THE AUTOMATIC MAGNETIC CALIBRATION OF MICROWAVE ISOLATORS AND CIRCULATORS

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Extract

Many areas of manufacturing in microwave devices have seen significant improvements and increased efficiencies in production, yet the magnetic calibration (also know as demagnetisation, setting or treating) has remained a manual operation based upon low capital cost magnetic equipment. This paper will cover the basics of magnetics, magnetic calibration and the dramatic improvements in production rates, quality and economics that can be achieved with modern automatic magnetic calibration* equipment. (* also known as setters, demagnetisers or treaters).

Introduction

While the last 60 years have recognised the revolution in microwave technology that has touched people in their every day lives, a similar revolution in magnetic materials is often overlooked and a reputation of a “black art” persist even into the production areas of some of the leading manufactures in the world today.

This paper is intended to explain some of the “Black Art” and to explain the magnetic techniques that can have a dramatic impact upon the Quality, Rate of manufacture, and economics of the magnetic calibration of microwave devices such as isolators and circulator.

Magnetic arrangements of microwave devices

In terms of magnetics, the devices are rather simple, consisting of a ceramic material (YIG) which needs to be subjected to a specific magnetic flux density level. This is achieved through a permanent magnet (or hard magnetic material) and a magnetic circuit of soft magnetic material to create a flux return path.

Microwave device

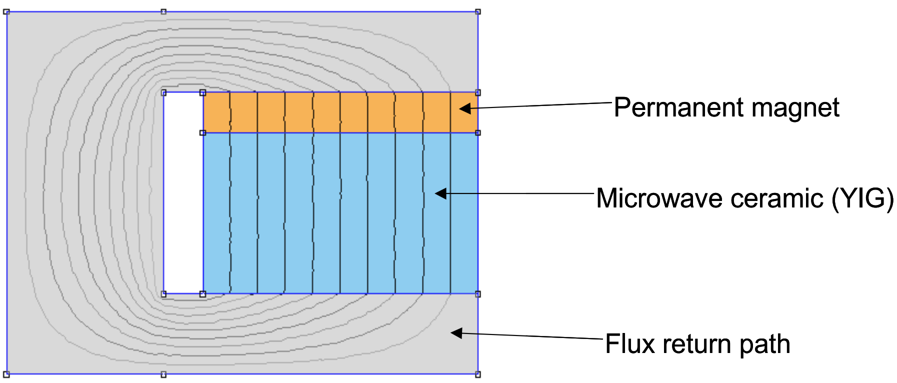

Figure 1. Simplistic magnetic arrangement of a microwave device

The soft magnetic material does not have a particularly demanding magnetic requirement but key to the magnetic system is that of the permanent magnet.

Permanent magnet materials

A wide range of magnet materials is available. Each offering different qualities and at wide range of different costs. The two main materials used in microwave devices are Samarium Cobalt (Sm_2Co_{17}) and Barium or Strontium Ferrite. Samarium Cobalt offers very good long term stability and temperature characteristics, but at a high cost and requiring high energies in magnetic processing. Ferrites have truly awful temperature characteristics, but they are very low cost and widely used in temperature controlled environments.

