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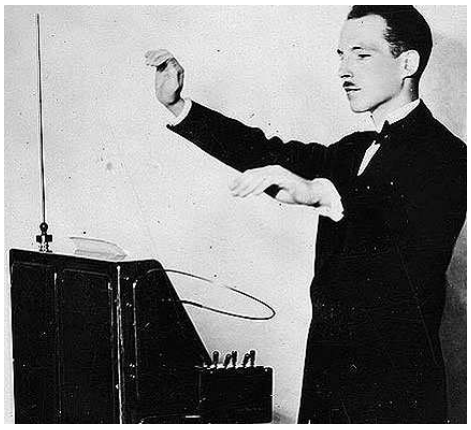
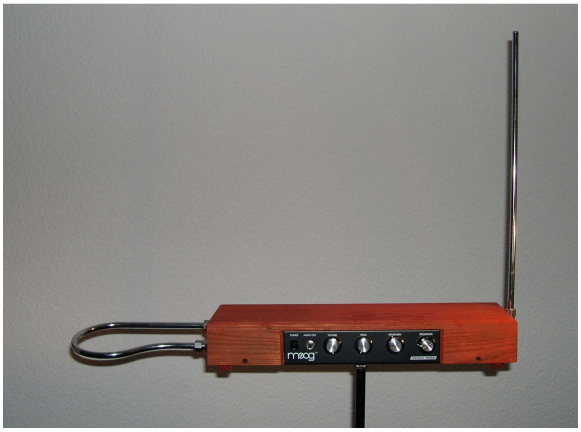
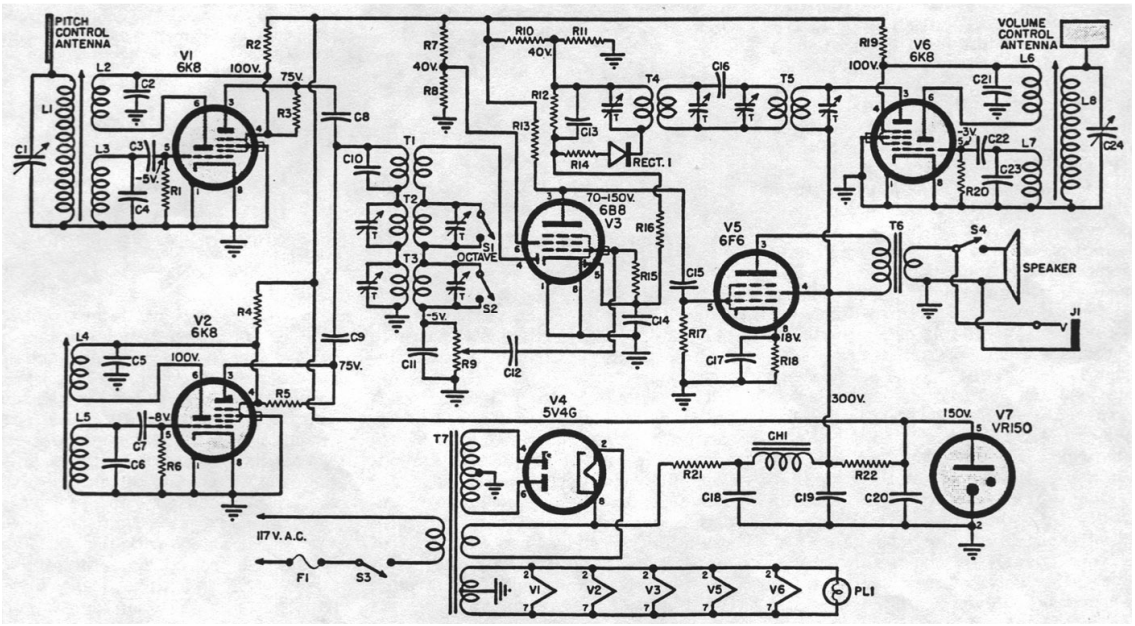
Exploring the Theremin
Comparisons in Transistor Amplifier Design

