ABOVE AND BEYOND

VHF and Above Operation

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Microwave Considerations for Resistors and Capacitors

This month, let's cover resistors and capacitors as they relate to microwave construction. This topic is in direct relationship to the PUFF microwave design program I described last month. Special components are required for microwave construction so I thought that covering some of those considerations would be a good topic for you while you wait for your PUFF program to arrive. The selection rules are general and can be used in most construction for VHF through microwave.

Selecting a proper component can not only provide proper operation at higher frequencies, but it can also prevent poor performance in a project. Components should not be selected for value, but for *type* of component. Construction and case style are important factors to consider. You must consider mechanical and electrical parameters as they affect the circuit at a rated frequency. Failure to observe proper component selection could lead to project failure.

Choose Your Components Carefully

Being a parts junkie, I collect component parts in quantity from many different surplus sources. The variety of components I see run from Mil-Spec high tolerance devices to garden variety resistors and capacitors. Using junk parts is cost effective.

In retrospect, one project comes to mind that I had difficulty with—it would not function at first. What I constructed was a 70 MHz IF amplifier, eight stages with log output for a spectrum analyzer. It was supposed to have 90 dB of gain at 70 MHz, but in testing, all stages were very numb. Total gain with full tune-up was about 25 dB. Well, to make a long story short, I traced the trouble to the high precision resistors I used—1% high quality Mil-Spec resistors. They were inductive wire-wound types, and operated like RFCs (RF chokes). Replacing them with junk box carbon 1/4 watt types solved the problem.

For low frequency work the 1% resistors were spectacular, but at RF they were the pits. I should have known better. Now when I obtain surplus components I refer to catalogs to determine their suitability and mark that on the envelope that I store them in. In this case I was careless and did not heed my own advice, and it bit me. Don't get bitten. Obtain a general catalog and keep it on hand. Two very good parts suppliers are Allied Electronics and Mouser Electronics (addresses below). Both are good sources for information/catalogs, in addition to supplying components for your projects.

Resistors

Resistor lead length can also be critical. In some circuits this can be put to use in either a positive or negative way. For example, let's assume a resistor lead length of 1/2", at a frequency of 30 MHz. That equates to such a small inductance at 30 MHz that it can be totally ignored (0.006 µH or so). However, at microwave frequencies this lead length would represent quite a bit of inductance and function as an RF choke, a negative example.

The exception, where a resistor lead length forms an RF choke and is useful, is in an MMIC amplifier circuit where the long resistor lead length is coiled into a very effective RFC, and feeds DC power to the amplifier, isolating it. This DC feed resistor and lumped RFC provides good isolation to the power supply and uses one component. This provides for an inexpensive solution and circuit simplicity. This is one example of a device's long leads working for you in a positive way. It works well because the resistor and lead length RFC form a circuit in shunt with the device. If it had been in series with the device, it would have shut down the circuit operation.

Removing the leads on resistors, and changing the package style, resulted in a chip resistor. A resistor without the inductance associated with leads is suitable for very high frequency work. A chip resistor is constructed by placing a deposited carbon film on one side of a ceramic chip. Solder caps are provided for connections. These chips are well suited to strip line construction. You can buy a basic assortment of chip resistors (200 pieces) at Radio Shack for under $6, part #271-313. (See Figure 1.)

