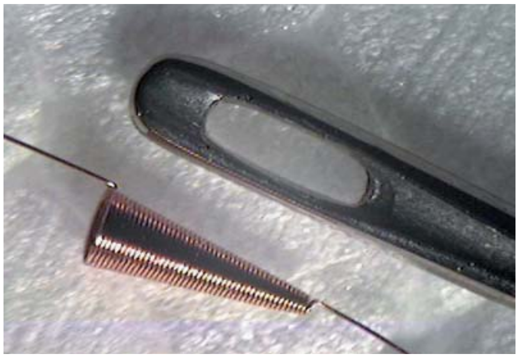

A BROADBAND MICROWAVE CHOKE

All microwave devices that use DC power must have a method for preventing the microwave energy from entering the power supply. It is common practice to connect a microwave choke between the active microwave device and the power supply to prevent microwave energy from shorting out through the power supply. The power supply is microwave isolated from the microstrip circuit, and the DC power is typically blocked using a capacitor. This geometry is commonly known as a bias tee. The circuit is used in almost every microwave device as well as fiber-optic terminators.

The optimum device for this application would permit the use of a single component for virtually all applications. Unfortunately, microwave chokes typically operate in very narrow frequency ranges. They must exhibit high impedance at microwave frequencies but have low DC impedance. A broader band of microwave frequencies is often processed by the active device compared to the electrical characteristics of the choke. Thus, it is common for series resonances in the critical frequency range to degrade performance. It is highly desirable (but extremely difficult) to eliminate these series resonances in the desired microwave band. It is a simple matter to design a choke with series resonances outside of a narrow band of frequencies. However, when the band is widened, the task becomes more difficult.

Stray capacitance is the primary problem with high frequency chokes because it reduces the inductor's self-resonant frequency. Basically, there are two places where stray capacitance can be found. One possibility is between the individual turns of an inductor; the other is between the device and a ground plane. There are usually many self-resonances in an inductor. Series self-resonances appear as a short circuit across the active device and are the most undesirable. The most critical parameter is the lowest series self-resonance, which is generally referred to as the self-resonance. Small, conventionally designed, low value chokes may have up to 15 GHz as the lowest self-resonance but only an acceptable high impedance bandwidth of 5 to 10 GHz. The impedance is highly dependent upon frequency, therefore, any single device is generally only useful in a narrow frequency band.

There are many approaches to getting DC power into a microwave device. All of these approaches employ the general construction known as the bias tee. This configuration uses a choke as a high impedance to the operating frequency but very low impedance to the DC power source. The choke can be constructed in many different ways. One method is to use a ferrite toroid core with fine wire wound

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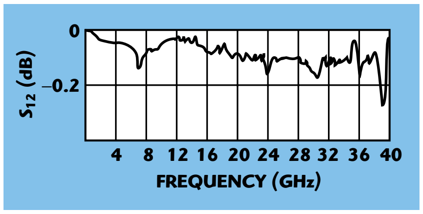
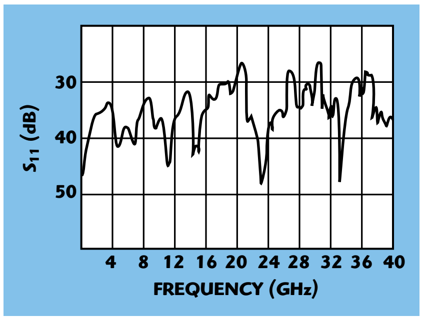


▲ *Fig. 1 Reverse transmission of a 110-turn conical choke.*

Fig. 2 Forward reflection of a 110-turn conical choke. ▼



around one-half of the toroid. This device has relatively high inductance and is adequate for many low frequency applications up to 3 GHz. Another approach is to use a small air-core choke (outside diameter is typically 0.020") with two to 100 turns. These devices have low inductance but are adequate in a narrow bandwidth. A third approach is to use a small inductor with a magnetic core. These devices can be made with diameters of 0.020" to 0.040" and have larger inductance, but operate at considerably lower frequencies.

