TECHNICAL INFORMATION

THE ACCU-L MULTI-LAYER INDUCTOR FOR HIGH FREQUENCY APPLICATIONS

by Barry N. Breen, Chaim Goldberger
and Leonid Talalaevsky

AVX Israel Ltd
P.O.B. 23383, Jerusalem 91233, Israel

Abstract:

The telecommunications industry today is undergoing changes. The miniaturization of electronic circuits and the use of higher frequencies in radio communication systems such as Cellular Telephones, PCN and GPS places new demands on passive components. High frequency inductors have not kept pace with the demands. AVX has responded to these requirements by putting to market a miniature (0805) high frequency SMD inductor based on thin film technology.

This article presents the basic concepts of high frequency inductors and how such low value inductors are measured and characterized. Here, too, there is a lag between the high frequency designer's need for ever tighter tolerance parts and the ability of off-the-shelf test equipment to provide high accuracy measurement.

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The miniaturization of electronic circuits and the use of higher frequencies in radio communication systems such as Cellular Telephones, PCN, GPS, etc., has created a need for an improved SMD inductor chip for high frequency applications.

The AVX SMD coil, designated ACCU-L, has been developed using thin film technology (see Fig. 1). This technology makes it possible to achieve a small and true SMD coil chip (no wound wire) with high Q and high SRF. The inductor is available in size 0805 (2x1.5x0.9mm).

Introduction

The telecommunications industry today is undergoing changes. The major industry trends, particularly in cellular telephone, are: equipment designed for higher operating frequencies and the use of miniature surface mount devices (SMD). Typical sizes for passive SMD components are 1206 (3.0x1.6mm) and 0805 (2.0x1.3mm). The operating frequencies for cellular telephone is presently 450MHz and 900MHz, while future frequencies are already planned for 1700MHz and 1900MHz.

The trends of miniaturization and the utilization of higher operating frequencies dictate the introduction of modifications to the physical and electrical characteristics of the individual components used in circuits. Of the major passive components, adaptation of capacitors and resistors to these demands has kept pace with the requirements. One major component which has proven to be somewhat problematic, however, is the inductor.

Typical SMD Inductors in Present Use

The SMD type inductor most commonly utilized at present for high frequency applications is wire wound around a non-magnetic core (Fig. 2). The use of a non-magnetic core is clearly essential for high frequency operations since magnetic materials typically exhibit severe property changes above a few megahertz. The use of copper wire as the conductor is also appropriate for this device since high conductivity is important to high Q at these frequencies.

The major drawback of these inductors is their physical construction. There are several inherent mechanical problems in the wire wound design.

