The SMARTGUN electronic tag board.

Designed by, built by, and obtainable from: Dave Bodger.

DIY Construction Guide & 'Frequently Asked Questions'

This guide is to help you get the most from your SmartGun circuit by passing on a few practical hints and tips about construction and other matters which have been compiled over the years.

Contents

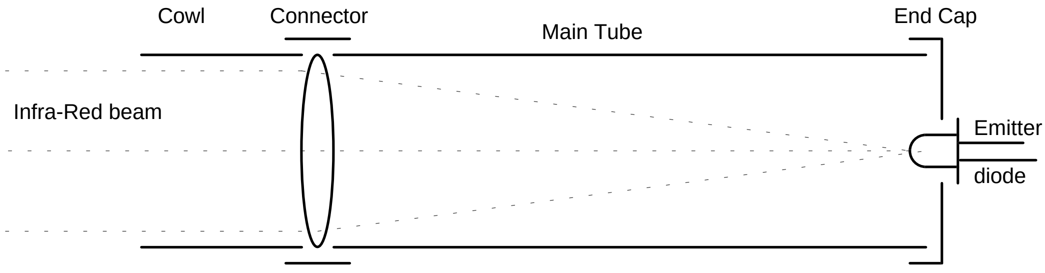
Anatomy of a Tag gun.

All lasertag guns consist of the same main ingredients in differing proportions:

- An infra-red emitter diode (possibly fitted into a lens assembly of some sort).
- An electronic circuit to generate and control the tag pulses.
- An arrangement of switches to control the circuit.
- A power source, normally a battery.
- Something to generate a 'bang' sound, often connected to an amplifier and loudspeaker.
- An ammo-counter with display or a cut-out timer to limit fire rate.
- A mess of wires to connect it all together.
- A body made of some rigid material to physically house all of the other components.
- Accessories to make it easy to use; telescopic sights, carry straps and the like.

Lenses and emitters (theory).

Lens assembly



On its own an emitter diode produces a beam of infra-red light which spreads out by anything from 10 to 60 degrees or more as it moves away from the source. This is normally only enough for a range of about 20 to 30 meters. To get a reasonable range you need to concentrate the beam before it becomes too dispersed. This is commonly done with a convex (magnifying) lens, as shown in the diagram above, in conjunction with some 50mm diameter plastic drain pipe and fittings. The difficult part is finding the correct distance between the emitter and the lens such that the maximum amount of IR light is captured and made to travel forwards in a concentrated beam. Much has been said about focal lengths of lenses, and how to calculate them exactly, but in my experience there are too many variables involved to get a good result purely by calculation. The best method I have devised is to view the beam when it has been projected onto a wall in a darkened room by using an IR sensitive CCD security camera (I got mine from Maplins). This allows you to move the emitter backwards and forwards and see the resultant beam spread on the wall. Using this method I have obtained ranges in excess of 400 meters from a high-powered emitter assembly (6.5 amps through an OD50L emitter and a 3" 1.75x magnification lens).

There is a trade-off involved here however. A tightly focused beam will be more difficult to aim accurately. Sometimes it is better to have a softer focus and allow the beam to spread a little to make aiming easier. This is at the expense of range, however I think ranges in excess of 200 meters are of little practical use except on the very odd occasion when you are playing on an airfield runway. The sort of terrain tag games are played over precludes contact distances of more than 100 meters in most cases. Many people fit their guns with a secondary lens unit with a wider spread of 20 to 40 degrees for close quarters combat. These units often only have a range of 30 meters or so.

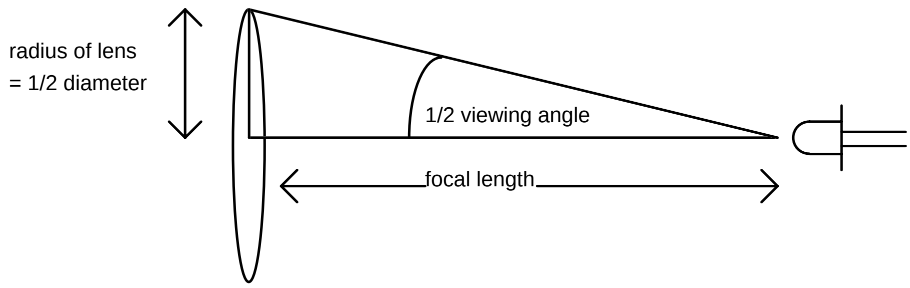
Lenses of diameters varying from 12mm up to 100mm and more have all been used successfully in the construction of tag guns. Designing your own lens assembly requires you to make some decisions about several elements, all of which interact. A "good" lens assembly is one which collects the maximum available IR and sends it out in a beam of the right shape to give you the coverage you want. Here are the design steps as I see them.

1. Decide what sort of gun you are constructing and hence what range and spread you require.

2. Pick your emitter diode and find out what its "half-intensity angle" or "viewing angle" is.

3. If you are going for maximum range pick a lens of about 2x magnification or less. If you want a good spread but less range, pick a lens of 4x magnification or greater.

4. The lens diameter required will depend on both the viewing angle of the emitter diode and the magnification of the lens. To best match the emitter to lens, you want to make sure the diameter of the lens is at least big enough to catch the beam from the emitter all the way out to the limit of its viewing angle. Some simple mathematics is required here.



The focal length of the lens is related to the magnification by the formula:-

Focal Length *in mm* = 250 / (Magnification - 1)
and/or
Magnification = (250 / Focal Length *in mm***) + 1**

The other way of describing a lens which you may encounter is in Diopters, which is a measure of the power of a lens. This is related to focal length by the formula:-

Focal Length *in mm* = 1000 / Diopters.

Therefore by substitution:-

Diopters = 4 x (Magnification - 1) and/or **Magnification = (Diopters / 4) + 1**

From all this you should be able to calculate the radius of the lens by the following formula:-

Lens diameter ≅ Focal Length x (TANGENT of the viewing angle)

Example 1. Take an emitter with a viewing angle of 16 degrees which is about the best you can get in cheap high power emitter diodes. Decide to go for long range (2x magnification).

Focal Length = 250 / (2 - 1) = 250 mm.

Lens Diameter = 250 x TAN(16º) = 71.69mm

Therefore Lens Diameter should be at least 72mm. The nearest readily available lenses are 75mm.

Example 2. Using the same emitter as example 1, decide to make a close range "blaster" (8x magnification).

Focal Length = 250 / (8 - 1) = 35.71 mm.

Lens Diameter = 35.71 x TAN(16º) = 10.24 mm

Therefore Lens Diameter should be at least 10mm. Anything from 12mm to 25mm would be a good choice.

Example 3. You already have a lens 50mm in diameter and have measured its focal length as being 110mm as close as you can estimate.

Magnification = (250 / 110) + 1 = 3.27 (Power in Diopters = 1000 / 110 = 9.09)

Viewing angle = the angle whose TANGENT is 50 / 110 = 24.44º

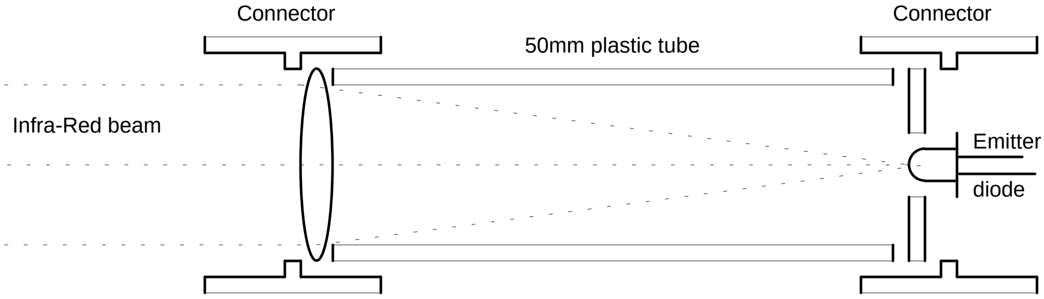
Therefore an emitter with a viewing angle of 24º or less would be the best match. The magnification of just over 3x should give a reasonable range with moderate spread.

Note that there are still worthwhile amounts of IR produced outside of the viewing angle of the emitter, so if possible always use the largest diameter lens you can get which has the focal length you want and treat the calculations here as a minimum.

The SMARTGUN electronic tag board.

Designed by, built by, and obtainable from: Dave Bodger.

Practical lens assemblies.



To help beginners, I have designed a lens assembly which can be made from readily available materials at low cost. It will not deliver top of the range performance but should allow you to obtain ranges of around 200 meters, if used in conjunction with a telescopic sight, which should at least let you play on a more level footing.

To make one, find a supplier of "Hunter" plastic drainpipe in your area (I got mine from Homebase) and purchase the following 50mm grey drainpipe fittings :-

- 2 - straight pipe connectors.
- 1 - 200mm length offcut of 50mm diameter pipe. (or buy a 2 meter length and make 10 !)

Buy a '2 inch Pocket Magnifier' from Maplin Electronics, which costs £1.95. It has a magnification of approximately 3x. See table for other lens/tube/emitter combinations.

Buy a LED chrome bezel (Order Code FM38R) from Maplin Electronics to mount the emitter in. Costs 50p.

Buy a Siemens SFH484-2 emitter diode. (available from "Bodger's Bits" or Farnell Electronics - Order Code 212-672). Costs 60p.

Make a 50mm disc from 18 gauge aluminium or thick plasticard or thin plywood. Drill a 7.5mm hole in the middle, as central as you can make it. (or buy one from "Bodger's Bits", ready drilled and accurately cut from 18 gauge aluminium and available in two sizes, 25mm or 50mm, for £1.50 each.)

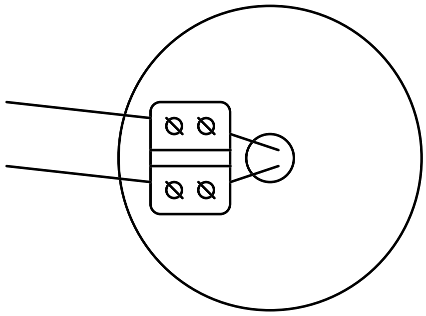
Fit the bezel in the hole and tighten the nut.

Fit the SFH484-2 emitter in to the black rubber grommet provided with the bezel and push this into the hole in the bezel until it's all the way home. If you prefer not to solder, connect a wiring block to the disc and use it to attach the wires to the main circuit board (see diagram).

Get the lens out of its housing by pushing it out carefully.

