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Precision Electro-Acoustic Research Laboratory. *Hand-Builders of Fine Music-Reproduction Equipment*

VACUUM TUBE ELECTRONICS
REVIEWS OF THE MAJOR TEXTS

Selected and annotated by Scott Frankland

If the current tube renaissance continues, future designers will want to know about the following texts, as replacements are not forthcoming. In order to show historical precedence, books are listed chronologically by first edition. The most recent edition is nonetheless considered to be definitive.

This survey is by no means intended to be exhaustive—on the contrary, only the most widely quoted texts are considered for inclusion here (widely quoted texts are considered to be both authoritative and influential.) Books marked with a "☞" will be of greatest interest to the audio designer (although each book listed provides a different slant on the subject, and is thereby useful in its own right.)

It is the author's intention to expand this list as books are discovered that may equal in quality of content the high standards set by those listed below. The interested reader is hereby encouraged to contribute title suggestions for inclusion in future editions of this survey.

Part I of this series includes books of a general nature that are particularly clear about at least one aspect of tube amplifier design. Part II covers books on electric circuit theory, Part III covers books on electromagnetics and tube theory, while books of a more specialized nature, such as those on transformer design, tube manufacturing, etc., are included in Part IV of this series Books of a supplementary nature, such as acoustics, bibliographies, tube manuals, etc., will appear in Part III. Books of an incidental nature, such as biographies, histories, music appreciation, etc., will appear in Part IV.

The entire survey, subject to updates, appears as a permanent feature of the PEARL *Audio Notes and the* PEARL *Vacuum-Tube Technology Archive. Compiled by Bill Perkins, the 'Archive consists of approximately 1000 technical articles related to tube amplifier design. To obtain a copy of the latest revision of the Audio Notes, which contains an 'Archive index, contact* PEARL, INC. *at: Ph. 403 244 4434; Fx. 403 244 9026; email:* custserv@pearl-hifi.com. *Or visit* PEARL*'s website:* http://www.pearl-hifi.com, *where you can download the entire set of Audio Note articles along with many other items of interest.*

PART I
THE CLASSIC TEXTS

1920
Theory of the Thermionic Tube and Its Applications
H.J. van der Bijl
(McGraw-Hill Book Co., Inc., NY.)

Hendrik Johannes van der Bijl is the father of electron tube theory.[1—6] In 1913, van der Bijl deduced the fundamental functional relationships of triodes; and from these, derived the tube constants and gain equations.[7] These feats won for him a post at the Western Electric Company where he functioned as Senior Research Physicist until the publication of his seminal book in 1920. Many believe that Irving Langmuir, a research chemist for the General Electric Company, deserves the patriarch's mantle; but Langmuir's research focused on thermionic emission. Langmuir's landmark theory, published in 1913,[8] capped a materials research phase begun by Richardson[9] and Child.[10] Langmuir's paper refuted the long held belief that electric current could flow through a vacuum only by means of ionization (the infamous "blue glow".) Harold Arnold, head of the Western Electric research division for tube development, echoed Langmuir's belief in pure thermionic emission.[11] But until the advent of the molecular vacuum pump[†] in 1912, no one could prove otherwise. Van der Bijl's book guided designers, teachers, and researchers throughout the 1920s. Today, it remains useful as a broad source of information with respect to the earliest contributors to the vacuum tube art.

1932
Radio Engineering,
Frederick Emmons Terman
(McGraw-Hill Book Co., Inc., NY.)

Terman was for many years Dean of Engineering at Stanford. Terman published the 4th edition of his book in 1955 which he then renamed *Electronic and Radio Engineering* to emphasize "the general techniques of electronics, without regard to the extent of their use in radio systems." While useful

[†] By means of this device, very low gas pressures could be achieved within vacuum tubes. The consequent low density of gas-molecules was then demonstrated to be insufficient to support, by ionization alone, the electron flow that could be drawn through a thermionic emitter to an adjacent anode. *bp.*

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The PEARL Vacuum Tube Technology Archive

THE following is a complete index of the articles contained in the Pearl Archive.

Covering a wide range of topics and spanning 15 separate volumes, the 'Archive is a collection of approximately 850 articles chronicling the history of vacuum tube implementation in the audio-reproduction chain. The earliest articles date from the 1930s and the latest are present-day publications.

The complete 'Archive-set is supplied as double-sided copy in 15, 3-ring binders. Individual indices appear at the front of each volume and a separate, master index is supplied in a soft cover, 8½″x11″ plastic-spine-bound format. Within each volume, the articles are separated by full-page, card-stock tabbed sheets; each is labeled with the article number, title, author and page count. Copies are available of separate articles, reader-chosen groups or complete volumes as listed below. We will supply any selection of complete, individual volumes you require. Due to the unreasonable effort and time required, we do *not* make up customized, 3-ring binders containing reader-selected articles from the various volumes, a unique index and tabbed, article separators. If you want such a selection, the articles will be supplied in a soft cover, 8½″x11″ plastic-spine-bound format with green, full-page, untabbed card-stock separators.

For complete ordering and pricing information, see the snip-out order form that appears at the end of this master index.

For a listing of those companies and individuals who've purchased the 'Archive, see AN2.1.1, pg.4

VOLUME 1: POWER AMPLIFIERS

SECTION 1: AMPLIFIER BASICS - 15 ARTICLES

001	Puzzled About Amplifiers?	N.H. Crowhurst	4 Pgs.
002	Amplifiers	Edgar M. Villchur	6 Pgs.
005	High-Power Audio Amplifiers	M. Horowitz	4 Pgs.
010	Push Pull in Hi Fi	M. Horowitz	4 Pgs.
015	Simplified Push-Pull Theory	Julius Postal	8 Pgs.
020	Push-Pull Audio Frequency Amplifiers	K.R. Sturley	6 Pgs.
025	Hi-Fi Power Amps.	Robert F. Scott	3 Pgs.
030	Circuit Features in Hi-Fi Power Amplifiers	Robert F. Scott	3 Pgs.
035	Why Do Amps Sound Different?	N.H. Crowhurst	3 Pgs.
040	High-Power vs. Low-Power Amps	N.H. Crowhurst	4 Pgs.
045	Audio Power Requirements and Statistics	C. Nicholas Pryor	3 Pgs.
050	Audio Designer's Handbook: Part 1	David Saslaw	5 Pgs.
055	Audio Designer's Handbook: Part 2	David Saslaw	6 Pgs.
060	Thoughts on Amplifier Design	Stewart Hegeman	2 Pgs.
065	System Design Factors for Audio Amps	M.V. Kiebert	16 Pgs.

SECTION 2: ULTRA-LINEAR AMPLIFIERS - 18 ARTICLES

070	Ultra Linear Amplifiers: Part 1	F. Langford-Smith	9 Pgs.
075	Ultra Linear Amplifiers: Part 2	F. Langford-Smith	5 Pgs.
080	Ultra Linear Amplifiers: Part 3	F. Langford-Smith	2 Pgs.

085	Ultra Linear Amplifiers	Wireless Engineer	2 Pgs.
090	Tetrodes with Screen Feedback	Author Unknown	3 Pgs.
095	Amplifiers and Superlatives	D.T.N. Williamson & P. Walker	5 Pgs.
100	Determining Screen Grid Dissipation in UL Amps.	Leonard Kaplan	2 Pgs.
105	U.L. Operation of the Williamson Amplifier	D Hafler & H. Keroes	3 Pgs.
115	Designing a U.L. Amplifier	Edward S. Miller	2 Pgs.
125	High-Quality Circuits	John K. Frieborn	3 Pgs.
135	Adapting the U.L. Williamson to 6550 Operation	Herbert I. Keroes	4 Pgs.
140	A 50 Watt Power Amplifier	David Hafler	5 Pgs.
145	120 Watts of Hi-Fi Power	David Hafler	3 Pgs.
150	U.L. Operation of 6V6 Tubes	David Hafler	4 Pgs.
155	New 25 Watt Power Amplifier	Norman Kramer	2 Pgs.
160	A 60 Watt UL Amplifier	Author Unknown	4 Pgs.
165	The UL II	Author Unknown	2 Pgs.
170	40 or 60 Watt Hi-Fi Amp with Tertiary Feedback	Thomas F. Burroughs	4 Pgs.

