TROUBLESHOOTING
Analog Circuits

PART 3

Troubleshooting gets down to the component level

In recent issues, this series has covered the philosophy of troubleshooting analog circuits and the tools and equipment you need to do so. But if you're working on a circuit and are not aware of what can cause component failure, finding the root of your problem could be difficult. Hence, this installment covers resistors, inductors, and transformers; their possible modes of failure; and the unsuspected problems that may occur if you use the wrong type of component. Capacitors will be covered in the next installment.

Robert A Pease, *National Semiconductor Corp*

Troubleshooting circuits often boils down to finding problems in passive components. These problems can range from improper component selection in the design phase to damaged components that hurt the circuit's performance. Resistors, inductors, and transformers can each be a source of trouble.

Resistors are certainly the most basic passive component, and, barring any extreme or obscure situations, you won't usually run into problems with the parts themselves. I don't mean to say that you'll never see any problems, but most of them will be due to the way you use and specify resistors. In other cases, some other part of the circuit may be causing damage to a resistor, and the failure of the resistor is just a symptom of a larger problem.

You may eventually have to track down a wide variety of problems involving resistors to achieve a working design. Some will seem obvious. For example, your circuit needs a 10-kΩ resistor. The technician reaches into the drawer for one and instead gets a 1-kΩ resistor, which then mistakenly gets inserted into your board. This example illustrates the most common source of resistor trouble in our lab. Consequently, I ask my technicians and assemblers to install resistors so that their values are easy to read.

Sometimes a resistor gets mismarked; sometimes a resistor's value shifts due to aging, overheating, or temperature cycling. Recently, we found a batch of metal-film resistors whose values had increased by 20 to 900% after just a few dozen cycles of −55 to +125°C. As it turned out, our QC department had okayed only certain resistors to be used in burn-in boards, and these particular resistors had not been okayed.

Resistor characteristics can vary widely

You should be familiar with the different resistor types in order to select the most appropriate type for your application; the most common types and some of their characteristics are summarized in **Table 1.** A component type that's good for one application can be disas-

Transformer problems can be due to an incorrect turns ratio or an incorrect winding polarity.

TABLE 1—TYPICAL RESISTOR CHARACTERISTICS

RESISTOR TYPE	RANGE* (Ω)	TC (±PPM/°C)	PARASITIC EFFECTS	COST
COMPOSITION	1–22M	HIGH	LOW	LOW
METAL FILM	10–1M	LOW	MEDIUM	MEDIUM
CARBON FILM	10–10M	MEDIUM	MEDIUM	MEDIUM
WIREWOUND	1–273k	LOW	HIGH	HIGH
THIN-FILM	25–100k	LOW	LOW	MEDIUM
THICK-FILM	10–1M	LOW	LOW	MEDIUM
DIFFUSED	20–50k	HIGH	HIGH	LOW

*RANGE MAY VARY BY MANUFACTURER.

trous in another. For example, I often see an engineer specify a carbon-composition resistor in a case where stability and low TC are required. Sometimes it was just a bad choice, and a conversion to a stable metal-film resistor with a TC of 100 ppm/°C max considerably improves accuracy and stability. In other cases, the engineer says, "No, I tried a metal-film resistor there, but, when I put in the carbon resistor, the overall TC was improved." In this case, the engineer was relying on the carbon-composition resistor to have a consistent TC. I have found that you can't rely on consistent TC with the carbon-composition type, and I do not recommend them in applications where precision and stability are required.

However, carbon-composition resistors do have their place. I was recently reviewing a military specification that spelled out the necessary equipment for the ESD testing of circuits. An accurate 1500Ω resistor was required for use as the series resistor during discharge of the high-voltage capacitor. In this case, you would assume that a metal-film resistor would be suitable; however, a metal-film resistor is made by cutting a spiral into the film on the resistor's ceramic core **(Fig 1a)**. Under severe overvoltage conditions, the spiral gaps can break down and cause the resistor to pass a lot more current than Ohm's Law predicts—the resistor will start to destroy itself. Therefore, the spec should have called for the use of a carbon-composition resistor, whose resistive element is a large chunk of resistive material **(Fig 1b)**. This resistor can handle large overloads for a short time without any such flashover. Even when you are applying a 200 to 400%

