6565 DC Bias unit innovation award application

Background

Inductor test is a common requirement in today's component market. Inductors find their way into a whole range of consumer electronic products with possibly the greatest application being in switched mode power supplies. These power almost any item of domestic and industrial equipment that one would care to think of ranging from battery and mobile phone chargers, computer power supplies to really large systems for aircraft and marine use. In order to design and performance check these inductors it is necessary to subject them to a bias current within their working range to ensure that they are correctly meeting their specification. Such testing is necessary both in the design laboratory and also on the production line where the inductors are tested as part of an automated process.

Inductors for these supplies usually have an iron oxide based core material to increase the inductance value. At high magnetic flux densities these will usually begin to saturate with a corresponding reduction of inductance. This occurs when the current in the inductor is approaching its specified limit. Heating in the windings is another by-product of high operating current. This raises the winding resistance, and in turn, heats up the magnetic core. As a consequence of this, the saturation flux density reduces and with it the inductance value of the core. Inductor losses of this nature are particularly undesirable for power supply manufacturers as the system can overheat and eventually enter thermal runaway with consequential failure of the unit.

In order to save on weight, space and cost, power supply manufacturers are increasingly turning their attention towards switching at higher frequencies. The benefit is that lower value and hence smaller inductors can be used for a given power throughput. New semiconductors with faster switching speeds and also new core materials with reduced losses at high frequencies are enjoying ongoing development to help with these new requirements.

The test equipment needed to evaluate the performance of a core would typically consist of an automatic impedance analyser linked to a dc bias unit capable of supplying the maximum working current to be used in the device under test. The impedance analyser has to be able to test to at least to the maximum working frequency requirement and similarly the dc bias unit must be able to operate with the impedance analyser under these conditions.

To date, bias units available on the market hit a frequency limit typically in the region of about 3 MHz. This is because of the difficulties in providing a suitable high Bias current source that is capable of operating with the impedance analyser at high frequency. The problems are not restricted to the bias current alone because the component fixture and cabling also have to be taken into account too.

The Wayne Kerr 6500 series of impedance analysers has been available on the market for about 6 years now. It can make impedance measurements over a wide frequency range from 20Hz to 120MHz. The purpose of the 6565 design was to make a suitable bias unit capable of testing up to 40A and up to the full 120MHz bandwidth of the 6500. This should fill a gap in the test equipment market that is anticipated to grow year by year in line with the requirements of inductor testing.

Innovative aspects of the 6565

The 6565 has been developed for use with the Wayne Kerr 6500 Impedance Analyser. The 6500 on its own can be used to measure passive component values in the frequency range from 20Hz to 120MHz. The 6565 dc bias unit can supply up to 10A of current to an inductor under test while the 6500 is measuring the component value. Furthermore, up to 4 bias units may be connected together to provide a maximum current of 40A and operate up to 120MHz.

This may not seem a necessarily a difficult task at first sight, but high current semiconductors invariably exhibit high associated stray junction capacitance, slow switching speed and often low output impedance over a broadband range. This creates significant RF problems in isolating the tiny measuring signals of the impedance analyser from the loading effects associated with applying a large dc bias current. Not only must any capacitative or resistive loading be kept small, but it must also be kept as constant as possible for a very wide range of different bias currents. Failure to do this limits the accuracy of the impedance analyser and any resulting measurements. To date there is no known bias unit that is capable of operating up to this high frequency and with this high level of current output (120MHz up to 40A with 4 off 6565 units).