Section 3: The Mcintosh Unity-Coupled Amplifier - 8 Articles

175	Description & Analysis of a New 50 Watt Amplifier Circuit	F.H. Mcintosh & G. Gow	5 Pgs.
180	A New 30 Watt Power Amplifier	S. Corderman & F. Mcintosh	6 Pgs.
185	Realistic Audio Engineering Philosophy	Norman H. Crowhurst	11 Pgs.
190	Hi-Fi at Low Cost with Twin-Coupled Amplifier	Norman H. Crowhurst	6 Pgs.
195	Radio Electronics Twin Coupled Amplifier	Norman H. Crowhurst	6 Pgs.
200	Updating the R-E Twin-Coupled Amplifier	Norman H. Crowhurst	3 Pgs.
205	High Efficiency-High Quality AF Power Amp.	Alexander B. Bereskin	13 Pgs.
206	Circuit Features of High Fidelity Power Amplifiers	Robert F. Scott	3 Pgs.

Section 4: Triode-Connected Tetrodes - 3 Articles

210	Triode Operation of KT88's	R.M. Voss & R. Ellis	3 Pgs.
215	High-Power Triode Amplifier	W.T. Selsted & R. H. Snyder	3 Pgs.
216	Pentodes & Tetrodes Operating as Triodes	C.C. McCallum	2 Pgs.

Section 5: Constant-Current Output Stages - 3 Articles

220	Constant-Current Operation of Power Amplifiers	H.T. Sterling & A.Sobel	6 Pgs.
230	Constant-Current Audio Power Amplifiers	H.T. Sterling & A. Sobel	4 Pgs.
235	Constant-Current D-C. Amplifiers	Donald Mcdonald	2 Pgs.

Section 6: The Williamson Amplifier - 6 Articles

236	High-Quality Amplifier: Basic Requirements	D.T.N. Williamson	8 Pgs.
237	High-Quality Amplifier: New Version; Further Notes	D.T.N. Williamson	16 Pgs.
238	High-Quality Amplifier: Letters from Builders	D.T.N. Williamson	1 Pgs.
239	Modernize Your Williamson Amplifier	David Hafler	3 Pgs.
240	Improving the Williamson Amplifier	Talbot M. Wright	3 Pgs.
241	The "Williamson Type" Amplifier Brought Up to Date	M.V. Kiebert	3 Pgs.

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Tube Coolers and Equipment Reliability

A TUBE COOLER is a device that reduces the operating temperature of a glass-bulb vacuum tube. Although some of the elements within the tube are required to operate at high temperatures, the surrounding glass enclosure is quite vulnerable to elevated temperatures. Through the action of several mechanisms, this weakness drastically reduces tube life.

Although it has been common knowledge in other sectors of the electronics industry for decades, this information seems to have escaped the attention of most designers of tube-type home entertainment equipment.

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

- 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
- it must withstand high operating temperatures, substantial attendant temperature gradients and consequent physical stress; without failure.

As the foregoing is essentially the 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 glasses are quite stable at low temperatures, deterioration begins to occur as temperature increases. *Over-temperature operation is the biggest reliability problem encountered in glass-bulb vacuum-tube operation where long working-life is a major consideration.*

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

The MARCONI 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

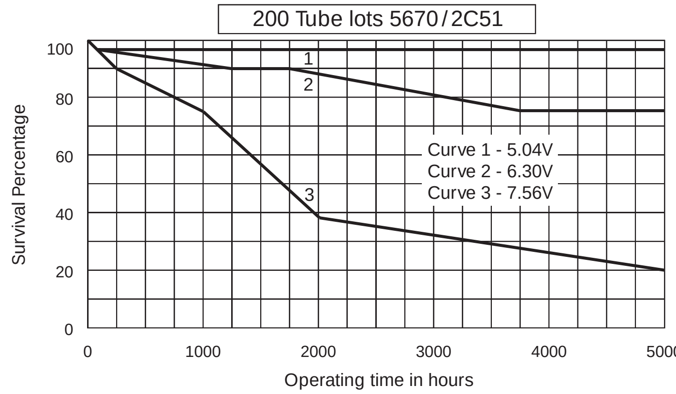
With increasing equipment complexity during and after WW II, the causes of equipment failure came under intense scrutiny from a number of agencies. The commercial airlines in the USA formed and maintained the non-profit organization, Aeronautical Radio Inc. (ARINC) to coordinate the development of electronic 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] The consensus of this work was that while resistor and capacitor failures accounted for approximately 7% of

[†]Tempilaq is such a product and is available from: TEMPIL, a div. of Air Liquide America, S. Plainfield, N.J., Ph. 1-908-757-8300; Fx. 1-908-757-9273

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:



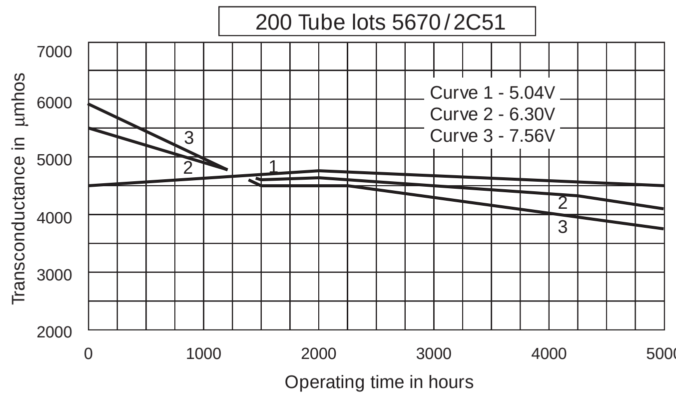


Fig. 1. Tube transconductance and working-life are shown plotted as a function of filament voltage. Note that operation of this particular tube at its rated filament voltage results in a 27% drop in transconductance during the first 1500 hrs. of operation. Operation of the filament at a 20% reduction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

- 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 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* (described later in this article) operating in tubes run over-temperature and also the result 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 (14 & 15) 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 material coming adrift within the envelope.
- glass failure, with attendant loss of vacuum, if

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A Little Input on Audio-Output Transformers

THE PRIMARY FUNCTION of most transformers is to facilitate the transfer of power between circuits whose voltage-to-current ratios and/or DC levels are different. Transformers designed for use as impedance converters do not function in purely DC circuits, although it is sometimes necessary to allow direct current to flow through an audio transformer, such as a push-pull or single-ended coupling or output device.

An audio-output transformer is usually required to couple a high source-impedance power-amplifying stage capable of several hundred volts of swing at an output of a few hundred milliamps to a low-impedance, frequently ground-referenced load requiring a few tens of volts drive at currents of several amps.

In $Watts_{rms}$, the power developed in a circuit is the product of the current flow through the circuit, in $Amps_{rms}$, and the applied voltage in $Volts_{rms}$. This relationship holds for DC circuits and for AC circuits where voltage and current reach their respective peak and zero values at the same instant.

In the case of an ideal (i.e. 100% efficient, no distortion, no losses, etc.) single-ended, transformer-coupled, Class A amplifier capable of delivering 32W into 8Ω, a 16.0V output forces 2.0A to flow through the 8Ω load, yielding 16.0V x 2.0A = 32W of power. If the turns ratio of the transformer is 16:1, the voltage swing across the primary is 16 x 16V and the current flow is 2/16A. The power developed is $16^2/8$ = 32W.

If an attempt is made to force the tube output stage of this same amp to drive an 8Ω speaker directly, a tremendous reduction in the power available will be seen. The maximum current the output stage can deliver is limited to about 0.5A; as only 4.0V are required to force such a current through 8Ω, the volt/amp product yields a figure of only 2 watts!

It can be readily seen that the ratio of primary voltage to secondary voltage is $16/16^2 = 16$ while the current ratio is .125/2 = .0625.

Either of these relationships can be used to determine the *turns ratio* of the transformer, although the use of the voltage figures usually makes measurements easier. In the present case, looking from the primary to the secondary, the ratio is 16:1, i.e. for every 16 turns on the primary, there is one turn on the secondary.

