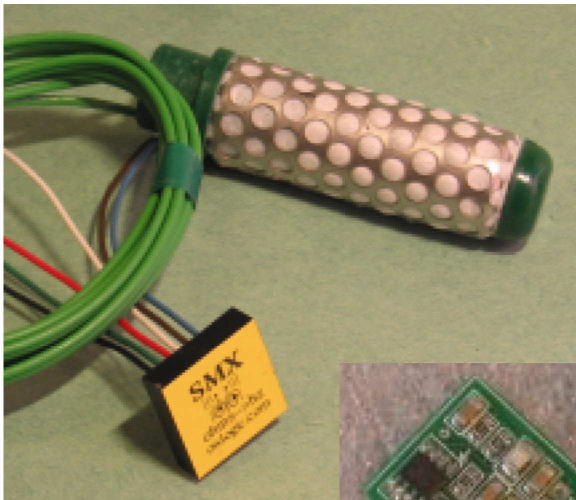
SMX

Electrical Interface for moisture sensors — IrrometerWATERMARK™

The SMX is an interface module for sensors that measure the electrical resistance of moist substrates. It provides three types of outputs, allowing the sensor to easily interface with a wide range of general purpose data logging equipment and meters. Additionally, it prevents corrosion of the sensor (using AC excitation), and galvanically isolates it from unwanted underground currents.

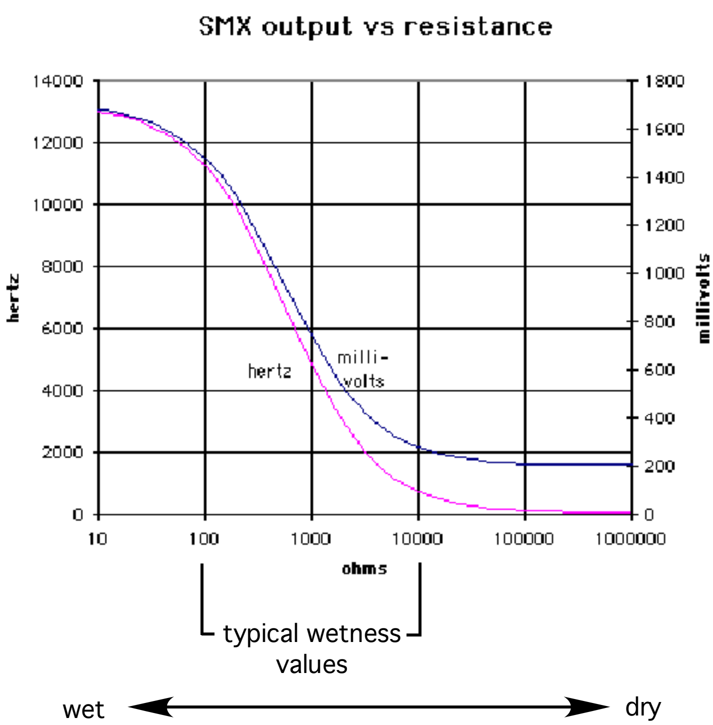


The SMX is available as an OEM assembled circuit board, suitable for incorporation into custom systems. It is also available potted in industrial epoxy with 6 wire leads, suitable for outdoor deployment.

The SMX is commonly used with the IRROMETER WATERMARK™ sensor. When buried at root depth, the WATERMARK reaches equilibrium with the local soil moisture and produces electrical resistance that is inversely proportional to soil moisture. (It also depends slightly on temperature.) The SMX transmits the measured resistance as a voltage, current or frequency that can be read by data-loggers or irrigation controllers.

