PIÈCE DE RÉSISTANCE, PART I

By Ben Duncan

Resistors are the simplest of electronic components: a concentrated parcel of resistance abutted between a pair of wires. Provided the actual resistance is linear and invariant—and also agrees with the value coded on the body (with three or more color stripes)—we're in business. Or are we?

Resistors are also the mainstay component in electronic circuits. A quick glimpse under the lid of any audio device is convincing: analog boards awash with resistors. If not, let's not forget that every IC package contains upwards of ten resistors. But *why* so many? Well, resistors are the universal stuff of defining all the currents and voltages in a circuit (*Fig. 1*). Every day, millions of them act out the linear drama V = I × R, written by Georg Ohm in the early years of the 19th century (V for volts, I for amps & R for ohms). It's sobering to think that Ohm's law is one of two stars around which the whole universe of electronics modelling revolves—the other is Kirchhoff's; and that common-sense verification of Ohm's law itself hinges on the existence of linear resistance, thereby upon the resistors of everyday life.

On our mental screens resistors may be visualized as setting the proportions of a circuit. And when resistors are in error, the architecture of voltages and currents becomes crazily, if subtly, distorted. Agents that may pervert the course of Ohm's law include seven fields of first-order deviation. But hark! shall we first make our acquaintance with the actors?

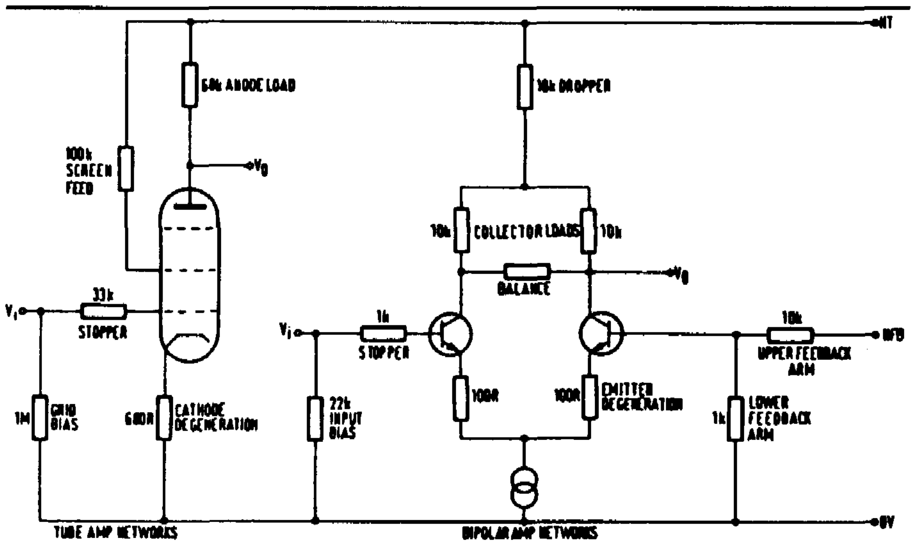

FIGURE 1: Sample schematic showing the prevalence of resistors in a circuit.

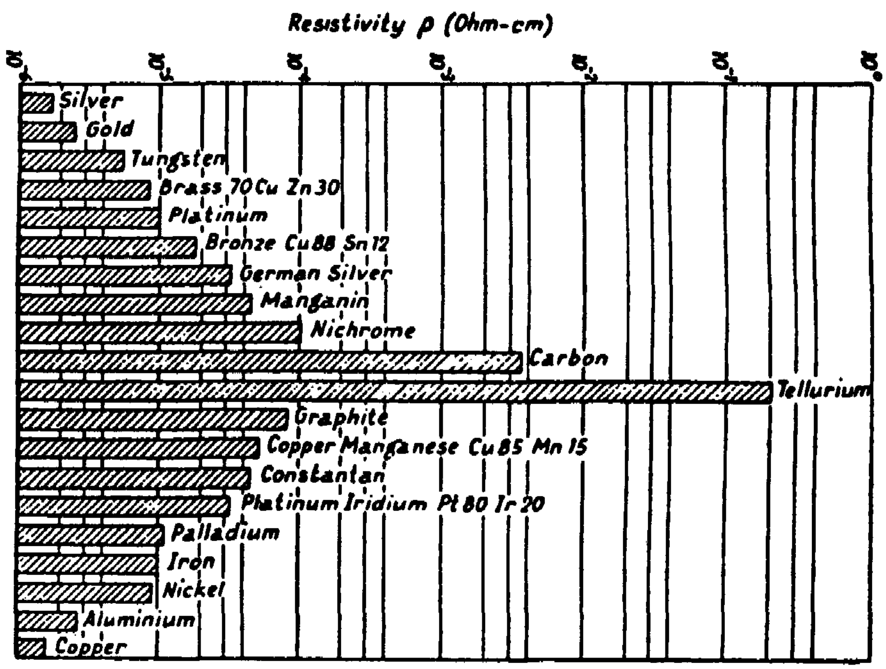

FIGURE 2: Relative resistance of metals, alloys, and metalloids.

