final report

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Electro Resonant Stimulation Electronics Development

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Executive Summary

Magnetic pulse medical therapy developed for humans has been reengineered for trials on feedlot cattle in an attempt to improve growth rate and eating quality. The first trial used compromise equipment because of cost constraints and trial results suggested a possible small effect that is not commercially significant.

Since the conclusion of Trial 1, developments in low cost but much higher powered equipment (from China) have made a less compromised trial possible using energy levels comparable to the successful European laboratory trials on cattle. The results of Trial 2 are not conclusive and it is recommended that no further research is conducted in this area.

Contents

Introduction

A human medical apparatus, the "Bemer 3000" has been shown to stimulate increased growth rate in both sheep and cattle. (Warsaw University trials).

The Bemer 3000 applies very low levels (<30 uTesla) of pulsed magnetic fields over a large surface area of the body. This is usually applied using a coil containing blanket which positions the source of the magnetic field close to the body.

The pulsed magnetic field has a unique waveform which is defined mathematically by the general equation:-

Magnetic Field Strength = $Kt^3e^{\sin(\text{kt cubed})}$ (where K is a constant and t equals time) and is shown in graphical form in Figure 1 below.

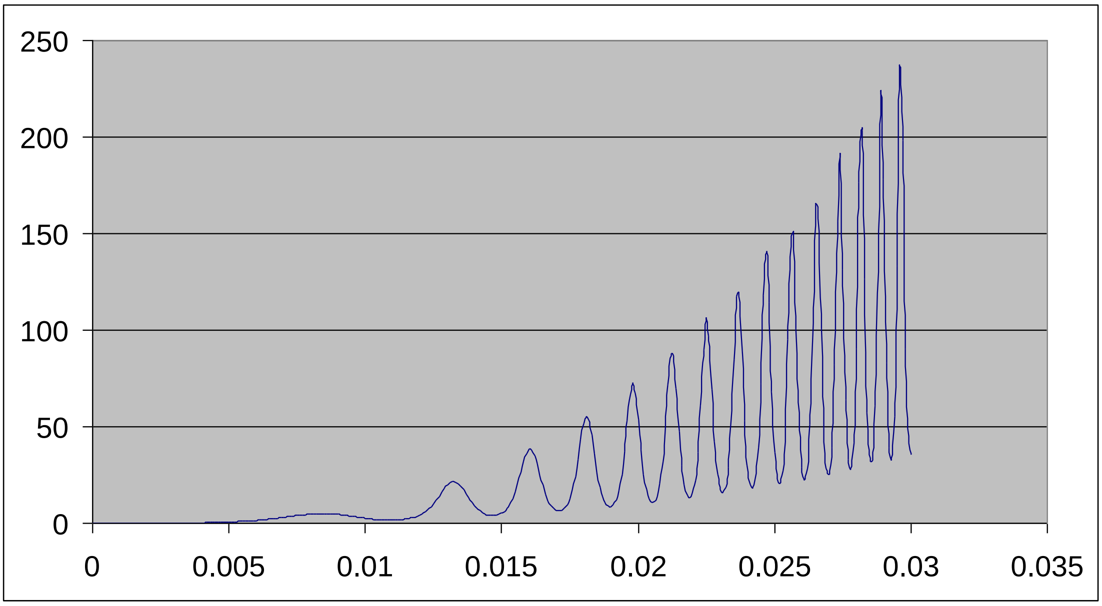

Figure 1.

This waveform is patented in Europe and the USA but not Australia and it was thought safe to proceed with copying the waveform for use in Australia.

This project aimed to test the possibilities of using this field to accelerate growth rates in feedlot cattle in a cost effective way.

2. Methodology

2.1 Signal source development

Developing the signal source which electrically represented the mathematical equation above was the main challenge. This was achieved by the following steps:

- Represent the equation as a series of data points in a spreadsheet.
- Developing software which converted the spreadsheet data to binary code for input into a microcomputer.
- Developing microcomputer operating code which converted the binary data to an analogue signal using inbuilt digital to analogue converters.
- Designing suitable filtering and buffering circuitry which produced a smoothed version of the waveform without digital noise.

