Vacuum Tubes and Transistors: Can an Age-Old Problem Be Solved by Modern Design Thinking?

Barbour, E. "The cool sound of tubes [vacuum tube musical applications]," in *IEEE Spectrum*, vol. 35, no. 8, pp. 24-35, Aug. 1998, doi: 10.1109/6.708439.

This article examines different types of tubes in audio gear and explains why they're preferred both scientifically and subjectively. The author argues that transistors can't replace vacuum tubes specifically for the music community and brings in knowledge from performing musicians, recording engineers, and amp designers giving reinforced support across three fields. It also lists examples of about 20 different tubes and their technical specifications which will be helpful for citing detailed examples.

Bardeen, J., and W. H. Brattain. "The Transistor, a Semi-Conductor Triode." *Physical Review* 74, no. 2 (1948): 230–31. https://doi.org/10.1103/physrev.74.230.

This article was written at the beginning of the development of transistor technology and explains the benefits and uses of transistors as a replacement for tubes. This paper also goes into the technical details of transistor design in the late 1940s, which traces the history of the transition from tubes to transistors. The technical details here also amplify the similarities and differences between tubes and transistors, which helps to support the claim that the two technologies are not mutually exclusive.

Clarke, Rachel Ivy, and Center for the Future of Libraries. *Design Thinking*. Library Futures Series, 4. Chicago: ALA Neal-Schuman, 2020.

This is a design textbook that will be used to briefly explain the concept of design thinking. Design thinking is a process used to solve human-centered design issues and implement them through observation and revision. The objective is to not only solve minor design flaws but to attempt to solve bigger issues through empathy and engaging with users. With design thinking, it becomes easier to see the scope of an entire issue. This would make a case for the fact that

transistors were being implemented before understanding the full scope of why vacuum tubes were important and how using modern design processes could help solve the issue on a larger scale.

Fink, D. G. “Transistors Versus Vacuum Tubes.” *Proceedings of the Ire* 44, no. 4 (1956). https://doi-org.libezp.lib.lsu.edu/10.1109/JRPROC.1956.274926.

This article is an early example of comparing the two technologies. It emphasizes the need for both in different fields which supports the claim that design and technology development isn’t always linear. Since this is an older article, it can be used to emphasize that this discussion has been ongoing since the onset of transistors. This article goes into detail about the technical superiority of transistors while making note that tubes are still preferred in a lot of fields for reasons other than efficiency. This supports the claim that sometimes designing for one issue (i.e., inefficiency) isn’t always a complete solution.

Guarnieri, Massimo. “Seventy Years of Getting Transistorized [Historical].” *Ieee Industrial Electronics Magazine* 11, no. 4 (2017). https://doi-org.libezp.lib.lsu.edu/10.1109/MIE.2017.2757775.

Guarnieri, Massimo. “Solidifying Power Electronics [Historical].” *Ieee Industrial Electronics Magazine* 12, no. 1 (2018). https://doi-org.libezp.lib.lsu.edu/10.1109/MIE.2018.2791062.

Guarnieri, M. “The Age of Vacuum Tubes: Merging with Digital Computing [Historical].” *Ieee Industrial Electronics Magazine* 6, no. 3 (2012). https://doi-org.libezp.lib.lsu.edu/10.1109/MIE.2012.2207830.

These three short articles have similar themes and discuss the history and development of the transition from vacuum tubes to transistors. All three go into the various uses of tubes and transistors across different technologies including watches, computers, hearing aids, and some audio gear. This information sets the stage historically for how tubes and transistors developed and coexisted. The first article touches on the history of the transistor, the second article describes the technical specifications of the transistor, and the third article discusses the benefits

of transistors. All three describe different types of transistors and their uses which show the scope of transistors, how they're integral to the progression of certain technologies, and why tubes are not always a viable option.

Hamm, R.O. "Tubes Versus Transistors-Is There an Audible Difference," J. Audio Eng. Soc., vol. 21, no. 4, pp. 267-273, May 1973.

This paper examines the audible differences between tubes and transistors by discussing experiments done in a recording studio and some of the elements of psychoacoustics that are involved. The author, who is an audio engineer, compares a variety of audio gear in a recording studio setting which will be helpful in illustrating the ubiquity of vacuum tubes across all the stages of the recording process. Many papers have been written by electrical engineers or amp designers, so this paper brings in the opinion and experience of a recording and acoustics specialist.

