

BOSCH & BOGEN:

An investigation into two radios separated by a quarter-century

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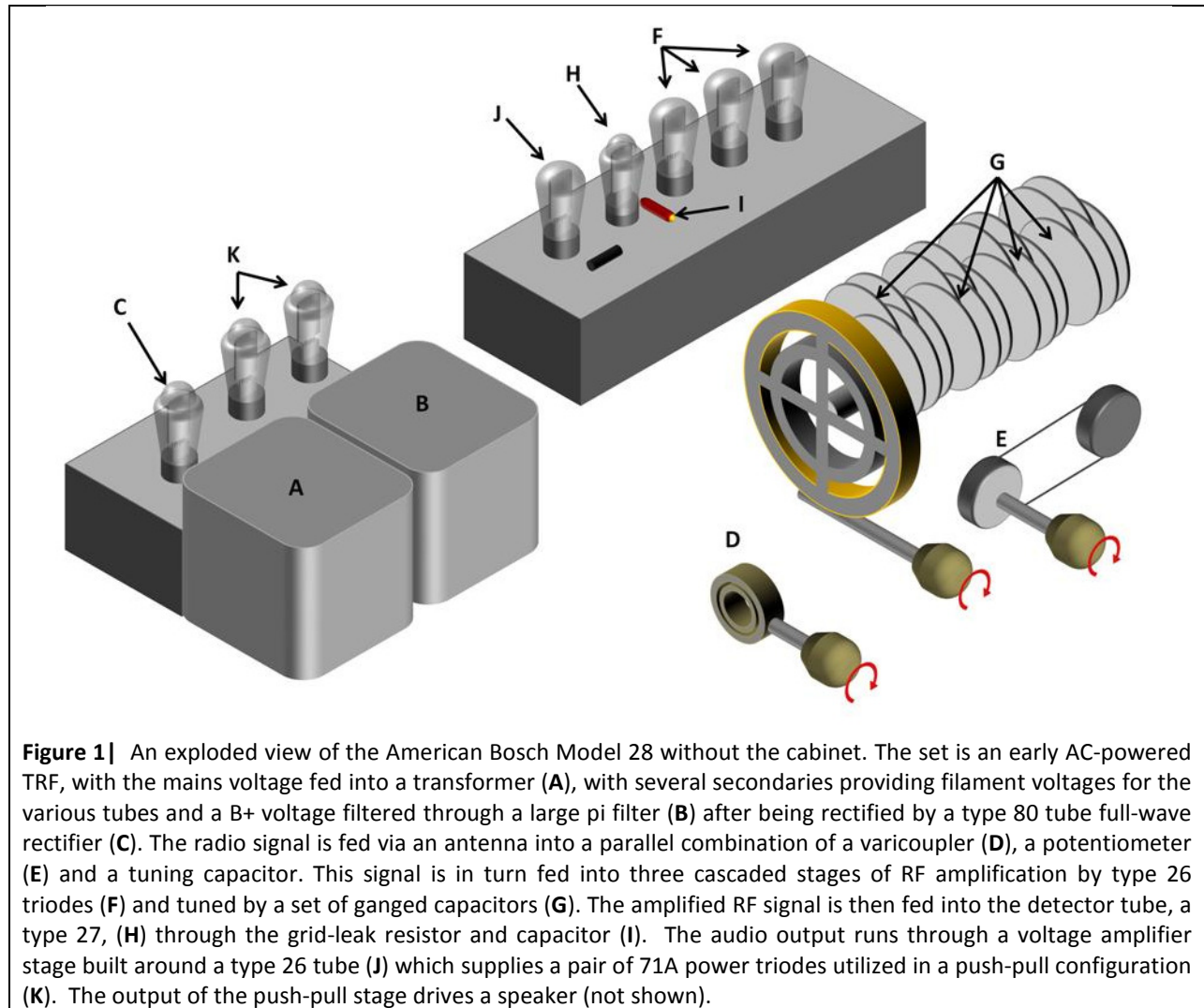
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ABSTRACT

I investigate two radios, one a 1928 American Bosch Magneto Corporation TRF receiver, and the second a 1952 Bogen FM superheterodyne tuner. The paper details and discusses the initial testing, repairs, restoration, circuit design, and functional operation of the two vastly different sets, as well as looks at the two radios in terms of their historical context.



AMERICAN BOSCH MODEL 28

History of Bosch

Robert Bosch founded the company which bears his name in Stuttgart, Germany in 1886, and within two decades it became a major player in the international market of magnetos and spark plugs. Bosch set up extremely successful American factories, sales teams, and markets in the first decade of the twentieth century, and soon expanded into other areas of products including electronics, but when the United States entered the First World War on the side of the Allies, all manufacturing facilities, including the plant located at Springfield, MA (Fig. 2B), were confiscated by the United States government and rolled into one unit known as American Bosch Magneto Corporation to distinguish it from its German-owned parent.



Figure 2 | The Model 28 originally sold for “\$132.50 less tubes” in 1928 (A). As a point of comparison, the Model T automobile by Ford cost approximately \$300 in 1925. Bosch, a German company based in Stuttgart, had all of its American assets confiscated by the United States Government during the First World War in 1918. The company was reorganized under a group of American investors and was renamed as the “American Bosch Magneto Corporation”. The Model 28 was manufactured in the company’s Springfield, MA plant (B). While a separate company from Bosch in Germany, it still maintained many vestiges of its parent company such as the famous “Mephisto” found on the radio dial of the Model 28 (C), which was the common mascot for most Bosch equipment up through the 1930’s (D). The Model 28 was among the first generation of radio sets intended to be seen not as an amateur piece of equipment but rather a piece of furniture around which the entire living experience could now focus...hence the construction of solid mahogany and complete weight of forty pounds. The Model 28 was one of a number of “breadbox” radios incorporated by the Pooley Cabinet Corporation into radio desks¹. Note the speaker hanging below the set (E). It also featured an AC output socket for supplying powered speakers such as those manufactured by RCA. Image A reprinted with permission from collection of William Noble. Image D from Bosch Archives².

With its new, and distinctly patriotic name, American Bosch began to manufacture radios in the 1920’s. The Model 28 along with its slightly modified sister radio, the Model 29, were released at the height of the company’s radio production. Eventually, in 1931, American Bosch Magneto Corporation was re-merged with the post-war American manifestation of the German Bosch, forming United American Bosch³. The sections below detail the circuit.

Tubes used in the Model 28

Much to my happiness, all of the tubes that came with the Model 28 tested at sufficient levels (see Table 1 below). A brief overview of the four tube types utilized follows:

Type 26 Medium-Mu Triode: A very common general use triode with a 1.6 V filament and amplification factor of 8.3. The tube is used for all three RF amplifier stages as well as the first audio/voltage amplifier of the Model 28.

Type 27 Medium-Mu Triode: Used as the AM detector for the Model 28, the 27 is special in that it was the first tube manufactured in North America with an indirectly heated cathode, a necessity due to the fact that the set is AC-powered. The filament voltage is 2.5 V, and the amplification factor is 9.

Type 71-A Power Triode: A somewhat common power triode for sets of this era, the 71-A has a 5 V filament and an amplification factor of 3 (!). Important for its usage in the Model 28, in a Class A configuration the maximum undistorted power delivered by a 71-A is 0.79 W.

Type 80 Full-Wave Rectifier: The predecessor of the ever-so-common 5Y3GT tube found in many later sets.

Tube	Minimum Conductance (μU)	Measured Conductance (μU)	Function in Circuit
26	725	910	RF Stage 1
26	725	890	RF Stage 2
26	725	750	RF Stage 3
26	725	700	First Audio/Voltage Amplifier
27	630	700	Detector
71-A	1040	1200	Push-Pull Amp (1/2)
71-A	1040	1150	Push-Pull Amp (1/2)
80	Diode	98 V	Rectifier

Table 1 | Tube Testing Chart for Bosch Model 28

The Circuit:

The Model 28 was one of the first AC-powered TRF sets available. Consequently, the design of the radio reveals a sense of modularity, with the RF stages, detector, and first audio, completely separated from the power supply and push-pull output by means of a cable and primitive plug-and-socket configuration. I believe the “radio” portion of the set was originally designed with battery power in mind and the “power pack” was designed to function with and supply the pre-existing portion.