Resistor Types

The first resistors arose naturally, with the advent of the electric telegraph, c. 1845. Resistance is the No. 1 property and primary antagonist of any length of conductor—especially if it's not shiny and noble, like silver, gold, and copper. Taking a highway for simple analogy, a good conductor is like a ten lane, where even dense traffic (a high current) can make steady progress. Resistance amounts to having to slow down, or overtake; or switching lanes. It's particularly severe

ABOUT THE AUTHOR

Ben Duncan has worked as an international freelance audio design consultant since 1979. He has designed over 40 products used globally in concert sound reinforcement by top recording studios, broadcasters, and audiophiles. He has published nearly 400 articles, reviews, and research papers on audio electronics and quality, including DIY projects. He lives in the English countryside and enjoys gardening and guest attendance at diverse musical events.

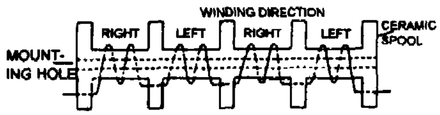

FIGURE 3: A slotted-form, noninductive, wirewound resistor. Low inductance achieved by reverse connected bobbins.

if the highway is constricted—a one-lane "contra flow" section.

The total resistance encountered is also proportional to length, just as extra hassle is statistically inevitable as a motorway journey lengthens. Although resistance impedes the flow of traffic (electrons) and creates hot tempers (a temperature rise), it doesn't altogether prevent the flow of traffic (current); in even the worst traffic jams, someone, somewhere is inching forward. The only sure antithesis of conductance (traffic flow) is a good insulating medium. In our ten-laner analogy, insulation is modeled when the temperature drops swiftly to −30°C, and vehicles are frozen solid along the route.

Of course, this traffic analogy only befits simple, direct current "signals." For asymmetric AC (i.e., music signals), the visuals would be somewhat more complex. Summing up, conductors advance the mobility of electrons, increasing resistance implies the progressive degradation of mobility, while insulators forbid it absolutely.

Figure 2 displays the relative resistance of some common metals, alloys, and metalloids. Metals with *resistivities* below 30×10^{-6} ohm cm ("Roes") are regarded as conductors, the stuff of interconnection.[1] Above this line, the logarithmic scaling moves up sharply into realms where resistance is the overriding property, especially for small cross-sectional areas. To quote the Professor, "*Armm.* When an alloy like steel is drawn into thin wires, what makes a satisfactory conductor for electrified rail traction becomes a resistance wire." Further extemporizing into full-scale Gallic oratory the professor says "*Ici! Uhn fee de raysizstonce,*" meanwhile whipping the table with a length of extension cord, for extra effect.

Assuming our conductor's cross-sectional area is constant, the resistance is proportional to length, so we can concentrate a lot of ohms into a small package by coiling up a long wire. To further magnify the resistance, we could go on and select a material from the table which develops M Ω/m (where M stands for Maximum). Except that for more subtlety, we'd better use a kosher material. It mustn't melt or deform, for instance. Or develop thick layers of oxide crud.

In everyday life, wire-wound (WW) resistors comprise a length of copper-nickel alloy or nickel-chromium ("Nichrome"), wrapped around a ceramic former. At this stage the resistor looks like a miniature electric "heating" element, but before leaving the factory, it's embedded in a vitreous or ceramic housing, or coated with ceramic cement.

An altogether higher species of WW resistor is produced for test instruments, and wherever very stable and accurate resistance is at issue. Precision wirewounds aren't intended for high current levels, rather developing linearity and keeping exactly to their indicated value by virtue of being used at a fraction of their rated power, since coolness equates with long-term stability. Inside, the wire is spooled onto a series of bobbins, alternately reversed (*Fig. 3*) or *bifilar* wound (*Fig. 4*) to cancel the winding's inductance. The terminal wires are welded directly to the coil ends.

Figure 5 shows a typical design from Rhopoint in the US. Notice how the leadout wires are brought deep into the bobbin, to relieve the element of any physical stress that might wreck subsequent accuracy. Before encapsulation, the windings are "stabilized" by burning in at currents well above the rated value, for a week or more. Aside from driving off moisture, the winding is aged, which is good for exposing any duds. Then

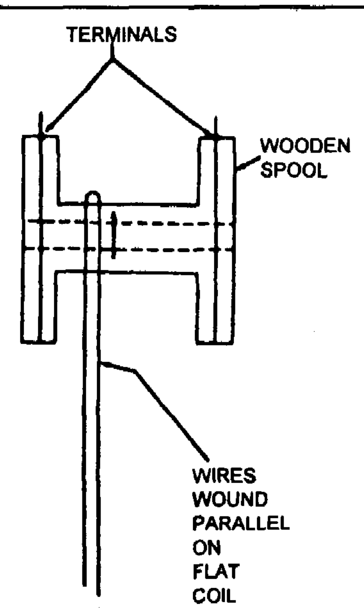

FIGURE 4: A parallel-wound (bifilar) noninductive, wirewound resistor. Bifilar winding cancels inductance.