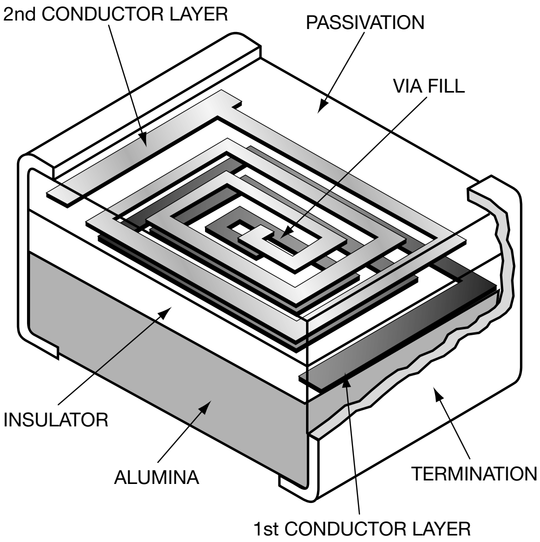


Fig. 1. Multi-Layer SMD Inductor Chip for High Frequency Applications

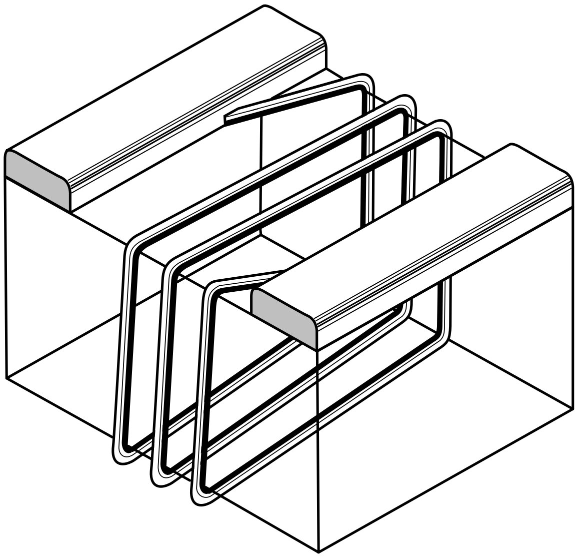


Fig. 2. Typical Wire-Wound Inductor Chip Design

The device must be quite thick (high profile) since the lines of flux are parallel to its axis (i.e. inductor cross section is width x thickness) and therefore, a thin part cannot be efficiently designed. Such high profile devices may actually skid across the board during high speed pick-and-place assembly. End terminations of the part are only partial. Furthermore, the wire conductor is delicate, particularly at its point of contact with the termination, leading to reliability concerns.

A New Design for SMD Inductors

An alternative approach which provides for a high frequency inductor that is both small and rugged is to construct the device from layers on a substrate. This approach, a common method of forming inductors on hybrids and which is also utilized in various wire bondable inductor chips, has now been incorporated into a true SMD device.

Figure 1 depicts the structure of the ACCU-L inductor. Multiple inductor layers are constructed on a nonmagnetic substrate of alumina. Each layer consists of a conductor spiral which is coated with an insulating layer. The insulator includes a via connect to the overlaying spiral. The uppermost layer seals the device. The total thickness of these layers is typically less than 0.3mm and the device thickness (substrate plus inductor layers) is only 0.9mm.

The manufacturing method used in building this inductor is photolithography. This technique, which has been extensively developed in the microelectronics industry, allows simultaneous formation of thousands of devices on a single substrate. The individual devices may then be separated from each other upon completion of all layers.

Bare inductor chips would, of course, be incompatible with surface mount assembly techniques. Figure 1 shows that this inductor includes full end termination with lands. These terminations are formed of solder coated nickel plate. It is this termination which converts the inductor chip into a true SMD inductor.

Summary

The ACCU-L SMD inductor meets both present and future needs of high frequency applications. It is small, rugged, includes full end terminations and exhibits excellent electrical performance. The multilayer construction provides a high level of control on the electrical and physical characteristics of the inductor, giving consistent characteristics within a lot and on a lot-to-lot basis. The ACCU-L inductor fills a void created by the inability of earlier technologies to satisfy continuing miniaturization and manufacturability requirements of high frequency circuits.

SMD Inductor Guide

A Glossary of Important Inductor Parameters for High Frequency Applications

Inductance. High inductance values are not a factor in most high frequency applications. 1.8nH to 39nH is typically the range of interest. The critical factors are the stability and tolerance of the inductance at operating frequency. Note that accurate measurement of these low values is not trivial. Even at low frequencies (~10MHz), instruments available today exhibit measurement accuracy of no better than about ±5% for an inductance of 10nH. At typical application frequencies (≥450MHz), measurement accuracy may be even further degraded by parasitic capacitance of inadequately characterized test fixtures.

Parasitic Capacitance. All inductors include a certain capacitance characteristic. This capacitance is derived from the mutual proximity of the coil windings. The capacitance is further magnified by the inductor structural materials, especially if these are of high dielectric constant. It is critical for high frequency inductors that the parasitic capacitance be minimized since it determines the device SRF.

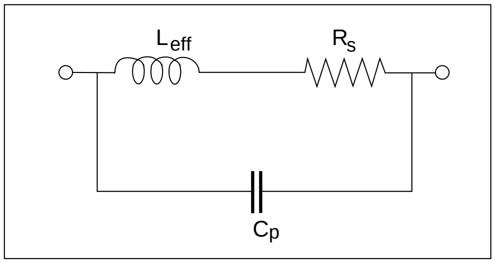
SRF. Self resonant frequency of the inductor is that frequency at which parallel resonance is achieved between the device inductance and parasitic capacitance. Inductor Q drops to zero at SRF. It is quite important, therefore, that inductor SRF be much higher than the application frequency.