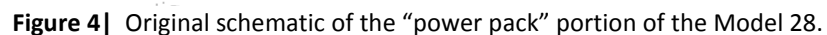
Front-End: As shown in Figure 3, an antenna feeds the RF signal into the front-end of the circuit, which is composed of a parallel RLC circuit, with the “C” portion being the first ganged tuning capacitor, the “L” portion being a varicoupler composed of two inter-coupled inductors adjustable by a knob on front, and the “R” portion being a 500 k Ω potentiometer used as a volume/gain control by tapping off a portion of the voltage across this resonance circuit and feeding it into the grid of the first 26 tube.

RF Cascade (Tubes 7, 8, and 9 in Figure 3): Seeing as this set is a TRF, the core of the tuning comes from a set of three RF amplifiers/tuners run in series. Each subunit, based around a 26 tube, is almost identical with the other two. They are transformer coupled to one another and are neutralized using assemblies consisting of a pair of metal washers, a mica sheet, and screws. Each circuit is tuned using one of the ganged capacitors.

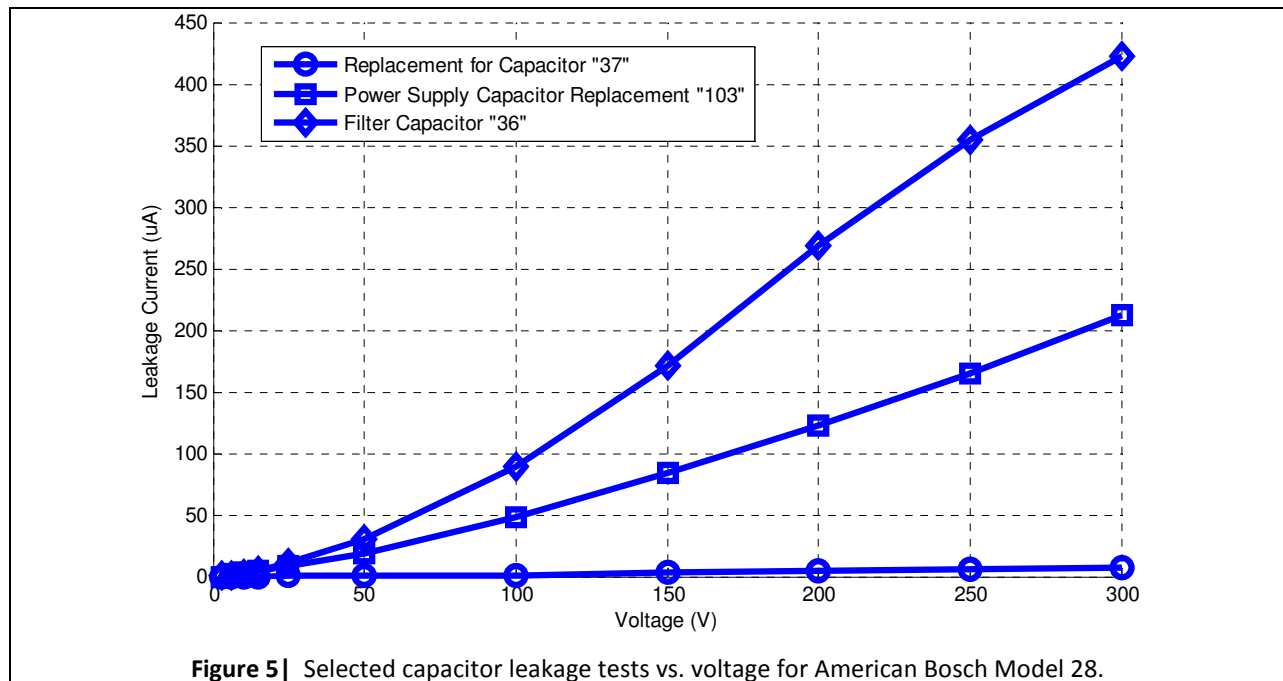
Detector (Tube 10 in Figure 3): The output of the RF amplifier cascade is fed through a grid-leak composed of a 2.2 M Ω resistor (3 M Ω according to the schematic) in parallel with a 250 nF capacitor. The detector tube is a type 27 with a separate cathode grounded to chassis. While the four 26 tubes used in the circuit have plate voltages of approximately 90 V, the potential drop across the 50 k Ω plate resistor (“27”) results in a 20 V plate potential for the 27 detector tube. This was done because the tube, being used as a grid-leak detector, relies on space-charge accumulation on the grid for biasing, and without a control or suppressor grid present, as is the case in a pentode, the plate voltage must be kept relatively low to avoid stripping electrons off of the grid, ruining the bias.

Power Supply: The power supply on the Model 28, shown in Figure 4, is quite interesting, in part because it was one of the major selling points of the radio, the first AC-powered sets having been released the previous year. At the time of release, however, AC voltage was still not well-regulated, so to deal with this issue, the primary of the power transformer has three taps for accepting AC voltages of 105 V_{RMS}, 115 V_{RMS}, of 125 V_{RMS}. A fancy plug assembly with three sockets and a plug connector allowed the user to select the closest tap to his/her specific AC voltage, guaranteeing the appropriate flux density through the iron core to generate the necessary secondary voltages.

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A total of nine capacitors (all but two of the entire set's capacitors with the exception of the mica neutralization capacitors) were found to be leaky at their standard operating voltages and replaced. The original Capacitor "37" was leaking a full 5 mA at its standard B+ operating level of 90 V, and had been replaced by a wax capacitor which was only slightly leaky over its operation range (shown below). Numerous other B+ filter caps were also faulty; the plot of capacitor "36" is shown in Figure 5 below. The smoothing capacitors "102" and "103" were both found to be significantly faulty at voltages above 50V. These two capacitors normally operate at 320 V in the set, so a previous user cut the leads from both capacitors and replaced the 2 μ F "103" with a gigantic 1 μ F paper capacitor which was little better when I tested it (shown below), having a leakage of >200 μ A at its standard operating voltage.



Fire Damage: Cause, Effects and Solutions

The specific Model 28 which I worked on experienced a significant fire at some point in its history. The definite cause of the fire is unknown, although the fact that it happened right at the location of the AC-voltage selector, leads me to hypothesize that the original filter capacitors across the mains, unlabeled in the schematic in Figure 4, located next to the AC-voltage selector switch and taps ("15"), became defective and at some point in time, perhaps twenty or thirty years after being built (or perhaps much sooner), someone turned on the set, one or both of the capacitors shorted to ground, caught fire, and consequently destroyed all components in the neighborhood.

Limited repairs and modifications were made to the set by someone long before I came into possession of the radio in order to remedy the fire damage. With the AC-voltage selector switch destroyed, the 115 VAC tap had been hard-wired to the mains. In the course of my repairs I decided to change to the 125 VAC tap just to be on the safe side. The original repair person also replaced the 5 k Ω resistor used for setting the B+ voltage with a 300 Ω Candohm resistor (by the Muter Co.) Why this choice of resistor was made is beyond me because it resulted in a 300 V plate voltage, which is beyond the maximum ratings of some of the tubes. I re-replaced this resistor with a proper value and I made further repairs and replacements to the fire-damaged wire-resistors at the output of the secondary taps.

The fire caused the set housing to become severely warped, as is visible in Fig. 6(a) below. This in turn caused one of the pin holders of the 71A tube to disconnect. I repaired this by inserting the tube into its mounting, placing the loose pin holder onto its appropriate position on the pin, and gluing it back to the chassis using Loctite 404 adhesive. After drying for 24 hours the bond was surprisingly sturdy.

