SOLID STATE TRIODE series AMT “WARM STONE”

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INTRODUCTION

Tube sounding almost initially became a kind of standard guitar sound, and it is so to this day. The most frequently used in guitar amplifiers, low power dual triodes such as ECC83 (12AX7). Despite the undoubted musical merits of this triode, it does have some drawbacks common to all vacuum tubes (fragility, low efficiency, limited resources, deterioration of characteristics over time, etc.), therefore has long led development engineers to think about creating devices which will replace the tubes, but devoid of the above-mentioned drawbacks.

Back in the 70 years of the twentieth century in the music industry have been carried out first attempts to use low-power semiconductor tube replacements. In some models of company Mesa-Boogie, for example, in the first stage instead of the usual triode 12AX7 was used the components of the company Fetron. It should be noted that the Fetron's components was intended primarily for telephone exchanges, where they had been used since the late 60's in order to save electricity. Substitutes of tubes from FETRON were built in a cascode schematic, which provided the ability to operate at high voltages, but they have a pentode output characteristics, which is clearly visible in the graphs the output current-voltage characteristics [1, 2], therefore, a direct replacement for triode devices with pentode's CVC led to significant differences in the sound. This circumstance, of course, played a considerable role in that how cold enough the musical community met such innovation in guitar amplifiers and, as time has shown, substitutes of tubes from FETRON not taken root in the world of music.

Some time ago the other companies have also implemented a significant try to the “tube heights”. Unfortunately, the manufacturers have not accompanied its products with sufficient technical documentation, so we have no right to speak about conformity of triode current-voltage characteristics (CVC), or other aspects of the triode vacuum behavior emulation, especially when dealing with high signal levels. We’re just stating a fact of issue some semiconductor tubes, leaving to the music community itself the right to form an opinion about the sound properties of these devices.

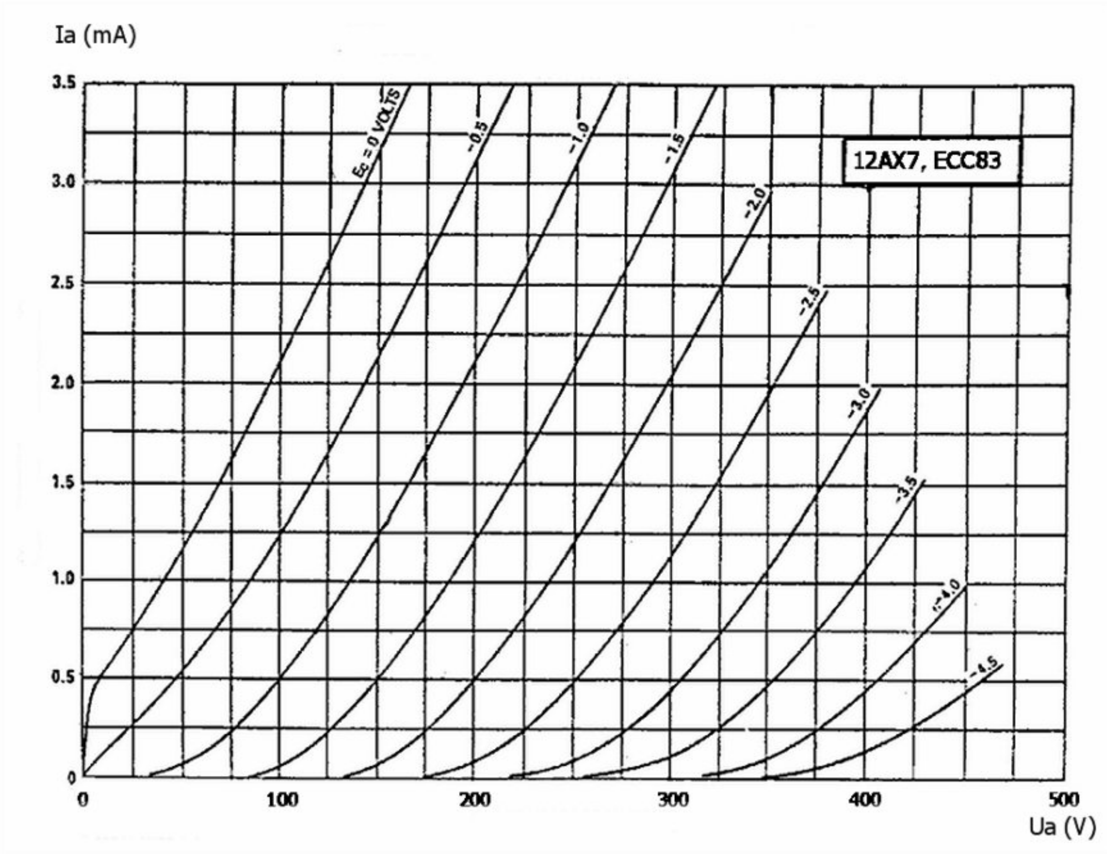
AMT Electronics has its own tradition of building tube replacements. In 2007, the company's engineers used their version of the cascode switching-on JFET and NPN bipolar transistor in the SS-20 preamp, allowing to accelerate the signal without limitation to several hundred volts with a minimum of noise floor. Then, were introduced circuits into the cascades that simulate the grid limitation, and the shape of the signal became very close to that of the signal on the 12AX7. In 2007, on the basis of article [4] the company started the development of low-voltage cascades that emulate the behavior of triode at the restrictions. Despite the use of field-effect transistors with a pentode characteristics, engineers managed to get the waveforms of signals which are similar to restrictions of a vacuum triode and in 2008, the world saw the first series of preamps LegendAmps (LA). In 2011, as a result of hard work on the modernization of low-voltage cascades, a series LA2 were born, which continues the tradition of using field-effect transistors in guitar preamps.