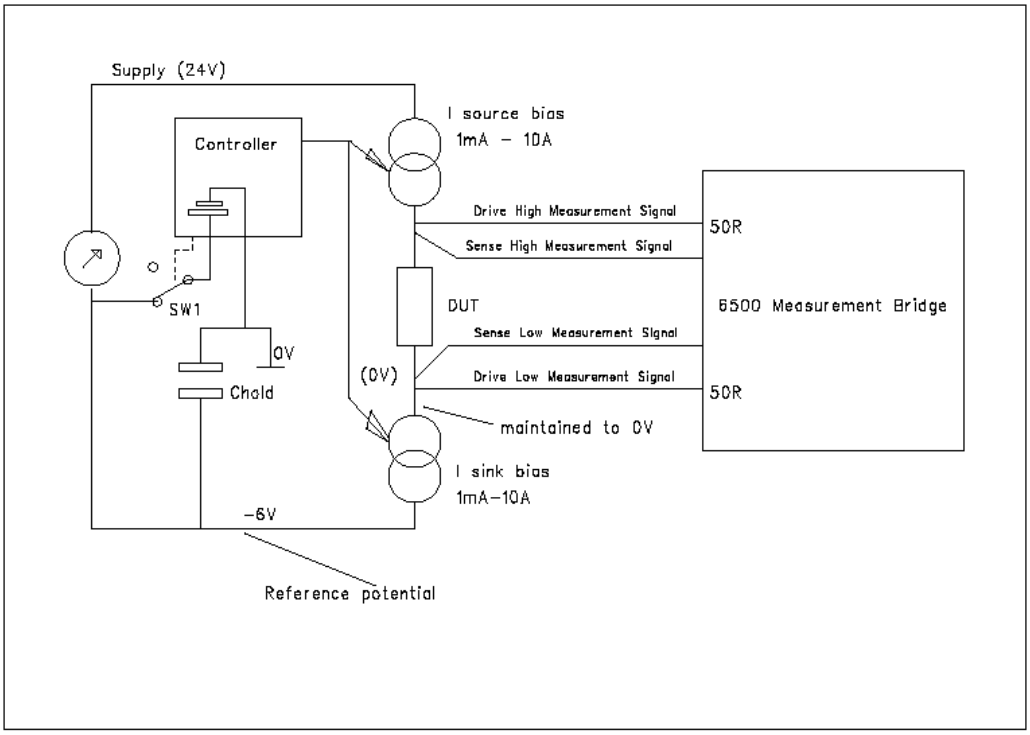


Fig. 1 **Showing a prior art design current bias unit operating with an impedance measurement bridge.**

Referring to fig1, this shows a typical bias unit made to a prior art design. It consists of two opposing current sources set to the same current value by the controller unit. These supply the bias current through the Device Under Test (DUT). A large capacitor, Chold forms a reservoir to hold about 6V for the working voltage of the sink circuitry. When the bias is off, this potential is maintained by a control circuit via SW1. When the bias is active, this voltage is maintained by differential control of the two current sources. The Impedance Analyser (6500) will then measure the value of the DUT at the set bias current.

In fig 2 we see that the bias current sources are not perfect but instead have significant stray capacitances Cx and Cy associated with them. Each can be of the order of 10,000pF. These capacitances are highly undesirable as they both shunt and cross-couple signal currents across the bridge network of the Impedance Analyser via the 24V supply. Since the 24V supply can be considered as an ac signal short circuit, if we perform a T to Π transformation as in Fig3 we can see that there are 3 impedances formed, Z1, Z2 and Z3. Z2 is particularly unwelcome because it appears in parallel with the DUT. Furthermore, these impedances can also be highly variable with bias current and hence make them impossible to trim out effectively.