2.2 Power amplifier development, Trial 1

To generate the required intensity of magnetic field an amplifier was needed to amplify the signal source to a very high level and accurately reproduce the signal. The magnetic field strength is directly proportional to the current flowing in an air coil so a DC amplifier with output current proportional to input voltage was required. This became a challenging task when it was calculated that the amplifier was required to drive a large inductive load (multiple coils) as a current source with delivered power greater than 200 watts peak.

The final solution was achieved by performing a mathematical transformation of the required output current into a voltage waveform which delivered the required current waveform into a known, series combination of inductance and resistance as represented by the air coils. This mathematical transformation was then incorporated into the signal generation spreadsheet. The power amplifier was then built as a more stable voltage source output which produced the required transformed waveform.

2.3 Power amplifier development, Trial 2

Since the conclusion of Trial 1, the recent availability of very high powered yet low cost amplifiers from China (3000 watt, AC public address amplifiers) and the idea of superimposing a DC bias field in parallel with the AC field have made it economically possible to create the required waveform.

The Amplifier (Titan Audio TDJ-4000) was modified by increasing the heat sink airflow using 10 axial fans and the sustainable peak output power was increased from 500 to 3000 watts. Because the amplifier could not output a low frequency DC offset as required for the Bemer 3000 signal, an adjustable voltage DC power supply (24 volt) was used to create the DC offset by sending DC current through a 3 turn coil running in parallel with the coil driven by the Titan amplifier. (See file, Trial 2 Coil Driver for details).

2.4 Magnetic sensor development

Precise magnetic field measurement required the design and construction of a magnetic field sensor capable of accurately reproducing the magnetic field as a voltage waveform visible on an oscilloscope.

Appendix 4 gives construction details.

2.5 Air coil development

Extensive modelling of the magnetic field strength generated by a variety of air coils was performed using FEMM magnetic modelling software. The challenge was to emulate the magnetic field strength at the surface of the Bemer 3000 blanket at a point in space above the feed trough in a feedlot.

The coil design chosen for Trial 1 was a compromise between cost and extent of spacial distribution of the field. The coil design used is depicted in Figure 2, below, where a continuous series of narrow coils is laid along the feedlot feed trough. A compromise was required because the input energy required to energise a coil to a set magnetic field strength is approximately proportional to the coil width cubed.

The ideal coil design as used in Trial 2 is shown in Figure 3. This design covers the animal with a far more extensive magnetic field than that used in Figure 2. However, the input energy requirements are 15 times that needed for the Figure 2 coil. The solution to generating this higher energy is outlined in section 2.3.

