UNIVERSITY OF CAMBRIDGE

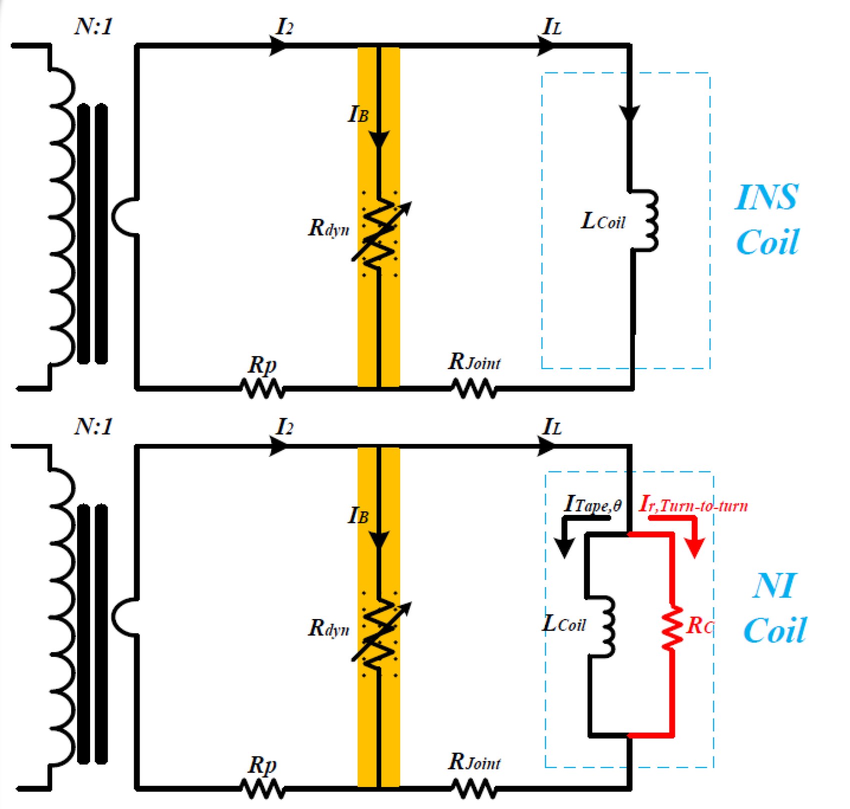
Ultra-high field HTS flux-pumped magnets

T. A. Coombs, J. Geng, C. Li, J.D.D. Gawith, J. Ma
Electrical Engineering Division, University of Cambridge,
9 JJ Thomson Avenue, Cambridge CB3 0FA , tac1000@cam.ac.uk

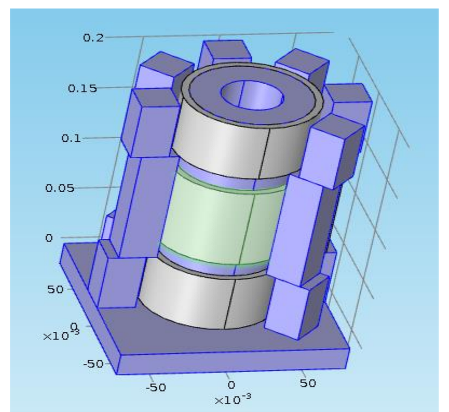
Introduction

Flux pumped ultra-high field magnets have the potential to produce fields which surpass the nearly 20 year old record of 45 T in a DC field Bitter magnet in a relatively cost effective manner. These higher fields will undoubtedly require superconducting cables capable of carrying thousands of amps and the means to deliver those very high currents. Current leads could be used but at currents in the 10s of thousands of amps they represent a very high cost and heating overhead. Higher currents mean lower conductor cost, lower magnet inductances shorter charging times and lower quench voltages. Flux pump technology and the latest dynamic bridge switching method will be key to providing these high currents with minimal heat loads and minimal infrastructure in comparison to expensive high-current power supplies and warm-to-cold current leads. The resultant effect is that the purchase and running costs of high-field magnets will decrease substantially. Crucially also infra-structure costs will be slashed. A flux pumped HTS magnet does not require high current power supplies and current leads neither does it require copious amounts of water cooling to dissipate the waste heat. Thus it is realistic to expect HTS flux pumped magnets to be available which could be installed in any UK (or international) university enabling a radical sea change in the use of high field magnets to support research. Further down the line it is conceivable that HTS flux pumped magnets could enable the creation of practical fusion devices a goal which has eluded us for many years.