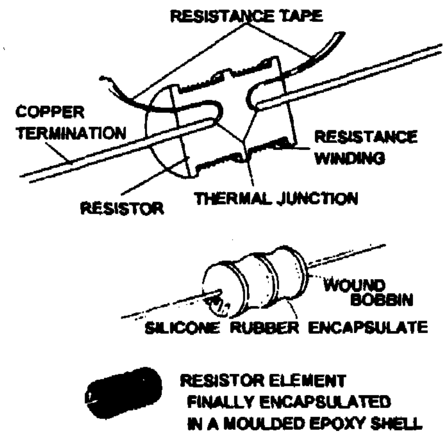

FIGURE 5: Precision wirewound construction.

before they've even cooled, the windings undergo impregnation, in a steaming tub of a thick'n'wholesome varnish. The finished assembly is ideally sealed in an overall aluminum tube, or epoxied for "cast-iron" protection against the ingress of moisture or chemical reagents.

A Carbonic Composition (CC)

A prodigal Englishman, C.S. Bradley, developed and patented the first carbon composition resistor, some years before it was needed, in 1885![2] Large-scale production in Germany, the UK, and the USA began c. 1925, coincident with the wireless broadcast boom. Thereafter, carbon composition resistors remained the mainstay of "consumer" equipment, up to the mid '60s in the UK. Nearly 20 years later, they're still being spotted in the occasional item of US audio equipment, long after two generations (no less!) of superior film resistors have become economic enough to satisfy even European and Japanese consumer goods manufacturers. Curious.

What about the recipe? Carbon "composition" is an alias for finely ground carbon mixed with a nondescript, nonconductive filler (NCF), bound with a resin adhesive. For a slug of given cross-sectional area, we can achieve different resistance values by varying the mixture of carbon versus NCF, i.e., vary the material's resistivity. An individual CC resistor is born from an extruded cylindrical slug that is cooked in a hot oven, then chopped up to length—say, 15mm.

The offcut becomes a fully fledged resistor after its ends have been metallized, followed by the soldering on of the leadouts. Or the wires may be soldered to a cap, itself crimped over the metallized ends (*Fig. 6*). Afterward, the slug is fitted with a snug phenolic jacket—the familiar brown body—and finally, it receives its color stripes.

The Crack Films (CF)

By the '50s, manufacturing technique "evolved," harking back to what Gambrell & Harris (UK) had developed and patented in 1897[2]: a thin film of the carbon-composition mix is deposited on a ceramic rod, to which the leadout wires are preattached. Only this time, the deposition was made with hydrocarbons, which are then cracked (i.e., decomposed into carbon) *in situ*. Carbon film resistors made in this way are variously known as *cracked carbon* or *pyrolitic* resistors.

For a deposition of given resistivity, the resistance depends on the film's thickness, but there's a limit to how thin you can go. In practice, high values are attained by spiraling. The process was originally patented in Germany by Kruger in 1919. It involves cutting a spiral groove along the resistor's surface, to translate surface area into length, thereby increasing the resistance. The same technique is applied to all the other film resistors: in conjunction with a limited choice of practical resistivities, spiraling makes it feasible to manufacture film resistors in more than 1,200 "E192 series" values spanning 1Ω to 10M, where stability dictates.

Compared with CC, the crack films were immediately superior yet cheap to make. So they were soon established as the standard part in the consumer electronics of the '60s and '70s: they were less hissy, could be had at an economical price in tightened tolerances, even (gasp!) ±2%, and their resistance remained more "stable" over time, lending the nickname "histabs."

The Metal Oxide Films (MO)

Resistors using a film of metal oxide first came into widespread use in the early '50s, as electronics came into its own in jet aircraft, ballistic missiles, et al., and designers cried out for stable, high-performance components. W.F.G. Swann had observed and patented the qualities of thin metal films in 1913. By 1955, the recipe involved spraying Stannic (Tin) Chloride onto the ceramic former, at red heat. The resulting hydrolysis yields a milky, translucent layer of tin oxide. A vital additive is antimony trichloride; given the right amount (about 7%), it yields MO resistors with *low* temperature coefficients. This mixture has a low resistivity, but then higher values can be attained by spiraling.

