Revisiting the amp that gave *"Solid-State"* a bad name: the

Fender Solid-State Twin Reverb

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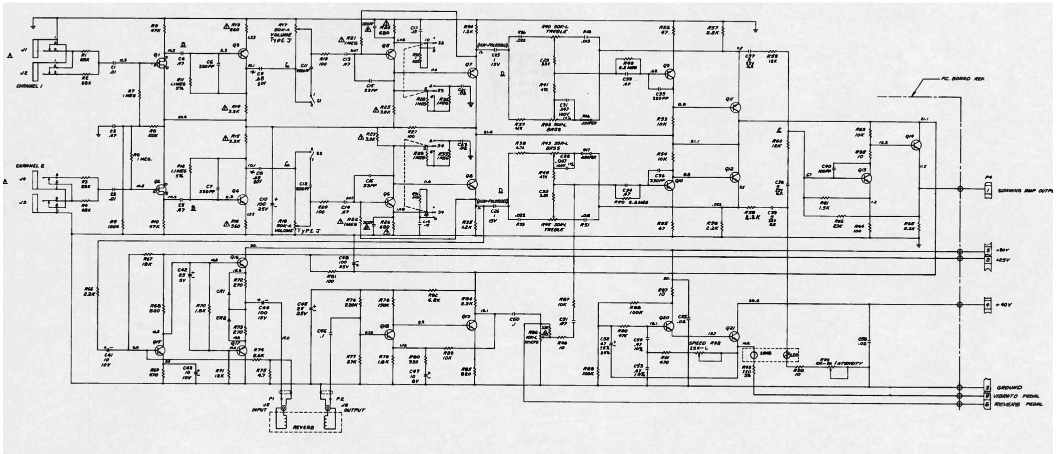
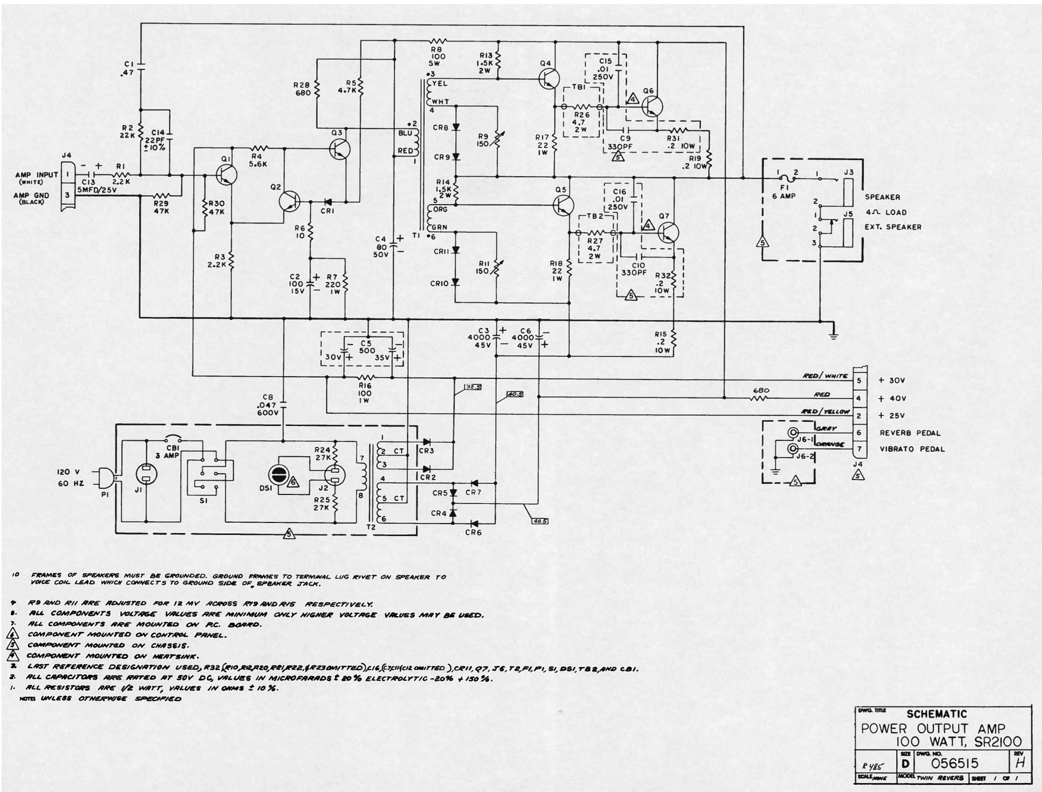
Part 2

Circuit design





5. Electronic circuit design analysis and measurements

5.0 Circuit diagrams and some general observations

The Fender customer-support department showed exemplary commitment in finding circuit diagrams for the Solid-State Twin Reverb (abbreviated in the following with ***SS TR***) - this is much appreciated. Unfortunately, the resolution of some of the scans (or the quality of the original diagrams) is not very high so it is difficult to make out some of the details and component values. Nevertheless the overall structure is clear. The diagrams we received are found in the appendix. Excerpts are shown with the corresp. sections as they are discussed.

On the printed circuit board, there are some spaces for components left empty. Possibly they were reserved for other versions of the SS amplifiers, since the same circuit board was used for the SS Pro Reverb, SS Super Reverb, and the SS Twin Reverb, with only the SS Twin-Reverb having a "Style Control" in both Channels.

We have not verified in detail whether every component and every connection in our SS TR was a match to the available circuit diagrams. It is in any case highly likely that there were several closely related but not identical versions of this series of the Fender solid-state amplifiers - as was always the case for Fender tube amps, as well. Any differences between the versions will be, however, so small that the discussions and conclusions elaborated below hold in general for all the amps of the series.

5.1 Preamp (1st & 2nd stage, volume control & "Bright"-switch) in both channels

The first thing the signal from the guitar signal "sees" entering the amplifier is very familiar: the passive circuit with inputs "1" (high sensitivity & impedance) and "2" (lower sensitivity & impedance), 2 decoupling resistors of 68 kΩ each, and 1 MΩ to AC-ground (**Fig. 10**, left-hand section). There is an additional coupling capacitor that most tube amps would not have, but the resulting high-pass has a cutoff frequency of 15 Hz – low enough not to be of consequence for a guitar signal.

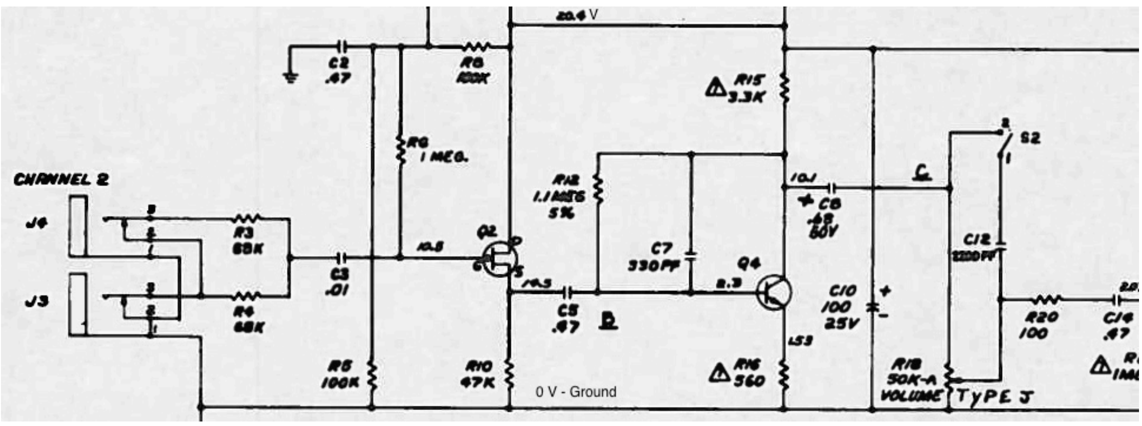


Fig. 10: Left to right Input circuit, FET impedance converter, first gain stage and "Volume"-control with "Bright" switch