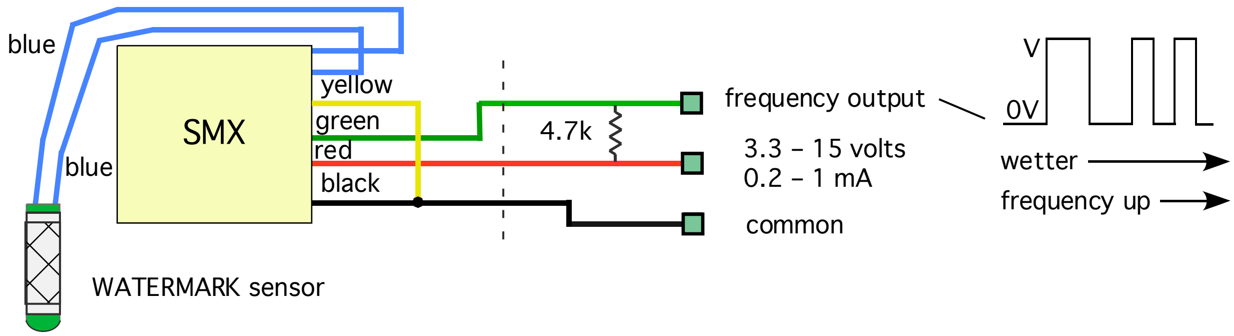
Specifications:

- Supply voltage: 3.3 to 15 VDC
- Frequency output: 50 Hz (dry) to 7 kHz (wet) open collector square wave (needs pull-up resistor to read out frequency.)
- Frequency output with sensor short circuit: ~13 kHz
- Typical voltage output: 0.2 volts (dry) to 1.0 volt (wet)
- Voltage output with sensor short circuit: ~1.7 V
- Typical current output (also supply current): 0.2 mA (dry) to 1.0 mA (wet)
- Current output with sensor short circuit: ~1.7 mA
- Supply variation: < 0.01% per volt.
- Operating temperature: -0°C to +50°C
- Temperatures below 0°C: no meaningful signal

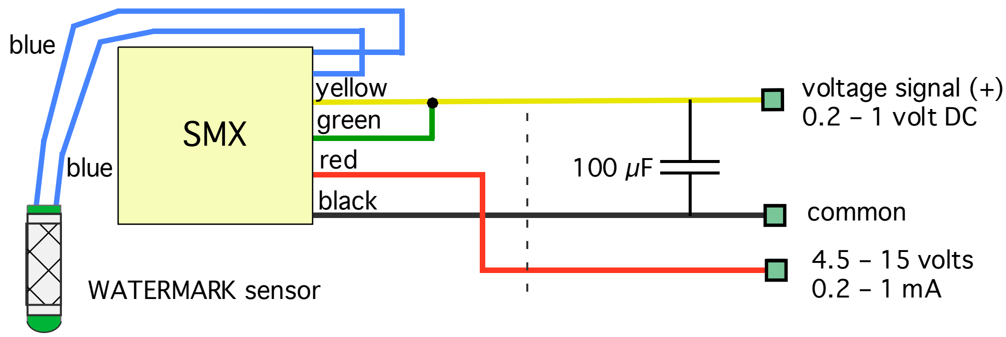


SMX output configurations

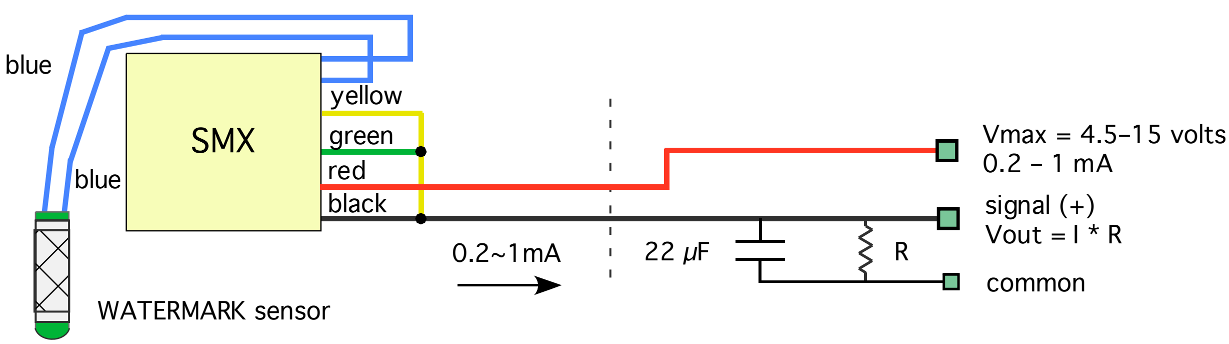
I. Digital Frequency Output: 50 – 10,000 Hz. This output can be measured using a COUNT or PERIOD function on a data logger.



