Bias: Just how accurate does one need to be for a Scott Tube amp?

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Revision history

Date	Who	What
8/17/2003	Daev	Creation

Synopsis:

Some theoretical and practical research into bias setting techniques against the effects on measured specifications and sound quality.

Predicates:

1) The Scott bias circuits are fairly soft (high impedance) and have no regulation. This makes them rather poor current sources, at least by modern standards. This can be observed by the rather high degree of interaction between the channels while adjusting the bias; a hard current source wouldn't interact like this.

2) In 1955, the typical service VOM was not very accurate at sub 1 volt levels, nor at sub 10 ohm levels.

3) In 1955, the typical service VOM presented a fairly low resistance load, thereby affecting the measurement accuracy.

4) In 1955, it was more practical (read cheaper) to make a high accuracy mA meter than it was to make a high accuracy VTVM for sub 1 volt level and sub 10 ohm measurements.

The theory

Points to address include:

1) Measuring techniques
2) Tolerances
3) Impact to THD and power

1) The Scott engineers likely decided that measuring current **using commonly available tools of the day** was more likely to yield a correct bias setting than measuring low ohm values and millivolts.

2) Observe this was 1955, however, and state of the art has marched on since then. A bit anyway... Today, a "typical" DMM will yield a more accurate setting via ohms law than it will measuring current via the Scott method. Likewise, the typically available single range mA meter is inferior at measuring current via the Scott method. (Where typical translates into "cheap and available at Radio Shacks everywhere.) This discrepancy is due to the relatively high internal shunt resistance used in today's millimeters.

Test Cautions:

1) I've only completely tested one Scott LK-48B. I assume these results will apply to all 7189 based amps, but this should be confirmed on a few other samples.
2) Theory suggests these results also apply to 7591 based amps, but this should (and will be) validated as a separate experiment as well.

Test equipment:

2 TEK 254 DMM, 4.5 digits, true RMS
Rated at ± .3% + 2 digits on the 400 mV range. The resolution is 100 uV on the 400 mV range, and 1 mV on the 4 volt range. Input impedance is 10 megohms.
DMM one has a 1.7 ohm internal resistance on the 400 mA range
DMM two has a 2.0 ohm internal resistance on the 400 mA range

1 Kelvin Pro 400 3.5 digit DMM, a cheapie - Used to monitor bias supply voltage

1 Cen-Tech P35761, 3.5 digit DMM, a cheapie - Used to monitor B+ supply voltage

1 Calrad cheapie 0-200 mA meter, rated at 2% accuracy. Has an internal resistance of .2 ohms. However, it only has marks every 5 mA, and no mirrored scale. That implies about a 2.5 mA error in reading and a 4 mA error in accuracy for a possible total error of 6.5 mA

1 Radio Shack Micronta VOM. part #22-204C 25K/ohm per volt
Internal resistance of 5.6 ohms on the 50 Ma range

1 Audio Precision One lab tester, Dual domain. Including test jigs and cabling, actual testing baselines are:
Frequency Response: 10-30kHz, -.1+.02dB
THD: <.002%, 10-30Khz
Noise floor: -115dB, 10-30Khz

2 200 watt dummy loads - Non-inductive loads, trimmed to 8 ohms resistance (cold)

1 TEK 2465A Scope, 4 trace 350 mHz

1 Variac General Radio W10MT3 - 0-140VAC, 10 amp

1 Custom built AC monitor box w meters, fusing, and a DPST AVC isolation switch

Scott LK-48-B, SN 1004768, 6U8A splitters

Test setup:

The LK-48-B plugged into monitor box and variac. 6U8A splitters pulled, volume at 0. (It is verified and expected that volume setting has no effect on bias current under a no signal case.)
8 ohm dummy loads (Author note: Scott spec actually calls for 16 ohm loads, need to validate that this indeed has no effect on bias)
Cathode resistors are 9.7 (L) and 9.9 (R), measured cold. Pair of DMMs set to measure 400 mV full range across the resistors. Ohms law tells me I should adjust to .426 (R) and .435(L) to get a 44 mA bias point. I do this at precisely 120VAC.

Test Group A: bias interactions and measuring errors

Experiment 1: AC line voltage vs various voltages and effect on bias current

After setting the bias point correctly at 120 VAC, I varied the voltage from 105 to 125 VAC. (the range from the Service note)
Results are:

Line	Power supplies				BIAS		BIAS		BIAS
			(1)		Bias R drop		Cathode current		
(VAC)	(VDC) B+	(-V)		(mV)		(mA)		(-V)	
105	370		44.2		366/365		37 mA		16.12/17.15
110	387		46.5		382/384		39 mA		17.16/18.21
115	407		48.9		404/408		41 mA		18.08/19.21
120	426		51.8		430/440		43 mA		19.10/20.26
125	439		53.0		443/453		45 mA		19.91/21.14

(1) Bias supply at first filter cap, just after the bias supply dropping resistor
(2) Voltage across the cathode resistors which are 9.7 and 9.9 ohms cold
(3) 7189 Grid (pin 2) voltage

A) The bias current varies by an 8 mA range or close to a 20% variation! This suggests setting the bias 5-10% low would ensure high line conditions don't stress the outputs.

