## Summary

Some may never experience microphonics in audio, and others may have a long recollection of problems and solutions. For valve amplifiers, microphonics is an ever-present generator of spurious signals – but usually of a low level that is not noticeable.

When a valve vibrates, new signals related to just the valve internal structure can be generated and amplified. A guitar combo is an excellent way for these valve structure signals to be generated, due to local speaker vibrations that easily couple into the amplifiers' chassis and then to the valves, where oscillatory feedback can then occur. Microphonics can exhibit itself as a resonant howl or squeal, similar to feedback when you place the stage microphone or a guitar in front of the PA speaker. Microphonics also relates to anything in your gear that can vibrate and cause added signals – parts such as pot wipers, some types of ceramic capacitors, bad solder joints, and oxidised pins in sockets are known to have caused problems.

## Contents



If you experience microphonic valves and check the forums, or books, for solutions then the typical advice is to swap valves, or give up on using a certain type of valve. This is good advice, and you can often do a quick fix and get back to other more important things, but microphonics is an interesting issue and well worth knowing more about preventative measures.

Microphonics became problematic in early vintage radios, phonograms, and guitar amplifier/speaker combos – due to the close mechanical coupling of a speaker to the valve equipment. The valve most prone to microphonics is a high gain type positioned at the input of an audio amplifier. In the early guitar combo days of the 1950's, the very high gain EF86 used by Vox (AC-15, AC-30) became notorious for microphonics. The gain of the ubiquitous 12AX7 is not as high as an EF86, so most amps don't suffer noticeable problems.

In the early days, valve manufacturers and equipment designers grappled with microphonics as best they could, and the effect even had its own official definition "The periodic voltage output of a tube produced by mechanical resonance of its elements as a result of sustaining mechanical excitation"!

> <u>Microphonic effect</u>
>
> A sensitivity of 0.5 mV for an output of 50 mW (or 5 mV for an output of 5 W) is permissible in those equipments where an output of 50 mW in the loudspeaker does not produce an average acceleration on the tube higher than 0.015 g at any frequency higher than 500 Hz or higher than 0.06 g at any frequency lower than 500 Hz.

Some manufacturers even specified microphonic performance in datasheets [eg. EF86 Philips datasheet]. Mullard's investigation into microphonics, published in 1962 [Ref 1], has provided the most enlightening set of experimental results to help characterise microphonic signals generated in a vibrating valve.

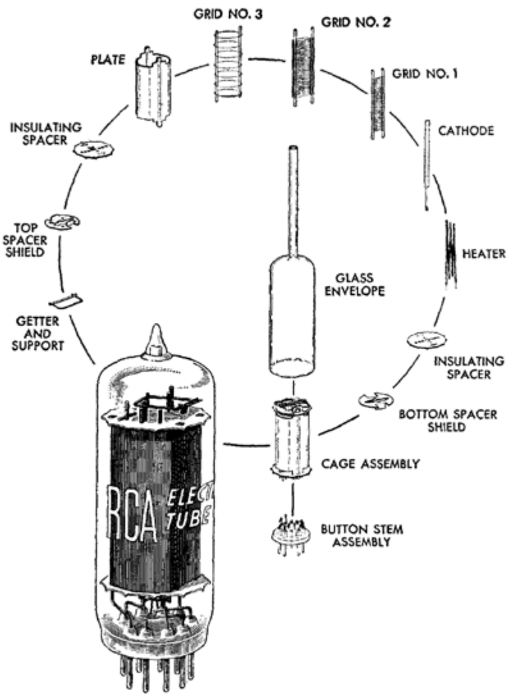
## Vibration

Vibration of a valve, like the vibration of a speaker cone, involves movement backwards and forwards in a certain direction, however unlike a valve, a speaker cone is restricted to movement in just one direction only (unless really cranked!). Vibration, and its effects, are scientifically characterised by the term acceleration, and the direction of that acceleration. To relate to acceleration, think of turning up the amplifier volume and watching the bass speaker cone move more – the cone experiences an increasing acceleration level as the sound gets louder. When listening to a single frequency, the time taken for the speaker cone to make one cycle in and out doesn't change, but the speaker cone has to accelerate at a higher level to reach the increased deflection distance within the same time, and the result is more air is moved to make our ears hear a louder signal. So a valve that experiences a higher level of vibration is, in a scientific sense, experiencing a higher level of acceleration, and hence a higher level of deflection distance of internal parts.