The audio output transformer was damaged beyond repair by the fire. Both output wires had their insulation burned off, and one half of the secondary was open. Since this transformer was designed for driving high-impedance speakers, anyways, I took the opportunity to replace it with a 125 J series audio transformer (Hammond Mfg.) in order to allow the 71A push-pull output to drive a modern low-impedance (either 8 Ω or 4 Ω) speaker. The new transformer is visible in Figure 8(d) below.

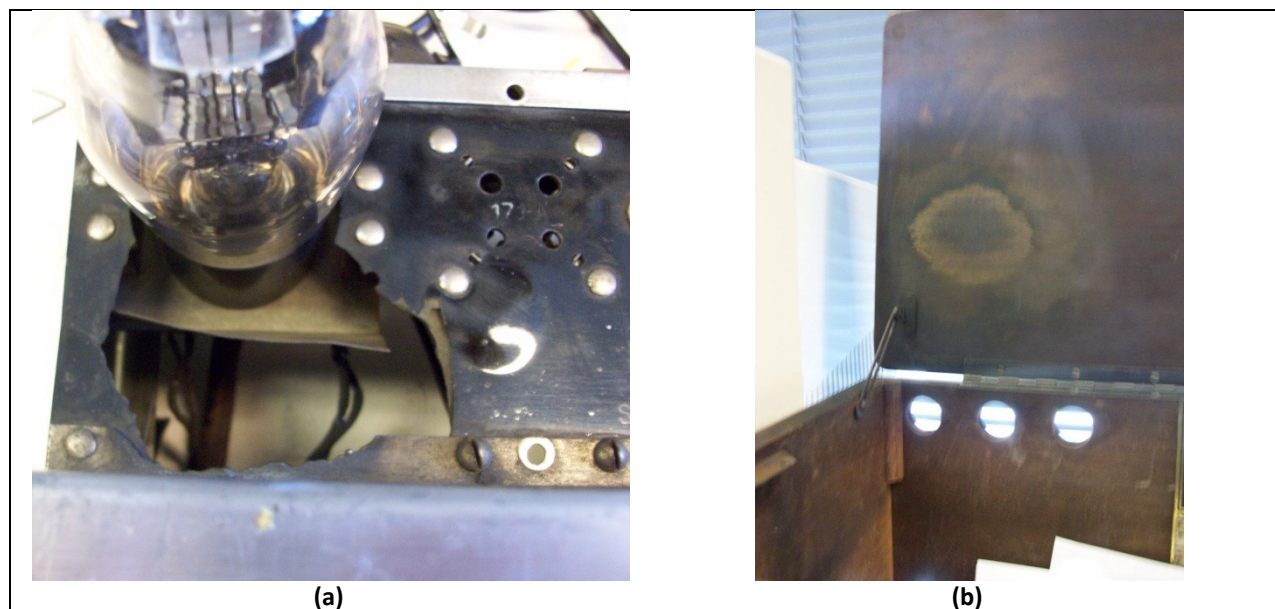


Figure 6] Fire damage in the set occurred at the location of the original AC-voltage selectable switch in front of the rectifier tube. Significant damage to the power pack housing occurred (a) and evidence of the fire is clearly evident in the damage of the wood finish directly above the rectifier tube (b).

Frequency Response

With the set running, a loop antenna was placed nearby and transmitted AM-modulated tones at frequencies of 550 kHz, 1000 kHz, and 1550 kHz. The results are plotted in Figure 7 below. It is interesting to note that while overall, the circuit does not have very good frequency response, it varies significantly depending on RF, performing much better at the extremes of the tuning range than at the middle of the AM band.

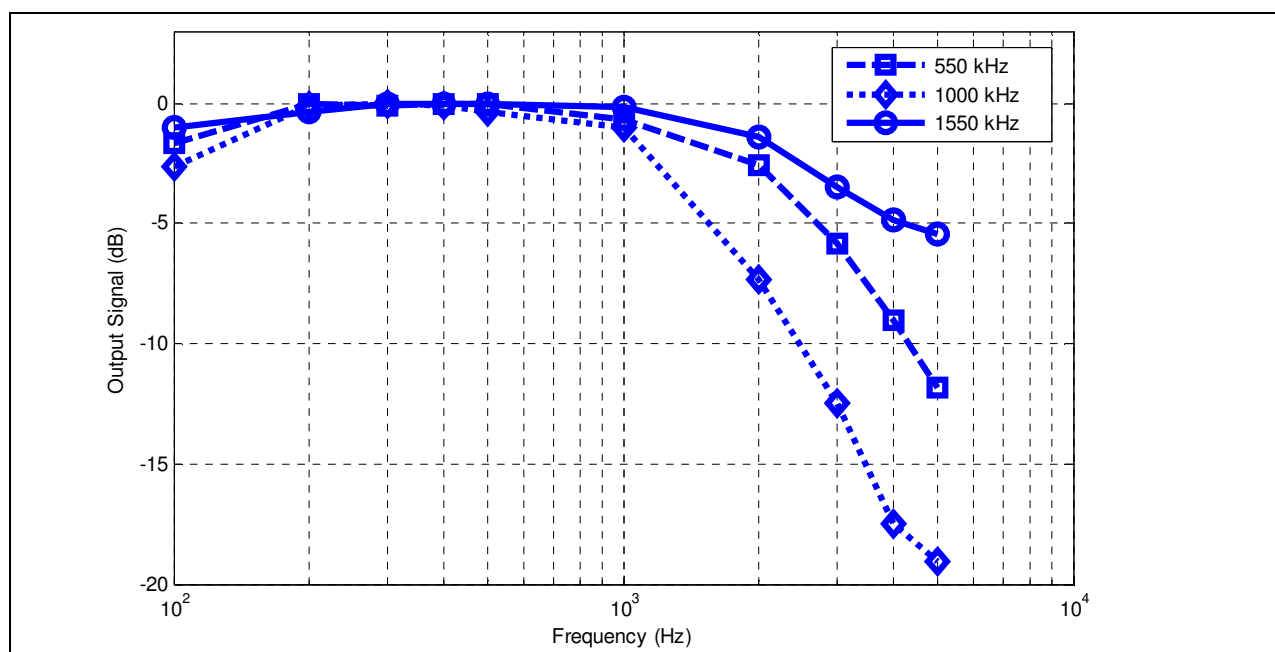
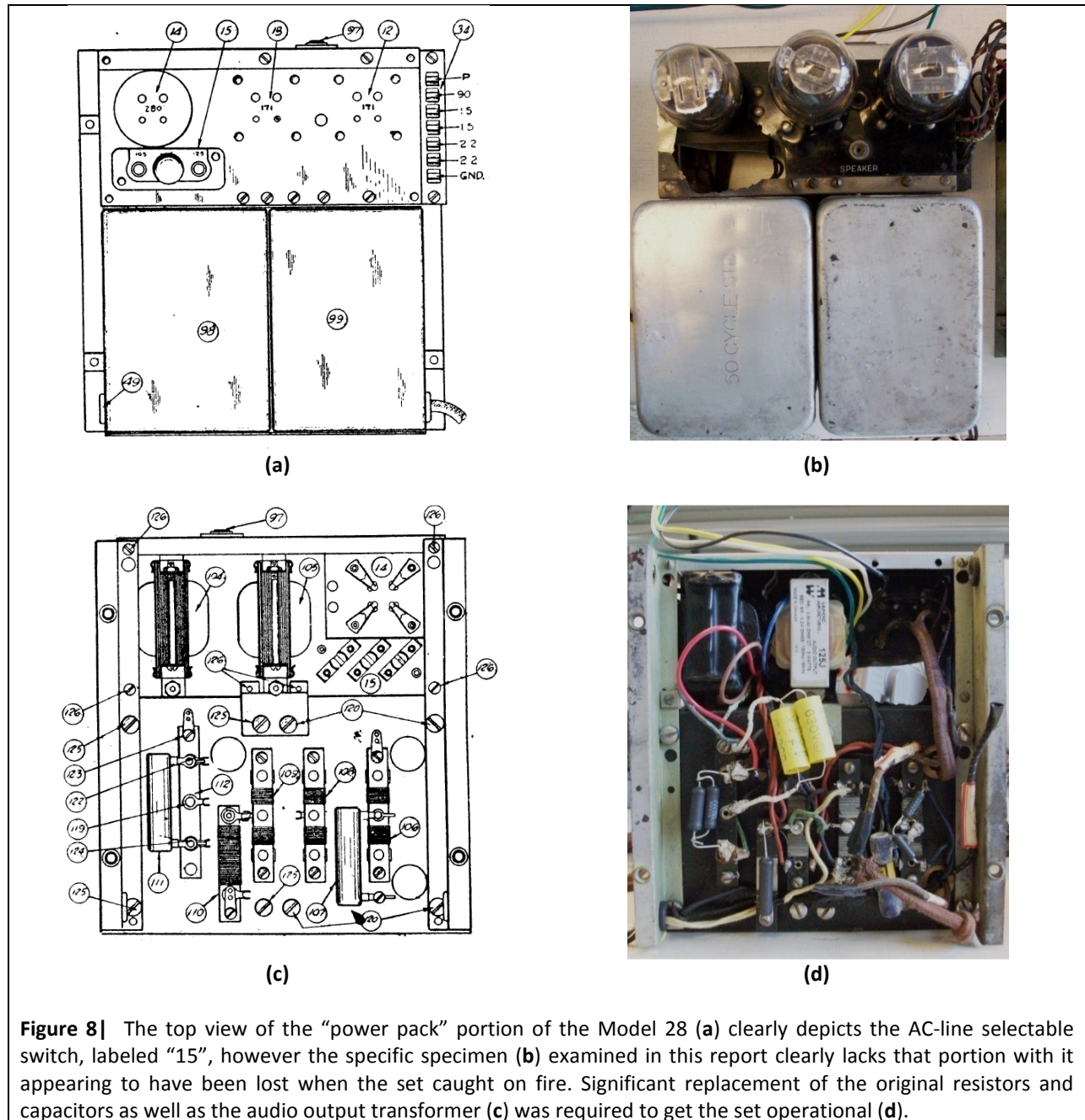


