

On A Sound Controlled Fan- Regulator

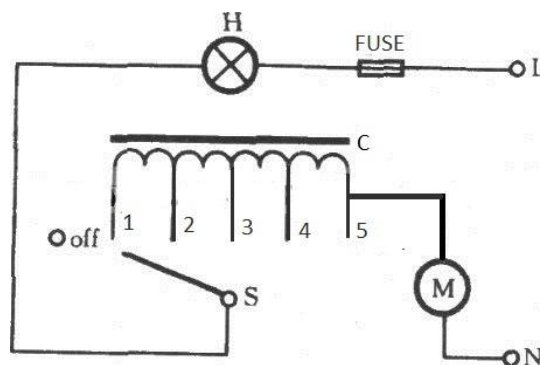
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ABSTRACT: Here we shall describe an electronic regulator which will be able to regulate a fan/lamp or any kind of similar load, simply in response with ambient sound. Its architecture will be discussed in full detail and in several alternative ways (for example, utilizing Arduino microcontroller), including a possible power saving scheme. Moreover the work will be presented in a generalized fashion, not depending on particular components or circuits. This regulator has been fully tested and successfully operated by author himself.

I. INTRODUCTION

The regulators usually we consume from electronic markets, are of two types. One is resistor based early regulators, which upon rotating the knob of the regulator, connects the load to different resistor values, and thus controls the current drawn by the load. As we know well, these types of regulators can't control the power of the load effectively, or in other words, we're to pay extra cost for electricity for reduced power usage! Since, the overall circuit is to dissipate additional power to deliver the requisite power to the load. The simplified circuit diagram of such a regulator is like below:



An Old Fashioned Regulator Circuit Diagram (courtesy: www.seekic.com)

Here C is the resistor coil, S is the controlling knob, V is a voltage source and M is load.

The second type of regulator, which is currently overwhelming in markets, works in a completely new principle. They are built by diac and triac, and the firing angle of the triac is controlled by a variable resistor, and the effective ac



voltage is chopped off during conduction through the load by controlling at which instants current will flow, thereby

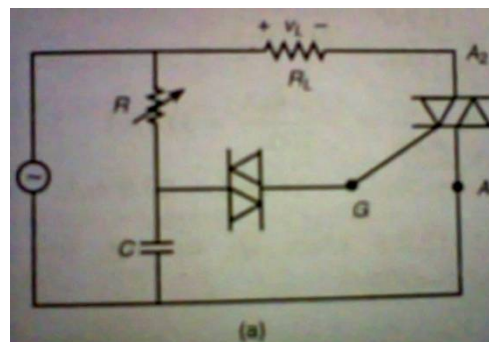
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reducing the effective r.m.s. voltage. Thus it can control how much power will be supplied to the load from the voltage source. Therefore, if the load is a fan, lesser speed will consume lesser power, unlike resistor based regulators. This is one of the great advantages of such regulators. Another advantage is that it is possible to control load power smoothly by such regulators. However, the main disadvantage of such regulators is that due to turning on/off the load at high switching speeds, the voltage surges may often make them prone to failure.

One possible circuit diagram of such regulators is like below:



A DIAC-TRIAC based regulator (courtesy: Fundamental Principles of Electronics by B. Ghosh)

A third kind of regulator, based on capacitors, is also sometimes used, which also offers many advantages.

11. RELATED WORKS

Sound operated devices were described by some earlier authors in some papers, like Elechi Promise⁽¹⁾, who described a sound controlled door-lock system in 2015. Though papers/mainstream works related to sound operated regulators are not much seen in various journals, yet some related works are found in several websites⁽²⁾, though no variation is observed in their basic construction. In our present article however, we shall describe such a device in various alternative forms, including microcontroller implementation. Also our work will be presented in a generalized format, not bound to a limited number of channels, or particular components/circuits.

11.1. MATERIALS AND METHODS

Now we shall enter into our original motto. To describe an electronic regulator, which will respond at ambient sound. First we shall discuss about the way of its construction, and after that we shall enter into its detail architecture. Finally we shall discuss how this design can be developed for more facilities.