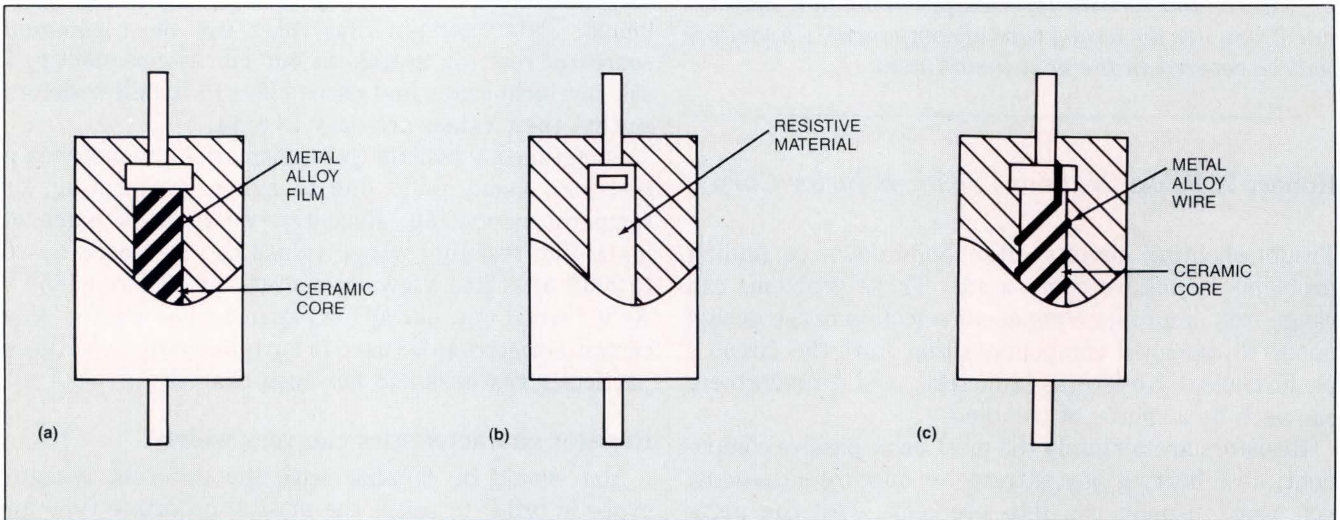


***Fig 1—Film resistors (a) are made by cutting a spiral into a layer of metal or carbon** deposited on a nonconductive core. Carbon composition types **(b)** have a solid core of resistive material; wirewound resistors are formed by winding resistive wire on a nonconductive core **(c)**.*

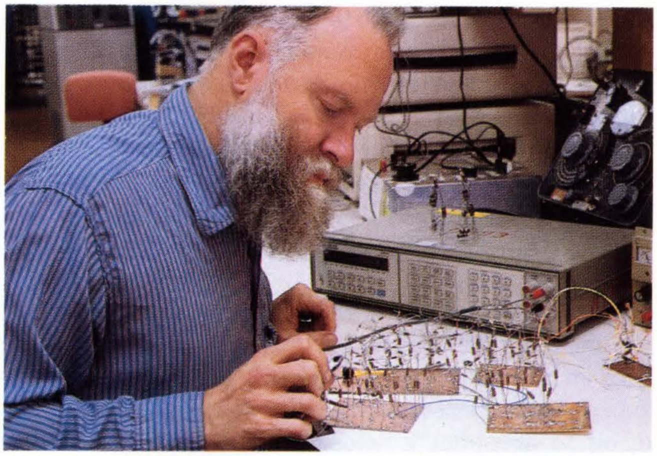
overload for just a short time, the nonuniform heating of the spiralled section of a metal-film resistor can cause the resistor to become unreliable. You can get around this problem by using a series connection of metal-film resistors. If you put fifteen 100Ω, ¼W metal-film resistors in series, an individual resistor would not see overvoltage or excessive power.

Carbon-film resistors are now quite inexpensive and have become the most common type of resistor around most labs. Their main drawback is that they are very similar in appearance to metal-film resistors and have some similar characteristics: Carbon-film resistors have 1% tolerances, are normally manufactured with spiral cuts, and have the same kind of voltage-overload limitations as metal-film types. But, carbon-film resistors have much higher TCs—500 to 800 ppm/°C. It's easy to mistakenly substitute a drifty carbon-film resistor for the intended metal-film type. Don't confuse the two.

Precision-film resistors, on the other hand, are available with greatly improved accuracy and TC. Compared to ordinary RN55D and RN55C resistors with TCs of 100 or 50 ppm/°C, these resistors have TCs as good as 20, 10, 5 or 2 ppm/°C and accuracies as good as 0.01%. These resistors are comparable to small precision wirewound resistors but are generally smaller and less expensive. They also have less inductance than the wirewound types and, thus, are suitable for higher-speed operation. A few spirals on a film substrate add negligible inductance compared to the hundreds or thousands of turns on a wirewound resistor's bobbin. Precision-film resistors are also available in matched sets of discrete resistors whose relative accuracy and TC tracking are better than those of individual resistors.

