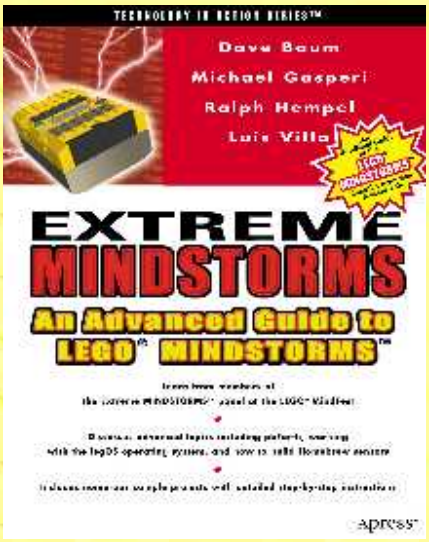
EXHIBIT B3

MindStorms RCX Sensor Input Page



Extreme Mindstorms: An Advanced Guide to Lego Mindstorms by Dave Baum, Michael Gasperi, Ralph Hempel and Luis Villa. It has information about programming the RCX in NQC, Forth, and using legOS, but most importantly it has two whole chapters that I wrote on Building Homebrew Sensors. These chapters take the time to go through the construction process step-by-step in easy to follow instructions. Click the box below to find out more about the book and how to purchase it online. I receive a referral fee from Amazon if you actually purchase it by following this link.

There is a nice article about LEGO Mindstorms in the IEEE Spectrum that can be read online.

Contents:

A few words of background:

- The not so fine print: This page is not connected with or endorsed by The LEGO Group. LEGO, LEGO SYSTEM, LEGO TECHNIC, LEGO DACTA, LEGO MINDSTORMS are trademarks of the LEGO Group.

- I started these pages in October 1998. Since then many experimenters have contributed to the knowledge presented here. I hope that I have identified all of you properly, given your e-mail address and links to your pages. I thank those who are courteous enough to return the favor.

- The usual caveats apply. If following any instructions provided here causes damage to your RCX or anything else in the universe, it is your own tough luck.

- Many people write me with questions about the projects described on these pages and I try to answer all of them. However, you will probably find the following booklets helpful in obtaining the electronics knowledge needed to build the projects and a lot more. They are available from Radio Shack for only $1.99 each and were written by my personal idol Forrest Mims III. In order of my preference: *Sensor Projects 62-5026, Science Projects 62-5018, and Environmental Projects 62-5019.* I have also learned a lot about building projects by reading printed magazines like *Popular Electronics* and *Electronics Now* by Gernsback and *Everyday Practical Electronics* published online by EPEMAG.

Sensor Basics:

The work was done mostly using the Spirit OCX and a Visual Basic program that let me directly select sensor types and poll for their readings. The timing and voltages were made with a scope and the pull up resistances were calculated by loading the inputs and measuring the voltage drop.

The RCX reads Touch, Temperature and Light sensors in the pretty much the same way. Rotation is a lot like Light but will be covered later. The voltage on the input is converted to an internal RAW value in the range 0V=0 to 5V=1023. Depending on the sensor type, the RAW number is converted into the number you see in the program, Test Panel or View.

- Touch sensors: If the RAW value is less than about 450 it becomes a 1 and if the RAW value is greater than about 565 it becomes a 0.

- Temperature sensors: In degrees C, Temp=(785-RAW)/8 within the range -20C to +70C.

- For Light sensors: Light=146-RAW/7 within the range 0 to 100.

- Summary Input Table

Volt	Raw	Sensor Ohms	Light	Temp C	Touch
0.0	0	0	-	-	1
1.1	225	2816	-	70.0	1

2.8	565	12309	65	27.5	0
3.8	785	32845	34	0.0	0
4.6	945	119620	11	-20.0	0
5.0	1023	Inf	0	-	0

For Touch and Temperature type input, the RCX has a 10,000ohm resistor pulling up the input to 5V. The sensor only needs to provide some resistance to create a reading. You can create a fake temperature sensor by hooking a 4,700ohm resistor in series with a 50,000ohm potentiometer (both available from Radio Shack). This will read from about -11C to +60C. With Touch or Temperature sensors there is no reason why you can't overdrive the input to whatever voltage you want within the 0V to 5V range.

You should NOT try to overdrive an input that thinks it has a Light or Rotation Sensor type on it. Use one of the general purpose analog interfaces. The RCX has a 120ohm resistor pulling up to about 8V (probably a diode drop from the battery voltage) to power the red LED for about 3ms and then looks at the sensor voltage during a short 0.1ms time. During the short time the sensor is read just like the Touch or Temperature sensors. The fake Temperature sensor from above will read Light values from 100 down to about 22 without the risk of damaging the RCX since it never loads the input with less than 4,700ohms. I doubt any real damage would occur to the RCX since people could accidentally connect a Touch sensor where a Light sensor should be or even a motor output to a sensor input. I can't imagine LEGO letting this destroy the RCX. Don't say I didn't warn you.