Fit the lens in one straight pipe connector and the disc with the emitter in it in the other one.

Cut the pipe to exactly 112mm long and plug the two connectors on to it so that the lens and emitter disc are sandwiched by the tube (see diagram).



Using a screw-connector block to attach wires to the emitter.

Either drill and screw two small self-tapping screws through the connectors and pipe to hold them in place, or glue them using solvent-weld or some other suitable glue, to finish off. If the connectors are a nice tight fit, you may consider not fixing them as it will make it much easier to remove the lens for cleaning at a later date. If you do glue, use something like UHU which is easy to take apart later.

Paint the assembly to match your gun and affix with screws or clamps.

A variation on this is to recess the SmartGun LED display board into the end of the pipe connector, with the ribbon cable plug fitted through a slot cut into the connector. You will find that if you fit a ring of pipe 20mm long into the rear of the pipe connector which houses the emitter and cut the corners of the display board at 45 degrees so you cut into the mounting holes and cut a slot 10mm deep and the width of the ribbon connector, it should all fit quite snugly. To finish it off, and keep the weather out, you can fit a 50mm diameter circle of perspex over the display board. See diagram for details. The whole assembly can then be mounted on top of your gun, or along the left or right sides, where the display will be visible to you but not to anyone in front of you or to either flank.

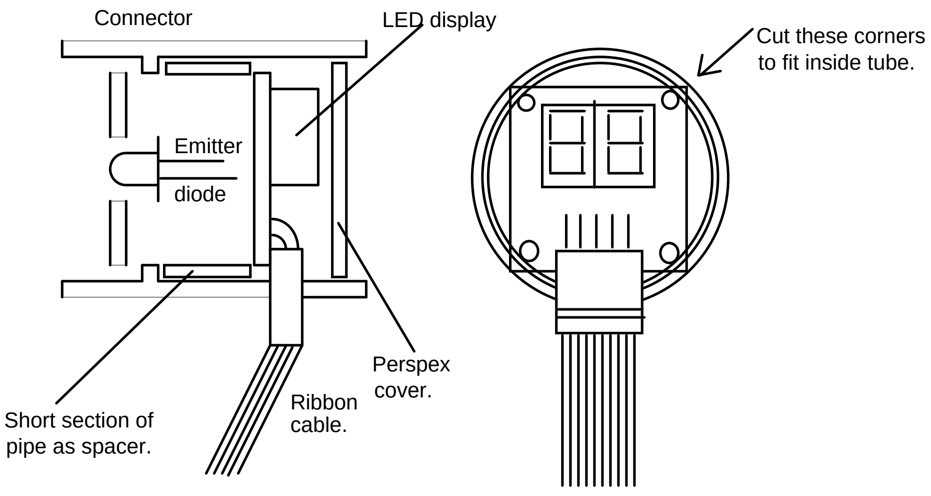


Table of lens/tube assembly measurements.

Type of lens	*Type of emitter*	*Pipe length in mm.*
50mm Draper	SFH484-2	120
2" Maplin pocket magnifier	OD8810	110
2" Maplin pocket magnifier	SFH484-2	112
2" Maplin pocket magnifier	OD50L	125
50mm HiRanger	SFH484-2	160

50mm HiRanger	SFH484-2 in Farnell lens housing	150
25mm Maplin Eye Glass fitted in 25mm plastic conduit pipe.	SFH484-2	90.5

An example toy gun conversion.

Using the above method of constructing a lens assembly and display housing I have converted a "Combat Series MP50A by Larami" bought from "Toys-R-Us". I used the flexibility of the SmartGun system to allow me to retain the gun's own sound generator (which I quite liked) for the shot and magazine change sounds. I did not use the sound board provided with the SmartGun circuit, which saved a little space. I added a 10mm ultra-bright (14 candela) LED from Electromail, fitted in the hole in the middle of the "barrel", to provide a serious muzzle flash. I fitted a small push-to-make switch on the left side of the casing near the front above the front hand grip where it can be easily operated by thumb; this was connected to the "grenade launcher function". A small cluster of three more push-to-make switches was fitted on the left side just above the trigger, for the up/down brightness controls and the display off function. One final push button switch on the left just above the handle grip (where the dummy plastic fire selector switch is) was fitted to activate the fire selector function.

Internally, the SmartGun main board fits nicely in front of the unused battery compartment. This compartment shows the history of this plastic casing - it is the same moulding Larami used to use for their motorised water pistols! The yellow wire from the front trigger post is disconnected and inserted into socket hole number 5 on the SmartGun sound connector. The rear yellow wire is removed and discarded. The two trigger post connections are now available for the trigger function. The original magazine change sound switch is left in place and a small micro-switch is screwed to the plastic next to it, bearing on the magazine in such a way that the switch is made when the magazine is withdrawn and broken when it is re-inserted, to provide the magazine change function.

I got 6 AA sized NiMH batteries (Farnell Order Code 507-040), the type with solder tags fitted, and made up a 7.2 volt battery pack to fit in the "unused" battery compartment to power the SmartGun board, emitter and muzzle flash. A small power connector was fitted, accessible through a 6mm hole in the gun body, so the batteries could be recharged in situ. As I was retaining the original sound system and triggering it from the SmartGun board, it was necessary to connect the negative of my new battery pack to the negative of the original batteries (hidden inside the magazine) at the point where they plugged in.

The lens assembly was screwed to the right hand side of the gun, in line with the "real" barrel. The cable for the display was fed through the slight gap between the internal battery compartment cover and the gun body. Two wires for the emitter were soldered to two thick pieces of stiff copper wire which were poked through holes drilled in the gun body to mate up with the screw connector block in the lens assembly.

A good coat of matte black spray paint finished it off nicely. The resultant gun is compact and well balanced, with enough weight to make it feel "right" without making me feel my arm is about to drop off at the end of the day.

Electronic Circuits.

You will not be surprised to hear me recommend the SmartGun circuit to you here !
However it is possible you already have some other circuit that you wish to use. Good luck !
The "Worlds of Wonder" StarSensor is most sensitive to an approximately 1800Hz signal ±100Hz modulated over a 58KHz carrier. Therefore a circuit which generates a clean signal of this form is to be recommended. The SmartGun uses a 57600Hz signal to carry a precise 1800Hz tone.
If you are thinking of designing your own circuit, have a look at the example circuit I designed for my first tag gun (later on in this document).

Switches.

These should all be of the push-to-make variety. You can use some fairly crude switches, such as bent pieces of wire, but you will find that they tend to give multiple connections from one push (known as "switch bounce") which may cause erratic operation of some of the circuits functions. It is best to use proper switches which are obtainable from suppliers such as Maplins.

I personally prefer to use micro-switches for the trigger and magazine change functions. They are very reliable and give a positive "click" when operated. They can also be bought with various types of operating lever fitted which can be bent to shape, which makes them more flexible in placement. Because they are always of the "momentary action change-over" type, they can be used in both push-to-make and release-to-make roles.

Note that the switch for the magazine change function needs to be "made" and "broken" to invoke a change of magazine clip. It may be necessary to use a release-to-make switch if you are fitting a physical representation of a magazine, arranged so that it makes a connection when the magazine is ejected and breaks the connection when the magazine is reinserted.

Also note that only one switch should be pressed at any one time. For example, if you press and hold down the brightness switch then try to press the trigger, the gun will not fire until both switches have been released. If your gun seems to stop working during a game but the display is still illuminated, check you have not accidentally jammed a switch down (by running into a tree for example).

Because the SmartGun circuit was designed to be used in a variety of roles (it will form the heart of the armourer and medic boxes for example) it was designed with a keypad in mind for use as a data entry device. The keypad is not necessary in its role as a gun board; however if you do decide to use one (possible because you think it looks good!) you will find that the 12 way telephone style keypad from Maplins (Order Code JM09K) which costs £2.59 will connect up directly and matches the switch matrix layout in the installation guide. Keys which do not have an associated function in the gun mode will simply be ignored except that pressing them will illuminate the display. Even with a keypad fitted you still need to have separate switches for trigger and magazine change.

Batteries & Chargers.

I think it is fair to assume that you will be running the circuit from batteries, so I will not discuss mains operated supplies here. The best choice for batteries at the moment is Nickel Cadmium. There are other types of battery available but Ni-Cads have several advantages (along with a few disadvantages).

- They are rechargeable. You can cover the cost of buying them and the charger unit after a handful of cycles. Chargers are available which can run off of a car battery so you can recharge them "in the field".

- They are ideal for supplying large amounts of current in short bursts, because of their chemical and electrical construction. They are far better in this respect than an equivalent sized alkaline battery.

- They are only slightly heavier than the zinc or alkaline batteries they replace.

- They retain a significant proportion of their charge for up to a month after charging.

Their main disadvantage is a problem called "memory effect". If you recharge them after using only a small proportion of their whole charge, after a few cycles the capacity of the battery seems to drop down to the level of that small proportion. The problem seems worse if you regularly "fast charge" them. This is caused by the chemicals used in their manufacture. It can be avoided by allowing the batteries to become fully discharged (down to 1 volt per cell) and then recharging them slowly (normally for 14 hours) once every 5 or so cycles. Special chargers are available which have an automatic discharge circuit which can be used to prevent this effect. As these chargers are little more expensive than a standard charger, they are to be preferred if you have a choice when buying. The Maplins Universal NiCad Battery Charger & Discharger (Order Code RZ18U) is useful in this respect if you have separate batteries rather than a battery pack.

Duracell Special Batteries Ltd. sell the DX15 battery charger which will fast charge NiCad battery packs and remove the memory effect at the same time. It costs £99 unfortunately, but could be a good club purchase as you can recharge 2 or 3 packs per hour off of a car battery with it.

If you allow NiCads to become completely flat (less than 1 volt per cell) it is possible that recharging will not recover them and you may have to throw them away. Allowing them to get too hot (more than 40ºC) during charging can cause the same problem. Beware of hot summer days ! Always recharge them the day before a tag event to ensure peak performance.