By 2012, the AMT engineers had accumulated a lot of experience in the development of semiconductor stages, which are in one way or another substituting the vacuum triodes, and in early 2012 the company AMT began intensive work on creating a complete functional semiconductor analogs of popular tubes used in guitar amplifiers.

In this article, we introduce the reader to the main points that characterize the sound of the vacuum triode in guitar amplifiers and their implementation in the solid-state triode **AMT WARM STONE**. Description of high-power solid-state penthodes and tetrodes expected in the near future in a separate article.

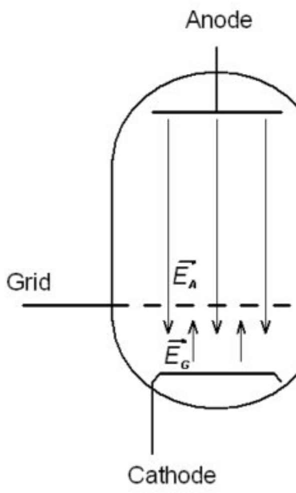
Basic principle operation of the semiconductor triode.

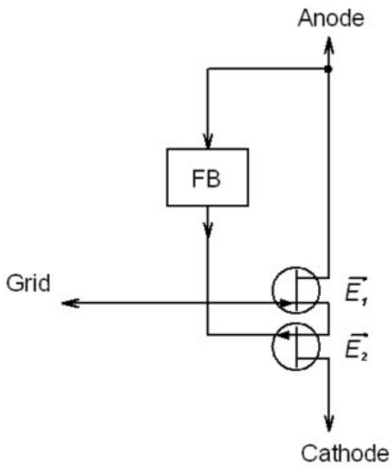
1. "Triode character" of sound of the vacuum triode in the linear region is largely determined by the shape of the output characteristics, namely, by the strong dependence of the anode current **Ia** from anode voltage **Ua** at a fixed potential of the control grid **Ug** = **const** (pic. 1).



Picture 1. The anode current-voltage characteristics of the 12AX7, ECC83

In triode the change of anode potential U_A under the influence of the signal on the grid U_G led to a change in electric field $\vec{E}_A$ between the anode and the cathode, which is summed up with a field of the control grid $\vec{E}_G$ in such a manner that prevents the change of the grid field under the influence of U_G (Pic. 2), that determines the presence of the inner negative feedback connection in the triode - parallel to NFB by voltage [4].