Figure 7] Frequency response of the Model 28 at the AM frequencies of 550 kHz, 1000 kHz, and 1550 kHz.



Operation

When running the Model 28 at one o’clock in the afternoon in the lab at MIT where all testing was carried out, a total of 16 individual stations were able to be clearly picked up across the entire band. At the time of submission, a slight squeal on some of the higher stations presents itself occasionally, and this is most likely the result of the neutralizing capacitors requiring re-adjustment.

When driving an 8Ω speaker through the replacement output transformer, a voltage of up to approximately 1 V_{rms} or an average power of 100 mW can be generated without significant distortion. Even at 100 mW, the signal is very loud coming out of the speaker.

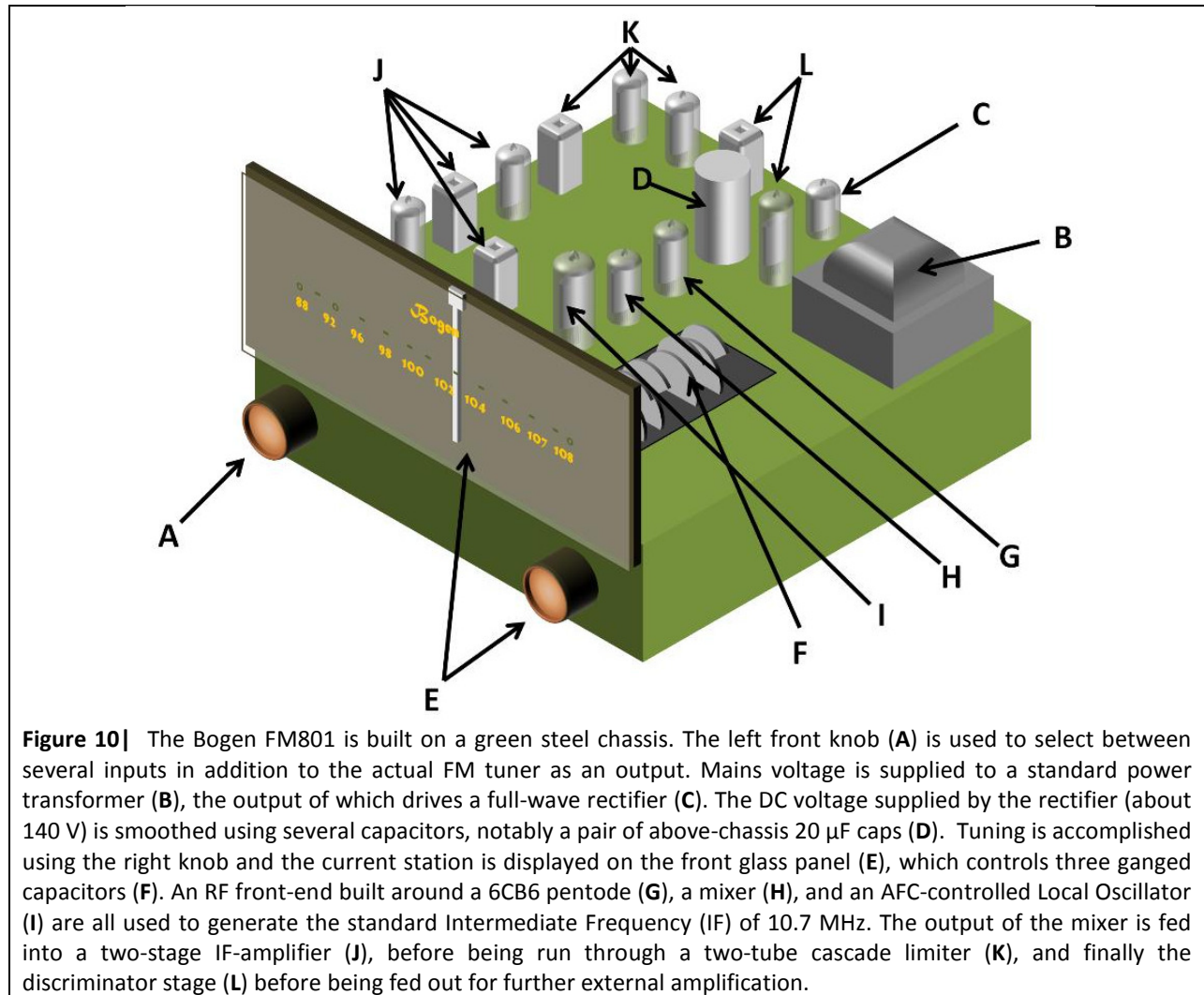


(a)



(b)

Figure 9 | The Model 28 mounted in its mahogany case with all electronics exposed (a), and with its cover/shield in place (b).



BOGEN FM TUNER MODEL FM801 (1952)

Twenty-four tumultuous years after the American Bosch Model 28 was released, David Bogen & Co., (founded in 1932), released their FM801 Tuner⁴. The set, consisting of nine miniature glass tubes, in an open chassis, is depicted in Figure 10 above for clarity. Photographs are found in sections below. In a 1953 Allied Catalog, the tuner sold for \$115. As a point of reference, a new car would have cost around \$1500 to \$1700 in 1953. By the time the FM801 was being produced in 1952, Bogen was a well-respected manufacturer of high-end and reliable radios and PA systems.

While my initial feelings about the set were that it may perhaps been a “bucket of tubes” design, after examining the circuit as a whole in detail and hearing its output, I am pretty satisfied to conclude that it is a no less than very well-designed high-end FM tuner that provides remarkably good reception.

Tubes

Of the nine tubes in the FM801, only three needed to be replaced. Luckily these three tubes were all the rather common 6AU6’s so replacing them was not a big deal.

6CB6: A sharp-cutoff pentode often used in IF stages or VHF RF front-ends, and utilized for RF amplification in the FM801.

6AB4: High-mu triode often used in the FM801 converter.

12AT7: A dual high-mu triode, which is still heavily used in guitar amplifiers today. The 6.3 V filaments for the two triodes are strung in series giving a total series filament voltage of 12.6 V (hence the part numbering).