Resistance. In addition to inductance and parasitic capacitance, the inductor also exhibits resistance. At low frequencies, the resistance of the conductor track is the determining factor in inductor Q. At very high frequencies, the resistivity of the conductor material is more important than the resistance.

$$\left(\text{resistance} = \text{resistivity} \times \frac{\text{conductor length}}{\text{cross section}}\right)$$

This is due to the skin effect whereby high frequency current flow is largely restricted to the surface layer of the conductor. For high Q at high frequency, it is therefore important that the coil conductor be constructed of a metal with low resistivity.

Inductor Equivalent Circuit



L = Intrinsic inductance

R_S = Resistance including skin effect

C_P = Parasitic Capacitance

L_{eff} = Effective inductance

Quality Factor. This is the most important measure of inductor performance after inductance stability. Q factor is the ratio of reactive impedance to equivalent series resistance (ESR, see below). It is a measure of the degree to which the device is lossy. High Q means low dissipation and low Q means high dissipation.

$$Q = \frac{Xi}{ESR} = \frac{\omega Leff}{ESR}$$

Where:

$ESR = R_S/(1-\omega^2 LC)^2$

$\omega = 2\pi$ x frequency

R_S = resistance including skin effect

$R_S \approx R_{dc}\, xt/\delta$ (for thick conductors: $t>5\delta$)
where t is conductor thickness.

R_{dc} = DC resistance

δ = skin depth = $\left[\frac{2\rho}{\mu\,\omega}\right]^{1/2}$

ρ = conductor resistivity (Ω-cm)

μ = permeability, $4\pi \times 10^{-9}$ H/cm

Xi = Reactive Impedance

Effective Inductance. Even non-magnetic inductors will exhibit increased measured inductance with frequency when the measurement is performed on an impedance analyzer. This is due to the effective impedance from the device parasitic capacitance.

$$L_{effective} = \frac{Xi,\ measured}{\omega} = \frac{1}{\frac{1}{L} - \omega^2 C_p}$$

Power Handling. For inductors, this is basically the maximum current that the device can carry without overheating. Power handling capability depends primarily on three traits of the inductor: ESR, thermal conductivity of the inductor materials and maximum allowable operating temperature. ESR determines the amount of power dissipated in the inductor. Material thermal conductivity and allowable operating temperature determine the capacity of the device to remove the heat generated.

Power handling is not a relevant parameter for all high frequency circuits. It must be considered only when the circuit also includes high currents.

Dimensions. Circuit board space considerations today demand small, thin parts. High profile parts may result in assembly problems.

Terminations. Full end terminations with lands is the preferred termination geometry. The material should be solder coated nickel plate. This type of termination provides optimum solderability, strength and leach resistance for the inductor.

Environmental Reliability. Inductors must be built to withstand a number of environmental stresses incurred during circuit assembly and subsequent field operation. These include exposure to a variety of chemicals, humidity, temperature, mechanical stress and thermal cycling. Most of the stresses occur while current and voltage bias exist on the device. The inductor construction must be such that the part will not fail as a result of these environmental stresses.

Measuring SMD Inductors at High Frequencies

Low value SMD inductors, particularly below 20nH, present a very difficult measurement challenge. Measurement accuracy better than 1% is straight-forward for components such as capacitors and resistors, including low values. For inductors, even the best off-the-shelf equipment cannot provide measurement accuracy better than 5% for 10nH parts.

Until recently, the limitation of 5% to 10% measurement accuracy for low value parts was not significant. Suppliers offered inductors with tolerances of ±10% or ±20% and this was adequate for circuit designers' requirements.

The rapidly expanding high frequency telecommunications industry has dramatically changed this situation. Poor tolerance inductors lead to added cost in mass produced cellular sets and similar high frequency devices. Conversely, use of tight tolerance inductors can actually allow a redesign to reduce parts count and, therefore, reduce manufacturing cost.

ACCU-L is designed for tight tolerance on inductance. The low variance of ACCU-L, however, cannot be characterized by available instruments and fixturing due to the poor accuracy of these instruments.