The first active component in the SS TR is a most pleasant surprise: a field effect transistor (FET, **Fig. 10**, center) performs an impedance conversion. Its presence indicates that the engineers at Fender – even under CBS reign – knew well what an electric guitar with magnetic pickups requires. To retain its character and signal quality, the magnetic pickup needs to see a high impedance /5/ – which is just what the FET delivers. With it, the input impedance of the amp is determined mainly by the resistor connected between the input-line and ground. This resistor amounts to 1 MΩ – exactly what the Fender tube amps had at their inputs. We have measured an input impedance of 800 kΩ ... close enough. So: "*Well done, design team!*" - this is better than what many other transistor amps of the era featured ... low impedance inputs were unfortunately designed into transistor amps all too often. It should also be noted that at the time when the Fender solid-state series was designed, FET were a brand-new development. To include such a true state-of-the-art component is quite a remarkable feat for a guitar amplifier company. This kind of approach was a positive aspect of the fact that CBS brought in new engineers (some of them with experience in aerospace development, /3/) to build up an R&D-team. Incidentally, some (non linear) characteristics of FET's are much more tube-like than the corresponding characteristics in bipolar transistors. Whether this aspect was known or played any role when the amp was designed is unknown.

The FET does not provide any gain, its sole purpose is the high impedance at the amplifier input. A side effect of this is that the FET will not be easily overdriven and any transient phenomena due to re-charging of the input capacitor will be minimal – a very clean input stage indeed.

The second stage (**Fig. 10,**, center right) consists of a bi-polar transistor and has considerable gain. It feeds the Volume control located quite early in the overall circuit. This approach can create some noise issues (and indeed the amp is relatively noisy) but performs very well in keeping distortion low. Because the volume control influences all drive levels of the subsequent stages, any uncontrollable overdrive can only happen in the first gain stage - and here only with very strong pickups.

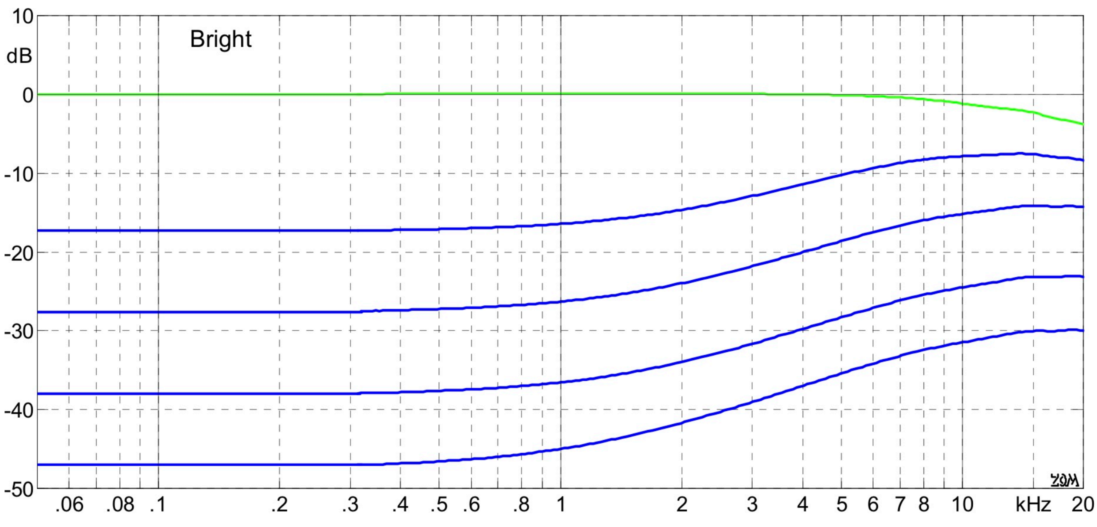


Fig. 11: Frequency responses generated by activated the "Bright"-switch in various positions of the volume control. The higher the volume is set, the less effective the "Bright"-function becomes - just like in all Fender tube-amps. Actual measurement of the overall frequency response of the amp from input to output (16 Ω load).

The volume control (**Fig. 10**, left-hand section) can be bridged by the "Bright" capacitor via the "Bright Switch" - this circuit corresponds exactly to the one used in Fender tube amps - it is merely mapped to the lower impedance levels in the SS TR. As is the case in Fender tube amps, the effect of this "Bright Switch" is very strong at low volume settings but decreases as the volume is turned up and vanishes at full volume (**Fig. 11**).

The electronics where low signal levels are processed have an extra shield to reduce interference (see Fig. 7 on the right-hand side of the preamp module).

5.2 Intermediate amps (including Style Switch) in both channels

The next transistor stage provides more gain, and also drives the "Style Switch" that author TZ admired so much (at least on paper) back in the day. It is noteworthy that never before or after did Fender amplifiers include such a mysterious and seemingly cool (but also disappointing - see below) feature.

"Style" is an important issue in music. If an amplifier offers a choice of "styles", we can assume it will adapt its sound to the specific needs of a musician playing in the given style. Of course, what is attributed to a "style" sound-wise will depend much on the background, experience and resulting expectations of any given user. Today, we would probably expect either a soft sound, or a bright, clear but not very aggressive sound for "Pop", a raunchy, distorted sound for "Rock'n'Roll" and a bright, cutting sound for "Country". These are quite different sounds that require different linear and non-linear processing - i.e. in terms of circuitry, we would surmise that "style" is serious business with quite a bit of change in the character of the amplification.

As the first in the line of its control elements in each channel, the SS TR prominently offers a "Style"-switch, offering three positions: "Pop", "Normal" and "CW/RR". From a modern perspective, this labeling triggers three thoughts immediately:
- a) what on earth might "Normal" indicate? What is a "Normal" style? Would any musician want to be labeled "Normal"? Would we always seek to be special rather than normal?
- b) why is Country and Rock'n'Roll given one and the same setting? Aren't these REALLY different styles? Well ... today they are – but back in the day, maybe both were just "bright"?
- c) what about other styles? If there is "Pop" and "CW", shouldn't "Jazz" be somehow also be in there? Could "Normal" indicate "Jazz"? No, that can't be ... when was Jazz ever "normal"?

The 1968 and 69 Fender catalogs /9/ /10/ relate in the section "special amplifier features" that the style switch regulates the middle register ... in any case, we are left a bit puzzled by this style switch, and we better take a look at the associated schematics (and – later – listen, as well).

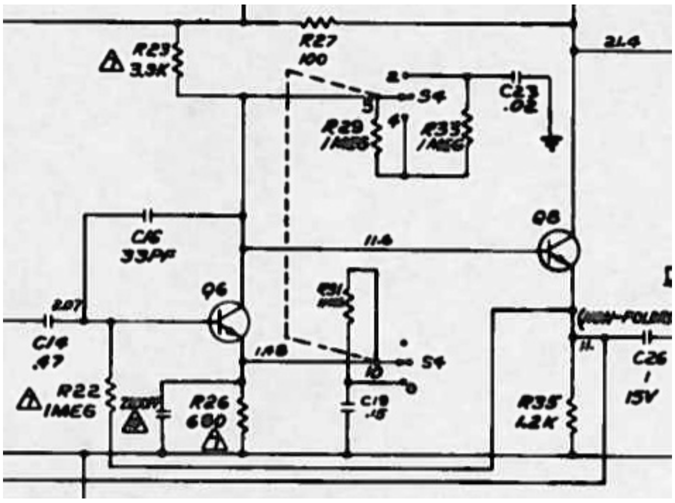


Fig. 12: Second gain stage (right) with "Style-Switch" (center) and common-collector-driver for the next stage (right)

It turns out that, circuit-wise (**Fig. 12**), the style switch is merely a linear filter of the simplest sort. The switch interacts with the preceding transistor and makes a connection of either the collector or the emitter with a respective capacitor (to ground). This has the effect of a treble cut for the former connection ("Pop") or a treble boost for the latter ("CW/RR"). In a middle position, neither capacitor is connected i.e. the transmission characteristic for "Normal" is flat. There are some resistors in the circuit, as well, but these only have the job to avoid any build up of DC in the capacitors and to suppress any "popping" that could appear when the switch position is changed.