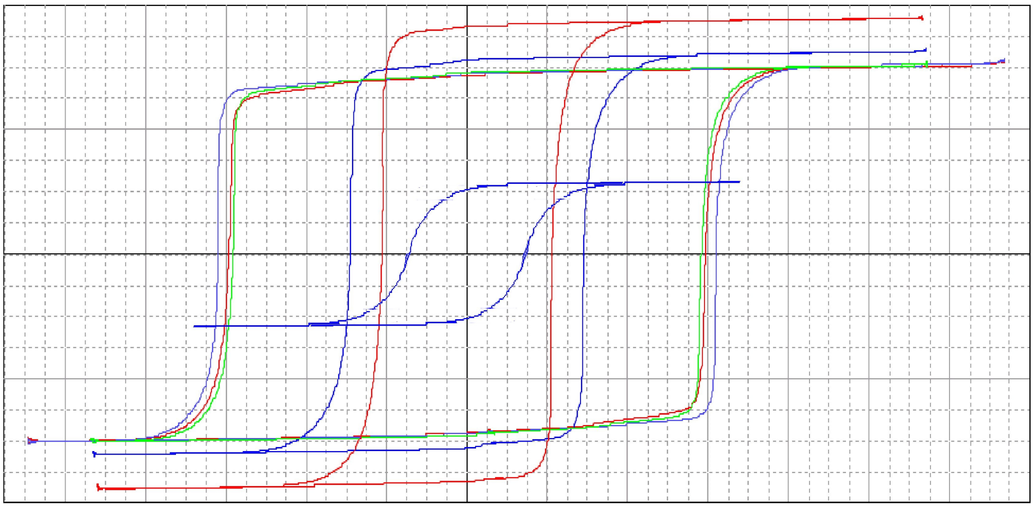

Figure 2. Characteristics of different Permanent Magnet Materials

Magnetisation

The magnetisation of magnetic materials can be effectively described using the following model. Figure 3 shows an array of natural “domains” within a magnetic material. The individual domains are magnetised, but the orientation are randomised. The net effect is an un-magnetised material. By externally applying an overall magnetic field to the material, all the “domains” become orientated in the same direction to give an overall magnetisation. If all domains are aligned in this way, the material can be considered to be saturated, as shown by figure 4.

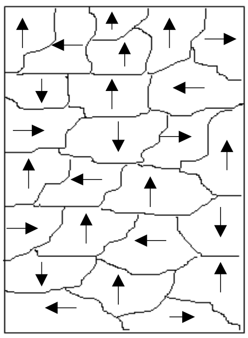

Figure 3. Un-magnetised material

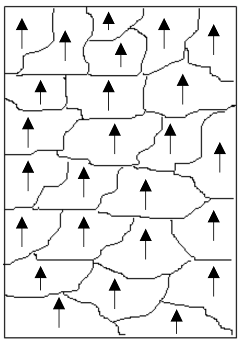

Figure *4. Magnetised material (saturated)*

If an un-magnetised magnet is subjected to an increasing magnetising filed the magnet material becomes increasingly magnetised until saturation is reached, where no further magnetisation due to the material can be achieved. The first domains to re align can be considered as the domains that are influenced by the weakest applied fields and are those that are most subject to change during the life time of the magnet.

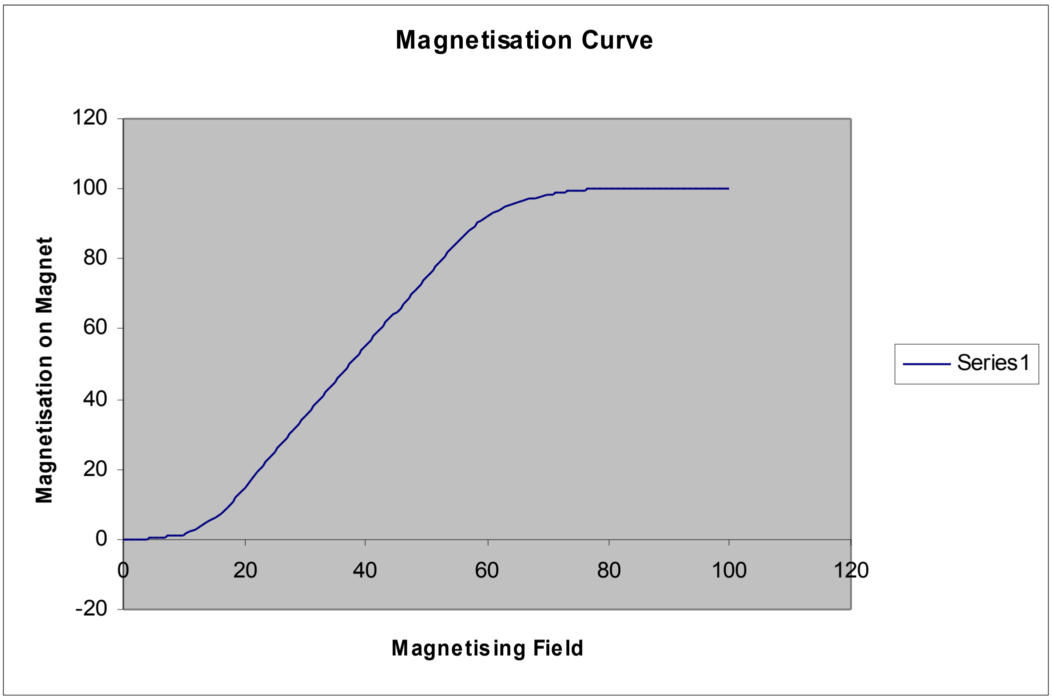

Figure 5. A magnetisation curve showing typical behavior of a permanent magnet material

<u>Magnetic calibration</u>

When calibrating a magnet, (also known as treating, setting, demagnetising and aging) the magnet has its level of magnetism reduced from its saturated state. This is achieved by “randomising” the weaker domains during the calibration process.

