6SN7 Mu Follower Distortion

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Introduction

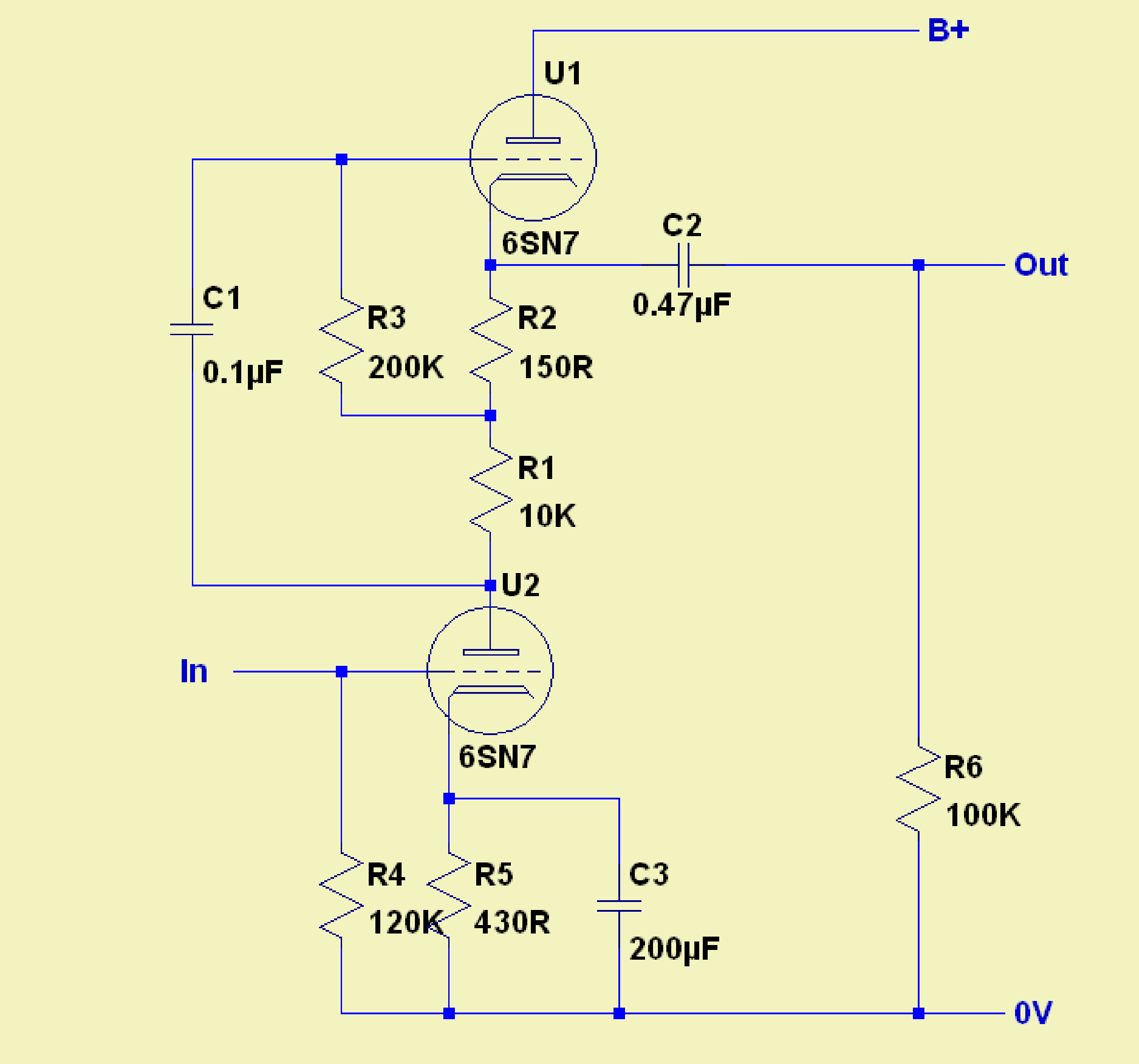
This short paper describes the work done in investigating the distortion produced in a mu follower stage using a 6SN7 valve and its related equivalents. The 6SN7 et al was chosen because it has a reputation for low inherent harmonic distortion which has already been established by Morgan Jones. As I have an interest in developing low distortion microphone preamplifiers I was interested to discover just how well a 6SN7 mu follower stage could perform. In addition, most other microphone preamplifier topologies based on twin triodes such as the 6SN7, employ global negative feedback (NFB) around two or more gain stages with its attendant stability problems. The 6SN7 mu follower stage held out the prospect of a reasonable gain (25dB) at low distortion without the use of global NFB. In addition, the 6SN7 family has a reputation for producing predominantly second harmonic distortion with very low levels f higher order harmonics. A 6SN7 mu follower stage therefore seemed likely to produce relatively benign distortion.