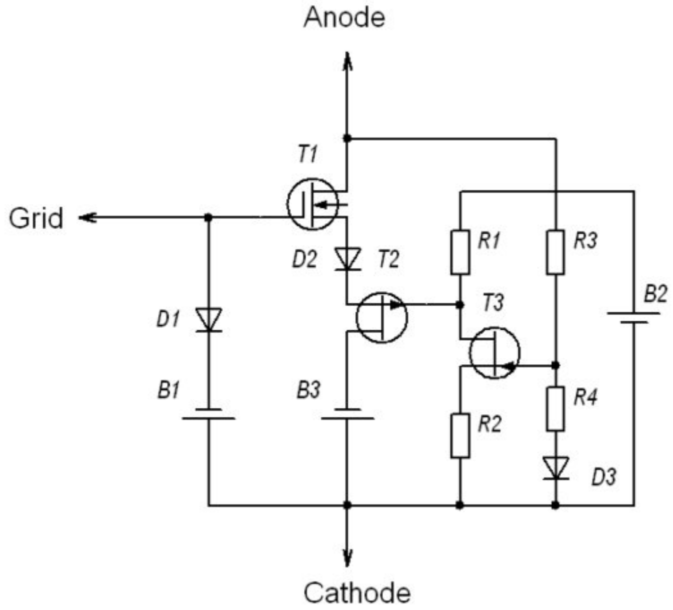




Picture 2. NFB of vacuum triode and organization of management of the field in triode by AMT Electronics.

The summarized field which controls the current through the triode $\vec{E}_{\Sigma} = \vec{E}_G + \vec{E}_A$, is different from the field of grid device with the pentode CVC by having component $\vec{E}_A$ [5]. Thus, by introducing the external control from anode by the field of input grid into a pentode device - we get a triode (in the case of electron-vacuum pentode it is enough to connect the screen grid to the «anode»).

Among semiconductor devices closest to Pentodes CVC have FETs, combined combination of which allows the ability to be simultaneously field-controled both from the input grid and from "anode" (Pic. 2).
At the relevant organization of feedback, of lower transistor (while providing conditions: $\vec{E}_2 \approx \vec{E}_A$ и $\vec{E}_1 \approx \vec{E}_G$), the structure operates as a triode, wherein the current control as in the vacuum devices is carried out by an electric field.
The base scheme of the transistor AMT 12AX7WS shown in Figure 3.

