

Electronics Division Technical Note No. 190

Calculations of Magnetic Circuits for SIS Mixers

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January 23, 2002

Introduction

Recent measurements by Kirk Crady have shown that the present magnetic circuits for the Band 6 SIS mixers saturate at unacceptably low field strengths and it was decided to analyze the circuit using the magnetic field software MAXWELL 3D [1]. The analysis results will be given along with suggestions for improvements to the circuit.

Analysis

A drawing of the present circuit is shown in Figure 1. The red cylinder shows a coil made up of 6,000 windings of type M superconducting wire [2]; the solid green cylinder is the core of the solenoid, made of Hiperco 27 magnetic alloy [3]; the diameter is 0.120 inches (3.048 mm); and the length is 2.250 inches (57.15 mm). The cross arms (1.511 x 0.250 x 0.125 inches, 38.38 x 6.35 x 3.175 mm) and pole pieces (1.010 x 0.120 x 0.095 inches, 25.654 x 3.048 x 2.413 mm) which direct the field to the vicinity of the SIS junctions in the mixer block are also made of Hiperco 27 and are shown as open green boxes.

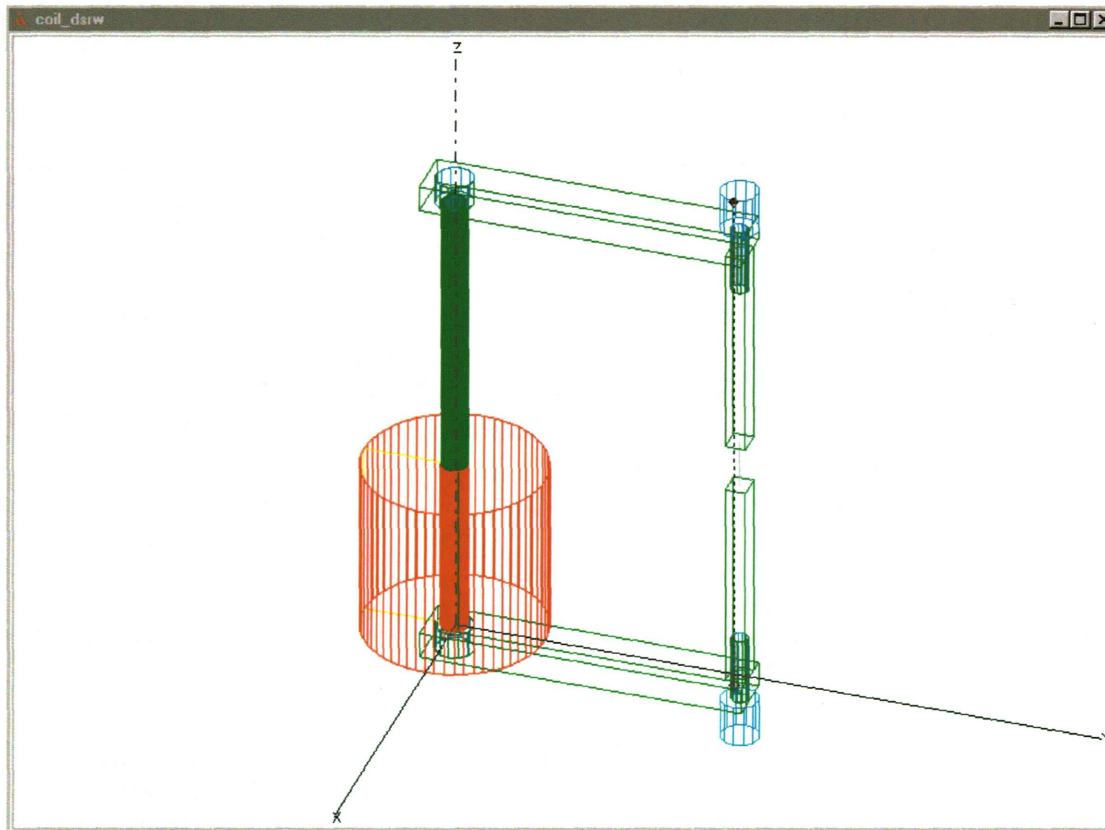


Figure 1. Original circuit.

The original structure is screwed together by four stainless steel screws (shown light blue) at the junctions of the pieces. (This is not quite accurate as all screws are countersunk, but as is seen this has very little effect.) Also due to space constraints in previous mixer blocks, the coil is not symmetrically placed on the core. In the analysis, the coil is assumed to be a multi-stranded coil made of copper driven by the necessary number of amp-turns (which, in the results below, have been converted to drive current in mA).

The B-H curve for Hiperco 27 was entered by hand from the data sheets and is shown in Figure 2. Only 11 points were used but these points clearly show the saturation of this material at higher B fields. Note that there is no hysteresis in this curve, but some hysteresis is measured in the actual circuit, as the real material has a residual magnetization of approximately 20-50 amp/meter which is not taken into account in the model. It could also be due to the fact that the material is not annealed after machining as recommended by the manufacturer, and, possibly, also due to some residual magnetization of the screws.