You can also buy custom thin-film resistor networks on a single substrate if your requirements are critical. A more economical route is to use four, seven, or eight matched precision thin-film resistors in a DIP. I have found the TC tracking of these devices from several manufacturers to be better than 1 ppm/°C. These sets are ideal for precision amplifier stages and DACs. Also, when you buy resistors, leave them on the tape. When you need matched sets, you can pull off adjacent resistors and be reasonably confident that they will match and track well.

Traditionally, the best, most stable resistors have been wirewound resistors **(Fig 1c)**. These days, film resistors can match wirewound resistors quite well for almost any set of specifications. However, for a resistor whose value is between 200 kΩ and 1 MΩ, wirewound resistors are more expensive and come only in larger packages. Wirewound resistors also have one major disadvantage: the inductance of an ordinary wirewound resistor makes achieving fast (sub-μsec) settling impossible. However, you can specify a special winding pattern that can greatly cut down the inductance of the windings. This type is listed in several manufacturers' catalogs as "Type HS." But I've found that there are two different types of HS: one type has almost zero inductance and greatly increased interwinding capacitance; the other type has low inductance and low capacitance and is well suited for fast-settling amplifiers. Be cautious of manufacturers' oversimplified statements.



Bob uses carefully selected precision resistors *to model the resistance of the metal runs of a FET op amp.*

A tricky problem popped up a couple of years ago when we assembled a precision amplifier with wirewound resistors. The output was drifting all over the place, but the amplifier, zeners, and transistors were stable. What was drifting? It turned out that a wirewound resistor was "drifting" because we had mistakenly used a special temperature-compensating resistor with a TC of +3300 ppm/°C. This type of temperature-compensating resistor is often used for correcting the TC of transistor logging circuits, but it wasn't labelled in an obvious way. When we put this resistor in a circuit where a low-TC resistor was required, it took us a couple of hours of troubleshooting to pinpoint the problem.

Match the TC to the application

Diffused resistors, commonly used in ICs, have some strange characteristics. Their TC is high—+1600 ppm/°C—and includes a nonlinear, or quadratic, term. Thus, *Resistor problems are often due to using the wrong type of resistor for your application.*

the resistance goes up faster at high temperatures than it falls at cold temperatures. These resistors would be useless except for one minor detail: They track at the rate of approximately ±5 ppm/°C. Since it is very inexpensive to make matched pairs or sets of these resistors in a monolithic integrated circuit, their use is popular among IC designers. If you're not designing an IC, though, you probably won't meet up with diffused resistors very often.

Many ICs, such as DACs and voltage references, are made with thin-film (sichrome or nichrome) resistors on the chip. Compared with most other resistor types, these resistors have the somewhat lower TCs of 50 to 350 ppm/°C, closer ratios, better long-term stability, better TC tracking, and less nonlinearity of the "voltage coefficient." This last term refers to the nonlinearities in Ohm's Law that occur when there is a large voltage drop across a resistor; the effect is most common in resistors with large values.

Therefore, when you drive the reference input to a DAC, you should be aware that the R_{in} will only shift 1 to 3% over the entire temperature range. However, there may still be a broad tolerance, as it is not easy to keep tight tolerances on the "sheet rho," or resistivity, during the IC's production. For example, a typical DACs R_{in} specification is 15 kΩ±33%. These film resistors have even better tracking TC than diffused resistors, often better than 1 ppm/°C.

In addition to the TC, you might also be concerned with the shunt capacitance of a resistor. Recently, I was trying to build a high-impedance probe with low shunt capacitance. I wanted to put a number of 2.5-MΩ resistors in series to make 10 MΩ. I measured the shunt capacitance of several resistors with our lab's impedance bridge. A single Allen-Bradley carbon-composition resistor had a 0.3-pF capacitance, so the effective capacitance of four in series would be down near 0.08 pF—not bad (**Fig 2**). Then I measured a Beyschlag carbon-film resistor. Its capacitance was slightly lower, 0.26 pF. The capacitance of a Dale RN60D was 0.08 pF; the capacitance of four in series would be almost unmeasurable.

It would be an improper generalization to state that certain resistor types have less shunt capacitance than others. However, the main point is that if you need a resistance with low shunt capacitance, you can connect lower-value resistors in series.