I began this semester not certain where I wanted to go with my student project. Given the limits of funds, many tantalizing but expensive options such as quality tube amps were not viable options. In considering what would be worthwhile, it struck upon me the uniqueness and universal recognition that the Theremin holds - especially in a classically Doctor Who appreciating physics community. The theremin is a musical instrument patented by Professor Léon Theremin in 1928, originally known as an aetherphone due to its eerie sound and the manor in which it is played. At the time the sound was such a new and alien experience that when Theremin played his "magical" new instrument at the Paris Opera, police were called to keep order among the crowds. Two antennas extend from the instrument, and the musician chooses his frequency/pitch and volume by moving his hands closer too and farther away from those antennas. The principle is simple and elegant; the musician's hand acts as a grounded plate, the antenna and hand effectively becoming a variable capacitor within the circuit. Within the theremin are two frequency generators, one of which is set to a constant frequency, and the other is variably set by the capacitance at the pitch antenna. These two frequencies are combined using the heterodyne principle to make a new signal, which is then sent to a amplification circuit and onwards to the speakers. Volume is controlled in a similar fashion.

- Léon Theremin with his original theremin, and a modern theremin for comparison.

- Below is a schematic of a 1954 Moog tube theremin - popular among studios at the time, and the first of several theremin designs I investigated.