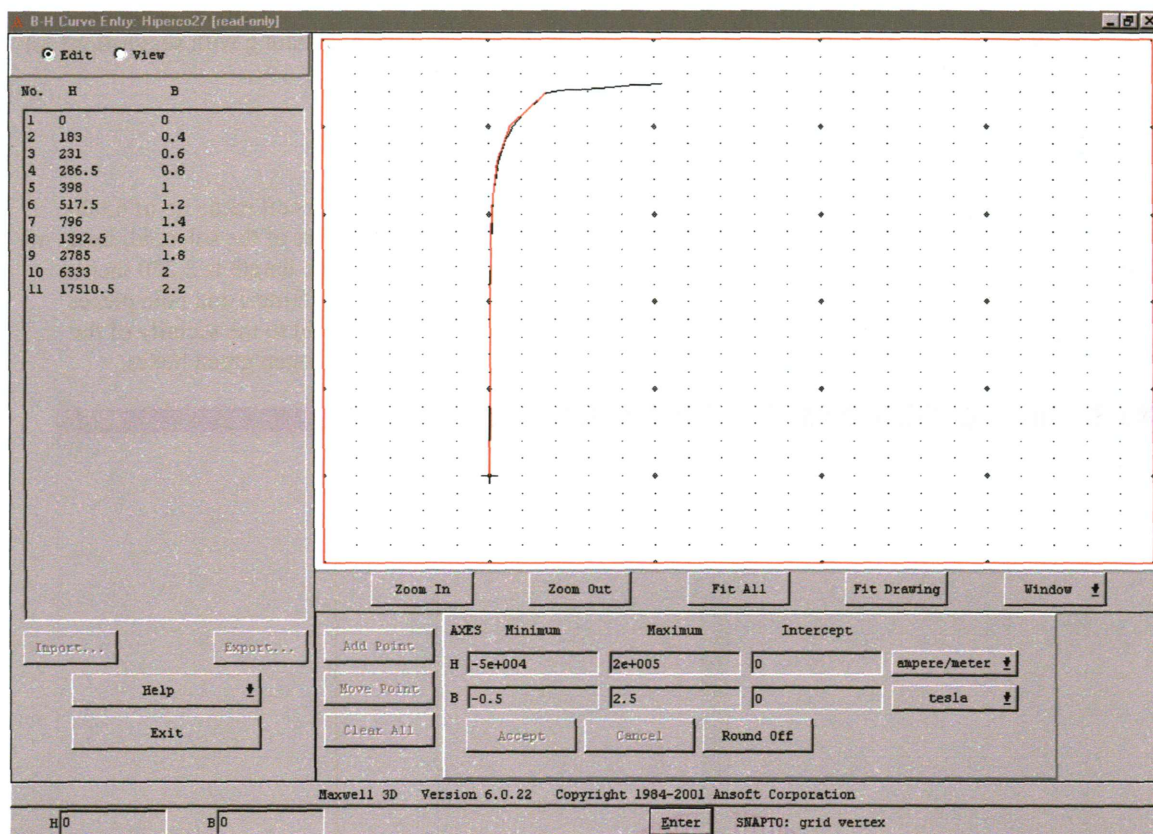


Figure 2. Hiperco 27 B-H curve (B on horizontal axis, H on vertical axis).

Figure 3 shows the results of a calculation for the structure shown in Figure 1. It shows clearly the disturbed fields from the coil due to the non-symmetry of the structure. It also shows the concentrating effect of the arms and pole pieces, and also shows that the core is saturating within the coil for very low drive currents (12 mA in this case).

Figure 4 shows a close-up of the junction of the core and the cross arm with screw, and Figure 5 the junction of the cross arm and the pole piece. As can be seen, there is little penetration of the field into the screw, and the small cross-sectional area of Hiperco in the vicinity of the screw limits the coupling of the field across these junctions. For comparison, Figure 6 shows a junction with no screw. Some leakage of the field around the joint can also be seen.

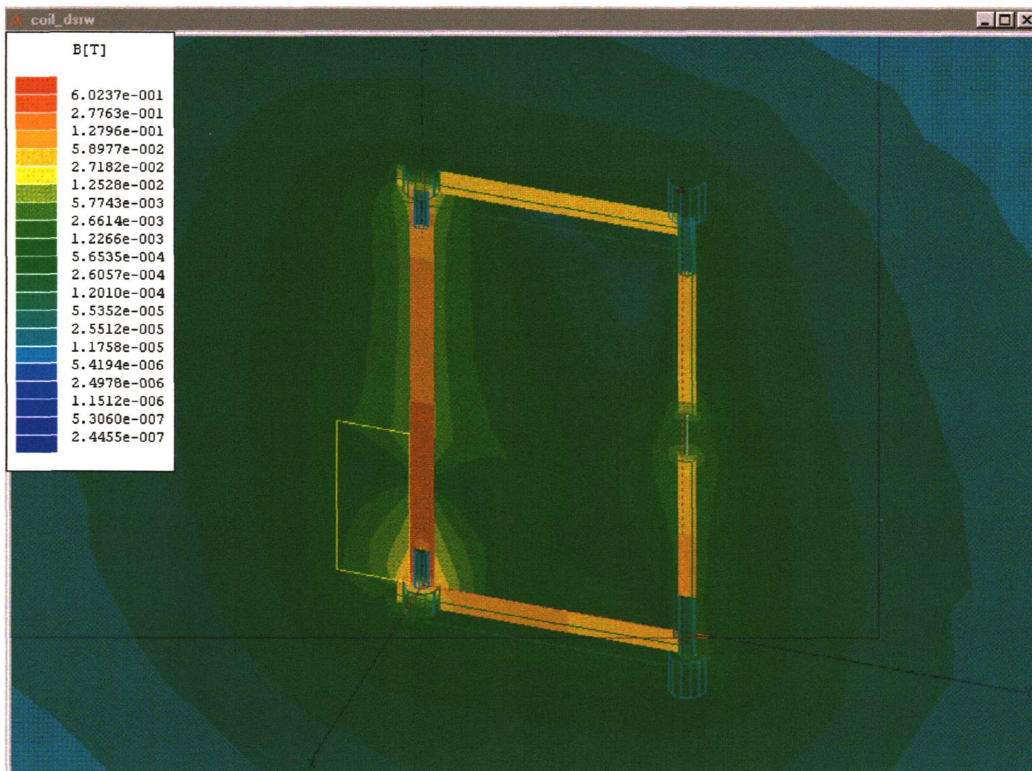


Figure 3. B field (Tesla).

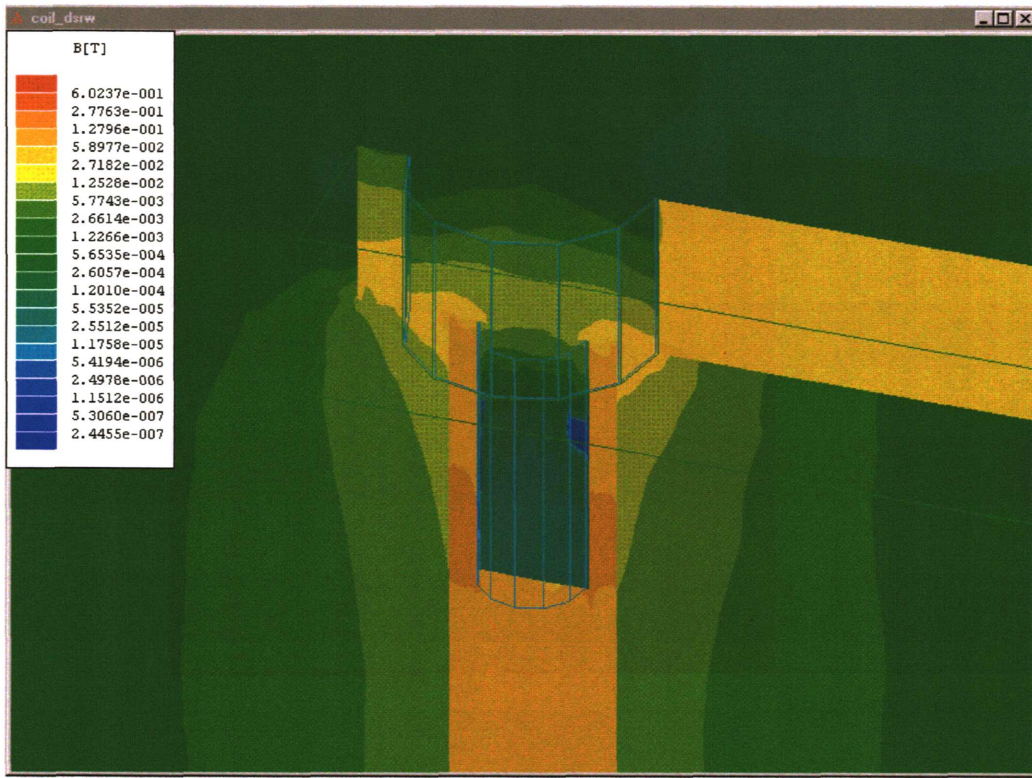


Figure 4. Detail of core/arm junction with stainless steel screw.