As with the fixed resistors discussed so far, there are many kinds and types of variable resistors, such as trimming potentiometers, potentiometers, and rheo-

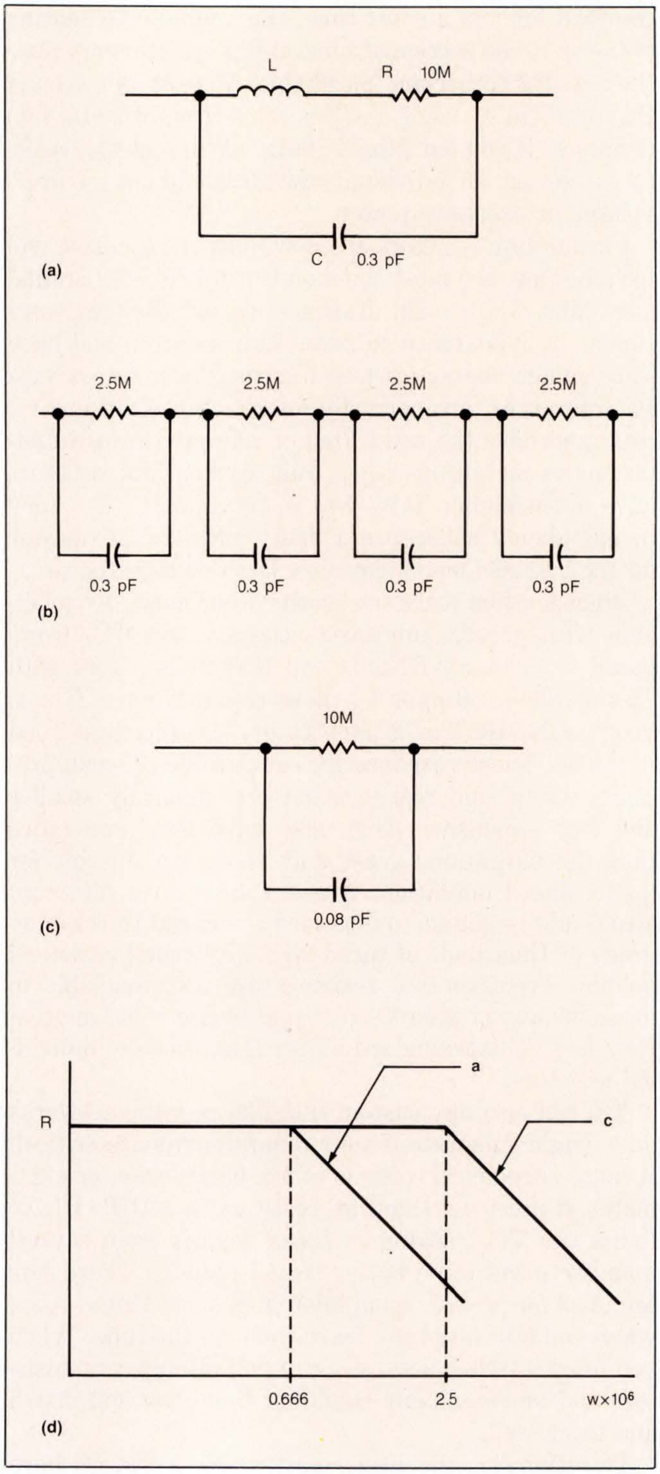


Fig 2—You can reduce the capacitance *of a single resistor **(a)** by using several resistors in series as shown in **b** (assume the inductance is negligible). This series resistor configuration has one fourth of the single resistor's capacitance **(c)** and extends the resistor's frequency response as shown in **d**.*

stats. These resistors are made with many different resistive elements, such as carbon, cermet, conductive plastic, and wire. As with fixed resistors, be careful of inexpensive carbon resistors, which may have such poor TC that the manufacturer avoids any mention of it on the data sheet. These carbon resistors would have a poor TC when used as a rheostat but might have a good TC when used as a variable voltage divider or a potentiometer. On the other hand, some of the cermet resistors have many excellent characteristics but are not recommended for applications that involve many hundreds of wiper cycles. For example, a cermet resistor would be inappropriate for a volume control on a radio.

The major problem area for variable resistors is their resolution, or "settability." Some variable resistors claim to have infinite resolution; but, if you apply 2V across a variable resistor's ends and try to trim the wiper voltage to any or every millivolt in between, you may find that there are some voltage levels you can't achieve. So much for infinite resolution. As a rule of thumb, a good pot can usually be set to a resolution of 0.1%, or every 2 mV in the previous case. Thus, counting on a settability of 0.2% is conservative.

Good settability includes not only being able to set the wiper to any desired position but also having it stay there. But, I still see people advertising multiturn pots with the claimed advantage of superior settability. The next time you need a pot with superior settability, evaluate a multiturn pot and a single-turn pot. Set each one to the desired value, tap the pots with a pencil, and tell me which one stays put. I normally expect a multiturn pot, whether it has a linear or circular layout, to be a factor of 2 to 4 worse than a single-turn pot because the mechanical layout of a single-turn pot is more stable and balanced. Does anyone know of an example in which the multiturn pot is better?