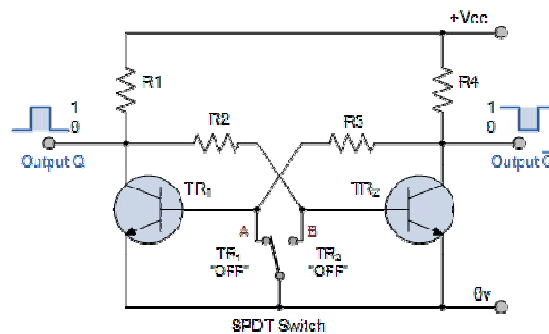
As we know quite well, to utilize sound in an electrical device, the first and foremost task is to convert it into electrical energy. So this will be our first object. There can be several ways to accomplish this. For example, often ordinary speakers are used in this purpose, which converts the incident sound into electrical energy by electromagnetic induction. Also in early days, carbon microphones were used in this purpose, invented by great American inventor Thomas Edison (also independently by David Edward Hughes)⁽³⁾, and were largely employed in voice telephony. But perhaps the most popular and lightweight device to perform this task at present time is electret microphone. This was invented in 1961 by James West and Gerhard Sessler⁽⁴⁾ in Bell Laboratories. These sorts of microphones utilize materials called electrets with permanent embedded static charge. Incident sound changes the capacitance of the system, and hence a proportional change in voltage due to fixed charge in electret, and this change is further amplified by a small transistor, usually a JFET, which is also packed in the microphone enclosure. In our device, we shall use this type of microphone.

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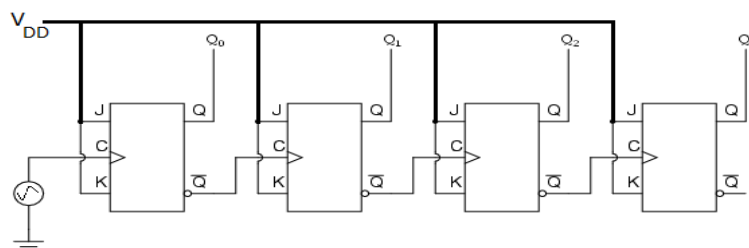
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Our next task will be to use this electrical energy. Since, the electrical energy, we get in this way is very small, we first are to amplify this energy to suit our purpose (Here we shall use a simple transistorised amplifier, but very wide varieties of amplifiers can be employed to do the amplification). After this amplification, clearly we are to activate some other electronic circuit, which will respond to this electrical signal. Now clearly the device, which we are describing, should act in some stable states; for example, if it is regulating a fan in a particular speed, the fan should withstand that speed, until a further operation is made on the device. Thus we can guess that we shall have to use some flip flop like device, which can have more than one well defined states, and can be triggered to stay in any one of them. A very well known circuit is a bistable multivibrator like below:



A bistable multivibrator (courtesy: www.electronics-tutorials.ws)

These kinds of circuits are often used in ordinary clap switches, which after receiving a sound, changes the state of the circuit, and makes the circuit in on/off state accordingly. But can we use such circuit for our purpose? Yes, we can. But with some disadvantage. As we are discussing about a regulator, we want to include the possibility to keep the circuit in several modes; three, four or more. So that the load can be regulated in several possible ways. Therefore we are to find some other similar circuit, which can stay in a number of stable states much more than two. Fortunately, we can have such device! Cascading a number of flip-flops (actually a special class of flip-flops, called JK flip-flops) we can construct a device called “ripple counter” which can count input pulses applied in the circuit, in binary numbers. Block diagram of such a counter is like below:



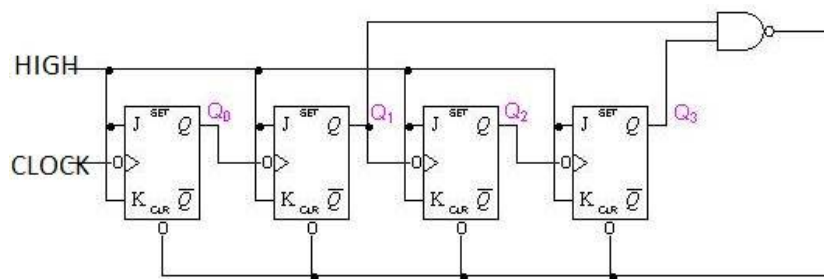
A ripple counter (courtesy: www.allaboutcircuits.com)

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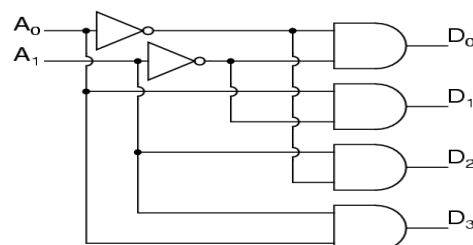
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In this diagram, each rectangular block represents a JK flip-flop. System of “n” such JK flip flops can count up to $2^n - 1$ pulses, and called modulus- 2^n counter. For example, the device above can count 15 pulses, and it’s a mod-4 counter. Attaching NAND gate to the output, it’s also possible to have counters with modulus other than 2^n . For example, the block diagram below is of a decade or modulus-10 ripple counter:



A decade ripple counter (courtesy: www.functionspace.com)

Now if we attach a “1-of-n decoder”⁽⁵⁾(the figure below is an example) with such a ripple counter, the output may have many stable states, as many as one wants. For example, if we couple such a decoder with a Mod-16 counter, the output may have 16 stable states and 10 stable states for a decade counter.