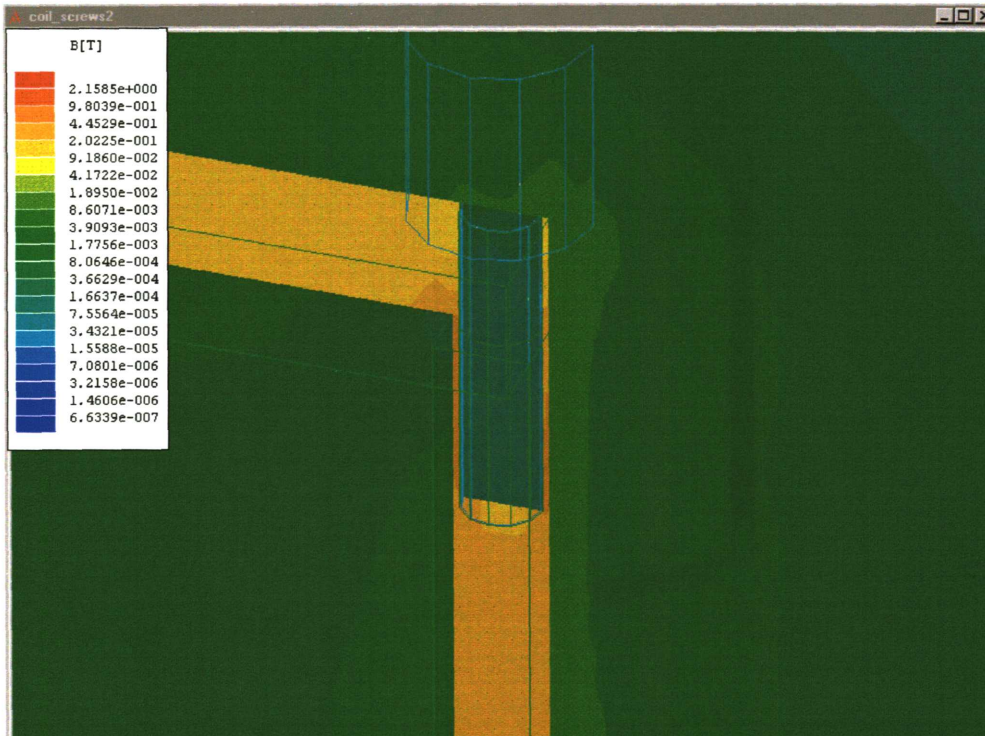


Figure 5. Cross arm/pole pieces junction.

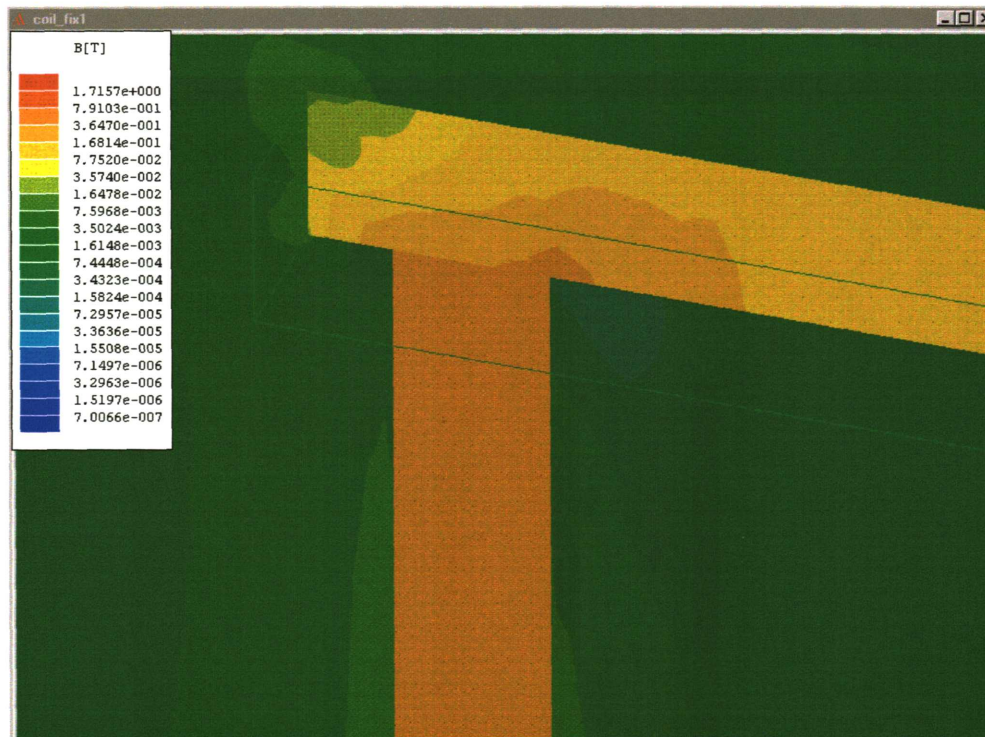


Figure 6. Junction with no screw.

Figure 7 shows the field in the gap between the pole pieces. Figure 8 shows an “arrow” plot of the field lines and Figure 9 shows the field strength across the gap. This shows the asymmetry of the field and the lack of smoothness due to the finite accuracy at which the program stopped.