Don't exceed your pot's I and V ratings

How do variable resistors fail? If you put a constant voltage between the wiper and one end and turn the resistance way down, you will exceed the maximum wiper current rating and soon damage or destroy the wiper contact. Note that the power rating of most variable resistors is based on the assumption that the power dissipation is uniformly distributed over the entire element. If half of the element is required to dissipate the device's rated power, the pot may last for a short while. However, if a quarter of the element is required to dissipate this same amount of power, the pot will fail quickly. For example, many years ago, the only ohmmeters available might put as much as 50 mA into a 1-Ω resistor. When a 50-kΩ, 10-turn precision potentiometer (think of a $20 item) was tested at

Consider the effects of magnetic fields

One problem recently illustrated the foibles of inductor design: Our applications engineers had designed several dc/dc converters to run off 5V and to put out various voltages, such as +15V and −15V dc. One engineer built his converter using the least expensive components, including a 16-cent, 300-μH inductor wound on a ferrite rod. Another engineer built the same basic circuit but used a toroidal inductor that cost almost a dollar. Each engineer did a full evaluation of his converter; both designs worked well.

Then the engineers swapped breadboards with each other. The data on the toroid-equipped converter was quite repeatable. But, they couldn't obtain repeatable measurements on the cheaper version. After several hours of poking and fiddling, the engineers realized that the rod-shaped inductor radiated so much flux into the adjacent area that all measurements of ac voltage and current were affected. With the toroid, the flux was nicely contained inside the core, and there were no problems making measurements. The engineers concluded that they could build the cheapest possible converter, but any nearby circuit would be subject to such large magnetic fields that the converter might be useless.

When I am building a complicated precision test box, I don't even try to build the power supply in the main box because I know that the magnetic fields from the power transformer will preclude low-noise measurements and the heat from the transformer and regulators will degrade the instrument's accuracy. Instead, I build a separate power-supply box on the end of a 3-ft cable; the heat and magnetic flux are properly banished from my precision circuits.

The easiest way to spot problems with resistors and inductors is to follow your nose.

incoming inspection using such an ohmmeter, the tester would turn the pot down to the end where the 50 mA was sufficient to burn out the delicate wirewound element—an inefficient way to test parts.

Some trimming potentiometers are not rated to carry any significant dc current through the wiper. This dc current—even a microampere—could cause electromigration, leading to an open circuit or noisy, unreliable wiper action. Carbon pots are not likely to be degraded by this failure mode. If you have any questions about the suitability of your favorite trimming potentiometers for rheostat service, you or your components engineer should ask the pot's manufacturer.

How do you spot resistor problems? The most obvious way is to follow your nose. When a resistor is dying it gets quite hot, and sometimes the strong smell leads right to the abused component. Just be careful not to burn your fingers.

You may also encounter situations in which a resistor hasn't truly failed but doesn't seem to be doing its job, either. Something seems to be wrong with the circuit, and a resistor of the wrong value is the easiest explanation. So, you measure the resistor in question, and 90% of the time the resistor is just fine—usually the trouble is elsewhere. A resistor doesn't usually fail all by itself. Its failure is often a symptom that a transistor or circuit has failed; if you just replace the resistor, the new one will also burn out or exhibit the same strange characteristics.

How do you check for resistor errors? If you're desperate, you can disconnect one end of the resistor and actually measure its value. It's often easier to just measure the $I \times R$ drops in the network and deduce which resistor, if any, seems to be of the wrong value. If one resistor is suspected of being temperature sensitive, you can heat it with a soldering iron or cool it with freeze mist as you monitor its effect. In some solid-state circuits, the signals are currents, so it's not easy to probe the circuit with a voltmeter. In this case, you may have to make implicit measurements to decide if a resistor is the problem. Also, remember that a sneak path of current can often cause the same effect as a bad resistor.

Watch out for damaged components

Damaged resistors can also be the source of trouble. A resistor that's cracked can be noisy or intermittent. When resistors are overheated with excess power, such as 2 or 3W in a ¼W resistor, they tend to fail "open"—they may crack apart, but they don't go to low ohms or to a short circuit. The accuracy or stability of a high-value resistor (10^8 to $10^{12}\Omega$) can be badly degraded if dirt or fingerprints touch its body. Careful handling and cleaning are important for these high-value resistors and high-impedance circuits.