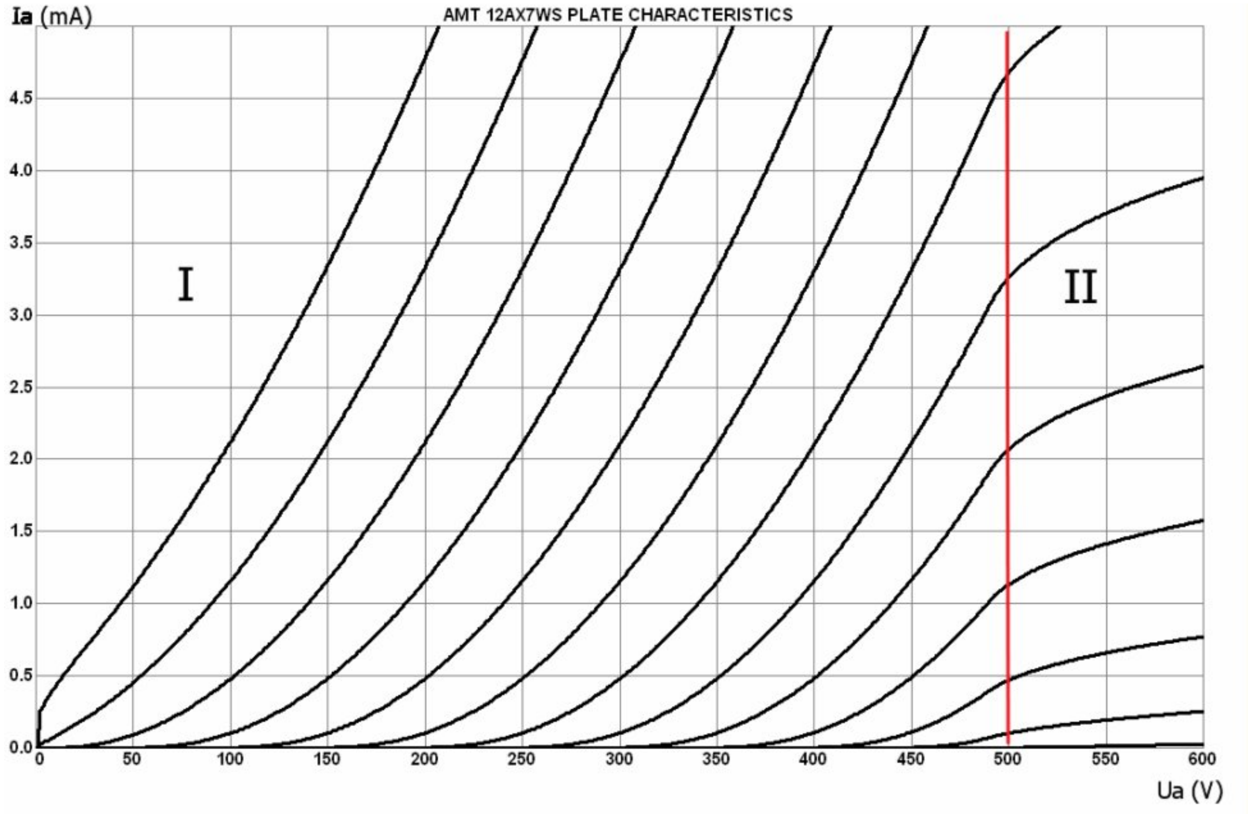


Picture 3. The scheme of the triode with field control.

In the shown base scheme (Pic. 3) T1 - MOS transistor depleted type, ie the device with pentode CVC.

Node of CVC correction is implemented in the cascade at T3. The required non-linearity of the cascade for accurately reproduce the vacuum triode CVC determined by the presence diode D3 and the nonlinearity of resistance of the channel T2, included as an repeater. Transistor T2, controllable by a cascade at T3, maintains the necessary capacity on source T1, providing the required CVC. Attitude R1 and (R2 + g), where g - is the resistance channel T2, determines the extent of fan-shapes of the current-voltage characteristics, as well as in conjunction with a divider R3R4 sets the internal gain of the triode - μ (Mu). D3 forms the CVC at low anode voltage in region of the voltage on the grid, close to zero.

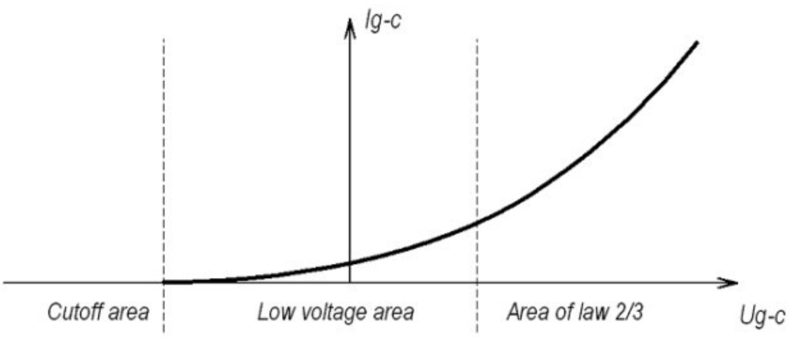
Diode D2 - is dividing. It provides a cutoff of the anode current at any negative voltages below the voltage closing of the "Tube". [6] Moreover, D2 is involved in the formation of a significant in the sound a smooth bend of CVC at the region of low anode current.



Picture 4. Triode and pentode regions of anode CVC. Triode with field control.

The boundary of transition into the pentode region depends on the parameters of the applied components and in triode AMT-12AX7-WS is not less than 500V.