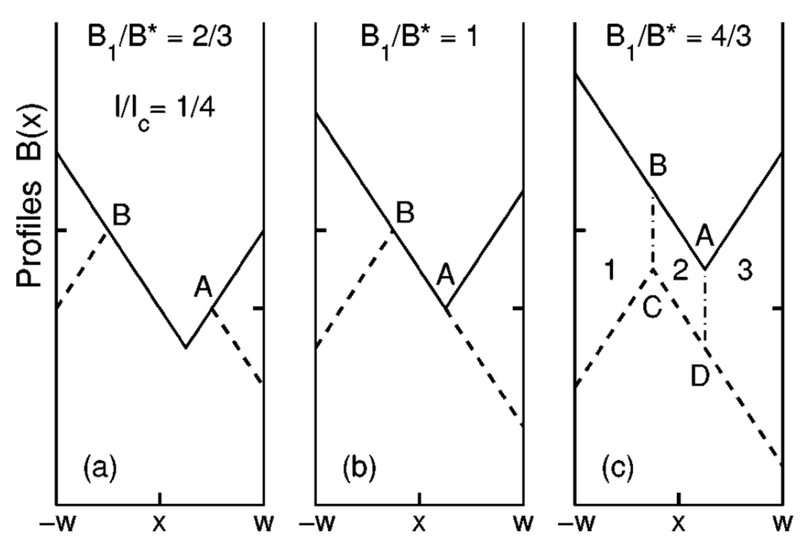
Dynamic Bridge Flux Pumps



Circuit diagrams for flux pump
Connected to insulated & non-insulated coils

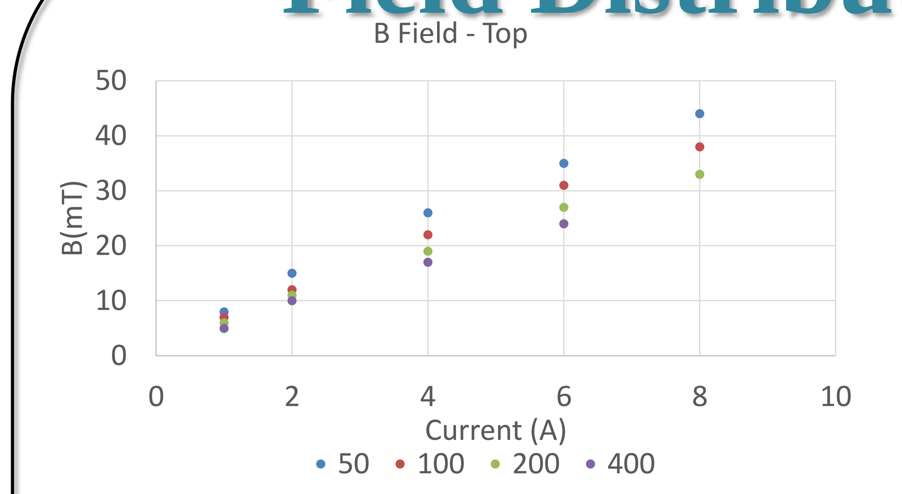


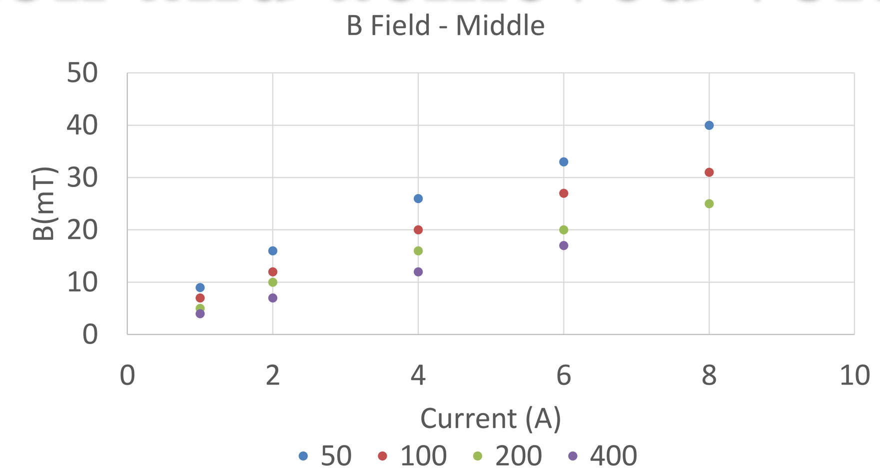
Photograph and model of dynamic bridge

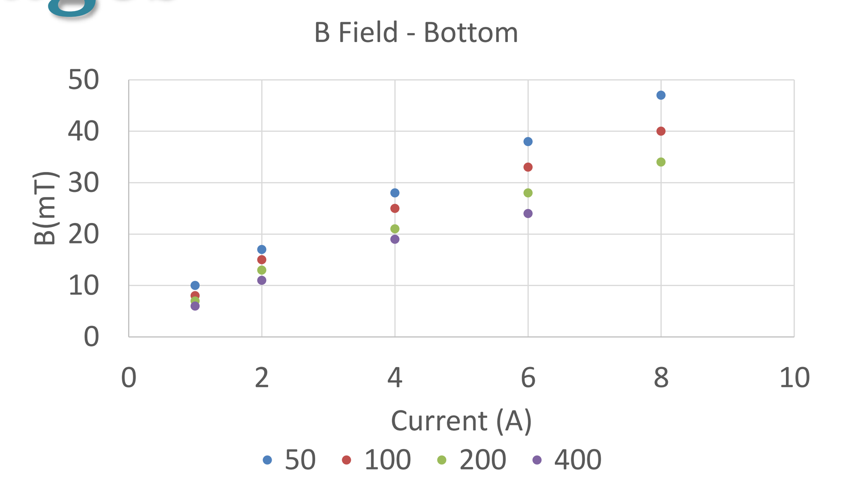


Origin of Bridge Voltage