One other contender is the lead acid "gel-cell", so called because of the acidic jelly-like compound used as an electrolyte. These are of heavier construction than NiCads and take up more room but can be easily obtained in very large capacities and are normally of 12 volt rating, although 6 volt versions are available. They are capable of delivering very high currents, but their output voltage drops more than a NiCad would while they are doing it. They also need careful charging and should not be charged with a car battery charger, which can damage lower capacity cells by over charging them. They must be charged with a constant voltage, current limited, supply - limits are normally shown on the battery casing. They are good for static weapons, such as sentry guns. **The standard SmartGun circuit should not be operated from a 12 volt battery without prior modification - contact Dave Bodger if you are thinking of doing so.**

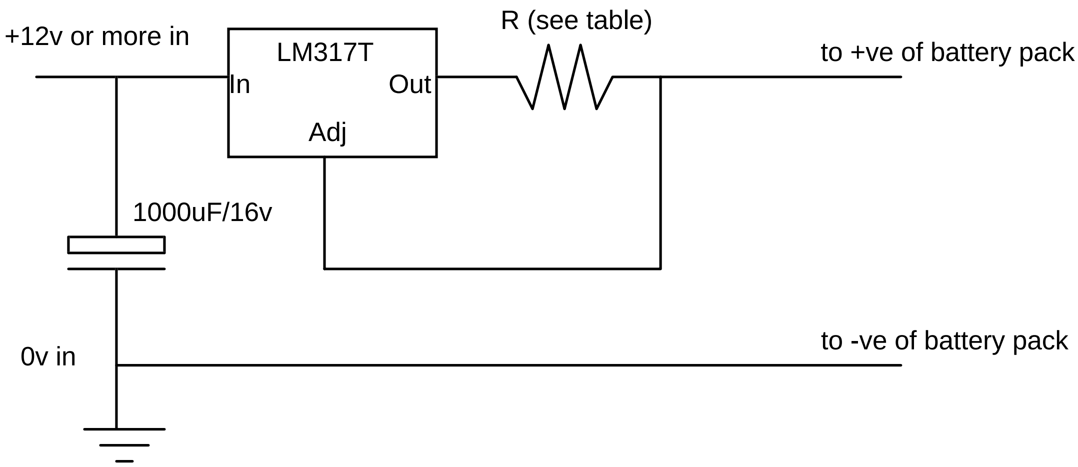
The SMARTGUN electronic tag board.

Designed by, built by, and obtainable from: Dave Bodger.

The new NiMH (Nickel Metal Hydride) batteries look good, and do not suffer from memory effect, but in practice you have to recharge them the night before use as they have a high self-discharge rate compared with NiCads. Leave them for 3 or 4 weeks without use and they will be virtually flat! They are a fairly new technology however, so expect capacities to go up and self-discharge rates to improve in the future. As long as you are happy to pay attention to preparation they can be a good choice. They are often called "Green" batteries as they are "Eco-Friendly" and use no heavy metals in their construction.

Farnell Electronic Components now sell a good range of improved high capacity NiCad batteries at reasonable prices. In particular they do a PP3 with 150mAH capacity (Order Code 451-472), and an AA with 850mAH capacity (Order Code 451-411 not tagged, 451-423 tagged). They also do the AA sized NiMH 1200mAH capacity batteries (Order Code 507-039 not tagged, 507-040 tagged). The tags allow you to solder the batteries together to make up your own packs.

A simple constant current charger can be assembled from a few cheap components for those people who are trying to save money. For a few pence more this can be made to produce several different charging rates by the addition of a switch and a few resistors. For battery packs of up to 6 cells (7.2v race pack) the power can come from a car battery or 12v mains adapter. For higher pack voltages you need to provide an input of at least 3 volts above the peak charged voltage of the pack (i.e. 7 cells needs 13.5v, 8 cells needs 15v, 10 cells needs 17.5v). Maplin Electronics sell all the parts required.

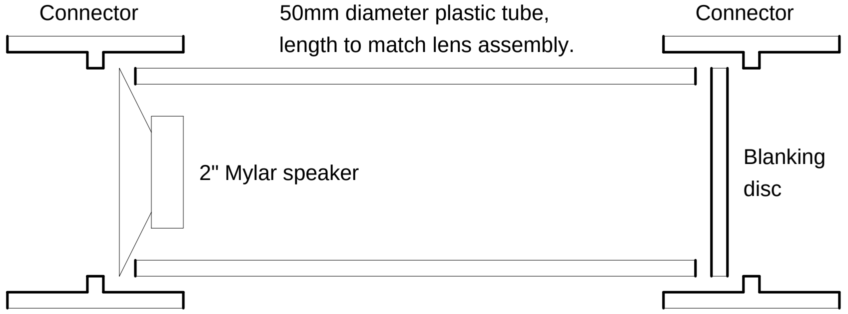


Value of R	Charge current	Charge rate for 1200mAH battery.	Time to recharge
20Ω	63mA	½ standard rate	28h
10Ω	125mA	Standard rate	14h
4.7Ω	266mA	Double standard rate	7h
3.3Ω	379mA	Triple standard rate	4h 40m
110Ω	11mA	for ordinary 110mAH PP3	14h
82Ω	15mA	for hi-capacity 150mAH PP3	14h

Resistor "R" can be calculated from V=IR if you know that the LM317T works by imposing a voltage of 1.25v between its output terminal and its adjustment terminal. I have provided a table of pre-calculated values. These are suitable for various types of battery pack. You have to decide how fast you want to recharge your batteries. For example if you recharge a 1200mAH battery pack at 120mA it would take 14 hours to recharge. 'C' is often used to describe the capacity of a battery pack. 'Standard Charge' is normally $^1/_{10}$ C applied for 14 hours (1.4 times the '10 hour rate'), in this case 1200/10=120mA. Therefore 60mA for 28 hours, 240mA for 7 hours, etc., will all recharge the battery fully. If you were charging 600mAH AA cells then you would simply scale the values by halving the current. In practice you must be careful if charging above double the standard charge rate in case the batteries get too hot through over-charging. It is normal for batteries to get warm while being charged, but more than 40°C can destroy them. You can use an alarm clock as a timer. You could use a switch to switch in various resistors to make a more flexible device. I have included resistor values for PP3 NiCad batteries as well, but remember these must always be charged for 14 hours and <u>never</u> charged any faster or at higher currents (they can get very hot and explode!)

Loudspeakers and enclosures.

I have found that the Maplins Mylar speaker range is ideally suited to use with the SmartGun circuit, they have plastic cones which are suited to outdoor applications. The 2" speaker (Order Code YM97F) is actually 50mm in diameter and can be used in conjunction with a plastic drainpipe enclosure in much the same way as the lens assembly mentioned previously. The square 3" speaker (Order Code YN01B) is the most robust unit and gives some powerful bass resonance's when fitted to an air-tight enclosure. Remember that any speaker you decide to use should be 8Ω.



Infra Red Emitters and their driver circuitry.

The emitter driver resistor, the one in line with the emitter diode, may need to be recalculated for other diodes or supply voltages. It can be worthwhile doing this even within the normal supply range of 7.2v - 9v when you are trying to achieve maximum range by running the emitter at the extremes of it performance envelope. In particular note that if you are trying to put 10 amps through an OD50L diode you must use a different output transistor because the ZTX689B transistor on the SmartGun board cannot sustain more than 5 amps. Power MosFets are the best thing to use but it can be difficult arranging a sufficiently high base drive voltage. New devices are now available and I recommend the IRLZ24 for all new designs. It can handle 16 amps and requires minimal drive current. It is ideally matched to the output from the PIC16C84 chip. It must not be driven by more than 5 volts though, so you cannot retrofit it to old CMOS designs running at full battery voltage. The IRFZ24 would be a better device in that case, but it needs 6 or more volts at its gate to turn on fully. Careful study of data books is required to select suitable mosfets, and they must be protected from static during construction.

The SMARTGUN electronic tag board.

Designed by, built by, and obtainable from: Dave Bodger.

The resistor calculation is (battery voltage minus 0.5 volts for the transistor {or 0.1 times the current for an IRLZ24} minus something between 3 to 4 volts depending on the diode and the amount of current you want to drive through it) divided by the current you want to put through the diode.

Example Drive 1.5 amps through an SFH484-2 diode (3.5v drop at 1.5Amps) from a 7.2v Ni-Cad racing battery pack using a ZTX689B transistor (0.5v drop).

$$\frac{7.2 - 0.5 - 3.5}{1.5} = 2.1333 \text{ ohms; i.e. nearest value = 2R2.}$$

Power dissipation will be around current squared times resistance, i.e. for this example :-

$$1.5 * 1.5 * 2.1333 = 4.8 \text{ Watts}$$

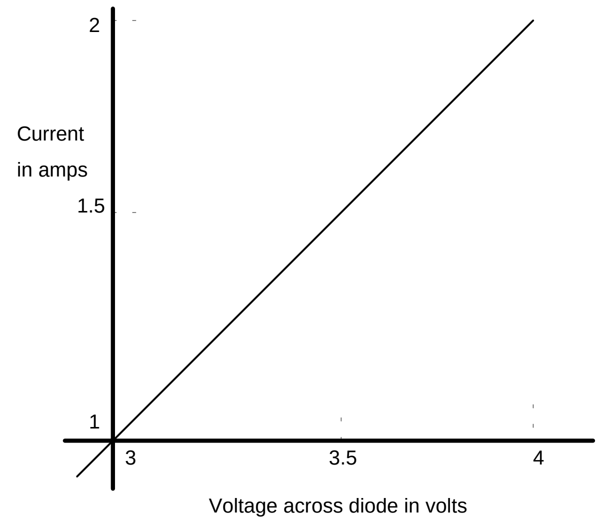
This is reduced by the duty cycle of the signal - for example a standard tag shot of 50mS fired 5 times per second has a duty cycle of 6.25%. 6.25% of 4.8 watts is 300 mW, which is well within the capability of Maplins 0.6w resistors.

The duty cycle can be calculated by examining the structure of the tag pulse. The 57600Hz carrier frequency is a square wave with a duty cycle of 50%. This is modulated buy an 1800Hz signal which also has its own 50% duty cycle, therefore the overall duty cycle is 50% of 50% = 25% for a continuous stream of tag. We reduce this again by only firing short "shot" pulses. If you fire 5 shots per second, the shots will repeat every 200mS. The shot pulse itself is only 50 mS long, therefore the duty cycle of this is 50/200=25%. This is in addition to the previous calculations, therefore the overall duty cycle for 5rpm with 50mS shots is 25% of 25% = 6.25%. The shortest shot pulse produced by the SmartGun circuit is 50mS (Assault rifle) at 10rpm = 12.5% duty cycle; the longest is 140mS at 1 rpm = 3.5% duty cycle. Other duty cycles may be calculated in a similar fashion.