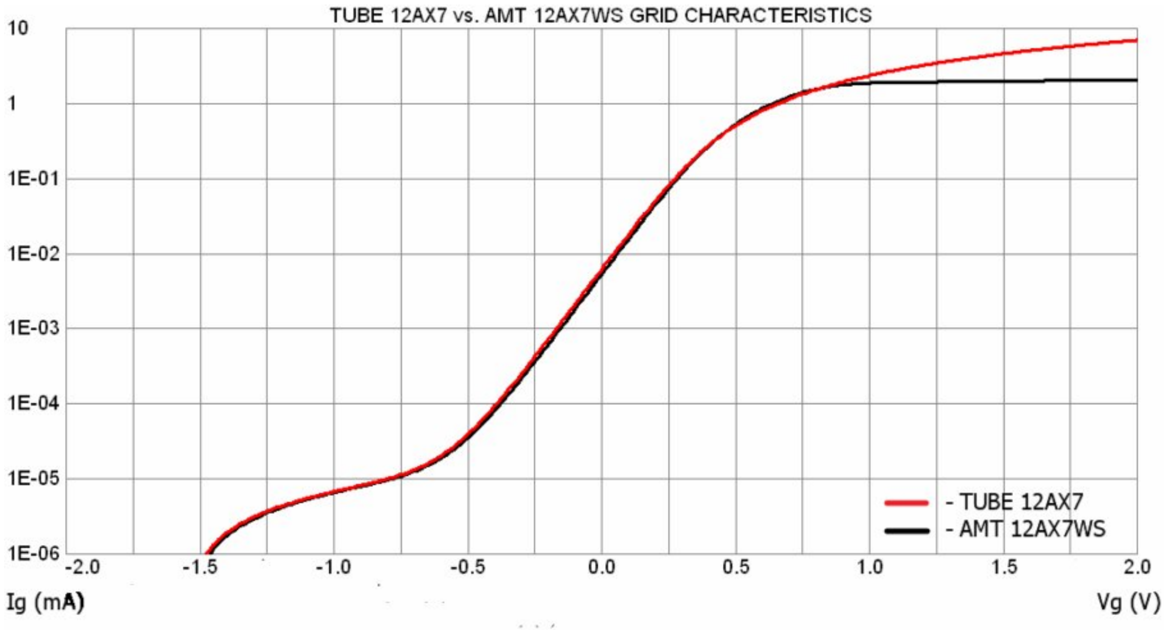
2. The second important feature of the vacuum triode, largely determines the sound, especially in the overloaded guitar amps, is the presence of current cathode-grid at close to zero voltage on the grid relative to the cathode [3].



Picture 5. Generalized dependence of the current grid from the voltage grid-cathode.

At pic. 5 seen that in the vacuum triode even at zero voltage on the grid relative to the cathode the electron current flows from the cathode into the grid. This effect is due to the fact that the fastest electrons overcome the potential well of an electron cloud space charge near the cathode and attracted to the grid. For 12AX7 the full cutoff of the grid current occurs only when applying a locking negative voltage of the order of -1.5 V and below.

In the development of a series triodes WarmStone special attention was paid to reproduce the cutoff levels of the grid current and the preserving the dependence of voltage - current, at the low voltages region in accordance with the analogical characteristics of the vacuum 12AX7. The node forming of the grid current is realized from source of negative voltage B2 and from chain of semiconductor diodes D1 (Pic. 3), jointly implementing the necessary current-voltage characteristic of input diode grid-cathode. Selecting the type and number of diodes, as well as the bias voltage in the grid circuit AMT 12AX7WS carried out on the basis of the criterion of the most exact match of dependence current - voltage to the vacuum prototype (Picture 6).