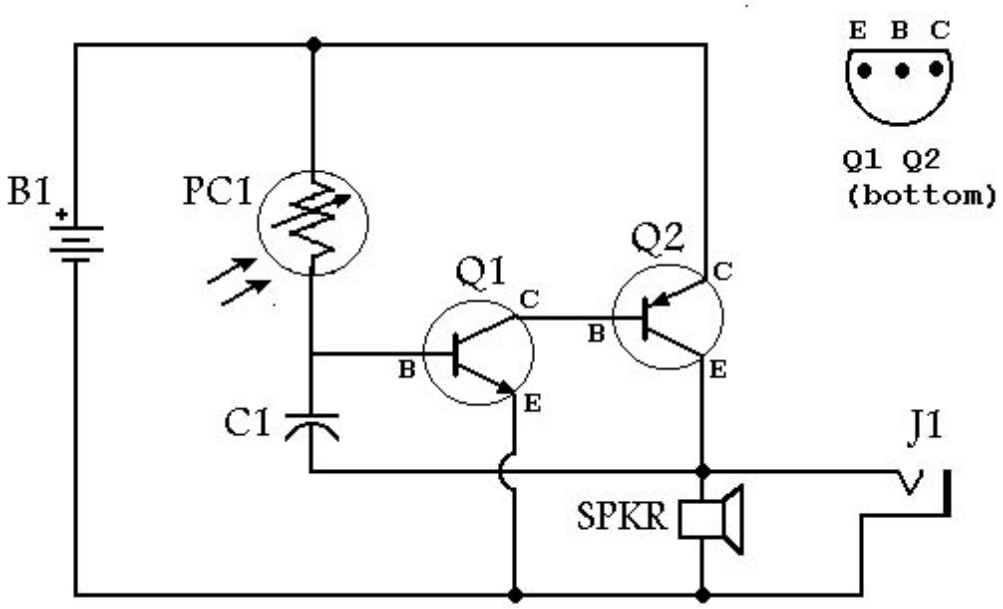


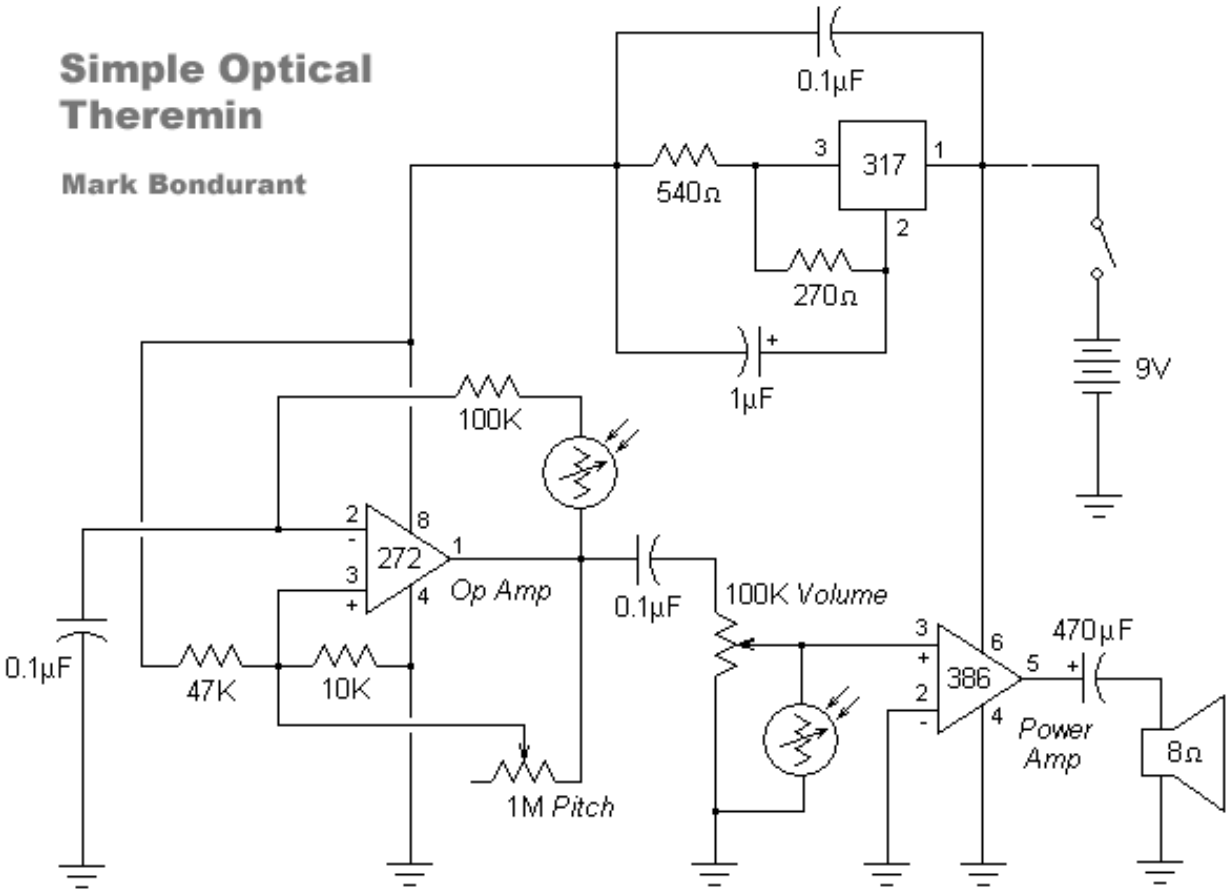
While the tube design did appeal to me, as previously mentioned, the cost and difficulty in constructing a 1954 Moog Theremin proved to be more an exercise in tracking down parts than an informative project - simply following the schematics wasn't going to teach me much more. Thus my project took a turn - I moved away from the classic tube designs and began investigating alternative transistor based designs. Many versions used IC-chips to handle large portions of the circuit - thus obscuring their internal functions. Chips which can perform relatively complex tasks reliably and easily are certainly an excellent choice for the average Do-It-Yourself'er, however such designs wouldn't do much for my revised goals - chief among them the understanding of what's happening in the circuit from source/signal all the way through to speaker.

There is a stage in most theremin designs where there is an output feeding into some sort of amplifier circuit. I say most, not all, since some more cleverly designed theremins cannibalize portions of the volume antenna circuitry into the amplifier circuitry, such as in the above circuit where the volume antenna is setting the gain across the amplifier directly as opposed to the pitch/volume circuitry working towards a low power signal which is then fed into a discrete amplifier. Having recognized this, I immediately split my project into two portions - one set of circuitry to produce the theremin sound, and a transistor amplifier!