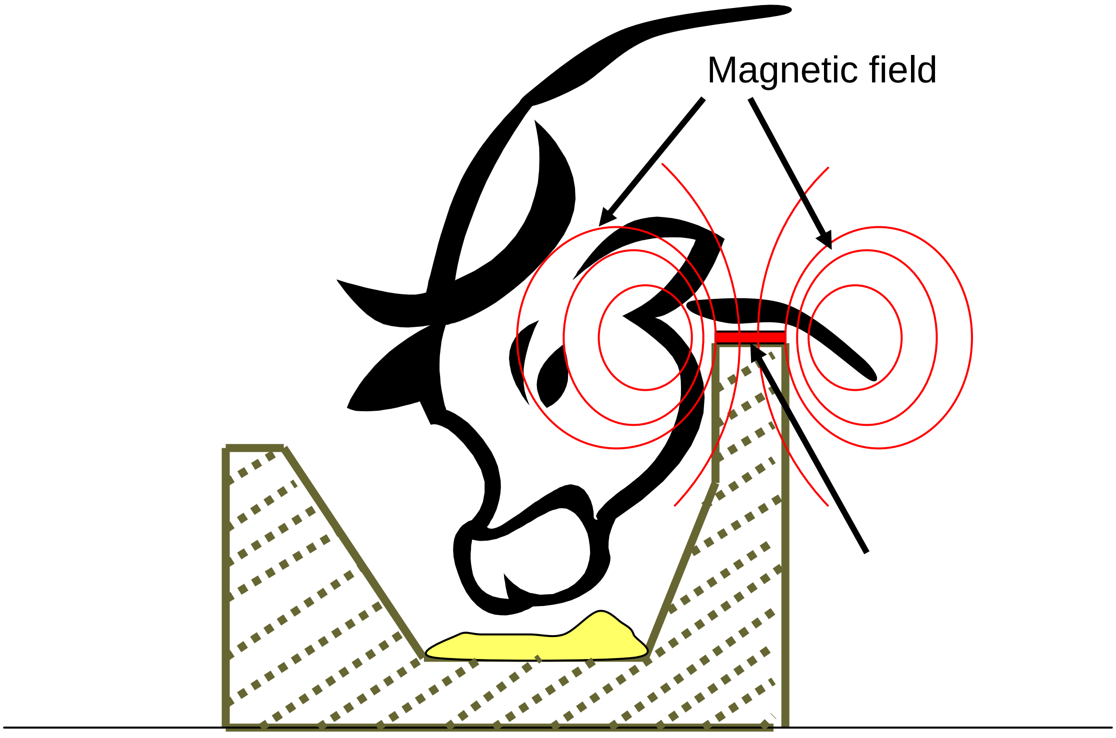

Figure 2.

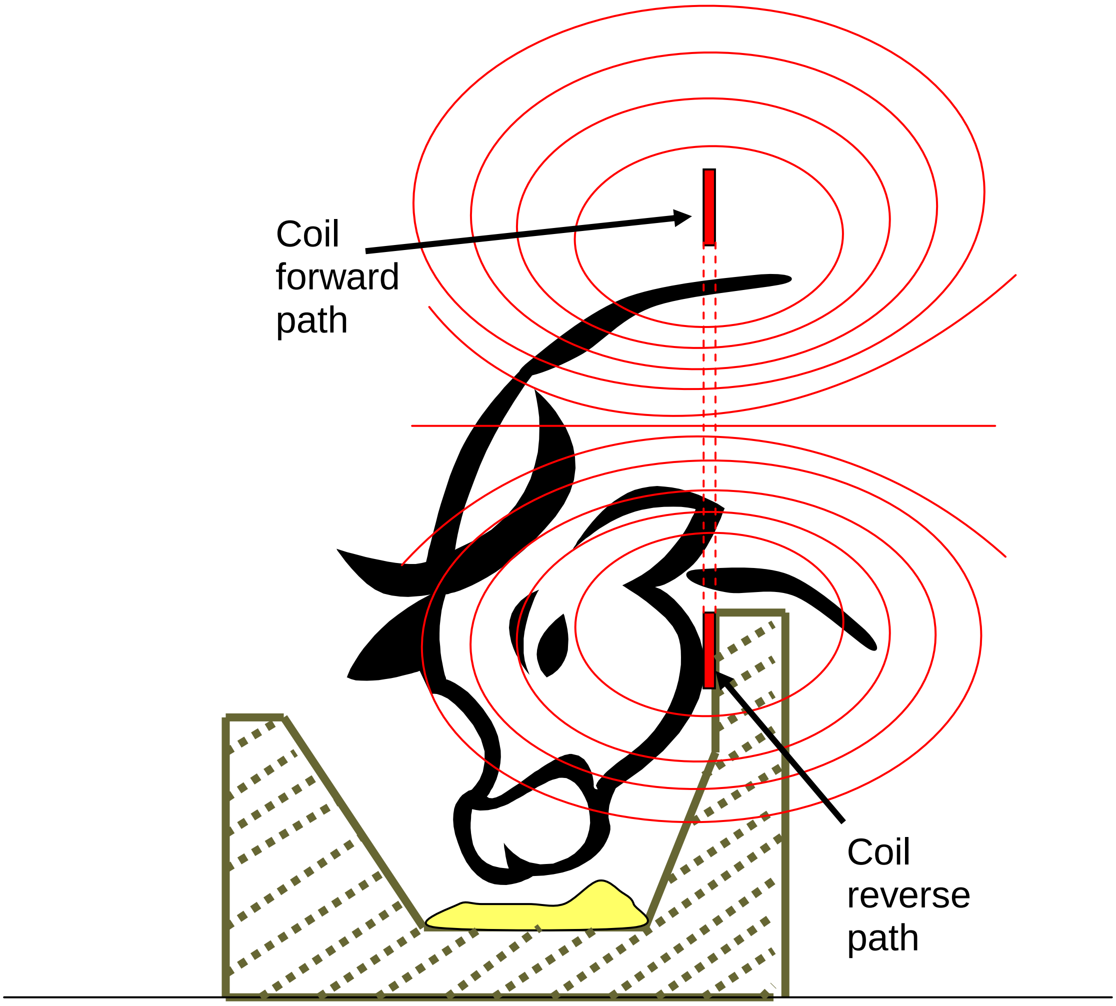

Figure 3.

