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Ducati Monster 797 Air Temperature Sensor fuel quantity regulation

1. Introduction

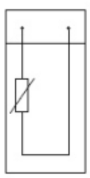
When installing a racing exhaust system on your motorcycle, the exhaust gases can flow out smoother, and also a small part of the fresh mixture (air + fuel) flowing in the cylinder during intake phase could flow out from the exhaust valve during the overlapping phase (when both intake and exhaust valve are open together) without being burnt. As a consequence, the concentration of fuel in the cylinder during combustion becomes smaller, and unless the gasoline quantity is increased a bit, the mixture is likely to become “lean” (too much air, too few fuel) and the combustion becomes worse, with the risk of overheating the engine. In other words, the engine runs in dangerous conditions.
When the engine works in “closed loop” control mode using the lambda sensor, the fuel-air ratio is controlled by adjusting the injection quantity to keep the target ratio, and therefore there’s no issue to combustion, but during full throttle accelerations, when the engine control unit runs in “open loop” mode, there’s high risk to have a lean mixture.
In order to avoid that, it is necessary to somehow increase the fuel injection quantity with respect to the “standard” map included in the original ECU. This could be achieved by installing expensive additional modules such as Power Commander or similar, but the remap work is very hard, moreover the weight of the motorcycle increases, and you get a reduction of reliability (one more additional part which could break and stop the engine, in case of failure).
So far, if your target is to increase the fuel by just few percentage points, the cheapest, reliable and most effective method is to work on the **air temperature sensor** to trick the ECU and make it think that the air temperature is lower than the real one. In fact, air density (therefore oxygen concentration) increases when temperature reduces, and the software in the ECU compensates the increase of oxygen by adding more fuel, in case it detects low temperature.
Conclusion: if you can trick the Engine Control Unit to think that the temperature is, let’s say, 10℃ less than the real air temperature, you can get an increase of about 3% of fuel injected quantity. The ideas explained in this paper are the same ones applied on the commercially available product **“Booster Plug”**: by following this guide, you can make a similar product by yourself spending just 20 dollars, instead of 200 dollars for the Booster Plug available on market.

2. Air temperature sensor characteristic introduction

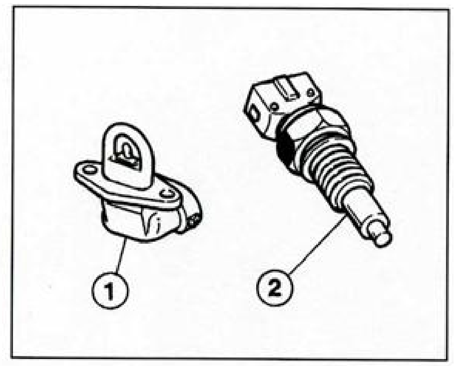
Most Ducati motorcycles on the market are equipped with the following sensor. It is an **NTC (Negative Temperature Coefficient) thermistor** manufactured by Magneti Marelli (code: **ATS05**), the Ducati part number is **55240121A**.

Original sensor characteristic (Temperature-Resistance).

Theoretical Feature Soll-Eigenschaft Theoretisch Kenmerk	
Temperature °C Temperatur °C Temperatuur °C	Resistance Kohm Widerstand Kohm Weerstand Kohm
-40	100,950
-30	53,100
-20	29,121
-10	16,599
0	9,750
+10	5,970
+20	3,747
+25	3,000
+30	2,417
+40	1,598
+50	1,080
+60	0,746
+70	0,526
+80	0,377
+90	0,275
+100	0,204
+110	0,153
+125	0,102

