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Noise Measurements of the LSK389B Dual JFET

By Dennis Colin

Good noise performance with reasonable consistency was observed on a shipment of 20 units.

The LSK389 dual JFET by Linear Systems (800-359-4023 or 510-490-9160, Fax 510-353-0261, www.linearsystems.com) has been advertised for some time in *audioXpress*. (See ad in this issue on p. 41.) In this ad, the voltage noise density (input reference) at a drain current (I_d) of 3mA is graphed at 1.3nV/√Hz at 1kHz, and 1.0nV/√Hz at 20kHz.

I've heard some concern about the consistency of this part. On Sept. 22, 2006, I ordered ten units of the LSK389B-TO71. The "B" category is an I_{dss} (saturation drain current, at zero gate-source voltage) range of 6-12mA. (There's also the "A" with 2.6-6.5mA, and the "C" with 10-20mA.)

Of the ten units, three had a voltage noise density (from now on called simply "noise") ranging between 2 and 3nV/√Hz, while the other seven were between 1.0 and 1.8nV/√Hz. This was a measurement averaged over 1kHz-10kHz. Meanwhile, the datasheet specifies 0.9 typical, 1.9 maximum nV/√Hz at 1kHz. From the downsloping noise versus frequency graph shown in Linear Systems' ad, the 1-10kHz averaging I used will show a lower noise voltage than the level at 1kHz. Therefore, the three noisiest of my ten units were significantly out-of-spec.

MY TWO APPLICATIONS, THUS FAR

I used this JFET in my "Low-Noise Measurement Preamp" (*aX*, April '07, p. 26) and in "The LP797 Ultra-Low Distortion Phono Preamp" (*aX*, Sept. '07, p. 6). I was concerned—particularly in the phono preamp—about consistently obtaining the very-low noise performance these JFETs are capable of. Note that the ad is titled "1nV Low Noise Dual JFET."

FAST-FORWARD 14 MONTHS

On November 29, 2007, I ordered 20 units of the LSK389B-TO71. I received them three days later—lot no. JF300-214-4, date code 0551. As **Table 1** shows, the 1-20kHz averaged noise density (with I_d per FET ranging from 4.4-6.8mA; more on this later) was:

TABLE 1 Linear Systems LSK389B-TO71 Dual JFET Bias and Equivalent Input Noise
Ship date 11/23/07 Date Code 0551 Lot # JF300-214-4 Test Date 12/4/07

Sample No.	V_D V	I * mA	Noise 20Hz-20kHz nV RMS	Noise "A" nV RMS	Noise 1kHz-20kHz nV RMS	Noise, each FET 1kHz-20kHz Avg. nV/√Hz
1	5.79	10.55	164.2	134.6	140.4	1.321
2	6.51	8.85	177.8	145.8	146.0	1.384
3	4.31	12.00	138.8	112.9	120.8	1.099
4	4.64	11.51	157.3	129.1	132.5	1.232
5	6.00	9.59	147.3	120.1	127.1	1.171
6	6.18	9.32	126.3	105.1	114.1	1.020
7	3.27	13.48	120.9	99.3	108.4	0.953
8	5.46	10.36	153.2	128.1	132.9	1.237
9	5.32	10.59	144.3	120.1	126.8	1.168
10	5.20	10.73	154.3	128.8	133.2	1.240
11	4.95	11.08	144.1	119.0	125.9	1.157
12	5.40	10.47	144.6	120.4	126.9	1.169
13	4.76	11.36	156.1	131.1	134.8	1.258
14	5.23	10.69	147.9	124.4	130.3	1.207
15	5.14	10.81	141.9	118.5	125.5	1.153
16	3.22	13.55	118.8	97.4	107.4	0.941
17	5.97	9.59	156.2	131.4	135.5	1.266
18	4.77	11.33	136.2	112.9	120.7	1.097
19	3.95	12.51	120.9	99.3	108.8	0.957
20	6.30	9.16	156.0	131.1	135.1	1.262

Vdd ≈ +10V Rd = 509.8Ω RS = 10.00Ω gates grounded both FET sections, paralleled * combined current
10.877mA average 1.1646nV/√Hz average

range 0.941-1.84nV/√Hz (a 3.35dB range), median 1.1625; average 1.1646. The closeness of the median and average values is indicative of a well-behaved symmetrical distribution (more on this also later). **Table 2** shows the four units left from the 2006 group.