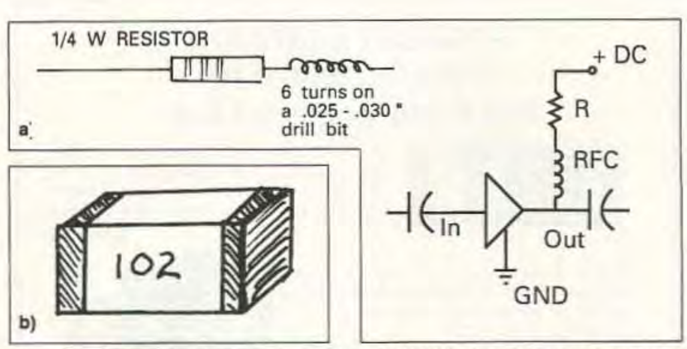

Figure 1. Standard and chip-type resistors. (a) MMIC Amplifier: You could combine the resistor and RFC by winding small RFC out of the resistor lead on one end. (b) Chip resistors are very small and are usable for microwave, within reason. Radio Shack's assortment has the value printed on the resistor. Examples: 102 = 10 + 2 zeros = 1,000Ω; 103 = 10 + 3 zeroes = 10,000Ω; 100 = 10 + 0 zeroes = 10Ω.

Basic Capacitors

Some of the more common types encountered are the poly, mylar, or mica and metal film types. Of these capacitor types, only the mica is suited for RF to the VHF/UHF frequency ranges. The disc ceramic and encapsulated chip types with leads (such as the CK-05) use a plated ceramic material to form the capacitor. They are quite good to 1,000 MHz. (See Figure 2.) At frequencies above 2,000 MHz, connecting leads on capacitors renders them ineffective, and other methods must be employed. The next generation of capacitor improvement at higher RF dictated a capacitor without leads. The uncased ceramic or early chip is an example of leadless capacitors. (See Figure 3.)

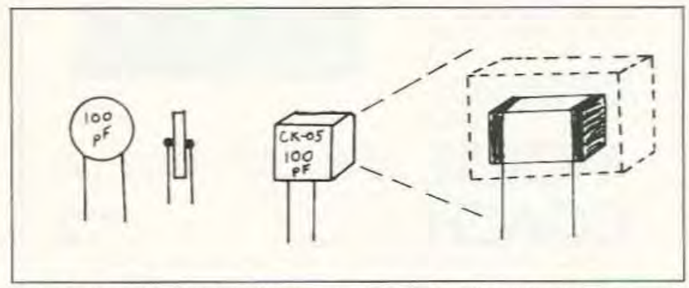

Figure 2. Ceramic capacitors. (a) Disc ceramic. The basic construction is a circular wafer with metalization on each side, forming the capacitor. Wire leads are soldered to the metalization. Sizes vary from 1/8" to larger. (b) CK-05 ceramic capacitor IS chip with packaged leads soldered to the side of the chip. The chip can be recovered by cracking the epoxy case and unsoldering the wire leads, making a lower inductance capacitor. The chip is approximately 0.15" x 0.15" square. Both the disc ceramic and CK-05 capacitors are good to 1 GHz and display lumped resistance and inductance degrading UHF operation.

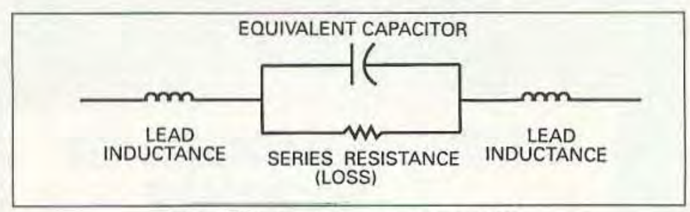

Figure 2(c). A typical capacitor at 1–2 GHz.

This leadless or chip capacitor can be a multi-layered high quality, high Q device. Values range from the small pF ranges for microwave capacitors (0.2 to 30 pF or so). Chip capacitors can be supplied even in the µF ranges. Of course, they are not suitable for microwave work—only the very low pF ranges are used at RF. The RF bypass capacitor is the exception. Other available chip type components include inductors, fuses, diodes transistors and about anything else you care to mention. Most components are made for low frequency work to reduce circuit size, and some are usable at the microwave level.

You must get into catalogs to make determinations on component suitability. I suspect that most of these components offered today, including surface-mount (chip) components obtained from scrap PC boards, are quite useful into the several hundred MHz ranges. With trial testing, this frequency generalization can be extended. On unknown components, testing through use is the only sure method to determine suitability at the microwave level.