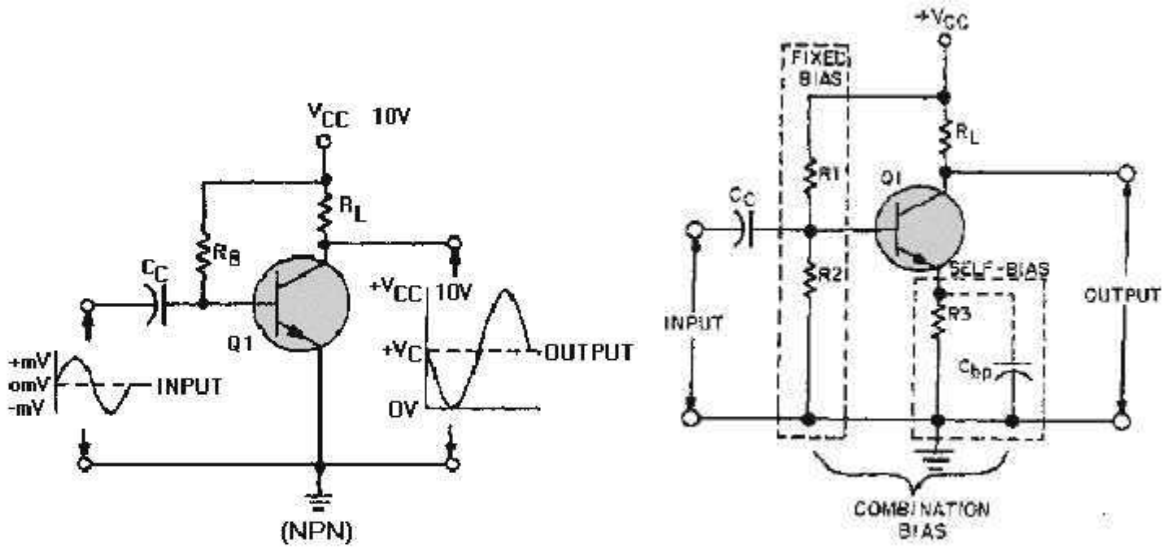
My research brought up a wealth of transistor based amplifier designs - all the way from simple op-amps to ludicrously complex AB amplifier designs. After looking through them for a while, learning the theory of how they operate, I found myself gravitating towards the transformerless amplifier circuit designs. This allowed me to simplify the operation of the circuit conceptually, and let me focus on the behavior and usage of the transistors in the design. As for the theremin circuit, I settled upon a photoresistor driven design. This provided my first glimpse into the flexibility and utility of transistors.

- The circuit design for my photo-theremin (below). This is really just a rather ugly squarewave generator with the photoresistor tuning the period of the wave. When played back into a speaker at a high enough rate however, (the general range of that rate being tuned by the capacitor) it produces a familiar theremin sound. This design only offers pitch control, not volume, though designs that offer both are certainly available. One that was referenced (but ultimately rejected due to its use of the 386 Power Amp) is proved on the next page.





My exploration of amplifier designs ranged from single transistor designs to ones worthy of being called audio amplifiers. One of the hardest parts for me was learning to bias the transistors properly - in many cases I had to switch out older transistors for their newer equivalents, which while similar, could have biases that were significantly different (the other trouble being that the bias for a transistor can vary with voltage, current, and temperature - it was certainly quite frustrating at times, but the practical education provided more than made up for it). Below is a collection of schematics I built as I progressed towards my final implemented design - many of which I kept intact throughout the project. The low cost of the transistors made this a highly appreciated option - being able to hear the difference from circuit to circuit was invaluable. Many of the transistors I required only cost around 10 cents each, with the exception of the power transistors - i.e. high current transistors - which were closer to $2-3 each.



- These two circuits (above) in particular taught me about how to adjust the bias a transistor properly. They also taught me how to make a 2n3904 bubble like a marshmallow over a campfire. The low cost of the transistors was truly an asset in this part of the project.