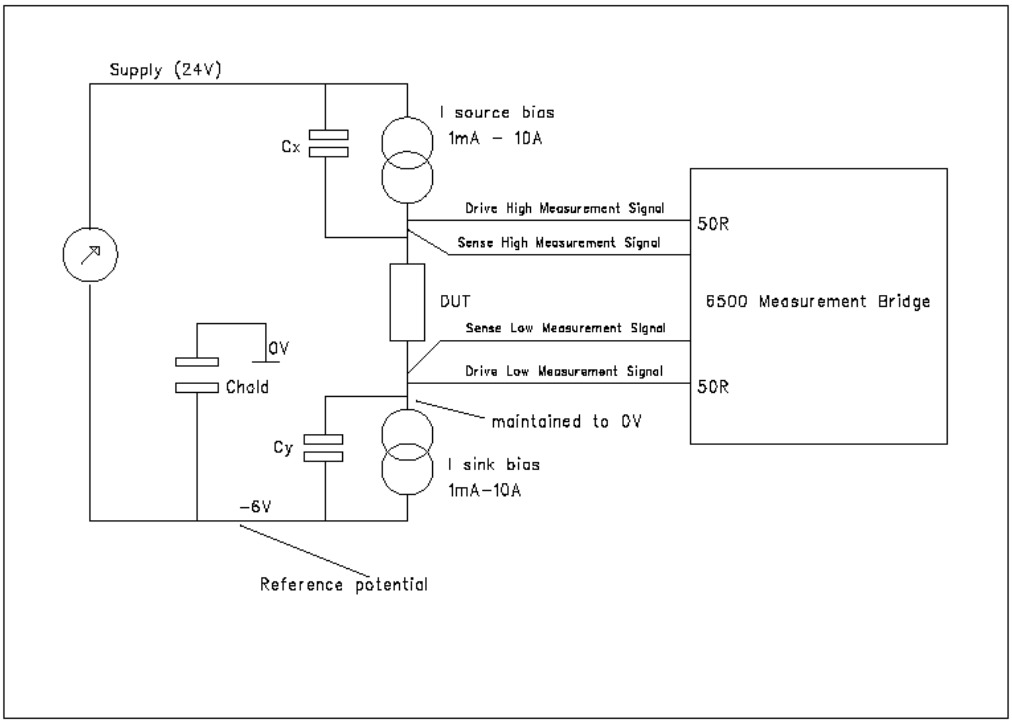


Fig. 2 Showing the same prior art design with stray capacitances Cx and Cy added.

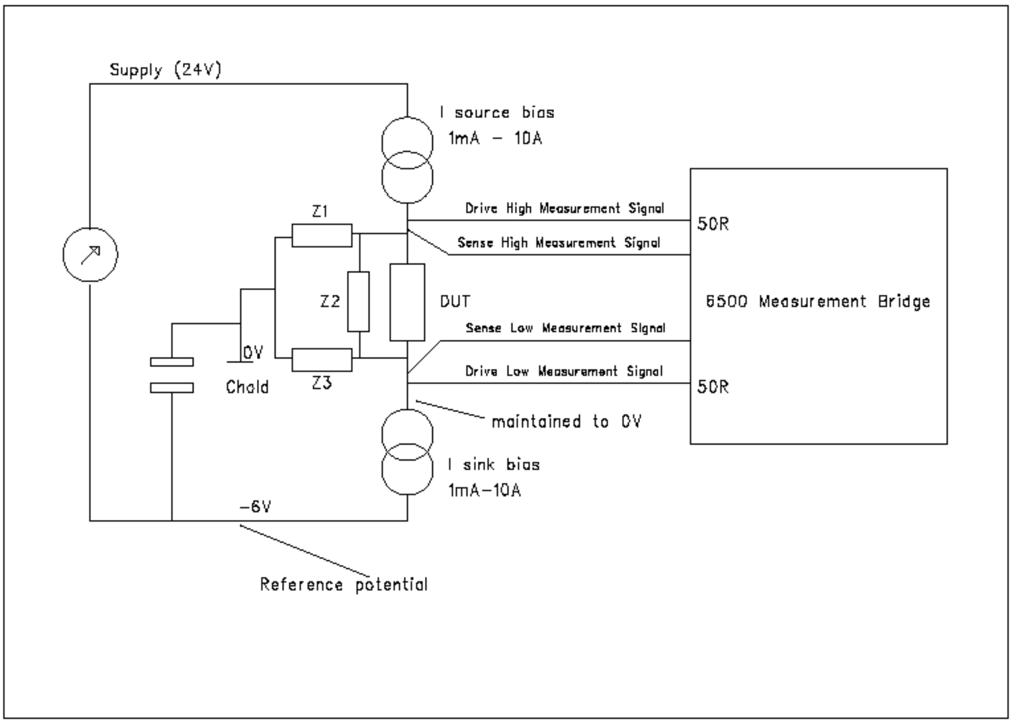
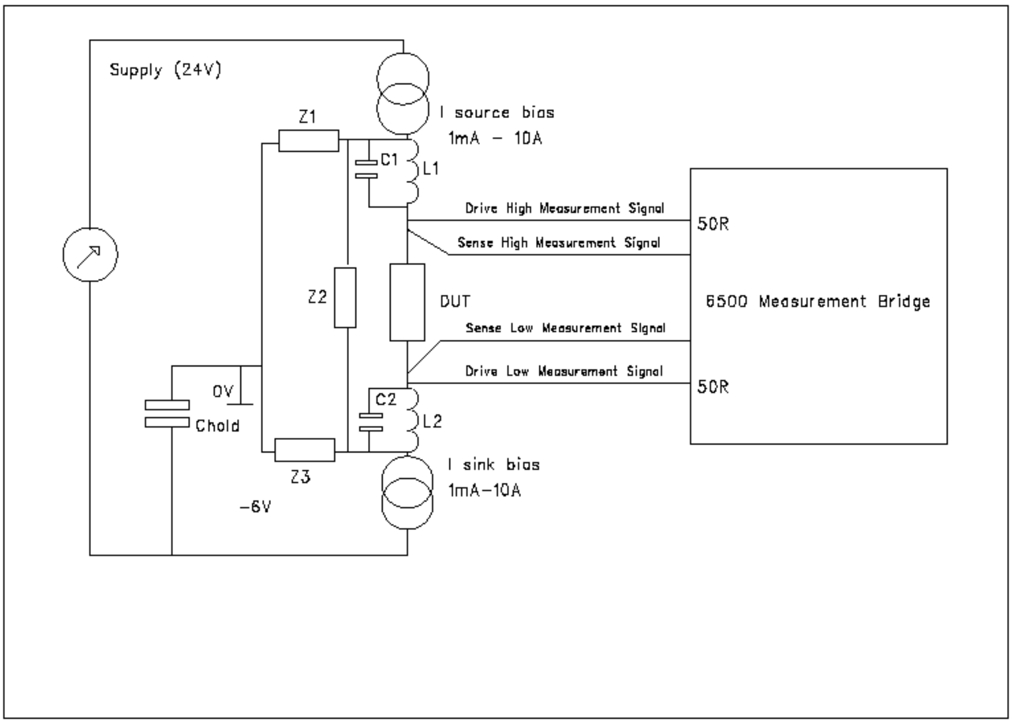