Since sufficiently accurate instruments are not available, measurement techniques were developed to accurately test the ACCU-L electrical parameters. This section presents these methods used to measure the major electrical parameters of ACCU-L inductance, Q-factor and self-resonant frequency (SRF).

Measurement of Self Resonant Frequency (SRF).

The most accurate and straight forward measurement of self resonant frequency for low value SMD inductors is obtained with a vector analyzer (eg. Wiltron Model 360 Vector Network Analyzer). Since these inductors have very high SRF (eg. 14GHz for ACCU-L 2.7nH), a vector analyzer with frequency capability to 20GHz or more is necessary. An appropriate fixture is a stripline of the design shown in Figure 3. SRF is that frequency at which forward transmission, S_{21}, is minimum (Fig. 4).

$$Z = \frac{R_S}{1-\omega^2 LC_P} + i\,\frac{\omega L}{1-\omega^2 LC_P}$$

When $\omega^2 = \dfrac{1}{LCp}$, $Z \to \infty$

therefore, $\mathrm{SRF} = \dfrac{1}{2\pi\sqrt{LC}}$

STRIP LINE FOR S.R.F. MEASUREMENT

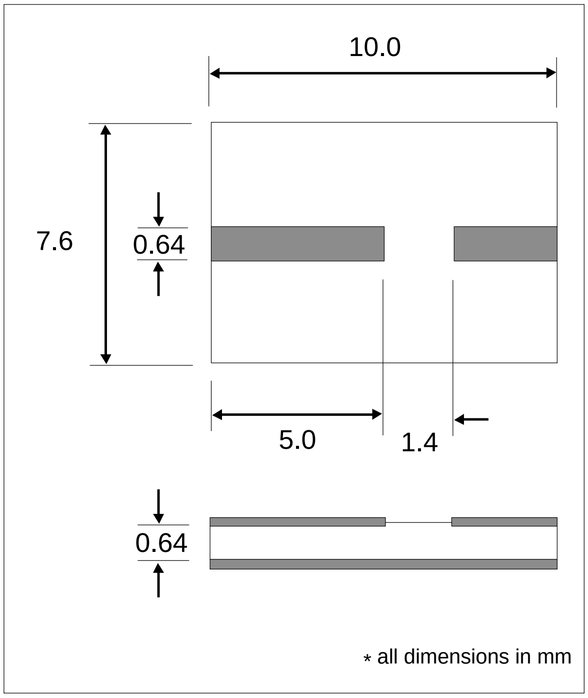


Fig. 3

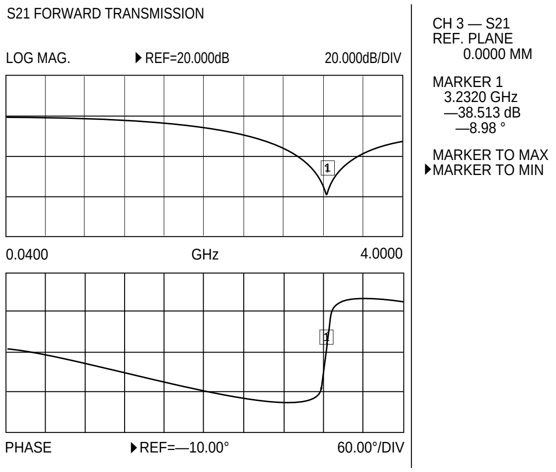


Fig. 4

Measurement of Inductance. Of all inductor parameters, inductance is the factor for which high accuracy measurement has the most significance. Optimal performance of high frequency circuits will generally be more sensitive to inductance variance than to variance of any other inductor characteristics. As discussed above, standard measurement instruments will not provide the required accuracy. By using a vector analyzer with a stripline fixture of the design presented in Figure 5, measurement accuracy of ±0.1nH is obtained at a measurement frequency of 450MHz. This means a measurement accuracy of ±1% for a 10nH device and ±3.7% for a 2.7nH device. A second generation fixture presently under development will further improve measurement accuracy of this technique to ±0.05nH.