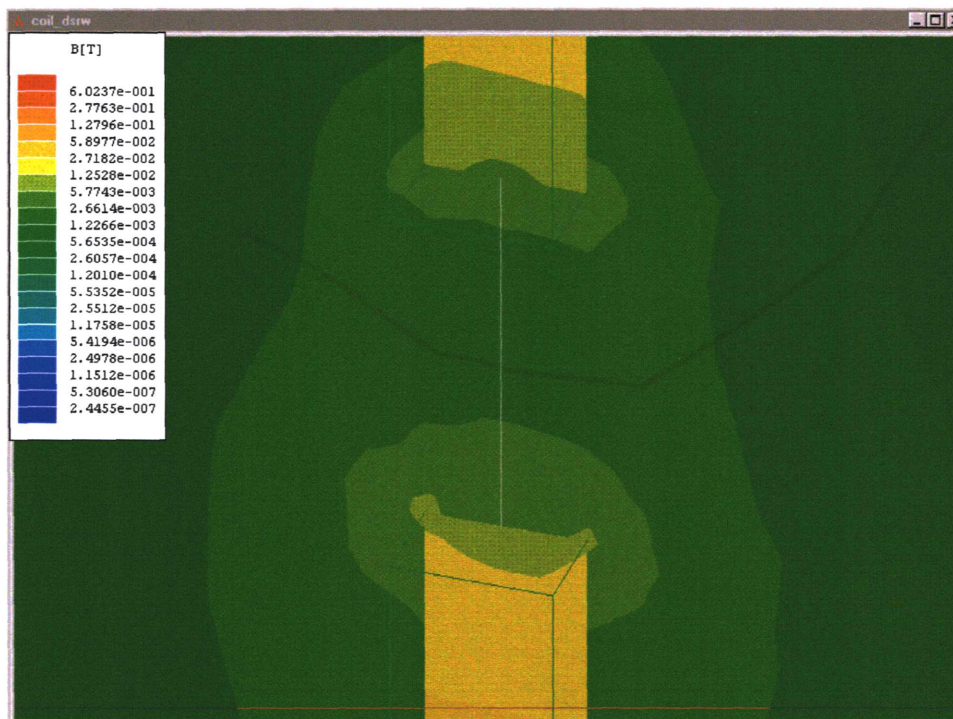


Figure 7. Field in gap.

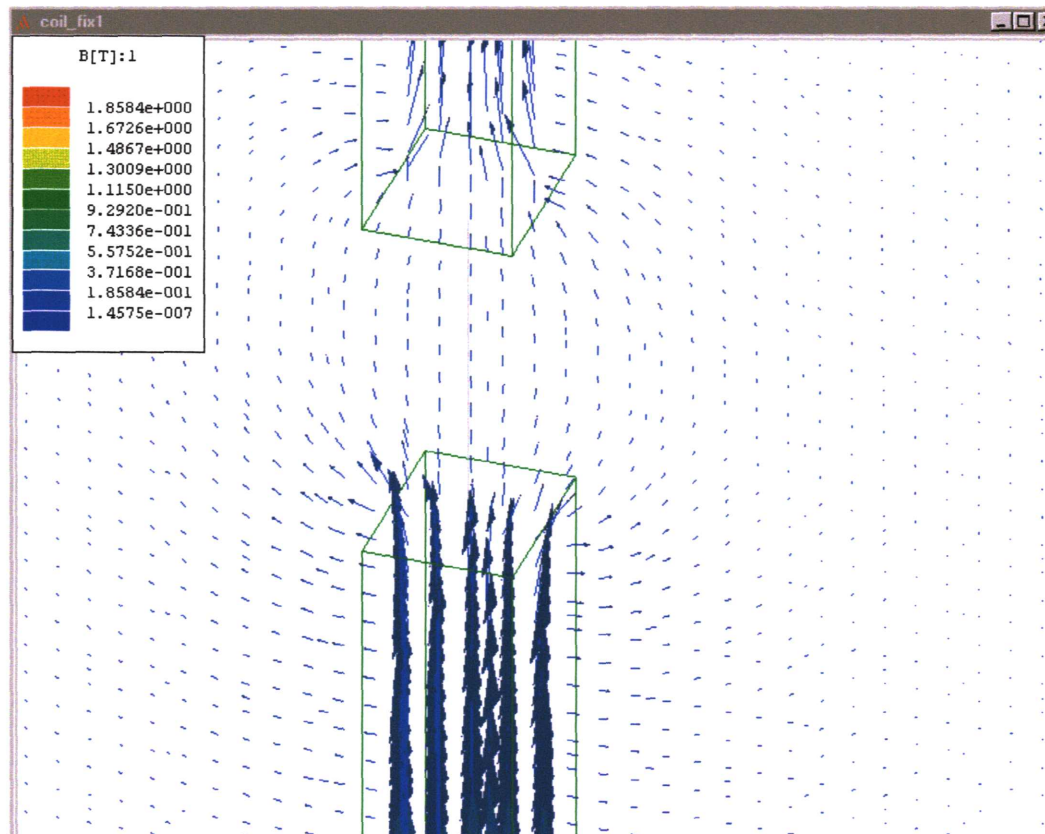


Figure 8. "Arrow" plot of field lines.

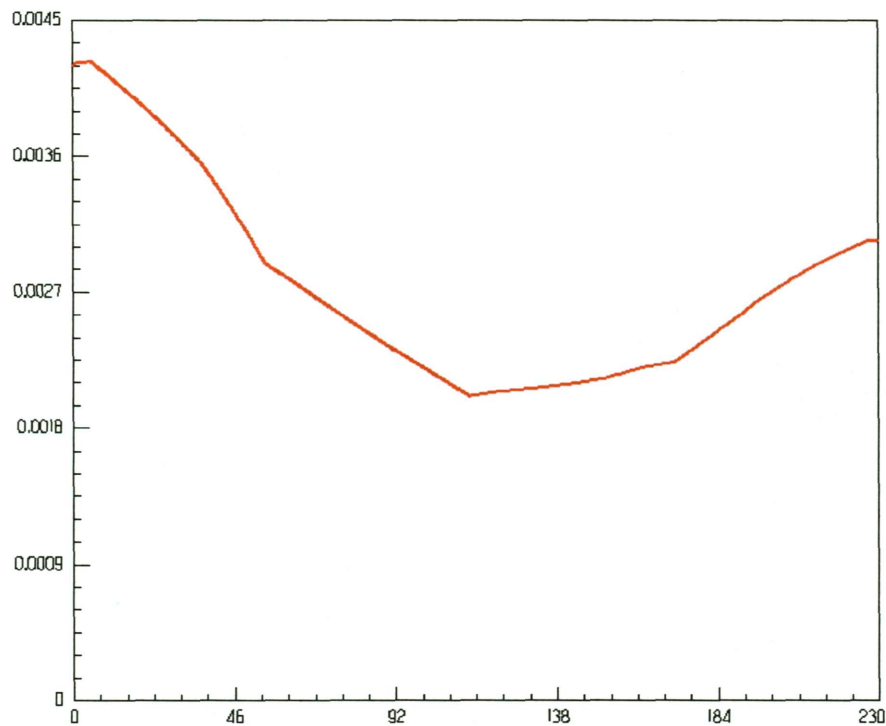


Figure 9. Field (Tesla) across gap (dimensions in mils).

Many calculations were made of the structure and these are summarized in Figure 10. The original circuit clearly saturates at approximately 200 Gauss when no screws are present. This is reduced to approximately 180 Gauss when screws are present, but 1010 steel screws show better performance at lower currents. The plot also shows the predicted performance if the solenoid core diameter is doubled (no screws), as shown in Figure 11. Saturation in the core does not take place for these currents and better coupling is made between the core and the cross arms. Figure 12 shows a 3-D plot of the fields when the coil is centered on the core, showing a much more symmetrical distribution (original diameter core). Figure 13 shows that the better coupling of the larger diameter core can lead to much higher fields in the cross arms and pole pieces (drive current 67 mA).