Fig. 3 Illustrates how the same capacitances Cx and Cy form Pi impedance across the DUT.

A method of avoiding this problem used in prior art designs was to employ the use of tuned circuits as shown in Fig 4. Here, L1, C1 and L2, C2 are arranged to give relatively high impedances at the frequency of test by tracking the test frequency used by the measurement bridge circuitry. This can be accomplished by switching in and out different inductors and capacitors in order to cover the necessary range of frequencies. There are several major problems with this technique. To provide coverage for



the mid-frequencies, the inductors need to have a modestly large value, say, 500uH. In order to carry the full bias current these coils and their cores must be physically large to avoid saturation effects and

Fig. 4 Showing the additional elements L1+C1 and L2+C2 to tune out the loading effects of Z1-Z3

in practice become quite heavy too. The method also necessitates high current switching and hence power relays of considerable current carrying capacity are needed. A further problem occurs at lower frequencies, well into the audio region where the LC resonance technique provides little or no benefit, but where the capacitance and other losses related to the current sources are still appreciable. This commonly occurs around 10KHz where the employment of a suitable inductor is impractical. What happens is that the losses create significant shunt impedances at the impedance analyser ports and various compensation techniques have to be employed to offset the errors these create. Likewise at the other end of the spectrum, large bulky chokes and high current relays are not suitable to isolate against high frequency RF signals.

A new approach

Clearly in order to buffer the bias circuitry from loading the sensitive high frequency circuits in the measurement engine a new method is necessary. It was a design objective that the new bias unit should be capable of operating up to the full bandwidth of the 6500 i.e. 120MHz and if possible to allow up to 40A of current to be available too. In the new design, the large high value inductors used in the prior art design have been replaced by much smaller values. This is achievable by the use of bootstrap techniques that minimise the loading on the external circuitry. The bootstrap signal approach gives coverage down to very low frequencies at one end of the spectrum and only starts to fall off at the very upper frequencies where the loading effects on the amplifiers becomes excessive. To this end only small, high frequency inductor values are then needed to buffer off the load and so the power loss and physical size is quite minimal. Fig 5 shows one of the new design current sources compared in size with the large inductor needed for the prior art design.

It was found in practice that the technique was highly effective and that now the worst part of the loading capacitance was presented not by the 6565's, themselves, but by the cabling connecting the 6565 units together. The cabling needs to be coaxial to shield the system from stray RF radiation and, at the same time, also needs to carry the high current for the bias. In Fig 6 is shown the performance of a damped series coil arrangement of 3 coils. Their values are chosen so that the resonant frequencies form an optimally flat band of phase and magnitude from about 10MHz upwards. When fitted inside the fixture this isolates the RF measuring terminals from the bias ports and thus decreases the loss effects due to the 6565 cabling.