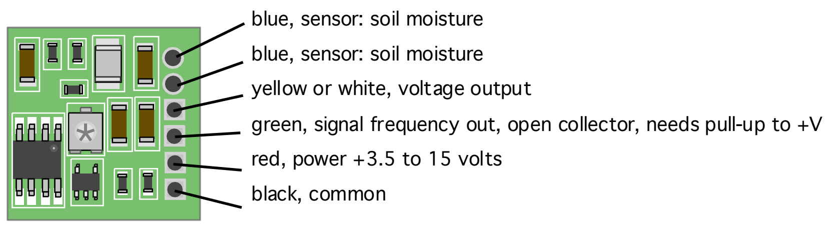
II. Voltage output: 0.2 – 1 volts. This can be measured using analog-to-digital on a data logger.



III. Two Wire Current Output: 0.2 – 1 mA. The current on the two wire circuit may be converted to a voltage at the input of the data logger. A 1 kΩ resistor will convert the 0.2 – 1.0 mA current into a 0.2 – 1 volt signal. This can be measured using analog-to-digital on a data logger.



SMX top view (component side)



Watermark installation:

"Plant" the sensors, following the Watermark instructions for presoaking. Install the sensors while they and the soil are wet, and maintain good contact with the surrounding soil. Use a slurry as “glue” if necessary.

The sensors will interact with one another if they are planted too close together. Keep them a foot or two apart if possible.

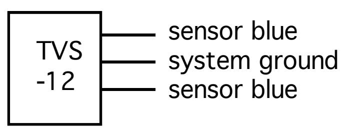
Install a temperature sensor at the same depth as the sensor, in order to implement the temperature compensation.

Be sure the Watermark sensor is in good contact with the soil matrix.

Lightning protection:

This circuit, like any that is installed in intimate contact with the soil, is subject to danger from lightning This is especially a problem if the soil moisture sensor is installed at a distance from the data logger or readout device that is monitoring the wetness, and the data logger has its own separate ground connection. If lightning strikes nearby, there can be large differences in ground potential between the two locations and currents will attempt to flow through the interconneting wires and through the sensitive circuit elements. The inputs on the blue and brown wires are protected to ±25 volts, however, this might not be enough in frequent lightning areas. Solutions:

1) Use a TVS (transient voltage suppressor, surge protector) rated at 12 volts across the sensor leads, with the ground of the TVS attached to the cable shield that leads up to the ground terminal on the data logger.



2) power the SMX from a separate battery, and transmit the data as a frequency using optical isolation.

3) install the data logger and the SMX in close physical proximity.

Programming:

A micro program should do the following
1) turn on the power to the SMX module
2) allows the reading to stabilize for 1 second
3) reads the raw millivolt value.
4) converts the raw millivolt value to ohms using a lookup table
5) standardize the resistance using the formula above
6) calculate the kPa value using the piecewise linear formula above
There may be an additional step, to average the readings over some period of time to go into the log file.

While the result will be a good first approximation, if you do have a reference instrument such as a tensiometer, your best results will come from developing your own calibration table for kPa vs resistance. It has been found that the curve does vary, even considerably, depending on the type of soil. The most important thing is to observe the plants and correllate the readings with real signs of health or stress.

Reading the sensor signal, frequency or voltage, example

Connect the SMX as in figure 2, for frequency output. This program is written in PBASIC for the BASIC Stamp, using the command COUNT to determine the SMX oscillation frequency. Similar methods are available on other microcontrollers such as the Parallax Propeller or the Arduino.

```
' simple test of the SMX operation, count input frequeny in Hz
result     var  word
loop:
  count 12,1000,result   ' count on Stamp P12 for 1 second
  debug ? result         ' show the result in counts
goto loop
```

The result should be between 50 Hertz (dry, infinite ohms) to 10000 Hertz drenched (550 ohms) or 13000 Hertz with a direct short circuit across the grid.