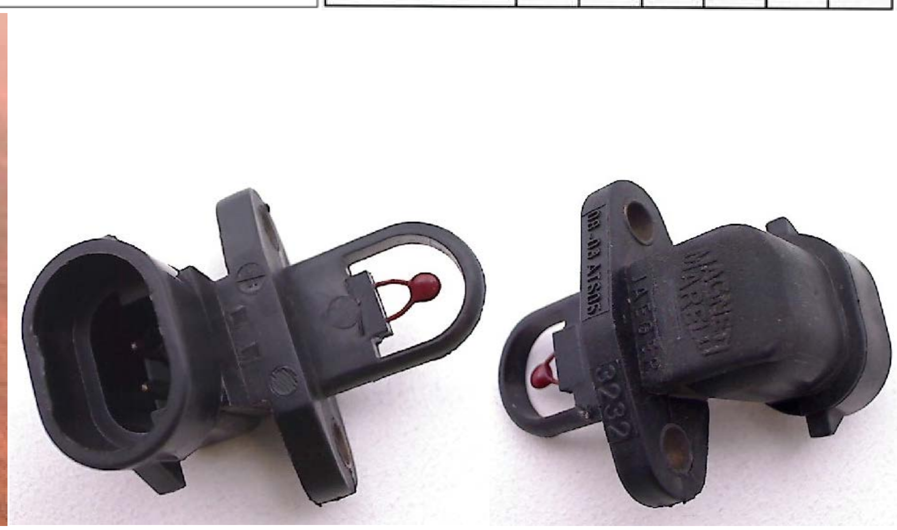


Electrical Symbol
Elektrisches Symbol
Elektrisch Symbool



Air temperature sensor (1)

Temperature ±1 degree °C		-20	-10	0	+20	+60	+80
Resistance (kohm) <	min.	27.66	15.76	9.26	2.85	0.71	0.35
	MAX.	30.51	17.42	10.23	3.15	0.78	0.39



```
% Input data
T_C_raw=[-40,-30,-20,-10,0,10,20,30,40,50,60,70,80,90,100,110,115];
R_raw=1000*[100.95,53.1,29.121,16.599,9.75,5.97,3.747,2.417,1.598,1.08,0.746,0.526,0.377,
0.275,0.204,0.153,0.102];
T_K_raw=T_C_raw+273.15;
```

Notes about variables listed above:

- **T_C_raw**: it is the air temperature array, in Celsius degrees.
- **R_raw**: it is the sensor resistance array (each resistance value is taken at the given temperature from the above array "T_C_raw").
- **T_K_raw**: it is the air temperature array, in Kelvin.

Thermistor simplified model

In order to simplify the following calculations, I used the simplified mathematical model shown below.
The model simplifies the thermistor characteristic assuming an exponential curve, therefore only 2 parameters are necessary to characterize a thermistor: a “beta” decay factor, and the resistance at a known temperature.

B or β parameter equation [edit]

NTC thermistors can also be characterised with the *B* (or *β*) parameter equation, which is essentially the Steinhart–Hart equation with $a = (1/T_0) - (1/B)\ln(R_0)$, $b = 1/B$ and $c = 0$,

$$\frac{1}{T} = \frac{1}{T_0} + \frac{1}{B}\ln\left(\frac{R}{R_0}\right),$$

where the temperatures are in kelvins, and R_0 is the resistance at temperature T_0 (25 °C = 298.15 K). Solving for *R* yields:

$$R = R_0 e^{B\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

or, alternatively,

$$R = r_\infty e^{B/T}$$

where $r_\infty = R_0 e^{-B/T_0}$.

This can be solved for the temperature:

$$T = \frac{B}{\ln\left(R/r_\infty\right)}$$

The B-parameter equation can also be written as $\ln R = B/T + \ln r_\infty$. This can be used to convert the function of resistance vs. temperature of a thermistor into a linear function of $\ln R$ vs. $1/T$. The average slope of this function will then yield an estimate of the value of the *B* parameter.