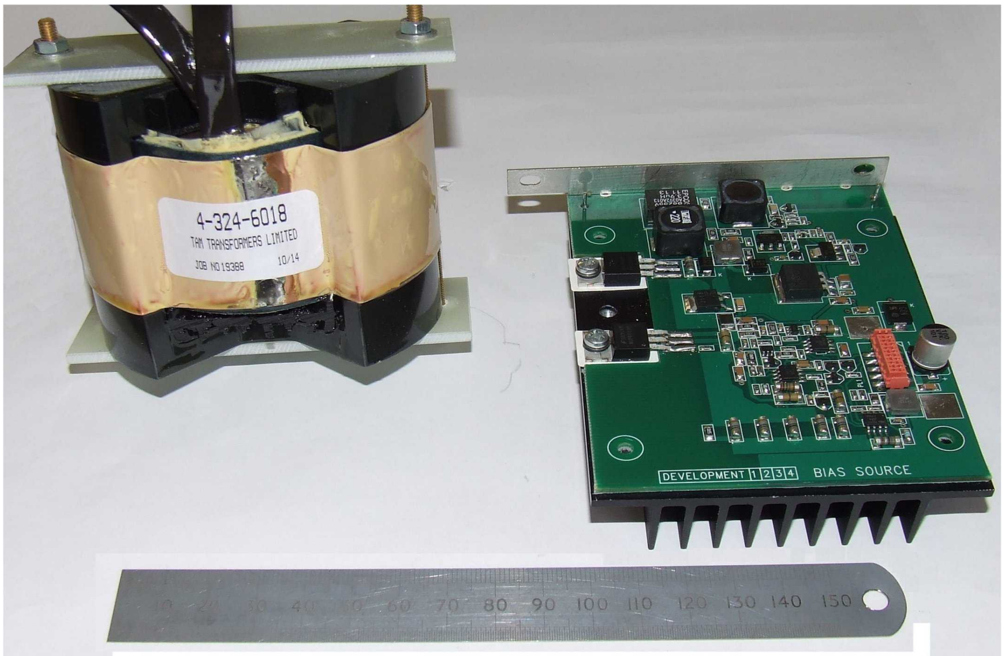


Fig 5 **Showing a large series coil used in the prior art design compared with a current source of the new design complete with bootstrap circuitry and series output coils.**

Fig. 6 Showing a 3 coil combination that achieves an impedance exceeding 500 ohms from 2 MHz to 120 MHz. Note that from 10 MHz upwards the choice of coils arranges the Z response to be optimally flat.

Cool n' Light

It can be quite likely that the device under test has a significant series resistance. Therefore the current sources in the bias unit need to be able to work with as much of this voltage drop as possible. Conversely, when dealing with a small, high current, inductor that drops very little voltage under bias the current source has to absorb the entire voltage reservoir needed for the previous situation. Normally when operating at maximum current, the bias unit can get quite hot since this voltage and hence power must be dissipated inside the unit. For example, if the bias compliance voltage is 10V and the maximum current is 10A then 100W is dissipated across the device under test and the bias unit runs relatively cool. If, however, the DUT only exhibits a few milliohms impedance then the full100W gets dissipated inside the bias unit, plus any further power due to minimum working voltages that must be allowed across the components in the two main current sources. This power must be got rid of somehow and the only way out is to use a combination of large heatsinks and fans to do it. Together with the large series inductors described previously this all add weight to the instrument.

A further disadvantage by allowing the current sources to stand the full range of voltage and current is that it puts heavy demands on the design of the current sources themselves since the accuracy of the system depends on their linearity.

In the 6565 a different type of power supply has been employed which allows the power output of the unit to track the voltage across the DUT. This means that the 6565 only dissipates the power actually needed to keep the current sources active and that the power dissipation remains unchanged whatever the dc resistance of the DUT is. As a result, the lost power is kept much lower than in prior art designs, and since the voltage across the working devices is kept constant then the variations resulting from the strays are minimised too. All of this ensures for a much lighter instrument that is cooler and needs lower fan power and less heatsinking to keep the internal ambient temperature within limits.