Alternatively, here is code using the voltage input version. Connect the SMX as in figure 3, for voltage output, and connect the voltage to an analog to digital converter, as for example an analog input of an OWL2e data logger.

```
' simple test of the SMX operation, voltage input.
result     var  word
DO
  GOSUB ADread          ' not shown here
  DEBUG ? result        ' show the result in millivolts
  PAUSE 1000            ' slow it down
LOOP
```

The result should come out between 200 millivolts (dry) to 1000 millivolts (drenched, ~550 Ω), to 1700 millivolts (direct short circuit across the grid). **IMPORTANT:** If two or more sensors are located in close proximity, the power should be turned on to only one at a time, to avoid interaction.

```
' simple test of the SMX operation, voltage input.
result var  word
DO
  HIGH power1                ' turn on power to the 1st SMX module
  PAUSE 1000                 ' allow reading to settle
  GOSUB ADread               ' read the value
  LOW power1                 ' turn off power to the 1st SMX
  DEBUG ? result             ' show the result in millivolts
  HIGH power2                ' turn on power to the 2nd SMX module
  PAUSE 1000                 ' allow reading to settle
  GOSUB ADread               ' read the value
  LOW power2                 ' turn off power to the 2nd SMX
  DEBUG ? result             ' show the result in millivolts
LOOP
```

The raw readings above can be used to establish thresholds for irrigation or other actions, based on observation of plant stress and well being. On the other hand, in order to obtain quantitative results that can be compared to the Irrometer tables and advice for use of the Watermark, the raw voltage or raw count can be transformed to resistance, temperature compensated, and converted to moisture units in kilopascals. The following paragraphs describe this procedure. The examples show this written in the PBASIC language for the BASIC Stamp, however, it is easy to understand and translate to other processors.

Interpret the readings, convert voltage or frequency to wetness.

The output of the SMX is a voltage, current or frequency that depends on the electrical resistance connected across the SMX input terminals. For a soil sensor, that in turn depends on its moisture content and the surrounding soil.

Here is a scheme to convert the millivolt reading directly to kPa moisture units. This applies specifically to the Watermark 200SS Granular Matrix sensor. The graph is a curve, not a straight line, so a small lookup table with interpolation is used for calculation.

kPa = 0	**for mV > 935**
kPa = 9 - (mV - 723) * .0425	**for 723 <= mV <= 935**
kPa = 15 - (mV - 517) * 0.0291	**for 517 <= mV <= 723**
kPa = 35 - (mV - 323) * 0.103	**for 323 <= mV <= 517**
kPa = 55 - (mV - 283) * 0.500	**for 283 <= mV <= 323**
kPa = 75 - (mV - 264) * 1.052	**for 264 <= mV <= 283**
kPa = 100 - (mV - 250) * 1.786	**for 250 <= mV <= 264**
kPa = 200 - (mV - 229) * 4.762	**for 229 <= mV <= 250**
kPa = 200	**for mV < 229**

And here is a corresponding scheme to convert the frequency reading in Hz directly to kPa.

kPa = 0	**for Hz > 6430**
kPa = 9 - (Hz - 4600) * 0.004286	**for 4330 <= Hz <= 6430**
kPa = 15 - (Hz - 2820) * 0.003974	**for 2820 <= Hz <= 4330**
kPa = 35 - (Hz - 1110) * 0.01170	**for 1110 <= Hz <= 2820**
kPa = 55 - (Hz - 770) * 0.05884	**for 770 <= Hz <= 1110**
kPa = 75 - (Hz - 600) * 0.1176	**for 600 <= Hz <= 770**
kPa = 100 - (Hz - 485) * 0.2174	**for 485 <= Hz <= 600**
kPa = 200 - (Hz - 293) * 0.5208	**for 293 <= Hz <= 485**
kPa = 200	**for Hz < 293**

One more step is necessary if the soil temperature deviates much from 24°C (75°F). The temperature may be known from a measurement, or, it may be estimated. The correction amounts to 1% per degree Fahrenheit. It adjusts the kPA reading to what it would be at the standard temperature 24°C (75°F).

$$kPa_{75} := kPa * (1 - 0.01 * (°F - 75))$$

or

$$kPa_{24} := kPa * (1 - 0.019 * (°C - 24)$$

The above formulae are derived from the calibration charts for the Watermark 200SS Granular Matrix sensor from Irrometer Corp., and comparison with the Irrometer handheld meter.. A diffent curve would apply to other conductivity sensors It is an approximation. Please see notes.