Fig. 13 shows the measured frequency responses for the three switch positions.

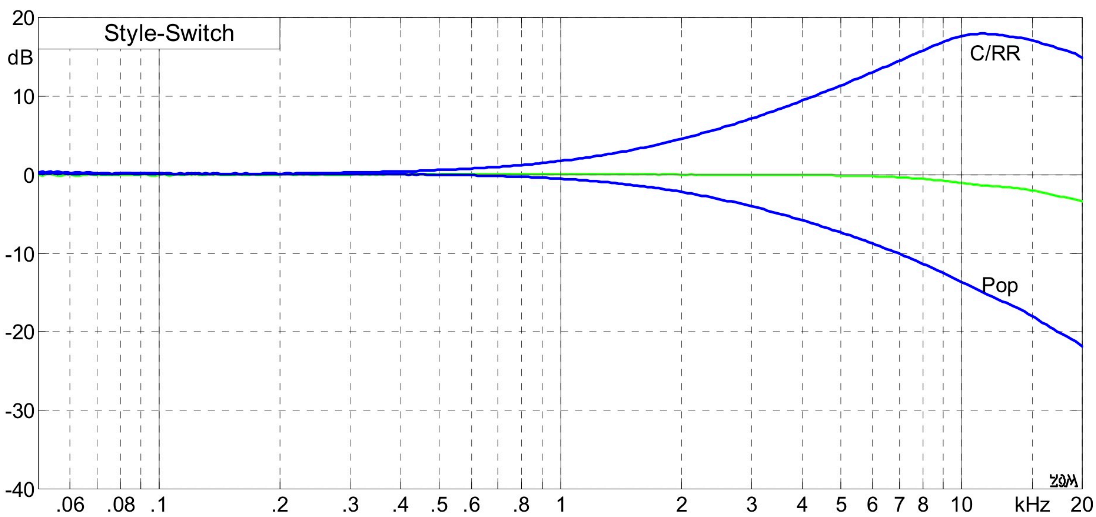


Fig. 13: Effect of the 3 settings of the "Style"-switch on the frequency response. "Normal" corresponds to the green line i.e. no effect. Actual measurement of the overall frequency response of the amp from input to output (16 Ω load).

Therefore, the "Style"-Switch is a bit of a let-down ... and as we will hear, the respective differences in sound match our disappointment. They are useful, but the labels "Pop" and "CW/RR" raised the expectations too high – and the explanation in the 1968 and 1969 Fender catalogs is simply wrong: it's a treble-filter, not one for middle.

5.3 Tone control stages in both channels (with a little bit of history thrown in)

The "Style"-switch was a Fender "first" (and "last", since it disappeared with this series of solid-state amps), indicating that Fender really tried to do something different with these amps. This approach fully continues with the tone-control stage. That the bass- and treble-controls are labeled "cut", "flat" and "boost" is a first indicator – but let's branch out a bit and look at traditional Fender – and other – tone controls first.

During the 1950's, Fender experimented a lot with tone controls. The (tube) amps progressed from a single "Tone" control offering merely cutting (and sometimes also boosting to some extent) the treble range via separate bass and treble controls to the classic tone-stack appearing for the first time in the 1958 Bassman amp. This circuit was so successful that all subsequent Fender tube amps based their tone control circuits on it. The interesting aspect of the "tone stack" (as e.g. found on the classic tube Twin Reverb) is that it does not allow for cutting either bass or treble frequencies relative to the middle frequency region, see e.g. **/6/**. Even set at "0", the bass- and treble-ranges are not attenuated but merely left at the minimum overall attenuation that the circuit inherently has depending on the setting of the "Middle" control. Turning up "Bass" or "Treble" will emphasize the respective frequency range – i.e. even setting "Bass" or "Treble" to low values such as "3" will already emphasize bass and treble relative to the middle frequencies. The tone-stack will thus generate a notch at the middle frequencies as soon as bass and treble are turned up. The depth of the notch depends on the setting of the "Middle"-control. The latter can however never actually emphasize the middle frequency range but only cut it; it thus has its impact "the other way round" compared to the bass and treble controls.

The tone stack works so well for electric guitars because it never generates a "thin" or "nasal" sound but always leaves a healthy dose of bass and treble while enabling the guitarist to tune out some "muddy" midrange via the Middle control if necessary. It is difficult to really dial-in a bad sound with the tone-stack - typically once you plug in, you have a decent sound irrespective of the settings and can optimize it further with the controls. No wonder Fender kept this circuit once it was discovered, and no wonder that almost all amplifiers anywhere have a version of this tone stack at the heart of their tone control circuitry. It is a great match for electric guitar and gives - with its "automatic" helpful coloring of the guitar sound – immediate gratification with tendency to always cut through the auditory "clutter" that often occurs in situations of people playing together.

In HiFi-audio, on the other hand, the Fender tone-stack was never even considered – exactly for the same reason: it colors the sound! For guitar, where the amp is part of the musical instrument producing the sound, you want that, but in HiFi, where you want **re-**produce recorded sound neutrally, this is death. In HiFi, you want to start with an unaffected sound and possible modify that to compensate for deficiencies in the loudspeakers or in the listening environment. Therefore, in this area, a different kind of tone control has been universally adopted: the so-called Baxandall-circuit named after Peter Baxandall who designed and published it in 1952.

This circuit has an overall attenuation that creates a flat frequency response with the bass and treble controls set midway to "5". As bass and treble are turned up or down the respective frequency range is actually cut or boosted relative to the middle frequency. The overall attenuation is typically compensated so that at "zero"-position of bass- and treble-controls, all frequencies can pass unaffected in the same way without any coloring of the sound. As "Bass" and "Treble" are turned up, a broad "notch" appears for the middle of the spectrum, and as they are turned down, the middle prominently remains in effect creating a mid-boost.

The one amplifier company that worked with the Baxandall circuit almost from the get-go and never really deviated from it (at least during their "classic" years) was the Ampeg company. The original goal of founder Everett Hull was to amplify the acoustic bass without changing the tonal character. He therefore was happy to have the "neutral" Baxandall circuit and included it in the legendary Ampeg B-15 amp and all its derivatives. It also found its way into the classic Ampeg guitar amps reaching their glorious peak in the Amped SVT and V4 (again with all their derivatives). In the latter amps, the Baxandall circuit was complemented by an active midrange control allowing for boost and cut at 3 selectable frequencies, and by high- and low-frequency boost-switches. Anybody not convinced that this tone control worked extremely well only needs to listen to the Rolling Stones' 1970 "Get Yer Ya-Ya's Out" live recording. It does not get much better than the sound Mick Taylor achieves with the Ampegs.

But let's get back to our solid-state Fender. It would appear that the design team, looking for something different compared to the traditional Fender amp (and sound), and possibly having in mind to arrive at a more flexible amp, opted to use a tone control based on the Baxandall-circuit. The result is shown in **Fig. 14**: a modification on the bass-side of the network and the use of a feedback path from the next two transistors (the first providing gain and the second being a common-collector-type-buffer) instead of ground as the reference. This is really quite elaborate, modern design work again emphasizing that the engineers working on the solid-state amps at Fender were no slouches.