In both my measurement and phono preamps, I use both FET sections in parallel; this divides the noise voltage by √2, a 3dB reduction. But I also use a 10Ω common source resistor, for both DC bias stability and a return point for negative feedback (from the AD797 op amp, which is cascaded with the JFET). The thermal noise of this 10Ω resistor (at +25° C) is 0.4057nV/√Hz, which is RMS-added (square root of sum of squares) to the input-referred parallel FET noise.

AS-USED NOISE EXAMPLES

I measured the FET's noise voltages in a circuit (**Fig. 1**) similar to that in the preamps, then calculated backwards, RMS subtracting the 10Ω resistor noise; and then multiplying by √2 to obtain the per-FET noise. (Two in parallel will halve the equivalent noise resistance.)

The column in **Table 1** labeled "Noise, 1kHz-20kHz" shows the directly measured integrated noise voltage, input referred, over this bandwidth. I followed the test circuit of **Fig. 1** (overall gain stabilized at close to 100 by the feedback) with the low-noise measurement preamp, its gain set to 1000. The latter's selectable noise bandwidths were used to measure 20Hz-20kHz, "A" weighted, and 1kHz-20kHz noise levels. **Figure 2** shows the overall noise test setup.

Taking the 1kHz-20kHz values and dividing by √19,000Hz, which is 137.84√Hz, gives the 1kHz-20kHz averaged noise density values, for the configuration of both FETs paralleled and the 10Ω source resistor. In the 20 unit sample, this ranges from 0.779 to 1.059nV/√Hz. The equivalent thermal noise resistance (+25° C) ranges from 36.9 to 68.1Ω. Note that these resistances would be 10Ω lower if the FET sources were directly grounded.

Table 2 Linear Systems LSK389B-TD071 Dual JFET Bias and Equivalent Input Noise

Ship date 9/22/06 date code 0447 Lot # JF 300-4-3 Test Date 12/4/07

Sample no.	V_d V	i* mA	Noise 20Hz-20kHz nV RMS	Noise "A" nV RMS	Noise 1kHz-20kHz nV RMS	Noise, each FET 1kHz-20kHz Avg. nV/√Hz
1	6.00	8.89	372.5	314.3	278.1	2.795
4	4.26	11.32	296.1	244.7	219.4	2.177
5	4.16	12.95	122.9	95.5	108.8	0.957
7	4.75	11.56	117.6	97.8	108.1	0.951 Tested 12/25/06

Vdd ≈ +10V RD = 509.8Ω Rs = 10.00Ω gates grounded both FET sections, paralleled * combined current

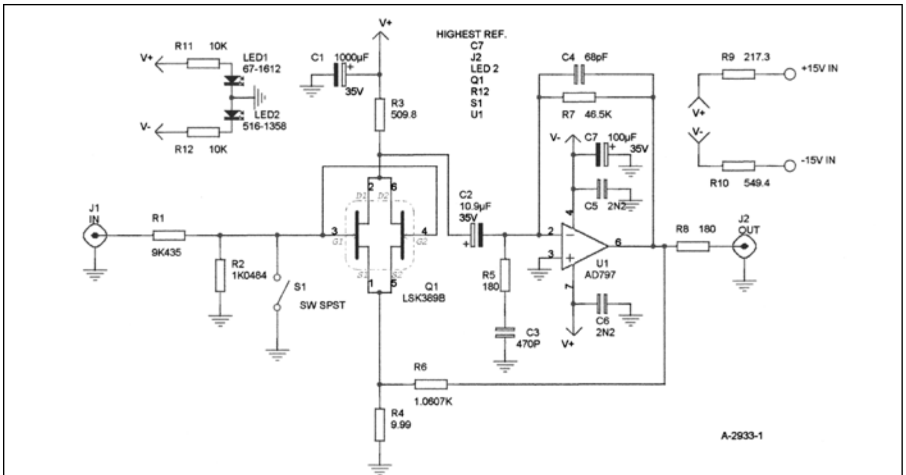

FIGURE 1: Linear Systems LSK389B Test Circuit. Cin to gates = 6.83pF. Rin to gates = 240MΩ.