Programming the conversion, example

Having measured the millivolt (mV) or frequency (Hz) output of the SMX, it is necessary to convert to wetness in units of kPa. This can best be done via interpolation in a lookup table. Some processors support floating point numbers, so the schemes shown on page 4 can be implemented directly with the fixed point multipliers shown. The following is syntax for the BASIC Stamp. This uses its ** operator, where fractions are expressed as a value F that satisfies (fraction = F/65536). The Propeller has a similar ** function that expresses the fraction with a denominator of 2^32, (fraction = F/4294967296). For example, the fraction 0.0425 is represented by the numerator 2785 on the BASIC Stamp, or by 182536110 on the Propeller, because 0.0425 = 2785/65536 = 182536110/4294967296.

```
Convert_mV_kPa:
    SELECT mV
      CASE > 935
        kPa = 0
      CASE < 229
        kPa = 200
      CASE 723 TO 935
        kPa = 9 - (mV - 723) ** 2785   ' 2785 = 0.0425 * 65536
      CASE 517 TO 723
        kPa = 15 - (mV - 517) ** 1907   ' 1900 = 0.0291 * 65536
      CASE 323 TO 517
        kPa = 35 - (mV - 323) ** 6750   ' 6750 = 0.103 * 65536
      CASE 283 TO 323
        kPa = 55 - (mV - 283) ** 32768  ' 32768 = 0.500 * 65536
      CASE 264 TO 283
        mV = mV - 264
        kPa = 75 - mV - (mV ** 3408)    ' 3408 = 0.052 * 65536
      CASE 250 TO 264
        mV = mV - 250
        kPa = 100 - mV - (mV ** 51511)  ' 51511 = 0.786 * 65536
      CASE 229 TO 250
        mV = mV - 229
        kPa = 200 - (mV * 4) - (mV ** 49938)   ' 49938 = 0.762 * 65536
      CASE <229
        kPa = 201
    RETURN

Convert_Hz_kPa:
    Select Hz
      CASE  > 6430
        kPa = 0
      CASE 4330 TO 6430
        kPa = 9 - (Hz - 4330) ** 281          ' 281 = 0.004286 * 65536
      CASE 2820 TO 4330
        kPa = 15 - (Hz - 2820) ** 260         ' 260 = 0.003974 * 65536
      CASE 1110 TO 2820
        kPa = 35 - (Hz - 1110) ** 767         ' 767 = 0.01170 * 65536
      CASE 770 TO 1110
        kPa = 55 - (Hz - 770) ** 3856         ' 3856 = 0.05884 * 65536
      CASE 600 TO 770
        kPa = 75 - (Hz - 600) ** 7707         ' 7707 = 0.1176 * 65536
      CASE 485 TO 600
        kPa = 100 - (Hz - 485) ** 14248       ' 14248 = 0.2174 * 65536
      CASE 293 TO 485
        kPa = 200 - (Hz - 293) ** 34131       ' 34131 = 0.5208 * 65536
      CASE < 293
        kPa = 200
     RETURN

TemperatureCompensate:
  kPa = kPa - (kPa * (degF - 75) / 100)
     ' or use Celsius * 9/5
  RETURN
```

Basis of the calculations:

Showing the resistance values that correspond to certain levels of soil water potential, specifically for the WATERMARK™ 200SS. This is a summary of Irrometer "Chart #3", composed of piecewise linear segments. The resistance values are taken or temperature compensated to 75 degrees Fahrenheit (24 degrees Celsius). This is the function that is programmed into the Irrometer moisture meters and data logger, and it is the basis for the SMX calibration equations in this manual.

