

Possible future directions for the Kibble Balance

E Edge¹, T Bergsten², J Berry¹, C Bull¹, K Cedergren², T Fielder¹, C Jarvis¹, K Karunaseelan¹,
L Mndebele³, P Potgieter¹, A Vie¹, I A Robinson¹

Email: emily.edge@npl.co.uk

- 1 National Physical Laboratory, Hampton Road, Teddington, Middlesex, TW11 0LW, UK
- 2 RISE Research Institutes of Sweden, Brinellgatan 4, 504 62 Borås, Sweden
- 3 National Metrology Institute of South Africa, Meiring Naudé Road, Brummeria, Pretoria, South Africa

Introduction

The Kibble balance was conceived by Bryan Kibble in 1975 as a technique for use at the highest levels of metrology for realising SI units.



The redefinition of the kilogram in 2019 motivated scientists to consider other applications such as directly traceable mass measurement at the point of need.

Principle

Kibble balances operate in two stages, weighing phase and moving phase, and the results combine to calculate mass [i].

Weighing

$$Mg = BLI$$

Moving

$$\frac{v}{u} = BL$$

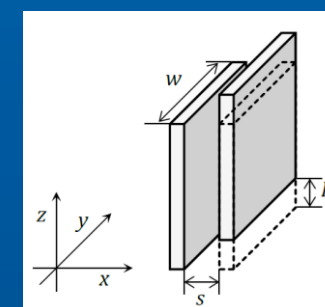
➔

Mass

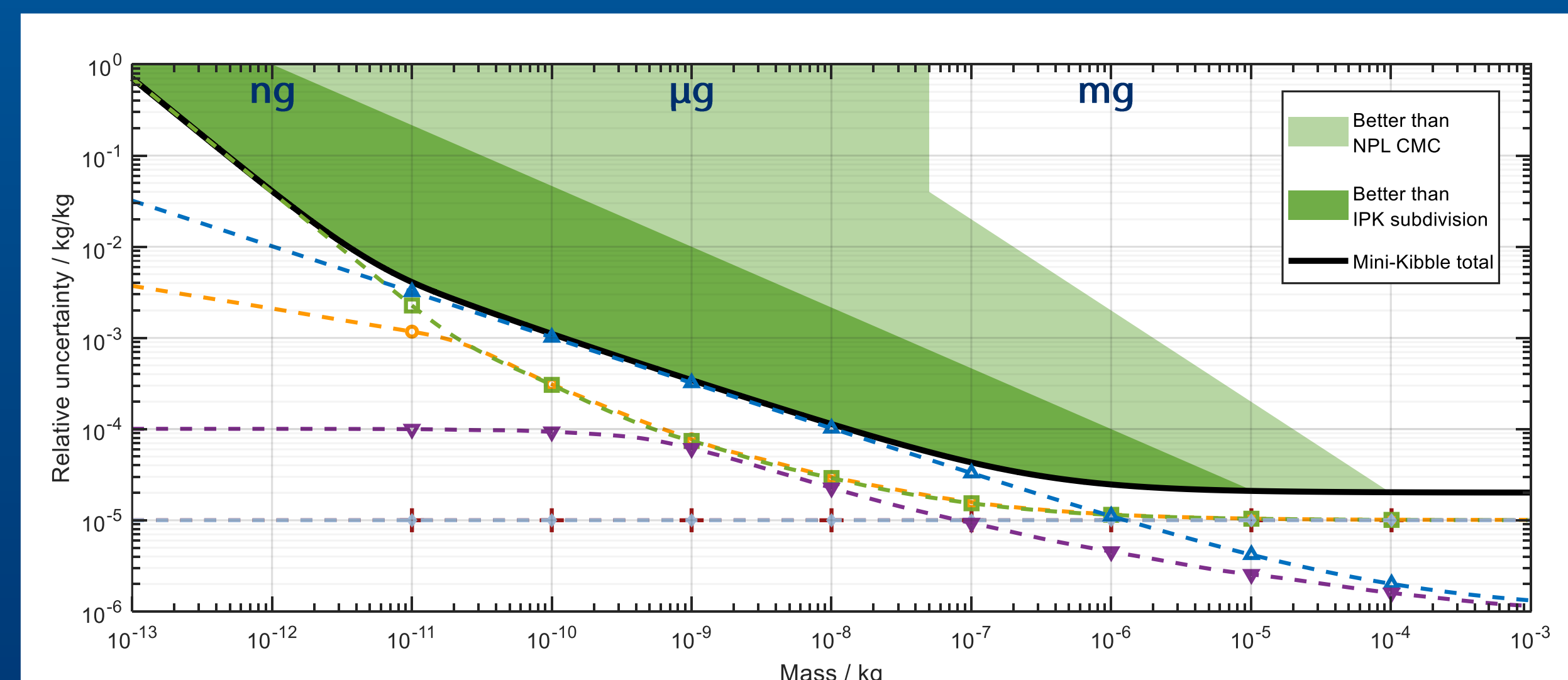
$$M = \frac{VI}{gu}$$

Scaling Feasibility

The Kibble balance principle can be converted from electromagnetic to electrostatic with the equivalent equation including a factor of a half.