The impedance reflected back to the primary side by an 8Ω load on the secondary is easily calculated: it's equal to the $(\text{turns-ratio})^2$ x (the load impedance). Thus, an 8Ω load reflects back to the primary as 2048Ω; a 16Ω load, 4096Ω; and a 4Ω load, 1024Ω. The point here is that a transformer does not have a fixed input or output impedance as such; it is a device used to match circuits to each other in such a way that, for instance, the maximum transfer of power can take place.

An irreducible limitation is that transformers are *band-pass filters*, which, by definition, exhibit a finite usable bandwidth. The geometric center frequency[†] of the usable band—the *pass-band*—is determined by the design of a given transformer and is broadly defined by the intended source and load impedances used as factors in the design. Other source and load impedances can be used, provided that their ratio is made equal to the source/load impedance ratio employed in the original design; then the geometric center of the passband will simply move either up or down in frequency. As this usually occurs without serious effects, the design center values should not be taken as rigidly fixed absolutes.[1]

ALAS... REALITY!

Upon leaving the world of the perfect 32W, Class A amplifier, life becomes rather more complex, and the difficult task of designing a high-power, wide-bandwidth, Class A(B) output transformer assumes its full proportions.

A tube type power-output stage can be configured in many ways: triode, fixed screen-voltage pentode/ beam tetrode, swinging screen-voltage pentode/ beam tetrode—ultra-linear—partially or fully cathode coupled, Class A_1 or A_2, Class AB_1 or AB_2, etc.[2, 3, 4, 5, 6, 7]

Much study of the numerous options has shown that a properly executed, ultra-linear, partially cathode-coupled, Class AB_1 output stage represents a well optimized, balanced solution to the various

[†] The geometric center frequency of any frequency band is equal to the square root of the product of the lower and upper frequencies, i.e. the geometric center of the 20Hz to 20kHz band equals the square root of 400,000, or 632.45Hz.

If a piece of frequency-response graph paper with frequency scaled logarithmically is folded in half so that the 20Hz line is laid over the 20kHz line, the crease will occur at 632Hz.

problems presented. Consequently the PEARL SC280 transformer has been specifically designed to operate in this manner. This by no means precludes its use in other output-stage configurations. The stage described presents serious design challenges; as these have been well met, the transformer will work admirably in more straightforward applications such as high idle-current class A triode stages or low idle-current, class AB_1, fixed screen voltage, pentode/ beam tetrode operation.

No matter the output stage configuration, good low-frequency response requires a high value of primary open circuit inductance, OCL.

A good rule is that for every 1000Ω of reflected primary impedance, the transformer should develop 70H of OCL from very low power upwards. This will yield a small-signal low-frequency –1dB point in the 3Hz region. It should be noted that the power-handling capacity of any transformer reduces to ¼ of its previous value for every halving of frequency. Thus, a device capable of a 300W output at 20Hz can meet only a 75W demand at 10Hz while at 1Hz its output capability has dwindled to a few hundred milliwatts. See Fig 1.[8]

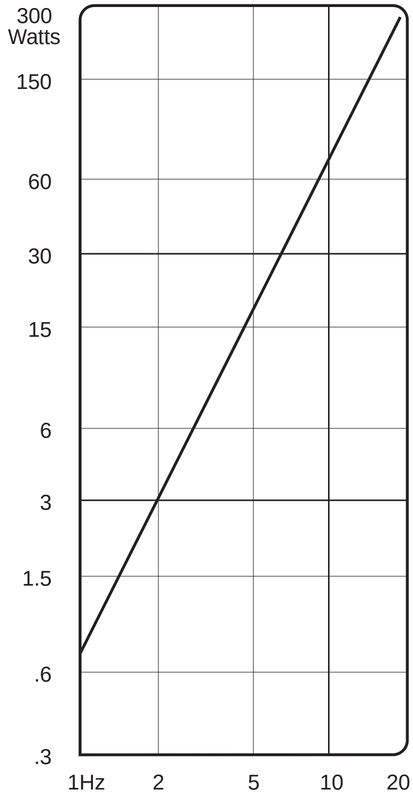

Fig. 1. The decrease of low-frequency output ability with decreasing frequency.

While good low-frequency extension is, relatively speaking, easily accomplished, smooth, extended high-frequency performance is always difficult to achieve. The physical characteristics of the sorts of windings required for extended low- vs. extended high-frequency response are exactly opposite in nature and there exists an ultimate limit on the usable bandwidth attainable for a given output power and unit cost. If the very best of modern materials are used and no effort is spared in the precise execution of the design, the bandwidth can be extended beyond that previously considered to be practically achievable.

Among the factors to be carefully minimized are the leakage inductance, L_L, and the inter-layer and inter-winding capacitances. Due consideration must be given to the inter-winding AC potential differences, as these directly affect the net charge, hence the effective capacitance, and therefore the characteristic impedance of a given section of the winding.

Mismatches in these values cause energy reflections within the windings and result in numerous high-frequency, self-resonant modes. These in turn produce a rough high-frequency response with ragged phase and group-delay figures that can make the application of loop feedback a perilous undertaking.

If the amplifier is intended to operate pentode class AB, the difficulties are further compounded by the need for fantastically tight inductive coupling between the two halves of the primary—which must be accomplished with an absolute minimum of capacitive coupling.

The need for low capacitive-coupling between the half primaries must be met, as any half-primary-to-half-primary capacitance acts—with an increase in driving frequency—as a decreasing value shunt load between the opposing halves of the output stage. At high frequencies, a lowered impedance between these two points will excessively load the output tubes and adversely affect the high-frequency output at the secondary. [9, 10, 11, 12, 13, 14, 15, 16, 17]

In a class A amplifier, current always flows in both halves of the primary, whereas pentode class AB operation results in the cessation of current flow in one or the other half-primary as the output stage makes the transition from class A into class B. Because the two half-primaries are never perfectly flux-coupled to each other, a back EMF spike is generated in the half-primary-to-half-primary L_L whenever current flow is abruptly terminated in either half primary.[†] This voltage acts to stimulate a resonant circuit consisting of the half-primary to half-primary L_L and some portion of the various capacitances present.

This causes the appearance of a pernicious form of *notch distortion*[††], resulting in upper-frequency common-mode signals that can partially couple into the load. As the feedback network samples the output from the amplifier at the point of interface with the load, this error voltage finds its way, via the feedback loop, throughout the entire amplifier.

Unfortunately, feedback can do nothing to reduce this particular distortion form. The circuit exhibiting the distortion being *downstream* from the output tube(s) biased into cutoff, feedback can only serve to aggravate the problem.[18, 19, 20]

[†] Triode and UL connections are not nearly as problematic in this respect as fixed-screen-voltage pentode/beam tetrode connections.

[††] Not to be confused with the *crossover distortion* exhibited by improperly biased solid-state amplifiers

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RB300-3CX
High Performance Audio-Triode

THE NEW RB300-3CX HIGH-PERFORMANCE TRIODE is a rugged, long-lived, extremely compact, external anode electron tube. It uses a metal/ceramic construction very successfully employed in the broadcast industry for decades. Amoung its unique characteristics are:

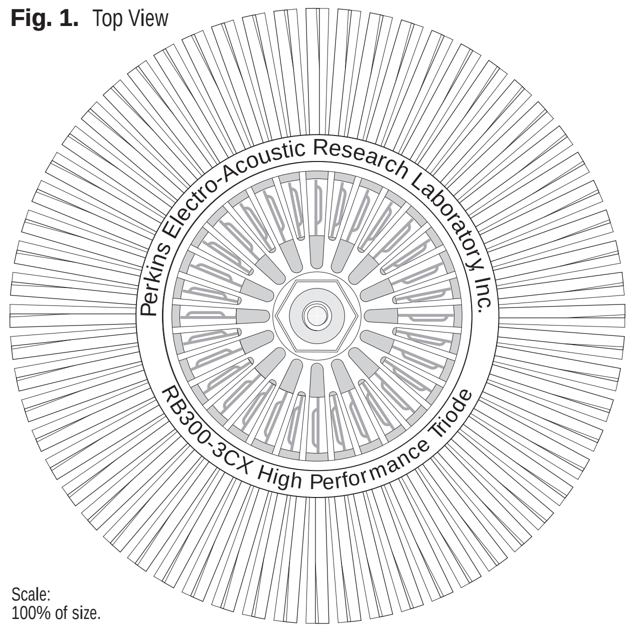
- very robust mechanical construction that features a highly precise and mechanically stable control grid, essentially free from the resonances that result in microphonic output. See Fig. 3, a 150% cross section of the tube
- a μ of 8, higher transconductance, g_m, and lower plate resistance, r_p, than conventional receiving tubes such as EL34, 6550, KT90, 845, 211, etc.
- an indirectly heated, high efficiency, oxide-coated cathode capable of short-term–peak current outputs in excess of 3A
- a modest filament-power requirement; only 2.6A @ 6.3VDC
- silver soldered or brazed, solid copper construction throughout
- large area, heavy gauge, solid copper heatsinking connected directly to the anode.