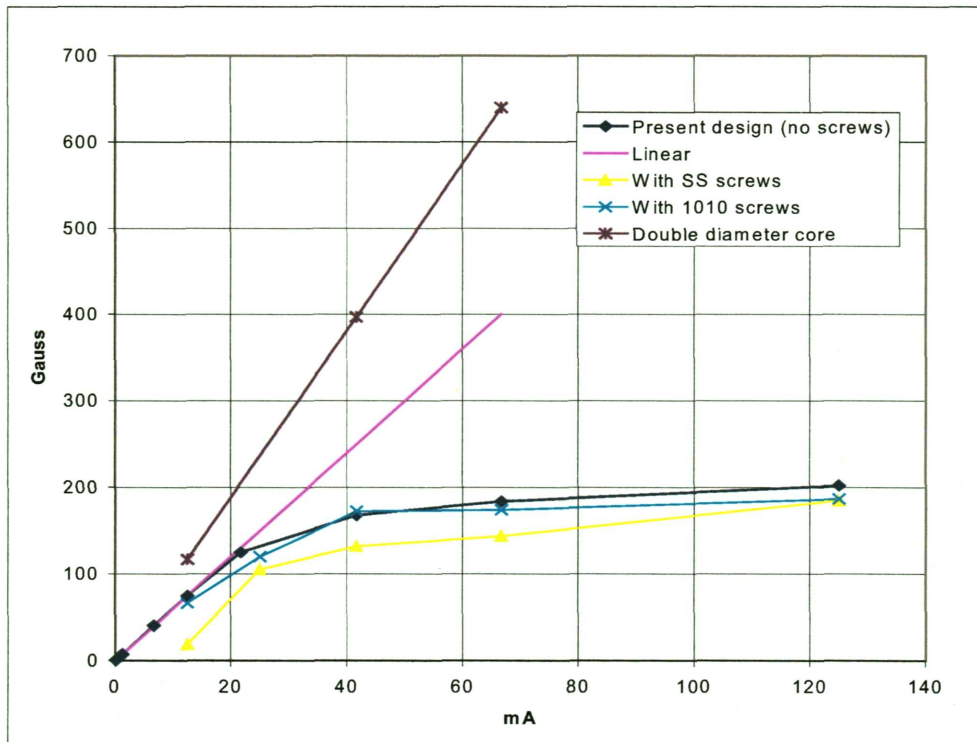


Figure 10. Field at junction (Note: 1 Tesla = 10K Gauss).

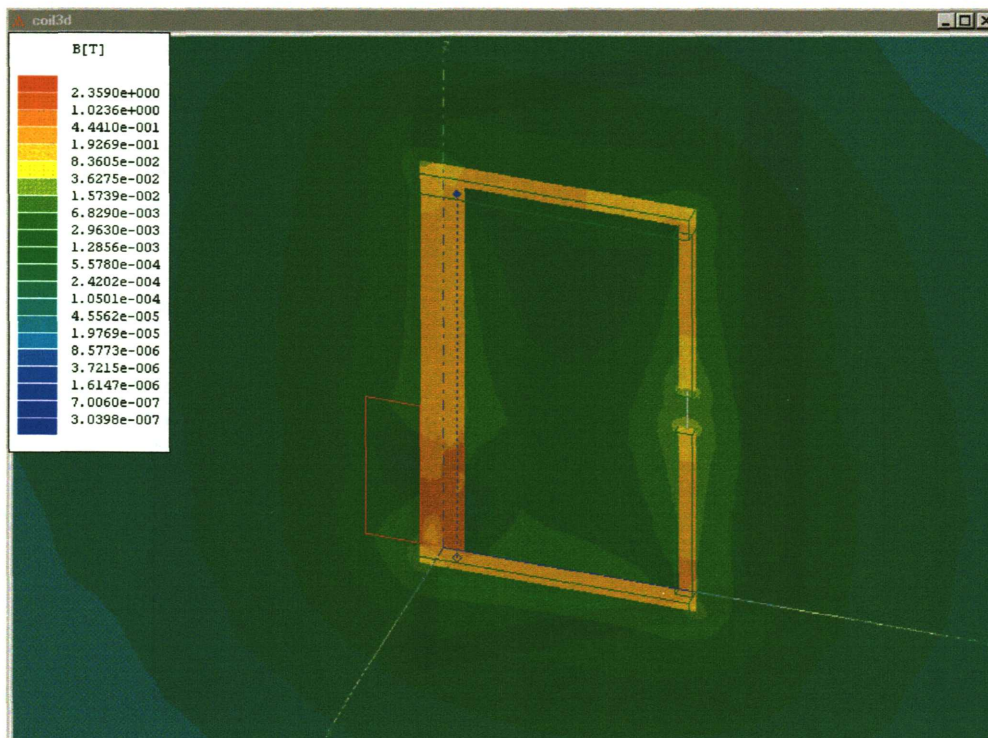


Figure 11. Double diameter core.

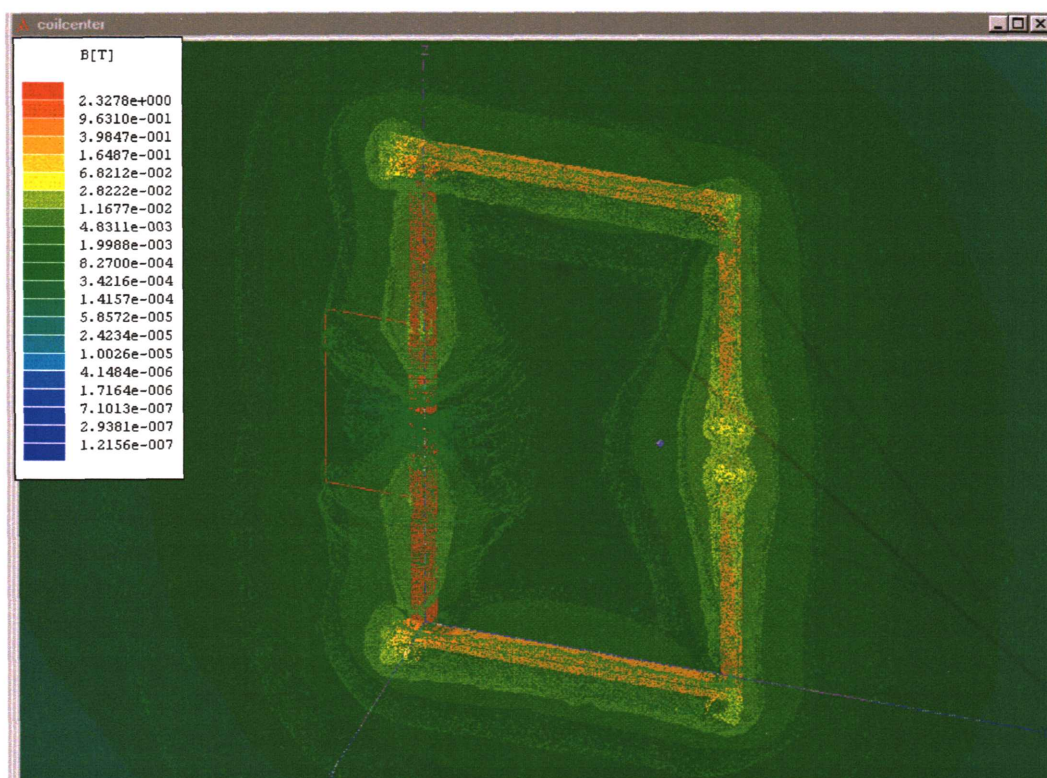


Figure 12. Symmetrical excitation (original core diameter).