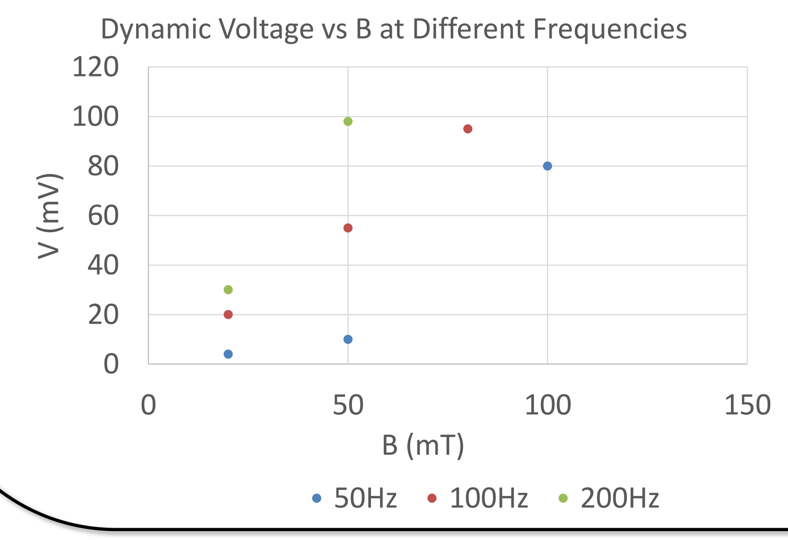
Field Distribution and achieved voltages

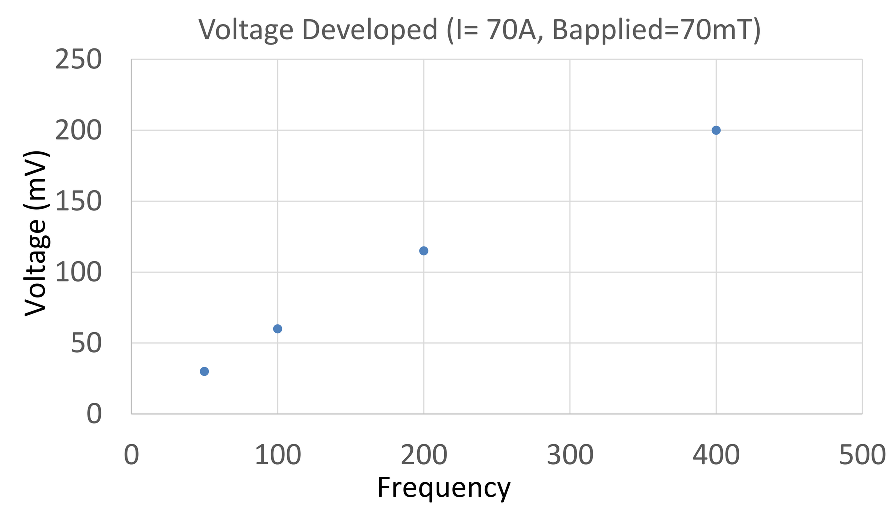






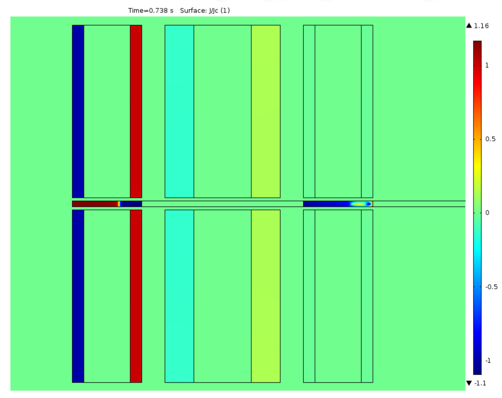
The figures in this panel show (above) the distribution of the field along the length of the central ferrite core. The dynamic bridge is formed by an 80cm length of Sunam 4mm tape wound around it.