Understanding the vibration term of acceleration is a big help when looking at the Mullard experimental graphs in [Ref 1]. In that reference, the first graph presented (fig.1) shows the different levels of acceleration experienced by a valve in an example radio receiver, as a function of frequency. It's like shaking the amplifier/receiver at a 20Hz frequency and seeing how large the acceleration of the valve is, and then comparing results for measurements taken from shaking at higher frequencies all the way through to 20kHz. From the graph we see that the valve can experience relatively high levels of acceleration at some frequencies specific to the construction of the amplifier/receiver.

### Valve structure

Of the many parts that make up a valve, the part that typically gets the blame for microphony is the wire forming the Grid No.1 structure (the typical input control grid), as the anode (plate) and cathode are more securely fixed, and the other grids, if any, have much less influence on circuit gain. A typical grid structure is an elliptical helix held between two vertical support wires. The thin but rigid grid wire forms half-ellipse "leaves" which vibrate freely when excited at the right frequency.




The mechanical structures in a valve have very little dampening, as they are in a hard vacuum, and the metal supports are rigid. All parts of a valve can vibrate, including the glass envelope. Valve designers make the supports as rigid as possibly to reduce the physical deflection of parts, and to push the resonant frequencies of parts as high as possible.

The earliest valves were made with the cathode, grid and anode parts standing up in the middle of a glass bulb, like the filament in an incandescent light bulb. You shake the light bulb, and the filament noticeably vibrates, sort of like a tuning fork. Valves in common use from the 1940's have the cathode, grid, and anode parts typically pinned between transparent mica discs, and the mica disks are squeezed into the cylindrical section of the valve's glass envelope during manufacture. Some preamp valves such as the EF86 only have one mica disc located towards the top end, with the base of the valve providing the other point of clamping. Clamping the parts and supports in more than one place reduces the deflection that occurs for a given acceleration of the whole valve, just like plucking a guitar string with a finger on the 20$^{th}$ fret position compared to an open string.

[Ref 2] illustrates some techniques to determine which part of the valve structure is generating microphonic signals, and in which frequency band. But unfortunately doesn't elaborate on how the tested valve was mounted, or the acceleration level experienced, so we can't glean much else from that reference.

### Generated signals

It is the physical deflection of parts, relative to other parts, that generates a microphonic signal. For example, when the spacing between the turns in grid-1 vary, the valve transfer function (gm - gain modulation) changes.

One test method used by manufacturers to detect 'vibrant' valves involved 'clanging' a valve with a striker, as shown in the picture from [Ref 1].

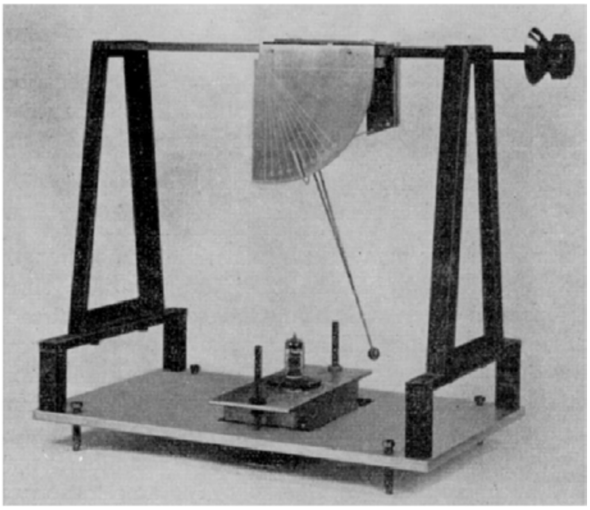
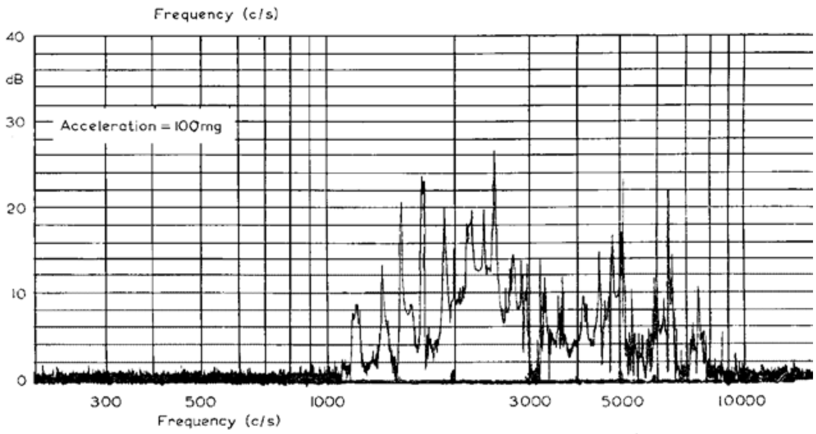