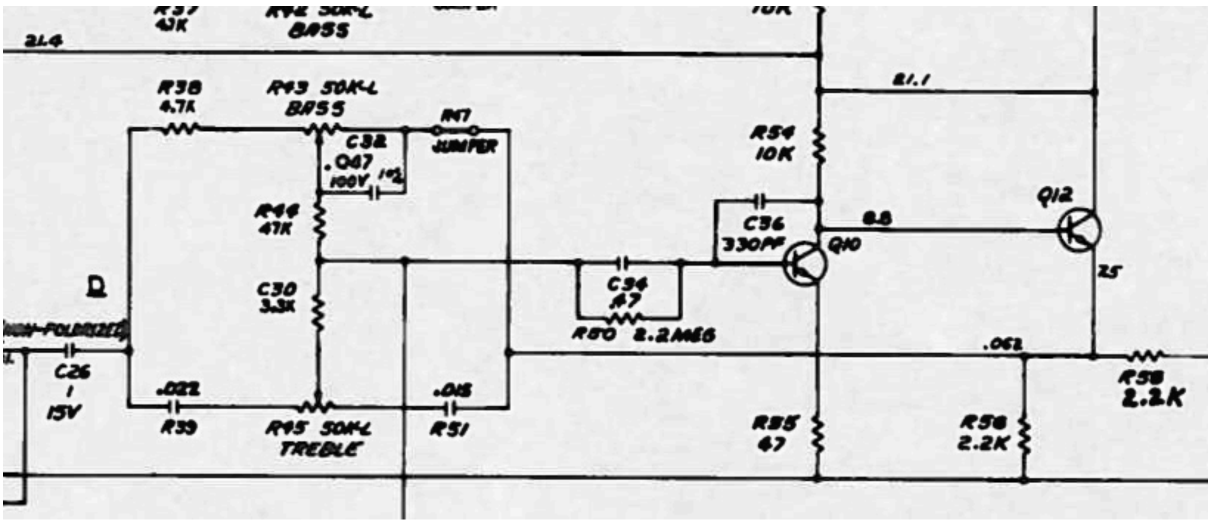


Fig. 14: Tone control network: a variation on the well-known Baxandall-circuit

In terms of frequency response (**Fig. 15**), this is an interesting circuit: turning up both bass- and treble-controls yields a frequency response not entirely unlike that of the typical tone-stack. Turning down both control gives a new response with both an actual bass- and treble-cut not possible with a traditional tone-stack. With both controls in the center, we get a rather flat frequency response.

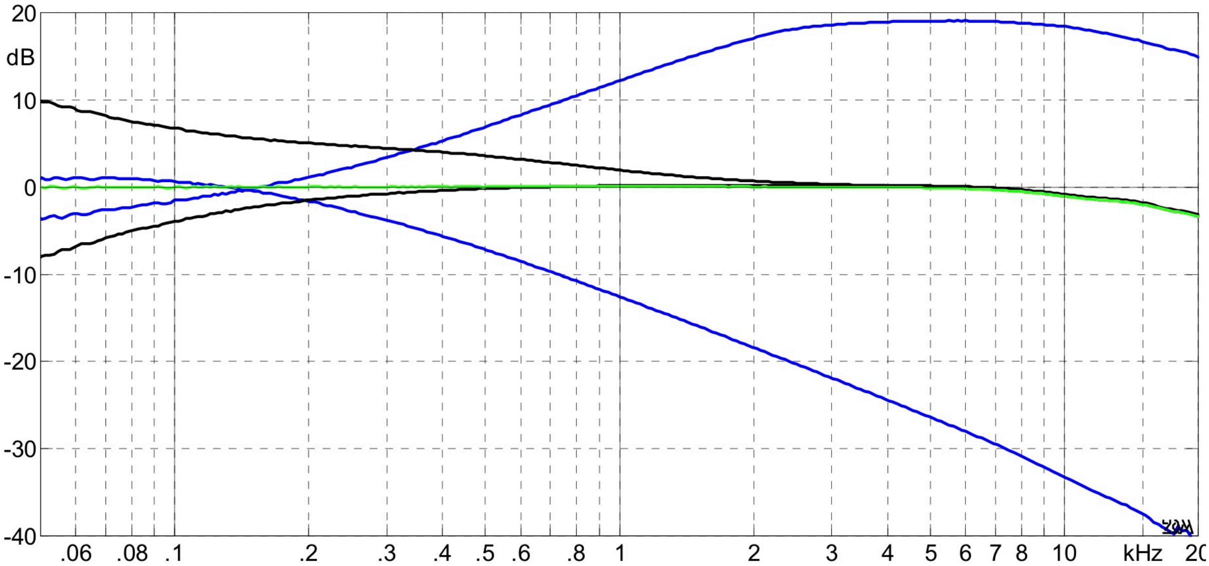


Fig. 15: Frequency responses achievable with the SS TR tone circuit. Blue: treble-control at max. and min. with bass-control set to "flat"; black: bass-control at max. and min. with treble-control set to "flat"; green: both controls set to "flat". Actual measurement of the overall frequency response of the amp from input to output (16 Ω load).

The treble-control is highly effective, working across an extended frequency band from 300 Hz upwards and maxing out at boost and cut levels of about 20 dB from 2 kHz (the cut range extends even further at higher frequencies). The bass-control, on the other hand, is a bit lackluster with less than 10 dB boost and cut at very low frequencies (and even less at guitar-relevant frequencies of above 80 Hz). However, bringing in the frequency responses of the Style-control and the Bright-switch (both of which operate at higher frequencies upward of about 2 kHz, overall frequency responses are possible with this amp (especially in the treble range) that would indeed put the old tone-stack to shame. Whether these are frequency responses that are actually desirable for the guitarist is an entirely different matter.

5.4 Mixer-stage for both channels

The mixer stage (**Fig. 16**) is nothing special unless multiple common-collector drivers are counted: each channel has one of them, driving a passive mixer with two 12-kΩ-resistors summing the signals from the two channels, and feed the resulting signal to yet another gain-stage-into-common-collector-driver circuit. The latter provides the output of the preamplifier module.

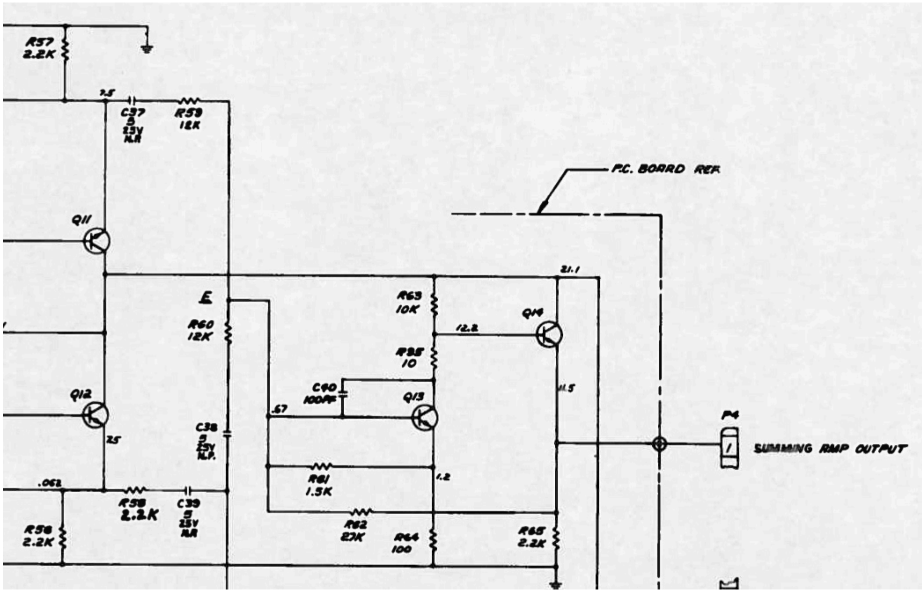


Fig. 16: Mixer stage and preamp-output amplifier. Note multiple common-collector drivers.