2.6 Experimental design, Trial 1

- Coils as shown in Figure 2 were positioned continuously along the top of the feed trough (60 metres) of one pen.

- 440 cattle were split into 2 similar groups and placed, one group in the coil pen and the second group in an adjoining control pen without coils.

- Both groups of cattle were weighed at induction and fed identically for 100 days.

- The test (coil) pen was activated by the magnetic field generator, continuously for the full 100 day trial with a magnetic field strength equal to the mid setting (position 6) of the Bemer 3000 at the surface of the blanket.

- After 100 days the cattle were slaughtered and Hot Carcase weights were recorded to compare growth rates.

- During processing MSA grading data was collected from both groups for comparison.

2.7 Experimental design, Trial 2

- Coils as shown in Figure 3 were positioned continuously along the top And bottom of the feed trough (60 metres) of one pen.
- 440 cattle were split into 2 similar groups and placed, one group in the coil pen and the second group in an adjoining control pen without coils.
- Both groups of cattle were weighed at induction and fed identically for 70 days.
- The test (coil) pen was activated by the magnetic field generator, continuously for the full 70 day trial with a magnetic field strength equal to a mid setting (position 5) of the Bemer 3000 in the centre of the coil.
- After 70 days the cattle were slaughtered and Hot Carcase weights were recorded to compare growth rates.
- During processing MSA grading data was collected from both groups for comparison.

3.Results

Trial 1

	Dentition	Marbling	p8fat	Ribfat	Colour	Ema
Lot 1 Trial	1.93	0.77	15.21	7.22	1.99	74.45
Lot 2 Control	1.92	0.75	15.02	6.98	1.93	74.88

	Initial wt	HSC weight	ph level	Bled Weight	Ossification
Lot 1 Trial	423.51	337.53	5.52	561.02	172.81
Lot 2 Control	423.65	337.29	5.54	560.72	173.59

Trial 2.

	Dentition	Marbling	p8fat	Ribfat	Colour	Ema
Lot 1 Trial	1.43	0.26	7.50	4.38	2.15	68.61
Lot 2 Control	1.71	0.28	7.71	4.18	2.00	68.69

	Initial wt	HSC weight	ph level	Bled Weight	Ossification
Lot 1 Trial	403.90	232.49	5.55		180.24
Lot 2 Control		235.07	5.57		177.67

4. Discussion

The data from Trial 1 shows that there may be a very small effect which shows up as a small positive bias on most of the important meat traits. This improvement may have been a noise effect and the next trial with a greater spatial distribution of energy was used to confirm or otherwise the Trial 1 data.

Trial 2 data in the table above shows a varied yet insignificant effect with some parameters showing improvement and others showing a negative effect. The key measurement of Hot Scales Carcase Weight (HSC weight) indicated a small decrease in growth rate.

5. Conclusion

The Trial 2 data show no significant effect even though 15 times more energy was used compared to Trial 1. The trial 1 data appeared to show a small effect which would need replication to confirm and failure of Trial 2 may be due to a saturation effect.

The literature suggests that it is possible to get a saturation effect when excessive energy is applied and more is not necessarily better. There would be many months of trials required to confirm this effect and considering the minimal commercial gain shown so far it is recommended that the project be terminated.

Appendix 1 - Signal Generation Design notes

- The published and patented equation representing the magnetic field waveform to be tested was written into a spreadsheet to create a digitised representation of the analogue waveform. See attached file; Bemer Calc v3.3

- The final spreadsheet (v3.3) included a transform equation to convert the basic Bemer equation into an equation representing the drive voltage. This transformed equation for voltage represented a signal necessary to drive a current matching the true Bemer signal into an inductive load using a voltage source amplifier. Note; the magnetic flux is proportional to current not voltage in the coil and a high power current source output amplifier was found to be unstable.

