Improving the coherence time of superconducting qubits by design

A procedure to calculate participation ratios

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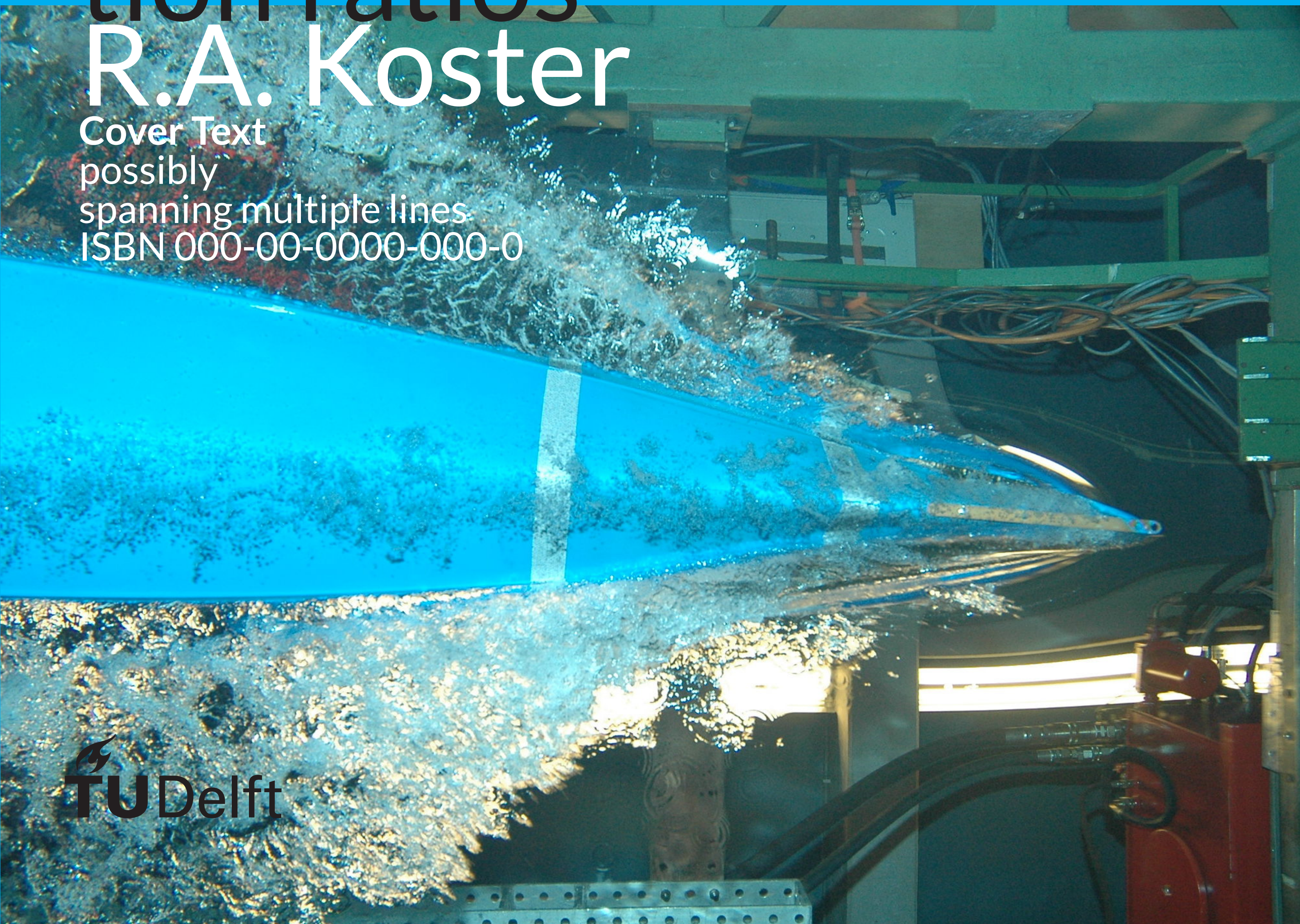

TU Delft

Improving the coherence time of superconducting qubits by design

A procedure to calculate participation ratios

by

R.A. Koster

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at the Delft University of Technology,
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TU Delft

Preface

Preface…

R.A. Koster
Delft, January 2016

Contents

1
Introduction

Since the introduction of the transmon quantum bit (transmon qubit) by Koch et al. in 2007 [2] as a promising candidate of qubits there have been investigations into sources of decoherence of these qubits. C. Wang et al. found that surface dielectric dissipation is probably still the major limiting factor for the coherence time of transmon qubits [3]. The different surface dielectrics introduced to the system during production have distinct material compositions [1] and as a result will have a different impact on the coherence time [3]. Qubit structure design itself will dictate how the Electric field is distributed through the dielectrics.
The goal of this research is to determine this distribution and to use this information to design a transmon qubit in such a way as to be able to avoid concentrating the Electric field in regions containing more lossy dielectric material. Being able to do so may better the ability to design transmon qubits with longer coherence times.
The following section will provide necessary background information to substantiate the above. Information particularly relevant to this research will be provided in the next chapter.