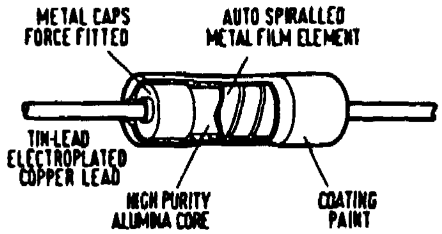

FIGURE 6: Cross section of a metal film resistor.

The resistance range was later extended as other doping substances came into use, namely the oxides of indium, bismuth and phosphorus. All of these have a *valency* in common, enabling them to combine with the tin ion (Sb^{5+}), converting it from a semiconducting substance into a linear resistance. Either way, oxide films born of this process are hard, they adhere well to glass and ceramics by fusing, and they are immune to common chemical reagents. They're also thicker (1μ, cf. 0.1μ for carbon films), which all goes to stress the themes of shock survival, chemical, and mechanical stability, and longevity.

Today's metal oxide resistors are manufactured by coating the film on a glass or ceramic rod. Either *substrate* needs to be produced with a very low alkaline content, otherwise free ions could drift in time, into the negative end of the resistor, and attack the film. After spiraling, silver is deposited at each end, and the end caps are forced on. Finally, the resistor is given a protective coating of silicone, or epoxy varnish.

Metal Alloy Films (MF)

Metal film (MF) resistors are a variation on metal oxide. However "metal" is a misnomer—strictly, we should be calling them "alloy film" resistors. British Thompson Houston Co. first patented "resistors compounded of metallic mixtures" in 1904. But it wasn't until 1957 that Alderton & Ashworth (UK) patented techniques for a practical, high-performance MF resistor, using a nickel-chromium (NiCr) mixture.[2] And until the '80s, they remained pricey and oddly esoteric, even though metal film techniques had long been applied to the microscopic resistors inside IC packages. From 1980, the learning curve paid up: dozens of brands of MF resistors with 1% tolerance have appeared at penny prices, swiftly displacing carbon films as the universal, ¼W resistor. *Figure 6* shows the construction of one such.

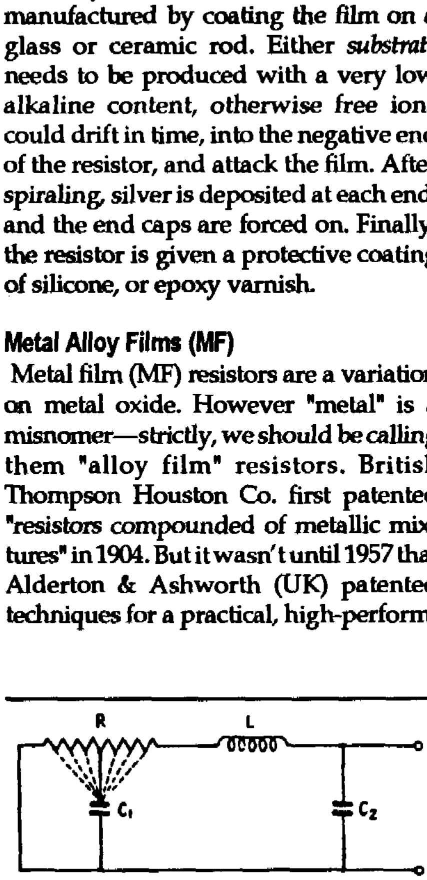

FIGURE 7: Resistor parasitics. R =pure resistive component; L =series resistance; C1 = distributed capacitance; C2 =shunt capacitance.

When evaporated and sprayed onto a glass substrate at high temperatures in a vacuum, the nichrome's resistive behavior is different from the wires in WW resistors and electric fire bars—the continuity between the particles isn't 100% homogeneous. If the manufacturer is greedy, and sprays the film too thinly, to achieve a higher resistivity, the particles swell. This lessens the incidence of particulate contact, leading to a resistance that's highly temperature sensitive, and noisy.

Manufacture is complicated by the fact that the nickel and chromium vaporize at different temperatures, not to mention the intervention of the small quantity of silicon in the nichrome alloy, which vaporizes between the two! Bad depositions show a negative temperature coefficient (tempco), like a semiconductor, whereas the most stable films show a slight positive tempco, around 50–100ppm/°C.

After deposition, aging in a hot oven is essential for long term stability, and helps the resistor to attain its final value, by oxidizing the surface. For example, Holco resistors are baked for eight hours at 300°C. When correctly made, the resulting film is immune to chemical attack, even by boiling hydrochloric acid.