Fig. 6—Apparatus for measuring microphony by shock excitation

All the parts in the valve are shocked into vibration simultaneously, and with the valve operating in an amplifier the test outcome was how loud the amplifier output became. Although it allowed comparative testing, nowadays such a tester would no doubt include digital spectrum analyser technology. But this mechanical contraption had scientific repeatability, and introduced the meritorious term of 'signal-to-clang ratio', which no doubt was abbreviated to 'SCR' in dB.

Another characteristic of the clang is how quickly it dies away – which refers to the damping, or resonant Q, of the parts that vibrate. More modern techniques such as 'waterfall' plots, which are commonly used in loudspeaker driver specifications, would be an excellent way to appreciate the decay in 'clang' with time.

Going back to the Mullard report [Ref 1], Fig.2 of the 2nd part shows the microphonic signals generated in an EF86 valve when shaken at a range of audio frequencies, with a range of accelerations. The plot on the right is for a high acceleration = 0.1g. Some microphonic frequencies (eg. about 2.8kHz) are up to 25dB louder than other nearby frequencies. Of interest for the EF86 is that negligible microphonic levels are generated for acceleration frequencies below 1kHz.




Similar to [Ref 2], the Mullard reports have photographs and test results for changes made to various structural parts, but are more enlightening as they compare signal levels generated.

However it is the third graph shown in [Ref 1] that is most significant, as it provides a basic understanding for how we can practically manage microphonics. That graph, shown on the right, indicates that for a population of the same valve, from the same maker and manufacturing batch, the relative level of microphonic signal can vary in examples by up to 10-to-1 ratio (ie. 20dB) – hence the advice to "swap valves until you get a good one".

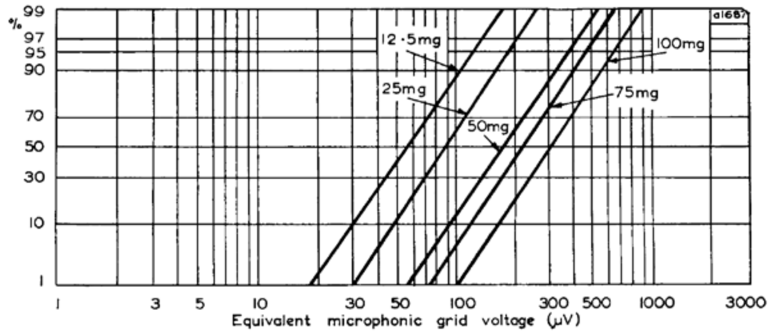



Fig. 3—Cumulative distribution characteristics of EF86 valves

The generic advice to swap valves comes with some major provisos. Firstly, you may not know if you have a bad, mediocre, or good valve to start with – so buying in more valves can get expensive. For the same valve model there can even be structural differences between valves made by different manufacturers, and even by the same manufacturer over time. And yes some manufacturers, and some vintages of a certain valve may well have across-the-board lower microphonic levels - but take all this with a grain of salt, as within each manufactured batch you are still likely to get a large variation.