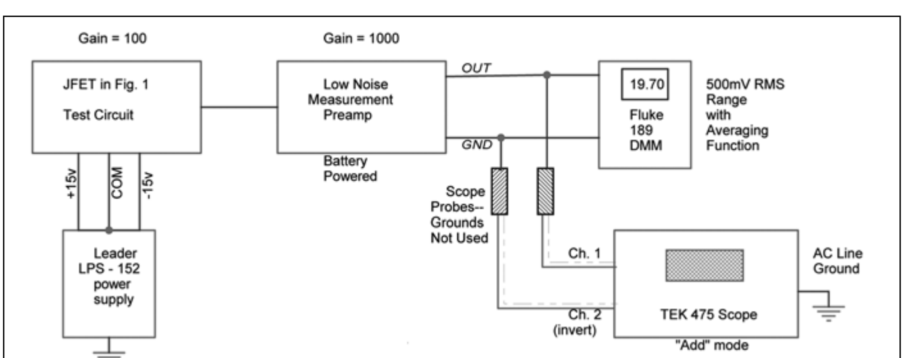

FIGURE 2: Noise test setup.

JFET CURRENT IN TEST CIRCUIT

Note that there's no overall negative feedback (NFB) at DC, because of the coupling cap C2. But the 10Ω source resistor R4 provides "source degeneration" (analogous to emitter degeneration in a bipolar transistor). This simply means negative feedback, and here the NFB extends to DC, because an increase in FET current generates a greater voltage drop across R4; this biases the sources more positive. This is equivalent to biasing the gates more negative regarding the sources (more negative Vgs). And this decreases the current, which has the effect of opposing the initial assumed attempt to increase the current.

This is useful in stabilizing the bias current (I_d) against unit-to-unit I_{dss} variations. The LSK389B is specified with an I_{dss} range of 6-12mA, a 2:1 range. I didn't measure I_{dss} on these 20 units, but I did on the previous shipment of ten units; I_{dss} was in-spec on all ten units.

In this test circuit, the FET current ranged from 8.85mA (unit #2) to 13.55mA (unit #16). This is for both FET sections paralleled, so if the two FETs in the package were matched, the range of per-FET currents would be 4.425-6.775mA. I had previously found that increasing the current above 3mA produced very little decrease in noise. Also, with a minimum of +10V at the top of the drain resistor (R3 in the test circuit), the current can be as high as 8mA per FET (16mA package total), while providing a drain voltage (V_d) of at least 2V.

The range of FET currents measured here is comfortably within the range that's allowable for proper, and low noise, operation in the LP797 phono preamp. In the low-noise measurement preamp, the FET sources (after the 10Ω resistor) are AC-coupled to ground, the current being highly stabilized with a large source bias resistor from a negative voltage supply. I didn't do this in the phono preamp because I didn't want an electrolytic cap (large value, 1000µF required) in the audio path. But for the noise measurement preamp, that's fine.

FURTHER NOTES ON TEST CIRCUIT

The FET's transconductance is specified at 20ms typical at 3mA (each FET), for the two in parallel that would be 40ms. With this value, the circuit's overall feedback loop gain would be 12.4 (21.9dB). With this loop gain, a 2:1 variation in FET sample transconductance (say, from 14 to 28ms per FET) produces a 5.4% overall closed-loop gain (0.46dB) variation. I observed much less variation. The circuit has a -3dB bandwidth of 1.4Hz-800kHz. Therefore, the noise measurement BW is, for all practical purposes, determined by the settings of the low-noise measurement preamp following the test circuit.

To achieve freedom from AC line hum corruption, I used a very well-filtered ±15V supply. The low-noise measurement preamp and the Fluke 189 true RMS meter are battery powered, avoiding ground loops.

I measured the level of 60/120Hz line ripple by temporarily shorting the **Fig. 1** test circuit output, and then connected the measurement preamp output to an oscilloscope. I used the scope's (Tektronix 475) inputs differentially: channel 1 connected to the preamp output, while channel 2 connected to the preamp's ground. Then I used the scope's subtraction ability by inverting channel 2 and setting to "Add" mode.

The scope's ground was not connected to the test circuit, except through the AC line plug's safety ground. The ±15V supply was also line grounded. This prevented large common-mode voltages from appearing at the scope (which could occur if the ±15V supply and/or scope ground were floating).

The observed AC line ripple was at least 20dB below the measured amplified FET noise, even with noise BW extending to 20Hz. Because noise is uncorrelated with AC line ripple (and any other signal, for that matter), an AC ripple level 20dB below the measured noise produces an error of only 0.04dB.