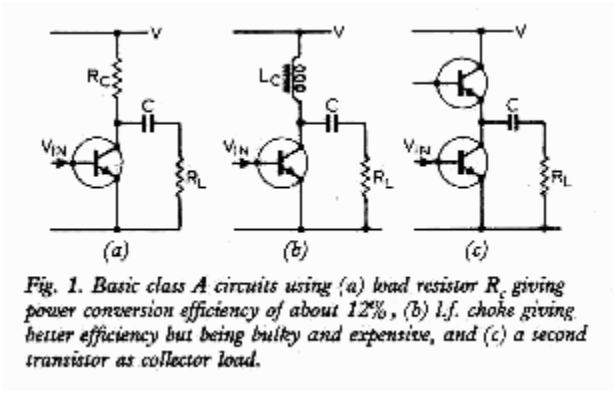


Fig. 1. Basic class A circuits using (a) load resistor R_c giving power conversion efficiency of about 12%, (b) l.f. choke giving better efficiency but being bulky and expensive, and (c) a second transistor as collector load.

(Not including the inductor circuit)

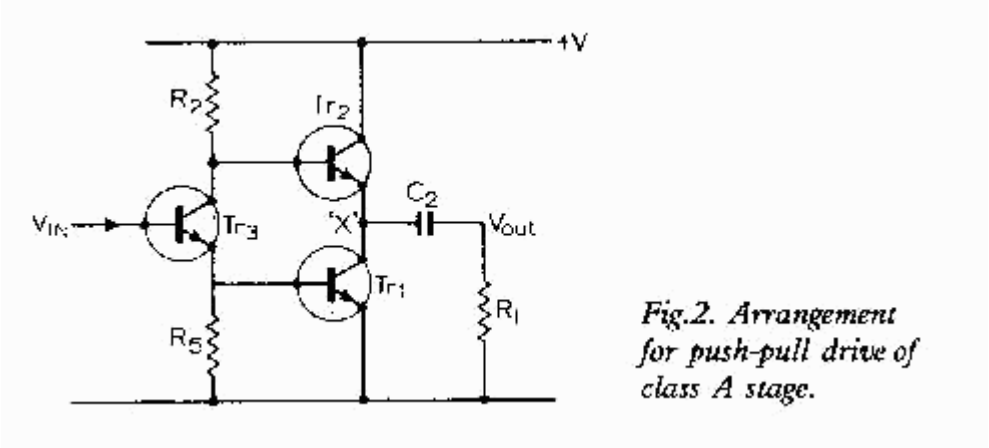
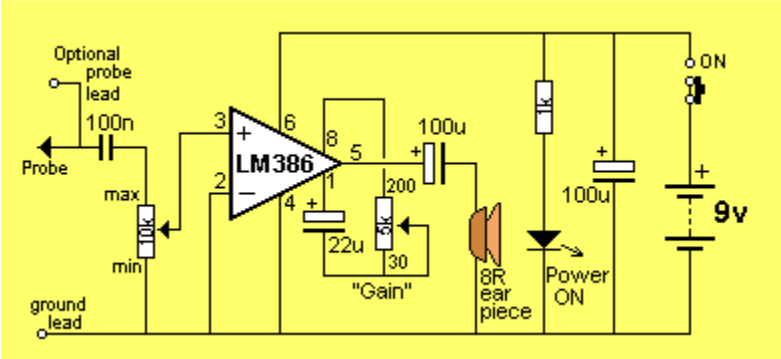
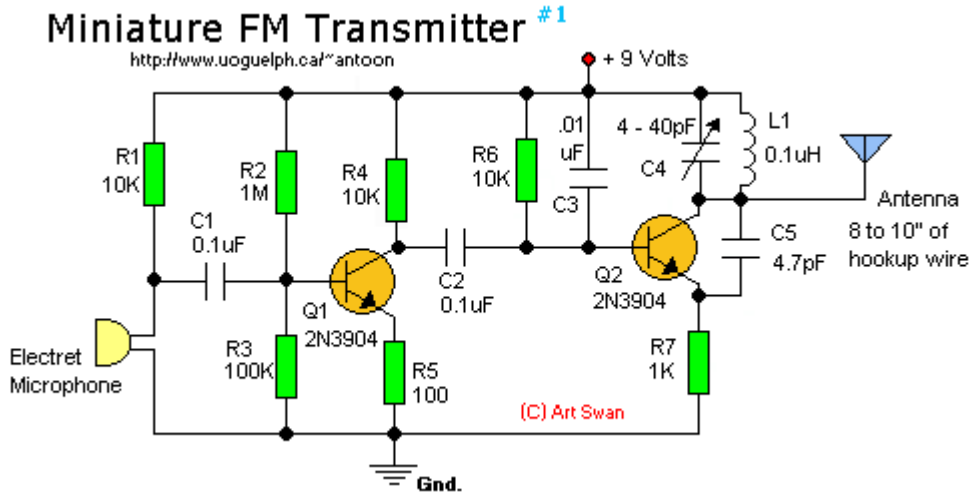


