Tube Coolers and Equipment Reliability

A TUBE COOLER is a device that reduces the operating temperature of the enclosing, glass envelope of an electron tube. While some elements within the envelope are required to operate at high temperatures, a surrounding enclosure of conventional, "soft" glass is quite vulnerable to elevated temperatures. Through the action of several mechanisms extensively outlined herein, this weakness can result in drastically reduced tube life.

Although common knowledge in other sectors of the electronics industry for decades, this important information seems to have escaped the attention of all designers of tube-type audio gear. We have, with just one notable exception, never seen tube coolers factory-fitted to any audio equipment modern or vintage.

The glass envelope, which must act as a high quality vacuum container, is required to perform several functions: [1]

- it must withstand high operating temperatures, substantial attendant temperature gradients and consequent physical stress; without failure.
- at high temperatures, it must resist the pressure differential between the internal high-vacuum and external atmospheric pressure
- it must be chemically inert, neither adsorbing gases during manufacture nor liberating them under high-temperature operation

As the foregoing is essentially a description of an ideal material, real problems must be anticipated if soft glass is expected to maintain a high vacuum over a long period under the conditions imposed by typical vacuum-tube operation.

While most types of glass are quite stable at low temperatures, soft glasses become "porous" and begin to outgas with temperature increases. Where long working-life is a primary consideration, over-temperature operation is the main reliability issue encountered in the operation of soft-glass enclosed vacuum tubes.

Tube manufacturers, the military and many large, commercial users have long been aware of the hazards of such operation and the benefits of reductions in bulb temperature. Tube makers in particular are aware that tube life is an inverse function of bulb temperature.[2, 3 (see also Appendix 3)]

The MULLARD OSRAM VALVE CO. in England printed the lettering and the Gold Lion logo on their famous KT 66-77-88 series with a temperature-sensitive lacquer† that would change colour on any tube run over-temperature. Tubes run too hot were then permanently indicated to be "...unsuitable for further reliable service".[4 (see also Appendix 1)]

The basic concept of glass envelope tube cooling was developed in the 1950s by International Electronic Research Corp. of Burbank, California working in conjunction with several branches of the US military, Cornell University Engineering Laboratories, various tube manufacturers and numerous large corporations. As a result of extensive research into causes of equipment failure and the remedies required, a large number of technical articles appeared in the literature of the period. Using this substantial and well documented body of work as a starting point, PEARL has developed a new and highly efficient type of cooler for simple, straightforward, retrofit installation to most existing audio equipment.

AN HISTORICAL & TECHNICAL OVERVIEW

With increasing equipment complexity during and after WW II, the causes of equipment failure came under intense scrutiny from a number of agencies. The commercial airlines in the USA formed and maintained the non-profit organization, Aeronautical Radio Inc. (ARINC) to coordinate the development of electronic equipment for their use, both ground and airborne.[6, 7] The military in particular, became very dissatisfied with the overall rate of equipment failure it was enduring. The cost of the ongoing maintenance effort required to keep its vast quantities of equipment safely and reliably operational grew to enormous proportions. Seeking to alleviate these problems, numerous tube manufacturers were contracted to produce studies that would detail the reasons for equipment failure in general and tube failure in particular.[8, 9, 10]

†Tempilaq is such a product and is available in North America from: TEMPIL, Div of Big 3 Industries, S. Plainfield, N.J., 201 757 8300

The consensus of this work was that while resistor and capacitor failures accounted for approximately 7% of failures, an amazing 75% of failures were due to tubes. Subsequent, detailed investigations carried out by numerous, widely separated researchers revealed that tubes will fail in a radically premature manner when forced or simply allowed to operate at excessive bulb temperatures.[10] (see also Appendix 3: ref's 7, 8, 9, 10, 11, 12)

A study of over 150,000 tubes of 20 different types undertaken by ARINC lists a number of procedures that increase the reliability of vacuum tubes.[8] Foremost amoung these measures is the operation of tubes in a manner that reduces bulb temperature.

In order of decreasing adverse effect on tube life, excessive bulb temperature causes:

- the evolution of gas within the tube, which causes the steady reduction of transconductance. Left unremedied, this process can cause the tube to glow with a lovely electric blue colour while acting as a forward biased diode.
- in part, the development of an interface resistance between the surface of the nickel tube that forms the body of the cathode and its electron emitting oxide-coating. This effect is partially the result of over-temperature operation of the cathode and can be caused by:
  - excessive filament current,
  - excessive overall operating temperature,
  - in some types, long periods of operation in a cut-off condition resulting in the development of such a high value of resistance that current flow will not restart when the tube is biased so as to resume current flow. This was a problem with the famous ENIAC (Electronic Numerical Integrator and Computor) developed as part of the Manhattan Project during WW II. Special tube types, 6SN7GTB & 5692 for example, were developed for such applications. Interface resistance is also responsible for reductions of transconductance.[10, 11, 12, 13] See Fig. 1.
- grid emission, a prime factor in the noise increases seen as tubes age. A slow accumulation of cathode material on the grid wires initiates an ever increasing, low-density electron flow from the grid to the plate. Flowing from ground through the grid resistor, this fluctuating current develops a noise voltage that appears between the grid and signal-ground. Being thereby applied to the input of the tube in the usual way, this noise voltage is likewise amplified in the usual way.

By parts, the deposition process is an outcome of the water cycle, later described, operating in tubes run over-temperature and also the result

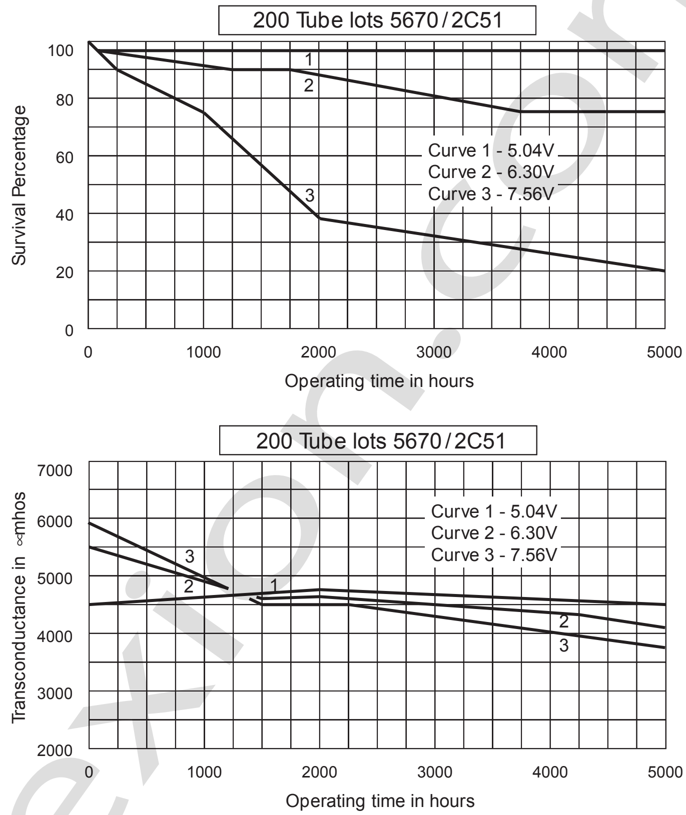


Fig. 1. Tube transconductance and working-life are shown plotted as a function of filament voltage. Note that operation of this particular tube at its rated filament voltage results in a 27% drop in transconductance during the first 1500 hrs. of operation. Operation of the filament at a 20% reduction in voltage results in very nearly constant transconductance over a much extended working-life.

of full B+, cold-cathode startups.

- cathode poisoning, resulting in a premature reduction of electron emitting capacity (perveance).[14, 15] The authors of these references state that:

"A new and unexpected source of cathode poisoning gas is seen to derive either directly or indirectly from the heated glass envelope. Such gas is more destructive in action than any of the normal gas so far examined This gas is believed to be water vapour which has been shown to have dire effects on cathodes operating in the vicinity of 725 °C."

- migration of both the getter patch and unflashed getter material, another likely result of the water cycle.
- interelectrode leakage, whereby voltages impressed upon specific elements within the tube wrongly appear on other electrodes. This can be caused by water cycle induced migration of conductive getter metals onto the insulating micas and to the base of the envelope, where the pins exit the tube, causing lowered resistance among the tube's elements.
- contamination, resulting in tiny bits of mater-

ial coming adrift within the envelope.

- glass failure, with attendant loss of vacuum if not outright failure.
- increased grid temperature that can result in increases in the normal thermionic emission from control grids. In poorly designed circuits this effect can cause grid runaway, where normal grid bias is lost and plate current rises to saturation levels in an uncontrolled manner. The typical outcome is the rapid demise of the tube in question.

The glass envelope of a tube presents a significant resistance to the flow of heat from the tube.[16] Glass is a very poor thermal conductor and is virtually opaque to thermal radiation at temperatures below 400°C. Consequently, the envelope absorbs nearly all of the heat radiated from the elements contained therein with the result that a hot-spot occurs in the glass adjacent the centre of the plate, the hottest part of the the tube structure. This hot-spot causes a substantial temperature gradient along the length of the envelope that can result in the centre of the envelope running 25 to 100°C. hotter than either of the cooler ends. This creates enormous physical stress within the glass and in extreme cases can result in failure. See Fig. 2.

An interesting piece of work done by Rogers Majestic Co. of Toronto in 1933 suggests a mechanism whereby something like atomic osmosis occurs at high glass temperatures.[17] The hypothesis is that the sodium in the glass becomes mobile and acts as an electrolyte thereby facilitating the bodily migration of atoms of atmospheric oxygen through the glass and into the tube. These reduce the usable life of the cathode by combining with its electron-emitting surface, creating oxides that reduce its effectiveness. It is likely that other gases evolve from this poisoning action and these can adversely effect the hard vacuum upon which the tube relies for linear and effective operation.†

Noted by workers in the incandescent lamp industry is the fact that glass envelopes will begin to outgas into the evacuated volume when the surface temperature exceeds 100°C. The evolution of gas is bought about by chemical decomposition and release of adsorbed molecules which are, principally, water vapour, carbon dioxide and nitrogen. With further increases in temperature this process dramatically intensifies and usable life is sharply reduced by the initiation of a water cycle described below.[18]

Water vapour is dissociated by the hot internal elements within the lamp or tube into hydrogen and oxygen. As well as reacting with the cathode material of the tube, the oxygen will react with the other metallic surfaces such as the getter patch†† and any unflashed getter material, with some of these areas being hot enough to blow off an oxide that can then deposit on various cooler surfaces. Meanwhile, the highly reductive hydrogen migrates to the deposit, reduces it—liberates the oxygen from the oxide—and leaves the deposit as recombined water vapour ready to begin the cycle all over again.

In its ionized form, the hydrogen acts to reduce the electrical resistivity of the vacuum by turning it into a partially conductive medium, thereby subtly, yet continuously, decreasing the tube's ability to accurately control electron flow through itself.

While gas penetration and out-gassing are significant mechanisms by which the vacuum is spoiled, excessive temperatures can cause various gases to evolve from the elements within the tube

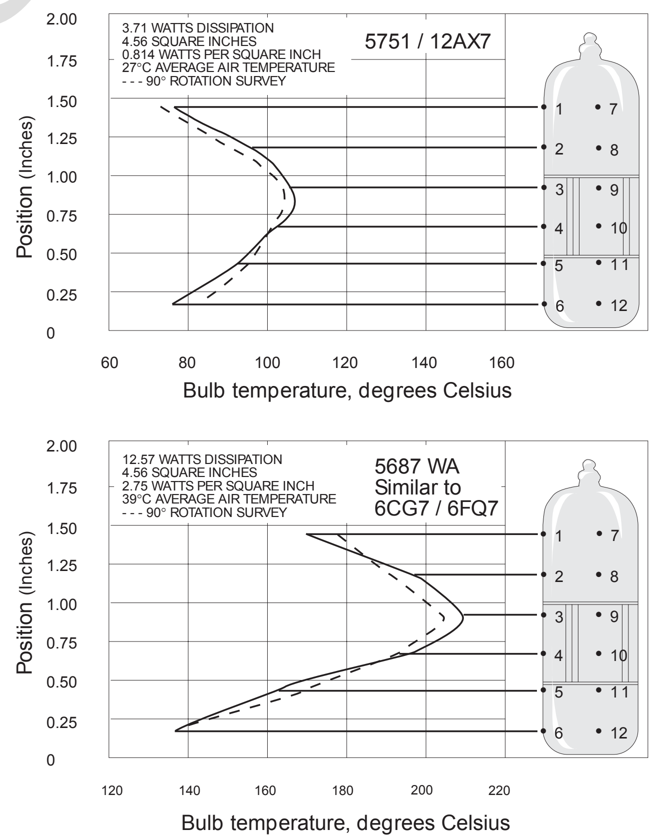


Fig. 2. Bulb temperature plotted as a function of position on the bulb. It is interesting to note that the 5751/12AX7, a relatively cool-running tube, is one of the most reliable and longest-lived of any used in audio.