6AU6: The most common tube in the FM801, with a total of four occurrences, the 6AU6 is a rather generic, workhorse RF pentode usable up to a frequency of 50 MHz.

6AL5: A high-perveance dual diode commonly used as a detector in FM and television circuits.

6X4: Full-wave vacuum rectifier (with a common cathode to both diodes).

Tube	Minimum Conductance	Measured Conductance	Function in Circuit
6CB6	3900	4800	RF Amp
6AB4	2500	2600	Mixer
12AT7	2500	3400, 2600	LO and AFC
6AU6	2500	2650	1 st IF Amp
6AU6	2500	2500	2 nd IF Amp
6AU6	2500	2550	1 st Limiter
6AU6	2500	2900	2 nd Limiter
6AL5	Diode	98, 100 V	Discriminator
6X4	Diode	90, 94 V	Full-wave Rectifier

Table 2| Tube Testing Chart for Bogen FM801

The Circuit

The FM801 is a pretty standard transformer-operated FM tuner. It was definitely a higher-end set, however with some interesting features present. I try to highlight these features below.

Power Supply:

The FM801 power supply is pictured in Figure 11 below. The AC line feeds the primary of the power transformer through the on/off/selector switch. Two secondaries are present, with a 6.3 VAC secondary lighting the pilot lamps and the filaments for all nine tubes (including the 12AT7 with its center-tapped filament). The larger secondary, which is center-tapped, is used in a full-wave rectifier based around the 6X4 tube. The DC output is run through a set of three smoothing capacitors and two power resistors to provide a B+ voltage of approximately 140 V.

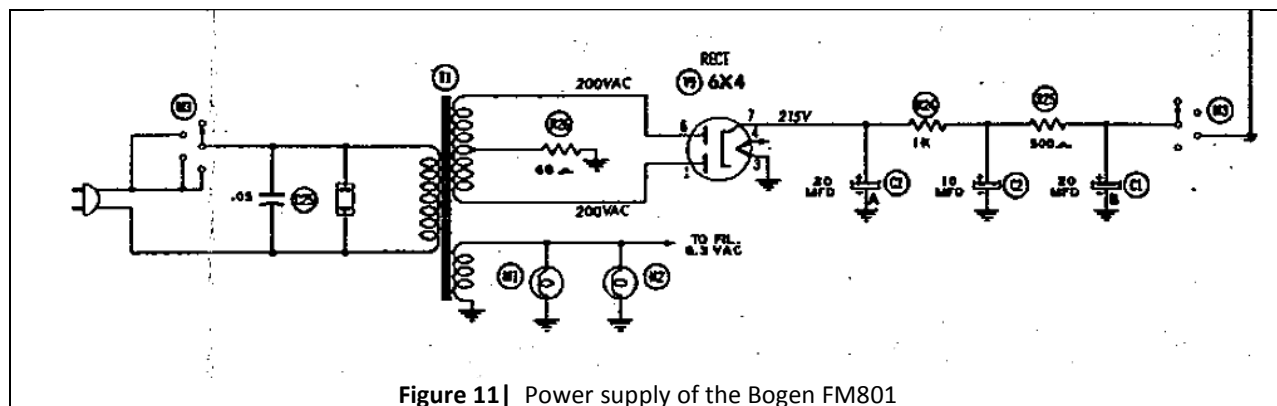


Figure 11| Power supply of the Bogen FM801

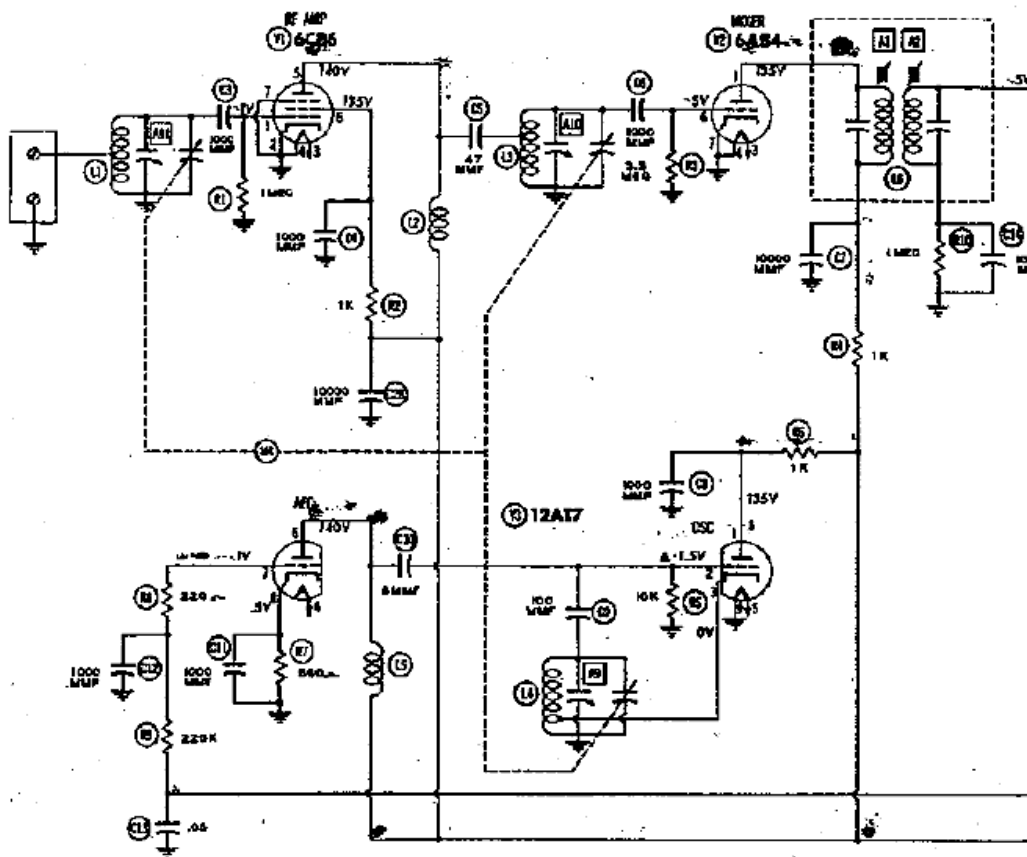
RF Front-End: As shown in the upper left-corner of Figure 12 below, a tuned-front-end feeds its signal into a 6CB6 pentode with plate voltage at 140 V. The tube is biased from space-charge, and drives an inductive load L2 to provide higher gain at RF frequencies. As a general note on the receiver design, the RF stage doesn't exist so much to add more gain as it does to provide increased signal-to-noise operation⁵.

Local Oscillator: A 12AT7 dual triode, located in the bottom-half of Figure 12, provides the LO signal. Half of the 12AT7 (one triode) is configured into a fairly traditional Hartley-type oscillator, while the other half (second triode) is used as a reactance tube in conjunction with an automatic frequency control (AFC) signal. The reactance tube is an amazing piece of technology which, when placed in parallel with the LO tank yields a voltage-controlled-oscillator (VCO) functionality. After reviewing the literature⁵, I think I have an acceptable understanding of how this AFC circuit functions and offer the following explanation:

The LC Hartley oscillator present in the bottom right of Figure 12, is wired in parallel to the AFC circuit via the 5 pF capacitor C10 which connects directly to the plate of the second 12AT7 triode (the first triode is used in the oscillator itself.). Let's ignore this capacitor C10 for the moment and assume the oscillator is directly attached to the plate. Because this is a triode, a significant Miller capacitance exists between the plate and the grid (approximately 1.5 pF⁶). Any voltage presented to the plate from the oscillator will generate a *leading* current into the Miller capacitance (remember CIVIL...in caps current leads voltage: CIV and in inductors voltage leads current: VIL). This leading current flows to the grid. Also attached to the grid is a 220Ω resistor, the other side of which is effectively incrementally grounded at LO frequencies through the 1 nF C12. Consequently, any leading current flowing into the grid will continue to flow into the grid resistor generating a *leading* voltage at the grid. In triodes, plate current follows grid voltage so the leading grid voltage generates a leading current. As a result, the voltage at the plate sees a leading current, meaning that the entire AFC circuit appears capacitive, and since the AFC and the oscillator both share a common ground this means that the AFC circuit is adding capacitance in parallel to the LC oscillator, in effect changing the frequency of oscillation. The exact numerical amount of current lead presented to the oscillator is based upon the bias point of the triode, which is based off of the AFC-controlled grid voltage. As a result by adjusting the AFC signal level one can change the value of capacitance shown to the LC oscillator, affecting the total capacitance in parallel in the tank and therefore affecting the frequency of oscillation.