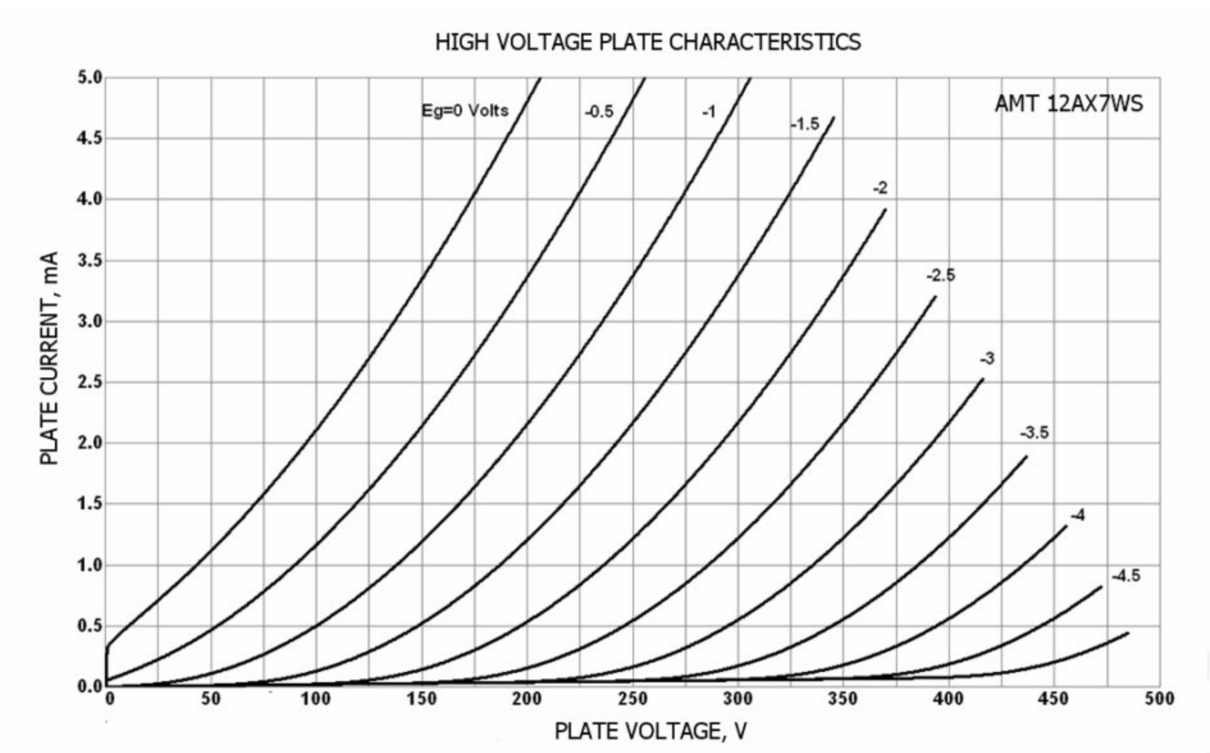
Picture 6. Dependence of the grid current from the voltage grid-cathode for vacuum and semiconductor triodes 12AX7

As seen from Fig.6 in region -1.5 ... +0.7V dependences practically coincide. At voltages above +0.7V the observed discrepancy does not affect the adequacy of the semiconductor triode functioning, because the value of the grid currents in real circuits of 12AX7 is almost always limited to the value of 0.5 ... 1 mA.
The saturation a current of the grid at the level of 2 mA is the result of a specific circuit design AMT-12AX7-WS and indicated to account for this feature in the case of special applications with significant currents of the grid.

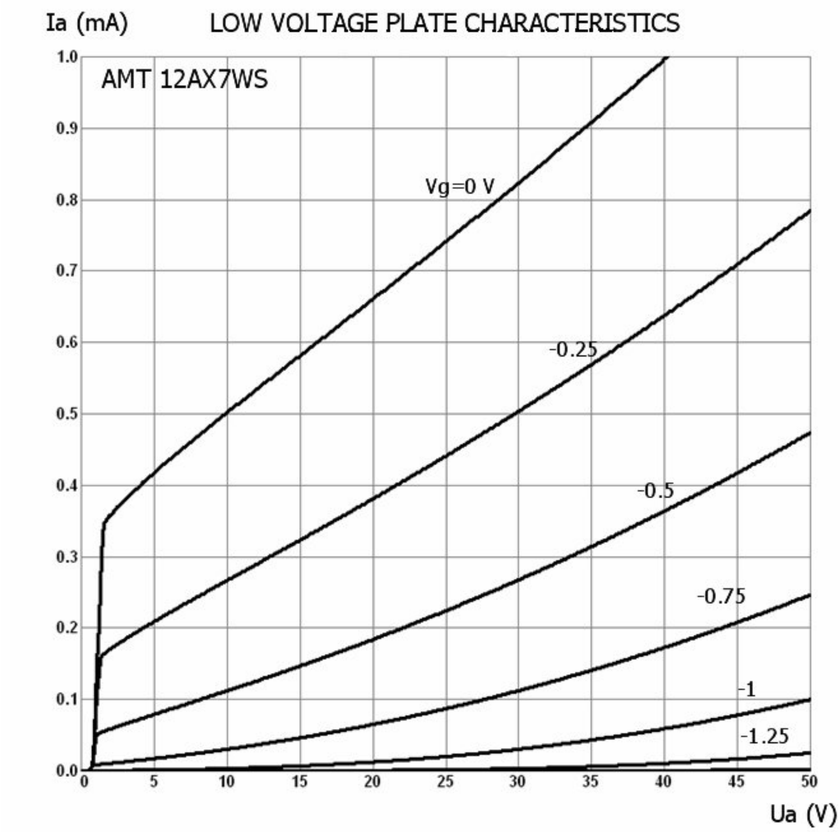
Note! Characteristics of vacuum devices from different manufacturers, and characteristics inside the series even at one and the same manufacturer sometimes vary considerably.