Fig.2. Arrangement for push-pull drive of class A stage.

- This circuit (above) was particularly important - without it I wouldn't of understood what was happing in the push-pull stage of my final circuit design nearly so well.



- While I did not use the LM386 amplifier chip in any amplifiers intended to be used in conjunction with the theremin circuit, it did prove useful in debugging my amplifier circuits - I built this little mini probe as I went along. The LM386 chip was somewhere between $1-2, with the rest of the parts all being standard stuff I had plenty of.



- Lacking an inductor, I wasn't able to use this for much, but it was fun seeing what else I could do with the 2n3904's I had in bulk. (Used a 20pF cap in the spot of the variable capacitor, leaving out the inductor entirely.)

-- There were several more circuits I built along the way, along with a simple tone generator based off of modifications to the optical theremin - the two circuits included on this page were particularly useful during my applied research as a tool and as an informative example (respectively).

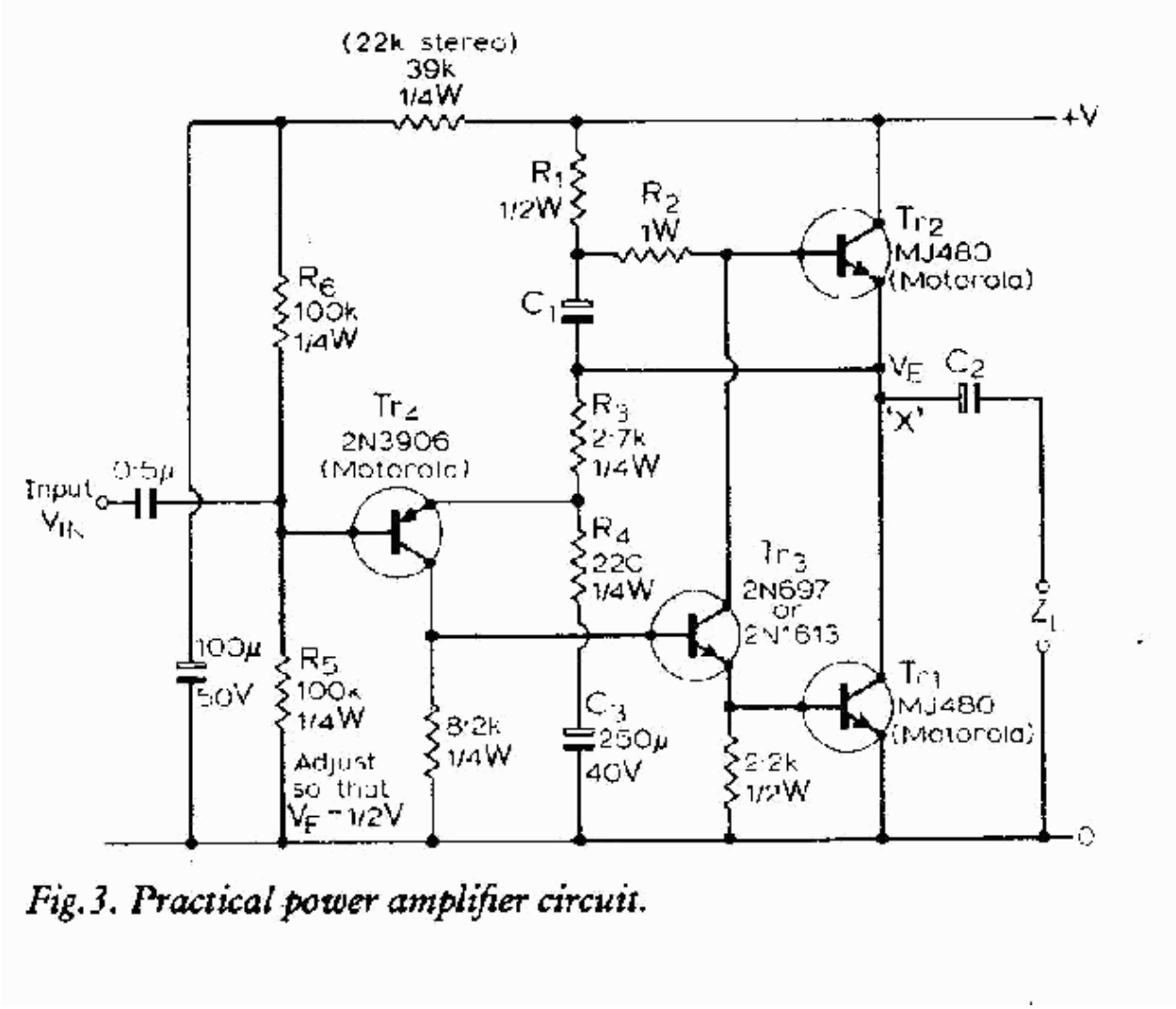


Fig. 3. Practical power amplifier circuit.

This is the circuit design I ended up choosing for my amplifier. It is a 10-W amplifier designed by J.L Linsley Hood in the late 1960's and is popular among amplifier builders due to its simplicity matched by excellent performance. The wealth of information on this circuit is profound, with forums readily available discussing every stage of its construction and countless variations on part choice and modifications. In my build I made the following part substitutions for transistors: MJ480 -> 2N3055, 2N697 -> BD159, and the 2N3906 remaining a 2N3906 (substitutions are available, but by most accounts the original choice is still the best choice).

Performance & Future Plans