Now if we reconsider the 5 pF C10 which actually connects the oscillator to the AFC circuit, we see that basically the entire oscillator sees two capacitive elements *in series*: C10 in series with C_{AFC}. Now aside from the obvious role of keeping the B+ bias voltage from screwing up the oscillator, I'm speculating that since C10 does not yield a negligible reactance at LO frequencies, I think it is serving a limiting purpose. Since the smaller series capacitor always dominates, if C_{AFC} < C10, the effective capacitance seen by the

Mixer: The output of the RF amp is filtered once more through a second tuned stage before being applied to the grid of the 6AB4 high-mu triode. The triode is biased using space-charge accumulation on its grid (which is why its cathode can be grounded). While not clearly shown in the schematic, the LO signal is supplied to the mixer circuit through the inductive coupling of coils L3 and L4 which are aligned in close proximity in the layout of the set. The output of the mixer provides the signal at the IF of 10.7 MHz.



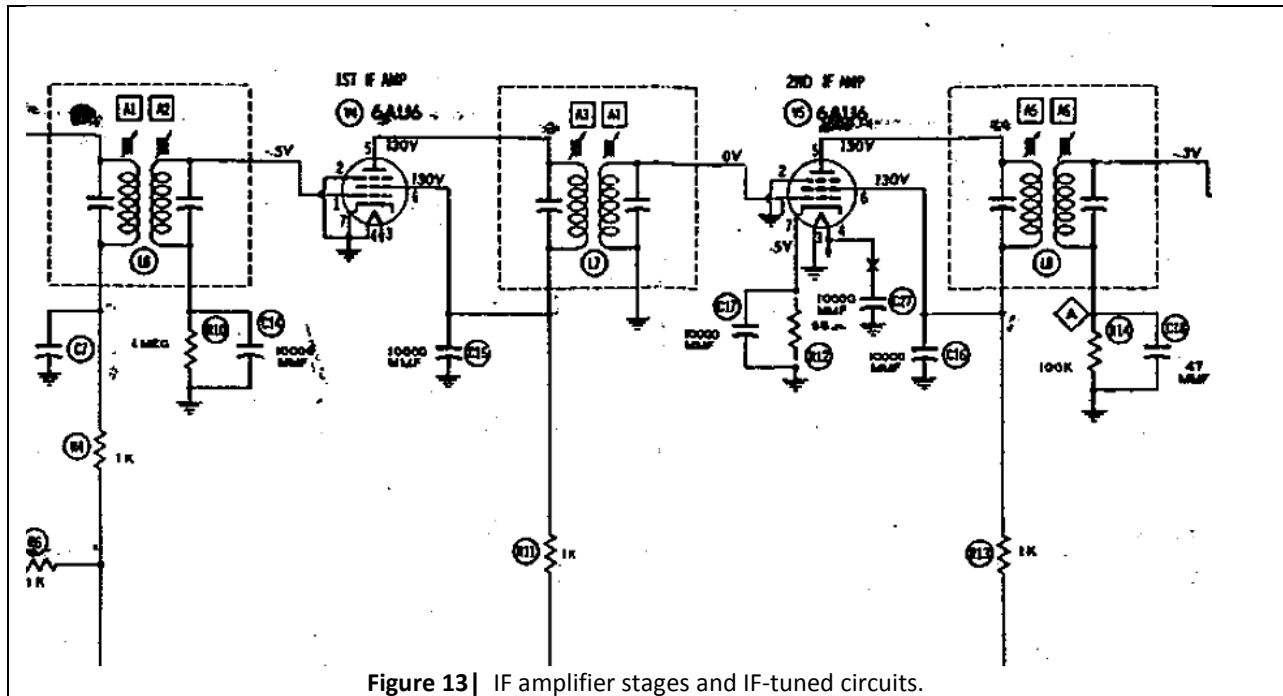


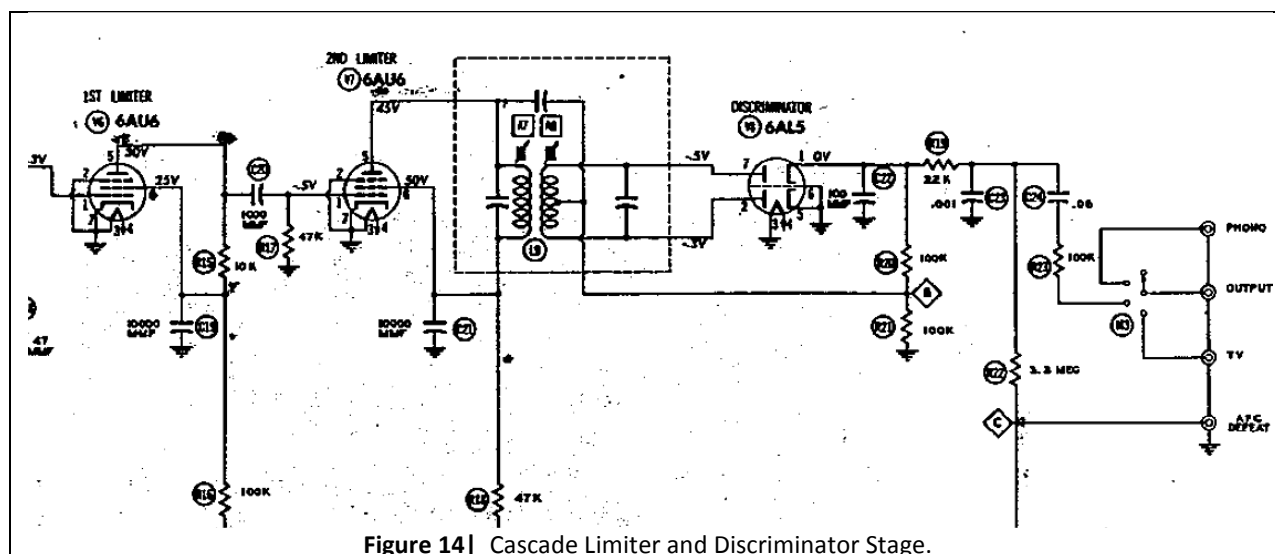
Figure 13 | IF amplifier stages and IF-tuned circuits.

IF Stages: A total of six IF-tuned circuits exist as well as two 6AU6 pentodes used for IF amplification. The tuned circuits are contained within three cans (two circuits each) and tuned using a flat-head screwdriver from above for one circuit and below for the other. The first IF amplifier is biased using space charge accumulation on the grid (grid voltage = -0.5 V and cathode voltage = 0V), most likely to provide the highest gain early on, since this would be advantageous (however miniscule) for keeping noise levels down. The second IF amplifier has its cathode connected to a bypassed 68 Ω resistor such that its grid voltage = 0 V and its cathode is at 0.5 V. Consequently both IF tubes have the same grid-cathode voltage of -0.5 V.

Limiters: As shown in Figure 14 below, the output of the IF amp stages feeds into a two-stage cascade limiter, constructed of two 6AU6 triodes running at significantly lower plate voltages (30 V plate, 25 V screen grid for Limiter 1 and 45 V plate, 50 V screen grid for Limiter 2). The rationale for these lower voltages is so that the tubes saturate at normal signal strengths rather than only with large signals; we want the tubes to saturate because that is what causes the limiting.