5.5 Reverb circuit ("Vibrato" channel)

There is not much to report regarding the reverb circuit (**Fig. 17a**). A gain stage is followed by a small push-pull power amp that drives the reverb spring, the latter hopefully having a well matched to a low-impedance input (we did not measure this). A two-stage recovery-amp (**Fig. 17b**) takes care of giving the reverb signal the necessary levels. If anything, the following is noteworthy:

- the push-pull stage of the reverb driver includes THE ONE PNP-transistor in the whole amplifier - all other transistors are of the NPN-kind.
- the reverb input signal is taken from ahead of the tone-control signal (the line branching off ahead of C26; left-hand side of Fig. 12), and the return signal is fed to the circuit after the tone control (the line joining resistors R44 and C30 in Fig. 12), i.e. the reverb is - for better or worse – not subject to the tone controls.
- at least in our SS TR, the reverb is overly strong – it is difficult to set the control to obtain a reverb level that could be called sensible in most musical settings. The reverb signal also seems somehow overdriven. We were tempted to modify the amp accordingly but opted not to do so because we did not want to alter such a historic piece, after all.

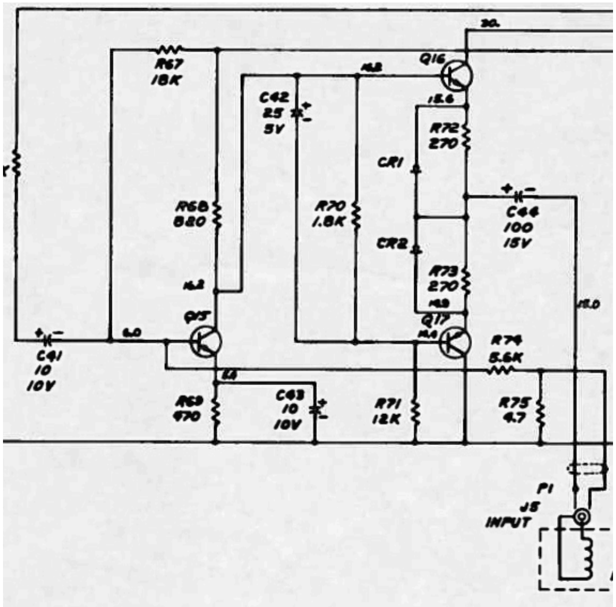


Fig. 17a: Reverb driver circuit. Note the one PNP-transistor in the whole amp!

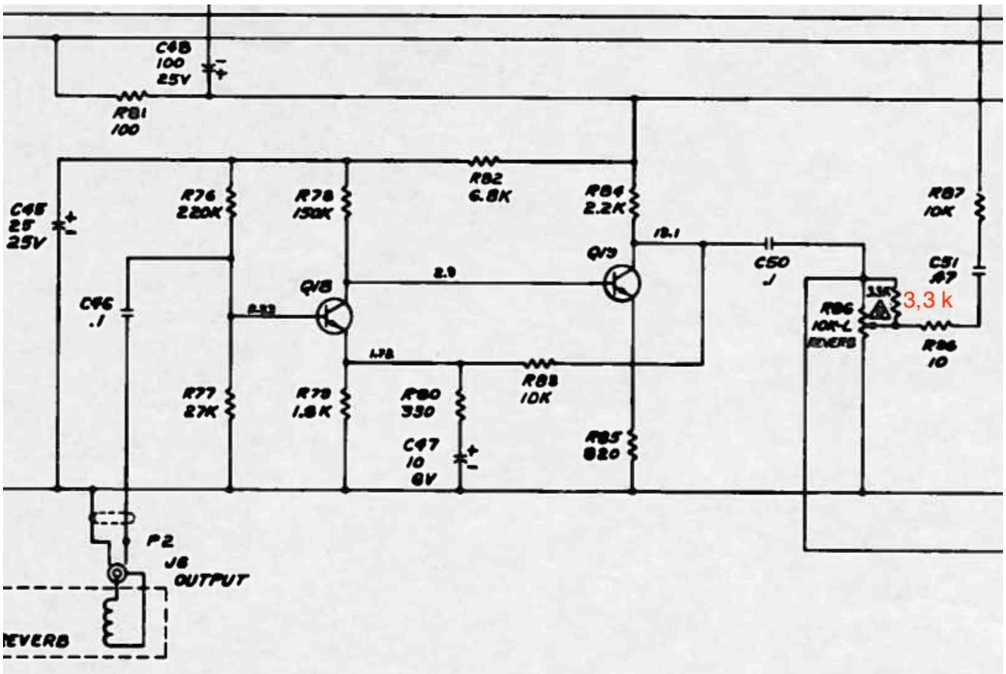


Fig. 17b: Reverb recovery circuit. Possibly, the 3,3-kΩ-resistor at the reverb control is the culprit that makes the reverb difficult to control. Incidentally, this is one of the few components soldered in by hand on the reverse side of the circuit board ...

5.6 Tremolo circuit ("Vibrato" channel)

Again, there is not anything very special about the tremolo circuitry. It is structurally very similar to the corresponding circuits in the Fender tube amps. A transistor with a phase-shifting-feedback-network acts as low-frequency-oscillator (LFO), and a second transistor as a buffer driving a lamp that interacts with an LDR. The latter loads the line going from the "Vibrato"-channel into the mixer circuit and imprints a corresponding rhythmic attenuation as the LFO rhythmically drives the lamp (**Fig 18**). The one noteworthy difference to the tube amps with LDR-tremolo is that the solid-state series employs an Edison-type lamp with filament, while the tube amps work with a glow-discharge lamp. The latter has a much faster reaction time that (depending on the overall circuit) may result in a much "harder" tremolo effect.