A 1-of-n decoder (courtesy: Wikipedia)

If we connect a Mod-2 counter, with the decoder above, each output will be active after 0th, 1st, 2nd and 3rd pulse, creating 4 stable states. After 3rd pulse, the system will be automatically reset.

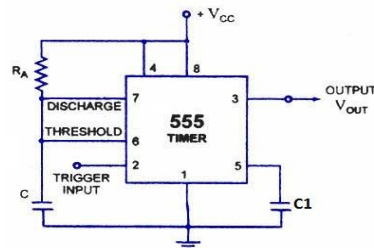
Thus we got an excellent multiple state circuit! Now if we use the electrical signal from the microphone (along with its amplifier) as a clock pulse, and trigger the counter-decoder combination by it, then after receiving each pulse generated by sound, each of the “n” output lines will be activated, and here is roughly the essential idea of our device. Though of course, our work is still not complete!

It’s true that it’s theoretically possible to trigger the above “counter-decoder” combination by the electrical signal generated by microphone, but in practice, it creates poor response. Since there will be no well defined width of this pulse. A single sound like clap can activate various output lines in succession, or even may not be able to change the output state sometimes, which are certainly undesired. To overcome this problem, it’s best to use a monostable multivibrator as the mediator of amplifier output and counter input. The output of amplifier will first trigger the monostable multivibrator, which in turn will trigger the counter, which is advantageous since the width of the pulse generated from this multivibrator is always very fixed and also well defined and can also be varied changing some circuit components. The easiest way to build a monostable multivibrator is to implement IC 555, as the following figure:

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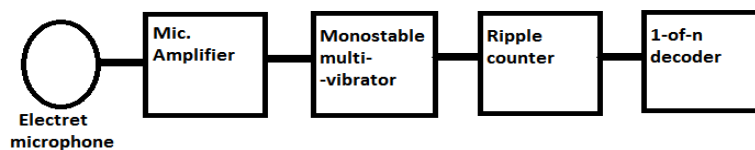
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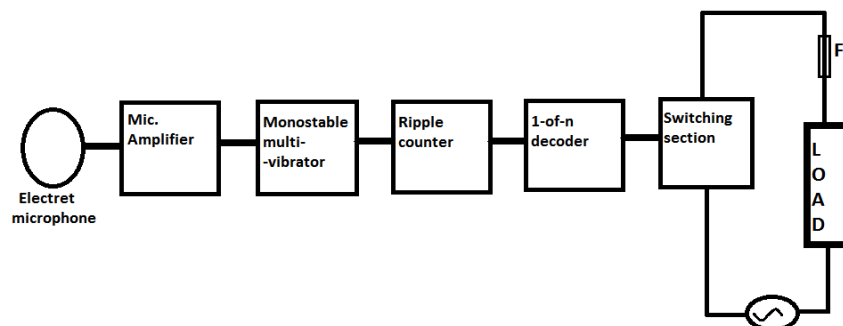


A monostable multivibrator using IC 555 (courtesy: www.circuitstoday.com)

It is theoretically calculated that the output pulse width of such multivibrator is $R_A C \log_e 3$,⁽⁶⁾ thus one can vary the width, by varying either the resistor or the capacitor value or both. So till now our device is like:



Now to utilize the decoder output, clearly we should add some switching section to it, so that it can take form of a regulator. Later we shall discuss about the switching section in some detail, and shall see it can be built in several ways. Therefore the block diagram of the complete device is like:



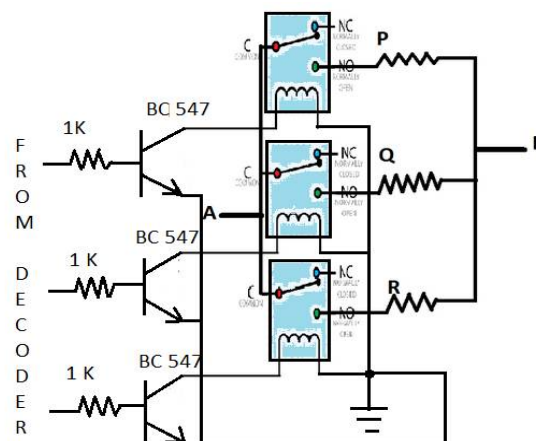
How can we build our switching section so that it will regulate the load in response with the decoder output? Well, we shall see that we can build it several possible ways, which we mentioned earlier. One way is of course to utilize relays, which we shall discuss first. In fact, relay based switching is one of the most popular ones. But in that case we are to