A simple model of a single-axis electrostatic Kibble balance was analytically studied with design variables optimised to estimate the minimal achievable measurement uncertainty [iii].

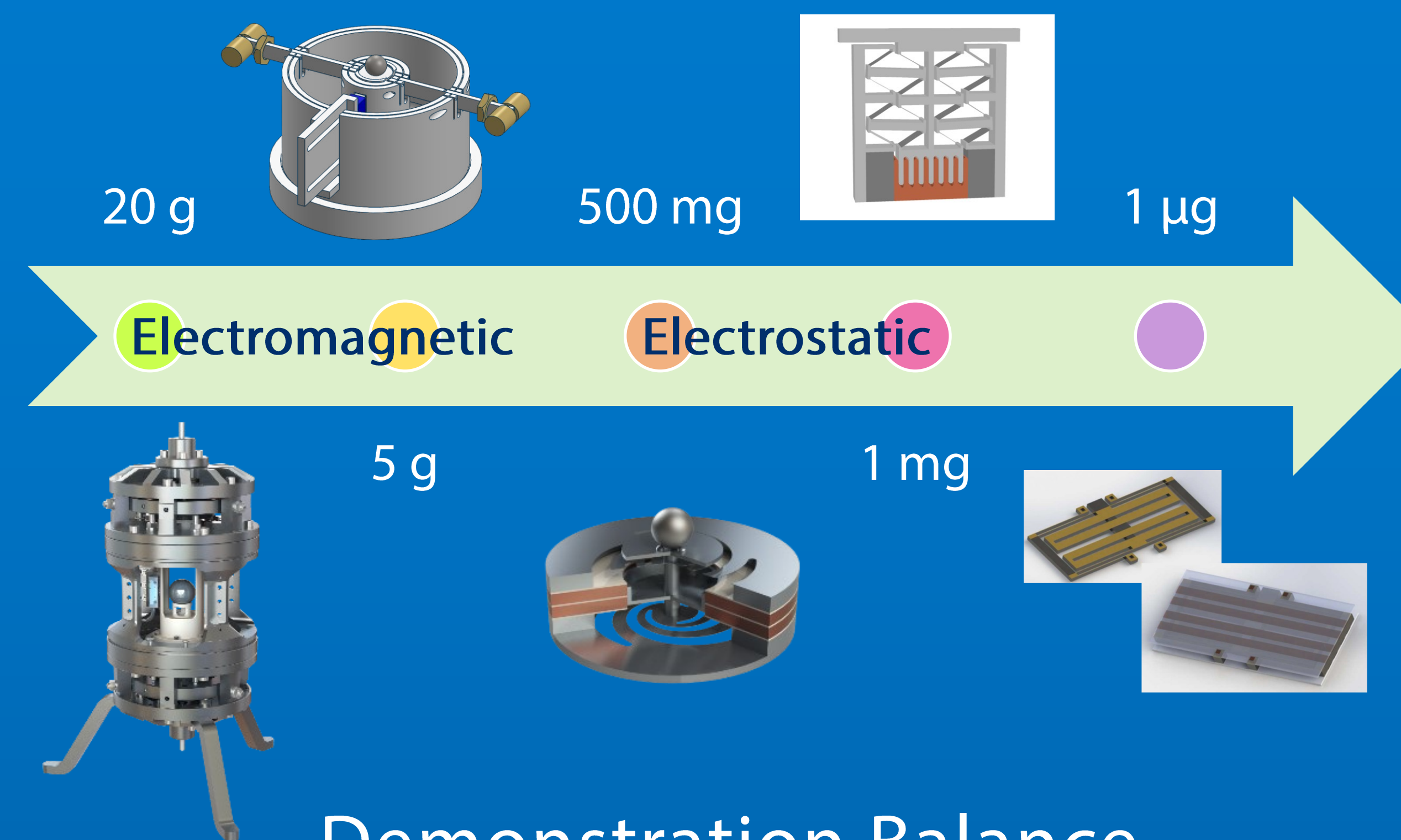


At the milligram scale the relative uncertainty of currently available traditional mass measurement increases to a level which provides an opportunity for Kibble balances with conventional electronics.

Creation of an electrostatic Microelectromechanical System (MEMS) Kibble balance offers a route to realisation of sub-milligram mass. An emerging field in the development and fabrication of MEMS is three-dimensional (3D) printing.