Set Up

A total of 14 6SN7 variants were tested, viz:

- 8off RCA 6SN7-GT kindly donated by Peter Weick
- 2off 7N7 loaned by Matt Barton-Hawkins
- 4off 6CG7 (Matsushita) purchased from Colomor Valves

The test circuit is based on that employed by Morgan Jones. The standing current is the same (8mA) and Jones' top pentode constant current source has been replaced by a normal mu follower triode. The circuit is shown below.



The 120K resistor across the lower grid represents the typical load expected by a microphone transformer. The 100K output load represents a typical interstage level potentiometer.

The signal source was a Ferrograph RTS2 Test Set oscillator which provides an output up to 2.5V rms at low distortion. Circuit distortion was measured using an HP344A Distortion Analyser.

The Ferrograph oscillator distortion is output dependent being lower at higher output levels. This makes it more difficult to measure distortion at lower signal levels. In addition, the spectrum of the Ferrograph oscillator's distortion is not known. It's specification is 0.025% or less at 1KHz.

The HP 344A Distortion Analyser is a broadband notch filter type which means it measures residual distortion and noise. Since, as will be seen, the broadband noise from the circuits tested is in the 50uV to 100uV region, distortion measurements below 0.01% will be masked by noise.

Overall, distortion measurements below 0.02% should be treated as unreliable.

Initial Tests

To obtain an initial feel for the levels of distortion that could be expected, some initial tests were undertaken at 1KHz and output voltages of 2V rms and 20V rms respectively. Output noise with the input shorted was also measured along with the dc voltages in the circuit. The four 6CG7 and the two 7N7 valves were tested.

The dc parameters are shown in the table below.

Parameter	6CG7	7N7
Supply (V)	325	318
Top cathode (V)	218	226
Bottom anode (V)	144	144
Bottom cathode (V)	3.13	3.44
Cathode current (mA)	7.3	8

There is very little difference in the dc conditions of the two valve types.

Distortion and and noise are shown in the table below.

Parameter	6CG7 #1	6CG7 #2	6CG7 #3	6CG7 #4	7N7 #1	7N7 #2
2V rms	0.045	0.030	0.040	0.046	0.020	0.030
20V rms	0.400	0.430	0.410	0.400	0.440	0.440
Noise	70uV	65uV	65uV	90uV	100uV	100uV

We note the following:

- Distortion at 20V rms is remarkably similar in both types of valve. We conclude that the 6CG7 is indeed a 6SN7 in a B9A envelope.
- The 7N7s appear to produce less distortion at 2V rms but the figures are in the region where measurements are suspect.
- The 7N7s are typically 3dB noisier than the 6CG7s.
- Total distortion at 20V rms is close to -48dB relative to the fundamental. This is only 2dB worse than Morgan Jones' measurement of inherent second harmonic in typical 6SN7 valves.

Next, distortion at 200Hz and 20KHz at 20V rms was measured. In all cases this was found to be close to 0.4% from which we conclude that distortion is largely independent of frequency.

Frequency response was also measured at 20V rms. It was found to be flat out to 150KHz (the limit of the Ferrograph oscillator) and the lower 3dB point was set by the output coupling capacitor and the load resistor.

Lastly,the effect of load on distortion and the output impedance were measured. Distortion versus load is shown in the table below.

Load	100K	25k	10K
Distortion @20V rms	0.41%	0.46%	0.52%

To measure output impedance, the load was set to 10K and the output adjusted to read 20V rms. The load was then changed to 100K and the output rose to 21.5V rms. This gives a calculated output impedance of 830 ohms.