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design the switching circuit in such a way, so that each relay will connect the load to a different path of conduction, among which the resistances are different. One possible way to do this is like below:



A switching circuit built with relays

HERE P, Q, R etc. are different resistors and points A and B are to be connected with load in series. The relays used here are of SPDT type. Some junction diodes may be connected (not shown above) at opposite polarity across the coils of the relays, to prevent the transistors from voltage surge, when the relay gets on/off. As is clear from the diagram, each decoder output will activate only one relay at a given instant through the driver transistors, and current will flow through the corresponding path. Here for convenience, we showed three channels only. But clearly the number of channels can be increased as much as required. If we keep one of the outputs of the decoder with no connection (no relay is attached to it), the regulator will also stay in off mode, like other regulators.

Though it's quite clear from our previous discussion how our device will work, but we shall tell it again for convenience. The incident sound will first be converted into electrical signal by electret microphone, which after being amplified will trigger the monostable multivibrator which in turn will trigger the counter-decoder combination, and the output will change to the next stable state, and will activate the corresponding relay making the current flow through the resistor attached to the relay. The pulse width of the monostable multivibrator can be adjusted suitably for faithful operation.

If we require not more than ten channels, we can implement some decade counter IC's in our device, which provide counter-decoder combination in single package. IC- CD 4017 is an excellent candidate. In that case, it can replace the counter decoder combination:

1V. IMPLEMENTING A MICROCONTROLLER:

There's another way to construct the entire circuitry excepting the switching section and amplifier. Since microcontroller based devices are becoming more popular now a days, it's quite customary to describe how we can employ a microcontroller to construct our device.

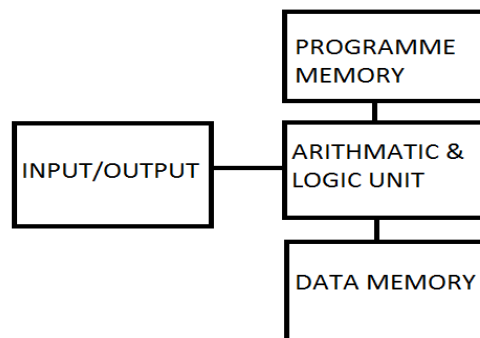
Microcontroller, as we know, is small computer-like device in a single integrated-circuit with processor and in-built memory (usually in the form of flash memory) along with input/output peripherals. Unlike an ordinary computer, which can perform multiple tasks, microcontrollers are used to do an assigned task. To make it perform the desired task, it's given a set of instructions called programme (by programmer, not manufacturer) which becomes loaded in its EPROM (erasable programmable read only memory) or EEPROM (electrically erasable programmable read only memory). On the other hand, contents of ROM can never be altered after delivery of the microcontroller, from its manufacture. Now a days, the programmes are usually written in high level language or assembly language, which is

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translated into machine language by compilers, and then burns the EPROM, enabling the microcontroller doing the specified task.



Block diagram of a microcontroller

The above building block of a microcontroller actually follows Harvard architecture. In Von-Neumann architecture, by contrast, there is only one memory for storage of programme and data⁽⁷⁾. 4 bit Intel 4004 was the first microcontroller released in 1971. Credit goes to Gary Boone and Michael Cochran for their first successful creation of microcontroller⁽⁸⁾.

In our purpose, we shall use one of the most popular microcontrollers at present time, named Arduino. The main advantage is that it is relatively easier to programme, which we can do in C language using Arduino IDE (Integrated Development Environment). Many types of Arduino boards are available in market like Arduino uno, Arduino nano, Arduino mega, Arduino pro⁽⁹⁾ etc. with more or less same basic features. We shall use however Arduino nano for our purpose since it is breadboard-friendly (though other Arduino products, even other microcontroller boards can also be used in this purpose), which is helpful for prototyping a device and also its cost is relatively low. This utilizes Atmega 168/328⁽¹⁰⁾ microcontroller IC for its operation.