Secondly, even if you do swap to a better valve, it will still be generating microphonic signals, albeit less noticeably – sort of like the rocks in the river being visible or being just under the level of the water. But this point moves the discussion into 'valve sound' and perceptions, as we start to talk about the 'quality' or 'colour' of extra sounds added to the original signal by the audio chain (eg. in guitar parlance this can be the type of guitar, string, pickup, lead, preamp valve, coupling capacitors, phase inverter topology, output stage bias level, output transformer manufacturer, speaker, level of overdrive, tone setting, the list goes on……).

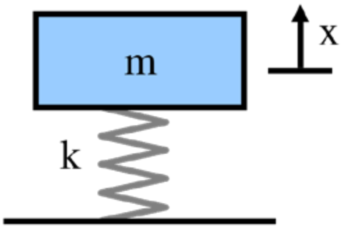
Thirdly, many people have experienced valves that become more microphonic with time. This is a sobering point when you lay it over the first and second points. Physically, this observation makes sense, as expansions and contractions and aging of metals are highly likely to change the tight grip of the mica disks to the valve parts and the glass envelope over time. And this apparent 'loosening' of a valve's internals may go some way to understanding why a fresh batch of valves from the same manufacturer can measure such large differences in microphonic levels.

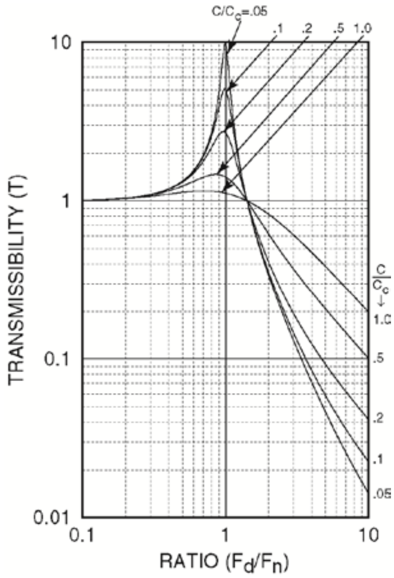
### Bad Vibes Man

As well as the choice of valve, the other countermeasure to alleviate microphonic levels is to reduce the level of vibration experienced by the valve. Certainly, for EF86, the focus is reducing valve vibration frequencies >1kHz. Over the decades there have certainly been a wide variety of solutions focussing on this area.

One obvious solution is to physically separate the amplifier (and its valves) from the source of vibration – whether the vibrations are continuous or shock/clang. In a hi-fi context this typically means placing the amplifier on a large mass, such as a concrete bench, and some distance from any speaker. But that is not practical in a guitar rig, where the head unit sits on a quad speaker box, or worse still, a combo with two 12" speakers positioned just a few inches from the input stage 12AX7 or EF86 and all parts mechanically linked.

Firstly, try to decouple the head unit, or the amplifier chassis, from the speaker box or rig. Any form of relatively soft, compliant interface is a good start (eg. foam rubber). For a head unit this could start with replacing old, hardened rubber feet (or lack thereof), or inserting sponge rubber under the base.



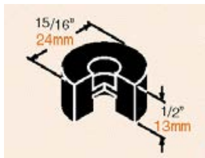

If a head unit was sitting on a cab with a spring in between (imagine a block of foam rubber as the spring), then the head should preferably vibrate at a natural frequency $F_N$ which is below the audio range (eg. 50Hz), as the head's vibration can be accentuated when the exciting frequency Fd is near $F_N$ (ie. $Fd/F_N$ ~1) when the spring has little damping (damping factor $C/C_C$ <<1). Vibration attenuation occurs when the vibrating frequency is above the self-resonant frequency (ie. $Fd/F_N$ >1), with better attenuation achieved with a less damped spring. Rubber and neoprene have $C/C_C$ ~0.05, whereas silicone rubber is ~0.15.

A simple method to measure the natural frequency $F_N$ (in Hz) is to measure the mass $m_1$ (kg) of the head, then add (or subtract) an extra mass ($m_2$ in kg) to the head, and measure the vertical distance d (in meter) moved by the head as it compresses the spring.