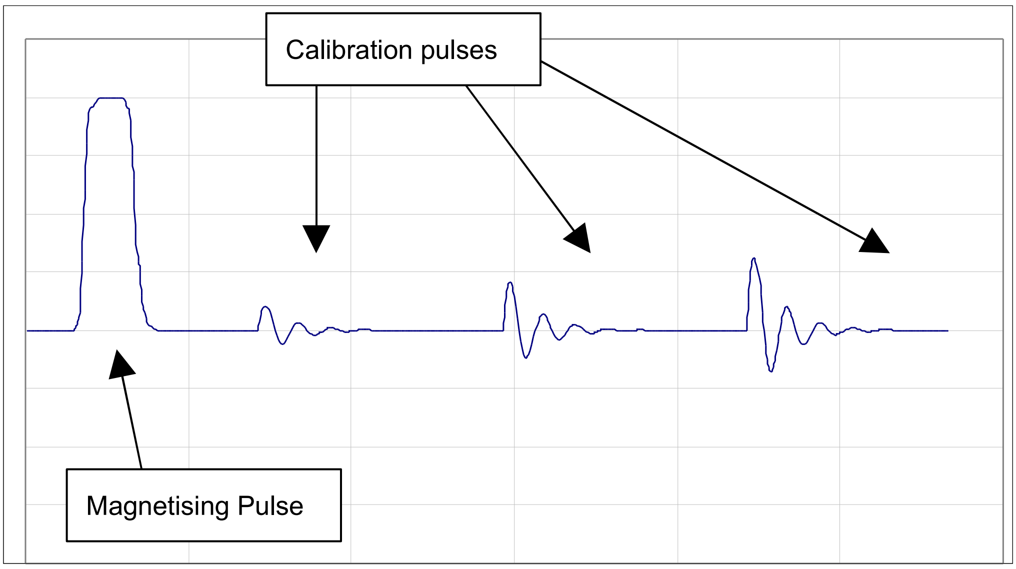

Figure 6. Magnetising and Calibration pulses (time domain)

The magnetisation process is achieved in a single pulse with a magnitude great enough to saturate the magnet (as deduced from the magnetisation curve). This will give the maximum magnetisation level which must be greater than that require for the final level. The magnet is then subjected to a sequence of calibration pulses. Each pulse will randomise the weaker domains giving an overall lower magnetic level. As the calibration field increases harder and hard domains are randomised. In a simple process the magnitude of the calibration pulse will continue to increase until the required magnetic level in the magnet is achieved.

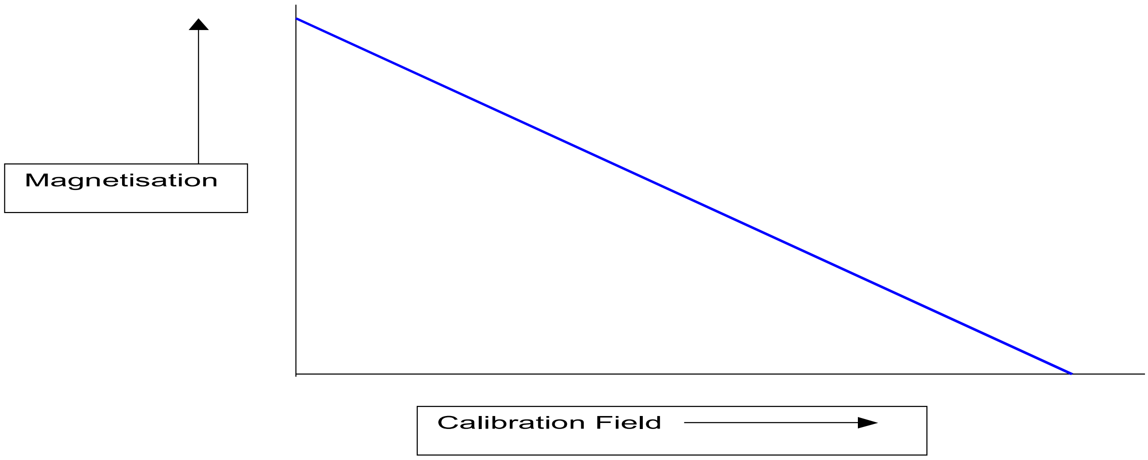

Figure 7. Calibration Curve illustrating a simple linear arrangement where the magnetic levels reduce linearly with applied field.