Several manufacturers' advertisements list the cost of microwave components as several factors higher in price than their low-frequency counterparts. Unfortunately, this is very true; microwave components are costly. An example can be made for not using cheaper chip caps instead of microwave varieties. One manufacturer depicts a microwave amplifier that has blown out. The power FET blew out, due to an overrated, cheap chip capacitor. The advertiser ridicules saving a dollar by buying a cheaper capacitor when you will end up having to replace that capacitor *plus* the expensive FET, at premium dollars. Net result: No savings at all.

Their claim, a very valid one, is that the device would not have been destroyed if the circuit designer had used a capacitor rated for low dissipation, low loss, at the frequency used. Circuit losses of several dBs are possible with low frequency components used in microwave frequencies. The circuits will work with low frequency components, but do not realize their full capability. I have observed capacitors so hot from circulating RF current that they squirm in a sea of molten solder that previously attached (soldered) them to the PC board.

I don't want to appear to be really tightly postured on component use, as there is no real right answer. Lots of substitutions can be made with good results. You just have to keep in mind what is happening to the component. Is RF passing through the component, or are you trying to bypass RF?

For RF coupling, the disc ceramic is very effective for low MHz to several hundred MHz operation. At the 500 to 1,000 MHz frequency range, a capacitor's lead length becomes a limiting factor in its use. Disc ceramic types can still be used, but their connecting leads must be kept to an absolute minimum for the capacitor to be effective. With long leads, the capacitor might as well not be used as its inductance (in the leads) could render it useless.

These considerations are not important below 30 MHz, as component size is a fraction of a wavelength (100 inches equals 1/4 wavelength at 30 MHz). However, at 5 GHz a 1/4 wavelength is quite small in respect to the component, so it deserves consideration. At 10 GHz, component size is twice as critical. At 24 GHz, soldering methods used to attach components can form RF notch filters in the solder connection if the component is not fully soldered to the PC board substrate in a fully-soldered trace. The gaps or bridges in partial solder can cause real trouble.

In an amplifier we constructed with MGF-1402 for 10 GHz, we had trouble obtaining gain at 10 GHz. We solved the problem by mounting the FET upside down. This made for much shorter source leads to ground, several thousandth's of an inch made the difference. Here again minimum inductance allowed the circuit to function.

These same inductance and circuit losses make other components unsuitable for higher frequency use. Package inductance and equivalent series resistance (ESR) make higher losses to increasing frequency. If you look at the frequency ratings and Q of capacitors, you find them rated at frequencies of 1 kHz and a few MHz. Q is quite high, but when measured at higher frequencies this is another matter. The construction of the capacitor plates adds inductance; resistance is formed and the IR and dielectric losses are different at increasing frequency.

Disc capacitors are usable at very high RF frequencies and were an early VHF/UHF type. They were shipped uncased, without connecting wire leads. These uncased disc capacitors resembled a wafer with a small deposited metallic contact on either side of the device. They were attached to the circuit directly, without connecting leads.

This technique is OK to about 2 GHz; higher frequencies dictate still different methods. Remove the coating on standard disc capacitors and you can unsolder the wires and have uncased caps. Be careful—they are very fragile.

Microwave Chip Capacitors

The need for lower inductance in capacitors for microwave frequencies has led to the development of chip capacitors of superior construction. They are different from surface mount capacitors (a form of chip cap), which are not suitable for use at microwave frequencies. Non-microwave capacitors are basically rectangular, unlike their microwave counterparts.