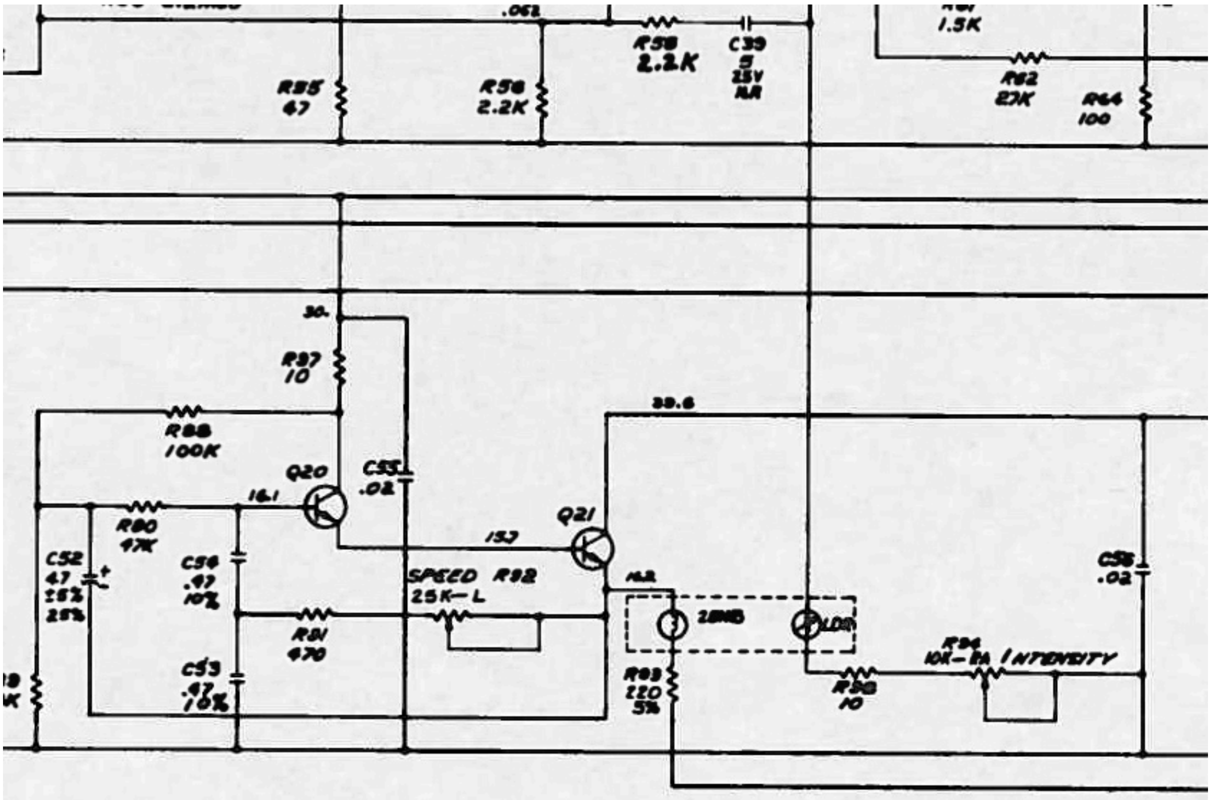


Fig. 18: Tremolo circuit: transistor Q20 is the heart of an LFO driving a lamp via buffer Q21. The LDR imprints the pulsation of the lamp onto the mixer line at C39.

Indeed, the tremolo-effect (often called "vibrato" in Fender lingo) in our solid-state Fender is not very deep but rather soft – quite pleasant and musically useful but different from the tube amps. This difference is in fact mentioned in the 1968 Fender catalog /9/, and the opto-coupler can easily be identified as a reason.

5.7 Power supply

Moving now over to the power-module, there is not much to relate about the power supply (**Fig. 19**), either. It is a typical unregulated bipolar power supply generating +40 V and -40V for supplying the power amplifier and taking the (lower) supply voltage (30 V) for the preamp electronics from a separate transformer winding, avoiding complicated or lossy electronic regulation.

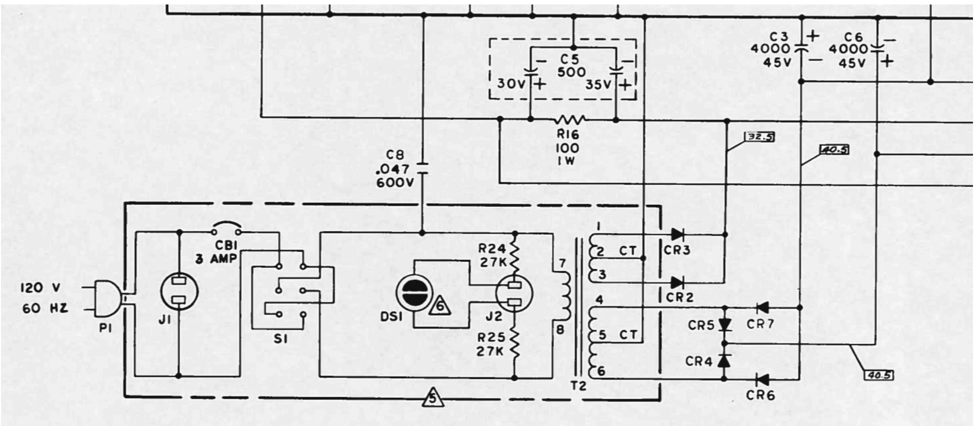


Fig. 19: Power Supply. Note separate transformer windings for the supply voltages for preamp and power-amp.

5.8 Power amplifier

The power amp design is interesting in that it does hold a transformer – albeit not a large, heavy output transformer as we find it in a tube amp, but a small transformer that aids the signal processing for the push-pull circuit (**Fig. 20**) i.e. works as phase splitter. The input signal to the power amp is fed to a 3-transistor gain-stage that drives this small transformer. The outputs of the transformer are counter-wound i.e. they provide perfect out-of-phase signals to the two identical branches of the push-pull output stage. Such designs with phase-splitter transformers were not uncommon in early transistor-amp design - for example, the power amps of the Leslie 760 used this approach. It made using exclusively NPN-power transistors possible.

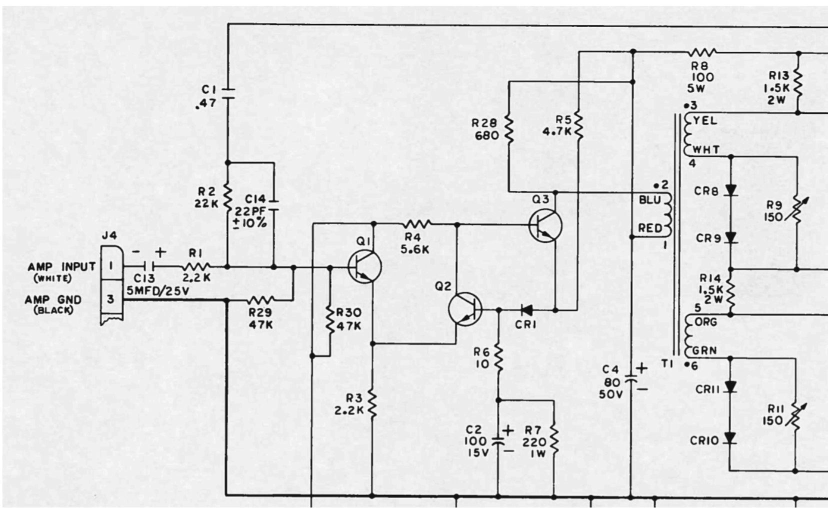


Fig. 20: Input section of the power amp up to the phase-splitter (transformer)

Two further driver-transistors feed their signal, at last, to the output section (**Fig. 21**).

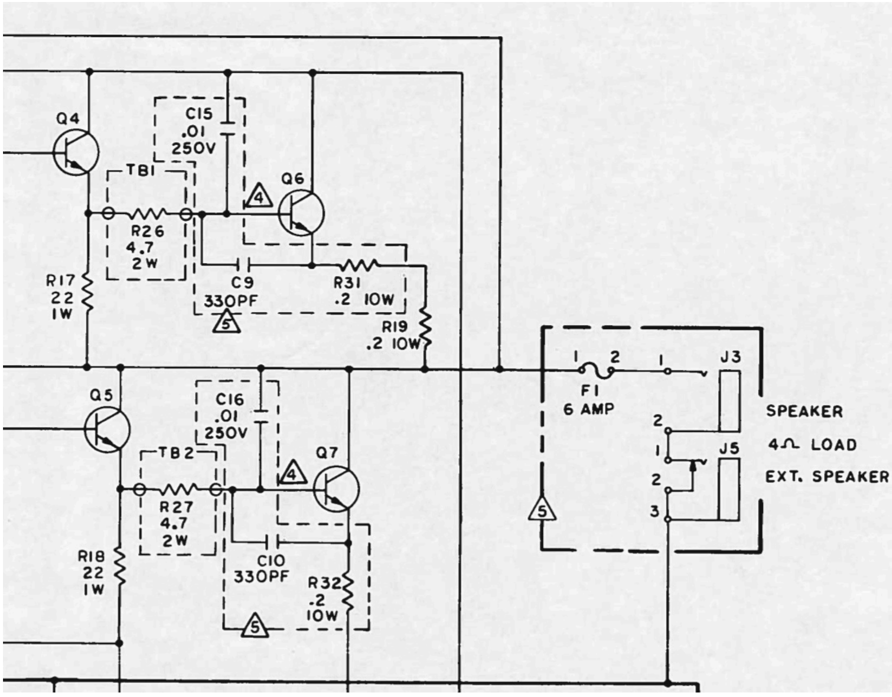


Fig. 21: Output stage. Note lack of electronic short-circuit-protection, fuse ... and no more than 2 power transistors.