STRIP LINE FOR INDUCTANCE MEASUREMENT

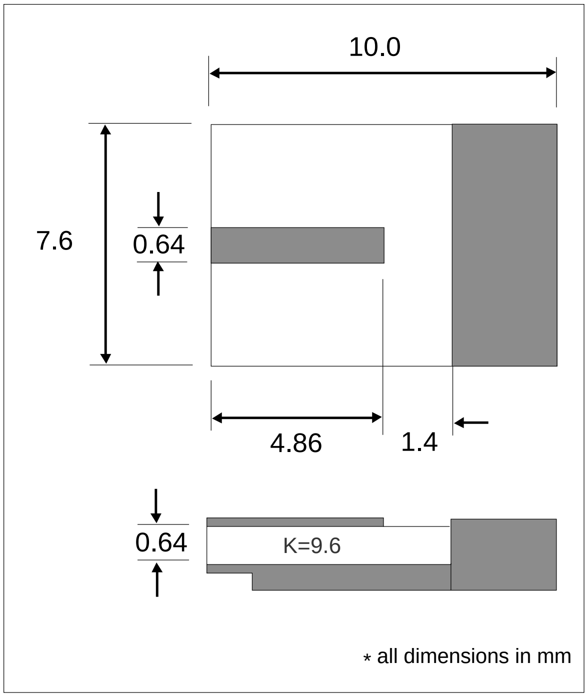


Fig. 5

This fixture is designed as a one port device where the S-parameter S_{11} is sufficient to calculate inductance. Note that the intention is to effective inductance:

$$L_{eff} = \frac{Zi}{\omega}$$

Intrinsic inductance, L could also be calculated after determining parasitic capacitance, C_p. This is generally not required since the circuit designer needs, in fact, the impedance value Xi or, alternatively the proportional term, L_{eff}.

Measurement of Quality Factor, Q.

Q-factor is measured with good accuracy using the Boonton Model 34A Resonant Transmission Line as described in the addendum to the Model 34A manual. The model 34A is a precisely characterized coax line which is formally supported by the two industry standards E1A RS-48 and ASTM F 752-82 for measuring capacitors. When used as described in the addendum, the Model 34A measures Q-factor of inductors with an accuracy of $\pm(3+Q^{0.35})\%$. For a typical inductor Q of 55, this means an accuracy of ±7%.

Note that the Model 34A can also measure inductance values in the range of 20nH to 1000nH with an accuracy of ±3%. However, accuracy of inductance measurement degrades significantly for inductance below 20nH.

Inductor Q factor can also be accurately measured using a vector analyzer with an appropriate fixture. Such a fixture is presently under development.

Applications

The ACCU-L characteristics give the circuit designer new possibilities to design circuits for higher frequency applications, tighter performance requirements, lower costs and ease of mass production.

The ACCU-L SMD inductor meets both present and future needs of high frequency applications. It is small, rugged, includes full end terminations and exhibits excellent electrical performance.

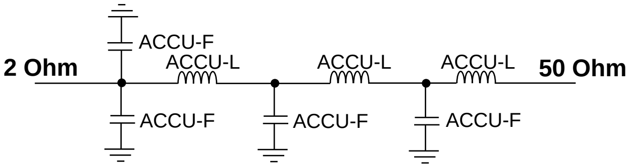
The ACCU-L minimizes the necessity of tuning elements and reduces drastically the "tweaking" of the final product — an important factor in high volume production.

The easy availability of tight inductance tolerances makes the ACCU-L the ideal choice in design of filters and matching networks (see diagrams of common applications).

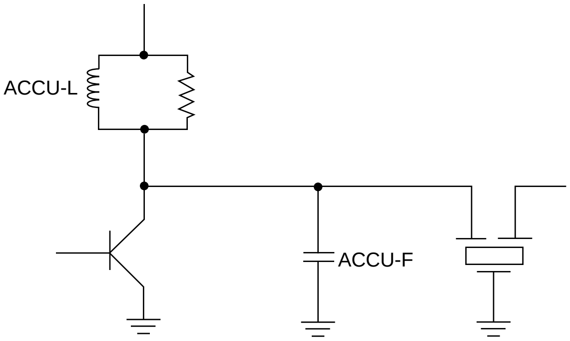
The following are some major applications of the ACCU-L.