The most common microwave chokes typically are small air-core inductors that have an outside diameter of 0.020" with five to 100 turns depending on the selected operating frequency range. These devices use very fine wire and have relatively low stray capacitance to a ground plane because of their small physical size. However, because these chokes have a relatively narrow bandwidth, an entire family of them is required to cover the usual frequency range.

Many approaches to increase the bandwidth have been tried with little success. Broadband bias coils can be made with two or more coils in series. The first coil is smaller to provide high frequency isolation. The subsequent coils are progressively larger to provide lower frequency isolation. This approach causes abrupt changes in characteristics, which in turn cause impedance anomalies in the S parameters. In addition, the approach may be unusable in frequency-sensitive systems because of instability in the electrical parameters.

Another approach to increase bandwidth is to use resistance wire for the inductor. However, the resistance wire is extremely difficult to wind and handle. The material is also incompatible with bonding techniques commonly used in microelectronic devices. In addition, the choke cannot handle as much power since it generates considerable heat if power is applied to it.

A third approach is to use a resistor in parallel with the choke. The problem with this design is that it dissipates considerable power and generates heat. Also, additional stray capacity associated with the resistor decreases the self-resonant frequency. None of these approaches yields the wide bandwidth needed for many applications.

A NEW DESIGN

A new and different RF choke design permits extremely broadband performance with few apparent series resonances. One choke can cover the frequency range of 10 MHz to 40 GHz. This inductor design uses special refinements on a conical geometry.

Conical geometry is known to broaden bandwidth but does not normally provide substantial improvement. The shape allows relatively low stray capacitance at the small high potential end. The diameter of the turns increases toward the larger low potential end, but the increased stray capacity is less detrimental for generating series resonances. Stray capacitance has less effect near the low RF potential end of the choke.

It was determined that a few modifications to the old conical air-core inductor design drastically improve the performance of the device. The first change is to fill the inductor with powdered iron. This material is not easily saturated and has lower permeability than ferrite. The magnetic filler must eliminate all air between the wire inside the conical structure. The intimate contact provides a maximum increase in permeability from the magnetic material. The powdered iron is typically mixed into a very low viscosity epoxy, allowing the magnetic material to be inserted in a liquid state into the core. The mixture contains very little epoxy so that maximum permeability is obtained from the magnetic material. The small percentage of epoxy used results in a high viscosity mixture that changes with temperature and time and is extremely difficult to handle.

The second modification permits a connection to the small end of the cone end with virtually zero lead length. Any extra wire in this location seriously degrades the electrical properties. The wire insulation is removed in advance by selectively stripping and plating, thus allowing the stripped portion to start one-quarter of a turn into the small end of the winding. The device then may be bonded with effectively zero lead length at this end. The other end is also selectively stripped and either gold or tin plated to permit soldering, welding or thermosonic bonding.

This new design has an extremely broadband characteristic, which was not previously considered possible to achieve. The typical S_{12} frequency response is relatively flat within one-half decibel from 10 MHz to 40 GHz, as shown in ***Figure 1***. There are very small deviations from a flat frequency characteristic over the entire microwave frequency range up to 40 GHz. ***Figure 2*** shows the choke's S_{11} return loss vs. frequency. The device eliminates the need for a large variety of different narrowband chokes to perform DC isolation. It is now possible to standardize on one choke for most applications.

Several different conical designs have been implemented to cover various microwave choke requirements. The best electrical characteristics are obtained from 110 turns of No. 47 wire. This device has an inductance of 10 µH and nearly flat characteristics out to 40 GHz. When space is at a premium, a 45-turn, 1 µH choke can be used. The electrical characteristics are somewhat poorer than the 110-turn device but still superior to other approaches. The volume of this device is approximately one-fourth that of the 110-turn device. However, the device's tiny size makes it considerably more difficult to make.