The relationship of the calibration fields and the resultant magnetisation of the magnet is rarely as simple as illustrated. Although the overall calibration curve characteristics will not be know accurately before magnetic calibration starts, the process can be applied as an iterative process until the required levels can be reached.

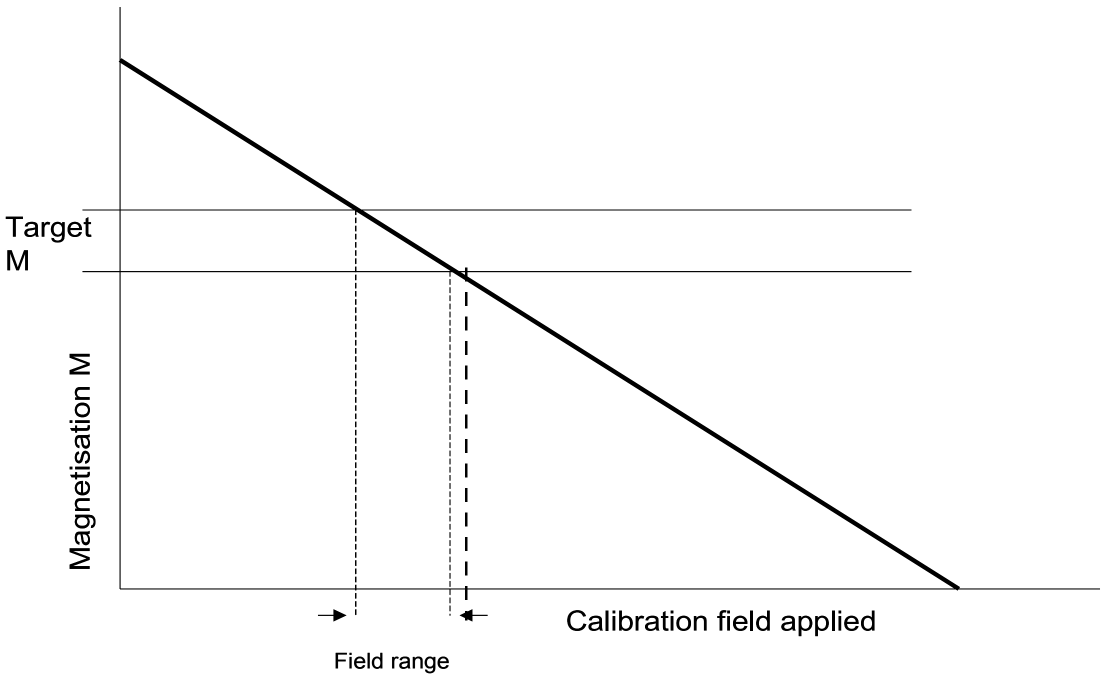

Figure 8. Demagnetisation Curve showing target calibration levels and the potential range of Calibration field.

Practical calibration

When dealing with multiple individual products the individual magnets will all have different characteristics. This means that the range of fields that will need to be applied to achieve a satisfactory calibration will be wider.