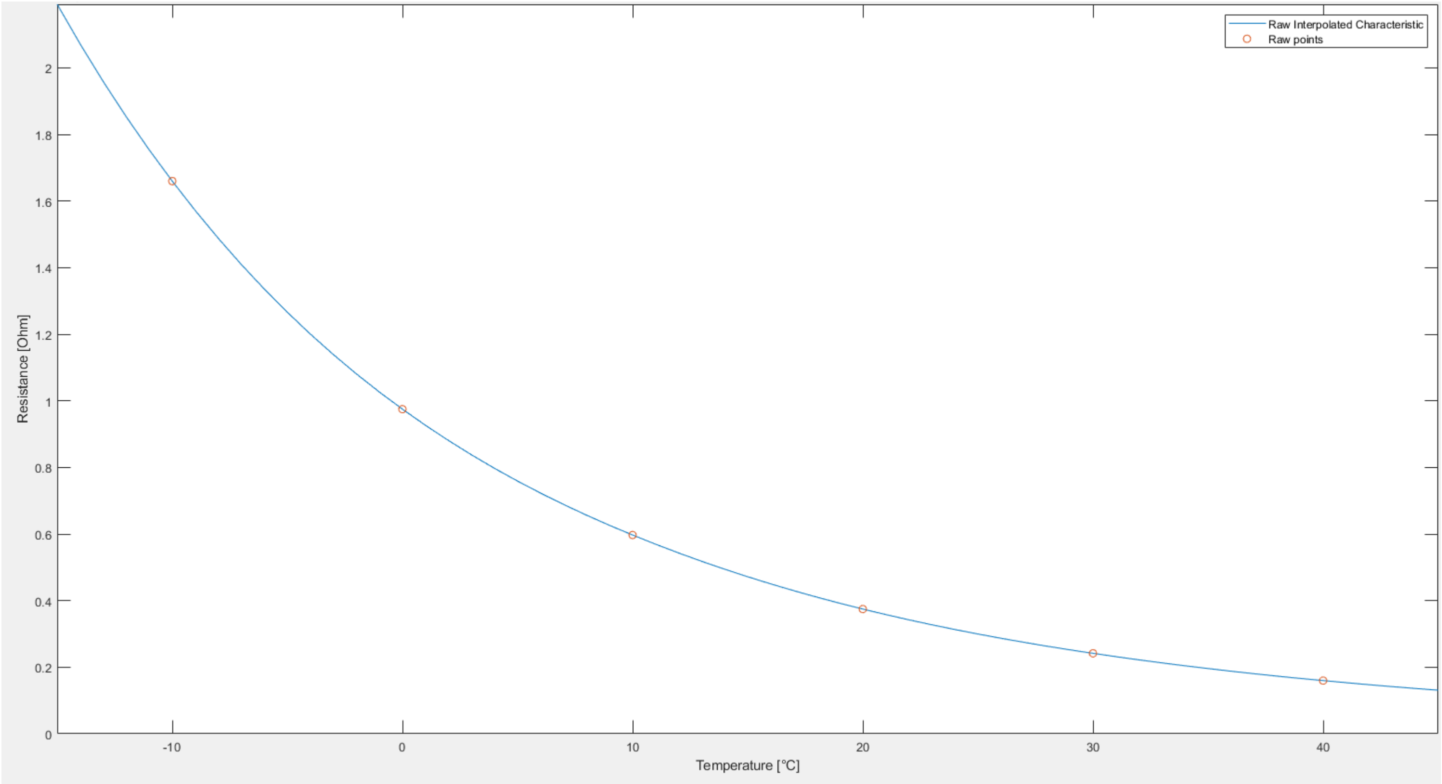
```
B_eq = (log(R_raw(5))- log(R_raw(8)))/(1/T_K_raw(5) - 1/T_K_raw(8));
r_inf = R_raw(5)*exp(-B_eq/T_K_raw(5));
R_eq = r_inf*exp(B_eq./T_K_int);
R_Tamb = interp1(T_C_raw,R_raw,25,'spline');
```

The simplified model characteristic has the following parameters:

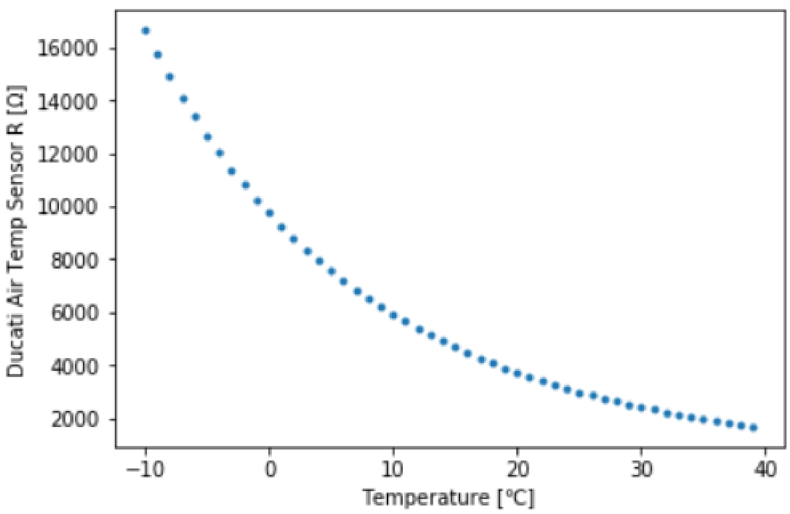
- **r_inf = 0.00738114142173356 Ω** → resistance at T=∞
- **B_eq = 3849.73500516414** → equivalent “B” (or “Beta”) factor
- **R_Tamb = 2997.60547838973 Ω**

The interpolated resistance at 25℃ is 2997.60547838973 Ω. And beta is 3849.73500516414.