King, Robert W. "Thermionic Vacuum Tubes and Their Applications." *The Bell System Technical Journal* 2, no. 4 (1923). https://doi-org.libezp.lib.lsu.edu/10.1002/j.1538-7305.1923.tb01293.x.

This paper goes into the technical specifications, physical makeup, and mathematics of thermionic vacuum tubes and their potential uses in 1923. This will be useful for describing and comparing the technical makeup of early tubes to modern tubes and why the need for transistors arose during that time period. This article also details some of the drawbacks to vacuum tubes and describes many of their limitations from the onset of their development.

Macak, Jaromir and Jiri Schimmel, "Simulation of a Vacuum-Tube Push-Pull Guitar Power Amplifier" Proc. Of the 14th International Conference on Digital Audio Effects (DAFx-11), Paris, France, September 19-23, 2011.

This paper details a digital simulation in Matlab of an analog vacuum tube amplifier which supports the claim that it is useful to revisit old design issues when new technology is available. This paper also goes into the technical aspects of the sound of tubes with the modern simulation

software which provides evidence that tube amplifiers have a fundamentally different sound than solid state (semiconductors / transistors).

Moe, R. E. “Tubes or Transistors: A Realistic Assessment.” *Transactions of the American Institute of Electrical Engineers, Part I: Communication and Electronics* 79, no. 2 (1960). https://doi-org.libezp.lib.lsu.edu/10.1109/TCE.1960.6368548.

This paper assesses the technical specification of tubes and transistors across non-audio fields. It goes into further details about the temperature and durability and their uses in the 1960s and discusses why tubes will outlast transistors in some fields. This paper supports the claim that there are elements of vacuum tubes that are important enough to outweigh their disadvantages.

Norman, Donald A. *The Design of Everyday Things*. New York: Basic Books, 2013.

Norman discusses usability, design thinking, practical problem solving, and human centered design across designing for various fields. This book describes design thinking in a similar way to the previous design source, Clarke (2020), but gives concrete examples and anecdotes which will be useful in examining what successful design processes look like and what can happen when the larger design problem is not considered. For example, when designing ergonomic doors, what happens when there is no knob or visible hinges? These examples will support the claim that although transistors helped move technology along in many ways, the larger design issue is still unsolved. Norman’s philosophies and processes will also be useful in attempting to convey other possible solutions to old design problems.

Pakarinen, Jyri and David T. Yeh, “A Review of Digital Techniques for Modeling Vacuum-Tube Guitar Amplifiers.” *Computer Music Journal,* vol. 33, no. 2, pp 85-100. Summer 2009: Massachusetts Institute of Technology.

This paper discusses the math behind accurately modeling vacuum tube sounds. However, unlike Macak (2011), this article is written as a review of multiple studies, rather than detailing one study, and catalogs a few different attempts at modeling tube amps and the math and conclusions associated with each. This article, in conjunction with the Macak paper, supports

the claim that the tube versus transistor debate continues and will do so until there is a viable solution that implements the benefits of both technologies.

Qiu, J.X, B Levush, J Pasour, A Katz, C.M Armstrong, D.R Whaley, J Tucek, K Kreischer, and D Gallagher. “Vacuum Tube Amplifiers.” *Ieee Microwave Magazine* 10, no. 7 (2009). https://doi-org.libezp.lib.lsu.edu/10.1109/MMM.2009.934517.

This is a more recent article discussing the technical specifications of tube amplifiers and their benefits and will be useful for detailing in-depth modern technical specifications of vacuum tubes. It also makes a case for continuing to use tube technology across different industries including radar, satellites, and microwave technology. It has some technical specifications, graphs, and equations that can support the claim that vacuum tube technology and transistors are both useful but not mutually exclusive.

Symons, R. S. "Tubes: still vital after all these years," in *IEEE Spectrum*, vol. 35, no. 4, pp. 52-63, April 1998, doi: 10.1109/6.666962.

This article is historical rather than scientific and discusses the history of tubes, how and why they were significant, and how they’re still significant today. There are two columns that describe the pros and cons for transistors and tubes. For the most part, studies typically discuss the pros and cons of one or the pros of one and con of the other, so being able to compare pros and cons of both from one researcher gives a broader, non-biased scope of the advantages and disadvantages of both technologies.