†The need for thorough bulb evacuation escaped the originator of the triode, Lee deForest. It was not until his successors started pulling a genuinely hard vacuum within the envelope that the wonderfully linear triodes presently enjoyed could be developed.

††The getter patch is the shiny, mirror-like spot seen on the inside of most receiving tubes. It results from the combustion—for want of a better term—of the getter, a sacrificial element placed within the tube. After the envelope has been pumped out and sealed, the getter is heated by RF induction to a high temperature. The special formulation of the getter combines with any remaining gases within the tube to form metallic compounds that subsequently boil themselves onto the inside of the glass wall creating a reflective spot on the glass.

structure itself, particularly from the plate. We suspect that these actions are responsible for the slight dimunition in sound quality often heard from tubes run too hot during the first few hundred hours of life even though conventional "usable life testing" will indicate that the tube is fine. It must be stressed that the various mechanisms of deterioration can operate as a higher-order exponential function of temperature increase. If the tube hot spot temperature is reduced 25 to 150°C. the rate of these various contaminating and poisoning actions can be reduced 2 to 50 fold. In other words, small decreases in bulb temperature often result in seemingly disproportionately large increases in tube life. See Fig. 3.

In dozens of studies, tube life has been shown to dramatically increase as overall bulb temperature is reduced. However this must be achieved by means that substantially eliminate the temperature gradient along the bulb length. For this reason simple fan cooling, while effectively reducing the ambient temperature within equipments (and thus the average temperature of the envelope), cannot approach the results obtained by a properly designed tube cooler.

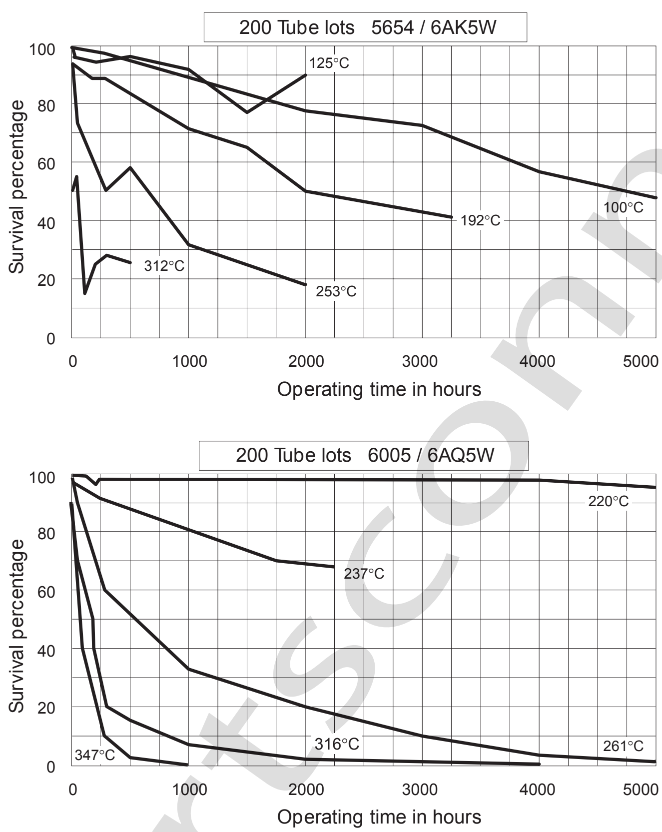


Fig. 3. Taken from GE's major study of vacuum-tube life done in 1954, these data illustrate the extremely harmful effects of elevated temperatures It is interesting to note just how very abruptly tubes will fail when operated at unreasonably elevated temperatures. For instance, after 2500 hours of operation, a mere 15% of a batch of 6005 tubes run at 261°C. are operational while 90% of those run 41 degrees cooler at 220°C. survive 5000 hours. That is the equivalent of 6 times as many tubes living twice as long.

Fig. 4 illustrates the sort of gradient equalization required to substantially increase tube life, while Fig. 5 illustrates the limited value of forced air cooling of bare bulbs. Fig. 6, derived from IERC'S work, shows that a tube with a properly designed cooler can run at a lower temperature in a simple convective environment than does the same tube running bare in a 500´/min forced air stream. Figs. 1,2 & 3 were taken from a landmark study of the factors effecting tube life conducted by W.S. Bowie at GE's Owensboro, Kentucky facility in 1954.

We spent 18 months researching the effects of glass temperature reduction and the development of our present coolers resulted from that work. We consider this project to have been successful in that the sorts temperature reductions and gradient elimination repeatedly shown to substantially increase tube life have been achieved.

Numerous military, institutional and commercial studies involving thousands of tubes in scores of operating environments and conditions have shown that bulb temperature reductions on the order of those achieved by our coolers yield tube life in the many thousands of hours. While many of these studies showed increases in tube life of 5 to 50 times, none showed improvements less than a doubling of previous life.

Illustrative of the sort of reliability gains obtainable by reducing bulb temperature is a study undertaken ARINC. [Appendix 1, ref 15] This was a two year long field observation of an equipment using 6-6005 miniature tubes. Prior to the commencement of the study, the average-tube-life was under 1000 hours. By simply outfitting the gear with heat-dissipating tube shields the average-tube-life skyrocketed to 12,000 hours. Study of Fig. 3 will reveal the plausibility of this result.

Several manufacturers of audio equipment list the expected life of power amplifier output tubes in the 1-2000 hr. range. By the simple application of tube coolers these short life expectancies can be at least doubled. Being a low-cost, reusable, one-time investment, tube coolers can yield substantial savings, not only in tube replacement costs but by way of a reduction in concern

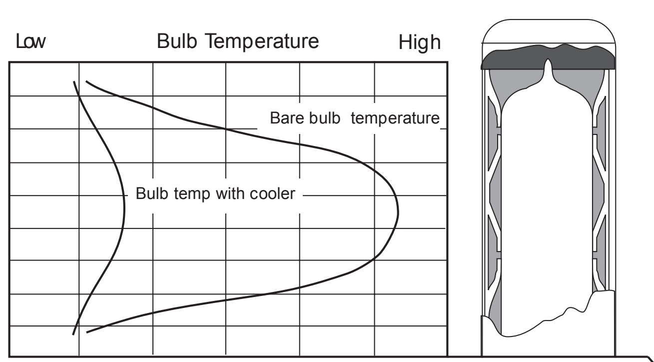


Fig. 4 . Tube-surface temperature gradient with proper cooling.

over the condition of the tubes in ones equipment. With tube gear costing what it does, no one's needs are well served by ongoing tube deterioration and the need for costly tube replacement every year or two

A Few Particulars of Design

It is somewhat unusual for a manufacturer to mention the products of other suppliers. However we feel a definite obligation to provide information about IERC's coolers as they were producing and selling their devices, by the hundred thousand, well before we took up our careers in audio.

The differences between our product and IERC's are significant and relate largely to the fact that printed circuit boards are a way of life in electronic manufacture today whereas during the 1950s, point-to-point wiring within a metal chassis was the order of the day.

As IERC's coolers are chassis-mounting devices, employing the ample sink provided by the equipment's metal work to dissipate heat, they are not well suited to installation on pc-board constructions.

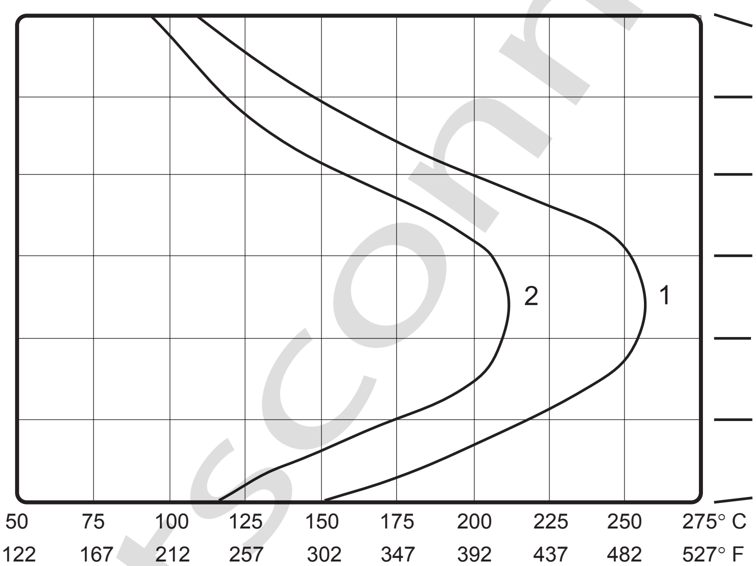
PEARL coolers dissipate heat directly into the atmosphere from a large area, radial fin arrangement and are not dependent upon the presence of any additional heatsinking metalwork. See Fig. 7.

While this has advantages for modern, stationary equipment such as home audio gear, we have been required to sacrifice the small size and tube retention capability of the IERC devices. Due to the conditions of extreme, acceleration, shock and vibration encountered in early guided missiles and other military hardware, IERC's coolers were designed to hold both the tube and themselves firmly in position.

As we don't expect that anyone who owns high performance audio gear is going to hammer it pell mell down 40 miles of washboard road in the back of a 4 x 4, we have designed and optimized our coolers to do three things; retrofit easily, effectively dissipate heat via convection and radiation and help damp the internal resonances that define the degree of microphonic output a tube will exhibit. Because of our differing design goals we have been able to concentrate quite single-mindedly on maximizing heat removal from the bulb.

In order to effectively sink heat from the glass envelope into any cooling device, a significant amount of metal must be placed in contact/close proximity with the glass surface.[19] This is rather difficult to do because the glass envelope of a tube is neither perfectly round nor parallel-sided.

Further complicating this situation is the need for firm metal-to-glass contact in spite of significant vari-



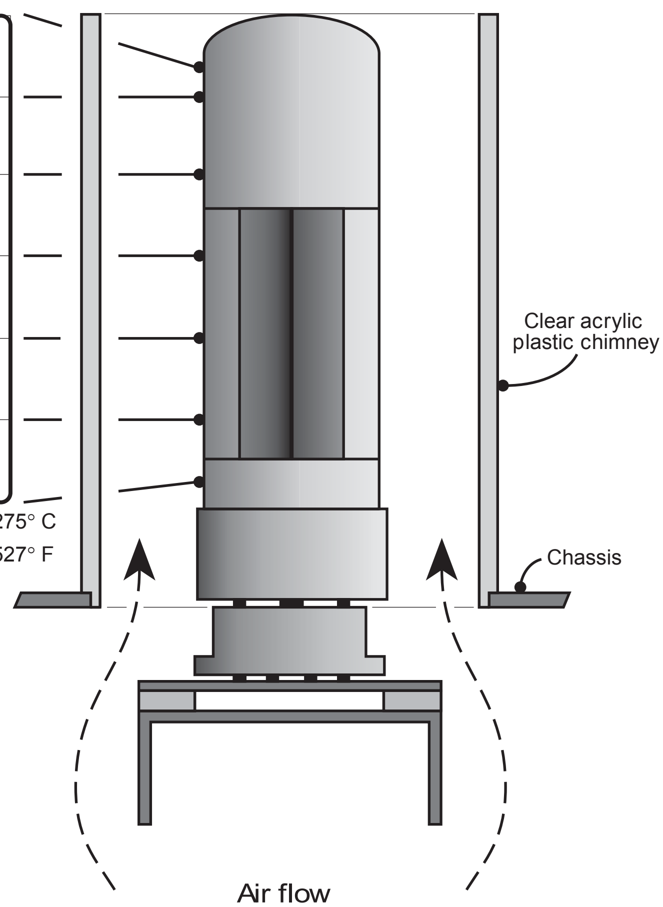


Fig. 5. Bulb temperature-gradient is shown for an EL34 running at maximum dissipation. Curve 1 is for a tube running in free air with no forced-air cooling. Curve 2 is for the same tube running in a 100ft/min air stream guided by a plastic chimney, as shown.

Note that while the average temperature of the bulb is reduced, the substantial gradient is essentially unchanged. The use of a chimney to direct a low-speed air-flow over the tube is a much better approach than gently blowing air, from some distance, at a tube. The temperature reduction, as shown here, is much greater than is otherwise the case. Tubes placed directly in high-velocity air-streams do show significant average temperature reductions with corresponding life extension.