It was sounding pretty good, though a bit weak - initially I only had a 12V power supply available for testing. Quickly building a 38V power supply out of a collection of lower voltage power supplies (chaining the grounds to the positive lines of the power supplies before them), I learned an important lesson. First off, don't do that. Secondly, if you do choose to do that (which will work actually), be sure you check that ALL of the little power supplies are actually DC. I mistakenly had chosen a couple AC ones not realizing it till it was too late. This made a rather startling amount of smoke come out of my first test speaker, and fried the BD159 and the 2N3906. The 2N3906 I had plenty of replacements for, the BD159 not so much. Eventually I was able to get the circuit working again using a 4401 transistor, but at that point what came out the speaker sounded softer than what had been going into the amp in the first place (the 4401 having a much lower gain than the BD159 - roughly 50 vs. 250.) Overall though, I was quite happy to have made a working amplifier that I could fully understand. My plans this summer include trying some of the modifications to the circuit design I ran across during my research. I'm especially curious about what some of the replacements for the 2N3055 power transistors will sound like, along with trying some builder tips such as running 1uF polyester caps parallel the electrolytics to increase the high frequency response of the amplifier.

References:

http://www.tcaas.btinternet.co.uk/jlh1969.pdf
http://www.freeinfosociety.com/electronics/schemview.php?id=1108
http://www.musicalmuseum.co.uk/theremin.html
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Special thanks to Leon Theremin, J.L Hood, and the dozens of helpful forums that were available for basic circuit information and technical assistance during circuit debugging.