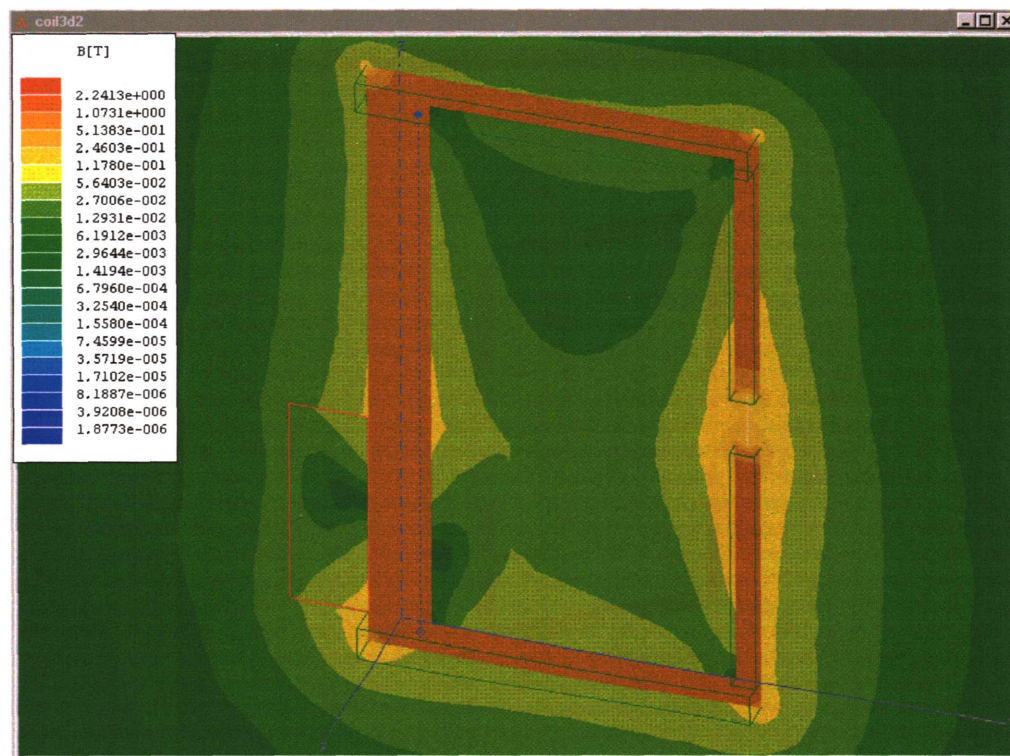


Figure 13. Higher saturation with double diameter core.

Permanent Magnets

As a temporary method of increasing the field at the junctions, two permanent magnets (2,000 Gauss) were placed at the ends of the pole pieces as shown in Figure 14. Depending upon their orientation and upon the direction of the current in the coil, they can add approximately 30 Gauss, subtract 30 Gauss, or have no effect on the field at the junction. This has been sufficient in the past to suppress the Josephson noise in the SIS mixers when the field produced by the coil alone has been inadequate.

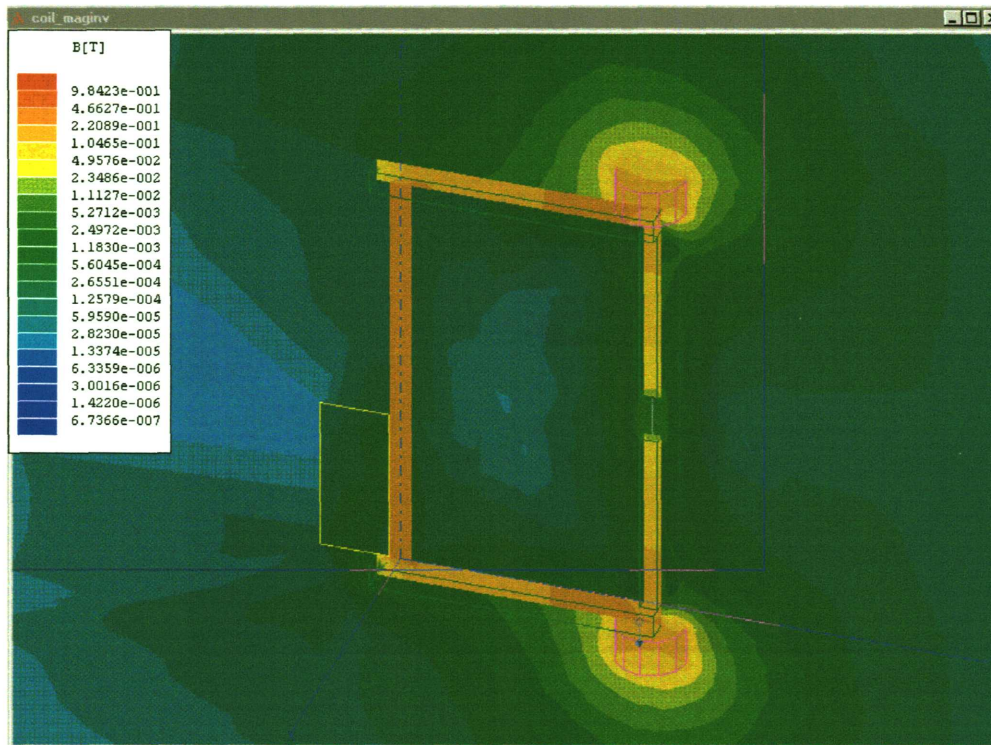


Figure 14. Permanent magnets attached at end of pole pieces.

Conclusions

From the above analysis, it is recommended that the magnet circuit be modified as follows to improve the performance:

- 1- Increase the diameter of the core and increase length of coil to maintain the number of windings.
- 2- Centralize the coil position.
- 3- Use magnetic material screws to reduce the reluctance of junctions between pieces of material.
- 4- Consider annealing the material after machining as recommended by the manufacturer.