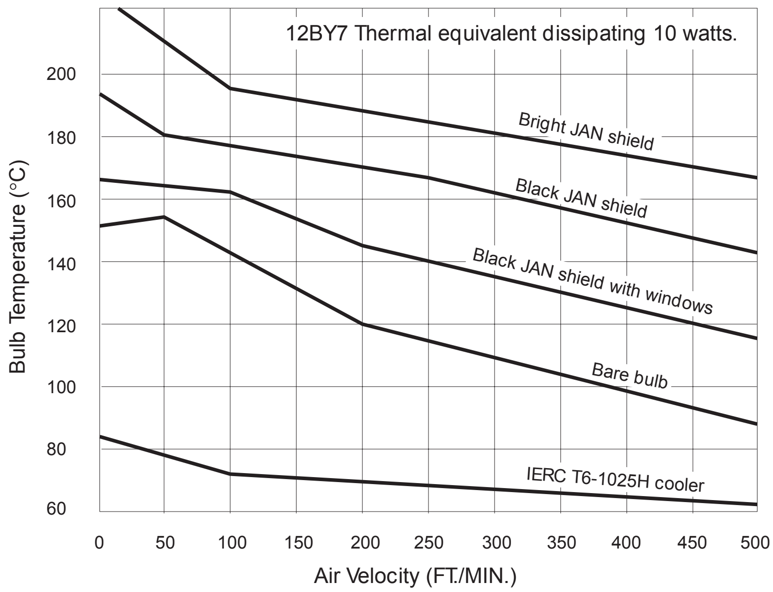


Fig. 6. The operation of a thermal-equivalent tube developed by Cornell Aeronautical Labs is shown under various conditions. Note that a bare bulb in a 500 ft/min airstream runs hotter than when properly cooled in still air. The Joint-Army-Navy—JAN—shield is the (usually) shiny slip-on affair most people recognize as a tube shield. Note the overall increase in temperature its application always causes. Such an increase has been repeatedly shown to shorten tube life and for that reason its use was virtually banned by the US military by 1960. This fact seems to have escaped the attention of designers & builders of Golden Age audio gear as it is by no means uncommon to encounter such equipment employing the worst-case-bright-JAN-shield.

ability in bulb size among different brands of the same tube type. For instance, the EL34 is found in bulbs of three different sizes, the 6550 in two sizes and so on.

Power tubes are typically enclosed within 1⅛″, 1¼″, 1½″, 1¾″, 2″ and 2½″ diameter bulbs, small signal octal tubes within 1⅛″ & 1¼″ dia. bulbs, 9 pin miniatures within .80″ to .84″ bulbs and 7 pin miniatures within .70″ to .73″ dia. bulbs.

The fairly small deviation in size among the 7-pin and 9-pin miniatures, allows us produce only one size of cooler to fit each type while achieving the required metal-to-glass intimacy. The most workable solution we have found to the problem presented by the wide variation in bulb size seen with power tubes is to produce coolers to individually fit the various bulb diameters encountered. As we need to know the diameter of the tube to be cooled, we supply a special order form that has a direct-reading, diameter-ruler printed at the bottom that is intended to be snipped off and wrapped around the tube. The diameter indicated is simply entered on the form so that we can supply the correct cooler.

PEARL coolers are held against the bulb by a compressive band arrangement, with round, high-temperature, elastomeric bands providing the compressive force.

In cases where tubes are placed too close together to allow the use of the compressive bands they can often be dispensed with and the coolers will hold themselves with adequate force against the glass. This way coolers can be fitted onto adjacent tubes that are as little as .55″ bulb-to-bulb from each other.

Our coolers are formed from solid copper foil into a radial fin arrangement that acts as a static fan to pull cooling air through the fins of the device. Being made from fairly thin material the cooler flexes easily and thereby accommodates deviation from bulb roundness and side-wall parallelism.

The coolers are easily fitted by simply placing the device on its end on a flat surface, pushing the tube into the centre hole and then sliding the cooler a further ¼″ to ½″ onto the bulb as required. The compressive bands can then be adjusted on the cooler to give a tidy appearance. In the event that a large bulb is forced into a cooler of an inappropriately small size, the fins will simply spread open and deform, no damage will occur to the tube and hence there is no possibility of receiving nasty cuts from the ragged edge of a bulb broken by excessive insertion force.

As a potential purchaser of PEARL tube coolers you can reasonably expect to get at least double the life from any new tube no matter how little power it is dissipating (ie. a 12AX7) and very probably three to five times the life from hot running power tubes in output stages where the amplifier is being driven hard and/or biased to run well into Class A operation.

Coolers are available to fit straight-sided envelopes only, with models to fit any such device from small 7-pin miniatures to fan-cooled applications involving large transmitting tubes such as the 813, a 100 watt pentode.

SOME POSSIBILITIES FOR SONIC IMPROVEMENT

Designers may select higher operating currents in pre-amp stages thereby realizing gains in transconductance and consequent noise reduction previously attainable only through ongoing aggravation and cost to the end-user due to constant tube deterioration and replacement. Such increases in current flow also result in a lowering of the plate resistance, r_p , and as a result of the smaller values of cathode resistor used to bias for increased current flow, the effective plate resistance, r_p'. This lowering of the voltage amplifier's output impedance allows improvements, for instance, in the ability of no-feedback line stages to drive the highly capacitive cables so (unfortunately) prevalent in high-end audio today.

Fig. 7. The various styles of PEARL coolers are illustrated above. The types for 7 & 9 pin miniatures and small-signal octals (6SN7, etc.) are essentially similar, differing only in the number of fins and the size of elastomeric band used to compress the cooler. The standard glass-to-glass spacing is .75” or 19mm however when tubes are too close together the O-rings can sometimes be omitted allowing the colers to be fitted where clearances are as marginal as .55″ or 14mm glass-to-glass.

Power stages may be biased somewhat further into Class A operation with an attendant sweetening of harmonic structure and gains in soundstaging, transparency and relaxed musicality These improvements are particularly impressive in those output stages operated fixed-screen-voltage pentode/beam tetrode; see our Audio Notes 2.1 & 2.1.1, A Little Input on Audio Output Transformers & Update for more information.

Several users have reported being rather perplexed by the improvements in sound quality that manifest when coolers are fitted “on the fly” to equipment that is operating. There is the immediate relaxation of the sound quality that we associate with reduced microphony and there is a further improvement with time as the bulb temperature reduces.

Radiant thermal energy from the plate structure is largely responsible for heating the glass, with the glass being a poor thermal conductor. It is reasonable to think that a build-up of heat in the glass causes a buildup of heat in the plate. If a cooler is applied to the glass, resulting in a reduction of glass temperature, it is reasonable to assume that the plate temperature will reduce as well.

We have reason to believe that there is a relationship between plate temperature and the thickness of an electron gas or film that must exist near the surface of the plate. Being in a state of chaotic motion, the electrons that make up this film will have the effect of modulating the density of the incoming electron beam in an unpredictable way. In other words, this film adds a noise component to the signal being amplified and does so to a degree that can be shown to be a function of plate temperature.

The presence of such a film is a near certainty in that the conditions necessary for its creation, ie. pure thermionic emission, cathode-splatter-aided thermionic emission and secondary emission, are all met by activity at the plate surface. Given the foregoing, it can be surmised that it’s possible for a cooler plate structure and a consequently reduced noise-film thickness to produce less of what could be called a signal induced noise. There are a great number of such SIN effects operating in audio devices of all kinds and their reduction nearly always results in a sound that is smoother, more natural and less grainy. Sonic improvements of exactly this sort are being reported by many users of tube coolers.

There are basically three mechanisms by which which a stray-electron film could be produced and these are outlined below:

- Thermionic Emission – If a material is heated in a vacuum, the presence of an electron cloud can usually be detected close to the material's surface. Thermionic emission has been shown to increase in intensity as a higher order function of increasing absolute temperature—measured in degrees Kelvin, which start with the O° point being absolute zero.[20, 21]

  In other words, many materials will emit electrons when heated and do so with an intensity that increases dramatically as temperature is increased. The outer-orbital electrons of the atoms of metals are not firmly bound to their nuclei and are believed to pass from atom to atom in bucket-brigade fashion, with this property widely held accountable for the electrical conductivity of metals. These loosely bound electrons are sometimes likened to the molecules of a heated liquid as they are in constant, unpredictable motion and often leap from the surface in an attempt to escape from it. Such departure induces a positive-electrostatically charged area within the host material that attracts the negatively charged electrons back to the surface from which they escaped. The force of re-attraction set up by the escaping electrons is called an image force

  In order for electrons to make good any attempt to leave the surface, some energy must be added to the electrons while they are contained within the metal—energy that provides the velocity required for escape and that will be lost upon the electron's emergence from the metallic surface.

  The kinetic energy lost in this manner differs in amount from one material to the next with the term electron affinity being used to describe the amount of energy that must be added to the material, usually by heating, to provide adequate electron escape velocity to overcome the image force. Materials with low electron affinity will emit substantial numbers of electrons with only moderate heating while those exhibiting high electron affinity require much higher temperatures for equivalent emission.

- Cathode-Splatter-Aided Thermionic Emission – During the process of tube manufacture some of the low-electron-affinity coating applied to the cathode almost invariably makes its way to the plate and other elements within the tube.[22] While the grids can sometimes be run hot enough to blow-off such deposits, some material tends to remain bound to the plate.[21]

  Additional cathode material is normally stripped off the cathode in circuitry where the B+ voltages are applied to tubes before the filament has heated the cathode to a suitable operating temperature. In this condition of no appreciable current flow through the tube, there is no significant voltage drop across the plate load resistor resulting in the presence of nearly the full B+ voltage on the plate of the tube. This voltage typically being at least twice the normal operating plate voltage, the electrostatic force of attraction from the plate acting on the cathode coating is likewise at least double that seen in normal operation. By these mechanisms the plate is usually contaminated with some amount of highly emissive, low-electron-affinity cathode-coating material.

- Secondary Emission – "When a solid body is subjected to bombardment by electrically charged particles, some electrons that may be detected under suitable conditions are always emitted. Although this process, commonly designated secondary emission has been seen to occur in various forms, by far the most widely investigated type is that in which an electron beam falling upon the surface of a target in a vacuum causes the emission of a stream of electrons from the surface upon which it impinges." [23.]

  Secondary emission of electrons from the plate of a tube results primarily from collisions between incoming electrons from the cathode—which may penetrate some distance into the material—with electrons in the material itself. The usual result is that several electrons are kicked out of their orbits within the plate material and into the space in front of the plate by every electron striking the surface. The secondary emission phenomena is unique in several ways as regards other types of electron emission activities. It does not appear to be effected by temperature nor overly much by the nature of the material being bombarded, with materials of widely varying characteristics showing variations in emission of only one order of magnitude all other things remaining equal. Conductors and insulators alike show quite similar patterns of secondary emission. There are however, a couple of factors effecting secondary emission that are pertinent to this discussion. Incoming electron velocity, whether generated by an accelerating gun or screen-grid arrangement (as in a pentode) or a positive potential on the target surface (as on the plate of a triode) shows a marked effect upon the liberation of secondaries. High incoming-electron velocity yields high secondary emission.

  The angle of incidence at which an incoming electron strikes the target shows a significant effect, with grazing angles of incidence yielding two to three times the secondary emission of normal, 90° impact.

In summary:

- the intensity with which thermionic emission takes place is very much a function of the temperature of the surface and the electron affinity of the material at the surface. Coatings as thin as one molecule in depth can have a radical effect on the operating electron-affinity of a material.[†]
- the intensity with which secondary emission takes place, as it concerns us here, is a function of incoming-electron velocity and the angle of incidence at which incoming electrons strike the surface.

Using this information it is possible to form a reasonable theory that can explain several seemingly peculiar phenomena that effect the sonic signature of different tube types. The basic idea is that the presence of a film of electrons at, and likely just penetrating, the plate surface will have a significant effect on the sound of a given tube.

This notion may be borne out by a couple of observations repeatedly made by audiophiles over the last thirty years.

The so-called 'flat-plate' Telefunken 12AX7 has long been regarded as the best sounding 12AX7 ever produced. As its name implies, the plates in the Telefunken part are flat while other brands have stiffening ribs pressed into the plates by way of depressions running across each plate. As previously explained, secondary emission is much greater when the incoming electron stream strikes obliquely against a surface.