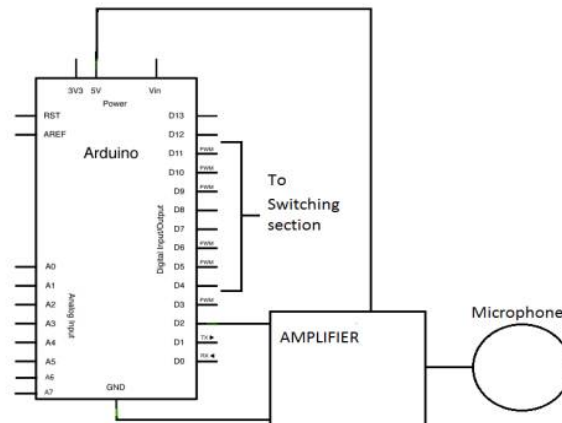
An Arduino nano microcontroller (courtesy: www.arduino.org)

Now we shall see, what kind of code will enable the microcontroller to do our required task. We are requiring the circuit, for example, to have the following set up:

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Set up of Arduino board for sound-controlled regulator

Now we get the desired operation from the microcontroller, we are to programme it in such a way that it will count the number of input pulses in a manner just as is done by a counter and 1-of-n decoder combination. One of the ways to accomplish this is like following:

```
#define relA 4//connecting relay A to PIN4
#define relB 5// connecting relay B to PIN5
#define relC 6// connecting relay C to PIN6
#define relD 7// connecting relay D to PIN7
int inpin=2;
int inputstate=0;
int lastinputstate=0;
int COUNT=0;
void setup()
{
  for (int i=4;i<=7;i++)
  {
    pinMode(i, OUTPUT);
  }
  pinMode(inpin, INPUT);
}
void loop()
{
  switch (COUNT)
  {
    case 0://when 1st RELAY is ON
      digitalWrite(relA, HIGH);
      digitalWrite(relB, LOW);
      digitalWrite(relC, LOW);
      digitalWrite(relD, LOW);
      break;
```


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```
case 1:// when 2nd RELAY is ON
    digitalWrite(relA, LOW);
    digitalWrite(relB, HIGH);
    digitalWrite(relC, LOW);
    digitalWrite(relD, LOW);
break;
case 2:// when 3rd RELAY is ON
    digitalWrite(relA, LOW);
    digitalWrite(relB, LOW);
    digitalWrite(relC, HIGH);
    digitalWrite(relD, LOW);
break;
case 2:// when 3rd RELAY is ON
    digitalWrite(relA, LOW);
    digitalWrite(relB, LOW);
    digitalWrite(relC, HIGH);
    digitalWrite(relD, LOW);
break;
case 3:// when 4th RELAY is ON(or no RELAY is ON, to indicate OFF state)
    digitalWrite(relA, LOW);
    digitalWrite(relB, LOW);
    digitalWrite(relC, LOW);
    digitalWrite(relD, HIGH);
break;
break;
}
inputstate = digitalRead(inpin);
if (inputstate!=lastinputstate) {