References

- [1] Ansoft Corp., Four Station Square, Pittsburgh, PA 15219. Tel: 412-261-3200.
- [2] Type M wire (Cu-clad Nb48%Ti). Supercon, Inc., 830 Boston Turnpike, Shrewsbury, MA 01545. Tel: 508-842-0847.
- [3] Hiperc 27 (Iron 26-28.5% Cobalt). Carpenter Technology Corp., P. O. Box 14662, Reading, PA 19612-4662.

Appendix 1

Magnetic Screws

Figures 15 and 16 show the fields around the screws when 1010 steel screws are used. They clearly show the penetration of the field into the screw and the better coupling across the core/cross arm (Figure 15) and cross arm/pole piece (Figure 16) junctions.

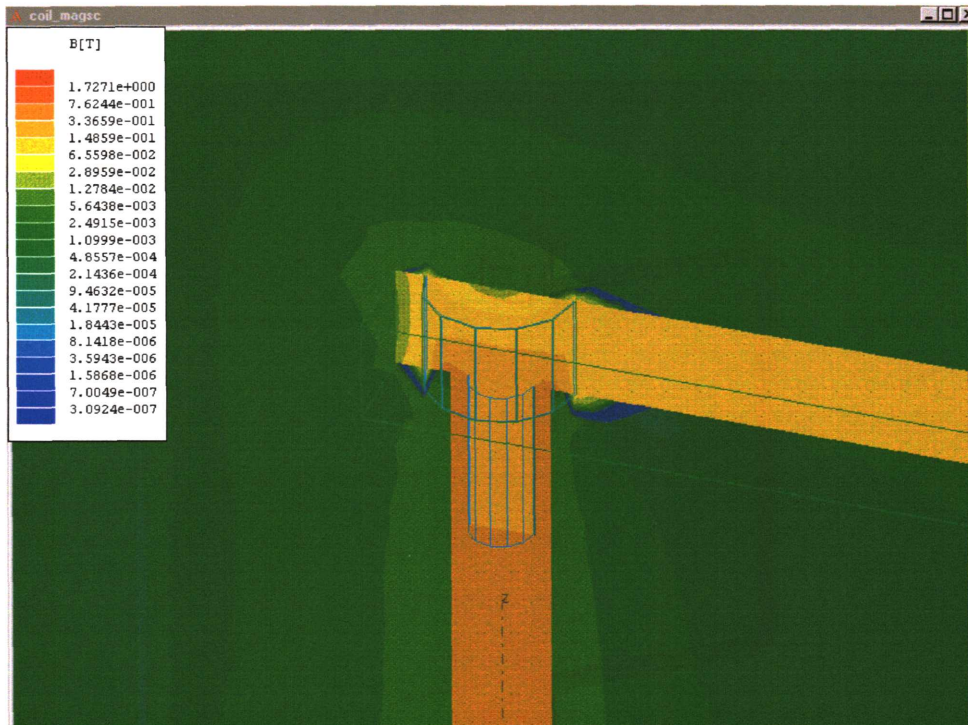


Figure 15. Core/cross arm magnetic screw.

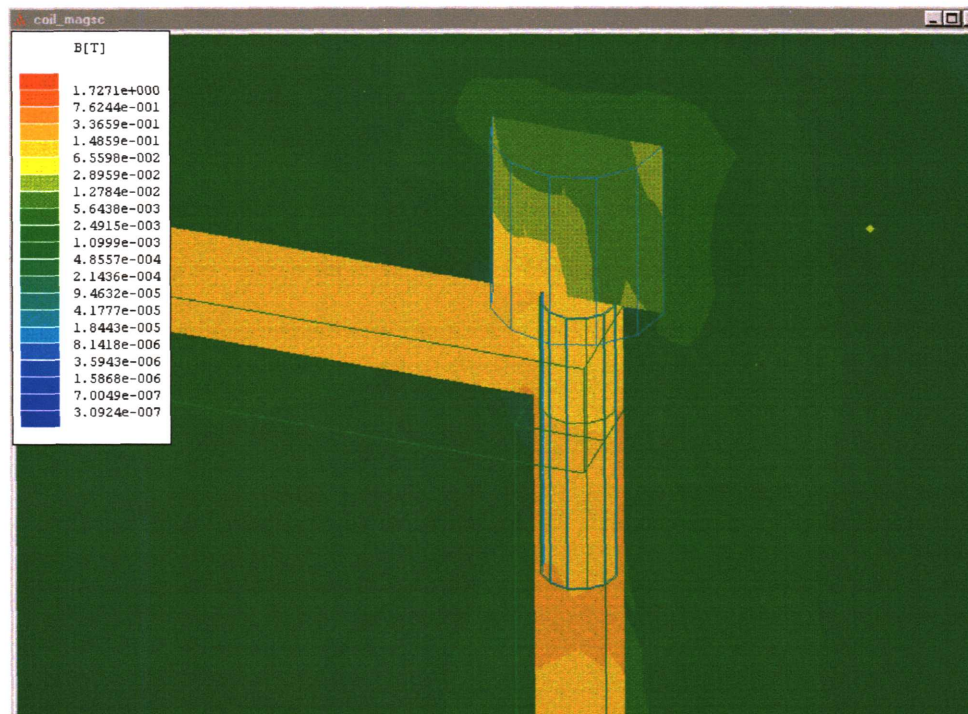


Figure 16. Cross arm/pole piece magnetic screw.

Appendix 2

Inserts

In future multi-junction mixer systems, two or more junctions could be placed in the gap at different non-centered positions. One possibility would then be to place a piece of magnetic material at the center of the gap to improve the field coupling. This was simulated as shown in Figure 17. The field between the pole pieces is shown in Figure 18. The concentration of the field in the magnetic material is clearly shown, but the field strength at positions at the centers of the two gaps is only approximately 30 Gauss higher than when the insert is not present (for the same drive current shown in Figure 19). This indicates that there is little value in using such an insert given the extra difficulty of machining and placing the insert in the correct position.