Incoming electrons striking the flat plate of the Telefunken style device will produce less secondary emission than when in collision with the ribbed plate of the conventional construction, thereby creating a lower electron-film density in the flat-plate part than in the ribbed-plate device. Because the 12AX7 is a cool running, low transconductance tube it likely does not suffer greatly from thermionic plate emission from either cause so most of the noise-producing electrons will be generated by secondary emission.

The second seemingly odd observation is that tubes with plate structures that are a shiny black appear to give a cleaner, more open sound than tubes of the same type with plates that have not been treated to produce that sort of surface. I presently believe that such a surface results from graphite dusting and subsequent hydrogen firing of the plate structure but more research is needed to confirm this speculation. Because carbon has a high electron affinity, thermionic emission from the plate will be lower than for untreated parts. Hence the electron film producing effect of plate emission will be lower for a carbon treated plate.

This thought is consistent with the foregoing ideas in that it strongly suggests that a reduction in plate emission—either thermionic or secondary—contributes to an improvement in sound quality.

Although changes in design of tube internals must be implemented by the manufacturer, there are a couple of ways that an end-user or designer can use this thinking to improve the sound of a given circuit.

The first, and easier of the two, is to reduce plate temperature by simply fitting a tube cooler.

The second is to carefully reduce the plate voltage. Such voltage reductions must be undertaken with the idea firmly in mind no panacea is at work and that the method is viable only in low-level circuitry where input voltages are low and individual triode gains are moderate—as in the bottom section of a conventional cascode in a phono input stage.

Attempts to run higher-level stages at low plate voltages can result in steady-state harmonic and IM distortion increases that will probably outweigh any gains this method might offer.

An as-yet-unexplored possibility for improvement is that which may accrue from negative potential operation of the coolers through 10MΩ resistors. It may be that the close proximity of a large area of metal, at some moderate minus—50-75V—potential, to the envelope will have the effect of reducing or eliminating regions of static charge in the bulb although any beneficial effects from this would likely take several hours, if not days, to manifest because of the loose electrical coupling between the cooler and the glass.[16] Such statically charged areas result from bombardment by stray electrons emitted from the cathode. Secondary emission is known to result from such collisions, with several electrons being knocked out of the glass by every impinging stray electron. These spuriously emitted electrons ultimately find their way to the plate where they add a noise component to the flow of current in the plate circuit.

In the region where secondaries have been driven out, a region of positive charge is created within the glass that naturally attracts further cathode-strays, thus establishing a self-stoking vicious cycle. In power tubes these areas can become extremely hot and such temperature rises can cause outright glass failure. In small signal tubes, these regions tend to migrate in a somewhat unpredictable fashion and some odd results can be imagined from this action.

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†This outcome has been exploited for decades in the creation of low electron-affinity surfaces for use as cathodes in vacuum tubes.

A Few Particulars Regarding the Use of Pearl Coolers

In the great majority situations the installation of standard PEARL coolers is very simple, requiring only that the cooler be placed on a flat surface and the tube forced into it. In cases where tubes are placed too close together for the standard coolers to fit without the elastomeric bands fouling each other, coolers from the close-fitting series can usually be fitted. Sometimes tubes are so tightly packed that the radial fins of adjacent coolers must be meshed like gear teeth. This generally requires a little fiddling but the effort is always worth it as tubes that are too close together radiate heat onto each other, with some very high bulb temperatures and short tube lives being the outcome.

In some situations it may beneficial to ground the coolers by soldering a light gauge, flexible lead to the device and tying that lead to signal ground. Where RF interference is a problem 1KΩ resistors should be fitted to both ends of the lead ie. a resistor is soldered to the cooler with the flex-lead being soldered to the other end of the first resistor with the second resistor being soldered to the other end of the flexlead.

Simply fitting coolers into tuners is generally not a good idea because the added capacitance from the plate-to-cooler-to-ground or other nearby components can upset tuner alignment. While this can usually be re-tweaked with little difficulty, coolers should be grounded via short leads before this is attempted.

In pre-amps where one dual triode is handling both left and right channel signals, the added capacitance between the adjacent plates within the tube can cause changes in sound-staging and it is recommended that coolers be grounded in these cases as well.

There are several situations where coolers may effect sound quality in a slight way, usually by changing the shape of the electrostatic fields that exist within all equipment, tube or solid-state. As these E-fields are not generally optimized in most equipment, changes can have unpredictable results. Sometimes the sound will improve and sometimes not. If there is any doubt, the best solution is to ground the coolers.

The Alternative to Pearl Coolers

As a courtesy to our forebears we publish IERC's particulars. We recommend their coolers when the following conditions prevail:

- the equipment has its tube sockets mounted directly to or directly below a metal chassis
- the tubes are very close together
- the equipment is subjected to extreme vibration or shock.

International Electronic Research Corp.,
135 West Magnolia Boulevard,
Burbank, Calif., 915027

Cathy Sparks: Inside Sales Manager

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APPENDIX 1

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APPENDIX 2

ham clinic

CHARLES J. SCHAUERS, F7FE / W6QLV
CQ Magazine, 300 W. 43rd St., N.Y. 36, N.Y.

Some Thoughts On Extending Tube Life

As pointed out in this column sometime ago, defective tubes cause the majority of failures in electronic equipment. Contrary to what the advocates of transistorization may think or say, we are going to have tubes and tube failures for a good long while yet

The care and feeding of tubes receives a lot of attention from equipment designers. Whenever possible, they design circuits so that the tubes are correctly operated and not allowed to run at high temperatures. But no matter the design approach, there will always be HEAT to contend with because a tube's cathode must get hot in order to operate properly. Now, when high voltages are applied to plates and screens, especially those in power tubes, there is yet more heat to dissipate.

Some years ago, I conducted experiments relative to the effects of high temperatures on tube operation and longevity. Although my test setup was crude and so were my test results, I assured myself of one thing: tubes do have longer life spans if they are not subjected to voltage and current overloads and high temperatures.

Every tube has its own critical operating temperature. This cannot be quickly determined without many hours of environmental testing using special equipment. As well, the how and where of a tube's mounting can have a lot to do with how long it will satisfactorily operate.

Heat is a major problem with tubes containing many elements such as pentode/triodes, double triodes, dual-diode/triodes etc. because the elements must, of necessity, be so close together. At this point, tribute must be paid to tube manufacturers for being able to come up with multi-element tubes that operate so well over a wide range of temperatures.

Overdriving a tube (with RF, line voltage surges, etc.) certainly takes its toll, but the one big "bugaboo" that receives little attention is H-E-A-T, spelled in large letters!

Sometime ago, I was fortunate to get a copy of a really fine report titled "Heat Dissipating Electron-Tube Shields and Their Relation to Tube Life and Equipment Reliability" prepared by John C. McAdam of International Electronic Research Corporation (IERC), 145 West Magnolia Blvd., Burbank, California. After reading it, I was convinced (as I know you will be if you read the whole report) that too little attention has been given to the conservation of tubes through heat reduction—this being especially true in ham radio equipment.

Few people realize that the ordinary JAN shield actually makes a tube run hotter than it would if operated bare. Take a look at Fig. A to see what I mean! Taken from Mr. McAdam's paper, this graph really shows the difference when an ordinary shield, no shield and IERC's special heat dissipating shields are compared. Note the curves for the TR and B type shields. Now look at Fig. B and note how much longer tubes will operate before going sour when properly designed tube shields are used. Amazing isn't it?

The findings of various research organizations indicate that the evolution of gas within a tube due to elevated temperatures is the principle cause of tube failure. Other high-temperature-caused failures are: getter migration, grid emission, glass failure, inter-electrode leakage, contamination, grid loading and loss of emission.

Of course, forced air cooling is a solution to the hot-tube problem and is generally used when possible to obtain maximum cooling efficiency. But the mere direction of air over or under a set of tubes is not always the answer because all tubes do not get the proper or the same amount of air due in part to forced mechanical design and circuit layout. Then too, forced air cooling is not always an expedient measure in ham equipment nor is it inexpensive!

The shiny surface of the JAN shield reflects heat back into the tube; nothing better for raising tube temperature except maybe a nearby, hot transformer. This is the main reason why all good tube shields are black inside and out—for heat absorption. Also, the air space found within the average JAN shield retains heat, further aggravating the situation.

Referring to Fig. C-1, you will see IERC's effective heat-dissipating tube shield. It dissipates the heat by radiation, conduction and convection. It grasps the hot tube bulb and distributes the heat from the hot spot over a large surface area. This way, it not only reduces the average temperature present on the tube glass but also greatly reduces the temperature gradient along the surface of the tube.

In Fig. C–2 is shown a retrofit shield developed by IERC to meet the problem of retaining the old JAN-style base. It merely snaps onto the old type base. It is capable of reducing the temperature of the tube bulb well below the bare-bulb temperature and nearly 100°C below JAN-shield temperatures. This is the shield most amateurs can use on the tubes in their equipment residing in the old-style JAN bases.

To increase tube life, a tube must be operated properly. This means current and voltages as low as consistent with proper operation. Neither a tube's filament nor its cathode appreciate voltage surges so if it's possible, use a surge-voltage limiting device: a variable transformer, Surgistor, etc. Some amateurs (those who can afford it and desire the utmost in stability) turn their receivers on and leave them on. In this way, the tubes are not subjected to starting surges but they still are affected heat-wise if they are using old-style heat shields. Forced air cooling is fine if (and this is a big IF) the air can be directed so that there are no outstanding hot spots. Why cool a tube's base when its envelope is boiling? If the base is of the heatsink type that's all well and good but otherwise you're wasting power. Remember that heat rises so top-mounted ventilation systems are best.

Sooner or later, most electronic manufacturers will get around to giving consideration to the use of the various types of specially constructed heat shields. I hope that those who make amateur radio equipment will give these items special attention. Even with properly operated and cooled tubes we will still have replacement requirements, so tube manufacturers can take heart. They may have to wait just a little longer for replacement orders and tube prices might rise slightly, but even the best cared for tubes—like humans—do not last forever.

No one can ever say unchallenged—in my presence anyway—that American hams are not personally generous or are disinterested in international goodwill! The response to my appeal to send foreign hams your old issues of CQ, QST, WRA, CRA, QSO etc. is heart warming! Bravo!

I am sure that the recipients of your magazines and call books will not look on your gifts as charity but rather as your contribution to solidifying international ham friendship. There will surely be some reciprocation and I sincerely hope that you will take the time out to thank the donor, whoever he may be.

Some foreign hams will be surprised and wonder what brought on this sudden generosity. All I can say in reply, is "72" to you: "Peace and Friendship in Freedom".

Note: I have taken substantial editorial liberties with this article. While the tone and content remain, it now reads rather more clearly. bp.

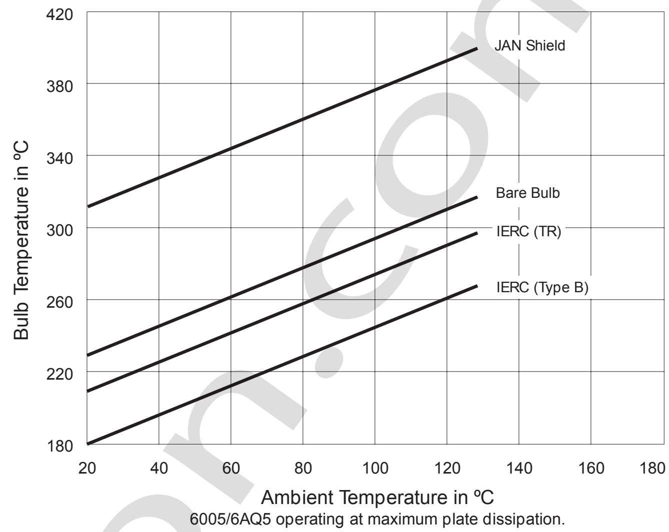


Fig. A. The temperature-effects of running a tube in various ways are shown above. Note the undesirable effect of using the brightly plated JAN-shield.

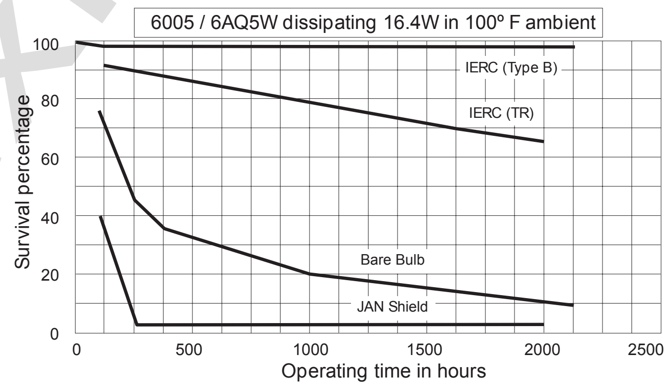


Fig. B. Tube life as a function of the sort of heat-dissipation mechanism employed. Note, once again, the dismal performance of the brightly plated JAN-shield.