Application	Frequency
Wireless LAN	2.4 GHz
Cellular Communications	450MHz and 900MHz
CT2	900MHz
PCN	1.7GHz to 2.3GHz
Radar Detector	UHF
Cable TV	800MHz to 900MHz
GPS	1.5GHz to 1.6GHz
Vehicle Location Systems	UHF
Paging	VHF - UHF
Military Communications	up to 10GHz
Test and Measurement	DC to 10GHz
Filters	VHF to UHF
RF Amplifiers	VHF to UHF
VCO's	VHF to UHF
Matching Networks	VHF to UHF

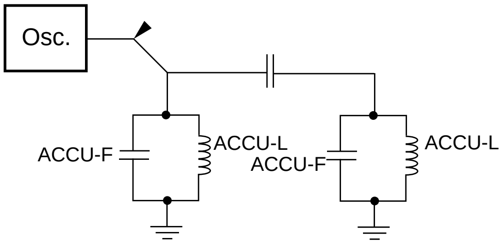
Matching Network



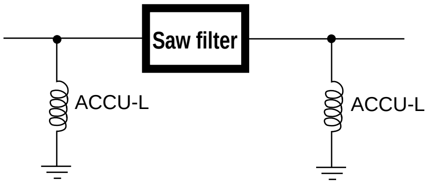
Front End Filter



Harmonic Suppressor



Harmonic Filter



USA

AVX Myrtle Beach, SC
Corporate Offices
Tel: 843-448-9411
FAX: 843-626-5292

AVX Northwest, WA
Tel: 360-699-8746
FAX: 360-699-8751

AVX North Central, IN
Tel: 317-848-7153
FAX: 317-844-9314

AVX Mid/Pacific, MN
Tel: 952-974-9155
FAX: 952-974-9179

AVX Southwest, AZ
Tel: 480-539-1496
FAX: 480-539-1501

AVX South Central, TX
Tel: 972-669-1223
FAX: 972-669-2090

AVX Southeast, NC
Tel: 919-878-6223
FAX: 919-878-6462

AVX Canada
Tel: 905-564-8959
FAX: 905-564-9728

EUROPE

AVX Limited, England
European Headquarters
Tel: ++44 (0) 1252 770000
FAX: ++44 (0) 1252 770001

AVX S.A., France
Tel: ++33 (1) 69.18.46.00
FAX: ++33 (1) 69.28.73.87

AVX GmbH, Germany - AVX
Tel: ++49 (0) 8131 9004-0
FAX: ++49 (0) 8131 9004-44

AVX GmbH, Germany - Elco
Tel: ++49 (0) 2741 2990
FAX: ++49 (0) 2741 299133

AVX srl, Italy
Tel: ++390 (0)2 614571
FAX: ++390 (0)2 614 2576

AVX Czech Republic, s.r.o.
Tel: ++420 (0)467 558340
FAX: ++420 (0)467 558345

ASIA-PACIFIC

AVX/Kyocera, Singapore
Asia-Pacific Headquarters
Tel: (65) 258-2833
FAX: (65) 350-4880

AVX/Kyocera, Hong Kong
Tel: (852) 2-363-3303
FAX: (852) 2-765-8185

AVX/Kyocera, Korea
Tel: (82) 2-785-6504
FAX: (82) 2-784-5411

AVX/Kyocera, Taiwan
Tel: (886) 2-2696-4636
FAX: (886) 2-2696-4237

AVX/Kyocera, China
Tel: (86) 21-6249-0314-16
FAX: (86) 21-6249-0313

AVX/Kyocera, Malaysia
Tel: (60) 4-228-1190
FAX: (60) 4-228-1196

Elco, Japan
Tel: 045-943-2906/7
FAX: 045-943-2910

Kyocera, Japan - AVX
Tel: (81) 75-604-3426
FAX: (81) 75-604-3425

Kyocera, Japan - KDP
Tel: (81) 75-604-3424
FAX: (81) 75-604-3425

Contact:

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