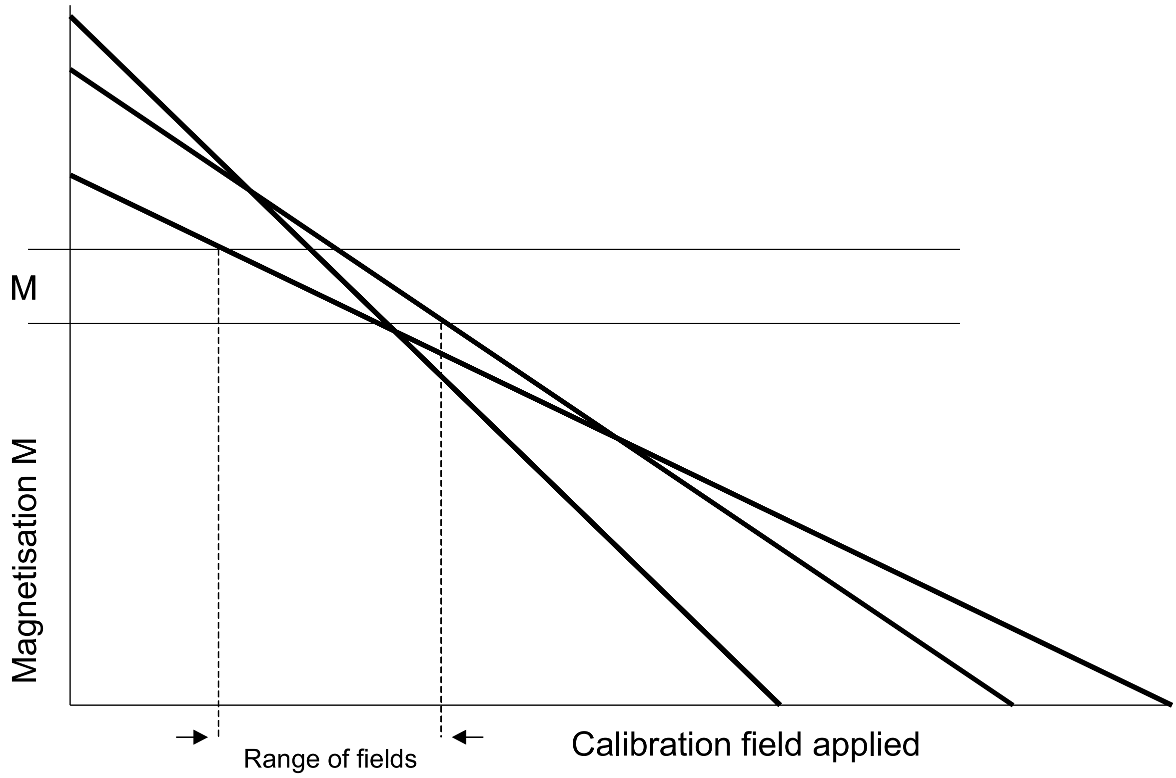

Figure 9. Multiple Calibration curves showing variation from magnet to magnet.

This variation leads to additional process time in manual systems and therefore greater manufacturing times. The typical spread of characteristics in the calibration curve is never documented on any data sheet, and is not something that is characterised by magnet manufacturers or suppliers, yet it is fundamental to many industries.

When a purchasing department is sourcing magnet material on price alone, and often from unknown manufacturing sources, this aspect of magnet quality can prove to be a costly pit fall.

Device calibration

So far, the calibration process has only been described in terms of magnetic levels. In reality few, if any, volume manufacturers of products using magnetic calibration in their manufacturing process actually measure a magnetic value. They all use the function of their product and measure its output. The output may be measured with a single quantity, or in a range of values, as in a frequency response.

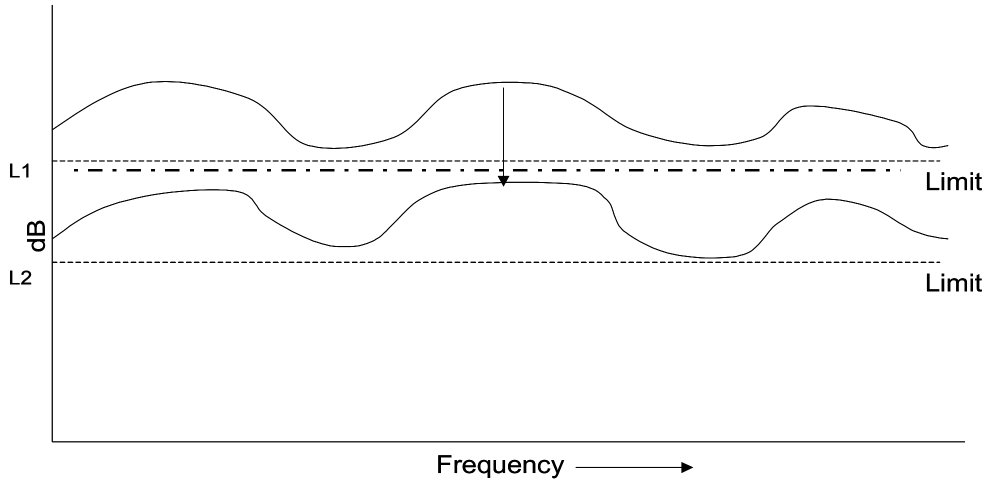

Figure 9. A frequency waveform representing the output of a magnetic, frequency based product.