Inductors that misbehave

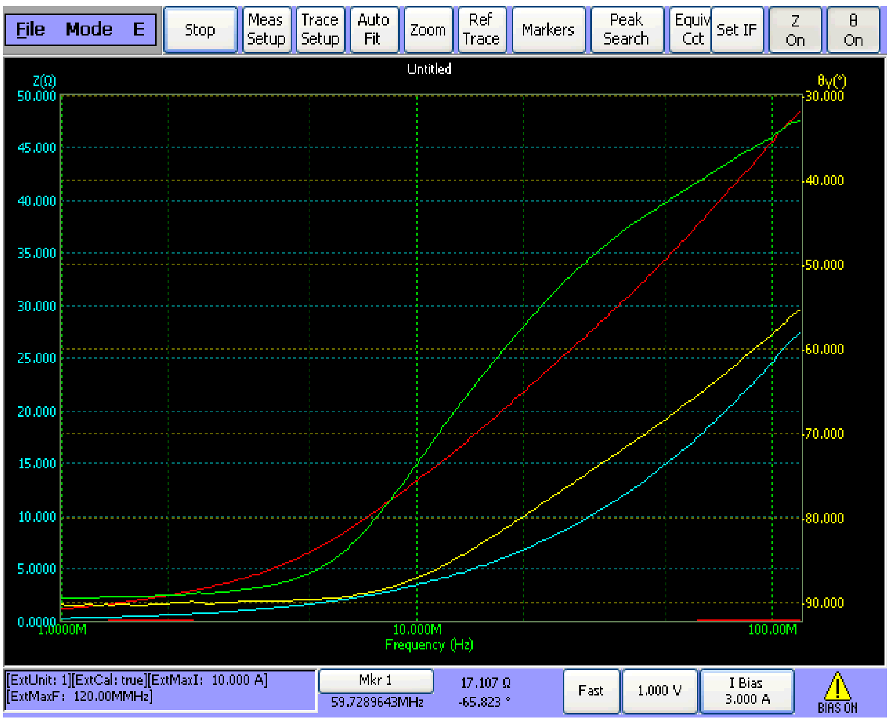


Fig. 7 Showing the impedance of a ferrite bead. The phase response behaves similarly where the green trace is with bias off and amber trace with bias on. The red trace shows performance at zero bias while the blue trace shows the impedance at 3A bias current.

Inductors are used in many applications, and ferrite beads are also very common elements. There is a common perspective that they will provide a known impedance according to the specification at a given frequency. In Fig 7 are shown the results of testing a small ferrite bead at first zero current and then with 3A flowing. As can be seen the impedance drops dramatically when current is applied. Furthermore, the phase response is similarly variable and this can adversely affect the stability of circuits where these have been used as suppression devices.

In Fig.8 is shown a 2.2uH high frequency inductor with the self-resonant frequency measured at 58MHz. The device is rated at 10A and the red trace shows the zero bias current plot up to 20MHz. The blue trace shows what happens to the inductance when a 10A bias current is applied, indicating an approximately 5% reduction in the inductance value. As the current is further increased in the inductor, the Isat limit is reached where some inductor manufacturers specify this drop as 10% and others as 20%. This corresponds to a point where the magnetic domains are becoming fully in alignment and the magnetic flux density is near the top or bottom end of the B-H curve.

The same coil is examined in Fig.9 where two sets of trace plots are presented for no bias and then 10A bias. Initially the self-resonant frequency of the coil is shown to be about 58MHz and the peak dynamic impedance as about 4.8 KΩ. After application of 10A bias, the dynamic impedance has dropped to 4.06K as the cursor shows. The self-resonant frequency has also increased. Both of these are consistent with the loss of inductance under bias mentioned earlier and the consequent change of Q.