NOISE VERSUS CURRENT CORRELATION GRAPH

Figure 3 contains 20 circled points, numbered with the LSK389B test samples. The horizontal scale is the per-FET operating current (I_o), and the vertical scale is the 1kHz-20kHz noise voltage density of the FET (for each one in the package). If a single FET were thus plotted over a range of currents, the graph would be a downsloping curve, because (within limits) increasing current increases transconductance because the FET's channel resistance becomes lower. This reduces

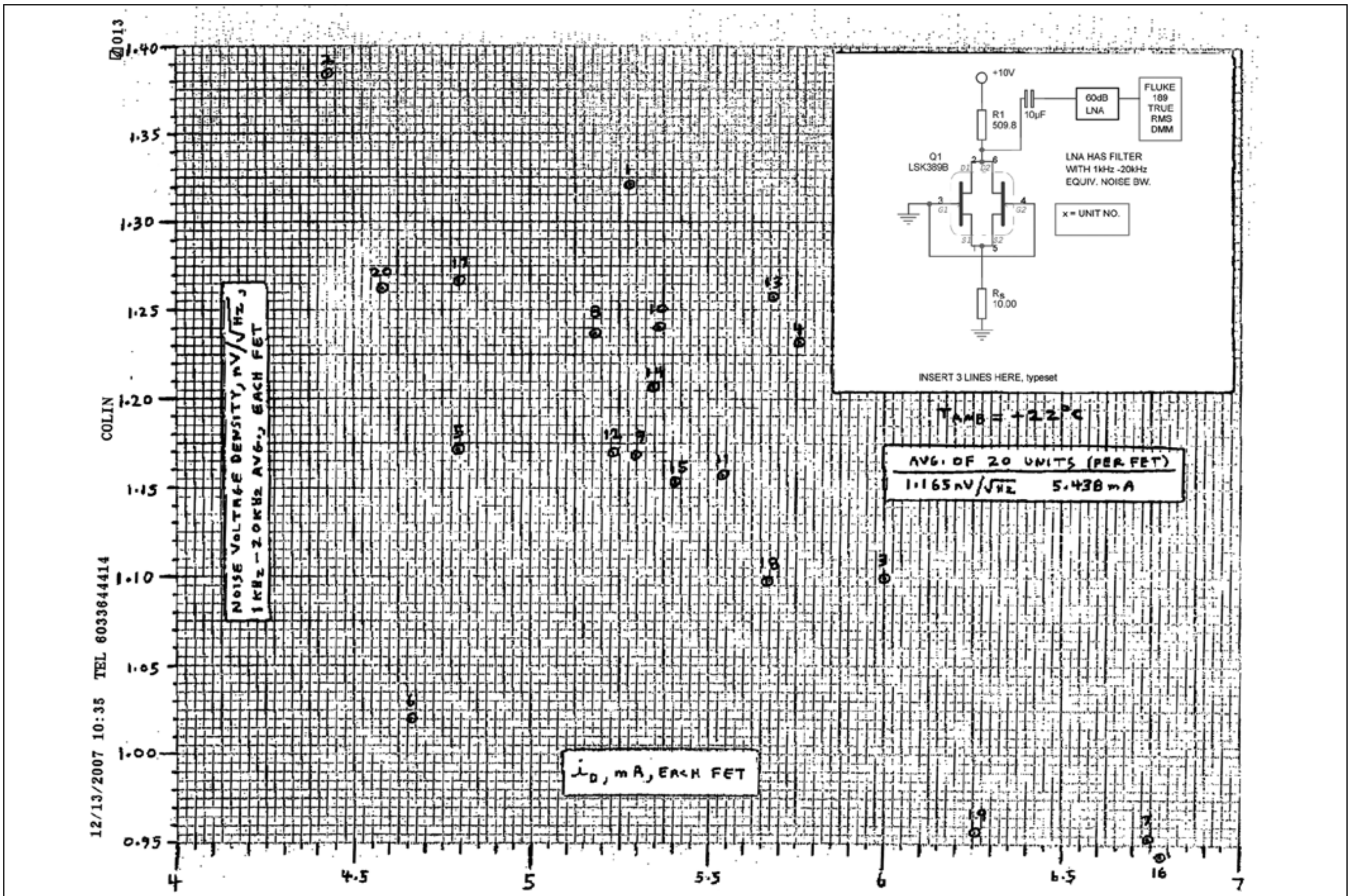

FIGURE 3: Noise (input-referred) vs. current. 20 units

Noise with Q1 sample(7):