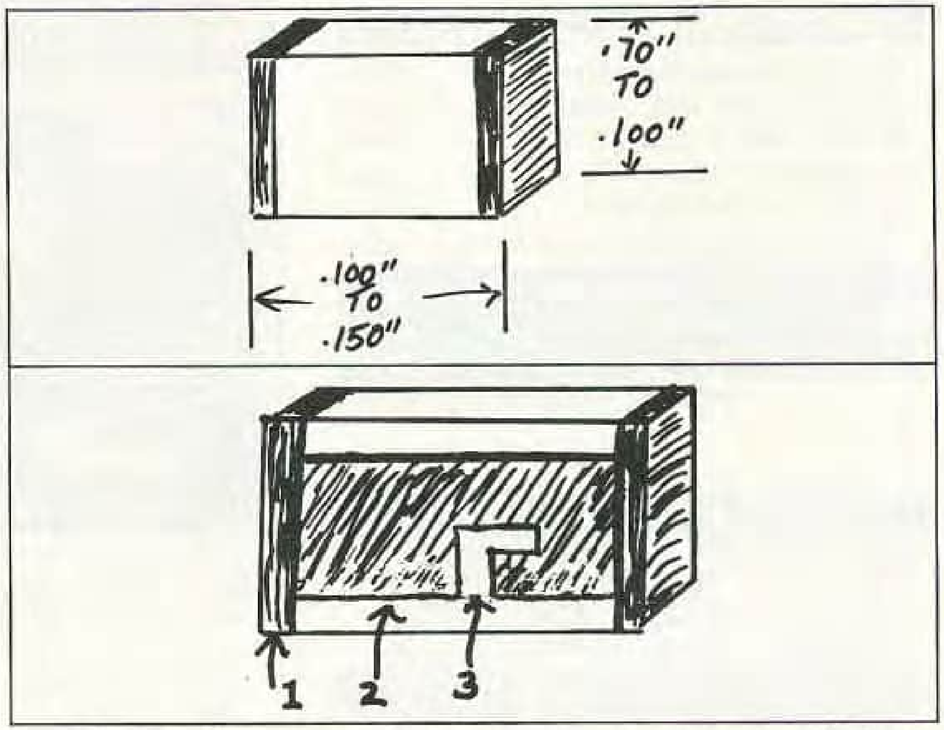

Figure 3. Surface mount device (SMD) chip capacitors and resistors. (a) Solder the capacitors on each end of the ceramic substrate. A lower Q at microwave levels produces a higher loss. This chip is usable to several GHz. The loss becomes unacceptable at 5 GHz. The normal stock value comes in large steps (2.2 pF–10 pF–47 pF, etc.) The value/size ratio is too large for most microwave projects. (b) First, solder the capacitors to each end of the ceramic substrate. Put film-deposited resistance material where indicated. Precision-trim the film, by laser cutting, to the test value. Under normal use, this model is good to 10 GHz for bias and voltage feeds in amplifiers.

The microwave chip capacitor is packaged in a 50- and 100-mil-square package to be compatible with strip line connections. It would not be acceptable to place a capacitor wider than a strip line on that strip line. It would upset the impedance of the circuit and increase loss. Most connections are made with 50 ohm strip-lines, such as amplifier input and outputs connected to coaxial connectors (50 ohm). Make the capacitors the same dimension, 0.050-inch-square, so that they match the strip line width well. Their porcelain insulation will provide lower losses to RF currents.

This porcelain substrate that forms the ceramic insulating structure is more expensive than your basic ceramic and is one of the prime reasons the capacitor will perform at microwave frequencies. ATC (American Technical Ceramics) makes the capacitors that are rated for microwave work. They are the ATC-100 style of chip caps. They have precious metal electrodes and low-loss porcelain to make microwave RF circuits work better.

A circuit tested at 500 MHz attained a 1.4 dB noise figure with a device rated at a 1.2 dB noise figure, demonstrating the capacitors' part in helping to give low loss characteristics. Any loss is directly added to the basic noise figure and degrades it. The lower losses can be put to real advantage, whether you are reaching for the ultimate or just looking for improvements in your basic system.

