. 5 : Interference patterns measured for each test circuit : SQUID-1 (a), SQUID-2 (b) and SQUID-4 (c), obtained by injecting a DC-current in the excitation line. We notice that, the more shielded the circuit is, the more current we need to inject to get one magnetic period : this illustrates the effectiveness of the shielding technique

CONCLUSION

→ The maximal measured frequency f_{MAX} of operation for the TFF cell, designed by the FLUXONICS foundry, is 47 ± 2 GHz for $\beta_c = 1$. From simulations, $f_{MAX} = 79$ GHz for $\beta_c = 3$.

→ The on-chip shielding technique is efficient for faint local magnetic fields, reducing the local field by a factor 4 for the best shielding configuration.

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