Convective dissipation is in excess of 125W per tube while quiet, low air-velocity fan-cooling will better than double that figure. Figs. 1, 2 and 3 detail the tube's construction while Fig. 5 shows a cross section of the forced-air cooling/high-voltage isolating arrangement for a push-pull pair RB300s.

Running a B+ on the order of 700V, a class AB_1 output power of approximately 150W derives from two pairs run in push-pull–parallel. The current-invariant, class A_1 power for this configuration is approximately 50W, more than enough to handle the information-rich, lower amplitude portions of the music envelope in a most musically satisfying way.

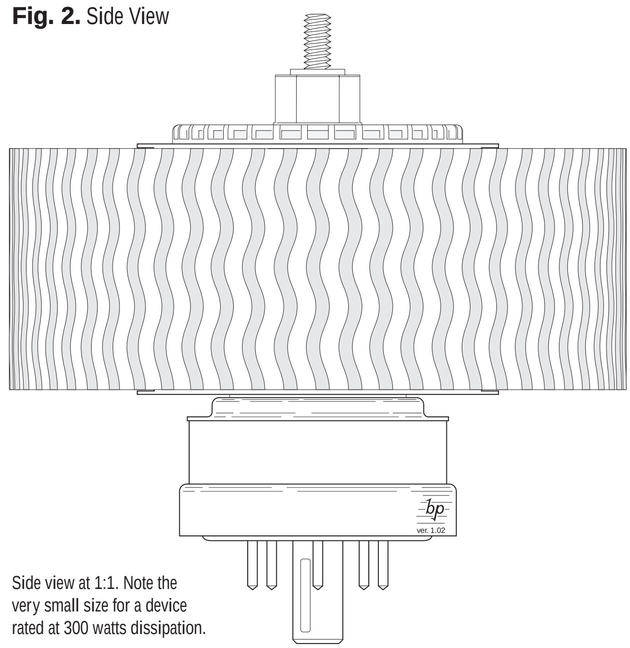
About the size of a hockey puck, the RB300 is decidedly different from conventional, glass tubes. Setting aside the undeniable aesthetics of "glowing glass," these envelopes present a serious obstruction to the penetration of infra-red radiation. In fact, it is usually the glass that first limits plate dissipation, not the metal parts contained within such an envelope. Seeking ways to increase the radiant capacity of

Fig. 1. Top View



Scale:
100% of size.

Fig. 2. Side View



Side view at 1:1. Note the very small size for a device rated at 300 watts dissipation.

large transmitting tubes, several companies developed metal-ceramic sealing technologies during the early 1940s.

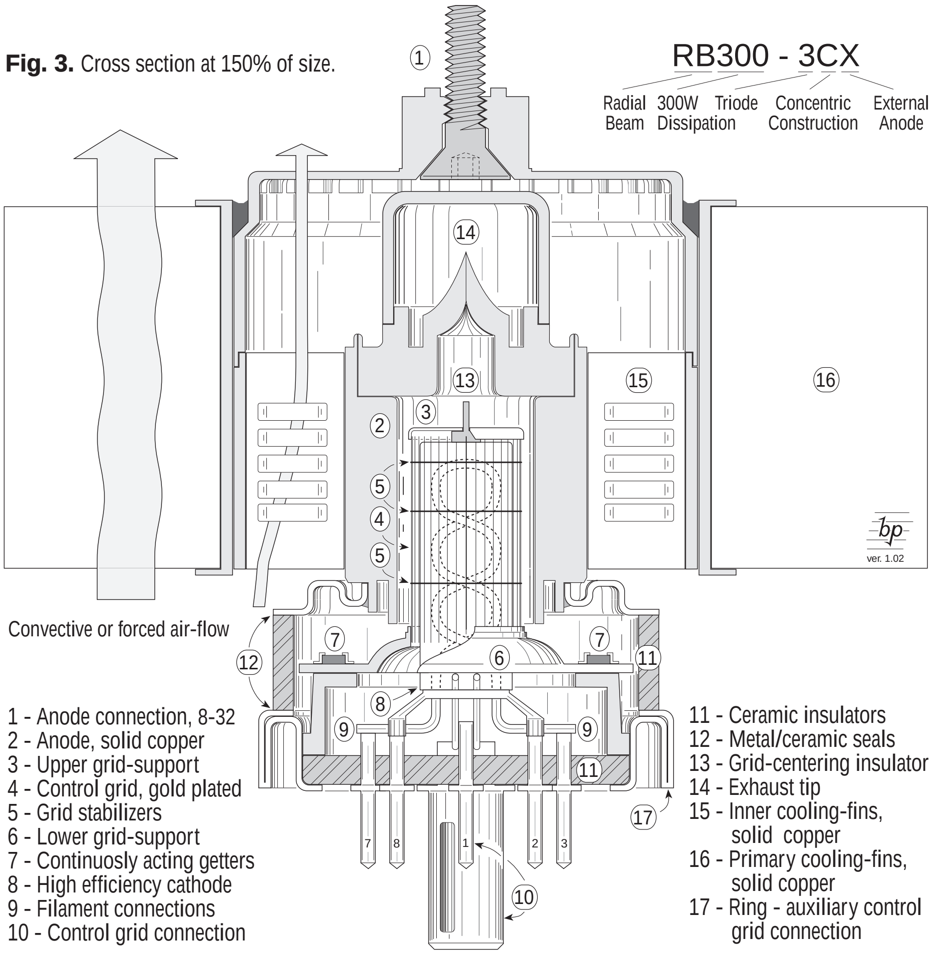
These processes allow designers to construct tubes with the plate configured as an element that *contains* a high vacuum rather than being contained *within* a high vacuum.

When anodes are directly cooled by radiation, convection, conduction and/or evaporation, much more compact designs are possible. By its high power-to-size ratio, the RB300-3CX solves many problems that have plagued designers of large, vacuum-tube amplifiers for better than half a century.

The RB 300's performance is guaranteed by a liberally administered 3 year/10,000hr. warranty subject only to limitations regarding abuse, over-temperature operation and normal, cathode-life effects.

Please call for details.

Fig. 3. Cross section at 150% of size.