The following picture shows the comparison between the simplified exponential model (blue line), and the circular points from the data-sheet of the sensor. As you can notice, the approximation is very good. The X-axis shows the temperature, in Celsius degrees, while the Y-axis shows the resistance of the sensor.



The following is the same picture plotted using Python.

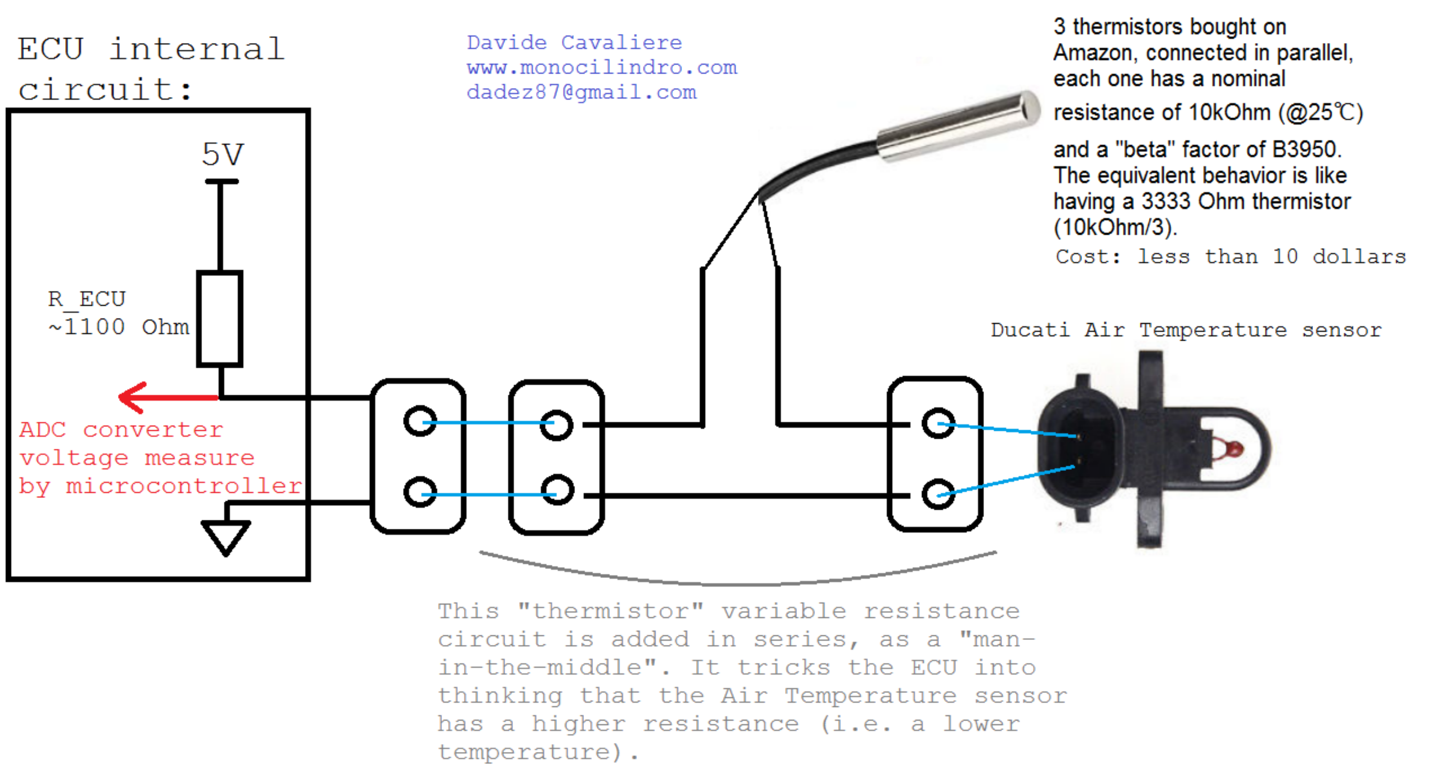


3. Circuit to build for making your own "Booster Plug"

The circuit that we have to realize is shown in the picture below. Basically, we are going to insert an additional resistance, as a "man-in-the-middle", between the original air temperature sensor (right) and the ECU (left). When adding a resistance in series, the total resistance is the sum, so the total resistance seen by the ECU is higher than the resistance of the sensor itself. Therefore, since (according to the thermistor exponential curve shown in the previous chapter), a higher resistance corresponds to a lower temperature, the ECU will be tricked to think that the air temperature is lower than what it really is.