Then calculate $F_N = 1/(2\pi) \times \sqrt{(k/m_1)}$, where stiffness $k = m_2 \cdot g / d$, where g is gravity (9.8 m/s). For example, adding $m_2$ = 10kg to a $m_1$ = 20kg head unit compressed the block of foam padding by a distance 5mm (d = 0.005 meter), so k = 10 x 9.8 / .002 = 49000 Nm, and hence $F_N$ = 0.16 x √(49000 / 20) = 8Hz and so this foam padding would attenuate vibrating frequencies above about 15-20Hz.

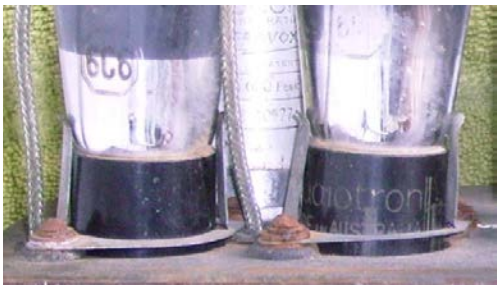
Datasheets for commercial isolator pads include 'load versus natural frequency curves' which allow a simple way of choosing a suitable pad when you know the weight of your head unit. Natural rubber feet, washers and grommets have little damping, so provide good vibration attenuation at higher frequencies – and nowadays have a service life in excess of 50yrs if not overheated.

A 12mm high, 25mm diameter, rubber foot with durometer hardness of 40 is likely to give a static deflection, $d_s$=0.6mm, for m=8kg (per foot), with $F_N$ ~ 21Hz. Reducing the foot dimensions will raise the natural frequency, which can be counteracted by lowering the hardness. Adding more rubber feet will reduce '$d_s$', raising stiffness 'k' and hence raising natural frequency $F_N$.




Re-positioning the location of an amplifier on top of a speaker cabinet can also help, as a speaker panel may have a noticeable resonant frequency, or generate large excursions (acceleration) in the middle of a panel.

Secondly, try to decouple the valve from the amplifier chassis. A common vintage method was to isolate a valve socket using rubber grommets - that went hard over time. Sometimes a small sub-chassis was isolated by rubber isolators, or the valve socket was spring loaded. The compliance of a small rubber grommet may appear stiff, with a high natural resonance, but can be effective when the natural resonance is below 1kHz – which means the valve and base may need to have weight added.



A simple homemade alternative is to 'float' the valve base away from the chassis with about 1mm of pliant sealant, or a strip of thin neoprene rubber as the interface. You may be lucky enough to do this without having to remove or replace the valve socket – eg. loosen the valve base retaining bolts (or rivets) and push the base clear of the chassis about 1-2mm and apply a flexible sealant into the gap (eg. Selleys All Clear universal co-polymer sealant), or fit neoprene rubber cut to shape, and then semi-tighten the nuts/bolts (when the sealant is dry). Nyloc nuts are useful to maintain a suitable compression without loosening over time. Note that the valve is lightweight and so the natural frequency may be high if the sealant (the 'spring') or rubber strip is too stiff. Adding mass to the valve will reduce the natural resonance frequency, and may be necessary to get any significant benefit – alternatively, using a valve base with a 'tree hanger' to mount local parts will also add mass to the sprung assembly.

Some modification to the wires and parts terminating on the valve base terminals may be required, to achieve effective isolation of the valve base from the chassis. The gallery photos shows an example of spiralled flexible wiring. Replace stiff wiring and reduce the number of wire connections where possible.

Lastly, try to reduce any tendency for the glass envelope of the valve to resonate by stiffening and dampening the glass region that acts as an integral structural part of the valve assembly. The technical reports cited in the references don't discuss glass vibration, but it will have resonances – as a cocktail glass can 'ring'.


A variety of commercial 'dampers' are available that fit onto the cylindrical section of a valve, and range from high-temperature silicon O-rings, to titanium C-rings with wheel pads [UltraSonic], to heavier brass tube rings. Also [4], [5], and see Gallery.

A simple homemade O-ring damper can be made using high-temperature silicone rubber engine gasket sealant - useable up to 230°C, which is well above typical preamp valve glass temperature that ranges from 100-150°C. A metal tube with a suitable inside diameter can be cut to a practical length and glued to the valve using the gasket sealer. Place the damper between top-most mica ring and the lower mica ring (or valve base if no lower ring), as that is the main region of unsupported glass, and also forms the return structure for the top mica disk.