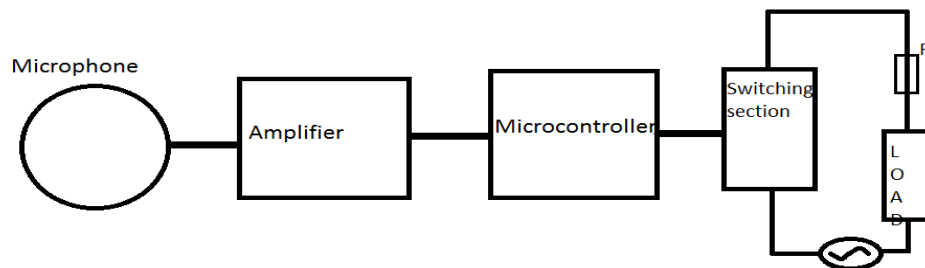
    if (inputstate==HIGH) {
        COUNT++;
    }
    else {
        COUNT=COUNT+0;
    }
}
delay(100);
lastinputstate=inputstate;
if (COUNT==4)
{
COUNT=0;
delay(100);
}
}
}
```

In the above example, the code has been written for four output channels, but the same procedure can be followed for more channels easily. The delay () function is necessary, to eliminate any possible noise which can cause a bouncing effect at the input. The code will occupy nearly 4% of programme memory of Arduino, if it's atmega 328 version. As is evident, using microcontroller, the construction of our device gets simpler than before (though relative cost is quite higher than discrete IC procedure):

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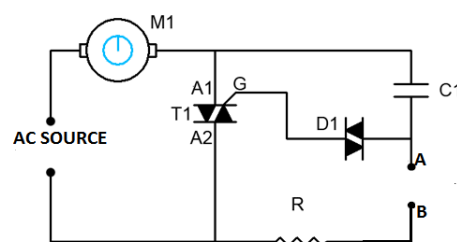


To get best result, the microcontroller here should be operated at around 5 volts. And in switching section, driver transistors are not required in this case.

V. POWER SAVING SWITCHING:

Still we have described our device which utilizes a relay based switching. But such procedure suffers a disadvantage. The problem is analogous to the problem in the early regulators. As is clear in the above switching circuit, though it regulates the load in an entirely different machinery, but it cannot reduce overall power used by the load in an effective way, since the current controlling procedure is same as early regulators.

We shall address this problem, by “mixing” a DIAC-TRIAC based regulator with our switching circuit. We saw before, in such regulators, a variable resistor along with a capacitor changes the firing angle of the TRIAC which effectively chops off the voltage waveform. Now if we connect the points A and B of the switching circuit we showed before, with the points A and B of the following circuit,



(courtesy: www.circuitstune.com)

then clearly can see, instead of controlling current directly as before, now different resistors adjacent to different relays will now control the firing angle of the TRIAC, and hence the whole circuit will now be able to control the power of the load. In this case, the resistors P, Q, R etc. can be chosen around 100 kilo ohms.

V1. SWITCHING WITHOUT RELAYS

In the two preceding switching circuits, we always used relays for operation. But the switching circuit can in fact be also built without relays. The alternative way is to use a single Field-Effect-Transistor. This may naturally greatly compactify the circuit, though it will not offer power saving facility like above. But, however, it can reduce the usage of power in switching circuit, since no power will then be required for relays to make one of them in on state. Since we shall here use the voltage sensitive resistance property of FET.

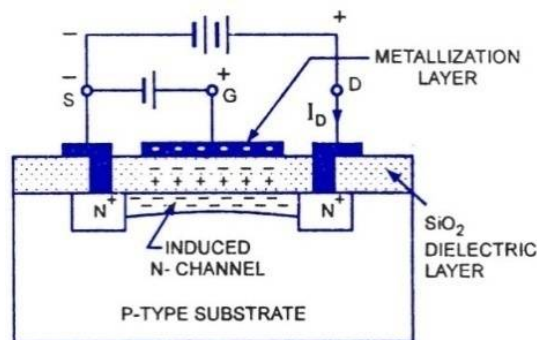
Field effect transistors were actually discovered much earlier (first patented by Julius Edgar Lilienfeld in 1926⁽¹¹⁾ and Oskar Heil in 1934⁽¹²⁾) than Bardeen, Shockley and Brattain's point contact transistor in 1947, who discovered it in Bell Laboratories⁽¹³⁾.

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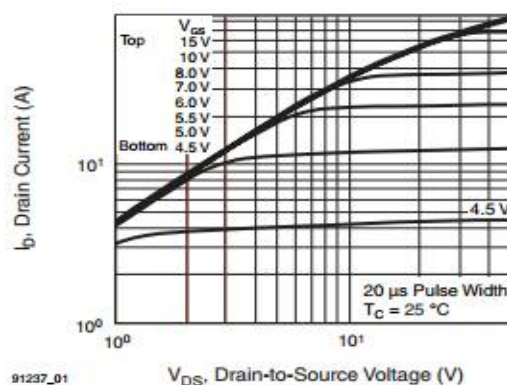