The arbitrary waveform in figure 9, is calibrated into the band between the require limits. This will quite often lead to changes in the overall characteristic. A PASS/FAIL decision on the calibration becomes more complex and the consideration of more data is required. While this can and is done, a measurement of a single quantity, if possible, makes the task easier and quicker.

Calibration configuration

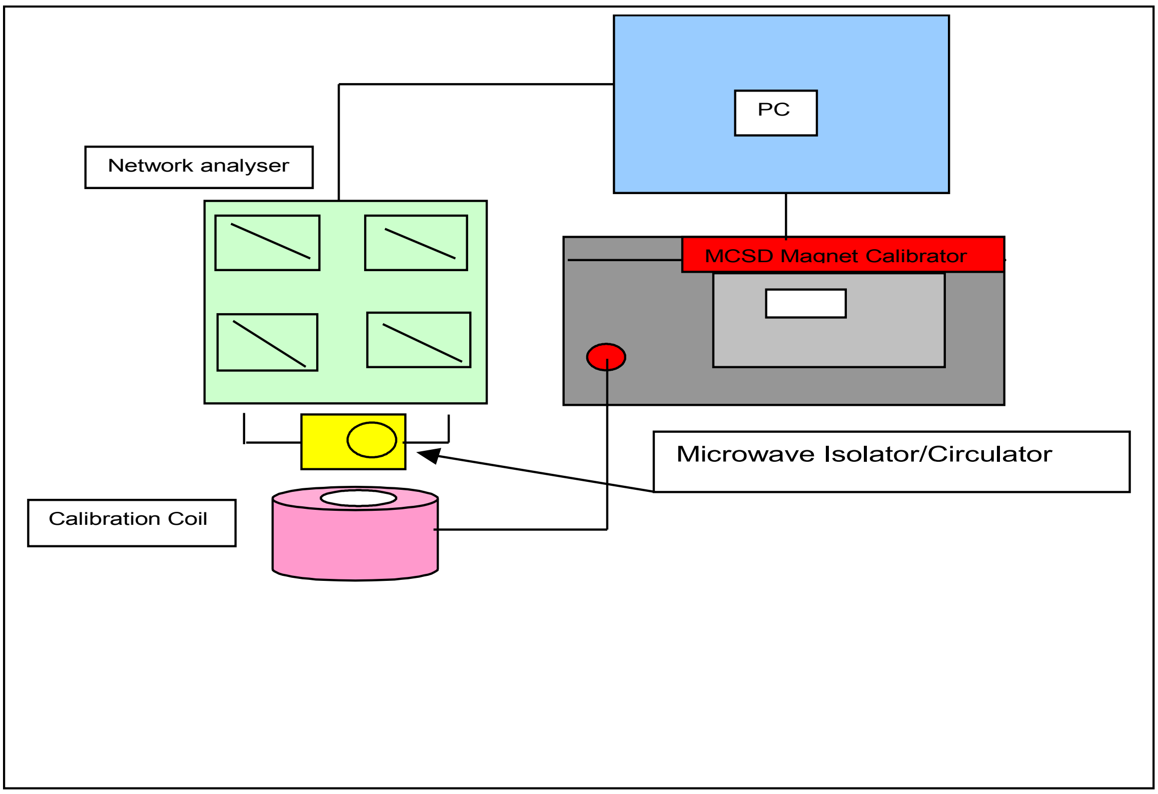

Figure 10. Illustration of a "minimal" embodiment of an automatic magnetic calibration system.

Figure 10 illustrates a "minimal" arrangement of an automatic magnetic calibration system. It consists of a network analyser and a calibration coil, as normal, however the magnetic calibrator (magnet treater, setter, demagnetiser or ager) is able to interface to the network analyser. This can be done directly, but due to the technical complexities of developing and updating software to interface between the units, a PC is often used to provide a more familiar programming platform.

Depending upon the specifics of the application, pre – magnetised, or un-magnetised microwave devices are loaded into the calibration position. Un-magnetised units are then magnetised to saturation. The operator will then initiate the calibration process and an automatic calibration will commence with the network analyser feeding data through to the MCSD unit. The iterative process will continue automatically until a satisfactory calibration has been achieved.