While so far the circuits we investigated in the SS TR could be assessed as well designed (input stage), pretentious but o.k. ("Style"-switch circuit), uncommon but effective (Baxandall-type tone-controls) and reasonably-well-working (tremolo and reverb sections), but now, in the final (power-amp) stage (sic!), it gets absolutely dicey (**Fig. 21**). To use a mere two power transistors in a musical instrument amplifier rated at 100 Watts is pushing every limit – and working with convection cooling only (i.e. no forced cooling by a fan) and a relatively small heat sink only adds insult to injury. Fender did believe in the way they designed the cooling of the heat sink, though: they even obtained a patent /8/ for it, reasoning that the ventilation they came up with (using the slits in the angled front panel) worked more reliably than conventional arrangements. That may indeed be correct in a way - but it's still only two transistors on a small heat sink! Experience has shown that at least 4 power transistors on a generous heat sink would be advisable to have the job done with conviction. While consequently already the first look at the power-amp raises a lot of eyebrows, further investigation shows that there is – gasp! – no electronic short-circuit protection ...

Given the rather high likelihood that an amplifier subjected to often abrasive handling on the road will sooner or later experience a shorted output (due to a damaged speaker connection or a blown speaker, or simply due to irresponsible treatment by the operator/guitarist), short circuit protection is a must for transistor amps.

Tube amps are rather tolerant animals that dislike an open output (if anything at all), but transistor amps – dealing well with an open output-circuit – hate shorts in the output; without protection, not only will the output transistors die a quick death but they are – due to the DC-coupling in the output stage – very likely to pull all other connected transistors (and possibly further components such as a pair of precious JBL D120-F's, in case you had ordered them with the amp as an option at considerable extra charge) into the darkness with them. The need for massive, costly repairs is immediate.

Checking the circuit diagram of the output stage SS TR, you could point to the fuse between output transistors and speaker jack. Indeed, this is meant to be the short circuit protection. The label on the amps says "6 A" for the fuse type. However, *if this works at all*, it makes for a very cumbersome operation in the case of a short at the output because the user will have to carry spare fuses and may go through quite a number of them in no time just because of e.g. a faulty speaker cable. Running out of fuses will render the amp inoperative even if the speaker cable is eventually repaired. Also, you have to have the right kind of fuse at hand: fuses rated at a smaller blow-current will die too early, fuses of a higher blow-value will not do any protection.

Incidentally, the 1968 Fender catalog mentions a re-settable protector (circuit breaker) but shows the regular fuse in the picture of the back of the amp. The 1969 Fender catalog actually show that it in later versions of the solid-state amp series, this protector replaced the regular fuse. The protector would sense the current and disconnect the output if the current was too strong. This indicates that the fuse-protection was an issue one way or another, and including the protector was a step in the right direction, if purely from a handling point of view: the user did not need to carry extra fuses. However, there is another problem here – indeed the above formulation "*if this works at all*" is an intentional choice.

One of "Murphy's laws" says: "a crucial, expensive component protected by a fast-blowing fuse will protect the fuse by blowing first". Indeed, there is such a danger: transistor amplifiers without short-protection can die incredibly fast - possibly faster than the fuse will blow. Moreover, given the rather puny heat-sink and a mere single pair of output transistors, the range between what can be considered a healthy, strong output current in operation at full volume on one hand, and a dangerously high current resulting from a short on the other hand will be quite narrow. Considering the tolerances that fuses (and re-settable protectors) have both in terms of the current at which they die (or switch off), and considering their reaction time, it is not guaranteed that this kind of protection will actually work **at all**. In particular the latter aspect is the scary one. "Fast" fuses are specified to blow after 20 ms if ten times the specified current passes (i.e. in our case after 20 ms of a current of 60 A). Unfortunately, there are conditions where high-power transistors (like the workhorse 2N3055) can die after only 1 ms of a current of 4 A ....

By the way, the output transistors used in our SS TR seem not to be of the run-of-the-mill kind; apparently they are OEM products holding the label RCA 101568. If we had to replace these components, we wouldn't really know what to use. Probably high-power 2N3773's would do the trick (relatively) reliably. But even such really high-power transistors may not survive the kind of makeshift protection afforded by a fuse. Electronic protection would react fast enough and should have been implemented in the solid-state Fenders.

In all fairness, though, we should not keep silent about many other transistor amps (even second-generation ones like the Roland JC-120 and its spin-offs) that did not have any short-circuit protection at their output, either. So the lack of such circuitry is not uncommon (especially in combo amps where there is - in contrast to the SS TR – a fixed speaker connection) – but that does not make it forgivable. In particular a company such as Fender should have done better, having the reputation to build the sturdiest and most dependable amps around.

In contrast to Fender tube amps where the two output speakers are connected in parallel, the two output jacks (speaker and extension speaker) of the solid state amps are connected in series. Under the circumstances, this is a smart move for two reasons:
- first, with the two internal speakers connected in parallel to already give the nominal load impedance of 4 Ω, connecting the external speaker will not lower the impedance further (which would dramatically increase the risk of overloading/damaging the amp or, at least, blowing the output fuse) but increase it i.e. making operation safer; and
- second, if the cable to the external speaker is faulty in that it contains a short, there will be no overload to the amp – the external speaker will simply not work while the internal speakers still will.

This series-connection of the speakers has a downside, though: although the power-capacity on the speaker-side is increased by an external speaker, the power amp will (due to the higher load impedance) provide less power so in that sense the arrangement may be safe but kind of counterproductive.

About **power output**: we measured 80 W (RMS) at the nominal load of 4 Ω (i.e. not bad for the 105 W catalog specification), 60 W at 8 Ω and 40 W at 16 Ω.

In section 4 above, we mentioned the **low degree of serviceability** (at least compared to Fender tube amps). It is very likely that the designers of the solid-state Fenders would have countered with the following reasoning: transistors amps, with a practically endless lifespan of the main components and the much longer lifespan of electrolytic capacitors (due to the much lower operating temperatures) will need considerably less service than a tube amp, or none at all. This argument would, however, only holds if the basic design of the transistor amp is solid. Which in the present case it is not really.

6. A second assessment: circuit design

Our analysis of the circuit reveals
- a well designed input stage,
- an o.k. preamp-design with an effective but unfamiliar tone control section that needs getting used to,
- an overly hot reverb section,
- a power amp output stage that is – with a mere two power transistors on a puny convection-cooled heat-sink – way undersized for an output of 100 Watts, and on top of this badly protected against a short circuit at the output.

It is the latter aspect that **fails to establish any trust** in the dependability of the amplifier at all. In fact, even if this amp would be the greatest sounding amp in the world, one would be ill advised to take it on the road. It is a wonder (or mere luck) that our SS TR has survived apparently without the need for repairs. We would think that not many of these amps were as fortunate.