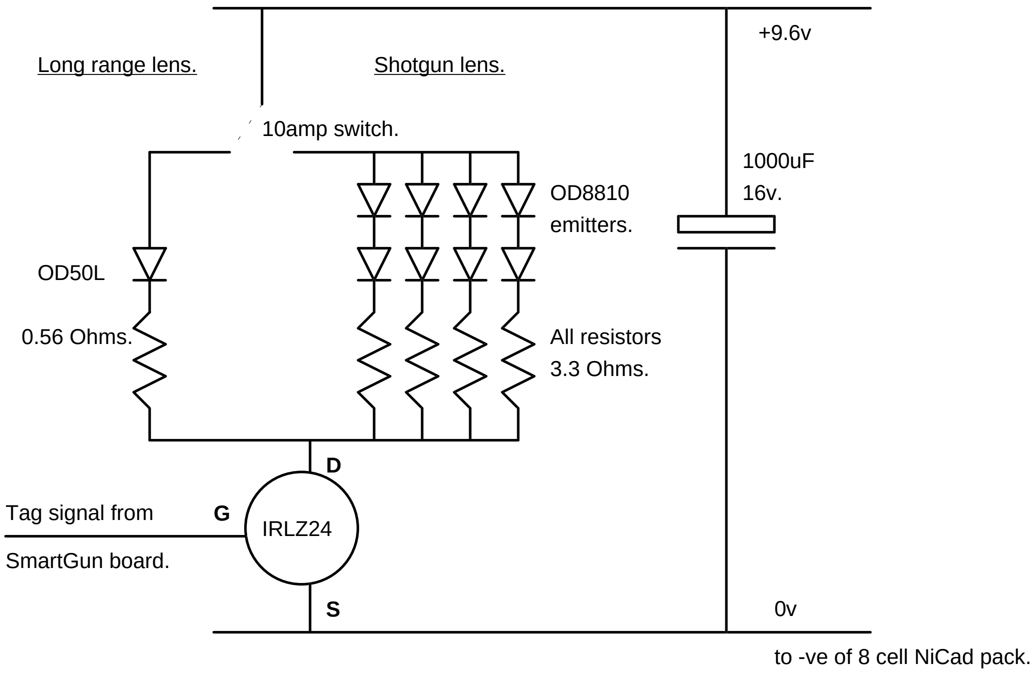
Here is a table of resistor values already calculated for you. You can use these as a starting point. Try performing the calculations and see how your values compare to mine. I have tried to choose the nearest available real component values.

	Battery Voltage ==>	6v	7.2v	8.4v	9v	9.6v	12v
IR Diode	Power Switch Device						
SFH484-2 x 1.5A	ZTX689B	1R5	2R2	2R7	3R3	3R9	5R6
OD8810A x 1.5A	IRLZ24	1R5	2R2	3R	3R6	3R9	5R6
OD50L x 8A	IRLZ24	0R1	0R27	0R47	0R47	0R56	0R82

The OD8810A and the SFH484-2 (or "lilac") diodes have virtually the same performance characteristics. The SFH484-2 produces a slightly tighter beam of 16° versus 20° for the OD8810A and costs half the price, thereby making it the diode of choice for long range guns. Both have a fairly linear relationship between voltage drop versus current in the area we operate them; see graph.



Here is a real-life example circuit I designed to give someone a high power rifle with switchable "shotgun" effect. The OD8810 emitters were arranged in a 4 by 2 array to cover an area ±10° vertical and ±30° horizontal. The drive signal is picked up from the PIC side of the resistor driving the emitter transistor; <u>not</u> from the cage-clamp connector ! (see diagram in installation guide)



At a current of 1.5 amps both the OD8810A and the SFH484-2 emit a total of approximately 300mW of IR. The data sheet for the SFH484-2 indicates that there can be a variation of ±50% in output power between minimum, typical and maximum; the data sheet for the OD8810A does not mention this parameter so it could be anything! This may account for reports of varying success with these devices. It may just depend on how good the batch was that your diode came from. One of the more common "high-power" TV remote controller diodes with a 40° beam coupled to a high magnification lens might be a better choice for a short range wide beam blaster.

The SmartGun electronic tag board.

Designed by, built by, and obtainable from: Dave Bodger.

At the present time there is only one real choice for serious output power - the OD50L from Opto-Diode Corp. This device can emit a total of 600mW of IR at 10 amps with a half intensity angle of only ±5°, producing the most powerful beam currently available. It is available from Electromail for £18.28 including VAT.

Output power is often quoted in mW/steradian. The number of mW per steradian is a measure of radiant intensity. This is a way of measuring the output power per unit area. The formula to find out how many steradians your beam is covering is $2\pi(1\text{-cos.}\frac{1}{2}\theta)$. See the table below for some ready calculated values. By understanding this value, which is often quoted by the manufacturers, you can easily compare the effective output of different emitters. Remember to check any tolerance figures; ±50% seems to be common and could seriously affect your calculations!

Also remember that they often quote "total" output power. This includes the portion of power emitted outside of the half-intensity angle, which can be substantial. If all the information you have about a particular emitter is its total power output and viewing angle it is sensible to divide the total power output by 2 to give a more realistic value per viewing angle. This will not give you an exact value but is the best you can do without careful examination of a graph of output power verses emission angle, which can be hard to obtain.

Half Intensity Angle or Viewing Angle	½ of H.I.Angle or Viewing Angle	Number of steradians this represents	Ratio relative to 1 steradian.	½ total output in mW.	mW/steradian for (x) device
10° (OD50L)	5°	0.02391	41.82	300	12547
16° (SFH484-2)	8°	0.06115	16.35	150	2452
20° (OD8810A)	10°	0.09546	10.48	150	1571
30° (???)	15°	0.21409	4.67	150	700
40° (???)	20°	0.37892	2.64	150	396

Note that at high currents (more than 2 amps) high frequency impedance along with actual wire resistance's come strongly to the fore, making it likely that you will find the actual current passed is less than that calculated and therefore output power is reduced. OD50L diodes require heavy duty wiring and high capacity batteries ! If you want to check the actual peak current, place the probe of an oscilloscope across the emitter resistance and record the result. Once you know the voltage dropped and the resistance it's across, it's easy to calculate the peak current using V=IR.

Muzzle Flash

Several people have asked me if the SmartGun circuit will drive a torch bulb for use as a muzzle flash. In its standard form it will not, as the muzzle flash pulse is limited to 100mA by a 22 ohm resistor and to 200mA by the driver transistor. However I can supply boards specially configured with the more powerful ZTX689B transistor which is rated at 5 amps. Reducing the 22Ω resistor to 1.5Ω and using a 4.5 volt torch bulb on a 9 volt supply works well, giving a very intense flash. It is also possible to wire one on in parallel with the current muzzle flash circuit, should you wish to use both.

Personally I prefer to use ultra-bright 3 candella LEDs which are available in 5mm or 10 mm diameter at low cost from most electronic suppliers. These give a nice bright red flash.

The disadvantage of a torch bulb muzzle flash is that the pulse draws a significant current, in the order of several amps, and this must be taken into account when deciding upon which batteries you are going to use. PP3 batteries would be unsuitable, C cells a minimum, and D cells preferable. It may also be necessary to "stiffen" the power supply by fitting a few 1000µF 16v electrolytic capacitors (high frequency versions preferred - Maplins Order Code JL56L) across the supply rails near to the battery connector and also where the supply wires connect into the main board; so as to accommodate the high-current surges generated by the torch bulb, sound amplifier and emitter all demanding current simultaneously. Connecting wire capable of passing 6 amps or more is recommended.

The SmartGun board was designed with ultra-bright high-power LEDs in mind. Using one of the 3 candela types (3000mcd), which can be obtained from most suppliers for under £1, will give a very intense flash easily visible in direct sunlight. These are available in various sizes, the 10mm diameter ones look particularly good. Farnell Components and Electromail do some very high intensity types, up to 15 candela output with a narrow ±4° beam, but they are rather expensive at around £9 each. However they can produce a beam which is a reasonable looking safe simulation of a targeting laser at night.

A word of warning on the subject of lasers.

There are now some quite reasonably priced units available from suppliers such as Maplins, which may make them appear appealing. If you have ever thought of fitting one to your tag gun for use as a real targeting laser - **PLEASE** DO NOT. Because of the widespread use of telescopic sights on many guns, even a low powered laser is hazardous to people's eyes. Once the beam has been concentrated another 10 or more times by a scope, the intensity is enough to do permanent damage to someone's retina. A 1mW Class II laser, the weakest sold by Maplins, is **NOT** eye safe !

As far as I am aware, ALL lasers are BANNED in all LRP tag games. Even if someone produced what they thought was an "eye safe" laser, the game organisers would have no way of determining the safety of such a device on the day. Unfortunately the standard method of checking the safety of LRP weapons (being hit with it yourself) is not acceptable here. (Hmm - let's just shine this laser in your eyes for a few minutes and see if you go blind !)

The lasers used in games such as Quasar and Laser Quest are Class I, and so low powered that you can hardly see them in anything other than total darkness; also telescopic sights are not used in those games and the targeting area is the chest, not the head as it is in LRP tag games so the risk of prolonged eye exposure and consequent damage is reduced.

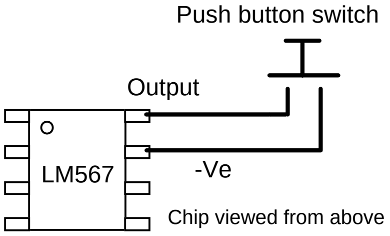
The word "Laser" in the name "Laser Tag" is there just for effect. The infra red beams we use are thousands of times less concentrated than a real laser beam and are little more dangerous than a TV remote controller at a distance.

I believe that in some states in the USA, home of litigation, there are some games where they are only allowed a fixed number of "laser" shots per game - 150 shots I think, just in case there might be an effect from cumulative hits. Once you run out, the gun still fires but only the IR beam comes out, making targetting a little tricky !

"Worlds of Wonder" sensor modifications.

Hit countdown button.

To make a sensor take a hit each time a button is pressed, connect a 'push-to-make' switch between TP8 which connects to pin 8 of the LM567 chip and TP4 which connects to pin 7. It will allow the sensor to be quickly and simply set to less than 6 hits at the start of a game.



Sensor 'blip' cure.