kPa = (ohms - 550) / 50 for 550 <= ohms <= 1000
kPa = 9 + (ohms - 1000) / 100 for 1000 <= ohms <= 1100
kPa = 10 + (ohms - 1100) / 180 for 1100 <= ohms <= 2000
kPa = 15 + (ohms - 2000) / 200 for 2000 <= ohms <= 6000
kPa = 35 + (ohms - 6000) / 160 for 6000 <= ohms <= 9200
kPa = 55 + (ohms - 9200) / 150 for 9200 <= ohms <= 12200
kPa = 75 + (ohms - 12200) / 135 for 12200 <= ohms <= 15575
Pa = 100 + (ohms - 15575) / 125 for 15575 <= ohms <= 28075

The calibration curves are based on a combination of research studies and applies best to sandy loam soils. It wont apply so well to soils of high sand or high clay content. It will tend to overestimate the water content of sandier soils. The important thing is to be aware of the plants, to find the reading that corresponds to the best point for irrigation.

Selected references:

• http://www.kimberly.uidaho.edu/water/swm/
• Shock, Barnum and Seddigh, "Calibration of the Watermark soil moisture sensors for irrigation management" Proceedings of the 1998 Irrigation Association Technical Conference
• Irmak & Haman, "Performance of the Watermark Granular Matrix Sensor in Sandy Soils", Applied Engineering in Agriculture, 17(6):787-795 2001

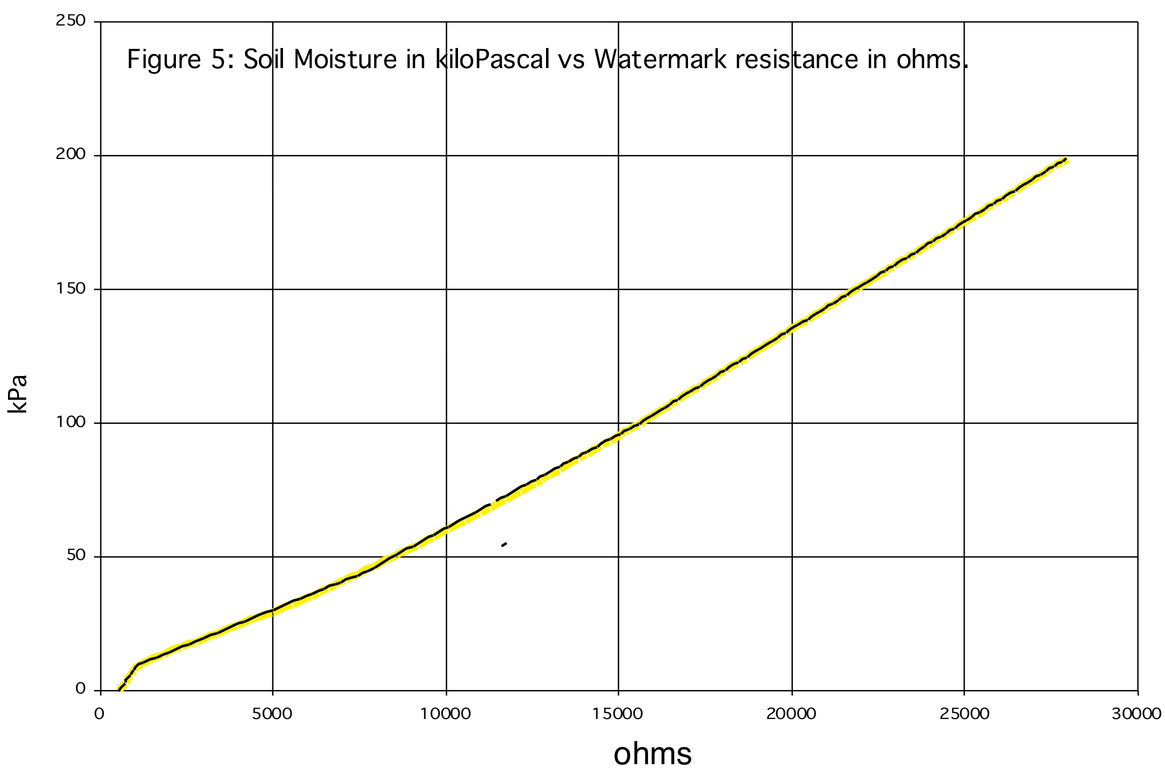
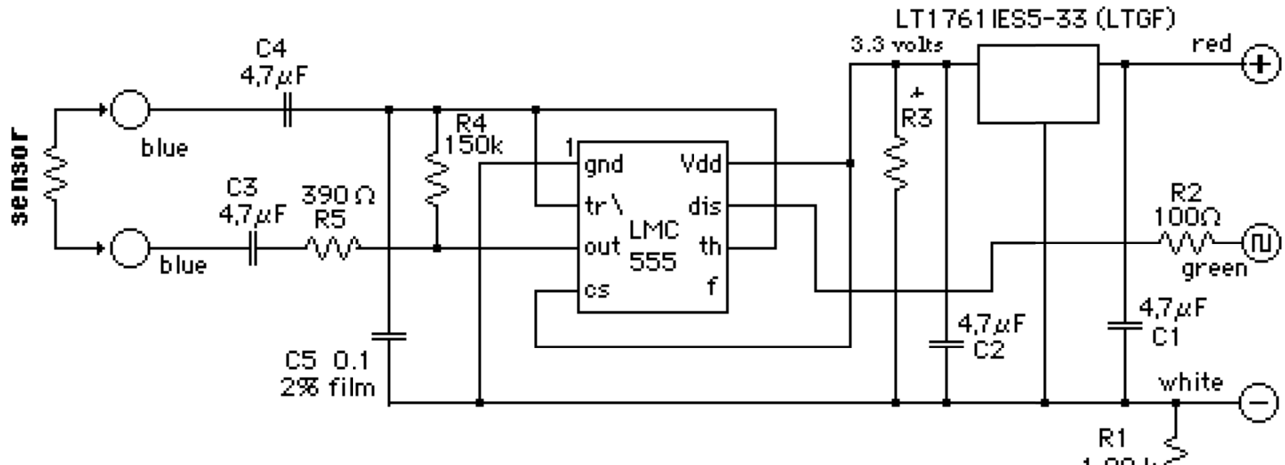