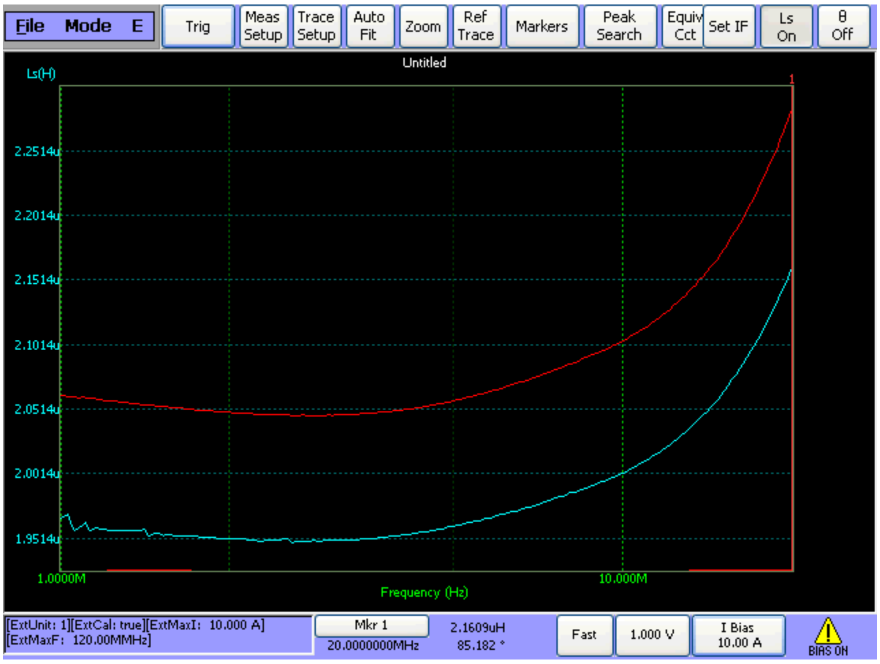


Fig. 8 Showing how a 2.2uH ferrite core rated at 10A behaves with bias. The red trace shows the original coil inductance variation between 1MHz and 20MHz. The blue trace shows the 5% inductance reduction at the rated current.

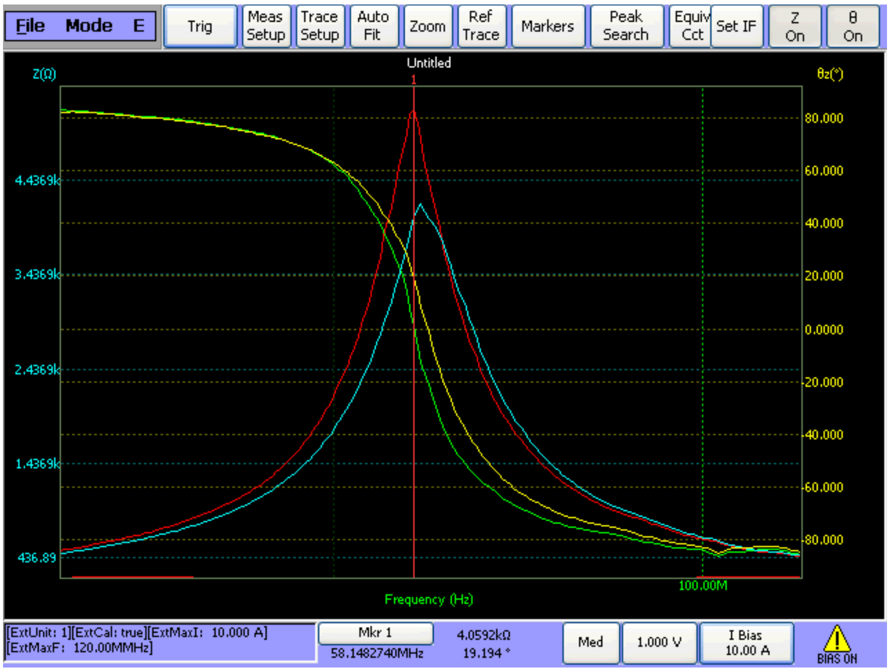


Fig.9 **Showing the same 2.2uH coil at resonance (approx 58 MHz). The red trace shows the magnitude (Z) response, while the green trace shows the phase. The blue and amber traces show how the coil behaves with 10A applied. Note that the resonant frequency has increased and the Q-factor has reduced.**