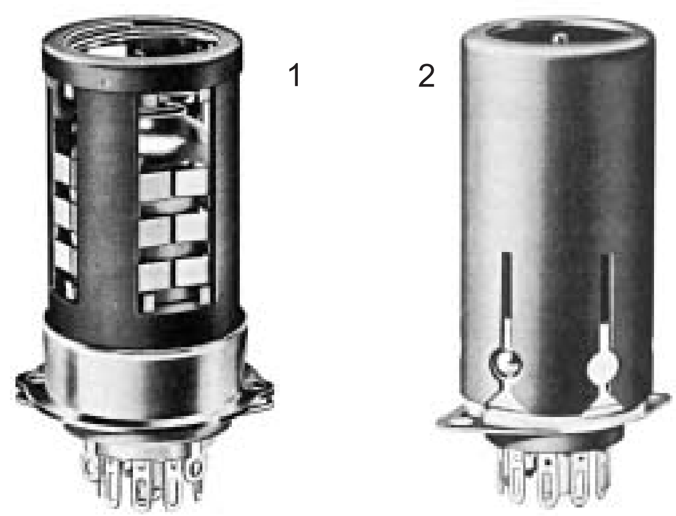


Fig. C. – 1 IERC's Type A heat dissipating tube shield. – 2 The IERC retrofit type shield. While not as effective as the Type A, it will fit on the JAN-type base.

APPENDIX 3

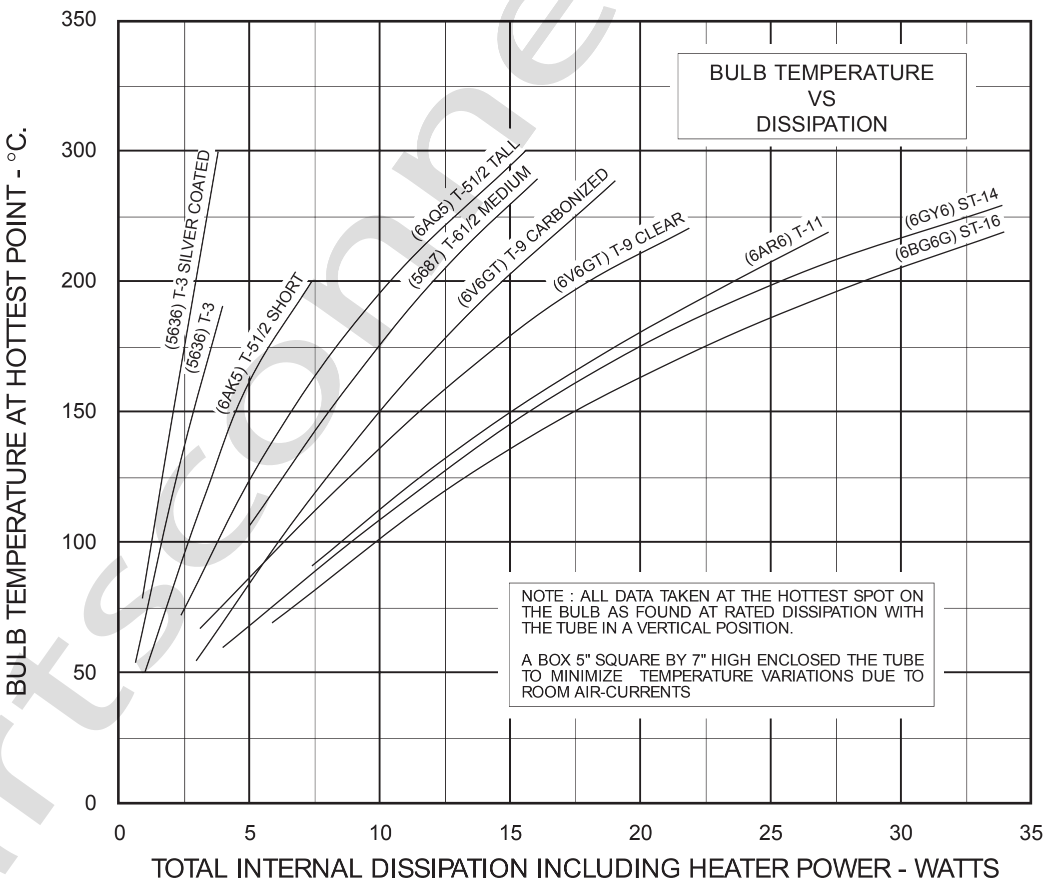
Fig. 8. These data are a re-drawing of an original plate from a Tung-Sol Tube-Data Manual.
† Emphasis added.

TUNG-SOL

BULB TEMPERATURE CURVES

One of the most important factors affecting the useful life of electron tubes is the temperature at which certain parts are required to operate.† In the past this has been controlled largely by electrode dissipation ratings. Recently a few, but now an increasing number of tube types have been rated for maximum allowable bulb temperature in addition to these dissipation ratings. The following curves relate the approximate "hot-spot" bulb temperature to the total dissipation (including heater power) for various sizes of bulbs under arbitrary reference conditions. Therefore, if the dissipation is known, these curves may be used to estimate whether or not the bulb temperature rating would be exceeded under such conditions. However, sufficient departure from these conditions would require actual temperature measurement.

The curves may also be used to find the approximate dissipation indirectly from bulb temperature when complex non-linear voltages and currents, such as are frequently encountered in radar, pulse and television service, make measurement by conventional direct methods very difficult if not impossible. Data for the curves were taken by applying DC voltages to the indicated representative types in a 5" x 5" x 7" enclosure, and measuring the hottest bulb temperature with an iron-constantan thermocouple made of .003" wire. This "hot-spot" is usually found two-thirds to three-quarters of the way up the plate structure near the place where the plate is closest to the glass. Any bulb temperature measurement should be made with a thermocouple that is made of very fine wire. In addition, great care must also be taken to minimize convection cooling, and to allow sufficient time to obtain a stable reading.



TUNG-SOL ELECTRIC, Inc. ELECTRON TUBE DIVISION NEWARK, NEW JERSEY, USA AUGUST 1, 1953 PLATE 3296

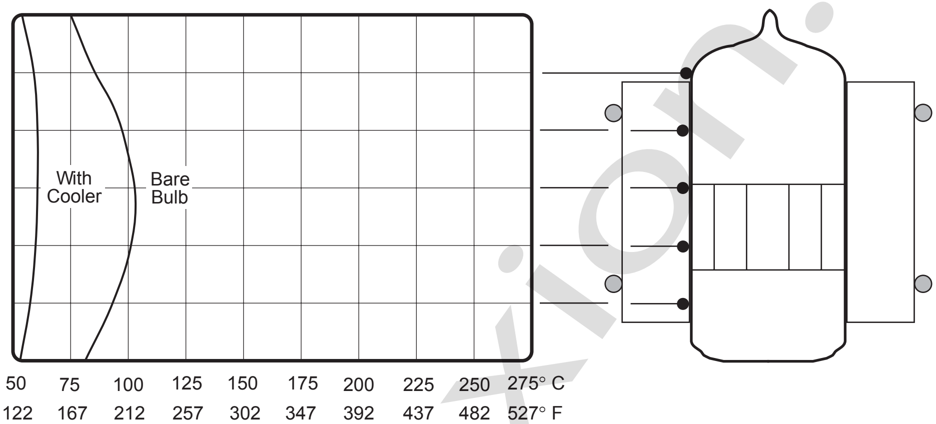
Lab Results

The outcome of our lab work is shown for various tube types under a wide range of operating conditions, both laboratory and real-world.

Please note the truly excellent thermal performance of our cooler-chimney-fan arrangement. This will be incorporated into our upcoming Single Channel 280W mono-block amplifier which will be available both in kit form and as a finished product.

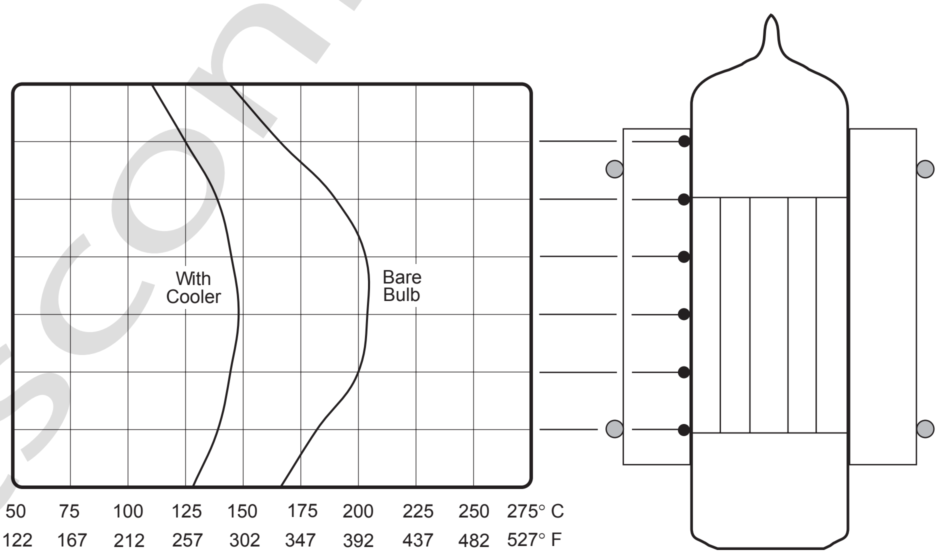
Bulb temperature vs. position for the 9-pin cooler

Fig. 9.



Equipment:	Test rig	Power – Fil:	2.25W	Notes:
Serial number:	n/a	Power – Plate(s):	1.5W	
Tube type:	6DJ8/ECC88	Power – Total:	3.75W	
Made by:	El – Yugo	Cooler type:	9-pin small signal	
Bulb diameter:	.80”	Cooler length:	1.25”	
Bulb area:	≈4.25 in.^{2}	Cooler area:	≈33.5 in.^{2}	

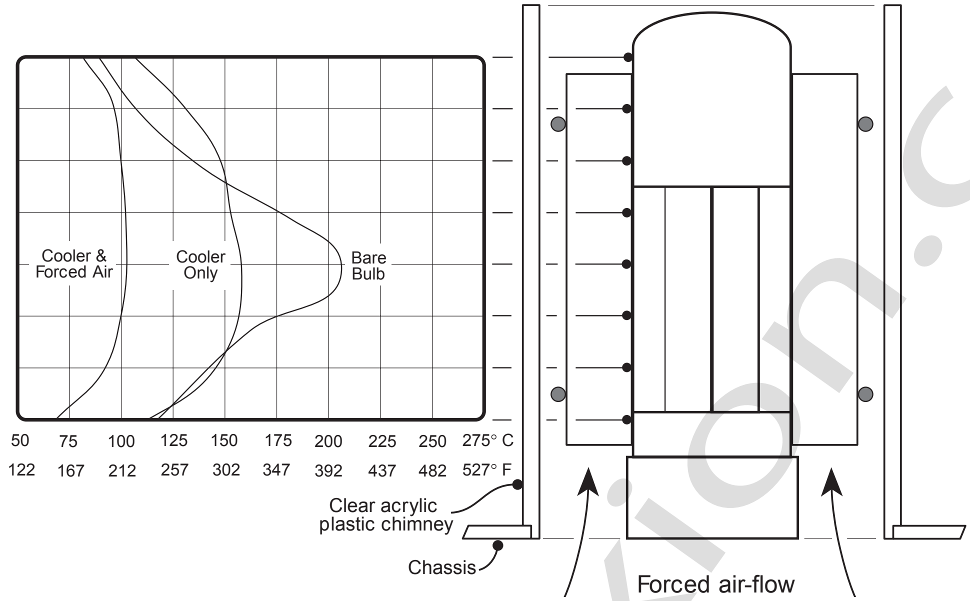
Fig. 10.