One problem that occurs with all resistors is related to the Seebeck effect: the production of an EMF in a circuit composed of two dissimilar metals when their two junctions are at different temperatures. In precision circuits, you should avoid thermal gradients that could cause a large temperature difference across a critical resistor. Many precision wirewound and film resistors have low Seebeck coefficients in the range 0.3 to 1.5 μV/°C. But avoid tin oxide resistors, which have a thermocouple effect as large as 100 μV/°C. If you are going to specifiy a resistor for a critical application where thermocouple errors could degrade circuit performance, check with the manufacturer.

So, know that resistors can present challenging troubleshooting problems. Rather than reinventing the wheel every time, try to learn from people with experience.

Inductors and transformers aren't so simple

Inductors and transformers are more complicated than resistors—nonlinearity is rife. Their cores come in many different shapes and sizes, from toroids to pot cores and from rods to stacks of laminations. Core materials range from air to iron to any of the ferrites. I am not going to presume to tell you how to design an inductor or transformer or how to design circuits that use them, but I will discuss the kinds of trouble you can have with these components. For example, you can have a good core material; but, if there is an air gap in the core and you don't carefully control the gap's width, the energy storage and the inductance of the component can vary wildly. If someone has substituted a core of the wrong material, you may have trouble spotting the change; an inductance meter or an impedance bridge can help. But even with one of those tools, you're not home free.

For most inductors and transformers with cores composed of ferromagnetic materials, you had better make sure that the test conditions—the ac voltage and the frequency that the measuring instrument applies to the device under test—closely approximate those the component will see in your real-life application. If you fail to take such precautions, your inductance measurements stand a good chance of seriously misleading you and making your troubleshooting task much more frustrating. The phenomena you are likely to run into as a result of incorrect test conditions include saturation, which can make the inductance look too low, and core loss, which can lower the Q of an inductor. For transformers, make sure you understand which of the inductances in the device's equivalent circuit you are measuring. (For more on transformer equivalent circuits see **box,** "Equivalent circuits demystify transformers.")

When you work with inductors or transformers, you have to think in terms of current: In any transformer or inductor, flux is directly proportional to the current, and resistive losses are directly proportional to the current squared. Therefore, be sure to have several current probes, so you can observe what the current waveforms are doing. After all, some of the weirdest, ugliest, and most nonideal waveforms you'll see are the waveforms associated with inductors.

In the absence of an instrument designed to measure inductance, parallel the inductor with a known capacitance to create a parallel resonant circuit. If you use a high-impedance source to apply a current pulse to this circuit, you can determine the inductor's value from the resonant frequency and the capacitance: $f=1/2\pi\cdot\sqrt{LC}$. If you look at the inductor's waveform on a scope, you can compare it to the waveform you get with a known-good inductor. This technique is also good for spotting a shorted turn, which reduces inductance nearly to zero. The L meter and the similar Q meter can help you ensure that good inductors haven't been

Equivalent circuits demystify transformers

You can represent a transformer with a turns ratio of N as a "T" network **(Fig A).** N equals N_1/N_2, where N_2 is the number of secondary turns and N_1 is the number of primary turns. However, if you plan to make measurements on transformers, it's helpful to keep the equivalent circuit shown in **Fig B** in mind. For example, the inductance you measure between terminals A and B is quite large if you leave terminals C and D open, but the measured inductance is quite small if you short terminals C and D together.

In the first case, you are measuring the mutual inductance plus the leakage inductance of the primary. But because the leakage inductance is normally much, much smaller than the mutual inductance, you are measuring the leakage inductance of the primary plus the reflected secondary leakage in the second case.