While at first I thought the usage of two limiters a bit extreme and even...dare I say, wasteful...I researched the circuit and discovered that there is indeed a reason to the madness. The limiter tubes are biased at Q-points that are close to saturation. Ideally signals fed into the limiter are very large, and will be limited on both their positive and negative half-cycles. However, if the input signals are small, such as those that would come from a weak station, only the positive half-cycle of the signal would get limited. The negative half-cycle would drive the limiter stage more into its linear region of operation, which is something we don't want.

If, however, you take the output of the first limiter and then feed that into a second limiter, the 180° phase inversion resulting from the common-cathode configuration of the first stage, will now allow the second limiter to saturate on the untouched half-cycles from the first stage. As a result, the cascade of limiters provides full-cycle limiting for both strong *and* weak signals, something that a single limiter stage cannot do.



Discriminator: A 6AL5 dual diode tube is used as the core of the discriminator circuit shown in Figure 14 above. The only real departure from a traditional discriminator layout is that a single capacitor to ground is used to tie the cathodes of the two diodes together rather than a pair of capacitors each tied to the feedback voltage (the “B” inside the diamond). Incrementally this really doesn’t make a difference, although there may be some hidden functionality which I have yet to comprehend. The AF signal is run through a RC low-pass filter with corner frequency of approximately 7.2 kHz before being sent out on its way to an external amplifier. The AF output is also run through an additional RC low-pass filter (3.3 M Ω , 60 nF, corner frequency 5 Hz), which is subsequently used to provide the AFC control signal.

Plate and Screen Voltage Measurements

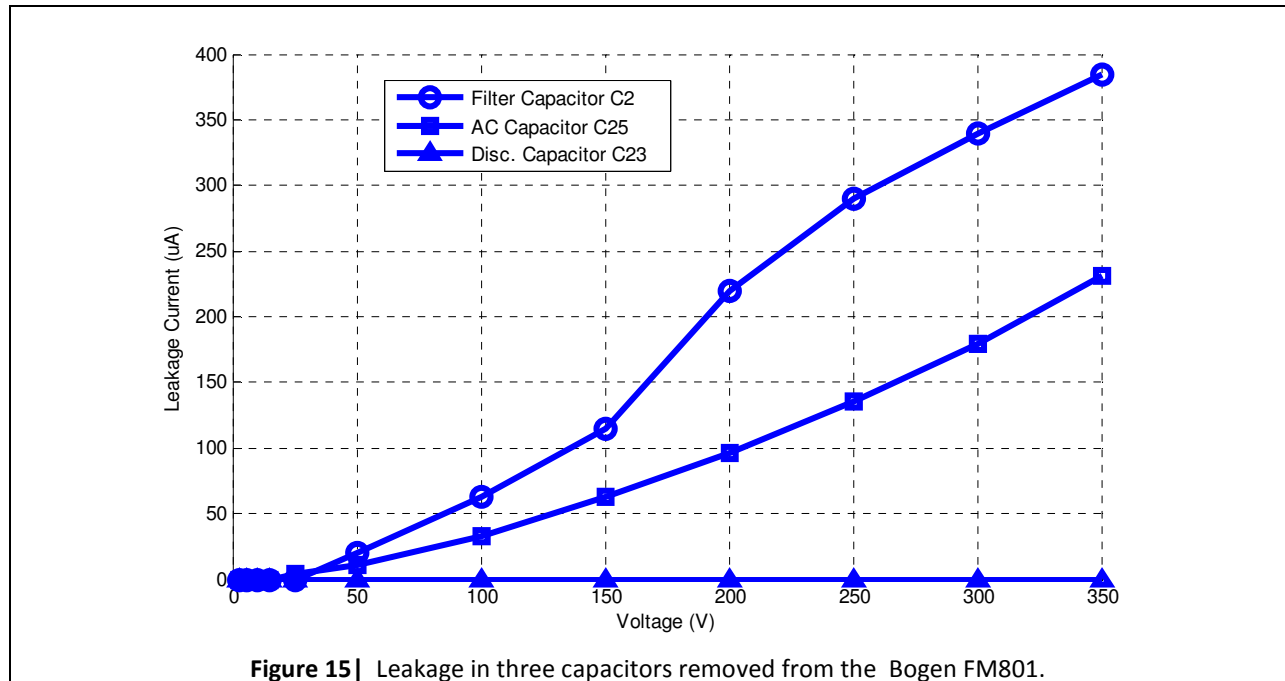
Upon measuring the plate and screen voltages in the set, it was discovered that all values were slightly lower than what they were listed as in the schematic. I traced this issue back to a lower B+ voltage, which I may try to remedy with additional capacitance at the output of the full-wave rectifier. Details of measurements are provided in Table 3 below.

Tube	Plate Voltage		Screen Grid Voltage	
	Schematic	Measured	Schematic	Measured
6CB6	140 V	131.9 V	135 V	129.2 V
6AB4	135 V	129.8 V	N/A (triode)	N/A (triode)
12AT7	140 / 135 V	133.1 / 127.3 V	N/A (triode)	N/A (triode)
6AU6	130 V	130 V	119.9 V	119.8 V
6AU6	130 V	130 V	119.5 V	120.5 V
6AU6	30 V	25 V	38.9 V	35.6 V
6AU6	45 V	50 V	48.9 V	48.9 V

Table 3 | Schematic-listed and measured plate and screen grid voltages for the tubes of the FM801

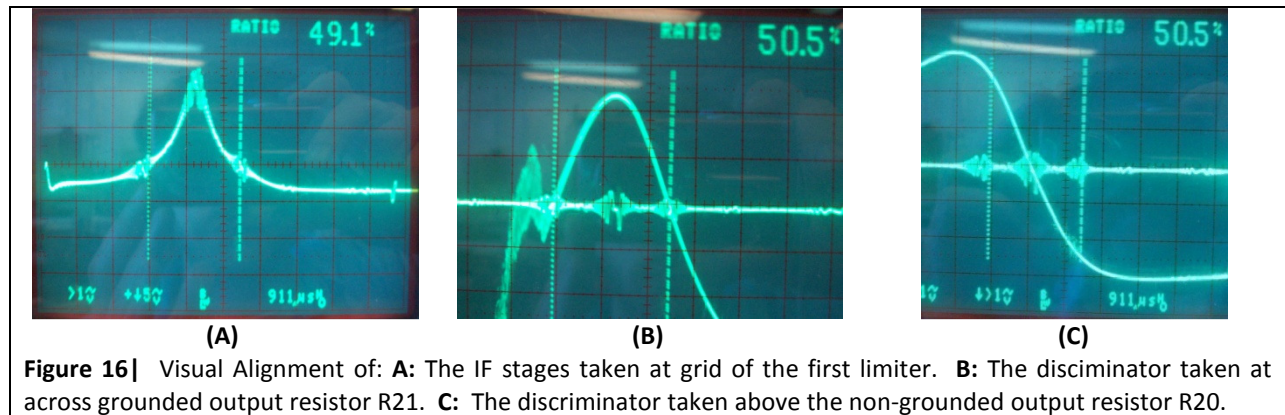
Capacitors Failure and Testing:

Unlike the sorry state of affairs in the American Bosch Model 28, most capacitors in the Bogen FM801 were fine. The only exceptions to this were the three smoothing capacitors at the output of the power supply and the filter capacitor located across the mains. A selection of the capacitors and their leakage ratings are depicted in Figure 15.



Alignment

The set was visually aligned over the course of about five hours of learning and trial-and-error sessions. Visual results of the alignment are depicted in Figure 16 below. After alignment, reception on the set was significantly improved.



Audio Characterization

With the set properly aligned, a signal generator was hooked up to the grid of the first IF amplifier, and a 10.7 MHz FM signal was used to test the audio characteristics of the set. Figure 17 depicts the output signal strength vs. frequency deviation, with the set seeming to max out at +/- 35 kHz deviation.

The audio frequency response for a +/-25 kHz signal is shown in Figure 18. The -3dB point occurs just shy of 5 kHz, which truth be told, is not that impressive. I think I'm going to try and remove the RC low-pass filter right at the output of the discriminator since its corner frequency of 7.4 kHz is not helping the situation.