Cermet (CMT)

The resistance mixture for cermet resistors and potentiometers comprises a

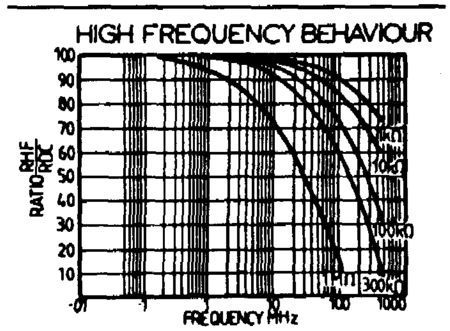

FIGURE 7a: Graph of the effects of resistance and frequency on a resistor.

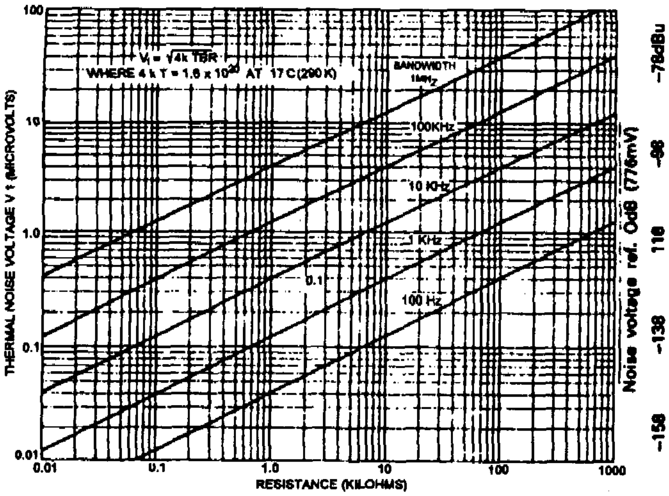

FIGURE 8: Thermal noise voltage as a function of resistance and bandwidth.

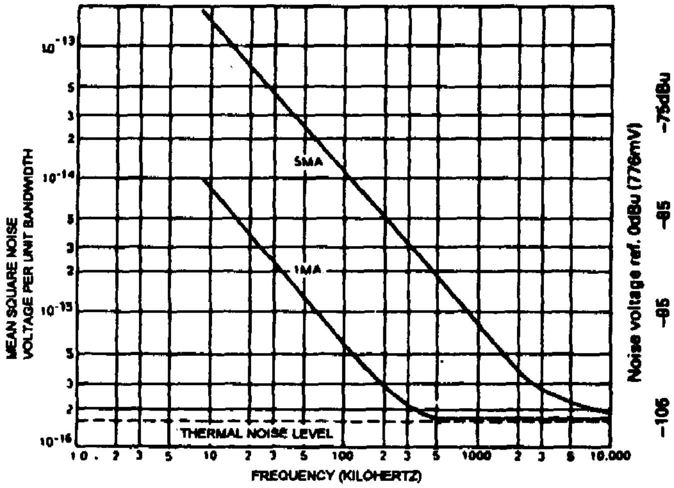

FIGURE 9: Noise versus current and frequency in a 10k CC resistor.

mélange of fine metal particles, metal oxide, and glass *frit*, variously applied to the former by screen or roller printing, spraying, or dipping. The deposition is then dried, and fired. A wide variety of chemicals can be used in the mix: some frits are of borosilicate glass, while the metals may include palladium, bismuth, rhodium, platinum, gold, and silver—and their oxides. (Hence cermet: a *ce*ramic *met*al concoction.)

With their varying proportions, the broad span of everyday resistance values between 10R and 1M can be readily fabricated without spiraling, and while temperature coefficients aren't as good as MF, cermet resistors are adept at withstanding long periods at high temperatures (>250°C) without grave changes in their ohmic value. Metal glaze is the trade name for a similar "thick film" cocktail, originated by IRC in the US: the film comprises precious metal alloys fused to a crystalline ceramic substrate. Only this time, film thickness is around 100μ, 100 times thicker than conventional metal oxide films.

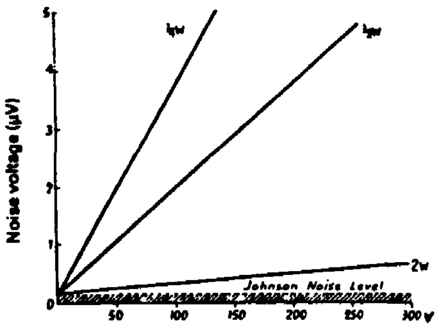

FIGURE 10: Noise in CC resistors versus wattage rating.

Conductive Plastic (CP)

First developed in the UK in the late '60s, conductive plastic rates as one of the purest resistive elements, though with irony, since it's really a high-tech development of our hoary old friend, the carbon composition mixture. In Penny & Giles' process, used for pots, carbon is carefully *diffused* to a depth of 20μ into a rugged plastic film, while cheaper "me too" CP elements are printed on a substrate with a carbon and plastic ink. *Caveat emptor.* Diffused CP shies away from dissipating power, so it's rarely encountered in fixed resistors.