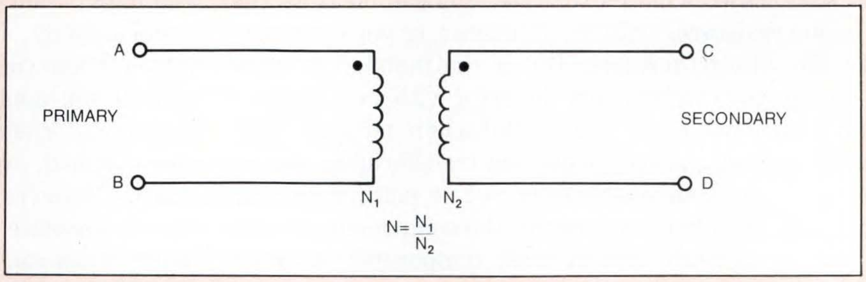


Fig A—In most instances, *you can represent a transformer by its turns ratio.*

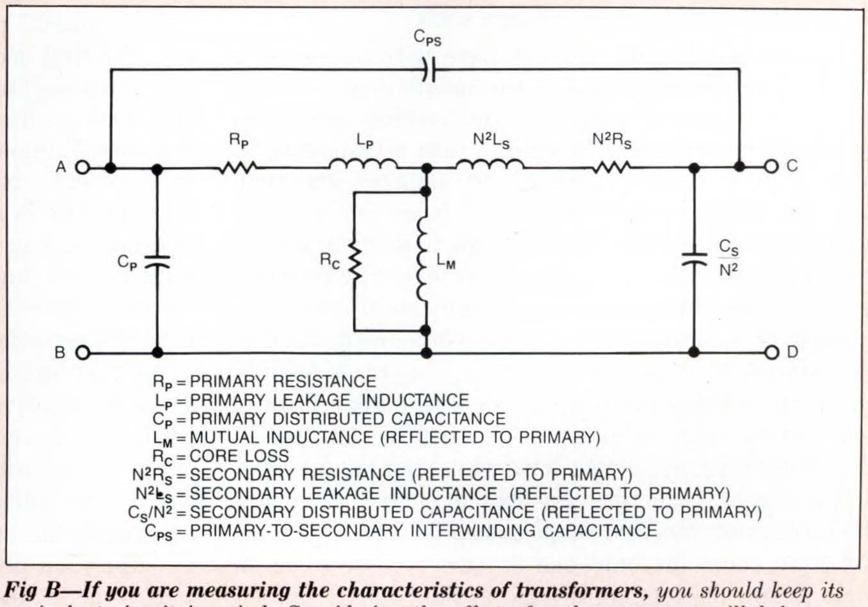


Fig B—If you are measuring the characteristics of transformers, *you should keep its equivalent circuit in mind. Considering the effect of each component will help you understand the results of your measurements.*

When working with inductors or transformers, think in terms of current and use current probes to view the waveforms.

damaged by saturation.

Incredible as it may sound, you can permanently damage an inductor by saturating it. Some ferrite toroids achieve their particular magnetic properties by dint of operation at a particular point on the material's magnetization curve. Saturating the core can move the operating point and drastically change the core's magnetic properties. The likelihood of your being able to return the material to its original operating point is small to nonexistent. In other cases, as a result of applying excessive current, the core temperature increases to a point where the core's magnetic properties change irreversibly. Regardless of the mechanism that caused the damage, you may have to do as I once did—package the inductors with a strongly worded tag to demand that nobody test them at Incoming Inspection.

If you choose too small a wire size for your windings, the wire losses will be excessive. You can measure the winding resistance with an ohmmeter, or you can measure the wire's thickness. But if the number of turns is wrong, you can best spot the error with an L meter—remember that $L \propto N^2$. Be careful when using an ohmmeter to make measurements on transformers and inductors—some ohmmeters put out so many milliamps that they are likely to saturate the component you are trying to measure and at least temporarily alter its characteristics.

Protect transistors from voltage kick

There is one trouble you can have with an inductor that will not do any harm to the magnetic device but will leave a trail of death and destruction among its associated components: When you use a transistor to draw a lot of current through an inductor and then turn the transistor off, the "kick" from the inductor can generate a voltage high enough to destroy almost any transistor. You can avoid this problem by connecting a suitable snubber, such as a diode, an RC network, a zener, or a combination of these components, across the inductor to soak up the energy. The use of a snubber is an obvious precaution, yet every year I see a relay driver with no clamp to protect the transistor. The transistor may survive for a while, but not for long.

The tiniest inductors are called beads. They are about the same size and shape as beads worn as jewelry and have room for only one or two or four turns of wire. Beads are commonly used in the base or emitter of a fast transistor to help keep it from oscillating. A bead not only acts inductive but also acts lossy at high frequencies, thus damping out ringing. In general, the choice of a bead is an empirical, seat-of-the-pants decision, but designers who have a lot of experience in this area make good guesses. This topic is one that I have not seen treated, except perhaps one sentence at a time, in any book or magazine. You'll just have to get a box of ferrite beads and experiment.

Transformers usually are susceptible to the same problems as inductors. In addition, the turns ratio may be wrong, or the winding polarity might be incorrect. And, if your wire-handling skills are sloppy, you might have poor isolation from one winding to another. Most ferrite materials are insulators, but some are conductive. So, if you've designed a toroidal transformer whose primary and secondary windings are on opposite sides of the toroid and you scrape off the core's insulating coating, you could lose your primary-secondary insulation. If the insulating coating isn't good enough, you might want to put tape over the toroid.

Fortunately, it's easy to establish comparisons between a known-good transformer and a questionable one. If you apply the same input to the primaries of both transformers, you can easily tell if the secondaries are matched, wound incorrectly, or connected backwards. If you're nervous about applying full line voltage to measure the voltages on a transformer, don't worry—you can drive the primary with a few volts of signal from a function generator and still see what the various windings are doing.