The 110- and 47-turn devices work at 200 mA CW and higher at pulse power levels. When more power is required, a larger wire may be used.

A 75-turn device of No. 36 wire will handle up to 600 mA CW, but the larger wire makes the device approximately four-times larger in volume than the 110-turn device and the frequency range is limited to 6 GHz. This device has an inductance of approximately 6 μH.

In order to produce the new chokes, several pieces of sophisticated machinery had to be designed. A selective wire stripping machine capable of stripping and plating ultrafine wire of 0.001" diameter without breaking or stretching was developed. This machine can plate either gold or tin to required lengths with an accuracy of ±0.001" regardless of the total length. In addition, the gold-plating quality and thickness are adequate for all gold-bonding methods used for bonding gold wires to substrates. The leads may be tin plated as required for soldering leads, however, the gold plating is compatible with soldering. Since the wire is not tinned with solder flux or stripped with chemicals, there is no contamination on the wire. The selective plating machine washes the wire with deionized water between each process and after the wire is plated. This procedure produces a major improvement in the wire. Previously, all microwave chokes used a stripping procedure, which left contamination on the wire. Also, since the machine is so accurate, chokes are wound from a spool of prestripped and plated wire, which guarantees absolute uniformity regarding the start of the stripped area on the coil. This uniformity is critical in all microwave applications. Most often, the chokes are inserted with a lead length that is as close to zero as possible on at least one end. Contamination in the transition area may cause unreliable bonding to occur.

A special epoxy filling machine is required to provide precision filling of the coil with epoxy. A controlled fill with accurate temperature, viscosity, time and pressure provides precision filling of the coil. Excessive or inadequate material degrades the performance. The small operating window for all parameters is met only by close tolerance automatic control of all parameters. Voids from air bubbles in the small end will seriously degrade the performance of the inductors. Therefore, it is essential to perform the entire filling process in a vacuum chamber. Any magnetic material protruding from the ends of the device seriously degrades the performance of the device, thus, the magnetic material must be inserted under very controlled conditions.

A completely new winding machine was necessary to yield the precision winding and tensioning of the conical inductor and provide extreme precision of the lead position with respect to the windings. The winding must be done under precision-controlled tension to achieve good mechanical contact between turns. The dimensions of the small diameter end are extremely critical if the proper high frequency characteristics are to be achieved.

MEASUREMENT PROBLEMS

The equipment most commonly used to measure the inductor's electrical characteristics is the vector network analyzer (VNA). The measurement procedure is so critical that two identical pieces of test equipment generally will not produce the same results. This measurement variation is due to the fact that there are so many different calibration procedures that may be used. In addition, fixturing is extremely critical. When working under 20 GHz, measurement results are typically close enough to show the differences between this device and previously available devices.

INSTALLATION PROBLEMS

The components will have drastically different electrical characteristics depending upon their exact placement on a stripline during installation. The small end should be bonded to the exact center of the microstrip line to obtain optimum performance. The lead length from the first turn to the microstrip line should be a maximum of 0.005", however, shorter is better. The first turn should be spaced 0.001" from the surface of the microstrip line. The large end should be spaced approximately two diameters or more away from the surface of the microstrip line. The entire device should be at right angles to the center conductor of the microstrip so that the ends of the strip are symmetrically referenced to the position of the inductor. If the device is not centered, S_{11} will not equal S_{22} and S_{12} will not equal S_{21}. Mechanical support may be achieved with a special low dielectric microwave epoxy attached only to the last few turns of the large end and to the surface of the microstrip.

The slightest deviation in construction or assembly will noticeably change the field pattern of the device and the response characteristics. If these coils are measured using conventional methods on an impedance analyzer, they will have a relatively low self-resonant frequency. The devices are designed to be installed on a microstrip and interact with the field of the microstrip to produce the required flat response. Circuit geometry is extremely critical for this component to work properly. Additional information may be obtained from the company's Web site at www.piconics.com.

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