Tolerance

The first of seven vices, tolerance reflects the nature of individual resistors in the realms of accuracy, stability, and reliability. As with capacitors, the allowable percentage deviation in a resistor's value (vis-à-vis the designer's target) differs, according to the job at hand. It's evident that the corresponding parts in stereo channels should be matched, whenever they define an audible parameter. Again, *absolute* values are sacrosanct in any EQ and filtration networks, as in RIAA stages, CD players and crossovers.[3,4,5]

For the resistors within gain stages (analog's building blocks), there's a new requirement. Inside IC op amps, it's impossible to produce resistors with anything like an absolute value. However, matching the ratio between two or more resistors on a chip is easily achieved to within +1%, or better.

Also, the chip's geometry can be arranged to keep them at the same temperature. Accordingly, the direct-coupled circuit topologies inside IC op amps were developed by Bob Widlar and others, to capitalize on this fact. More recently, the elegant topologies first used inside ICs have been progressively adopted by the designers of discrete circuits, so the importance of ratiometric matching has come to apply across the board.

Precision WW and MF resistors are available in the tightest tolerances, well below ±0.1%, if you're prepared to pay the price. Cermets, CP, and metal oxides are generally restricted to +1% or 2%, common wirewounds and carbon films are typically 5% at best, while composition resistors have a struggle keeping within ±10%. Generally the less precise resistors deviate more as they grow older.

Parasitics

Resistors aren't immune to the inductance and capacitance of the real world, but they're not afflicted as sorely as capacitors. This is evident from first principles: capacitors are concerned with storing and releasing energy, whereas resistors just dissipate it. Given a low enough value, this signals a wet blanket to any resonant tendencies.

In Dummer's classic,[1] the desirable properties for a resistor that's linear up to VHF (i.e., high RF) frequencies are cited succinctly:

"1. Its dimensions should be as small as possible; 2. It should be low in value; 3. A long thin resistor has a better frequency characteristic than a short fat one; 4. All connections . . . should be as short as possible. And 5. There should be no sudden geometrical discontinuity along its length."

Casting a glance at the equivalent circuit (*Fig. 7*), resistors exhibit a singular shunt capacitance across their leadouts (C_2), and a smaller, multiple, distributed capacitance from the film surface, to any adjacent conductor(s) or components (C_1). The effect of these is to reduce the effective value of a resistor above the frequency where the capacitative reactance begins to "bite." And the higher the resistance, the lower the frequency where a given error occurs (*Fig. 7a*).

In CC resistors, the shunt capacitance is quite high (say 5pF), enough to make even moderate values (c. 20k) hopelessly inaccurate above 1MHz. In film resistors, C_2 typically amounts to a mere 0.07 to 0.5pF, for ⅛ and 1W parts respectively. Physically large resistors also invoke extra longitudinal surface area, which only goes to emphasize distributed capacitance (C_1) to adjacent PCB tracks: much depends on the thickness of the resistor's jacket.

Inductance is a function of the resistor's length, so given the size of a ½ or ¼W part, it's principally extant in the leadouts, and mostly disappears once the resistors are soldered *tight* up to the PCB. Even at 2W rating, where the body length of a well-designed, modern part has doubled to about 18mm, a horizontally mounted resistor's inductance is generally below 0.2nH. Overall, it's evident that small (<1W), low-value (<10k) film resistors exhibit negligible stray in-

Excess Noise: A scoreboard

Maker	Model	Type	Value in Ohms	Noise* in μV/volt
—	—	wirewound	—	Essentially nil
Neohm	LR.1	metal film	10k	0.04
Piher	PM25		<270k	<0.1
			>270k	<0.5
Neohm	RGP0204	metal glaze	10k	0.05
Corning	FP2	metal oxide	<100k	<0.12
		(2 watt)	>100k	<0.6
Resista	WK5	(2 watt)	560k	1.0
Corning	LCA 0207	carbon film	<300k	<0.5
		(cracked)	>300k	<3
(USA)	MIL-R-11	carbon	10k	2.0
		composition	100k	4.0
			1M	6.0
			μV/V	

*Standard measurement bandwidth is 6000Hz, centered on 1kHz, but this isn't universally confirmed in maker's published data

FIGURE 11: How the resistors handle excess noise.

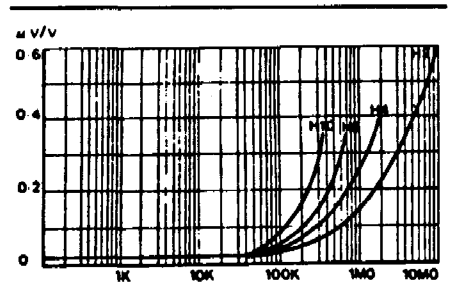

FIGURE 12: Noise versus resistance and wattage in Holco resistors.