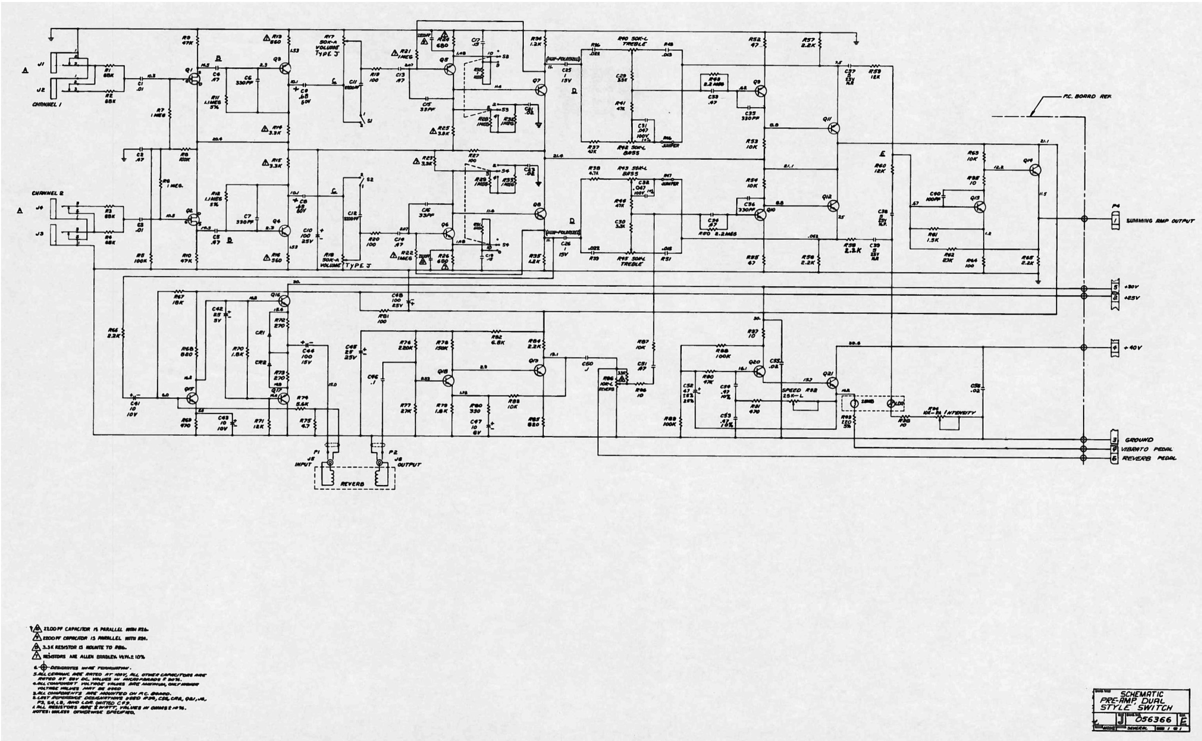
This output section alone is almost a death sentence for the amp ...

To be continued; in the third part of this article, we will – at long last – plug in and play and listen to the amp.

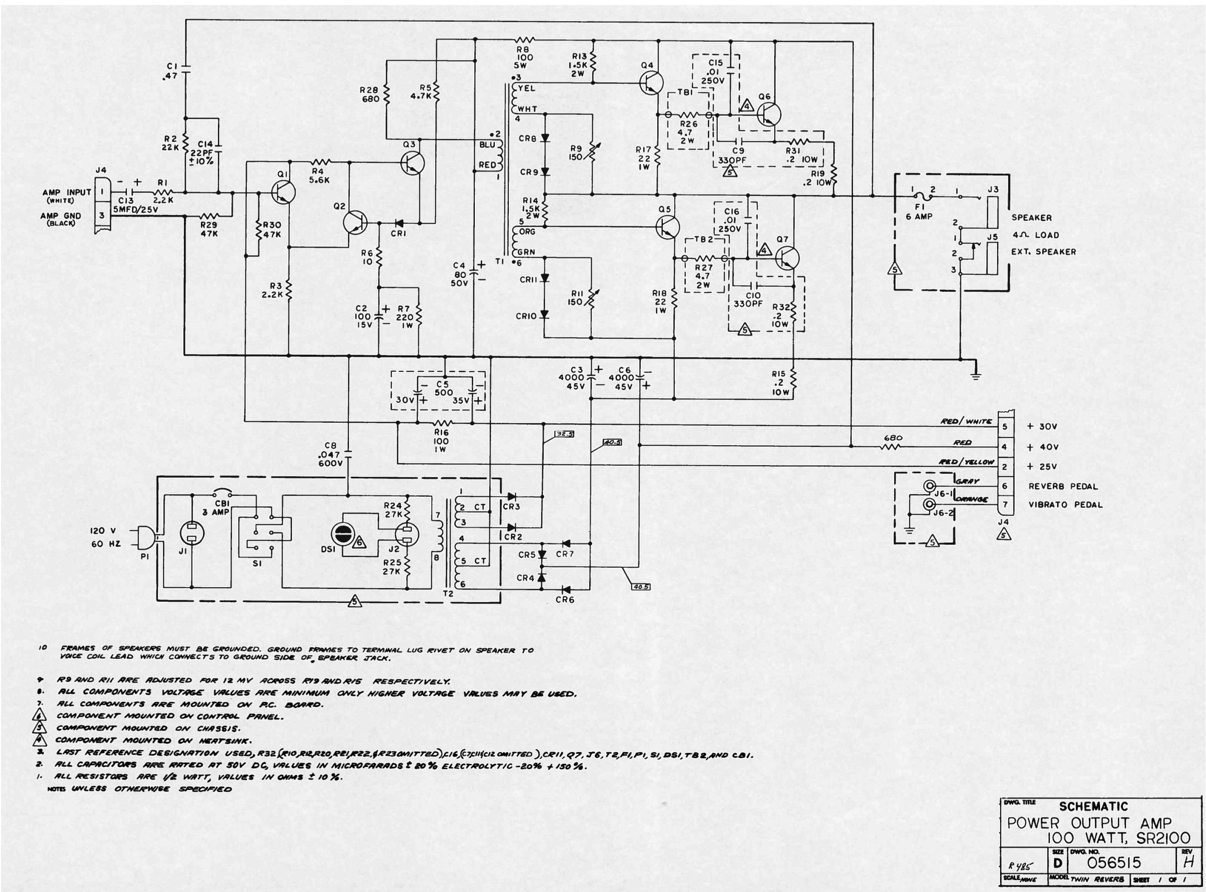
Appendix 1: Literature:

- /1/ Fender Amps - The first fifty years; John Teagle and John Sprung, Hal Leonard, 1995
- /2/ The Fender Amp Book; John Morrish, Balafon, 1995
- /3/ The Soul of Tone; Tom Wheeler, Hal Leonard, 2007
- /4/ Fender - The inside Story; Forrest White, Miller Freeman, 1994
- /5/ Electric Guitar - Sound Secrets and Technology, Helmut Lemme, Elektor, 2012
- /6/ Physik der Elektrogitarre Manfred Zollner, https://gitec-forum.de/wp/gitec-community/buch/; Translation: Physics of the Electric Guitar: https://gitec-forum.de/wp/en/gitec-community/the-book/
- /7/ Jim Marshall - The Father of Loud, Rich Maloof, United Entertainment Media, 2004
- /8/ Solid State Amplifier, and Control Panel Assembly incorporated therein, Paul Spranger (Inventor), Patent US-A-3 462 553A, 1969
- /9/ Fender Musical Instruments ... ON THE GO!, 1968 Catalog, Fender, 1967
- /10/ Fender lovin' care, 1969 Catalog, Fender, 1968

Appendix 2: complete circuit diagrams



2-Channel Preamplifier w/Reverb- & Tremolo-Circuits



Power supply and power amplifier