Theoretically, you could put a fixed resistor in series with the air temperature sensor, but in such case, the delta temperature at high air temperatures will be much higher than at low temperatures, so your motorcycle will have richer mixture at high temperatures, and leaner at low temperatures, which is not good.

In order to avoid this issue, we don't put in series a simple resistor, but a thermistor, which reduces its resistance at higher temperatures, so that the delta temperature is more stable, and therefore the increment of gasoline is more constant throughout all air temperature range (i.e. from -10℃ to 30℃, the increment percentage of gasoline will be quite constant, let's say 5-6%).



In my case, I put in parallel 3 thermistors which I bought on Amazon for just less than 10 dollars. These thermistors have a "beta" factor of 3950, and a nominal resistance at ambient temperature (25℃) of 10 kΩ (10000 Ω). By putting 3 of them in parallel, the overall resistance at a given temperature becomes one third, therefore at ambient temperature the resistance is 3333 Ω. In addition to that, to reduce a bit more the resistance, I added an additional fixed resistor in parallel, also 10 kΩ, so the total resistance in series is 2500 kΩ at 25℃ (because it's like having 4 resistors of 10 kΩ in parallel).

If I just put the 3 thermistors in parallel, the increment of injected gasoline would have been 5-6%. However, since I put an additional resistor in parallel, the actual increment is a bit smaller, 4-5%. Just remember this simple rule: the more is the resistance, the more you have an increment of fuel injected. By adding a resistor in parallel, I reduced the resistance.

The components you need to buy to implement the above circuit are:

Thermistors: I bought the following ones, 5 pieces, for 988 Yen (about 9 dollars). These thermistors with B=3950 and nominal resistance (@25℃) of 10kΩ are pretty common and cheap. You need to connect 3 of them in parallel. They already have a 1 meter long cable, so I did not need any additional cable. Putting 3 of these sensors will ensure an increase of injected fuel of 5% ~ 6% in the whole range of temperatures between -10℃ and 40℃. If you want to reduce it a bit, you can add another sensor (4 instead of 3), or simply put an additional constant 10kΩ resistor in parallel (you must buy it separately in an electronics store, it will cost few cents).

DROK　車用　温度計センサーケーブル　5Pcs 10k B3950温度プローブ、-25℃~125℃ 温度センサ、高感度ステンレスNTCサーミスタプローブ、車用コンピュータ温度センサ
販売: DROKING
返品期間：2018/12/08まで
￥ 988
再度購入

Connectors (female and male): you can buy cheap connectors on Aliexpress, for just 9 dollars (see the image above). You can search the following keywords: 12162193, 12162195, 12162215. The below connectors better fit the sensor side connector (fixing points on the side), but the above ones will already do their job, so the below ones are optional.

shhworldsea 5/30/100sets 1.5mm 2pin 2p kit male female auto waterproof connector 12162193 12162195
[Transaction Screenshot]

¥ 1,032 X1
Product properties: 5set male female

shhworldsea 5/30/100sets 1.5mm 2p kit wire assembly connector 12162215
[Transaction Screenshot]

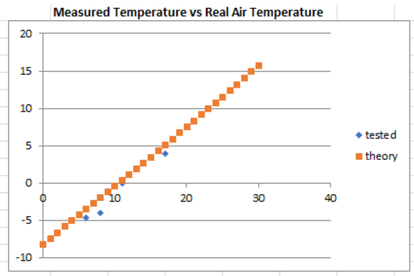
¥ 543 X1
Product properties: 5set

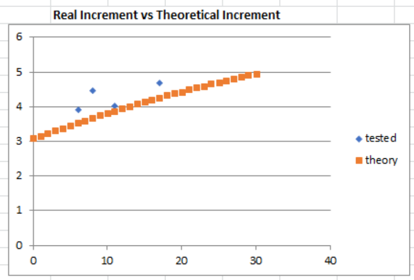
4. Experimental results

The graphs below show the results I obtained with a 10kΩ resistor in parallel to the 3 thermistors. Please refer to the orange curve (theoretical results). The increment is 3% at 0℃, and it rises up to 5% at 30℃. I have obtained the blue points by analyzing the OBD2 data that I got using a ELM 327 adapter. The actual increment is slightly bigger than the theoretical one, due to drift of the components, and measurement accuracy of ECU analog-to-digital converter.