Some ways to overcome the limits of only having 3 inputs:

- **Two or more touch sensors can be connected to the same input. This ORs their value. If any of the sensors are touched the input will be a 1. If all you want to do is reverse motors when you touch something this is the way to go.**
- **Tom Schumm has figured out how to orient the wires to allow two or more Touch sensors to be hooked in series to create the AND function. Here is his diagram.**
- **Brian Stormont suggested that a Light sensor and a Touch sensor could be connected to the same input. When the touch sensor is pushed the Light value will be 100, and when it is not, you get the normal Light values.**
- **Rob Stehlik has a way to use LEGO lamps to connect two Touch sensors to the same input and still determine which is pressed.**
- **Build a Three Touch Sensor Expander: Paul Haas originally suggested that you can put 3 Lego touch switches on one input by adding 3 resistors. I've built on Paul's idea and the Dean Husby cut-up LEGO electric plate method to design the Three Touch Sensor Expander.**
- **Build My Input Mux: Several people have suggested Multiplexing (Mux) the inputs. Most schemes involve using a motor output to switch either electrically or mechanically between various extra inputs. I'm working on a scheme that doesn't require using a motor output. I think it was first proposed by Sven Horstman.**
- **Dean Husby has a page that shows a way to make an expander similar to mine at TFM Lego Invention Page.**
- **Wes Matchett shows how to build a relay based switch that uses a motor output to select between different inputs or outputs on his extender page.**
- **Durwood Fletcher sent me this output expander design that uses a sensor input to toggle between a primary and secondary motor output.**
- **Lorenzo Zago has plans for a DAC based expander on his Boolean Input Multiplier page.**
- **Rob Duff has plans for an elaborate 6 touch input Mux on his RCX Input Page.**

How to see RAW values with only the standard RCX software:

- Open "Robotics Invention" Software and Login
- Go to "Program RCX"
- Go to "RCX Code"
- Bring out the "Test Panel" from lower right corner

- Click "Get Sensor Values" (Only Sensor 1 will show a value of 0)
- Now on the RCX itself, push View two times to select Sensor 2 (yes Sensor 3 does the same thing)
- The RCX display should now read 1023 if there is nothing connected
- Attach an electrical connector cable to Sensor 2 input
- On the under side of the unconnected end you can clip lead resistors, voltmeters, etc.
- 10,000ohms will give a View reading of 512 and 0ohms will give 0
- You can apply a voltage here if you are absolutely sure about its polarity and value etc.
- 0V will equal 0 and 5V will be 1023
- Unfortunately you can't do anything with the RAW values in RCX Code.

Homebrew Sensors:

- **My General Purpose Analog Interfaces can be used to interface many other sensors.**
- **My Temperature Sensor is made from a $2 Radio Shack part, some brass tubing and a cut-up LEGO block.**
- **My Sound Sensor gives your robot an ear that can be used to turn your $200 MindStorms into a Clapper (program included).**
- **My CdS Light Sensor is more sensitive to visible light than the LEGO Light sensor and is made from a $2.29 Radio Shack part.**
- **My Differential Light Sensor is better at tracking a light source because it uses two photocells and only sends the difference in light level to the RCX.**
- **My Rotation Sensor is built from 100% LEGO parts and can be interfaced with either software or hardware.**
- **My Post-in-Ring Sensor allows you to make an all around touch sensor.**
- **My Almost Ultrasonic Motion Sensor detects the motion of objects near to the RCX.**
- **My Motor Speed/Torque Sensor allows you to measure the speed or torque of a running motor.**
- **My Pressure Sensor can measure the actual pressure generated with LEGO pneumatics.**
- **My Simple Angle Sensor is made with a tiny potentiometer and reads angles up to 270 degrees.**
- **My Galvanic Skin Response Sensor measures the resistance of your skin to determine your emotional stress level.**
- **Sven Horstmann is developing a specialized sensor for Line Tracking .**
- **Brian Stormont has a page that discusses the details of making a Temperature Sensor like mine plus a Light and a Bend sensor at Homebrew Lego Sensors.**
- **Dean Husby has a page that shows a way to make a Temperature Sensor like mine by cutting LEGO electric plates into 2X2 connectors at TFM Lego Invention Page.**
- **Malcolm S Powell has an opto-interrupter based sensor that can be used to make a Zero Force Limit Switch, Rotation and Linear Motion Sensor.**
- **Imre Kabai has come up with an interesting connector idea. He replaces two studs of a regular LEGO block with 4/40 brass screws.**
- **Terry King uses copper foil to make connectors for his LED bricks.**
- **Bert van Dam has a page for the LEGO Cybermaster that contains a RCX compatible Temperature Sensor, Variable Resistor, and other projects at New Sensors.**
- **Wes Matchett has a couple of pages for making Touch Sensors from old PC mouse parts off his Mindstorms Page.**
- **There are photographs of LEGO compatible sensors at ESG Lego Robotics Seminar.**

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