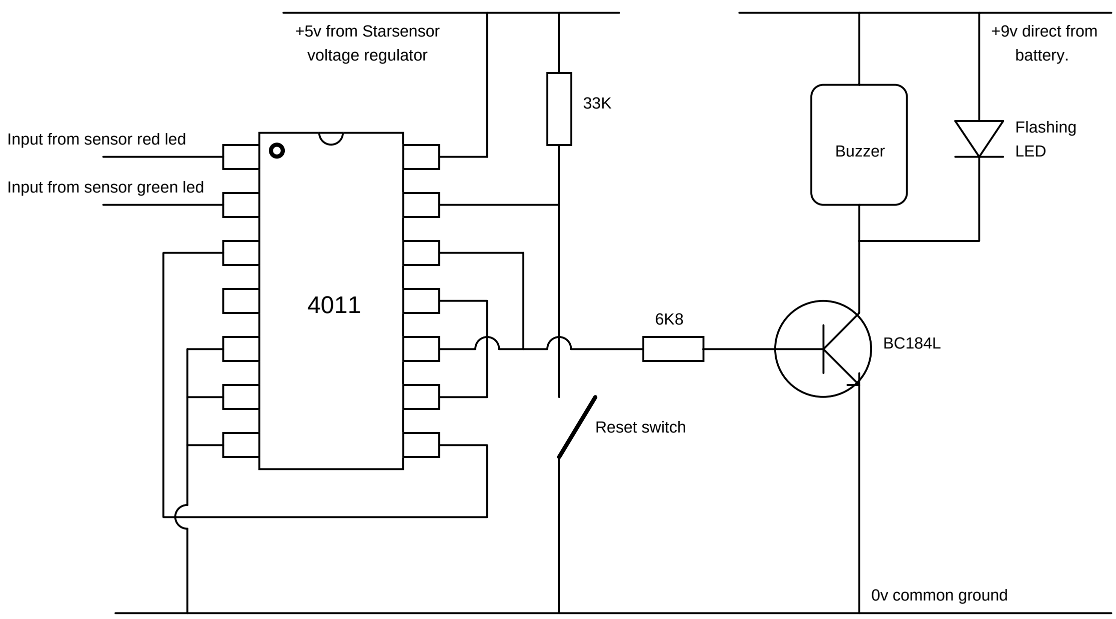
To stop the heartbeat blip driving you mad and stopping you hearing that alien creeping up on you, simply cut one of the wires on Resistor R10 on a StarSensor, R7 on a StarCap or R10 on a StarHelmet.

Turning off sensor lights

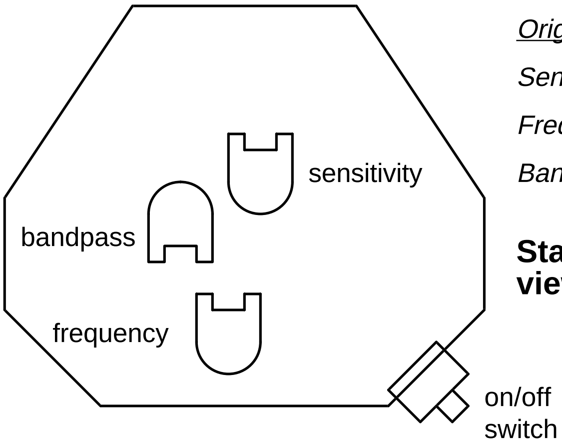
To disable the 'cylon' or 'bouncing ball' lights so they do not give your position away during a night game, cut R8 on a Starsensor, R5 on a star cap, R6 on a Star helmet (in the compartment behind the LEDs). It is wise to actually put a switch here so you can turn the function on and off - some club rules forbid the concealment of these lights. The other alternative is to cover the lights with black insulating tape which can be removed later.

Buzzer Board

It is sometimes difficult to hear your sensor 'die' when you are in the middle of a firefight. To ensure you notice this important fact you can add this little modification to sound a loud buzzer and additionally flash a bright LED in your face ! It works on the principle that the only time more than one hit light LED is illuminated is when you have just lost all your hits. It senses this condition and latches on, buzzing away until you press the reset button.



Sensor adjustment points



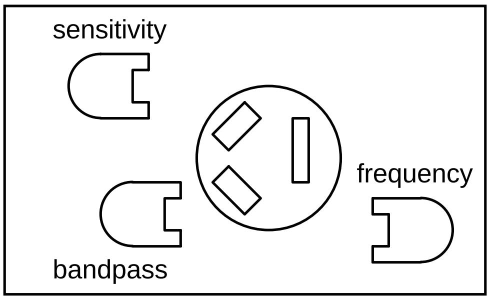
Original Component Values

Sensitivity = 200 R

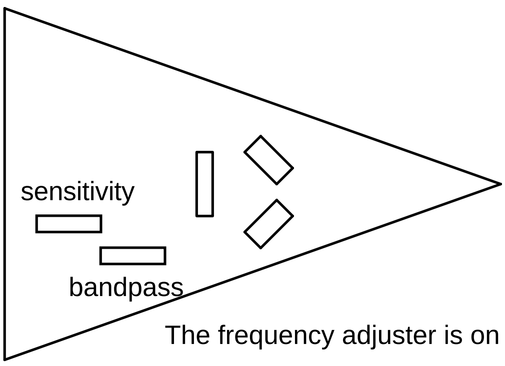
Frequency = 20 K

Bandpass = 200 K

Starsensor circuit board viewed from component side.



Starhelmet



Starcap

The frequency adjuster is on the other circuit board.

Attach frequency meter to pin 5 of the LM567 chip and turn frequency adjuster to set 1800Hz.

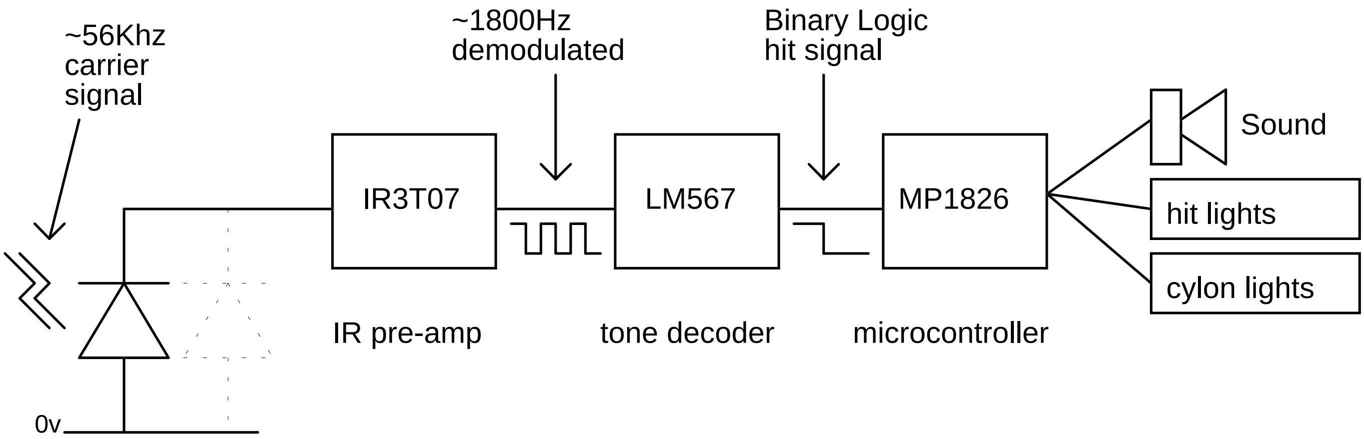
Adjust sensitivity until sensor takes hits from a Starlyte pistol, with lens removed, at 4 meters or greater. Try starting at 47 Ω.

Bandpass should not normally need adjusting. If you have to replace it because it has broken, set the new one to about 90KΩ by measuring it with an ohm meter before soldering it into place.

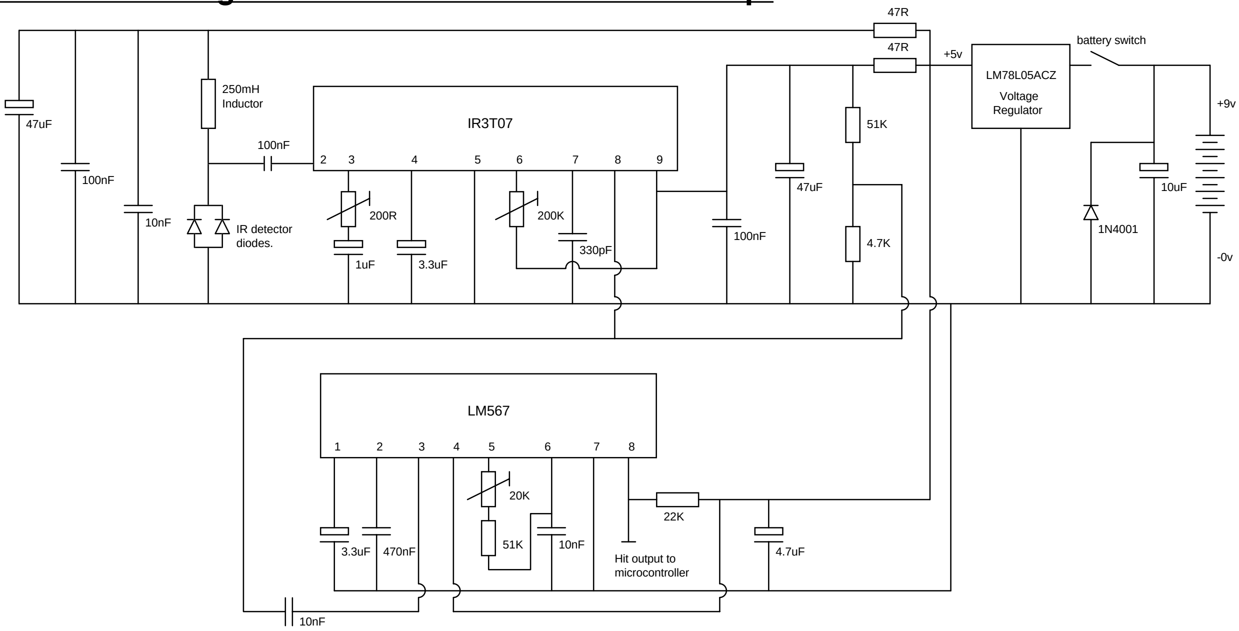
The SmartGun electronic tag board.

Designed by, built by, and obtainable from: Dave Bodger.

Simplified operational overview of WoW sensors.



Input circuit of original 'WoW' Starsensor and Starcap.