B) Observe that 120 VAC to 115 VAC (a mere 5 VAC line drop) causes a 4.5% bias change.

Experiment 2: How accurate are milliammeters for setting bias?

(In response to Craig's email about doing the shunt measurements)

Assertion: The only meter type that can be used for Scotts instructions (i.e. shunting the cathode resistor) is one that has less than about .2 ohms of internal resistance. These are typically a single range unit, and it must also have an intrinsic accuracy of 1% or better. Using any other kind of meter will measure as an erroneously low value, causing a dangerous over current condition in the outputs.

I tried three meters here:

1) Radio Shack Micronta VOM, PN #22-204C
25K/ohm per volt; I measured an internal resistance of 5.6 ohms on the 50 Ma range. (I can tell right off this one will be a bad choice for this application!)

2) A Calrad "cheapie 0-200 mA meter, rated at 2% accuracy. Has an internal resistance of .2 ohms

3) My reference TEK 254 DMM has a 2.0 ohm internal resistance on the 400 mA range, also probably not a good choice for this application.

Test data:

1) Using the VOM in this application (as a shunt mA meter) gave a highly erroneous 28 mA, (it should have been 44 mA). Just as telling the DMM voltmeter still registered a drop of 171 mV.

2) The Calrad read appx correct, but the scale calibrations were too coarse to be accurate enough. However, the DMM voltmeter got a 14.8 mV drop, which equates to a 1.4 mA error. So the Calrad meter is going to tell me to set the bias about 3% too high. This may be or not be a problem.

3) The Tek DMM read 38 mA and left 80 mV for the cathode resistor, for a 15% error. This is too inaccurate as well.

Summary of shunt style mA measurements for experiment 2:

1) Standard DMM and VOMS are clearly unacceptable as shunt mA meters. They have too much internal resistance, causing you to set the bias current too high. This risks damage to the amp.
2) The results suggest a proof positive method to verify suitability of a mA meter: Place your DMM (set to mV) across the cathode resistor and then use the single range shunt mA as Scott suggests. If you see much over 10 mV on the DMM, the ammeter should not be used in this application. (If you see 10 mV, you're already at 1 mA of error just in the measurement process, excluding the accuracy of the mA meter.)
3) Single range mA meters can be accurate enough, but they should be verified as to accuracy and internal resistance as discussed above.
4) Observe the accuracy data here is only valid for a 10 ohm cathode resistor or higher, although the general principle is the same regardless.

Experiment 3: What effect do the splitters have on bias?

Install the splitters, return AC Line to 120VAC.
Bias changes to .400 and .408 at 120 VAC, or 41 mA. Low precision ammeter confirms this.

The splitters are AC coupled to the outputs, so I did not expect them to change the initial bias current. Perhaps this is caused by the feedback loop?

Drop AC Line to 115 VAC. Bias changes to .384 and .391V, or 39 mA.
B+ at 406V. Again, we see a 2 mA drop against the AC line 5 volt change, which says the splitters also have no effect on the bias regulation. At this point we are 5 ma or about 11% lower in current than the spec suggests.

(Author note: Need to re-examine this and run max power THD test to confirm which method is correct.)

Experiment 4: What effect does a 25K ohm/volt VOM have on the bias voltage?

Using the standard test setup, observe the cathode resistor voltage drop on the DMM.
Using the Radio Shack meter, also measure the cathode resistors voltage drop.
See if the DMM changes value when the VOM is hooked up. This would indicate the VOM was loading down the bias circuit
Result: As expected, no change was seen. This would indicate a VOM is fine to use to measure the voltage drop across the cathode resistor and use ohms law to set the bias current.

Conclusions from Test group A:

1) The factory spec clearly says to pull the splitters to set bias. Failing to do so would appear to cause the bias to be set about 5% too hot, which may reduce output tube life.
2) Bias should obviously be set using the highest line voltage in your area.
3) The bias wanders quite a bit with AC line voltage changes, at least for a LK-48-B. This suggests the current precision mania for setting bias precisely may not be terribly important.

Experiment B: Effects of bias on sound quality

Goal: Further refine just how paranoid one must be about setting the bias, and what is "correctly set bias" anyway. Metrics for "bias correctness" will be THD vs power and power bandwidth. Using an Audio Precision System One, I will test for THD and power bandwidth at several bias points and line voltages to quantify the effects of the bias changes.

Unit under test is the LK-48 I've been messing with: LK48-B, sn 1004768

Two bias test points were selected, 44 mA and 40 mA.
Line voltage held steady at 120 VAC

Test ran were:
1) Frequency response
2) Power bandwidth (i.e. power output at 1% THD, 1 khz and 20-20kHz)
3) FFT (spectrum) of THD @ 1 watt
4) THD+N vs amplitude

Results:
1) Frequency response was unchanged
2) Power bandwidth @ 1% THD was 10 watts at 44 mA, 6 watts at 40 mA. (This is low, my 222C puts out 18 Watts. Perhaps the outputs are tired?) However. it's obvious bias has a great deal of effect on the power output vs the rated distortion.
3) FFT spectrum or THD at 1 watt shows no changes
4) THD vs amplitude like wise looks the same, about 10dB before clipping it gradually starts rising.