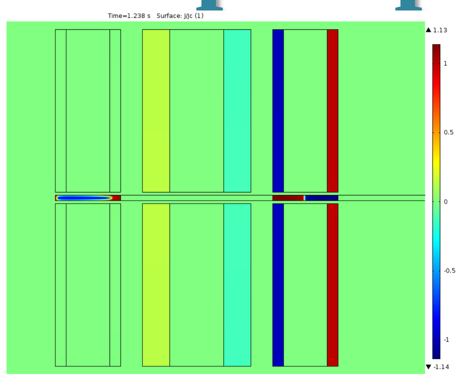


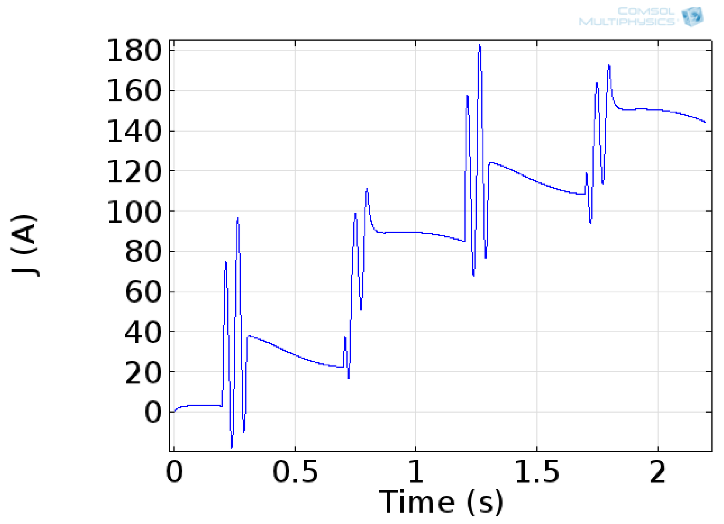


The two figures to the left show the voltage developed in the bridge when various different transport currents and various different fields are applied at a range of frequencies