### Feedback, Gain & Bass

And let's not forget electrical feedback as a solution! Feedback around the preamp valve circuit suppresses any internally generated distortion signal (which includes the microphonic signals) as the input signal, say from the guitar pickup, is compared to the amplified output signal. Most guitar amps shun the use of electrical feedback, and purposefully aim to accentuate valve distortion, so local feedback loops may not be appropriate to help alleviate microphonics – but the first stage generally introduces the least distortion/tone in a cranked guitar amp.

As a pentode stage typically has much more gain than a triode stage, some designers move the EF86 to the second stage, and use a triode for the first stage, to reduce the risk of EF86 microphonics being noticeable.

Bass response of the amplifier, and speaker, can be key facilitators of microphonics by allowing rumble and low frequency signals to cause large speaker cone excursions. Some applications such as guitar amps will often purposefully avoid extended bass response. Within an amplifier, the coupling capacitors between stages, and the following grid leak resistors, usually define the bass response roll-off, with guitar amps typically attenuating signal frequencies below about 70-100Hz. Similarly, a speaker for use in open backed cabinets can by design have more low-frequency roll-off than a speaker designed for hi-fi application.

### Does it work?

Trying to determine how well the above techniques work is easy in a qualitative way – you either still hear the microphonic howl, or you don't. Alternatively, you could check the clang output by hitting the amp, or could input a sweep tone and use a spectrum analyser (such as REW5.1) to look for aberrant signals above the noise floor that are not related to the tone or to hum (which can be quantified as 'THD+N' – 'THD'). This method can also be used to fault-find other sources of microphonic noise such as from parts or joints.

Acceleration can be measured using a simple, readily available analog output device such as MMA7361L, but it has a limited frequency response to 400Hz. New devices like FXLN837XQ have a response to 2.7kHz. With the amp on a solid surface, hitting the chassis and capturing the damped sine wave output of an acceleration sensor mounted on the chassis can identify the natural frequency $F_N$ due to the mounting feet [Ref 6]. This may be applicable to a sub-chassis or an isolated valve/base, depending on $F_N$ and the sensor.

Two sensors can be used to compare the performance of an anti-vibration solution such as rubber feet – one sensor is mounted to the supporting structure under the amp (eg. a speaker box), and the other sensor is mounted on the amp, and the speaker is driven with a swept tone signal (or discrete tones of frequency determined to excite resonances) and acts as the vibration source. The difference in the acceleration sensor signal levels indicates the improvement achieved. Similarly, a sensor could be mounted on a valve, and the other sensor on the amp, with the amp sitting on a vibration source (eg. speaker box).

## Gallery

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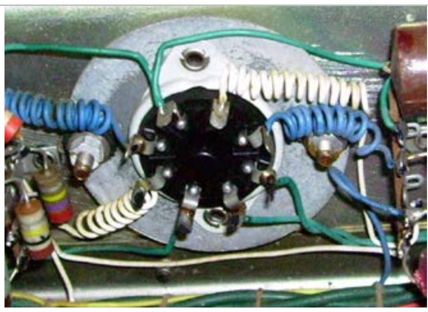
|---|---|---|---|
|  |  Very DIY ! |  1950's organ dampener for 6SN7. |  Internally dampened base. |
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|  |  |  |  |
|  |  2mm thick neoprene strip cut to shape. |  |  |

A variety of valve-based vibration attenuators.

**References:**


1) Valve Microphony, by S.S.Dagpunar, Mullard Technical Communications No. 61, Nov 1962 – Part 1 and Part 2. See www.thevalvepage.com/valvetek/microph/microph.htm
2) "The measurement of Microphonic Effects in Vacuum Tubes", R.Bird, Nov 1951. (http://www.pearl-hifi.com/06_Lit_Archive/01_Audio_Notes/Measuring_Microphony.pdf)
3) https://www.pearl-hifi.com/03_Prod_Serv/Kits_Parts/Iso_Sockets/Iso-socket_Install.pdf
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5) "Practical consideration in the design of low-microphonic tubes", T.M. Cunningham, Dec 1954. (RCA-Review-1954-Dec.pdf)
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