- The digitised representation of the required waveform in the spreadsheet was converted to an analogue voltage signal using custom designed software and electronics hardware developed by specialists in this field, Sensel Pty Ltd.

  Attached file, Magstim v3 is used to program the Micro using a USB debug adaptor. (see file, Magstim notes v3 for instructions) Attached file, Bemer SpreadSht Transform v3 is used to load the spreadsheet data into the micro using an RS232 cable.

Appendix 2 - Magnetic Modelling

- Free online software, Femm 4.0, was used to establish a comparative magnetic flux density for different coil configurations and sizes.

- Magnetic field measuring equipment was then used to establish a base line for magnetic field strength by measuring the actual field strength at the surface of a Bemer 3000 (Veterinary model) set at the centre of it's energy range.

- The field measuring equipment was then used to confirm field strengths in prototype test coils suitable for feedlot application by balancing coil turns and activation current.

- An optimised trade off between coil design and activation current was then used to design a suitable power amplifier with appropriate voltage and current drive capabilities.

Magnetic Field Strengths

Figure 1 below, shows the "axisymetric" layout used in the FEMM modelling software. By modelling the field strength of the commercial Bemer 3000 unit, then modelling various coil configurations suitable for feedlot installation.

Similar magnetic field strengths in the model would equate to similar real life fields.

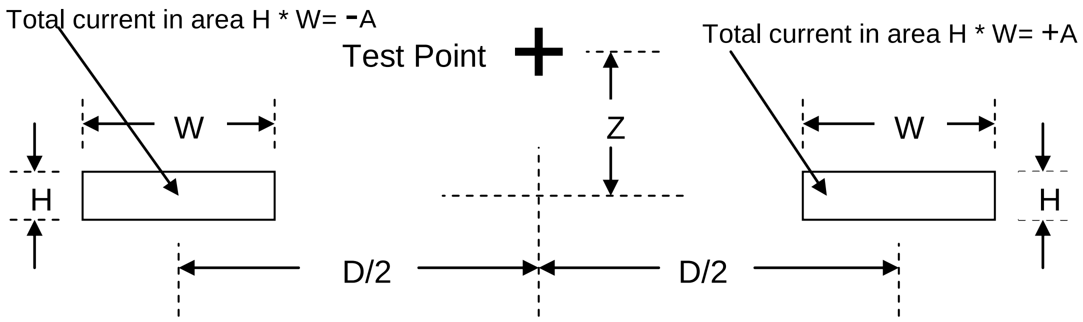

Figure 1.

Bemer 3000 Modelling

Figure 2 below, shows the modelling configuration for the Bemer 3000 where:

A = 20 turns*0.65 amp peak
= 13 amp.
D = 105 mm
H = 2 mm
W = 30 mm
Z = 0 for all modelling

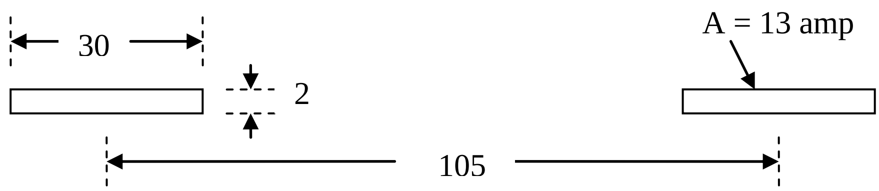

Figure 2.

Final Feedlot Trial 1 Coil Design (figure 3)

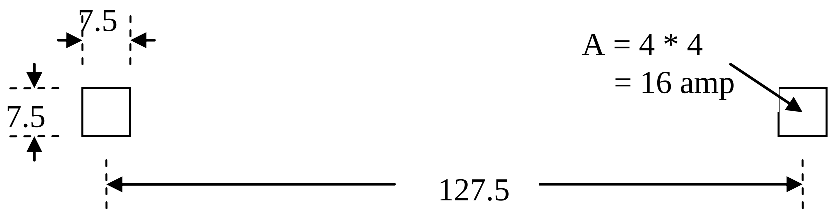

Figure 3.