A RESISTIVE GLOSSARY

Bifilar: A pair of windings connected back to back.

Frit: A ceramic or silica powder, a preparation for fusing or firing.

Resistivity: The comparative resistance of a substance, called ρ (pronounced "roe") given in ohm meters. Once length (l) and cross-sectional area (A) are known, the resistance (R) can be found: $R = \rho\, l/A$ ohms.

Substrate: A bedrock surface, prepared for the deposition of semiconducting and resistive layers.

Valency: Chemical numerology, a mating code for the chemical elements.

ductance and capacitance with respect to audio frequencies: at a push, they'll work happily up to 100MHz or above. Even when considerable spiraling is used to gain resistance, the incidental inductance has little effect below 50MHz.

In wirewound resistors, a bifilar winding (*Fig. 4*) can all but cancel inductance, but at the expense of emphasizing capacitance across the windings. For example, the 68k wirewounds used as anode loads in some tube amplifiers begin to look capacitative above 200kHz. An "Aryton-Perry" winding overcomes this by connecting four windings in series parallel, but uses four times as much wire in the process. In addition, wirewounds' body lengths are commonly in excess of 1½", which heightens the intrinsic inductance.

Capacitative reactance only becomes a real nuisance in audio, when we're forced into dealing with high-value resistors. Henry Ott, for example, reminds us that at 1MΩ, even a film resistor, with a 0.16pF shunt capacitance, presents an impedance of just 990k at 10kHz, and develops 3° of excess phase shift, rising to 34° at 500kHz.[6] This must be seen in the context of sundry, arbitrary, ancillary stray capacitances between components and conductors. Even so, it's small wonder the author has a calm, invariant preference for solid-state circuitry, where it's so much easier to work at low impedances: high-value resistors screw up amplifier phase margins, especially in tightly packed circuits where the distributed capacitance (C_1) comes into play.

Pure Noise

All resistors generate "Johnson Noise," alias "thermal noise." It originates in the agitation of electrons. Why agitation? Well, from the electrons' viewpoint, our comfortable listening temperature (20°C, referenced to melting ice!) is 293°C *above* their reference temperature, namely absolute zero (−273°K). And for any given temperature above zero, the electrons begin dancing. And the hotter they become, the more raucous their merrymaking. Since Johnson's discovery in the '20s, we've been hearing it often: it's white noise, the smooth and toppy hiss that emanates from vacant speakers and also FM broadcast frequencies.

In 1928, Nyquist in the USA made a breakthrough when he married electronics and thermodynamic physics with the famous formula: $V_T = \sqrt{4kTBR}$. Hmmm . . . The upshot is that for any given temperature, the thermal noise voltage (V_T) is proportional to the resistance across which it occurs. In other words, the higher the resistance value, the higher the Johnson noise. All other facts being equal, it's proportional to the square root of the resistance.

Except that we mustn't run away with the impression that the resistor generates this noise. Instead, it strictly *sustains* it, since the prime mover is arguably a noise current, which the resistance simply translates into a voltage: $I_T = \sqrt{4kTB/R}$. It follows that in audio circuits where the amplification is principally one of voltage, we'd best use low-value resistors for lowest noise, always provided we don't attenuate anything by doing so. *Figure 8* puts thermal noise into tangible form for a range of bandwidths, which just goes to show how "the wider you open the window, the more the dust blows in."

Noise to Excess

Thermal noise is unavoidable, a cosmic fact, but any others are strictly of the manufacturer's making, so whenever they're quoted in data sheets, it's under the banner "excess noise." Lumped together, they lack the neat Gaussian distribution of Johnson noise; the voltage varies erratically in time and against frequency. Frankly, these noises are dirty—a coarse, grainy burble that can easily fool the subliminal process of reconstructing ambient clues. In effect, subtle low-level information in a good recording is subject to a process like bad digital dither, insofar as our mental reconstruction of ambience and nuance is colored by the hues of the noise's prima donna spectral imbalance.

At this point, we mustn't lose sight of the fact that all active devices, be they tube, FET, or Bipolar, are fatuous and potentially overwhelming sources of dirty, 1/f noises, namely shot, flicker, and popcorn! And that the excess noise in resistors amounts to the same thing, a measure of particulate homogeneity.

Carbon composition resistors are the noisiest, since the multiple, imperfect contacts among thousands of discrete carbon particles are prone to fluctuate, with time, temperature, and vibration. The resulting contact noise is important, insofar as it's a magnified version of noise behavior in all other resistors, barring wirewounds. Contact noise varies widely among adjacent samples; if you've spent a lot of time using a phone with an old carbon microphone, the worst examples of contact noise are familiar enough. It may be aurally conjectured as the sound of hundreds of thousands of dirty switch contacts.