StarSensor modifications to extend battery life

Component ID	*Description*	*Standard type or value*	*Replace with*	*mA saved*	*New component cost (inc VAT)*
VR1	Voltage regulator	UA78L05AWC	LM2936Z-5	3	£1.21
CR12 & 13	LED	Green 3mm	Low current LED		£0.54
CR14 & 15	LED	Yellow 3mm	Low current LED		£0.54
CR16	LED	Red 3mm	Low current LED		£0.27
R11,12,13,14,15	Resistors	1K2	4K7	3	£0.15
R8 (Cylon light)	Resistor	1K2	2K4	2	£0.03
R17	Resistor	51K	33K		£0.03
C11	Capacitor	470nF disc.	47nF disc.		£0.09
C12	Capacitor	3.3µF electro.	reuse 470nF disc.		£0.00
C13	Capacitor	10nF	4.7nF ±1% poly.		£0.39
U2	Tone detector	LM567	LMC567CN	7	£1.39
R10	Heartbeat 'blip'	2K7	Cut resistor	0.2	£0.00

Total upgrade price £4.64

'Icing on the cake' mod.

CR4, 5, 6, 7, 8, 9, 10, 11.	8 x Cylon LEDs	Red 3mm	Low current LED		£2.16
R8	Resistor	2K4 (modified)	4K7	1	£0.03

A standard StarSensor with no modifications and a fresh battery consumes approximately 25mA with one hit light lit up, 21mA with no hit lights on. The above modifications reduce this to 11mA with one hit light on, 10mA without.

Also read the comments on the next page, which are applicable to both the Starsensor and Star Cap.

The SmartGun electronic tag board.

Designed by, built by, and obtainable from: Dave Bodger.

StarCap modifications to extend battery life

Component ID	*Description*	*Standard type or value*	*Replace with*	*mA saved*	*New component cost (inc VAT)*
VR1	Voltage regulator	MC78L05AC	LM2936Z-5	3	£1.21
CR1 & 2	LED	Green 3mm	Low current LED		£0.54
CR3 & 4	LED	Yellow 3mm	Low current LED		£0.54
CR5 & 6	LED	Red 3mm	Low current LED		£0.54
R8, 9, 10, 11,12	Resistors	1K2	4K7	2	£0.15
R5 (flashing led)	Resistor	1K2	4K7	2	£0.03
R13	Resistor	39K	22K		£0.03
C3	Capacitor	0.47µF electro.	47nF disc.		£0.09
C4	Capacitor	3.3µF electro.	reuse 0.47µF elec		£0.00
C5	Capacitor	10nF	4.7nF ±1% poly.		£0.39
U1	Tone detector	LM567	LMC567CN	6	£1.39
R7	Heartbeat 'blip'	2K7	Cut resistor	0.2	£0.00

Total upgrade price £4.91

A standard StarCap with no modifications and a fresh battery consumes approximately 21mA with one hit light lit up, 17mA with no hit lights on. The above modifications reduce this to approximately 9mA with one hit light on, 7mA without. The savings vary by a milli-amp or two from one circuit to another.

These modifications should in total more than double the battery life.

The original voltage regulator stopped regulating when the battery voltage dropped to 7 volts. The new one will keep on regulating down to 5.2 volts. This allows you to milk an extra 5% to 15%'ish out of an alkaline battery.

The LMC567 needs to be tuned to 3600Hz at pin 5 by adjusting R1. Or just turn the variable resistor left and right, noting when the sensor stops taking hits, then set it halfway between the two points. I will carry a frequency meter with me to games in the future so sensors can be accurately set.

I can provide small quantities of the LM2936 voltage regulator for £1 each and the LMC567 tone detector for £1.20 each. Add 30p postage & packing per order if you need me to post it to you; or catch me at a tag game to save a few coppers. Most of these bits can be obtained from Farnell Electronics, who you should contact if you want hundreds.

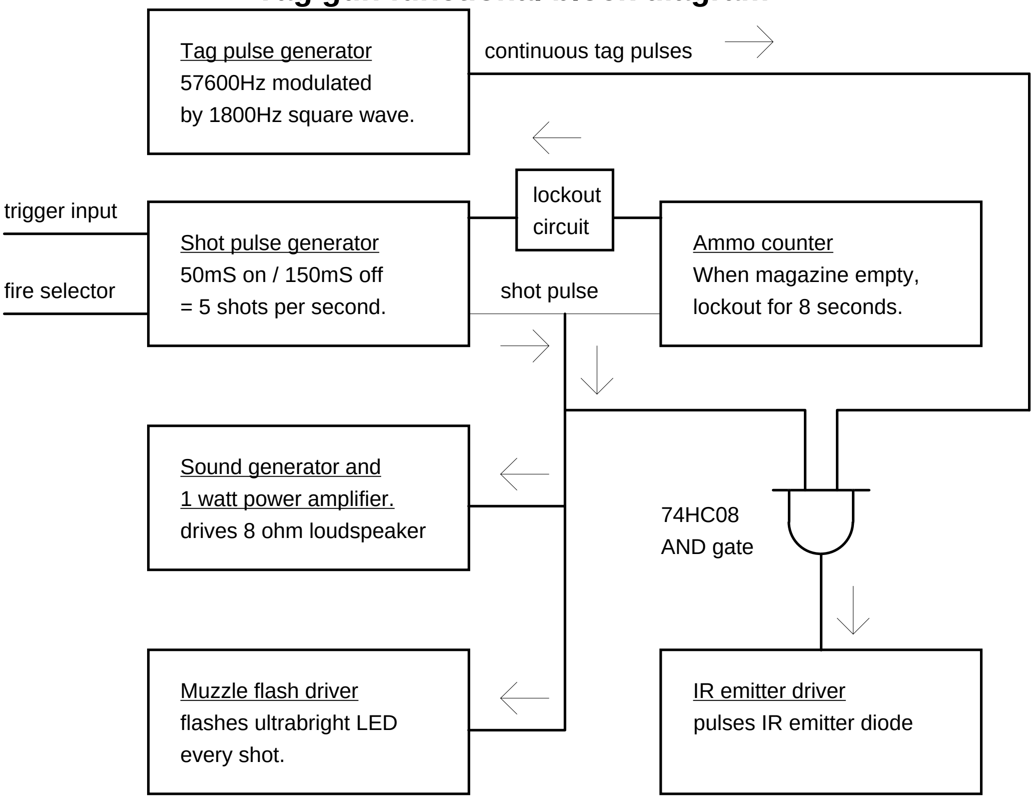
With the high cost of new alkaline batteries nowadays you should find yourself recouping the outlay for the upgrade within a few games. The savings could be even greater if it allowed you to switch over to rechargeables and you play more than a couple of games a year. (just remember to recharge them the day before the event!).

U.S.C.M. STATUTORY SENSOR HEALTH WARNING NOTICE: These notes are only for use by highly skilled 'techs' and should not be attempted by 'grunts'. All 'grunts' should contact their local 'tech' representative for assistance. (in other words - I deny liability for any damage you may do to your sensor while trying to perform the above modifications).

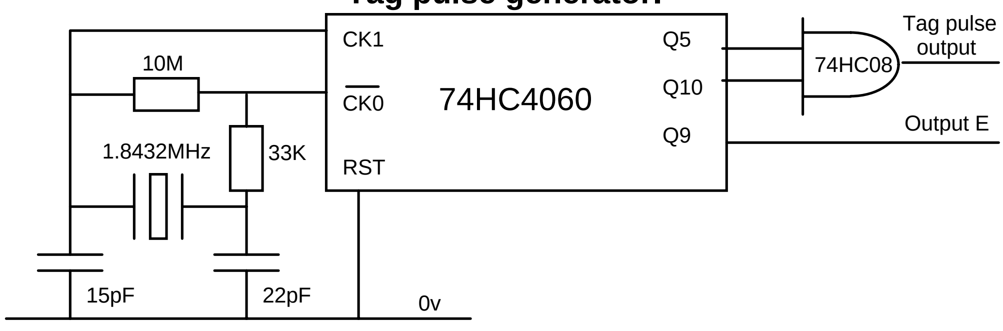
Example tag generating (i.e. gun) circuit.

These diagrams describe the tag gun circuit I designed from scratch, which powers my 'Big Green Gun' which has a range in excess of 400 meters using an OD50L emitter and home-brewed lens assembly.

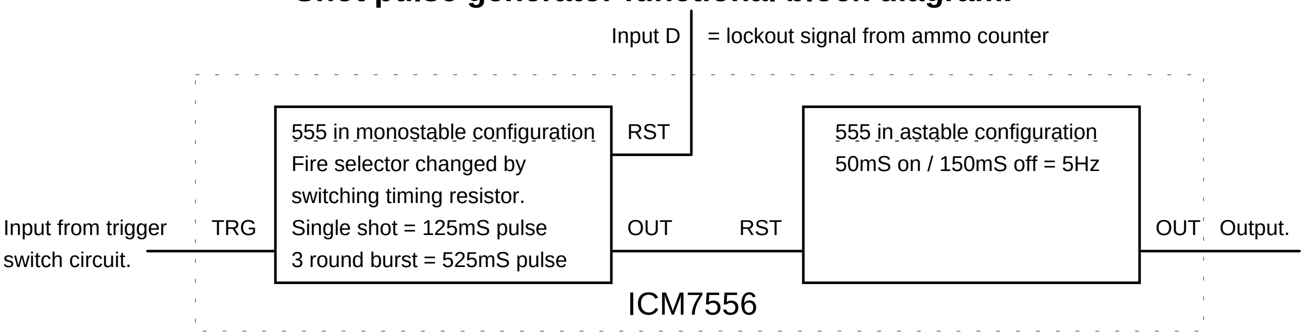
Tag gun functional block diagram.