Quantum computing and quantum bits

-General information about quantum computing. Benefits, application etc. -quantum bits; importance of longer coherence time

Restatement of the problem -Role of dielectric lossy materials -why is this research important?! -Knowing how design choices influence the participation ratio of lossy layers.

Restatement of the response - “In order to address this problem, I will ... ”.

Roadmap -How will the thesis proceed

2

Theory

The transmon qubit

The qubit under investigation during this project is the so called transmon qubit. A transmon qubit consists of

LC-circuits

The transmon qubit can be treated as a simple LC-circuit. The Josephson junction is replaced by an inductor and the different capacitors are replaced by an single equivalent capacitor. The resulting simplified system can be seen in figure 2.1.

Energy in an LC-circuit

In order to determine the participation ratio of the lossy layers in storing energy in the system, the total energy must be know. The total energy stored in an LC-circuit at any time can be calculated as follows:

$$W = \frac{1}{2}CV^2 \tag{2.1}$$

Where C is the total capacitance of the system and V the voltage over the systems.

Electric fields

Perfect Electric Conductor

As the qubit is supercooled to temperatures of only a few mK, the metal in the qubit is treated as a Perfect Electric Conductor (PEC).

Continuity rules

Stored energy

The energy stored in the Electric field in a material can be calculated using equation (2.2)

$$W = \frac{\epsilon}{2}\int |E|^2 dV \tag{2.2}$$

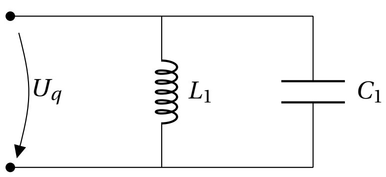

Figure 2.1: A simple parallel LC-circuit

Sources of decoherence

In order for the qubit to be coherent . . . The source in question during this project is the layers of lossy material in the system.

Lossy materials

During production of qubits, different procedures introduce lossy materials to the structure. An important property of each of these materials is their permittivity. It will determine the strength of the field and the energy stored inside the layers.

Two-Level Systems

The participation ratio

To determine what kind of structure design may improve coherence time the participation ratio of lossy layers can be calculated. If the assumption is made that the Electric field remains constant inside the lossy layer equation (2.2) can be rewritten as follows:

$$W = \frac{\epsilon}{2} t \int |E|^2 dA \tag{2.3}$$

Where ϵ is the permittivity of the material and t is the thickness of the lossy layer. Furthermore, A is the surface area of the lossy layer.

3

Model of the system

In order to calculate the participation ratio of the different lossy layers in an arbitrary structure it is simulated using 3D EM simulation software called CST.

Josephson junction

During simulation in CST, the Josephson junction is replaced by an inductor. By tuning the inductance together with the capacitance of the structure a specific resonance frequency can be reached.

Lossy layers

The relatively small thickness of the layers suggests that the impact they have on the Electric field is small. During simulation their impact is neglected and the layers are therefore omitted. The exclusion of thin lossy layers prevents the necessity for mesh elements with sub-nano meter size. This significantly reduces the number of mesh elements and in turn the computation time of the simulation. A simple representation of the structure can be seen in figure 3.1.

Ground

To further reduce the number of mesh elements, the ground pad is replaced by a thin sheet of PEC. Considering the field in the ground region is small compared to the field at the edges of the pads its contribution to the participation ratio is also small. Investing more computation time on the ground region by increasing the density of mesh elements there would therefore also have limited impact on the participation ratio.

title

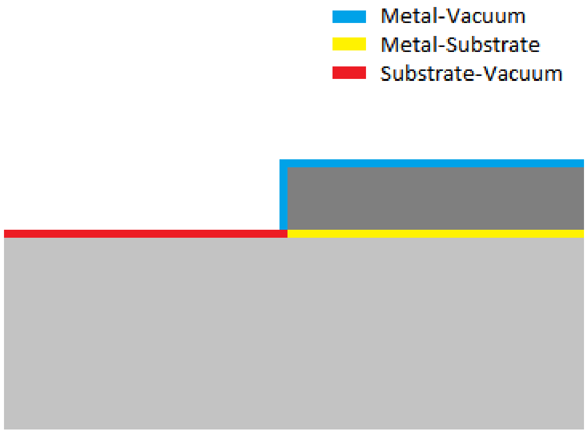

Figure 3.1: Simplification of the system including three lossy layers. The substrate and metal are depicted in light and dark grey respectively

4

CST procedure

Modeling
Meshing
Simulation setup
Post processing

5

Matlab procedure

Importing data
Separating data for different layers
Calculating energies and participation ratio

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