Figure 5: Soil Moisture in kiloPascal vs Watermark resistance in ohms.

Appendix 1: Technical information:



R3 sets the offset current, 200 µA, and in recent SMX modules is a 36.5 kΩ fixed resistor in series with a 10 kΩ trimmer. In earlier SMX, it was a selected resistor in the neighborhood of 40kΩ.

The power supply voltage is regulated at 3.3 volts DC by the micropower regulator. The power supply + input can be as low as 4 volts and as high as 15 volts. Filter capacitors are provided for stability and averaging of the supply current. The LMC555 timer operates in its direct feedback mode, with a square wave on the totem pole output from pin 3 charging or discharging the 0.1 µf polyester film timing capacitor through the network of fixed resistors in series/parallel with the moisture sensor. When the sensor is dry, the 150kΩ resistor sets a minimum oscillator frequency of 50 hertz. When the sensor is wet, or a short circuit, the 390Ω in series with the grid limits the upper frequency to about 13 khz. The current through the sensing grid is AC. Nonpolar ceramic capacitors isolate the circuit from the sensor, to assure that the average current is AC and to forestall galvanic interactions in the soil environment. The output frequency is transmitted to the logger from the open collector DIS output pin, protected from miswiring by the 100 Ω resistor. Normally a pullup resistor will be provided to give voltage transitions at the logger. The current drawn by the circuit varies linearly with the frequency due to the charge and discharge cycles of the 0.1¨F capacitor. The supply current is proportional to wetness, a voltage signal can be taken from across the 1kΩ resistor. The offset current is set to 200 µAby R3, 36.5 kΩ in series with 10kΩ trimmer.

There will be a small AC component on the DC output signal, that can be averaged in software. A 10µf capacitor in parallel with the output resistor will reduce the AC component to <5 millivolts.