Two general problems can afflict power transformers. The first occurs when you have large filter capacitors and a big high-efficiency power transformer. When you turn the line power switch on, the inrush current occasionally blows the fuse. You might install a larger value of fuse, but then you must check to make sure that the fuse is not too high to offer protection. As an alternative, you could specify the transformer to have a little more impedance in the secondary: Use smaller wire for the windings or put a small resistor in series with the secondary.

Another approach, often used in TV sets, is to install a small negative-TC thermistor in the line power's path. The thermistor starts out with a nominal impedance, so the surge currents are finite. But then the thermistor quickly heats up, and its resistance drops to a negligible value. Thus, the efficiency of the circuit is quite good after a brief interval. If the circuit is a switch-mode power supply, the control IC should start up in a "soft-start" mode. In this mode, the IC won't draw any extreme currents in an attempt to charge

In the absence of an instrument designed to measure inductance, parallel the inductor with a known capacitance to create a parallel resonant circuit.

up the output capacitors too quickly. However, you must use caution when you apply thermistors for inrush current limiting: Beware of removing the input power and then reapplying it before the thermistors have had a chance to cool. A warm thermistor has low resistance and will fail to limit the current; thus, you are again likely to blow a fuse.

The second general problem with a line transformer occurs when you have a small output filter capacitor. In our old LM317 and LM350 data sheets, we used to show typical applications for battery chargers with just a 10-μF filter. Our premise was that when the transformer's secondary voltage dropped every 8 msec, there was no harm in letting the regulator saturate. That premise was correct, but we began to see occasional failed regulators that blew up when we turned the power on.

After extensive investigations, we found the problem in the transformer: If the line power switch was turned off at exactly the wrong time of the cycle, the flux in the transformer's steel core could be stored at a high level. Then, if the line power switch was reconnected at exactly the wrong time in the cycle, the flux in the transformer would continue to build up until the transfomer saturated and produced a voltage spike of 70 to 90V on its secondary. This spike was enough to damage and destroy the regulator. The solution was to install a filter capacitor of at least 1000 μF, instead of just 10 μF. This change cut the failure rate from about 0.25% to near zero.

Another problem occurred when the LM317 was used as a battery charger. When the charger output was shorted to ground, the LM317 started drawing a lot of current. But, the transformer's inductance kept supplying more and more current until the LM317 went into current limit and could not draw any more current. At this point, the transformer's secondary voltage popped up to a very high voltage and destroyed the LM317. The addition of the 1000-μF snubber also solved this problem.

Inductors, like resistors, can overheat

How do you spot a bad inductor or transformer? I have already discussed several mechanisms that can cause the inductance or Q of an inductor to be inferior to that of a normal part. And, as with a resistor, you can smell an inductor that is severely overheating. Overheating can be caused by a faulty core, a shorted turn, incorrect wire gauge, or anything else that causes losses to increase. An open winding is easy to spot with an ohmmeter, as is a short from a primary to a secondary. If the pattern of winding has been changed from one transformer to another, you may not see it unless you test the components in a circuit that approximates the actual application. However, you may also be able to see such a discrepancy if you apply a fast pulse to the two transformers.

Tightly coupled windings, both bifilar and twisted pairs, have much better magnetic coupling and less leakage inductance than do well-separated primary and secondary windings. As the magnetic coupling improves, the capacitance between windings increases—but high capacitance between windings is often an undesirable effect in a transformer. An experienced transformer designer weighs all the tradeoffs and knows many design tricks—for example, the use of special pi windings and Litz wire. Mostly, you should know that these special techniques are powerful; if you ask the transformer designers the right questions, they can do amazing tricks.

I recently read about an engineer who designed an elegant shield made of mu-metal. However, the shield was difficult to install, so the technician had to tap on it with a hammer. When the engineer operated the circuit, the shielding seemed nonexistent—as if the shield were made of cardboard. After a lot of studying, the engineer realized that the mu-metal—which costs about $2 per 15 square inches, the same as a $2 bill—had been turned into perfectly worthless material by the pounding and hammering. In retrospect, the engineer had to admit that the mu-metal, when purchased, was prominently labelled with a caution against folding, bending, or hammering. So remember, in any area of electronics, there are problems with inductors and magnetic materials that can give you gray hair. EDN

Author's biography

For information about Bob Pease, see the box, "Who is Bob Pease, anyway?" in the January 5, 1988, edition of EDN.

Article Interest Quotient (Circle One)
High 485 Medium 486 Low 487