The results are faster and more accurate calibrations requiring lower operator skills and less training while generating a wealth of magnetic calibration data that can be supplied to a statistical process control system (SPC) for the management of the processes and components.

In some applications, the magnetic calibration process , in terms of the calibration cycle time, is only 50% of the overall cycle. Tuning processes, possibly involving "tuning paste" etc. can make up the other 50%. Under such circumstances the magnetic calibration equipment can be idle 50% of the time.

<u>Dual output system Configuration</u>

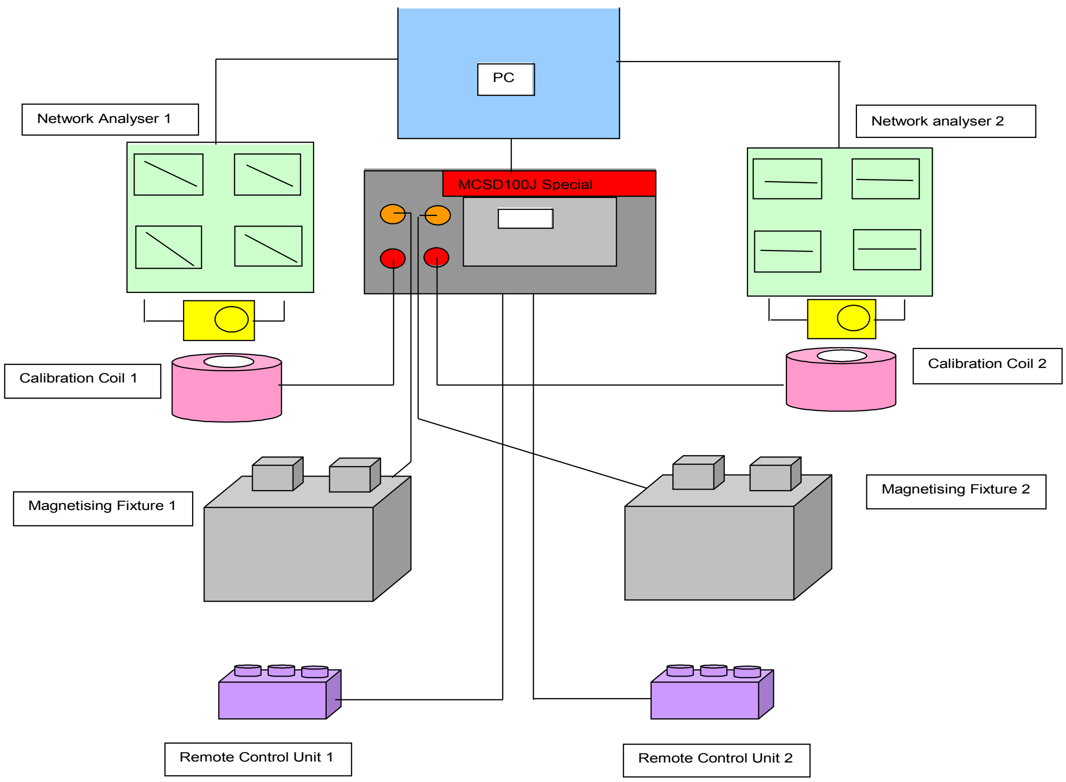

Figure 11. Illustration of a "maximal" embodiment of a dual output automatic magnetic calibration system.

The "maximal" system above illustrates an arrangement with two calibration stations working with two separate network analysers. When the operator is working on the "tuning" process on one station the equipment is magnetically calibrating on the other. The system also shows magnetising fixtures which, if required, offer a separate magnetising to saturation

Economics

A simplistic analysis of the economics of such equipment is misleading. While a manual magnetic calibration unit may be available for £3,000-£4,000, an MCSD unit (for ferrite) may cost £8000-£10,000

Results from existing customers based upon the minimal system, indicate a 20% increase in through put, with fewer failures and a significant quality improvement. These figures are for the overall cycle, including non magnetic “tuning” so that the magnetic calibration cycle can be considered to be a significant improvement ~40%

Considering the impact of this on the total investment in capital equipment at the calibration station, including network analysers (at approx £50,000 each) etc. Labour costs and overheads, the economics swing heavily in favour of the automatic calibration system.

Figure 12. Illustration of a “maximal” embodiment of a dual output automatic magnetic calibration system.