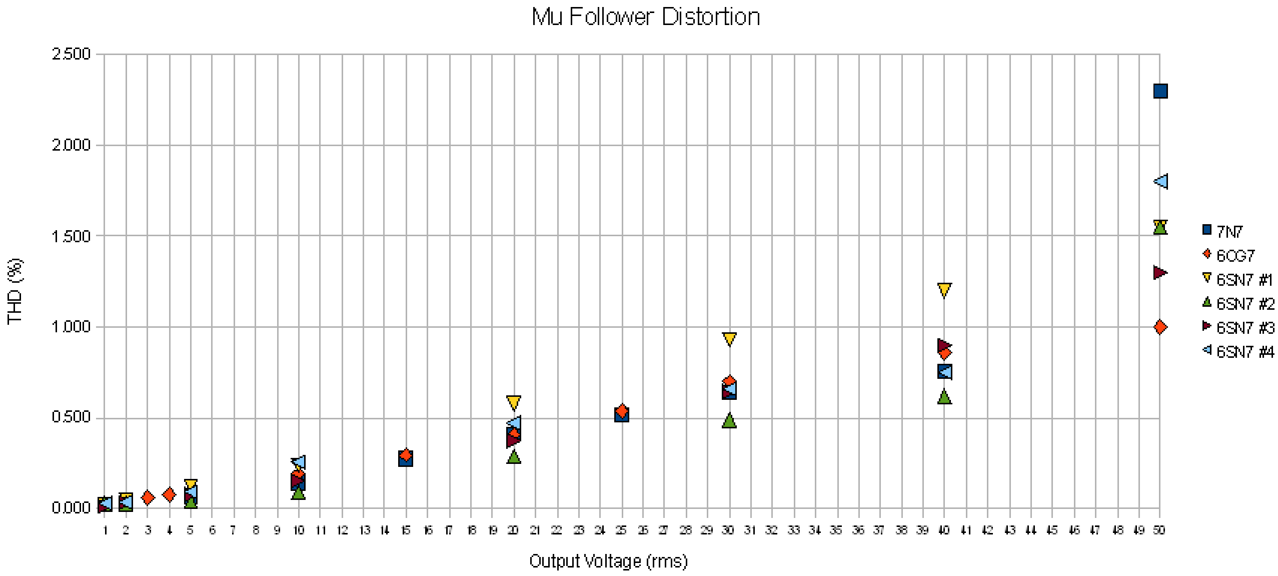
Detailed Measurements

Since initial tests showed that the mu follower distortion seems to be independent of frequency, subsequent details tests were conducted at a single frequency. 2KHz was chosen as it is in the middle of the audio spectrum and because the HP 344A has a 1KHz high pass filter and it was hoped this would improve its accuracy at low distortions.

A single 7N7, one 6CG7 and four 6SN7 valves were tested over a wide range of output voltages. Stage gain, noise, cathode voltage and current were also recorded. The resuslts are summarised in the table below.

Parameter	7N7	6CG7	6SN7 #1	6SN7 #2	6SN7 #3	6SN7 #4
1V dist'n	0.030	0.030	0.026	0.029	0.016	0.032
2V dist'n		0.042	0.050	0.029	0.035	0.036
3V dist'n		0.060				
4V dist'n		0.078				
5V dist'n	0.066	0.094	0.125	0.044	0.076	0.092
10V dist'n	0.145	0.190	0.240	0.092	0.155	0.255
15V dist'n	0.275	0.295				
20V dist'n	0.410	0.410	0.580	0.287	0.375	0.475
25V dist'n	0.520	0.540				
30V dist'n	0.640	0.700	0.930	0.490	0.645	0.660
40V dist'n	0.760	0.860	1.200	0.620	0.900	0.750
50V dist'n	2.300	1.000	1.500	1.550	1.300	1.800
Gain	~19	~20	18.2	21.74	20	20.66
Op Noise	100uV	65 - 96uV	120uV	85uV	110uV	120uV
Cathode V	3.44 – 3.52	~3.1	3.1	2.97	3.14	3.35
Cathode I	8 – 8.2mA	~7.3mA	7.2mA	6.9mA	7.3mA	7.8mA

Although there is variability in the above results, the majority lie within the +-10% production tolerances you would expect from valve manufacture. The following scatter diagram shows all the above distortion measurements on a single graph.