Equipment:	Test rig	Power – Fil:	4.75W	Notes:
Serial number:	n/a	Power – Plate(s):	14.0W	
Tube type:	6BQ5/EL84	Power – Total:	18.75W	
Made by:	Sylvania	Cooler type:	9-pin power	
Bulb diameter:	.80”	Cooler length:	1.75”	
Bulb area:	≈6.2 in.^{2}	Cooler area:	≈47 in.^{2}	

BULB TEMPERATURE VS. POSITION FOR THE STANDARD-FITTING POWER COOLER

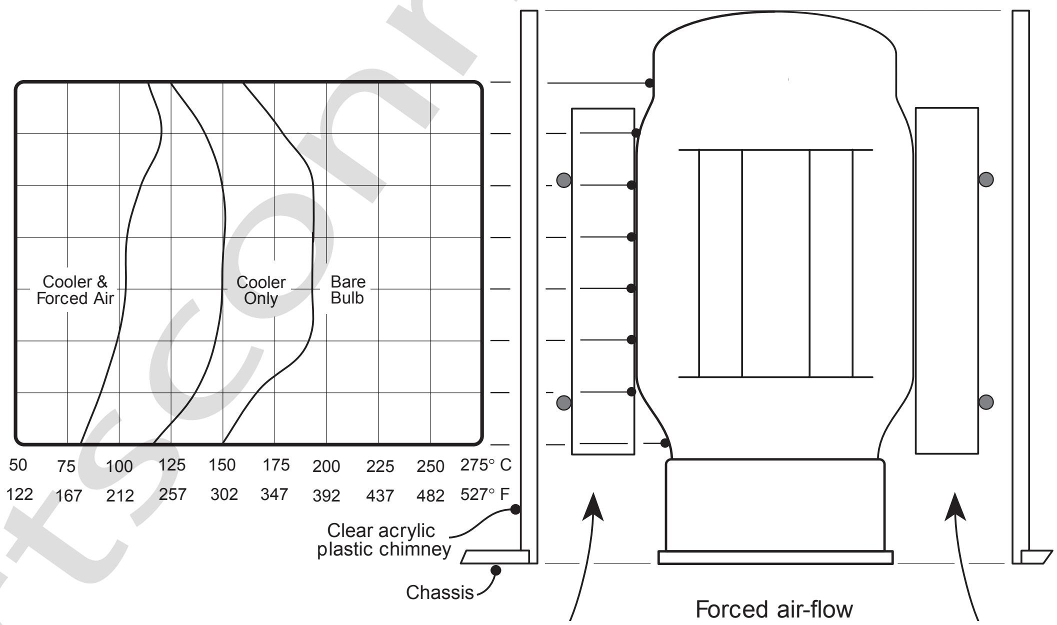
Fig.11.



Equipment:	Test rig	Power – Fil:	9.5W
Serial number:	n/a	Power – Plate(s):	22.5W
Tube type:	EL34	Power – Total:	32.0W
Made by:	Tesla	Cooler type:	1.25” Std
Bulb diameter:	1.125”	Cooler length:	2.5”
Bulb area:	≈13.0 in.^{2}	Cooler area:	103 in.^{2}

Notes: PEARL SC 280 cooling-system test rig. Air flow ≈50ft/ min. through a 2.5” i.d. clear acrylic-plastic chimney

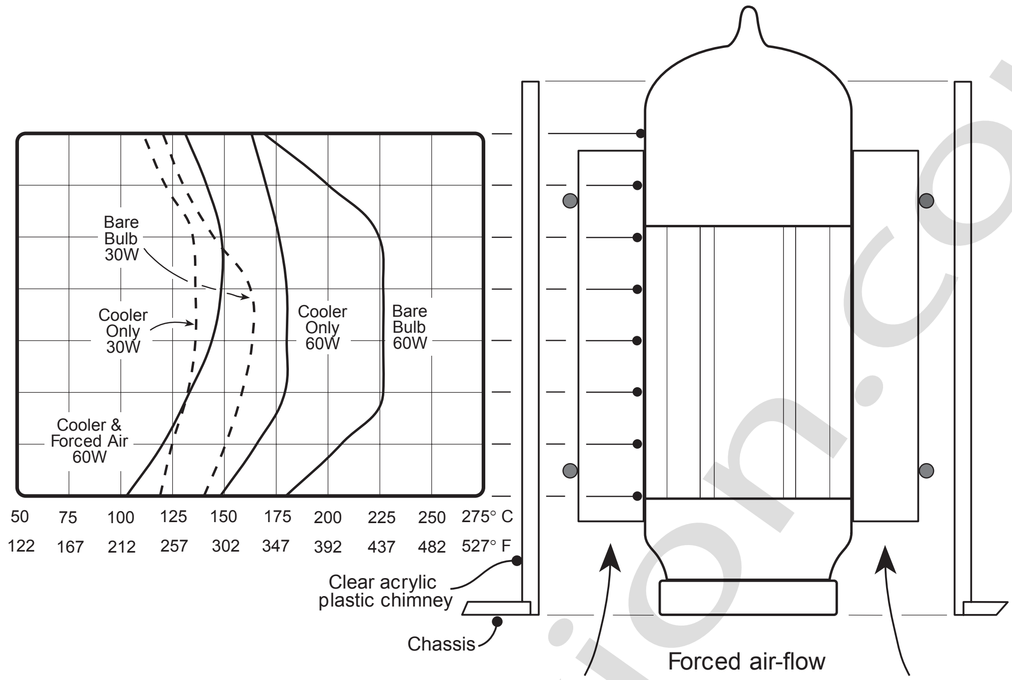
Fig. 12.



Equipment:	Test rig	Power – Fil:	10.0W
Serial number:	n/a	Power – Plate(s):	30.0W
Tube type:	KT88	Power – Total:	40.0W
Made by:	Chinese: (?)	Cooler type:	2.0” Std.
Bulb diameter:	2.0” max.	Cooler length:	2.5”
Bulb area:	≈19 in.^{2}	Cooler area:	150 in.^{2}

Notes: PEARL SC 280 cooling-system test rig. Air flow ≈50ft/ min. through a 3.0” i.d. clear acrylic-plastic chimney

Fig. 13.

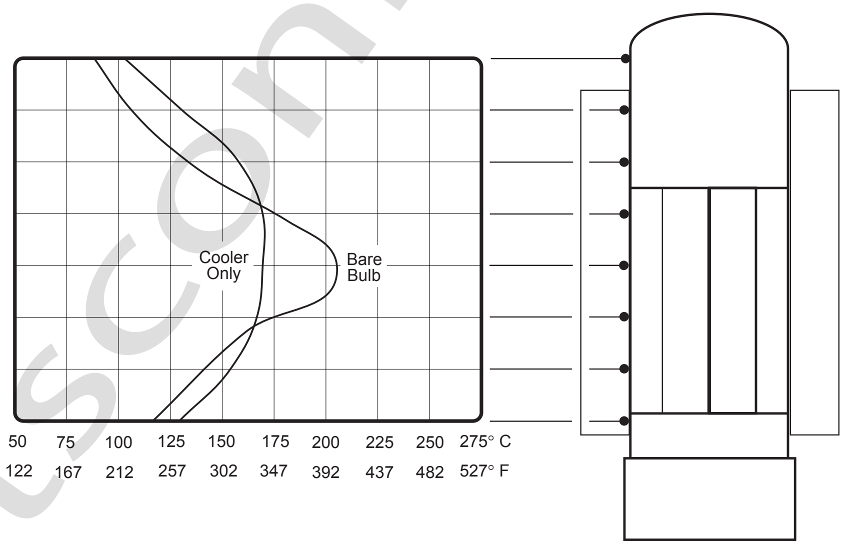


Equipment:	Test rig	Power – Fil:	10.0W
Serial number:	n/a	Power – Plate(s):	See notes
Tube type:	KT90A	Power – Total:	See notes
Made by:	El – Yugo.	Cooler type:	1.5” Std.
Bulb diameter:	1.5”	Cooler length:	2.5”
Bulb area:	≈19.5 in.^{2}	Cooler area:	120 in.^{2}

Notes: The KT90A is shown operating at several dissipations. The broken curves show bulb temperatures at 30W total dissipation while the solid curves show bulb temperatures at 60W total dissipation.

Bulb temperature vs. position for the close-fitting power cooler

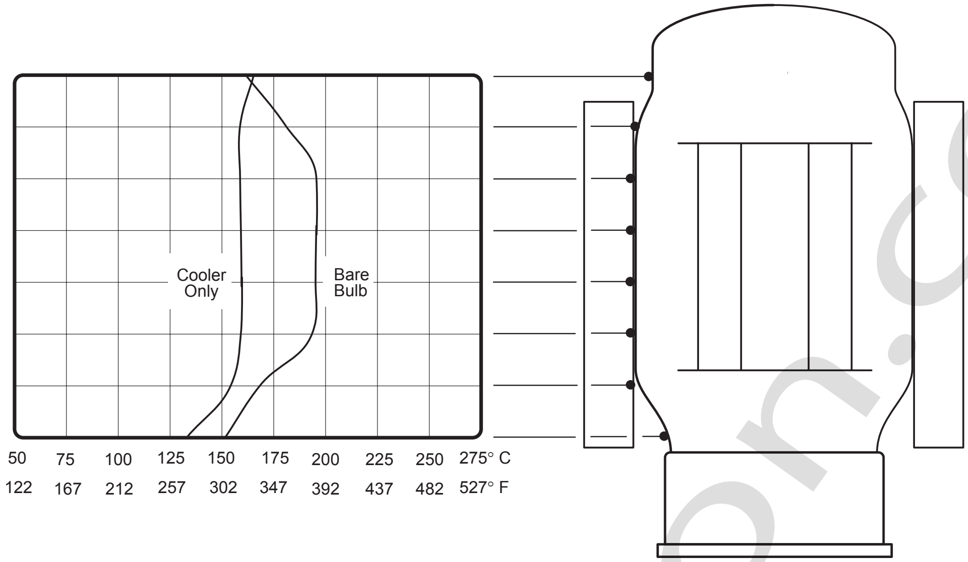
Fig. 14.



Equipment:	Test rig	Power – Fil:	9.5W
Serial number:	n/a	Power – Plate(s):	22.5W
Tube type:	EL34	Power – Total:	32.0W
Made by:	Tesla	Cooler type:	1.25” CF
Bulb diameter:	1.125”	Cooler length:	2.5”
Bulb area:	≈13.0 in.^{2}	Cooler area:	95 in.^{2}

Notes:

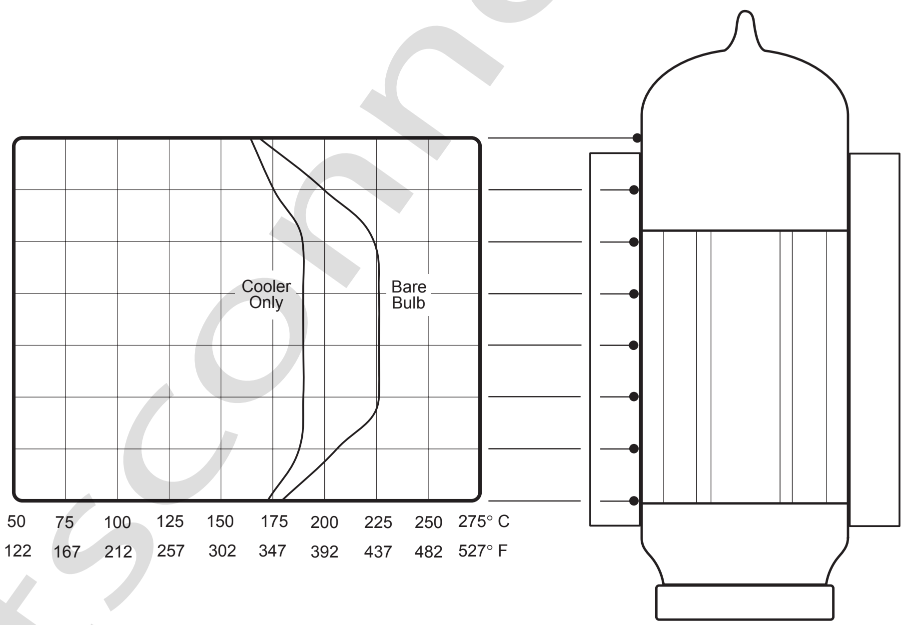
Fig. 15.



Equipment:	Test rig	Power – Fil:	10.0W
Serial number:	n/a	Power – Plate(s):	30.0W
Tube type:	KT88	Power – Total:	40.0W
Made by:	Chinese: (?)	Cooler type:	2.0” CF
Bulb diameter:	2.0” max.	Cooler length:	2.5”
Bulb area:	≈19 in.^{2}	Cooler area:	130 in.^{2}

Notes:

Fig 16.



Equipment:	Test rig	Power – Fil:	10.0W
Serial number:	n/a	Power – Plate(s):	50.0W
Tube type:	KT90A	Power – Total:	60.0W
Made by:	Ei – Yugo	Cooler type:	1.5” CF
Bulb diameter:	1.5”	Cooler length:	2.5”
Bulb area:	≈19 .5 in.^{2}	Cooler area:	115 in.^{2}

Notes:

Appendix 4.
Product reviews and comments.