Figure 9 shows how the noise voltage (expressed in V/Hz) increases with the passage of a higher current.[6] It also increases monotonically with descending frequency, so any masking of sonic detail is biased towards low frequencies. *Figure 10* illustrates the gist of Campbell & Chipman's work in 1949, showing how the pain of excess noise may be allayed, by employing CC resistors with excess wattage ratings. This is a sign that

Continued on page 42

REFERENCES

1. G.W.A. Dummer, *Fixed Resistors*, (Pitman, 1964).
2. G.W.A. Dummer, *Electronic Inventions & Discoveries* 3rd ed. (Pergamon, 1983).
3. B. Duncan, "With a Strange Device," *Hi-Fi News & Record Review* (Nov. 1986): 41.
4. B. Duncan, "State of the Art Preamplifier" Part VI, *HFN/RR* (Oct. 1984).
5. B. Duncan, "State of the Art Preamplifier" Part V, *HFN/RR* (Sept. 1984).
6. H. Ott, *Noise Reduction Techniques in Electronic Systems*, (Wiley Interscience, 1976).

Experienced design engineers can completely predict and avoid all such artifacts. The consensus holds that it makes more sense to split the gain and equalization, with a buffer head amp, first for the non-equalized signal: then the equalization occurs with comparatively low closed loop gain, but using *shunt* feedback. The buffer stage can be tailored to match the type of cartridge used. This technique solves all the attendant problems, and it is good practice to check everything with the cartridge in circuit.

REG WILLIAMSON
Staffs ST7 4DE, England

Wilfred Harms responds:

What is the "one elementary aspect" to which you refer? If it is the formula A(n + 1)/A + n + 1, students may be taught it, then usually remember only the approximate form of it. This is apparent because designs for RIAA equalization of the type shown with a "standard" network appear frequently, but with a limited-gain preamp. My article's purpose was to draw attention to the shortcomings and to provide a simple way to cope with the circumstances, with regard to the available gain "A" and the acceptable "G." So far as I am aware, this has not previously been demonstrated.

You mention two points—the harmonic distortion at the bottom end (bass?) and the deviation from linearity at the high end. Surely both of these are dealt with in paragraph 6: "G should not be less than 15 and not higher than A/30." The required VLF response (+20dB) is ten times that at 1kHz, and with G less than A/30, running out of feedback should not arise.

One can go on and on about RIAA equalization and what is the "best" arrangement to adopt. This, however, is another story. □

PASS ZEN AMPLIFIER

Continued from page 15

the dissipation and voltage ratings of the components are the elements which deserve attention.

Aside from better capacitors and such, are there other ways of making the circuit better? It so happens that there are, and the best of them is the subject of a patent recently granted to Pass Labs. If there is sufficient continued interest in this approach to amplification, perhaps it will form the basis of another article.

[If you are interested please send a postcard to MOSFET ZEN, Audio Amateur Publications, PO Box 576, Peterborough, NH 03458-0576. These cannot be acknowledged or answered—Ed.] □

PIÈCE DE RÉSISTANCE

Continued from page 24

contact noise relates to the resistor's dissipation, geometry, and the mix of resistive material.

Figure 11 charts typical excess noise for the remainder of the cast, while *Fig. 12* displays noise versus resistance versus wattage rating for Holco metal film resistors, succinctly illustrating the general behavior of film resistors: absolute noise is low, and in high values, it's least in the higher wattage ratings (H10 = ⅛W; H2 = 1W). Otherwise, it apparently increases disproportionately for high values (>50k in this instance).

But wait: notice how the noise level is given in µV/V (microvolts per volt), signifying there's a defined voltage applied across the resistor. Typically, the voltage is chosen to dissipate a constant power (e.g., 100mW), so the bias voltage varies from 200mV for values of a few ohms, up to 250V or more, for megohm values. From this, we may infer that the excessive noise of the high values only applies when high static voltages are imposed across them. As in tube amplifiers' anode loads, and in ESL networks. So high-value resistors can live quietly in most transistor signal paths, thanks to the absence of high DC voltages. □

MAKE YOUR OWN LOGOS

Continued from page 30

Step 5: Apply the Film

Trim the drafting film logo to provide at least ½" excess material on all sides of the emblem. Partially peel the backing material from the drafting film logo, and apply the film's exposed portion to the blank. Simultaneously peel off the remainder of the backing while smoothing the film onto the emblem blank. (This prevents trapped air bubbles.)

Cut vees into the excess film at each corner (*Photo 7*). Fold the excess film around the back of the emblem. This prevents the film from peeling and allows the edges of the emblem to be covered. Now attach the finished emblems to your speaker grilles or project faces with glue or double-sided tape. □