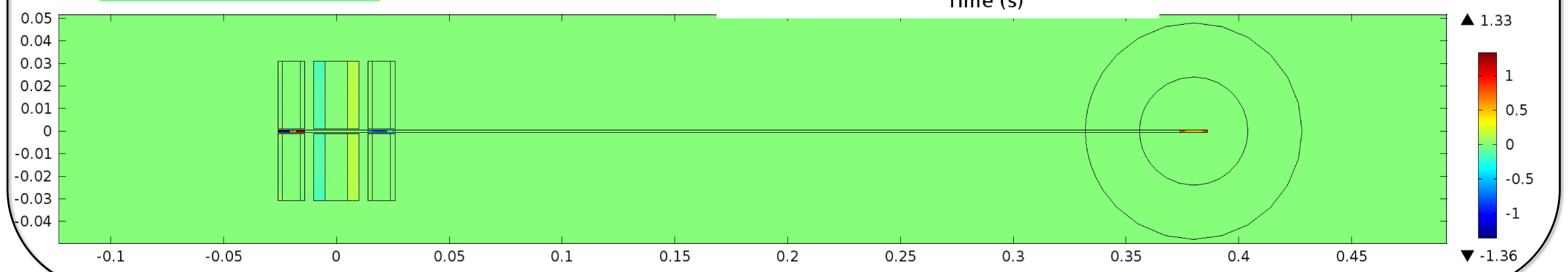
Model of Flux pump



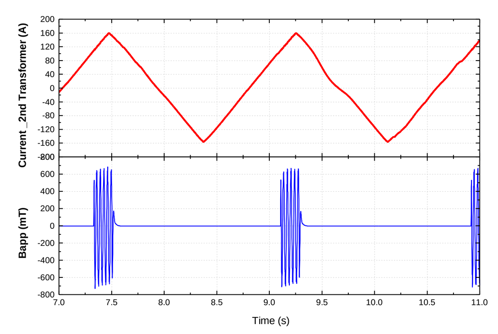




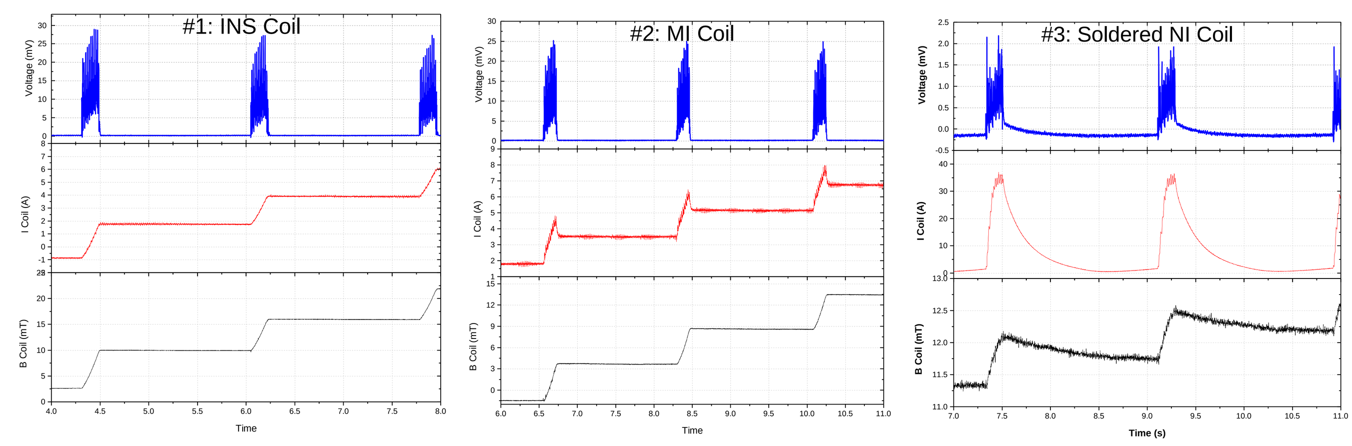
Here we show a model of the system constructed in Comsol. A transport current is induced in the superconductor by the centrally placed EM. Two further coils either side of the magnet are used to simulate the bridge.



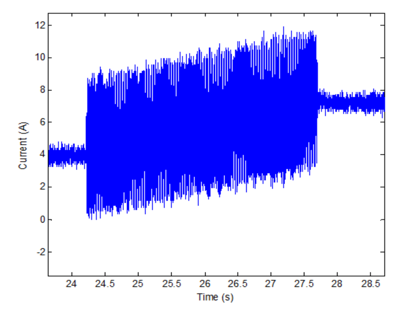
Experimental Results



Waveforms for transformer and bridge.



Results obtained for three coils 1) insulated with kapton tape 2) metal-insulated and 3) soldered non-insulated



Sample trace showing 100 cycles. The load was 1 micro-Henry and the flux change per cycle is 20 nWb.

References

[1] T. A. Coombs, “Method for changing magnetisation of a superconductor,” US patent, 8252726, 2006
[2] J. Geng and T.A. Coombs, “Appaaratus and methds for changing the magnetization of a superconductor”, WO2017021674 2017
[3]J. Geng and T. A. Coombs, “Mechanism of a high-Tc superconducting flux pump: Using alternating magnetic field to trigger flux flow,” Appl. Phys. Lett., vol. 107, no. 14, Oct. 2015, Art. no. 142601.
[4]J. Geng et al., “Operational research on a high-Tc rectifier-type superconducting flux pump,” Supercond. Sci. Technol., vol. 29, no. 3, Feb. 2016, Art. no. 035015.
[5] L. J. M. van de Klundert and H. H. J. ten Kate, “Fully superconducting rectifiers and flux pumps. Part 1: Realized methods for pumping flux,” Cryogenics, vol. 21, no. 4, pp. 195–206, Apr. 1981.
[6] M. P. Oomen et al., “HTS flux pump for cryogen free HTS magnets,” IEEE Trans. Appl. Supercond., vol. 15, no. 2, pp. 1465–1468, Jun. 2005.
[7] Y. Iwasa, “Microampere flux pumps for superconducting NMR magnets part 1 basic concept and microtesla flux measurement,” Cryogenics, vol. 41, pp. 385–391, 2001.
[8] G. P. Mikitik and E. H. Brandt,”Generation of a DC Voltage by an AC Magnetic Field in Type-II Superconductors”, Phys. Rev. B 64, 092502, 1-4 (2001).