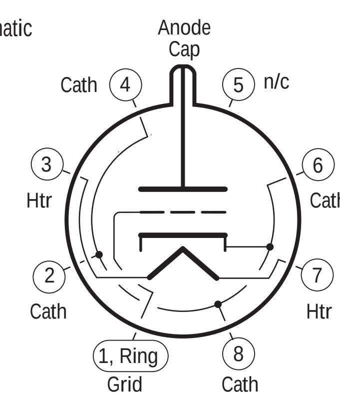


SPECIFICATIONS

Heater voltage 6.3V
Heater current 2.6A
Warmup time 2.0min
Basing . . . . . Special octal with center-pin–contact
Cathode . . . . . Oxide-coated, unipotential
Heater to cathode potential . . . . . ±150V
Cathode current (max. peak) 3.0A
Anode voltage (max. peak) 2.0kV
Anode dissipation (max.)
Convection cooling 125W
Forced air (200FPM, close-fitting chimney) 300W
Control grid dissipation 1W
Control grid, max. negative voltage . . . . . – 400V
Operating position:
Convection cooling . . . . . Vertical
Forced air (200FPM, close-fitting chimney) . . . . . Any
Max seal temperature:
Sustained . . . . . 200º C
Intermittent (5min or less) . . . . . 300º C
Seated height . . . . . 2.75"
Maximum diameter . . . . . 3.2"
Weight 420gms

Amplification Factor . . . . . 8±1
Transconductance:
(I_b = 500mA, E_b = 600V) 20mA/V
Capacitances (grounded cathode connection:)
Input . . . . . ≤15pF
Output . . . . . ≤1pF
Feed-through . . . . . ≤10pF

Fig. 4. Schematic



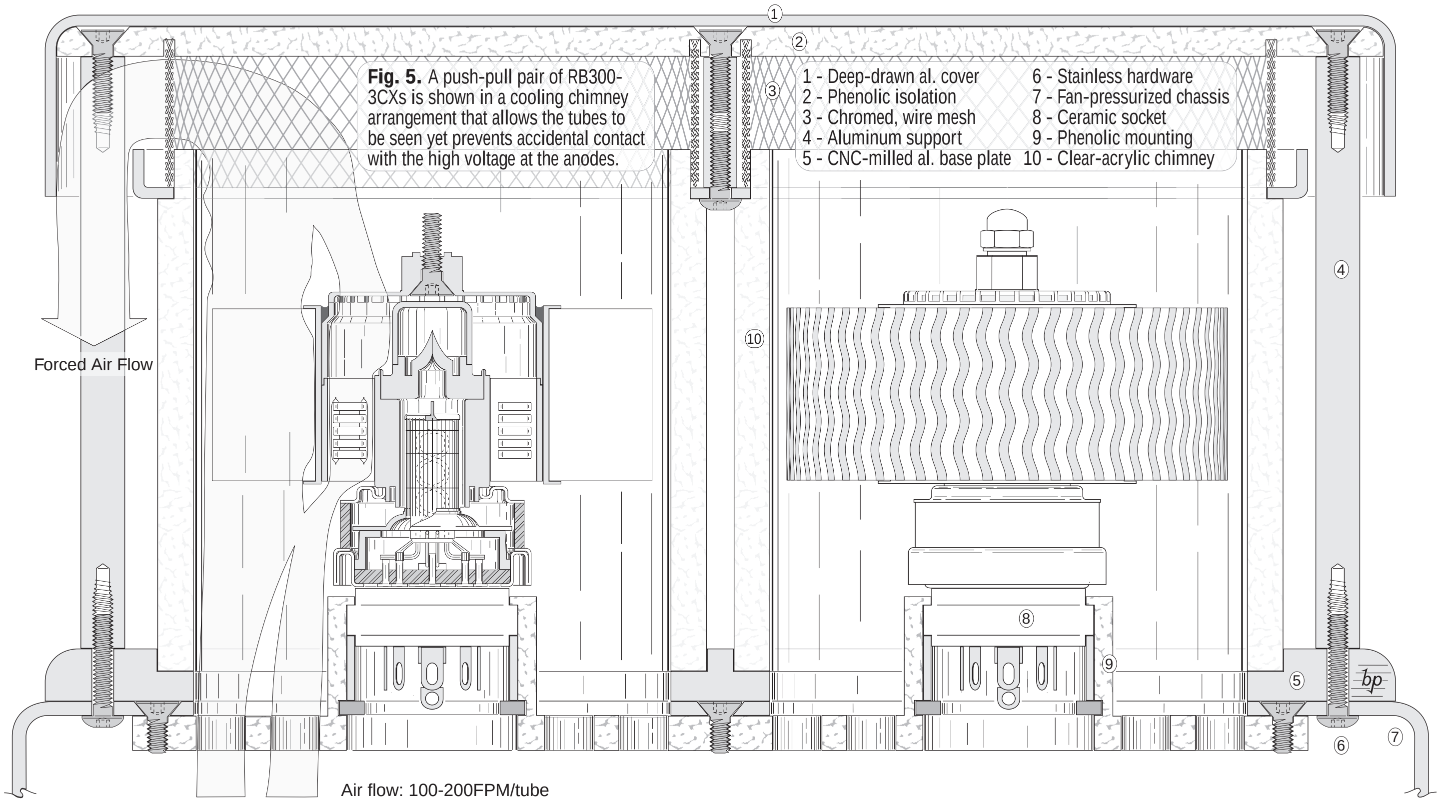


Fig. 5. A push-pull pair of RB300-3CXs is shown in a cooling chimney arrangement that allows the tubes to be seen yet prevents accidental contact with the high voltage at the anodes.

FAN COOLING

To many audiophiles, the prospect of fan cooling a piece of equipment is daunting at best. Quite simply, this is because most so-called “low-noise” fans are plainly audible, even all the way across a quiet listening room.

Moreover, the static and dynamic balance of the rotating impeller is often such than significant levels of vibration are launched into the chassis work; ultimately impacting any vibration transducing (microphonic) components in the equipment.

ETRI, INC. manufacture a series of fans that are exceptionally quiet and well-balanced. Available with either ball- or sleeve-bearings these units exhibit useful life spans of tens of thousands of hours while moving 13 or 15 CFM of free air at 50 or 60Hz. respectively.

The two-tube chimney arrangement shown above is effectively cooled by one ETRI 126LH as it will force an air flow of approximately 100 FPM past each of the tubes. Cooling 4 tubes therefore requires 2 fans and the chassis work in the PEARL power amplifiers is arranged around this dictate. Note that the acoustic output from a fan is a noise waveform rather than a regular sinusoid. Noise-signal amplitudes add as the root of the sum of their squares, resulting in an SPL increase of 3dB for every doubling of the number of sources.