It has been reported that other types of chip capacitors used in amplifier circuits have not produced proper gain and noise figure measurements. Improvements of 1 to 2 dB have been attained when switching to the low loss ATC-100 type capacitors at microwave frequencies. See Figure 4 for details about ATC-100 capacitors.

Our 10 GHz amplifier ATC-100 caps of 1 to 2 pF were used to couple the coaxial connectors to the amplifier and interstage coupling. By the way, a 0.9 pF capacitor is self-resonant at 10 GHz, 2.5 pF is self-resonant at 5.6 GHz, and 20 pF is resonant at 2.3 GHz. There are two schools of thought: (1) Use a self-resonant capacitor for frequency of design; and (2) Use a 10 pF capacitor and don't worry about self-resonance. Both seem to work well.

Standard chip caps, of surface mount type, can be used for the power supply bypass connections (100 pF to 0.001 μF or so). They do not have to be the low-loss RF types as we want them to bypass RF to ground. These are what we call surface mount devices (SMD). They are very good capacitors but they're just not rated for microwave stripline work at microwave frequencies. Basic ceramic SMD capacitors, while high Q devices when used in high current applications, can fail due to greater losses and over-dissipating in RF circuits.

The dielectric constants of the materials being used for microwave capacitors give smaller capacitor size for unit value. This reduces the inductance and equivalent resistance, making a higher "Q" device with less RF loss. This drives up product cost over the basic SMD ceramic chip capacitor quite a bit, but performance is markedly improved in the microwave region.

ATC makes several lines of excellent microwave chip capacitors that are a standard of excellence in construction, if not top-of-the-line. I have used SMD capacitors up to 4 to 5 GHz, but I always question their application. If in doubt, go for the better capacitor. The bottom line is how well you want your circuit to function.

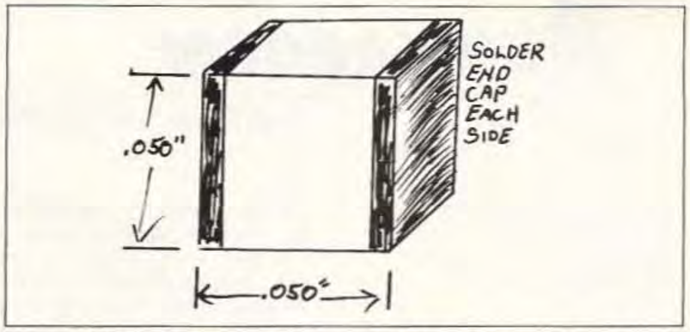

Figure 4. Standard microwave chip capacitor. This type usually comes 0.050" square for 5 and 10 GHz projects. The low loss ceramic porcelain material is rated for microwave use (low ESR—Equivalent Series Resistance. The case dimensions are well matched to microwave 50Ω strip line widths. These capacitors are supplied in very small fractional pF ranges: 0–1 pF, and higher values normally 0–30 pF. Examples: ATC-100 from American Technical Ceramics; S-910 from Johanson; and MA-18 from Murata/Erie.

The Manufacturers

Allied Electronics Administrative offices are at 4801 N Ravenswood Ave., Chicago IL 60640-4496; telephone: (312) 748–5100. They have distributors in most states, and in most provinces in Canada. Mouser Electronics is located at 11433 Woodside Ave., Santee CA 92071; telephone: (619) 449–2222. Their national number is (800) 346–6873. Mouser also offers full-line services to all of the U.S. and Canada. I have ordered from them and have had the order delivered the next day. They are very prompt. Both of these companies have catalogs available, low minimum orders, and a very good stock of components on hand.

Next month, when your copy of PUFF arrives, I will get into some considerations using PUFF. I will cover some of the problems Kerry and I ran into, and a short overview of PUFF.

Well, that's it for this month. As always, I will be glad to answer questions regarding this and other related topics. For a prompt answer, send an SASE. 73, Chuck WB6IGP.