The following is a review commissioned by a British magazine, the rights to it were acquired by our UK distributor:

Russ Andrews Turntable Accessories
Edgebank House
Skelsmergh, Kendal,
Cumbria, England
LA8 9AS

Reprinted with permission.

Pearl Coolers

Review by Roy Gregory

PEARL valve coolers are concertina, blackened copper sleeves that slip over a valve's glass bottle, and are clamped against it with thick rubber bands. They come in a whole range of sizes to fit virtually any available valve and fitting is fairly easy depending on the shape of the valve in question, 2A3s and old-style bulged and tapered 6550s are the worst.

The theory is simple. The black copper sleeves act as chimneys, conducting heat away from the tubes and thence to the air. This reduces operating temperatures and increases valve life. The clamped sleeve also damps the bottle and reduces microphony.

So much for theory. In practice your main problem is going to be space. The 'fins' that the coolers add to a valve increase its circumference substantially. Where valves are packed together PEARL suggest you don't use the rubber bands, and interlock the coolers, like cogs. I disagree. No, let me put that stronger. Don't do so under any circumstances. Now let me explain.

The PEARL coolers are certainly efficient chimneys. If you don't believe me just touch one. Remove the band(s) and you reduce that efficiency, but that's not the real problem. Long term testing will show how effective they are in prolonging valve life (and as I write a P35 MKII kindly donated by Beard is driving a dummy load, its valves variously cooled and uncooled) but their real value lies in the sonic difference they make as dampers. Add the PEARL coolers to an amp and you'll notice an immediate improvement in midrange clarity and focus. The top end gains sweetness and purity, losing grain and fog, and individual instruments are easy to pick out. Listen to a cymbal or triangle decay. More detail, clarity and a measured fading of the sound. Listening PEARL-less the same strike will be lost in glare and fuzz. A well worthwhile upgrade then.

The problem is that the coolers sans elastic bands can sound worse than no coolers at all, creating fuzz and grain right across the upper mid. I can only assume that they're picking up airborne vibration and rattling against the valves. Whatever the explanation is, I didn't like the result, so check your spacings with RATA before ordering (PEARL supply excellent data sheets with all their products, so confusion should be kept to a minimum). Oh, they look pretty post industrial too. I kind of like it now I've got used to it, but if your sole reason for owning valve equipment is to bask in its seductive glow, then these are not for you.

My success with the coolers encouraged me to try something a little more demanding, PEARL'S replacement valve bases. These come in a variety of forms with ultra high quality gold plated contacts and chassis or PCB mounts. I went for a quartet of the most elaborate version in which each socket floats on a pad of Sorbothane, connected to the circuit by fine, Litz wires. The long suffering P35 was pressed into service and after an hour or two I had a single pair of suspended output tubes per side, allowing direct comparison with the stock ceramic bases normally fitted.

The P35 is getting a bit long in the tooth but it always sounded better on single pairs of output tubes. Comparing the suspended valve bases to the normal ones revealed a huge, almost shocking difference. The coolers had improved things, but in largely cosmetic ways. The valve bases wrought a fundamental change. Prior to fitting them the P35 had sounded grainy and disjointed; nice enough but not very interesting. Using suspended output valves gave the music an immediate sense of cohesiveness and authority. It was almost as if all the information the amp had been passing was suddenly rearranged in the proper order. The stereo performance opened out; the bass went deeper and bounced along in time with the rest of the music; feet began to tap and the performance made sense.

Somewhat bemused I ran the comparison past friends and visitors, who were all similarly gobsmacked †, so I guess I'm not imagining it. Either way, the valve bases turned an also ran into a very real contender. They aren't cheap at around £25 each (!) but they made way more than £100 of difference to the P35. They also narrowed the gap between Gold Dragon EL84s and Sovteks, compensating in part for the valve quality. So far I've only tried them on output tubes, but low level valves (the phono stages in valve pre-amps!) are crying out for them. Beware of horizontal mounting, though, as the Sorbothane may well "flop", it's so spongy.††

The P35 in its final form, PEARL cooled-and-sus-

† A colloquialism that roughly translates to, "Slapped up the side of the head".

†† The horizontal mounting Iso-sockets don't use Sorbothane for exactly this reason. "Non-flopping" silicone foam is used instead, see Audio Note 6.1, Figs. 4, 5 & 7. bp.

pended with Sovteks in place, is an entirely different kettle of fish from the amp that arrived on my doorstep. Fitting the valve bases requires patience but unless you need bigger holes in your top plate, I can't see it giving any problems. The results are more than worth the cost and bother (PEARL make cheaper and less complex versions as well). Long term results on the coolers will have to wait a while, but we should get empirical evidence of the effectiveness (or lack of it). Meanwhile, they are the most effective tube dampers I've found, outperforming Sorbothane or Sicomin varieties, costing less and working with almost any valve! Those worried by their metal construction should remember that copper is non-magnetic and the preferred chassis material of the fine Japanese Audio Crazies. The PEARL products are perfect for those who want to improve their tube equipment, vintage or current, offering better sound from a straight substitution, and the pride of doing it yourself. A totally rebuilt Stereo 20 is definitely in the cards, Chez Gregory.

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BIRTH OF THE COOL

PEARL TUBE COOLERS are a worthy alternative to Audioquest's tube dampers !

For whatever reason, the tube damper from Audioquest is out of production, so it's time to find a replacement. And, after ruling out a few due to criminal pricing, we've settled on one which is more than just a bargain. It's multi-purpose.

Admittedly, the Pearl Tube Cooler is a cooler first and a damper second. The damping is almost incidental, a by-product of any device which clamps to a valve. And even though damping microphony is not is primary function, the Pearl Tube Cooler works almost as well as any in my arsenal. Boring and time-consuming though it was, I A B/C'd (in a Croft pre-amp) the Pearls against sorbothane, Kevlar and other types and found it 'almost, but not quite' provided the same kind of immunity from treble smearing and bass sogginess available from the Audioquest. But since the Pearl has another function (and costs a pittance), I'm not about to sit shiva for the Audioquest device.

Tube cooling is desirable for one main reason which should prove appealing to the more venal among you: cool-running tubes last longer. According to its maker, the use of a Pearl Tube Cooler should double a tube's life, in some cases extending it by a factor of five.

The Cooler itself is a clever design made from blackened sheet copper fashioned into a pleated sleeve. Because of its springiness, it's impossible for the Cooler to be 'too tight' should you order the wrong size. If a Cooler is fitted too large a valve, the pleats simply spread out a bit more than normal. But you shouldn't have a problem because six types are available, for everything from miniature valves like EL84s up to power tubes like EL34s and KT88s, and for tubes with lots of space around them or those nestling close together. With the exception of amplifiers like the Radford STA25, where the tubes are as close as this, most amps can be accommodated; the minimum space allowed between valves is just over one-half inch. The sleeves slip over the valves; those for more widely-spaced tubes come supplied with heat resistant rubber bands to keep them in place, while close-fitting types can be 'interwoven'.

I used the small, standard-fit Pearls with the GRAAF GM200, the Unison Research Simply Two and the latest Croft Micro. I found that the Pearls quickly grew scalding hot, conducting heat away from the tube by adding a large amount of heat sink surface area. Additionally, the Pearl Cooler's shape creates a chimney effect, so convection takes the heat away as well.

There's no way I can tell you about the life-extending properties of these devices after only a fortnight's usage, but I can attest to their worth as replacements for the Audioquest dampers.

Bottom line? I love 'em because they look so obscenely macho.

Note: Upon applying for Pearl Tube Coolers from the Accessory Club, you will receive a special order form with a measuring template and full instructions to help you select the correct size and type. Ken Kessler

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TUBE AID 2

Jack English looks at ways of improving tube performance & prolonging tube life

Many of us love the sound of tubes. Unfortunately, living with tubes often means living in fear fear of "tube mortality"; fear that they will fail when we turn something on; fear they will begin to deteriorate just before all our friends come over to listen; fear of the ubiquitous microphony appearing at the worst possible moment.

I keep an ample supply of replacement tubes on hand for all these inevitable occurrences, but while this is an effective strategy, it is an incomplete and expensive—one. Instead of simply accepting frequent tube failure as part of the price of living with the cherished fire bottles, we can do something about it.

The internal workings of tubes are mechanical; in use, they vibrate and resonate. When the resonance can be heard, the phenomenon is called microphony, one of the most common and frustrating aspects of tube behavior.

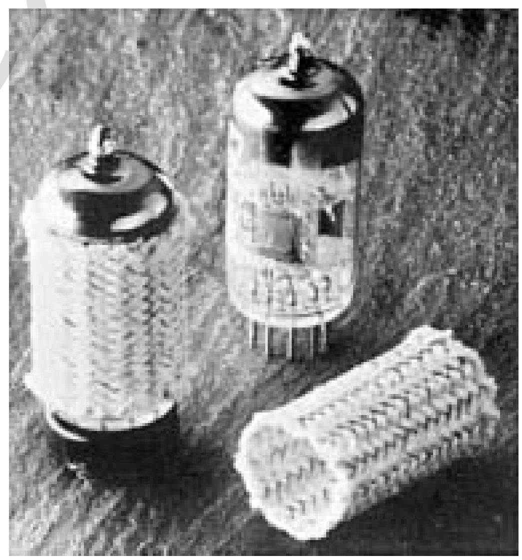
One solution readily available for this particular problem is the Sorbothane Tube Damper from AudioQuest, reviewed by Dick Olsher in February, Vol. 16 No. 2, p.176. Each Damper looks something like a very wide, thick black rubber washer. The Damper can easily be installed even if the tube is already in place: simply ease it over the glass casing of the tube, much like a fat rubber band. AQ suggests that two Dampers be located near the top and bottom of the tube to cause the least interference with radiant cooling. However, I have found the best damping to occur with the Dampers placed near the center of the tube.

One tube with a reputation for microphonics is the 6DJ8; for years I have used Tube Dampers on every 6DJ8 that has found its way into my system. I also use Dampers on all phono-stage tubes. While I may have been unusually lucky, I have not experienced the host of microphony problems that many audiophiles complain of. I attribute this to the effectiveness of the Dampers. Where I have had problems, the Tube Dampers have either helped or virtually eliminated the problem. While I can't absolutely say that the devices prevent microphony, my own experience has convinced me to continue using them religiously on all new tubes. Their only limitation is that of size: Tube Dampers are available only for small tubes (eg, 6DJ8s, 12AX7s). The second problem with Tube Dampers is that they are generally not reusable. In some cases they become bonded to the glass casing of the tube. In other cases, the heat of the tube actually melts the Sorbothane. Given Sorbothane's low melting point, Dampers cannot be used on power-supply or output tubes (eg, 6550s, KT88s), which generate considerably more heat.

Heat is the most common tube bugaboo. Here again, a number of useful solutions are available. One is the Tube Cooler from the Perkins Electro-Acoustic Research Laboratory (PEARL). These devices are claimed to significantly reduce the operating temperature of the tube's glass envelope, thus dramatically extending tube life. Extensive documentation to support these claims is available directly from Bill Perkins at PEARL in the form of a series of papers called "Audio Notes." Unlike Tube Dampers, Tube Coolers are available in multiple sizes to fit most tubes. The most popular sizes are the Small-Signal Coolers (for 6DJ8s, 12AX7s, etc.) and Power-Tube Coolers (for 6550s, KT88s, etc.). Since tubes from different manufacturers are often of different sizes, specifically sized Coolers are available for precise fits. Each Cooler is formed from blackened, foil into a radial fin arrangement looking much like the heatsinks found on the exteriors of amplifiers. The tube is inserted into the Cooler and held firmly in place by high-temperature-resistant elastomeric bands (two silicone O-rings per Cooler). End-on, the Cooler looks like a gear with the tube in the center and fins radiating outward, perpendicular to the tube's circumference. Being made of metal, the Coolers do introduce unpredictable changes to internal electrostatic fields. In some applications, users have reported negative sonic effects. In part to remedy these concerns, PEARL offers extensive installation advice. Each Cooler can be grounded three ways: with a simple piece of wire, using resistors at both ends of the ground wire, or using resistors and a small capacitor. Once grounded, the Coolers should continue to achieve their intended purpose of extending tube life with no audible drawbacks. As they are made of metal, it's possible for the Coolers themselves to vibrate. The dual O-rings, in addition to holding the Coolers firmly in place, act as dampers. I tried Coolers in both the CAT SL-1 Signature and the Melos 333 line-level preamp/phono stage combination. I heard no obvious mechanical problems, nor was I aware of any odd effects which could have been attributed to altered internal electrostatic fields. There were no sonic differences with the Coolers in place. Had there been, the Coolers could have been made inaudible via one of the suggested grounding approaches described above.