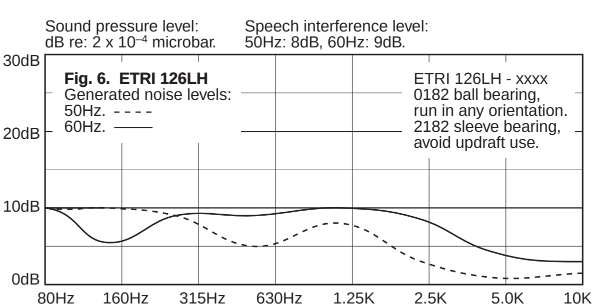


Fig. 6. ETRI 126LH

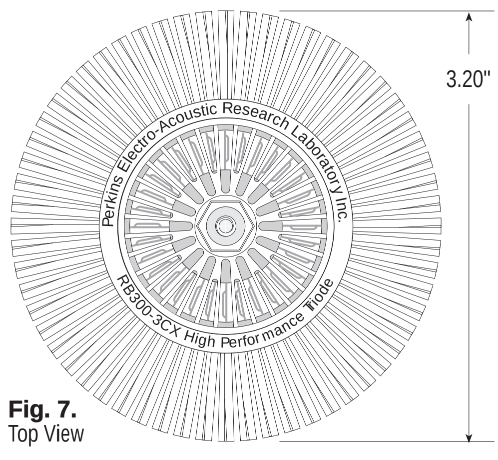


Fig. 7. Top View

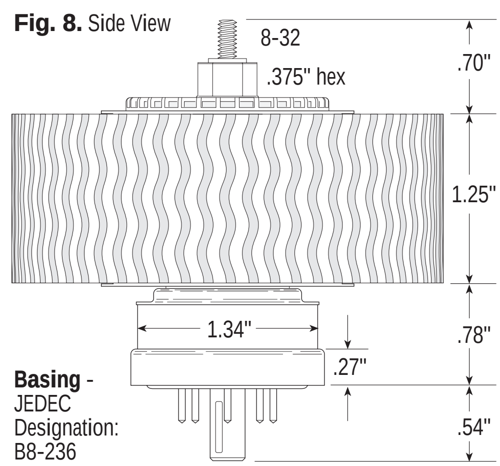
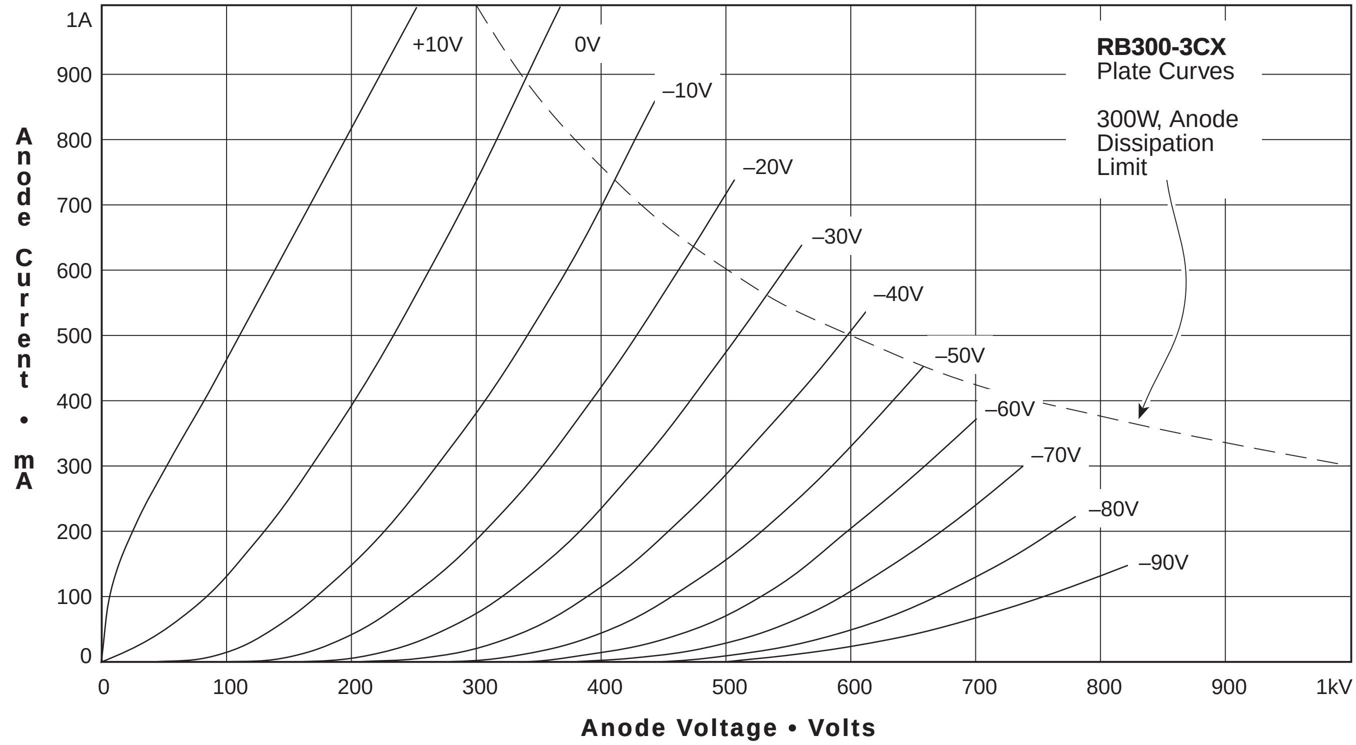


Fig. 8. Side View



Application data

Push Pull

Class AB_1	B+ Voltage			
	500V	**750V**	**1kV**	
Plate resistance	1.0	1.5	2.25	kΩ
Plate-to-plate load	2.0	3.0	4.5	kΩ
Idle current (per tube)	150	100	75	mA
Transconductance	8.0	5.3	3.6	mA/V
Control grid bias	50	90	125	–V
Control grid drive	100	180	250	V_{p-p}
Driving power	0	0	0	W
Output power AB_1	xx.	75		W
THD 1kHz.	xx.	xx	xx	%
Current invariant, Class A_1 power	xx.	25	xx	W
Anode dissipation:				
(Idle, per tube)	75	75	75	W
(Max output, per tube)	xx.	xx	xx	W

Single Ended

AN OVERVIEW OF THE TREATMENT AND GRADING PROCEDURES

The series of operations through which an electron tube must pass before it can be called a PEARL CRYOVAC is lengthy and in some ways, arduous.

As received, a typical electron tube exhibits several problems that deleteriously impact its sonic performance. Most serious are the many internal stresses in the construction materials that accumulate during most of the stages of manufacture and; a very hard, heavy oxide-coating on through-glass pins to which direct connection is made. Seven- & nine-pin miniature tubes are typical of those whose pins are heavily oxidized while power tubes such as KT88 and EL34 are fitted with bases whose pins are tinned. Where required, through-glass pins are etched clean and hot-dip, bright tinned with the result that contact quality is *much improved*. The degree of sonic improvement is *substantial*.

The initial 100hr. burn-in allows the tubes' characteristics to stabilize while providing an opportunity to cull any "infant mortals."

During cryogenic tempering, the tube is slowly cooled to the –196ºC/–320ºF temperature of liquid nitrogen, "soaked" for many hours then *slowly* returned to ambient. By means of this unique and vital process, the stresses interior to the materials of the tube are substantially and permanently relaxed. During a subsequent, high temperature anneal, the tube is heated to 175ºC/350ºF then *slowly* cooled to ambient. Although not as extensive, the results are similar to those achieved by the cryogenic treatment.

The "Q" of the (self) resonant (electro)mechanical systems responsible for the output of (self) microphonic spuriae is thereby drastically reduced. By this important reduction, both the peak amplitude and the "ring down" time of these systems is reduced with the result that the "apparent gain" of the device is increased—even in feedback controlled circuits—while the "dynamic noise floor" is lowered.

Grading for noise and microphonic performance involves both listening and instrument evaluation. Various instrumentation provides data on the noise, microphonic level and spectral content while the overall "sound" of the spuriae is critically evaluated. In particular, the evaluation of microphonic output is very much an experienced-judgement call.

Dual triodes are rated for overall noise performance by the noise-output level of the noisier "tube" or section. Thereby, it's possible for a tube given an overall "STANDARD" rating to contain an <u>u</u>ltra <u>l</u>ow-<u>n</u>oise section. ULN tubes however, always consist of two ULN sections, hence the cost.

The last few steps in our process are the standard yet essential procedures for the evaluation of many important electrical characteristics such as mu or amplification factor, plate current and transconductance. Additional data is generated indicative of the mu and DC balance of the tube's sections.

Quite simply, PEARL CRYOVACS are the electron tube of choice for virtually all high performance audio applications: your satisfaction is *guaranteed!*