In the process of design of AMT 12AX7WS, AMT company focused primarily on the standard passport data of 12AX7 (ECC83) and exemplars of tubes of different manufacturers that best meets industry standards for 12AX7.

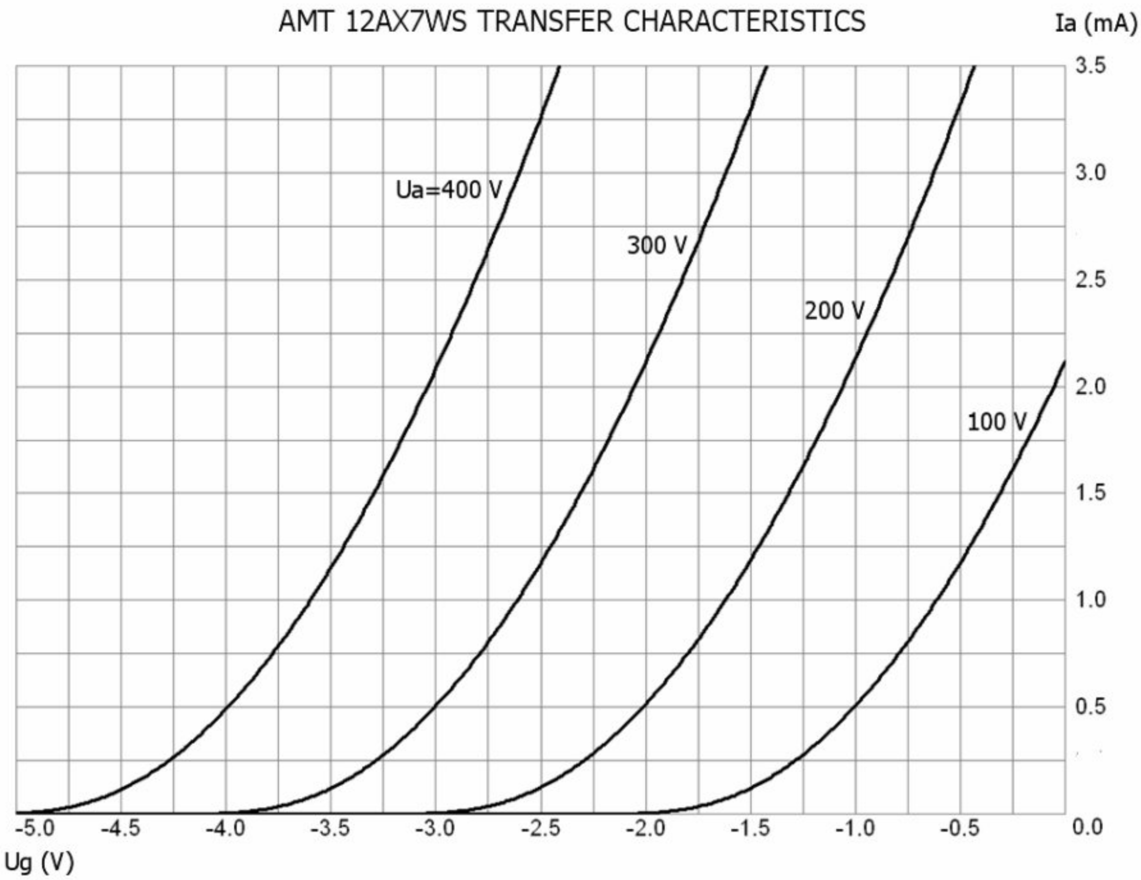
CURRENT-VOLTAGE CHARACTERISTICS



Picture 7. The output characteristics of *Ia=f(Ua)* *(Ug=0…-5V)*



Picture 8. The initial region of the output characteristics of *Ia=f(Ua)* *(Ug=0…-1.5V)*



Picture 9. Transfer characteristics AMT 12AX7WS

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