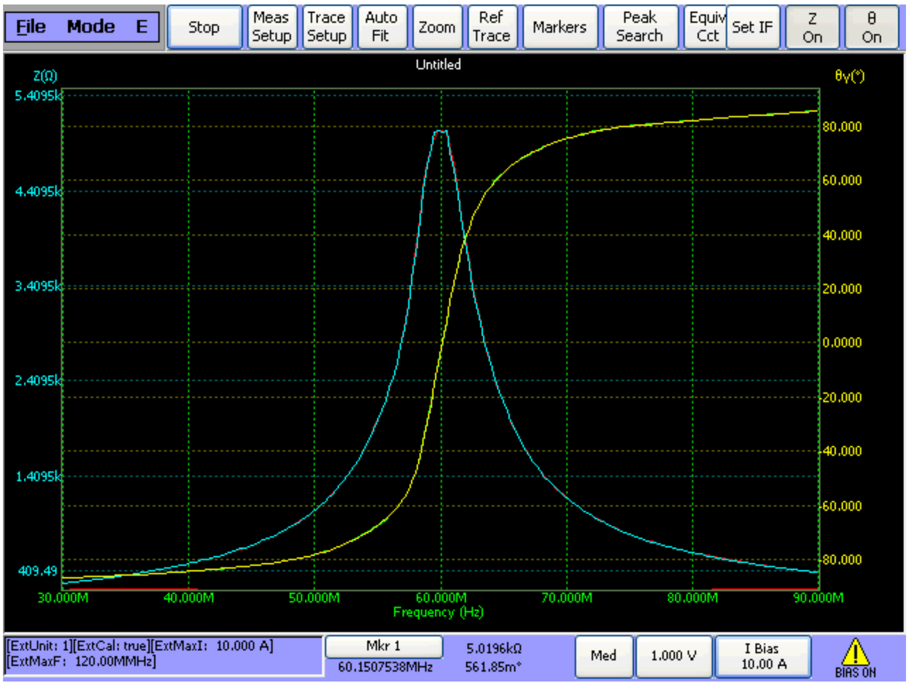


Fig. 10 **This screenshot shows and air-cored coil of similar value with the bias on plot compared to bias off. As can be seen the two sets of plots are very closely aligned.**

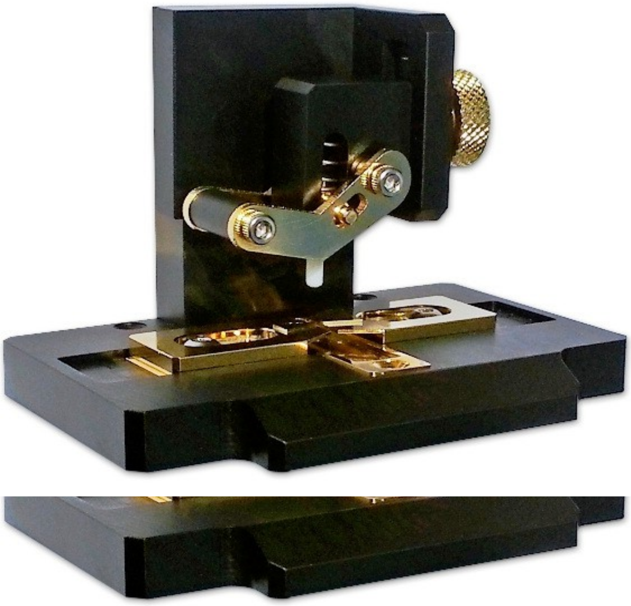
By using an air-cored coil where the parameters are not current dependent we can see that the impedance and phase plots of Fig 10 are very closely aligned. This adds proof for the case in Fig 9 that the inductor value is indeed changing its characteristics and that the effect is not simply due to a change in the measurement system. In Fig 10 Only very small changes are visible, possibly due to local heating effects in wiring of the test coil itself when the current is applied.

6565 10 Amp Bias Unit

Conclusions

The new design of the 6565 demonstrates that high current bias units can be mated up with high frequency impedance analysers without significantly compromising their performance. This opens up a whole new range of possibilities for inductor manufacturers who wish to specify their components in the high frequency zone above about 3MHz. Furthermore, voltage compliance and lost power in the new design of bias unit has become less of an issue since the power lost in the bias circuitry is maintained at a minimum value for any given bias current. A new design of fixture unit (1026 or 1027) allows up to 4 bias units to be connected to give a combined output of up to 40A and still obtain the full 120MHz bandwidth from the 6500 measurement bridge. With the inclusion of the 1031 surface mount adaptor a very wide range of sizes of surface-mounted components can also be tested up to the full specification.

6565's in 40A combination with 1027 fixture and 65120B Impedance Analyser



1031 Adaptor for Surface Mounted Components for use with 1027 fixture