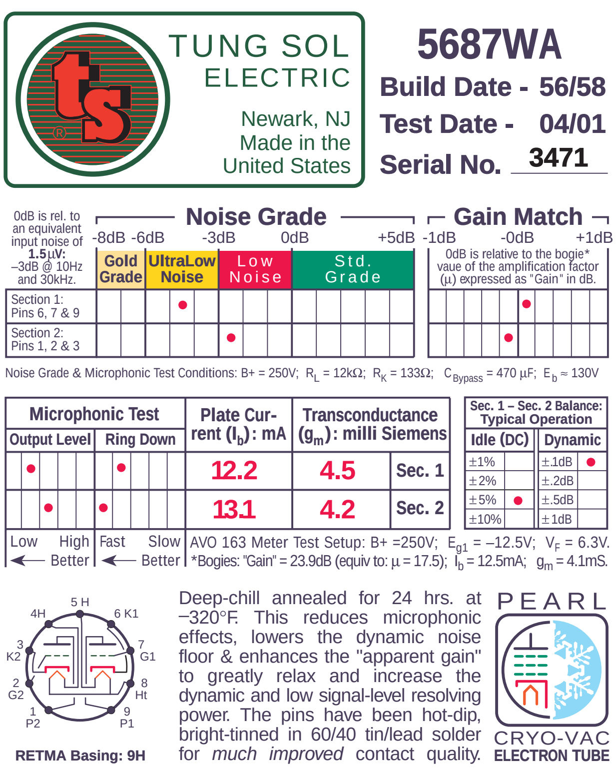
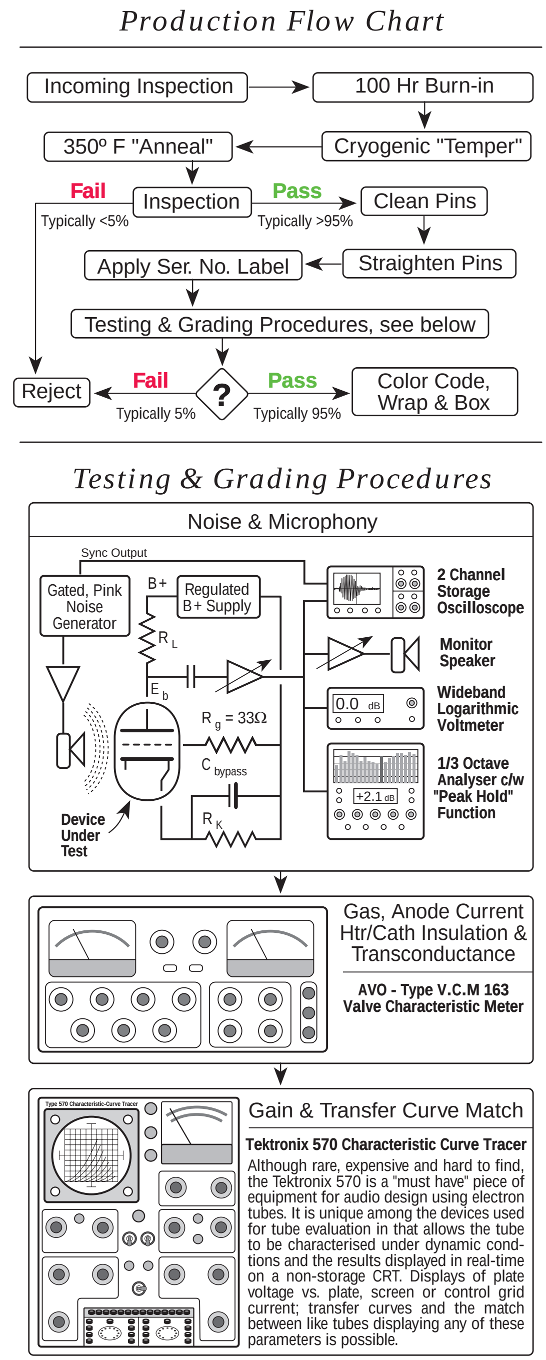


Fig. 1. Shown above is an artwork typical of those applied to the sides of the boxes in which all 7/9-pin CryoVac tubes are packed. All test data is written in by hand as the tube is passed through the various stages of our procedure. Every tube is subjected to assesment by instrumentation and actual listening tests.



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Web site: http://www.pearl-hifi.com
Email: custserv@pearl-hifi.com

Fig. 2. The complete production flow for PEARL CRYOVAC electron tubes is schematically rendered above. Unique in the audio industry, our methodology effectively addresses many issues relevant to the performance of electron tubes in high-quality audio and musical instrument applications. *CryoVacs will remarkably improve the sound of* any *tube type audio equipment.*

Users Comment on the Sonic Performance of PEARL CRYOVAC Treated Tubes

We maintain a strong relationship with:

http://www.tubeworld.com/cryovac.html

for whom we freeze and grade a simply awe inspiring variety of the the best of the best NOS. Where the owner, Brendan Biever, finds these tubes I simply cannot imagine, but find them he does.

So with out further ado, here are some comments from his web site headlined by a rave from the man himself:

I can hardly put into words how wonderful this new batch of NOS PEARL CRYOVAC tubes sounds, they are so outstanding, one is literally hypnotized by the music:

- *Great improvements in perceived dynamics due to reduced perceived-noise floor—blacker background.*
- *Very! focused and sweet midrange. Incredible top to bottom tightness to the music.*
- *Mid-bass articulation is excellent—tight!)*
- *Sub-sonic, deep-bass tracking is phenomenal, especially with hip hop bands*
- *Emotional recordings will bring you to tears!*
- *You can hear individual instrumentation in each channel in the mix much better. The foundation of each recording can be followed perfectly. You just hear more music! Cymbals have incredible shimmer!*
- *Sweeping musical passages rise and fall like a tidal wave*
- *Closely miked recordings are alive in your room. You find yourself inside the recording.*
- *Background vocals buried in a lot of mixes are readily apparent and become a bigger part of the recording.*
- *You can hear every waver in a singer's voice*

These are best sounding and graded NOS tubes you can buy!

Customer Comment on Pearl CryoVac Tubes:

To say impressed would not be enough! To say jaw droppingly astounded still would not approach my exact sentiments! To reach nirvana is close, but still doesn't describe it! But if you have ever wanted to treat yourself to pure musical purity and bliss, then you have go to be willing to buy some of these CRYOVAC tubes.

They are worth every penny they cost.

My system is comprised of Audio Prism's Mantissa Pre-amp and Debut MKII amplifier. First I bought some 6DJ8/Mullard CRYOVACS [and installed them] in my gain stage and I was very impressed with the overall changes in my system. More musical presence, clarity, bass enunciation and range that went on and on.

Later, I purchased some Gold Grade 12AU7 Mullards for my output pre-amp section , sat down to listen, and. . . I was struck by lightning. I never knew music could sound this beautiful. I could swear that whatever I put on, put the musicians were right in my living room. What enchantment, what beauty, *what out and out ecstasy.*

Please, if you can, try these tubes in your system, I'm sure you won't be sorry. I'd say more, but I want to get back to the music, I can't seem to turn it off anymore!

"CV4004 Mullard" CRYOVAC Customer Comments:

I am extremely satisfied with my purchase of the Mullard CRYOVAC CV4004 as well as the Telefunken CRYOVAC ECC801S which is been used in my upgraded Conrad Johnson PV4 preamp. The CV4004 has upgraded my system to a new dimension; overwhelming dynamics, wide, deep and well populated soundstage with great separation and air surrounding instruments, tight and extended lower bass as well as more definition on the uppers. Warm, rich, smooth mids with incredible shimmer on percussion. Inner detail is amazing, you hear more complete notes and everything just has more presence, but most of all it is extremely musical, making your listening session an enjoyable experience. This tube does everything right.

"Dutch 6DJ8 Mullard" CryoVac
Customer Comment:

I just wanted to write you a brief note to let you know how amazing these Mullard, Holland 6DJ8, Pearl CryoVac, Gold Grade tubes are in my AI Modulus 3A preamp! Fabulous midrange and treble clarity, while at the same time, as warm a sound as you could ever want; ie: female vocals. . . Whew! Bass has improved as well.

Of course, I also replaced the Mullard 6201s in my VTL MB450 monoblocks, with the Pearl CryoVac Telefunken ECC801Ss—so natural sounding—like music!

Thanks very much. The tubes are not inexpensive, but I think they are worth every penny.

"German 1960s ECC88/6DJ8 Siemens" CryoVac
Customer Comment:

Balanced sound, smooth and detailed, this tube does everything right, probably the best all-around 6DJ8, highly recommended.

"ECC88/6DJ8 Siemens" CryoVac
Customer Comment:

I recently ordered a 6087/5Y3WGTB, indirectly heated, slow-warmup ruggedized 5Y3GT rectifier tube from you for my Decware Zen SET amp along with a pair of ECC88/6DJ8 Siemens Germany NOS original boxes, same date codes, 1960s, for my Ah! Tjoeb 99 tubed CD player.

I wanted to let you know that both purchases are working out great. I started with the rectifier tube and noticed that the amp played louder with more bass and better rhythm.

After trying that alone for a while, last night I installed the old ECC88 Siemens tubes in my CD player. Wow! they are awesome. There is more and clearer sound in the upper registers, cymbals and triangles sound more realistic and percussion instruments sound tighter and more detailed. In addition, they keep everything that was already there in the music that I liked with the stock tubes.

Thanks for some great recommendations.

"6922" CryoVac Customer Comment:

Thank you for your sending of E88CC/6922 Philips Miniwatt-Cryovac. These tubes arrived safely and sound great. Actually they bring my system in much higher stage, like heaven. Quiet, smooth, dynamic and 3-dimensional sound. Music has become real. Always tubes you offer are nice.