Appendix 3 - Signal and Power Generation Circuits

See accompanying power-point files "Signal and Power Generation Circuits" and “Trial 2 Coil Driver”.

Appendix 4 - Magnetic Field Sensor and Measurement.

Commercial analogue magnetic field measuring equipment suitable for accurately measuring the waveform characteristics of the Bemer signal are expensive and not readily available. It was decided to design a suitable sensor based on the Honeywell HMC1021Z integrated circuit. File "Mag Circuit V1.0" contains the design for this sensor. File "Bemer Vet Calibration Against Honeywell Probe" contains voltage output data calibrated against the output settings of the Bemer equipment.

Appendix 5 - Stanbroke Trial 1, 17/6/09

Engineering Specifications and Measurements.

The power amplifier circuit used for the Stanbroke trial 1 is shown in file " Signal and Power Generation Circuits" headed "High Power Amplifier".

Load Coils

29 coils (4 turns/coil using 2.5 mm dia single strand copper) in series.

Measured inductance = 1.39 mH

Measured resistance = 2.2 ohm

Total series resistance = 2.2 + 2*0.82
(2*0.82 ohm o/p signal measuring resistors)
= 3.84 ohm

Measured Vp/Vpp (L=1.39, R=3.84) = 5.6/4.6 = 1.22.

Value for total R changed in transform equation (software) to R = 3.5 ohm.

Measured Vp/Vpp = 5.5/4.85 = 1.13, This value was used for the experiment.

Peak to Peak Voltage into Load
+30 Volts DC at maximum current (waveform limiting)
-16 Volts DC

24 volt DC supplies were used to supply I_{peak} = 4 amps as measured by the signal measuring resistors as 3.3 volts across 0.82 ohm.

Appendix 6 - Stanbroke Trial 2, 1/7/10

Engineering Specifications and Measurements.

Power Amplifier Output Calculation

The Titan Audio TDJ-4000 power amplifier used to drive the coil was chosen based on estimated power calculations. As a first assumption it was assumed that the energy in the magnetic field increased as the square of the linear width measurement of the coil.

Coil width (trial 1) = 127.5 mm
Coil width (trial 2) = 450 mm

Power increase ratio (Trial 2/Trial 1)
$= (450/127.5)^2$
$= 12.5$

Peakpower input in Trial 1
= 200 watts

Estimated peak power requirements for trial 2
= 2500 watts.

The TDJ-4000 was chosen as it's peak output power is 3000 watts.

Amplifier Reliability Testing and Development

The amplifier peak output power in bridge mode was tested at 3500 watts, however, the amplifier could not sustain this level for more than 5 minutes and shut down (non-destructively) on thermal overload. Investigations revealed that the fan cooling of the output transistors was far from adequate and testing was undertaken to try and improve the cooling efficiency. 10 strategically placed cooling fans coupled directly to the amplifier heat sinks enabled the amplifier to operate at a peak power of 3000 watts continuously when driven by the Bemer signal.

The development of the amplifier cooling was carried out at an ambient temperature of 22 deg C (MLA office) as it was considered too difficult to test the unit at the ambient temperature likely to be experienced at the Chinchilla feedlot. A confounding issue likely to be encountered at the feedlot was the high levels of dust in the air which would be drawn into the amplifier with the high air flow of the 10 fans. It was concluded that the best solution was to place the amplifier in a custom designed, dust tight, air-conditioned enclosure with effective dust filtering and this was done.

Coil Design

The peak output voltage of the amplifier has a limit of +100 volts and -100 volts and it was decided that the quickest coil design should be done experimentally based on guidelines established from the FEMM modelling.

Flat 4 mm twin, 2.5 mm earth, cable was used as a cost effective method of creating a 3 turn coil by cross connecting the conductors. The design approach was:

- start with one cable run of 3 turns spanning the full 60 metre of coil length.
- measure the maximum peak flux at maximum amplifier output (without waveform clipping) and compare with the required (Bemer level 5) flux level with the view of increasing the number of turns to achieve the required flux level.