Tested Tair	Tested Teng	delta	increase %
4	17	13	4.690939
-4	8	12	4.458812
0	11	11	4.027386
-4.5	6	10.5	3.908722
Sensore Ducati			
Rinf	0.0073811		
B_eq	3849.735		
Ramb	2997.6055		
Sensori esterni			
Ramb	3333		
B_eq	3950		
Rinf	0.0058768		

Calc Teng	Teng K	R duc sens	R ext sens	R ext par	R tot sum	T meas K	T meas C	delta C	
0	273.2	9750	11205.75	5284.3	15034.3	265.007	-8.14297	8.14297	3.07297
1	274.2	9261.4259	10629.98	5152.69	14414.1	265.778	-7.37224	8.37224	3.15033
2	275.2	8800.62234	10087.67	5021.82	13822.4	266.549	-6.60094	8.60094	3.22702
3	276.2	8365.83776	9576.654	4891.87	13257.7	267.321	-5.82886	8.82886	3.30296
4	277.2	7955.44136	9094.937	4763.01	12718.5	268.094	-5.05581	9.05581	3.3781
5	278.2	7567.9141	8640.657	4635.38	12203.3	268.868	-4.28162	9.28162	3.45236
6	279.2	7201.84046	8212.081	4509.14	11711	269.644	-3.50613	9.50613	3.5257
7	280.2	6855.90073	7807.598	4384.42	11240.3	270.421	-2.72918	9.72918	3.59806
8	281.2	6528.86408	7425.705	4261.35	10790.2	271.199	-1.95065	9.95065	3.6694
9	282.2	6219.58203	7065.003	4140.05	10359.6	271.98	-1.1704	10.1704	3.73967
10	283.2	5926.98247	6724.187	4020.64	9947.62	272.762	-0.38834	10.3883	3.80886
11	284.2	5650.06424	6402.038	3903.2	9553.26	273.546	0.39564	10.6044	3.87691
12	285.2	5387.89196	6097.423	3787.83	9175.72	274.332	1.18163	10.8184	3.94382
13	286.2	5139.59138	5809.281	3674.6	8814.19	275.12	1.9697	11.0303	4.00956
14	287.2	4904.34508	5536.622	3563.59	8467.94	275.91	2.75991	11.2401	4.07412
15	288.2	4681.38844	5278.521	3454.86	8136.25	276.702	3.55232	11.4477	4.13748
16	289.2	4470.00594	5034.114	3348.46	7818.47	277.497	4.34696	11.653	4.19964
17	290.2	4269.52775	4802.593	3244.43	7513.95	278.294	5.14388	11.8561	4.26059
18	291.2	4079.32657	4583.202	3142.8	7222.12	279.093	5.94309	12.0569	4.32034
19	292.2	3898.81471	4375.233	3043.59	6942.41	279.895	6.74461	12.2554	4.37889
20	293.2	3727.44134	4178.024	2946.83	6674.27	280.698	7.54845	12.4516	4.43623
21	294.2	3564.69005	3990.956	2852.53	6417.22	281.505	8.35461	12.6454	4.49239
22	295.2	3410.07644	3813.447	2760.68	6170.75	282.313	9.16308	12.8369	4.54737
23	296.2	3263.14602	3644.953	2671.28	5934.43	283.124	9.97385	13.0261	4.60119
24	297.2	3123.47218	3484.964	2584.33	5707.81	283.937	10.7869	13.2131	4.65386
25	298.2	2990.65435	3333	2499.81	5490.47	284.752	11.6022	13.3978	4.70539
26	299.2	2864.31626	3188.613	2417.7	5282.02	285.57	12.4198	13.5802	4.75581
27	300.2	2744.10433	3051.382	2337.98	5082.08	286.39	13.2395	13.7605	4.80514
28	301.2	2629.68624	2920.91	2260.61	4890.29	287.211	14.0615	13.9385	4.85339
29	302.2	2520.74945	2796.825	2185.56	4706.31	288.036	14.8855	14.1145	4.90059
30	303.2	2417	2678.779	2112.81	4529.81	288.862	15.7117	14.2883	4.94677





If you wish to achieve higher injected fuel percentage increment, you can avoid mounting the 10kΩ parallel resistor, and in such case the characteristic becomes as following. The increment is more stable, between 5% and 6% in the whole range of temperatures from 0℃ to 30℃. If you have a racing exhaust (such as Termignoni, Akrapovic, SC Project, etc.) and also a modified air filter, I suggest to use this configuration.