NBW	out μV RMS	in nV RMS	In, average nV/√Hz	per FET average nV/√Hz
20kHz-100kHz	22.31	223.1	0.789	
1kHz-100kHz	24.79	247.9	0.788	
1kHz-20kHz	10.81	108.1	0.784	0.951
20Hz-20kHz	11.76	117.6	0.832	1.029
"A"	9.78	97.8		
20Hz-1kHz	4.63	46.3	1.479	2.012

with Q1 sample (7)
1kHz gain = 10.0032
(100.027 regarding Q1 gates)
v+ = +10.64V, 20.1mA
V- = -10.29V, 8.6mA
Q1 Vd = +4.748V, io = 11.56mA**

Frequency response: -3dB BW = 1.4Hz - 800kHz
1kHz maximum out = 5.14V RMS
Vo DC = -2.0mV
**Both FETs combined
*lot JF300-4-3
date code 0447

thermal noise voltage.

But in **Fig. 3** the 20 points are fairly randomly scattered. There is a small amount of lower-noise versus higher-current correlation, but obviously other semiconductor physics effects influence the noise level. Notice, though, samples #2 and #16: unit #2 has the highest noise and lowest current, while it's vice versa for #16.

SUMMARY FROM TABLE 1 DATA

Here, I'll use the average values of the 20 samples: Integrated noise voltages of the two paralleled FETs with the 10Ω source resistor are 145.355nV (20Hz-20kHz BW) and 126.655nV (1kHz-20kHz BW). RMS subtracting these gives 71.320nV; this is the integrated (total) noise in a 20Hz-1kHz band. Dividing this by √980Hz gives a noise density of 2.278nV/√Hz, averaged over the 20Hz-1kHz band.

Then, RMS subtracting the 0.4057nV/√Hz thermal noise of the 10Ω resistor, and multiplying the result by √2 for each FET of the paralleled pair, gives 3.170nV/√Hz average noise voltage density in a 20Hz-1kHz band, for a single FET, at an average current of 5.44mA. This is 8.7dB higher than the 1.165nV/√Hz figure averaged over the 1kHz-20kHz band. This reflects the normal low-frequency noise increase of semiconductors, FET and bipolar.

However, as the "A" weighting curve shows, the ear is relatively insensitive to low-level, low-frequency sounds.

"A" WEIGHTED NOISE

This data in **Table 1** ranges from 97.4-145.8nV RMS, with an average (of the 20 samples) of 120.47nV RMS. This is for the as-tested configuration of two paralleled FETs and the 10Ω source resistor. Calculation of the "A" noise for a single FET (without source resistor) is difficult without knowing the resistor's "A" weighted noise, and will not be estimated here.

But because the as-tested configuration has proven to have reliable low-noise performance, the above "A" weighted input-referred noise voltage measurements are relevant. These levels range from -140.2dBV to -136.7dBV. The average is -138.4dBV.

CONCLUSION

Compared to my 2006 order (in which three of the ten units had out-of-spec noise), all 20 units of my 2007 order were comfortably within the noise spec.

Linear Systems offers low-noise screening for a fee (I don't yet know the cost), but if these 20 units are representative, that shouldn't be necessary.

If you build the LP797 phono preamp, I recommend using the specified DIP sockets for the JFETs. Then, by shorting the preamp inputs and measuring the output noise, you can select JFETs for lowest noise. For small-quantity orders from Linear Systems, it probably costs less to buy a few extra JFETs (so you can select the lowest noise units) than to pay Linear Systems for noise screening.

At this point, I'd say that the LSK389B is an excellent product, very suitable for low-noise audio applications. *aX*

Parts List	
C1	1000μF
C2	10.9μF
C3	470P
C4	68pF
C5, C6	2N2
C7	100μF
J1	IN
J2	OUT
LED1	67-1612
LED2	516-1358
Q1	LSK389B
R1	9K435
R2	1K0484
R3	509.8
R4	9.99
R5, R8	180
R6	1.067K
R7	46.5K
R9	217.3
R10	549.4
R11, R12	10K
S1	Switch SPST
U1	AD797