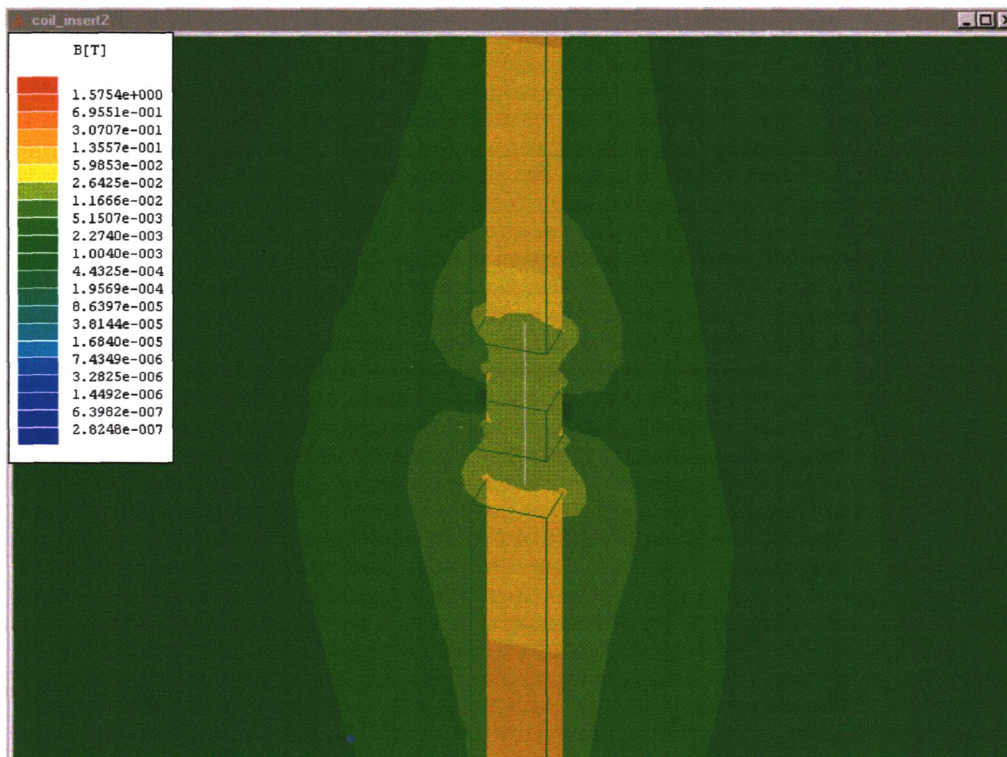


Figure 17. Insert in gap.

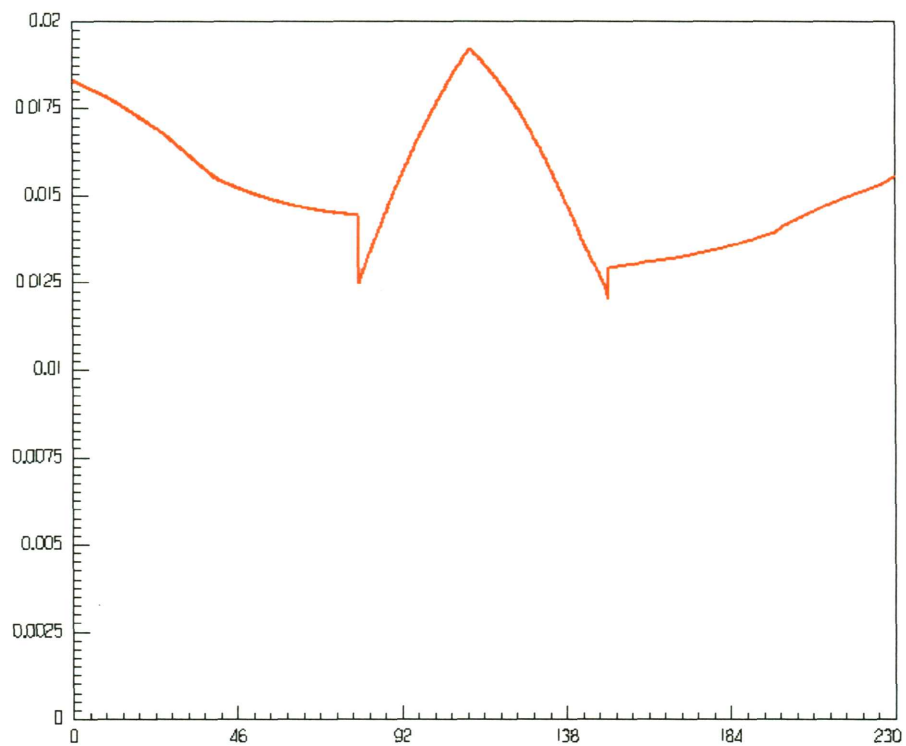


Figure 18. Field (Tesla) across gap with insert (dimension in mils).

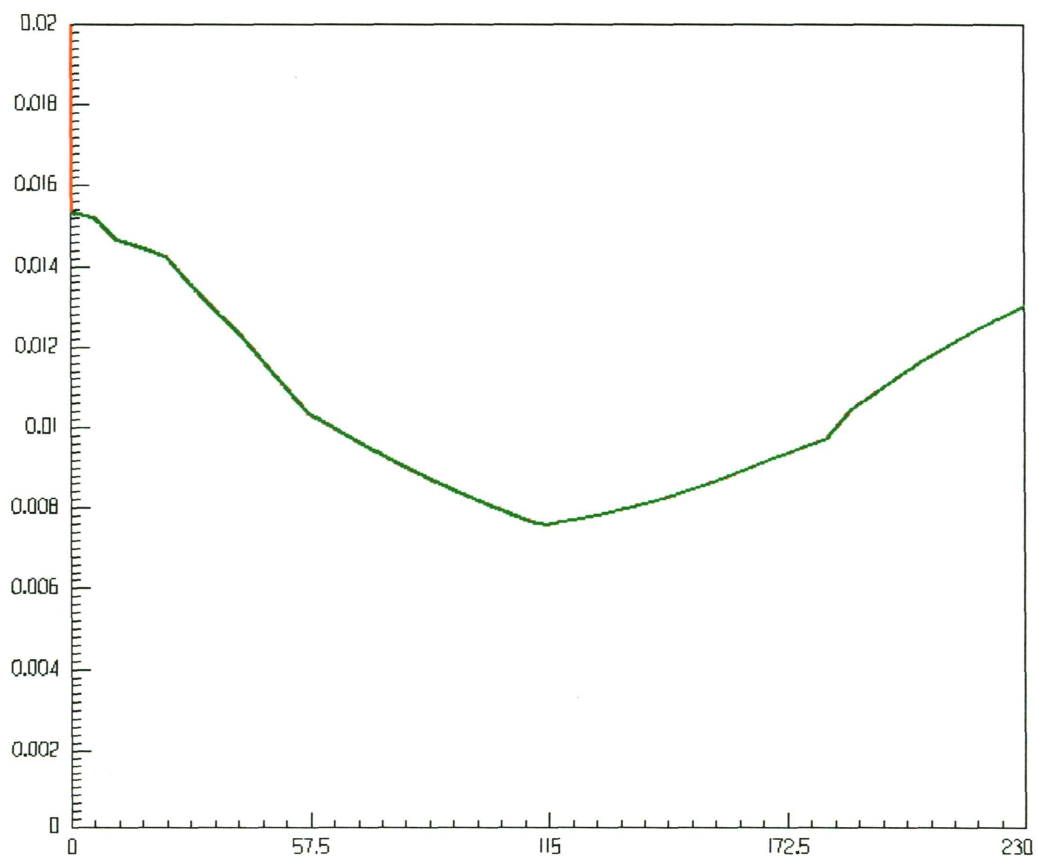


Figure 19. Field (Tesla) in gap without insert (dimension in mils).