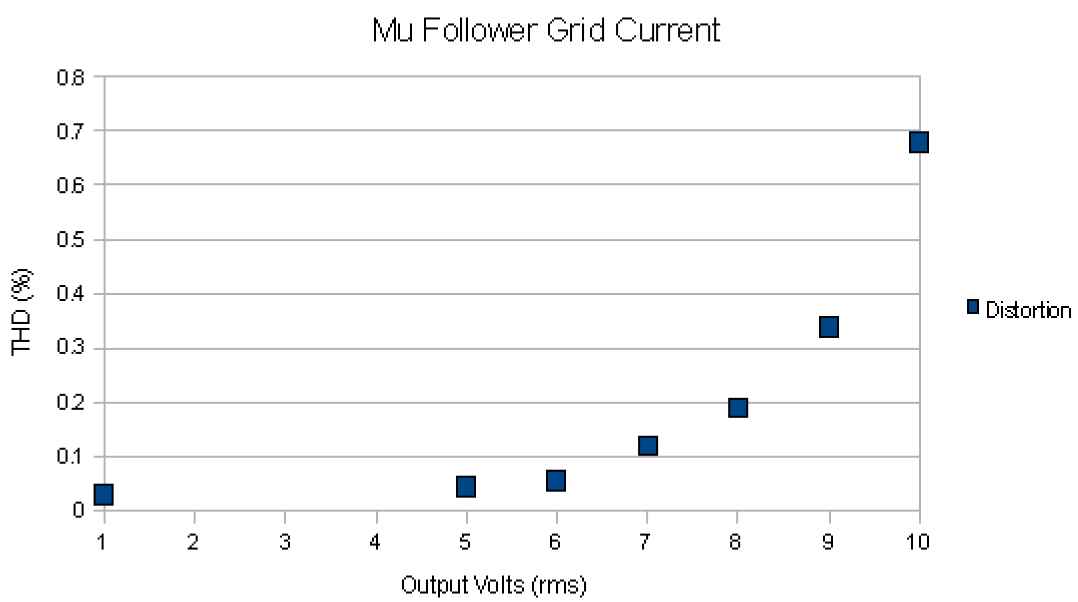
From this it is clear that distortion is roughly proportional to output level up to about 40V rms after which it begins to rise more sharply. This probably represents the onset of grid current. With an assumed gain of 20, a 40V rms output represents a peak input of 2.83 volts which is close to the bias point of just over 3 volts but grid distortion is probably masked by the low source impedance of the oscillator. To investigate the true onset of grid current, distortion measurements at various levels were measured with the oscillator fed via a 120K resistor. The results are shown in the table below.

Output Volts	7N7	6CG7
1	0.028	0.030
2		0.042
3		0.062
4		0.069
5	0.075	0.086
10	0.145	0.175
15	0.280	0.280
20	0.400	0.380
25	0.510	0.505

This demonstrates that there is no observable grid current at outputs up to 25V rms which represents a peak input of 1.77 volts. In order to see the effects of grid current, the lower triode was re-biassed for a grid voltage of -1.2 volts whilst maintaining the 8mA standing current. Output distortion was then measured with the oscillator fed via 120K. The results are shown in the table below.

Output Voltage (V)	Distortion (%)
1	0.03
5	0.044
6	0.056
7	0.12
8	0.19
9	0.34
10	0.68

The effect is best shown graphically.



Clearly, above 6V rms output the distortion begins to rise steeply. With an assumed gain of 20, this represent a peak input voltage of 425mV which implies grid current commences soon after the grid bias rises above -0.8V. This implies that with a bias of -3V, grid current should not commence until the outout reaches 30V rms.

Conclusions

In the sample of valves tested:

- The 6SN7 derivatives do exhibit the same low levels of distortion as the original 6SN7.
- The B9A derivatives are generally less noisy than the octal based types.
- Distortion is proportional to output level (up to the onset of grid current).
- The lower triode should be biased at least 3V negative to avoid grid current at high output levels.

- He mu follower topology achieves distortion levels within a couple of dB of the inherent distortion.

Further Work

The equipment used was unable to separate distortion products from each other and the broadband noise. Further work is needed to verify that the distortion produced is mostly second harmonic (Jones established it was so in his test set up but the mu follower is a different topology so it is not safe to assume its distortion spectra will be the same as Jones').

It is not clear exactly how low the distortion is at lower output levels (circa 2V), which represent typical operating levels, due to the inaccuracy of the test equipment. Further work should be done to establish the true levels of harmonic distortion at these output levels.

An operating point of V_g=-3.4V, I_a=8mA and V_a=145V has been assumed to be where lowest distortion occurs (as assumed by Jones). This may not be the case. Patrick Turner has suggested that V_g=-5V and I_a=5mA as an alternative operating point. This has the advantage of providing even greater immunity to grid current. A brief test of a 6CG7 mu follower with both top and bottom triodes biased close to this point (V_g=-4.45v and I_a=4.45mA) produced 0.036% distortion at 2V rms, 0.42% at 20V rms and 1.4% at 53V rms. Despite the significantly lower current the distortion figures are nearly identical to those obtained at 8mA which at least indicates that the 6CG7 is very tolerant of operating point. A lower operating current may allow a higher value of resistor in the first triode anode thus increasing the effective anode load and perhaps reducing distortion still further. On the other hand, lower standing current reduces the ability of the stage to deliver current into a load. The ideal operating point will most likely depend on the application – at least the 6SN7 family seems to perform well at a variety of operating points.

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