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There is a wide variety of field effect transistors available like JFET, MESFET, MOSFET, HEMT, IGBT etc. But among them, MOSFET (enhancement type) will be suitable for our purpose as we shall see. An Enhancement MOSFET (acronym of Metal Oxide Semiconductor Field Effect Transistor) is a type of field effect transistor, where there is no permanent channel for conduction. When voltage of its “gate” with respect to “source” exceeds a certain threshold voltage, an “inversion layer”⁽¹⁴⁾ is formed in the transistor, beneath its silicon oxide coating, through which the conduction occurs. Increase in gate voltage, increases the density of electrons in inversion layer, causing more conduction from source to drain. Thus increasing gate voltage enhances its channel conductance, which is the cause of its name. A schematic diagram of such a transistor is like below:



Schematic diagram of an NMOS transistor (courtesy: www.circuitstoday.com)

The output characteristic of such a MOSFET (here we took IRFP 460 as an example) is like below:



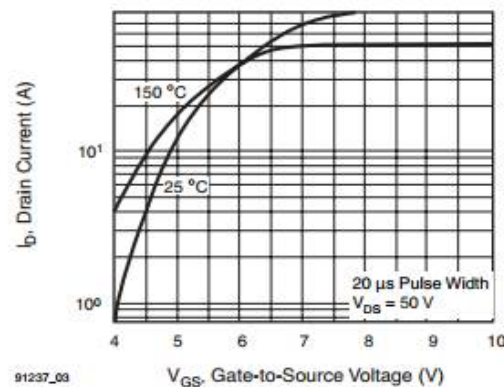
(courtesy: www.vishay.com)

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As is clear, in saturation region, drain current depends only on gate to source voltage (neglecting a small effect called “early effect”), and the dependence is graphically represented by transfer characteristics:



(courtesy: www.vishay.com)

Neglecting Early Effect, we can write,

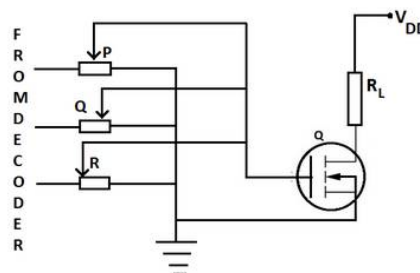
$$I_D = k(V_{GS} - V_{th})^2$$

for saturation region⁽¹⁵⁾. Here k is a constant⁽¹⁶⁾ and is given by

$$k = \mu_n C_{ox} \frac{W}{2L}$$

where μ_n is charge carrier mobility, C_{ox} is gate oxide capacitance per unit area, W is gate width and L is gate length. Thus we if we assume that the transistor is working in saturation region, then adjusting V_{GS} , we can control the current through the load. Also since there is almost no current flow due to V_{GS} , there will be no appreciable output power consumption like relay based circuit.

Now if we build a switching circuit like below,



then clearly the circuit will provide an equivalent function like relay based switching. Here P, Q and R act as three potentiometers, whose midpoints are at different voltages, and thus each decoder output will provide a different gate

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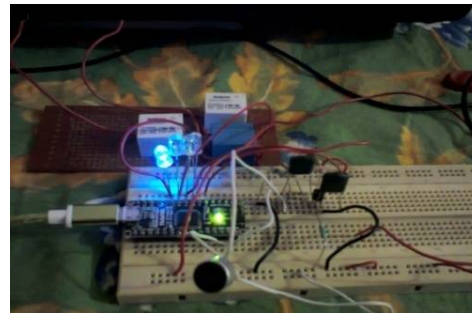
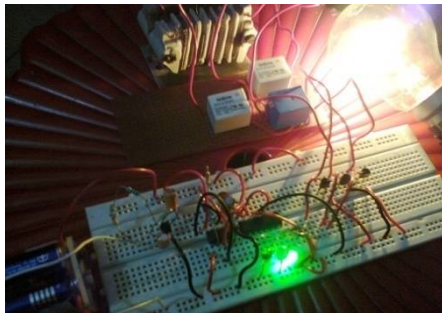
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voltage, and hence different drain current. The overall resistances of P, Q and R can be chosen large, so that very small current is drawn by each potentiometers/presets. This MOSFET based switching can also be used with microcontroller.

V11. RESULTS AND SIMULATION

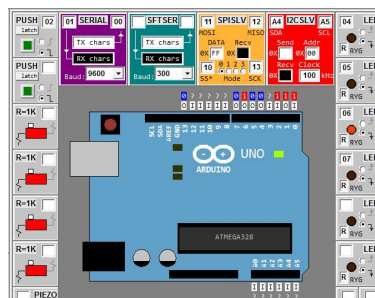
The experimental result of the device described above is like following. The pictures depicted below are the photographs of the sound controlled regulator constructed from discrete IC's (IC-555, CD-4017) and Arduino respectively. Both of the devices here shown to have 4 channels altogether (including the off state) with three relays, but the way of increasing the number of channels is straightforward. If IC CD-4017 is used, one can get maximum ten channels, and for any reduced number of channels, just the next decoded output pin is to be connected with the "reset" pin. For more than ten channels one can use ripple counters of higher moduli.



Prototypes of the device manufactured by author himself (first one by discrete IC's and second one by microcontroller)

In Arduino, the increasing or decreasing the number of channels just is just worth altering the programming code, as was mentioned earlier. Just by defining a different number of modes initially and altering number of elements in "digitalWrite" column, one can do this at ease. But at best, thirteen channels are possible in case of Arduino-nano, since the maximum number of digital input/output pins is fourteen in this case, and we implment one of them as digital input. On the other hand, Arduino Mega 2560, based on Atmega 2560⁽¹⁷⁾, contains fifty-four digital input/output pins, so a very large number of channels are achievable with it.