The newest entrant in the improved performance/tube-life extension category is Tubesox from Ensemble (also reviewed by Dick Olsher in February, Vol.16 No.2, p.176). What makes Tubesox unique is that they deal with microphony and heat. Each Tubesox is approximately 1¼" long and appears to be made of straw tightly interwoven with copper strands. The devices look much like "Chinese handcuffs": stick a finger in each end, try to pull them out, and the weave tightens, gripping your fingers. The woven construction damps the tube while the copper wire is intended to dissipate heat from the glass casing. Tubesox look enough like straw that I was concerned that they might be a fire hazard. I mentioned this to George Bischoff of Melos, who suggested trying to ignite one. With ashtray in place and matches in hand, I lit one of the Sox. It scorched with extensive exposure to the flame, but would not catch fire. As it turns out, the Sox are made of Kevlar and are definitely not flammable. Whew! Like the Dampers, Tubesox are available only for small tubes like 12AX7s and 6DJ8s; unlike Dampers, they are small enough to fit anywhere the tubes themselves will fit—each thin, glove-like Sox takes up far less room than a Damper or Cooler. In really tight spaces, the Tubesox might be the only possible choice among the products in this article. Like Dampers, Tubesox fit tightly around the glass casing of each tube, acting to restrict mechanical vibration and thus reduce unwanted microphony.

PEARL TUBE COOLERS



ENSEMBLE TUBESOX

Though both Coolers and Tubesox use copper as a means of dissipating heat, it is unlikely that the Tubesox would be nearly as effective at this, as the Coolers are much larger and made entirely of copper. I did not conduct experiments to verify this assumption, however. On the other hand, as the amount of metal in the Tubesox is minimal compared to that in the Coolers, the former are not as likely to create unpredictable effects in the tubes' internal electrostatic fields, nor are they likely to resonate. While all three of these products can help improve tube performance and/or prolong tube life, there are still some very basic things that should be done with all

More on TubeSox

After digesting my February review of the Tubesox (Vol. 16, No. 2. pg. 176), Ensemble's Urs Wagner called me to discuss a couple of specific points. First, concerning my finding that one size does not fit all—I was wrong. He pointed out that the sock diameter may be altered a few millimeters by stretching or squeezing it. Ah-ha! I tried it. Indeed, via this simple expedient I can securely fit Tubesox to any preamp tube I've got on hand.

Second, concerning the temperature measurements: while I found that the Tubesox caused a slow temperature-rise of several degrees at the top of the glass envelope, Wagner's data at a point under the Tubesox (closer to the plate) yielded a small temperature drop. What this appears to mean is that, although the average temperature of the tube rises with the Tubesox in place, the sock is effective in smoothing out hot spots on the surface of the tube. If this is the case (I haven't attempted as yet to duplicate Ensemble's measurements), the Tubesox could arguably be said to enhance tube life—but only if a small reduction in hot-spot intensity is more important than average tube temperature. However, let me emphasize again that the essential reason for using Tubesox is sonic, not thermal. Tubesox can elevate an ordinary-sounding preamp tube to the exalted status of a premium tube. —Dick Olsher.

tube equipment. First, proper ventilation is essential—higher temperatures definitely shorten tube life. Make sure there is adequate space around, and especially above, your equipment for proper ventilation; if possible, use low-noise fans. If the equipment has special turn-on circuitry, use it. If not, do not immediately put a signal through the gear. Turn it on and let it warm up for 20 or 30 minutes before using it. If the equipment has turn-off features (eg, a higher, noisier fan speed), use them when turning the equipment off. Another alternative comes in the form of specialized pieces of equipment—like the SimplyPhysics Variac—that allow current to be turned up gradually. We don't have to passively accept microphony and premature tube failure. Tube Dampers, Tube Coolers, and Tubesox offer ways to improve tube performance and longevity. Dampers help with microphony; Coolers dramatically extend tube life; and Tubesox help with microphony and offer some benefit for extending tube life.

Manufacturer's Comment

I appreciate Jack English's efforts in the evaluation of the Pearl, Inc. line of tube coolers, his comments about living "In Fear of Tube Mortality" really hit home around here. I have done a lot of investigative work to discover—and develop products that eliminate—several causes of the unreliability often experienced with late 20th-century, high-dollar, tube-type audio equipment. It turns out that the very reliability issues facing today's tube lovers were thoroughly researched and resolved 30 years ago. The old research work is not lost and can be brought to light once again for the price of a few Sunday afternoons' digging (alright... more than a few) through any of the many good technical libraries around the country. The Audio Note Series is a distillation of years of library archaeology and contains a lot of information that is useful to anyone who owns or uses tube equipment, the cost is $12.00US.

The reliability problems seen in present day tube gear are, with most American and European tubes, not the fault of tubes themselves but, those of the circuitry in which they are placed.

This is a time when many of the broadly experienced and deeply knowledgeable old-timers are either retired or no longer among us. There seems to be an attitude among present-day designers that on account of the loss of the "good old guys" from active audio work, there is unbridgable gap in the knowledge that can brought to bear on the design of tube circuitry. It is consequently far from uncommon to see glaring errors within tube circuitry; errors that cause tubes to run far outside their specified range of operation. Three of the most commonly seen mistakes are:

- the violation of the heater-to-cathode voltage rating
- the use of power supplies that apply full B+ to tubes whose cathodes have not been given time to get to operating temperature
- the packing together of power tubes like sardines in a tin.

The heater/cathode combination is the part seen glowing red-orange inside a correctly functioning tube. The heater is fitted inside a coated, nickel tube that it is the cathode. It is electrically insulated from the cathode by a thin and somewhat physically fragile ceramic coating that has very definitely defined voltage hold-off capabilities, typically on the order of ±100VDC. In typical tube circuitry, the heater supply is held at signal-ground potential ie. 0V. If the cathode is tied to ground by a resistor across which there is a voltage drop of 100VDC or more then the filament supply must be biased to some value that is within 100VDC of the cathode potential. The heater-to-cathode insulation can leak or, at worst, develop an outright short thereby connecting the cathode to the grounded heater. In the former situation the outcome can be some very peculiar intermittent noises while the latter case can result in the circuit going south with an unbridled vengeance.

Cathodes are damaged by the application of full B+ voltage to tubes that have not been given time come up to full operating temperature. It is neither complex nor expensive to build a slow-starting B+ supply, yet such circuitry is practically never seen today whereas 30 years ago tube rectification provided a simple, effective solution. [Guitar amplifiers from the '60s with solid-state rectification invariably switched the filament and B+ supplies separately and in that order for the same reason.—Ed.]

From about 1940 to 1965 the British and US Armed Forces and the airline/aerospace industry spent tens of millions researching the causes of and remedies for equipment failure. Fundamentally, the results were that tubes must be kept as cool as possible and either specially built to withstand shock and vibration or mounted in ways that provide mechanical isolation from those forces. In study after study it was found that tube-life could be at least doubled and often extended many times by the application of relatively simple measures to remedy these problems.

Given good quality tubes, correct circuitry and careful thermal and vibration management, there is no reason why tube-type audio gear cannot give thousands of hours of failure-free service.

One of the best examples of tube reliability is their use in the original trans-oceanic telephone lines. Scores of tube-type repeater amplifiers were permanently installed within the several-thousand-mile length of lines that were laid in the deep water between continents. Admittedly, the tubes were the best that Bell Labs and Western Electric could build but the fact remains that they ran and ran reliably for years on end with no service whatever.

Ma Bell didn't hire Captain Nemo to swap out a bunch of tubes every time Roosevelt wanted to talk to Churchill.

BILL PERKINS
PEARL, INC.
CALGARY, CANADA

PEARL Valve Coolers

by Roy Gregory

I've been using PEARL Valve Coolers on my Jadis JA30s since I first came across them, getting on for ten years ago. For the uninitiated, a PEARL cooler is a concertina sleeve constructed from sheet-copper which slips over an audio valve, acting as a heat sink. The copper fins are perforated with horizontal slots to improve airflow, and the whole thing acts as an extremely efficient chimney (If you want to know how efficient then PEARL can supply you with reams of data on the subject. The theory of course, is that the sleeve allows the valve to run at a lower temperature, leading to longer tube life and greater reliability But there's more to it than just that.

Along with the cooler you get a pair of stout rubber O-rings which are used to clamp it in place (Useful Tip: put the rings over the cooler and then slip it over the valve—it's a lot easier!). The sleeve now also acts as a damper, reducing microphony and improving sound quality And they work. You should notice a very real improvement in transparency focus, low level information and dynamic range once you've installed the coolers. Do they improve the reliability and longevity of your valves? Well, nothing has blown up and I'm still running the same Platinum Grade Gold Aero ECC82s and 83s as I was when the coolers were first installed. And they still sound much better than the stock items currently supplied with the JA100s. Given the price, that's a real relief. As regards the output tubes that's harder to gauge, but the EL34s seem to be lasting a lot longer than I'd expect as well.

Downsides? Apart from the fact that they hide the pretty glowing bottles, not much that I can mention. Me, I kind of like the Fritz Lang look. You need to check the space around your valves to make sure that there's enough room for the coolers. PEARL suggest that you can interlock the fins, rather like cogs. Don't. To do so you need to dispense with the O-rings, and the coolers end up rattling against the tube, adding to the microphony rather than damping it. In short, it'll make your amp sound worse. [See our comments below. PEARL] Also, if you've non-parallel sided tubes then the O-rings have a tendency to roll down to the narrow end under their own tension. The new Sovtek KT88 springs to mind. Finally, you need to order the right sizes. PEARL produce coolers in a whole host of dimensions, so it's worth taking a little trouble over getting things right. That aside it's a case of fit and forget.

In fact, it's so easy to forget about the PEARLs that the only thing that prompted me to write this piece, was the arrival through the post of a quartet of "improved" models for ECC83 sized valves. As this includes just about every low-level signal or driver valve used in audio electronics, that makes it very interesting indeed. I only use the coolers on my power amps, but experimentation suggests that they are every bit as effective on pre-amps. The "improvement" comes in the shape of a woven carbon fibre sleeve that fits between the cooler and the valve, improving the mechanical coupling. [Aug, 2010: The carbon fiber sleeves were dropped a number of years ago to be replaced with a high metallic content powder coat finish that provides considerable damping of the cooler and useful damping of the tube's resonant internal structures.. With time, pressure and temperature this coating slightly flows to conform to the inevitable irregulatities of the glass envelope, thereby increasing both thermal and mechanical coupling. PEARL]

Replacing the old-style coolers on the 30s with the be-stockinged variety produced a further subtle, but worthwhile benefit. Subtle in terms of putting your finger on it, far from subtle in terms of simply identifying it. Greater transparency and an increase in the air and space around and between performers, produced a noticeable increase in presence. At the same time, a further improvement in low level dynamics made instruments more vibrant and real. How big was the margin of difference? You didn't need to resort to ABA comparisons. The benefits were clearly(!) apparent, to the extent that Victoria commented on the improvement when she arrived home that evening. They're also the kind of changes that can be readily masked in a system wanting in the areas of resolution and low level dynamics, so if you fit PEARL coolers and don't hear a difference then either your valves are immune to vibration, or it's time to take a close look at your system and its set-up. And remember, I got these results simply upgrading half of the coolers on otherwise fully "PEARL-d" amps. The comparison between un-cooled tubes and the same valves with their modesty intact, running in the Graaf 13.5B, was absolutely huge, and out of all proportion with the costs involved.

The carbon socks are available separately but only come in ECC83 or EL84 sizes. Presumably although carbon fibre is a good conductor of heat (remember all those bright red brake shoes on Formula I cars), using it with the larger power tubes compromises the cooling effect. Personally I'm much more interested in the immediate sonic benefits than the possible increase in valve life, so I'm keen to try socking my EL34s too. Perhaps PEARL will give us the choice? [See our previous comments. PEARL]

PEARL Coolers are one of the most cost effective and sensible upgrades on offer to valve users. After all, if you don't like the results you simply take them off. At a cost of £7.00 each for the small size, including sock, and £9.50 for the EL84 size or larger ("Gee! Do you s'pose they do them for 845s?"), you need to be running a power station before the cost becomes prohibitive. If you already use the standard coolers, you can get socks for around £2.50 each. And yes I did try the socks on their own, and no they aren't nearly as good as the sock/cooler combination. I love these things. Cost effective and no-nonsense, they even have empirical data to back them up. Unlike too many things in hi-fi, buying these is an absolute no-brainer.

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