Bias Coil Design

The TDJ-4000 is an AC coupled amplifier and was chosen because the AC coupled amplifiers are much cheaper than DC coupled amplifiers. The ideal amplifier would be a DC coupled 3000 watt amplifier, however, the list price for this is $50,000 compared to $700 for the TDJ-4000.

The down side of using the AC amplifier is that the output waveform "floats" with a 0 volts average DC offset. The Bemer signal has a permanent DC offset (alternating every 2 minutes from + to -) and to create this signal a static DC magnetic field of the required level needed to be superimposed on the AC signal (DC field must also alternate in polarity every 2 minutes.).

The required DC field was created by driving a multi turn coil lying close to and parallel to the AC coil with a suitable DC voltage. In this case, the resistance of 3 turns of 0.5 mm square copper (3 core flex cross connected) driven by 27 volts gave the required DC bias.

Future Amplifier Design

Funds and time did not allow for an optimised amplifier development. However, new developments in Pulse Width Modulation (PWM) power amplifiers could be the best commercial solution if the project enters the commercial phase. The Cirris Logic MSA 260 integrated amplifier would be a good starting point for a custom designed amplifier which would be relatively low cost and have minimal cooling requirements and reliability issues.

Appendix 7 - Transform Mathematics

Figure 1. shows the equivalent circuit of the coil.

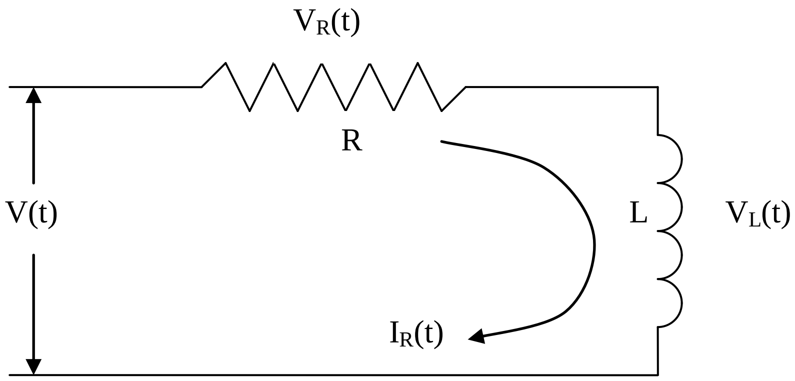

Figure 1.

Required Current $I_R(t) = (Kt)^3{}_e\sin(Kt)^3$ Equation **1**.
(magnetic flux is proportional to current)

Calculate the required voltage V(t) to achieve the Bemer current (above) in a series R, L circuit which represents a real life coil.

$$V(t) = R*I_R(t) + L * \frac{\partial I_R(t)}{\partial t}$$ Equation **2**.

Determine $$\frac{\partial I_R(t)}{\partial t} = \frac{\partial (Kt)^3{}_e\sin(Kt)^3}{\partial t}$$

$$\frac{\partial \sin(Kt)^3}{\partial t} = \cos(Kt)^3 * \mathbf{D}[K^3t^3]$$

$$\mathbf{D}[K^3t^3] = 3K^3t^2$$

$$\frac{\partial \sin(Kt)^3}{\partial t} = 3K^3t^2 * \cos(Kt)^3$$ (chain rule)

$$\frac{\partial\, {}_e\sin(Kt)^3}{\partial t} = {}_e\sin(Kt)^3 * 3K^3t^2 \quad \cos(Kt)^3$$ (chain rule)

$$\frac{\partial (Kt)^3\, {}_e\sin(Kt)^3}{\partial t} = K^3t^3 * \left({}_e\sin(Kt)^3 * 3K^3t^2 * \cos(Kt)^3\right) + 3K^3t^2 * {}_e\sin(Kt)^3$$
(product rule)

$$= 3K^6t^5 * {}_e\sin(Kt)^3 * \cos(Kt)^3 + 3K^3t^2 * {}_e\sin(Kt)^3$$

$$= K\left[3K^5t^5 * {}_e\sin(Kt)^3 + 3K^2t^2 * {}_e\sin(Kt)^3\right]$$ Equation **3**.

$$= \frac{\partial I_R(t)}{\partial t}$$

Solution: Substitute the formulae of equations 1 and 3 into equation 2.