The Arduino-code given in the microcontroller section can be tested using some simulation softwares, even without Arduino board. For example, one such source is www.sites.google.com/site/unoardusim . The profile of such a simulator is like following:



Profile of an Arduino Simulator

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The above profile is a snapshot while the software is running the above code. To test the code, here we can attach a push button (virtual) to pin 2, and four LED's to four outputs. If the code runs successfully, each time the button is "pressed", the button-state goes high, and consequently the Arduino will toggle to the next output state, exhibiting through LED's.

The code has been verified by such simulation software. Our experimental result is summarized in the following table:

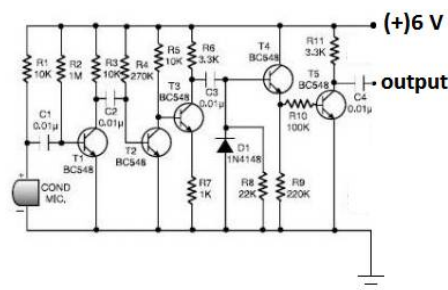
NAME OF EXPERIMENT	STATUS OF EXPERIMENTAL TEST
Sound Controlled Regulator (discrete IC construction)	OK
Sound Controlled Regulator (microcontroller construction)	OK

V111. CONCLUSION

We have successfully developed a regulator, which is capable of responding simply at ambient sound (of a very short duration). Successive generation of such sound will yield different mode of regulation by the device. We also discussed its architecture in several possible ways in detail.

APPENDIX:

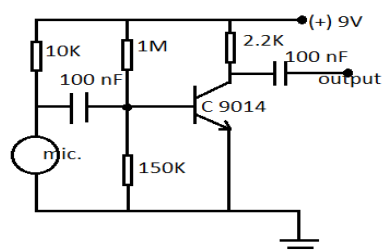
(A)



A suitable amplifier for sound controlled regulator (courtesy: www.extremecircuits.net)

(For discrete IC construction)

(B)



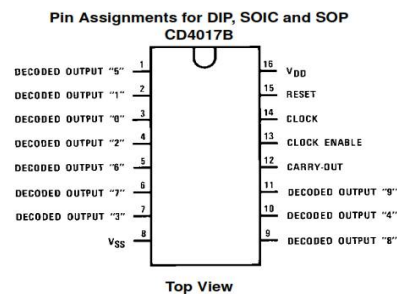
A suitable amplifier for the regulator (For microcontroller construction)

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(C)



Pin configuration of IC-CD 4017 (courtesy: www.futurlec.com)

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REFERENCES

- [1] Promise Elechi, "Design and Development of Sound Control Door Lock System", American Journal of Engineering Research, Volume-4, Issue-9, pp-96-107⁽¹⁾
- [2] www.electronicsproject.org, www.engineersgarage.com ⁽²⁾
- [3] Hugh Robjohns, A Brief History of Microphones ⁽³⁾
- [4] Sessler, G.M.; West J.E. (1962). "Self-biased condenser microphone with high capacitance". Journal of the Acoustical Society of America. 34(11):1787-1788 ⁽⁴⁾
- [5] Wikipedia ^{(5) (15) (16)}
- [6] B. Ghosh, Fundamental Principles of Electronics ^{(6) (14)}
- [7] Programming microcontrollers in C by Ted Van Sickle ⁽⁷⁾
- [8] The Most Widely Used Computer on a Chip: The TMS 1000 ⁽⁸⁾
- [9] www.arduino.cc ^{(9) (10) (17)}
- [10] US 1745175 Julius Edgar Lilienfeld: "Method and apparatus for controlling electric current" first filed in Canada on 22.10.1925 describing a device similar to MESFET ⁽¹¹⁾
- [11] GB 439457 Oskar Heil: "Improvements in or relating to electrical amplifiers and other control arrangements and devices" first filed in Germany on March 2, 1934 ⁽¹²⁾
- [12] Levine, Alaina G. "John Bardeen, William Shockley, Walter Brattain-Invention of the Transistor", 2008, American Physical Society Retrieved on October 6, 2010 ⁽¹³⁾
- [13] www.seekic.com
- [14] www.electronics-tutorials.ws
- [15] www.allaboutcircuits.com
- [16] www.functionspace.com
- [17] www.circuitstoday.com
- [18] www.circuitstune.com
- [19] www.vishay.com
- [20] www.extremecircuits.net
- [21] www.futurlec.com
- [22] www.arduino.org