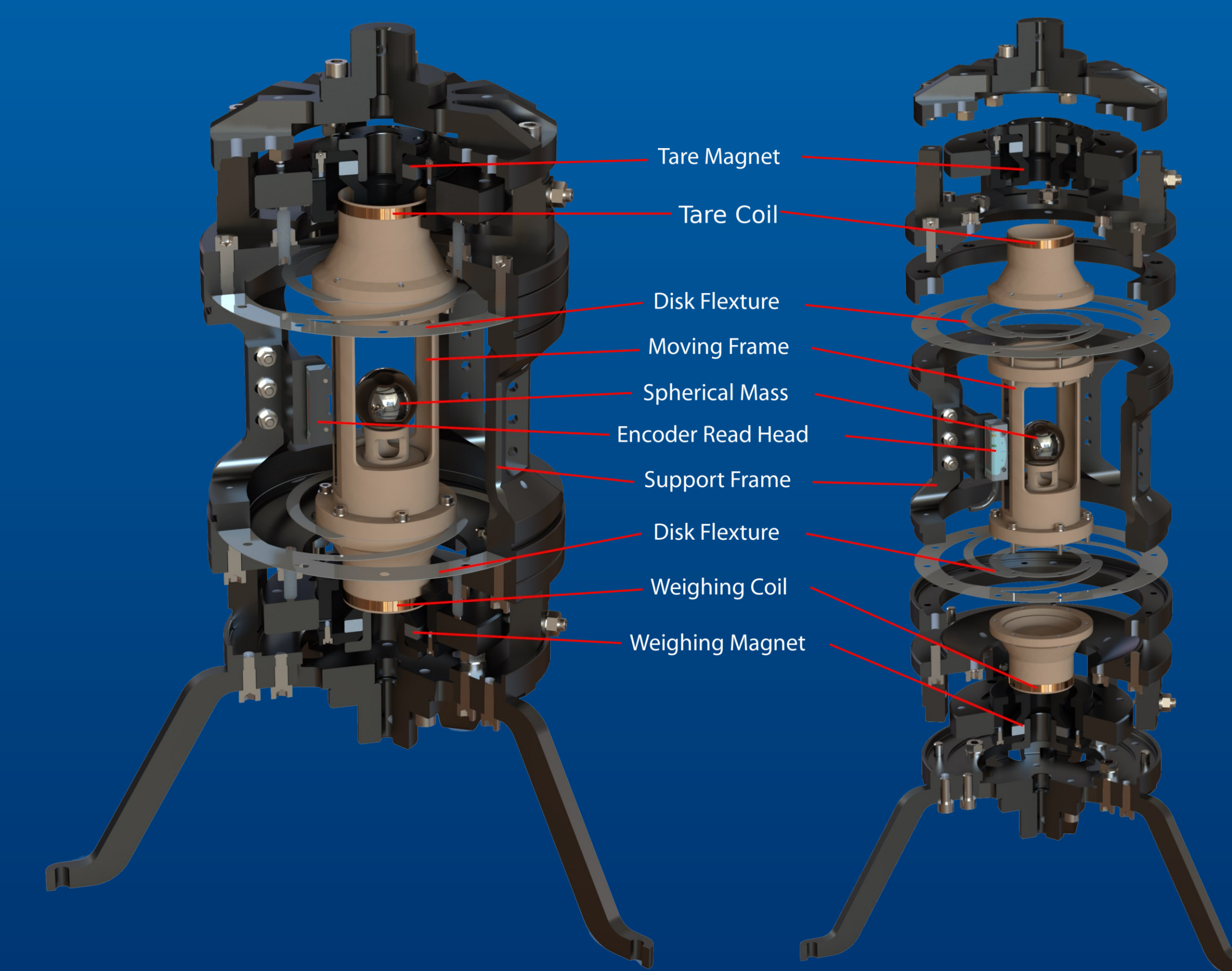
[i] B. P. Kibble, I. A. Robinson, "Principles of a new generation of simplified and accurate watt balances", Metrologia, vol. 51, pp. S132-S139, 2014 [ii] C. Jarvis, E. Webster, S. Davidson, I. A. Robinson, "A µKibble balance for direct realisation of small-scale masses and forces", 19th International Congress of Metrology, 14002, 2019

Route to micro-Kibble Balance



Demonstration Balance

Based on the concept design for the NPL Next Generation Kibble balance. There are three apparatus with common components and software in operation at collaboration partner laboratories in the UK, Sweden, and South Africa.



The weighing magnet and coil system contains a bi-filar coil allowing single mode two phase (SMTP) measurement. Initial mass results of a 20 g artefact from the demonstration balance at RISE typically produced a Type A Uncertainty of 50 ppm and a calculated mean within 30 ppm of a conventional mass calibration [iii].