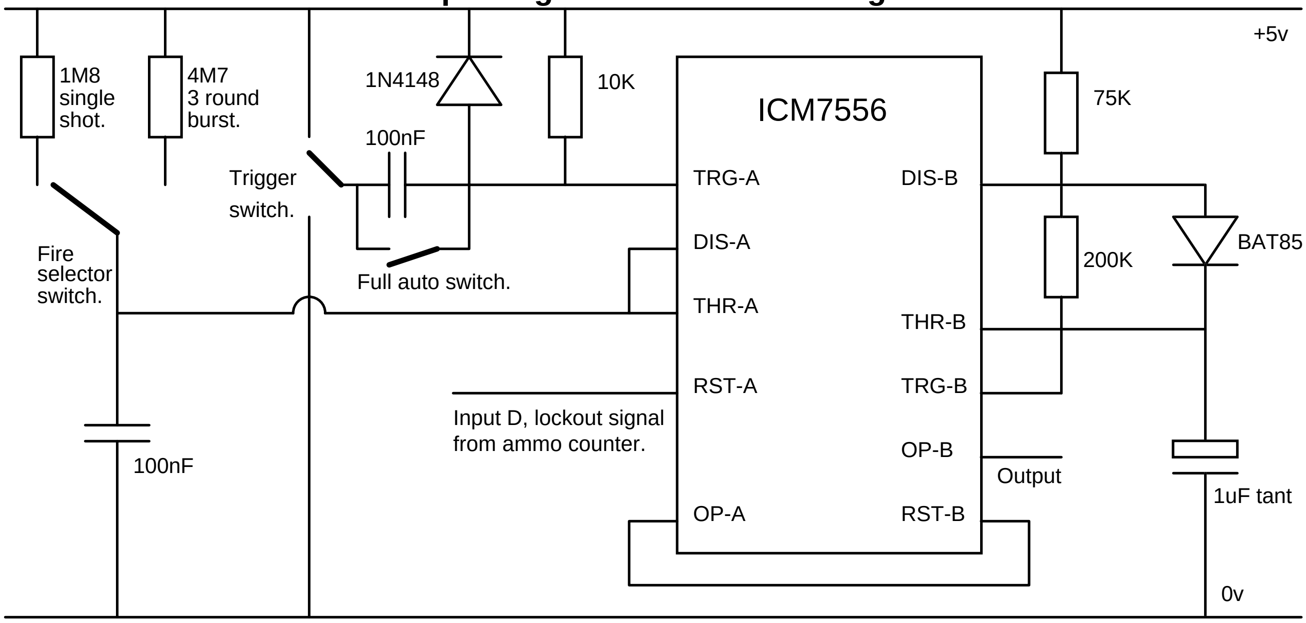
Tag pulse generator.



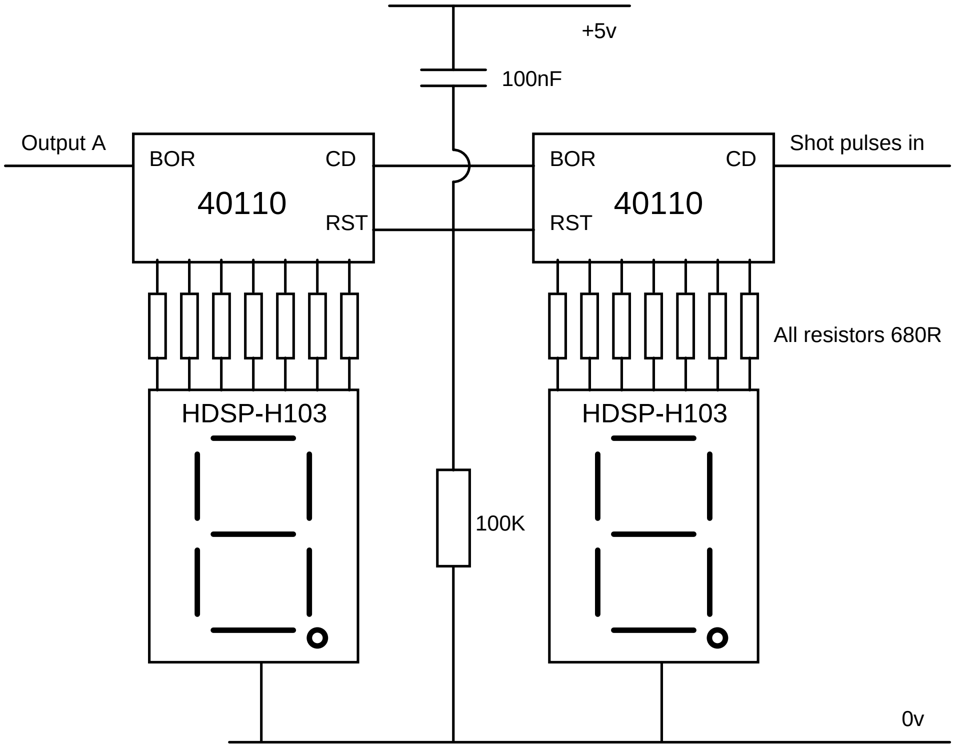
Shot pulse generator functional block diagram.



Shot pulse generator detailed diagram.



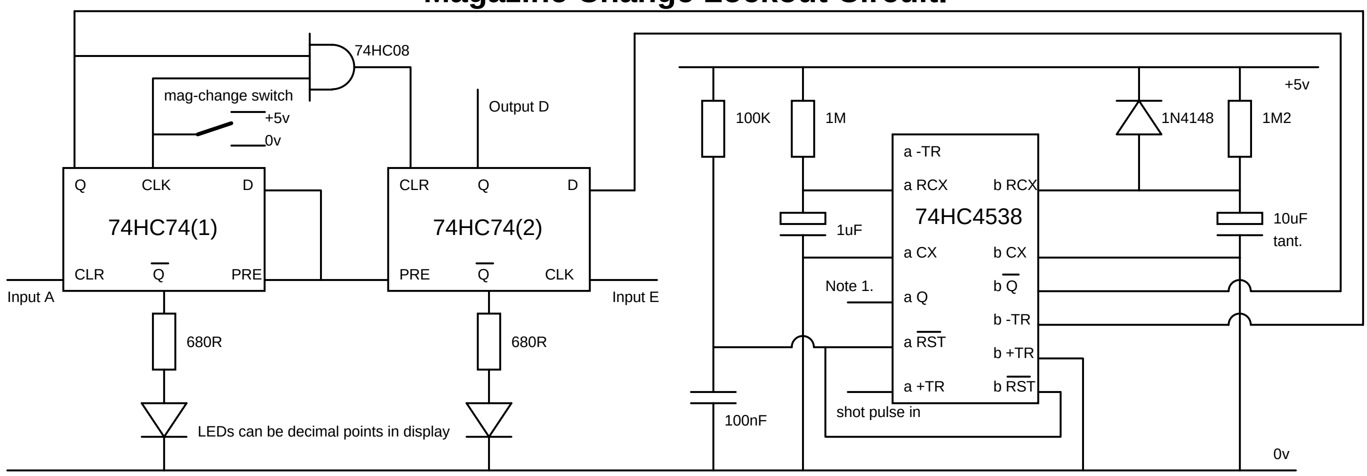
Ammo Counter.



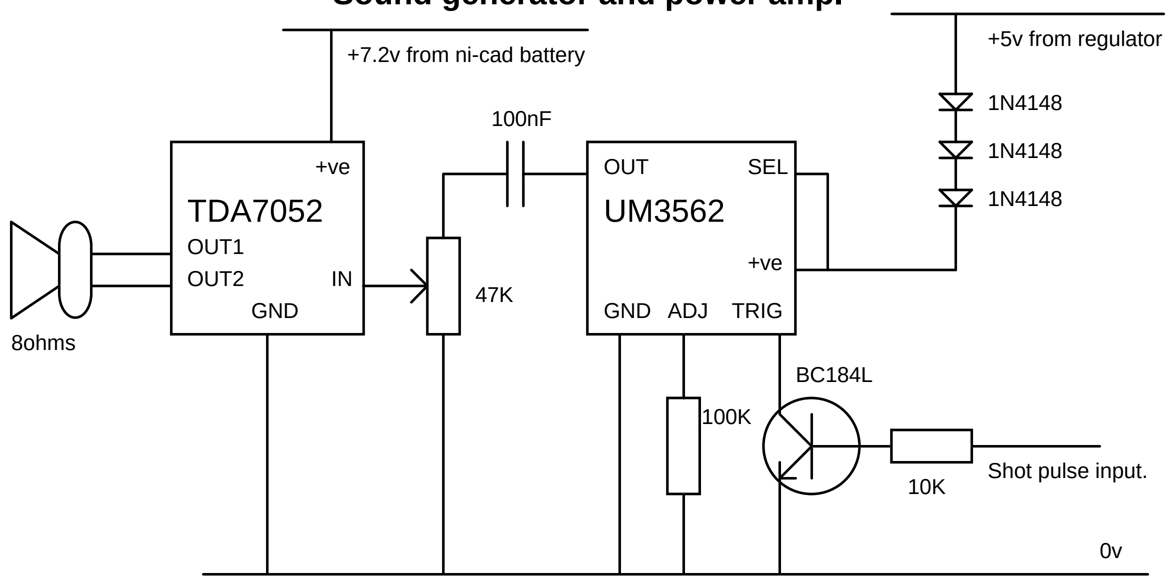
The SmartGun electronic tag board.

Designed by, built by, and obtainable from: Dave Bodger.

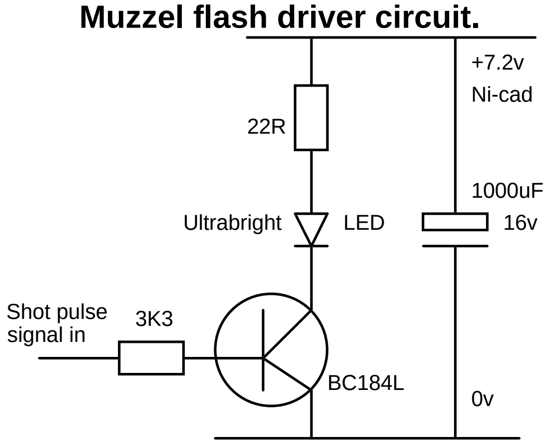
Magazine Change Lockout Circuit.



Sound generator and power amp.



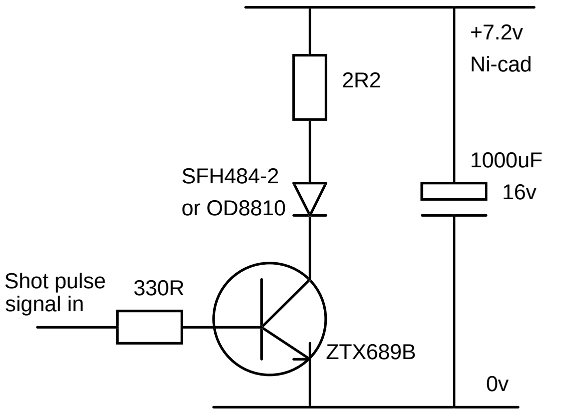
Muzzel flash driver circuit.