Conclusion:
So far, the only effect I see of running your amp 10% underbiased is a reduction of power. It appears THD and frequency responses are unchanged.
In this case, 10% underbiased equates to a 40% reduction in power, which is rather a lot.

Notes to investigate further:

1) Do other amps change the bias point when the splitters are pulled?
2) I wonder what effect a regulator would have on bias stability?
3) Verify loudness control setting doesn't affect bias w splitter pulled. (Verified on test LK48-B, 8/17/2003)
4) Verify 20K ohm/Volt meter doesn't change bias current when measuring mV across the cathode resistor ((Verified on test LK48-B, 8/17/2003)
4) Scott spec actually calls for 16 ohm loads, validate that 8 ohm dummy loads has no effect on bias setting & change comment above.

Appendix A:

Known variations:
(Ryan)

OK guys, below are the variations in models that I've actually seen:

222: Only one version.

222B: Only one version.

222C: Multiple versions.
Version #1:
This version of the 222C uses 7199 phase splitters, has DC Balance pots, but no Bias pots. The voltage ratings are:
Plate - 420VDC
Screen - 345VDC
Bias - Unknown

Version #2:
This version of the 222C uses 6U8 phase splitter tubes, has DC Balance pots, but no Bias pots. The voltage ratings are:
Plate - 420VDC
Screen - 345VDC
Bias - Unknown

Version #3:
This version of the 222C uses 6U8 phase splitter tubes, has no DC Balance pots, and has no Bias pots. This one is rare. The voltage ratings are:
Plate - 410VDC
Screen - 398VDC
Bias - 44 mA (-15V grid)

Version #4:
This version of the 222C uses 6U8 phase splitter tubes, has DC Balance pots, Bias pots, cathode current test points, and 10 ohm cathode resistors. It is identical to 222D late. The voltage ratings are:
Plate - 410VDC
Screen - 380VDC
Bias - 44 mA (-15 grid)

222D: Two versions:

Version #1:
This version of the 222D did NOT have cathode current test points or bias pots. It did include DC Balance pots. The circuit is identical to 222C, version #2.
Version #2:
This version of the 222D has bias test points, bias pots, DC Balance pots, and is identical to 222C version #4.

299A: Two versions:

Version #1:
This version of the 299 was Scotts first stereo integrated amplifier. It featured a single bias adjust pot for all four 7189 output tubes. Bias is calculated by measuring the voltage drop across the first B+ dropping resistor. The voltage drop

should be 24.5 VDC.

Version #2:

This version of the 299 featured bias adj. pots for each channel, had cathode current test points for each channel, and 18 ohm cathode resistors. Bias spec. is 55 mA per channel.

(Craig comments)

I have done at least 30 of these and have never seen one with bias test points or cathode resistors. They are similar in some ways to a 299B but no test points and the power supply is completely different then the #1 299A or the 299B.

299B: One version

(Craig comments)

There are indeed 2 versions of the 299B but the only difference is the output transformers. Some used the Identical transformer as the 222C and others used smaller transformers almost the same size as the 299A #2. The funny thing about the 299B with the same transformers as the 222C is the balance pots were still located next to the transformers and were real hard to get at to adjust. I have had to loosen the transformer and spread them and tinker to get where they are accessible from above chassis and you still need a slim rounded shaft screw driver.

299C:Multiple Versions

Version #1:

This is the original version of the 299C. It did NOT use bias pots or DC Balance pots. Bias was fixed and non-adjustable. Current spec per channel is 70 mA. Phase splitters were 7199's.

Version #2:

This version of the 299C uses 7199 phase splitters, and has DC Balance pots.

Version #3:

This version of the 299C uses 6U8 phase splitters, has DC Balance pots, and Bias pots. There are no test points to set bias, or cathode resistors. This one is rare. Also uses 4uF bypass capacitors on 6U8 pentode.

Version #4:

This version of the 299C uses 6U8 phase splitters, and has DC Balance pots only.

Version # 5:

They finally got it right this time! This version uses 6U8's, has DC Balance and Bias pots, along with cathode current test points and 10 ohm cathode resistors. Just fixed one of these in February. Very rare.

299D:

Two versions:

Version #1:

This version of the 299D featured a phase reversal switch and bias test points. Used big block output transformers.

Version #2:
This version of the 299D did NOT feature a phase reversal switch, and used small block output transformers.

233:
Two versions of this beast

Version #1:
This version of the 233 used big block output transformers

Version #2:
This version of the 233 used small block output transformers and didn't feature a phase reversal switch.

The kit versions, especially the LK48 and LK48B had production changes as well. Above are the most common Scott integrated amplifiers, and these are the versions that I have seen over my career in electronics. There may be more versions, if you see a version missing, please feel free to add it!