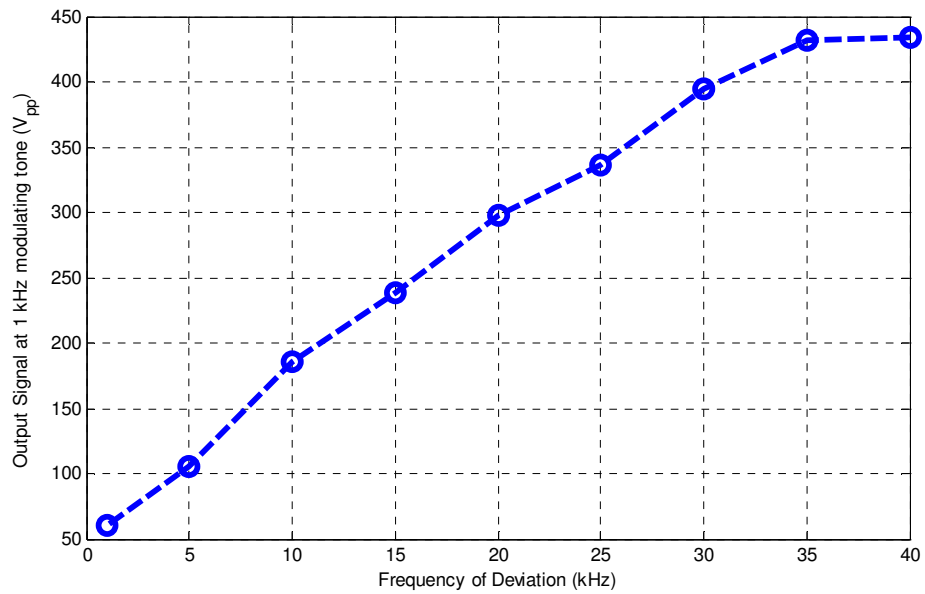


Figure 17| Plot of signal strength vs. frequency of deviation for 1 kHz tone. Above 35 kHz, the receiver did not generate a louder output.

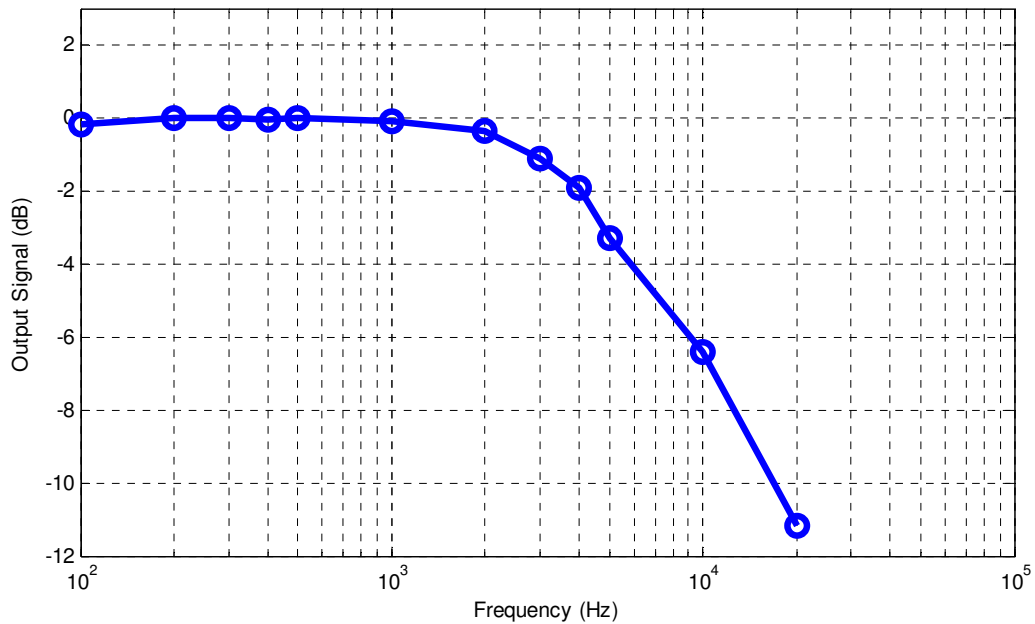


Figure 17| Frequency response of the Bogen FM801 taken at the phono plug output. The signal is down approximately 3.5 dB at 5 kHz.

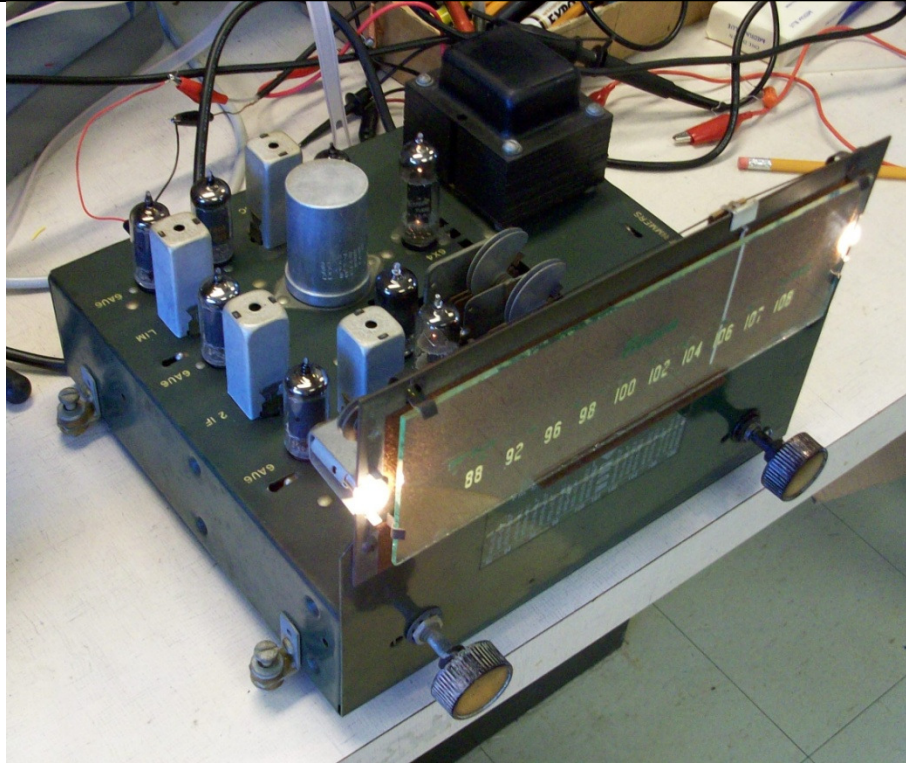


Figure 19| The restored Bogen in complete operational glory.

Operation of the Bogen

With an external antenna carefully mounted in the lab at MIT, the Bogen was able to pick up a total of 19 distinct stations at 2 pm in the afternoon. The set is significantly sensitive and selective, and on many of the mid-to-strong stations the sound quality out is as good as any modern radio to which I've listened.

FUTURE WORK AND DISCUSSION

There is still work to be done on both the Bogen and Bosch radio sets. I intend to replace the bulk of the wires in the Model 28 as well as add filter capacitors across the AC input, which is something I neglected to do since the originals were completely destroyed when the set caught fire and I ended up forgetting that they had ever been there in the first place. For the Bogen FM801, I intend to do some experimentation with modifying the bias schemes for both the limiter tubes, as well as attempt to improve the AF response and alter/experiment with the AFC circuitry.

The Model 28 is essentially a ridiculously well-designed brute force approach to AM reception, and the net result is a radio set that is more sensitive than any solid state radio I have in my apartment. In the FM801, the utilization of the Miller capacitance for AFC as well as the carefully designed limiter stages are amazingly clever solutions to common engineering needs and problems of the day. While the two radios discussed are drastically different in almost every way that two radios can be different, at a higher level, they both share the fact that they are the products of an absolutely remarkable amount of ingenuity on the part of their respective designers, and I hope that is what people take away with them when they view and read about the sets.

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