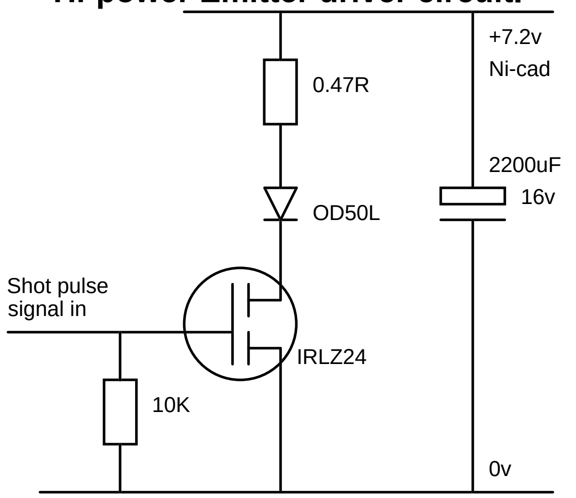
The SMARTGUN electronic tag board.

Designed by, built by, and obtainable from: Dave Bodger.

Standard Power Emitter driver circuit.



Hi-power Emitter driver circuit.



Note 1.
This output was used to drive a xenon strobe beacon via a BUZ10 MOSFET transistor switch, to provide a high-intensity 'tracer' style muzzel flash. It is on for .75 seconds, retriggered by each subsequent shot. This guarantees 1 flash for single shot, 1 or 2 flashes for 3 round burst and 2 flashes per second on full auto.

- All the logic chips require +5v from a regulated power supply to pin 16 (or 14 if they've only got 14 pins). All require 0v to pin 8 or 7 respectively. Check the datasheets to be sure. Using a 78L05 (100mA) voltage regulator should suffice for the +5v power supply.

- Note that the TDA7052 takes its power directly from the main batteries, not from the regulator. If you get a buzzing or humming from the speaker when it's not firing, you may need to add more smooting capacitance to the power rail. Try 4700µF or more. You may also need to use screened cable to its input if the distance is great or the wire is running next to other wires carrying high currents.

- Any unused chip inputs should be tied to +5v or 0v, not left floating.

- The 4060 chip should have pin 12 (reset) connected to 0v.

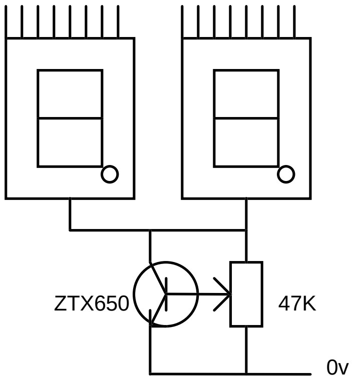
- On the 74HC74 chip the CLR pins are sometimes referred to as the RESET pins, they are one and the same thing.

- On the 74HC4538 the RST pins are sometimes referred to as the CLEAR pins, they are one and the same thing.

- A 74HC08 should be used as the source of the 2 input AND gates and should have all unused inputs connected to 0v or +5v, as stated previously.

- The 40110 chips require pins 4, 5 and 6 to be connected to 0v for correct operation. Also the unused count inputs should be connected to 0v.

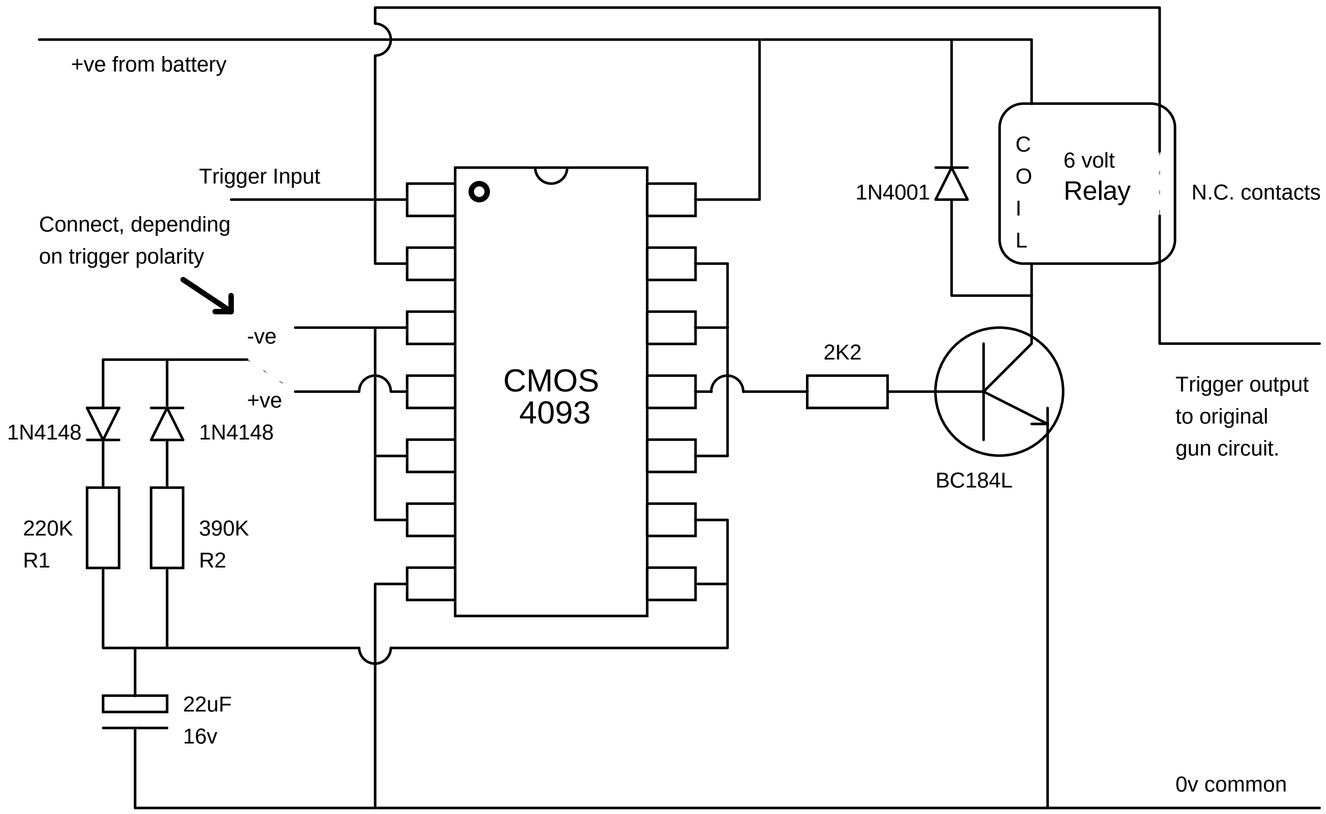
- In my original gun design I fitted a transistor between the common cathode connections and earth which was controlled by a variable potentiometer to control the brightness. This allows the display to be dimmed for night time use or turned down completely to preserve battery power. For simplicity you could just connect the common connections to earth via a push to make switch which would then only illuminate the display when the button was pushed.



- The Emitter driver resistor, the one in line with the emitter diode, will need to be recalculated for other diodes and battery voltages; see relevant section in construction notes.

- I recommend the IRLZ24 mosfet power switch for all new designs attempting to drive an OD50L. It can handle 16 amps and requires minimal drive current. It is ideally matched to the output from the 74HC series chips. It must not be driven by more than 5 volts though, so you cannot retrofit it to old CMOS designs running at full battery voltage. The IRFZ24 would be a better device in that case, but it needs 6 or more volts at its gate to turn on fully. Careful study of data books is required to select suitable mosfets, and they must be protected from static during construction.

Ammo timer / lockout circuit.



This circuit is in response to the latest inter-club rules which require that :-
'*Weapons with a rate of fire greater than one shot per second and a range greater than 100 meters should not have a sight fitted unless they have a fire limiting device (times lock-out, ammo counter, etc.) also fitted.*'

With the values shown, and running off of a 9 volt supply, it allows fire for 10 seconds and then cuts out for about 4 seconds (the 4 seconds does not start until the trigger is released). The 'on' time is controlled by the value of R1, the 'off' time is controlled by the value of R2. These values may be changed to 'tweak' the timings if you run a different battery voltage, or to change the ratio of on/off.

If short controlled bursts are used it is possible to fire without the lockout activating.

You must determine the polarity of your trigger to successfully utilise this circuit. See what voltage polarity you have on the trigger when it is pulled and set the connection to the two diodes to match.

This circuit is unlikely to work on microprocessor controlled guns which scan a matrix of function keys, but then that type of circuit will probably have some kind of fire limiting device programmed in anyway.

Laser Challenge Info

The new Laser Challenge (LC) equipment is cheap, plentiful, and **not** Worlds of Wonder (WoW) compatible.

It uses a 38KHz carrier frequency modulated by a 250Hz signal of 150 milliseconds duration to signify a hit, and a 185Hz signal of 500 milliseconds duration to reset the sensor.

If you fire a WoW gun at a LC sensor it will register hits most of the time (albeit at much reduced range compared to a WoW sensor) but occasionally it will reset the sensor. This 'side-effect' gets worse as the range increases, making it pointless to try using the LC sensors within a game with primarily WoW guns.

LC guns have no effect on WoW sensors.

The LC equipment is not alterable (other than the normal fitting of a lens assembly to increase range and extra amplification for sound) because it's circuitry is almost all contained within a custom chip which is not re-programmable.

The SmartGun circuit can fire a Laser Challenge tag pulse from version 1.6 onwards. This is in place of the normal WoW shot, you cannot fire both simultaneously. The SmartGun LC compatible pulse uses a 248Hz modulation over the normal 57.6KHz carrier, fired for 185mS. This appears to be accepted by LC sensors without any problem.

Useful addresses and phone numbers.

DSB Special Batteries Ltd
Ruben House
Crompton Way
Crawley
West Sussex
RH10 2QR
☎01293 611930

These people understand batteries inside-out.

Electromail
P.O. Box 33
Birchington Road
Corby
Northants
NN17 9EL
☎01536 204555

You have to pay for their catalogue

Farnell Electronics Components Ltd
Castleton Road
Armley
Leeds
LS12 2EN
☎0113 263 6311

They will send you a free catalogue

Maplin Electronics
☎01702 554000

Catalogue available at W H Smiths newsagents.

Dave Bodger's World Wide Web home page.
http://www.compulink.co.uk/~lasertag/
or
http://www.cix.co.uk/~lasertag/

MAIL: davebodger@bogo.co.uk

Dave Bodger's WWW Lasertag Info page.
lasertag.htm

Dave Bodger's Firefight Fanzine Info page.
ff.htm