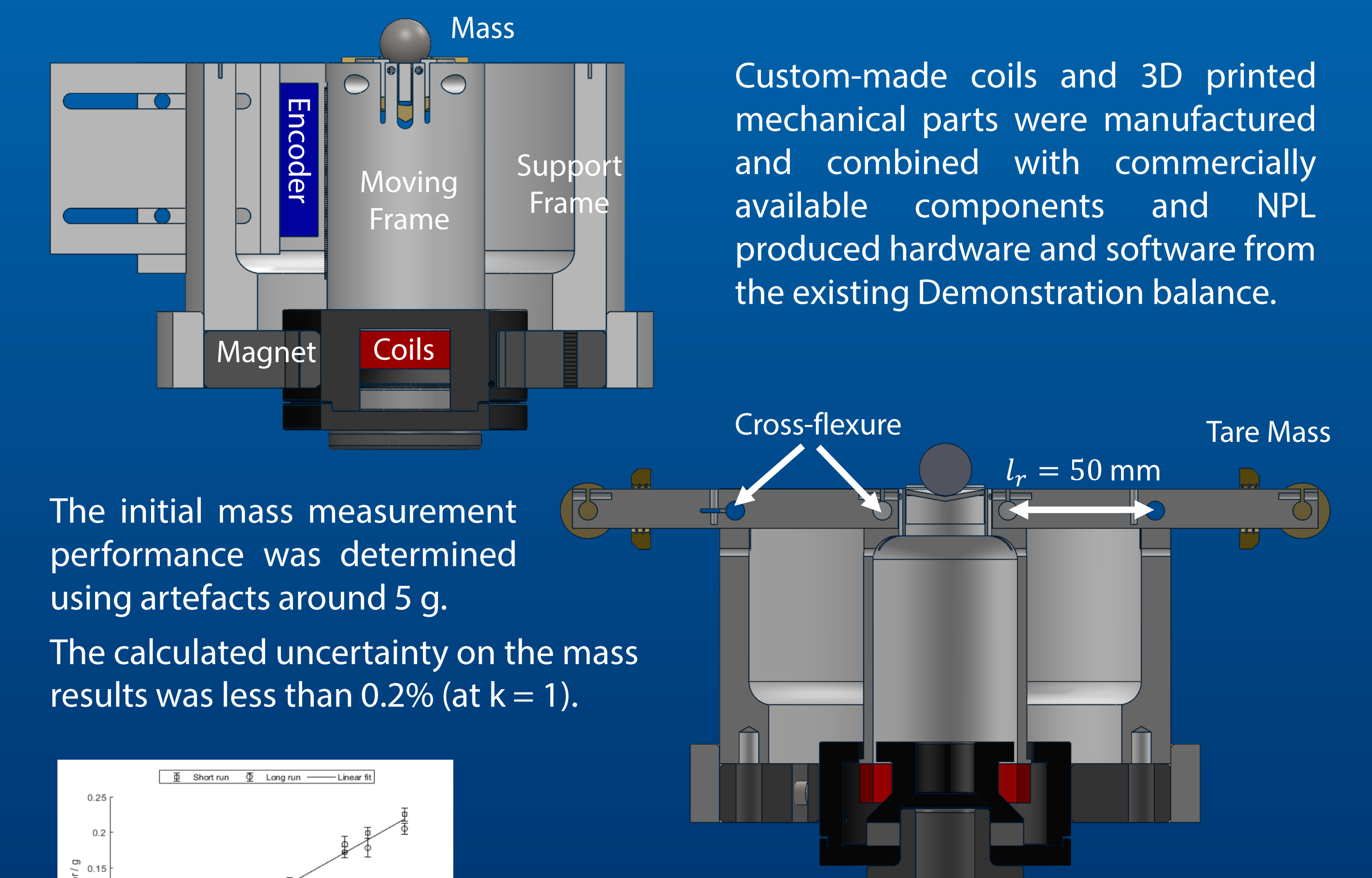
[iii] I. A. Robinson, A. E. Karsten, T. Marnett, L. Mndebele, K. Cedergren, T. Bergsten, C. Bull, "Progress on the NPL, NMISA, RISE Kibble Balance Collaboration", Conference on Precision Electromagnetic Measurements, 2024

Applications



3D Printed Balance

Proof-of-concept device to demonstrate the potential for miniaturisation to the sub-milligram level through 3D printed MEMS technology [iv].



The initial mass measurement performance was determined using artefacts around 5 g.

The calculated uncertainty on the mass results was less than 0.2% (at k = 1).

Comparison with a traditional mass calibration performed at NPL to ISO 17025 standard revealed a +3.6% systematic error in the prototype system.

Once identified, the source of this error can be eliminated to allow the device to be scaled to the micro-gram level within a target uncertainty of 0.5% (at k=1).

[iv] E Edge, "A miniature 3D-printed Kibble balance for mass sensing applications" PhD thesis, University of Southampton, 2025