Hoping everything goes fine for you.'

"ECC32/CV181 Mullard" CryoVac
Customer Comment:

I have a Meridian 508.24 CDP hooked up to a Cary 300SEI LX20 integrated amp. These newer versions use the pumped-up 20 watt 300B tubes by KR (which they name 300BXLS). I've been playing around with 6SN7 tubes for quite a while: from the cheap Sovteks and Shuguangs to the RCA 5692 Red Base to the 1940s Sylvania VT231/6SN7W and RCA VT231s. The best combination that I settled on was a pair of Sylvania VT231/6SN7Ws as drivers with a Platinum Select 1950s RCA Black Base 6SN7GTB as the input tube. It was crystal clear, vast, open and very pristine. Bass was sufficient for my listening as I listen mostly to classical (especially chamber) and acoustic jazz. With my wife being a (former professional) cellist, we listen to a lot of cello sonatas.

But today, everything changed with the ECC32 CryoVacs. The bass was more present but not loose. Right off the bat, the Mullards somehow sounded too good to be true—scary to think how they'll sound after breaking in. Strings, especially cello, suddenly sounded like real finely crafted wooden instruments. I said to my wife [that] I was hearing instruments; she phrased what I was really trying to say, "You can hear the sound (vibrations and output) coming from inside the cello." ie., "You can hear the wood!"

We were now hearing (more of) the wood of the cello instead of a perception of soundwaves emanating from the steel strings of a cello. I thought this was a significant revelation, not just because it's the first time we felt this way after hearing the cello from our audio system, but because it really does gets us *closer* to the music.

From the Mullard ECC32 CryoVacs, I was hearing, during a cello or oboe concerto, the 'background' massed violins very clearly (not thin sounding as weight of the clarity is never compromised) while the main instrument is weighty but still utterly clear. The other 6SN7 combinations I've tried did give me clear sound but there was a compromise as the main instrument was also thinned-out to mesh with the background clarity.

On the other hand, some more "sweet and rounded" sounding tubes (such as the Red Base) sounded too "closed-in" and "muffled." The extension and dynamics were not there and I had to turn up the volume higher to get the same perception of loudness—it was what they term a bit too "dark."

But my wife preferred the Red Base as the input tube as it gave less thin sounding harshness. In addition, the bass of the Mullards are extremely impressive. The echoing of the bass twang is more present and you can actually hear it fading.

For a tube that is not “in your face” I don’t know how the ECC32s do it—they have it all: very civilized but not gentle and bland; deep bass and clear open highs; just the right amount of hall effect (not too airy or echo-y); very open and spacious but not thin and light sounding; absolutely stunning for cello reproduction. Yes, some 6SN7s did give me more of a [sense of] “being right there” and an extremely well focused image, but they could not match the overall total package of the Mullards.

It just makes me wonder how these creations are made—how does a tube maker know how to let a piece of glass and metal produce such a fine sound? Simply amazing. Yeah, driving a BMW may give you an ultimate driving experience. But why drive when you can have a chaueffer drive you in your Rolls Royce; sit back and enjoy the ride!

Sorry if things kind of got too long-winded . . .

It’s so good that the thought of not being able to hear this sound makes me somewhat worrisome. I’m compelled to get another matched pair as back-up; I’ll take it to the grave if it’s never used.

Many thanks and I look forward to another pair of these wondrous and amazing tubes.

“12AU7 Mullard” CryoVac Customer Comment:

[I] just installed the 12AU7 Mullard CRYO and 7044 CRYOS in my Wheatfield HA-1 headphone amp. Terrific, sophisticated sound. The improvement is even more apparent when used as a preamp into a pair of Tannoy dual concentric monitors. Separation of instruments and the sweetness you described are certainly there but I was surprised by the stronger bottom that emerged. What an improvement.

“CV4004” Customer Comment:

When the new CV4004 came, I nearly went through the ceiling. Talk about detail and dynamics. Extreme intensity is the best way I can describe it. You’ve never heard such dynamics in a system.

It made music; clean, beautiful music, I couldn’t turn it off, only up. And I consider my system very good to begin with: Green Mountain’s Continuum II speakers (wow, these are good!). The cabling was by Audio Magic which is just fantastic analog sound to the hilt. And McIntosh amps. The tubes went into my E.A.R. phono stage, which carries 3 tubes—and thank goodness only 3, I couldn’t afford any more.

But I’ll never go to a tube dealer other than Tubeworld. He worked with me and picked out the tubes for my system. I had no idea what tubes were until he helped me. Thanks again and yes, these tubes will toast any solid state stuff, I firmly believe.

“Tung Sol 5687” Customer Comment:

I am extremely pleased with the [Tung Sol] 5687 CRYOVAC tubes I received recently. I concur with the testimonials from other buyers on your site, but I would further add that once you have listened to a CRYOVAC tube, you quickly lose interest in all other types regardless of make or pedigree.

The CRYOVAC treated tube does things no other tube can do. Even tubes that normally would be considered mediocre under normal circumstances, once treated exceed the performance of the more exotic varieties.

The last similar performance experience I had was when an Audionote Japan amplifier was trialed in my system. Unfortunately I could not afford the Ongaku, but I can afford the CRYOVACS.

“GE 5751” Customer Comment:

[The} noise floor dropped almost off the face of the earth. Macro dynamics seem to have an additional 3—5 db of headroom. But the inner microdynamics are, well, frightening. Hand claps on gospel music, stick work by drummers all seem to explode out of the speakers at me. It almost seems that I have a new amplifier!

I had been considering upgrading to the CJ Premier 12 monoblocks, which are better still, but just changing the front end tubes seems to have revitalized my entire system. Without question, the best $150.00 improvement I’ve ever made!

Another “GE 5751” Customer Wrote:

First of all thanks for the fast service. Secondly, the tubes have arrived in excellent state on Tuesday already. I have placed them in their respective positions. After warming up, I noticed immediately differences compared to the 12AX7. These tubes are very warm in sound very dynamic, focused, splendid overall range from top to bottom. What was most remarkable was a very, very deep and well defined bass.

==========================

From a PEARL customer who had his Chinese 6550s treated:

I received the tubes this past Thursday. They sound fantastic. I was unprepared for the increased transparency, tighter bass and increased airiness. They’re just flat out more musical than before.

I find that my KT90s now sound harsh in comparison!

From PEARL customer who had his Chinese 845s treated:

The use of PEARL's CRYOVAC tubes has been beneficial to my listening experience. I have used tube amps and had many different products for years now. I have owned a variety of gear from 845 single ended amps to 220 watt push pull 6550 amps and a lot of different pre amps, all of them using tubes.

I am not a scientist but I can honestly say that the PEARL CRYOVAC tubes sound better in my system than pre-cryo or untreated pieces. One of my most recent experiences is an experiment I conducted with my 845 amp:

My present stereo SE amp uses 4–845s. In one channel I fitted cryo-treated GE 845s while in the other channel I used regular Chinese 845s. I then listened to the amp.

The side with the Chinese tubes sounded congested, lacking impact and was veiled compared to the side using the cryo-treated US-made GE 845s. Then I sent the Chinese tubes off to be cryo-treated, the cost was not a factor in my decision as the treatment was rationally priced.

When the tubes came back I was not expecting a great change as the sound before was so different between the two sides. When I plugged in the Chinese tubes (with the GEs still in the same channel as before) the sound was stunning from both sides now. The cryo-treated Chinese tubes were keeping up with their US counterparts! It was a major difference I then had all my Chinese 845s treated and am using them exclusively.

I've also used PEARL's cryo-treated 12AX7s and compared them with Telefunken 12AX7 smooth plates as well as Mullards. Each time the CRYOVACS have held their own compared to these great brands. I now use a combination of both in all of my gear.

In closing, the above are simple tests, they use real-world audio in real-world circumstances. I am not a scientist and cannot debate the scientific merits of the CRYOVAC treatment processes with any authority but I can certainly say that the CRYOVAC tubes improve my system, cryo-d tubes simply sound better than their untreated counterparts.

This observation has been consistent in all the circumstances that I have used this product.