Tested Tair	Tested Teng	delta	increase %
-3	15	18	6.663458
Sensore Ducati			
Rinf	0.0073811		
B_eq	3849.735		
Ramb	2997.6055		
Sensori esterni			
Ramb	3333		
B_eq	3950		
Rinf	0.0058768		

Calc Teng	Teng K	R duc sens	R ext sens	R ext par	R tot sum	T meas K	T meas C	delta C	
0	273.2	9750	11205.75	11205.7	20955.7	259.084	-14.0655	14.0655	5.42935
1	274.2	9261.4259	10629.98	10630	19891.4	259.997	-13.1535	14.1535	5.44413
2	275.2	8800.62234	10087.67	10087.7	18888.3	260.908	-12.2417	14.2417	5.45891
3	276.2	8365.83776	9576.654	9576.65	17942.5	261.82	-11.3301	14.3301	5.4737
4	277.2	7955.44136	9094.937	9094.94	17050.4	262.731	-10.4189	14.4189	5.48848
5	278.2	7567.9141	8640.657	8640.66	16208.6	263.642	-9.50785	14.5078	5.50327
6	279.2	7201.84046	8212.081	8212.08	15413.9	264.553	-8.5971	14.5971	5.51807
7	280.2	6855.90073	7807.598	7807.6	14663.5	265.463	-7.68662	14.6866	5.53286
8	281.2	6528.86408	7425.705	7425.71	13954.6	266.374	-6.7764	14.7764	5.54766
9	282.2	6219.58203	7065.003	7065	13284.6	267.284	-5.86644	14.8664	5.56246
10	283.2	5926.98247	6724.187	6724.19	12651.2	268.193	-4.95674	14.9567	5.57727
11	284.2	5650.06424	6402.038	6402.04	12052.1	269.103	-4.04731	15.0473	5.59208
12	285.2	5387.89196	6097.423	6097.42	11485.3	270.012	-3.13814	15.1381	5.60689
13	286.2	5139.59138	5809.281	5809.28	10948.9	270.921	-2.22923	15.2292	5.6217
14	287.2	4904.34508	5536.622	5536.62	10441	271.829	-1.32059	15.3206	5.63652
15	288.2	4681.38844	5278.521	5278.52	9959.91	272.738	-0.4122	15.4122	5.65134
16	289.2	4470.00594	5034.114	5034.11	9504.12	273.646	0.49592	15.5041	5.66616
17	290.2	4269.52775	4802.593	4802.59	9072.12	274.554	1.40378	15.5962	5.68098
18	291.2	4079.32657	4583.202	4583.2	8662.53	275.461	2.31138	15.6886	5.69581
19	292.2	3898.81471	4375.233	4375.23	8274.05	276.369	3.21872	15.7813	5.71064
20	293.2	3727.44134	4178.024	4178.02	7905.47	277.276	4.12579	15.8742	5.72547
21	294.2	3564.69005	3990.956	3990.96	7555.65	278.183	5.03261	15.9674	5.74031
22	295.2	3410.07644	3813.447	3813.45	7223.52	279.089	5.93916	16.0608	5.75515
23	296.2	3263.14602	3644.953	3644.95	6908.1	279.995	6.84546	16.1545	5.76999
24	297.2	3123.47218	3484.964	3484.96	6608.44	280.901	7.75149	16.2485	5.78483
25	298.2	2990.65435	3333	3333	6323.65	281.807	8.65726	16.3427	5.79967
26	299.2	2864.31626	3188.613	3188.61	6052.93	282.713	9.56277	16.4372	5.81452
27	300.2	2744.10433	3051.382	3051.38	5795.49	283.618	10.468	16.532	5.82937
28	301.2	2629.68624	2920.91	2920.91	5550.6	284.523	11.373	16.627	5.84422
29	302.2	2520.74945	2796.825	2796.83	5317.57	285.428	12.2777	16.7223	5.85908
30	303.2	2417	2678.779	2678.78	5095.78	286.332	13.1822	16.8178	5.87394