70s MORSE CODE DECODER

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Business Field:

- Semiconductor Quality Assurance support in Japan for foreign semiconductor company
- Analog related Circuit Design

Book:

TITLE: Operational Amplifier Specifications and Applications (Japanese)

This book refer operational amplifier specification, measurement method and application of the specification. This book covers DC/AC/Noise specifications. "Application of the specification" mean calculation method of errors on the application circuit. This book also has some suggestions of calculation method and measurement method for cases that difficult to calculate from ideal models, "know-how" in other words. 452 pages.

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Recently, we can use computer technology (ex. personal computer and micro-controller) for Morse code decoder. Here is a decoder that doesn't use computer technology. This decoder is possible to build with 1970s devices. From this, I named "70s MORSE CODE DECODER" However I designed with recent devices of course, using C-MOS operational amplifier for example.

Features

- No radiation of digital noise
- Cheapness
- Widely dynamic range for input signal
- Easy Center Frequency tuning
- Speed tracking Noise Filter
- Lower power dissipation

This decoder is good material for analog/digital circuit study for beginners. This document provided circuit operation. Analog circuit contains active filter, full wave rectifier, differential amplifier, peak hold, variable current source, current mirror and integrator. In digital circuit, decoding method could be interesting.

After building the decoder, you can use Morse code generator software for operation check and there are some free softwares.

I also think, you can improve performance of the decoder. Because this a primitive decoder. "Add automatic speed tuning circuit" is the example of improvement. Please try!

Appendix 1 to 5 are all of circuit schematics of the decoder. Overview of the function for each schematic is the following :

- Appendix 1 is the circuit block for conversion from tone signal (Morse code) to 0-5[V] of digital signal
- Appendix 2 is the circuit block for dot/dash separation and conversion from serial signal (Morse code) to parallel signal
- Appendix 3 is the circuit block for LED display
- Appendix 4 is the circuit block for power supply
- Appendix 5 is the schematic of LED matrix

About Appendix 1

Input and output,

Input is tone signal of Morse code. Center frequency of the tone is 800[Hz]. ECM (Electret Condenser/Capacitor Microphone) and LINE of 2 way inputs are available. It works <3[mVrms] of small tone signal at LINE input.

Output is 0-5[V] of digital signal that correspond to Morse code. 0[V] is Mark state (correspond to period of the tone) and 5[V] is Space state. 5[V] is nominal value and it depend on power supply voltage.

Operation of the circuit,

Figure 1 indicates functionality of Appendix 1 and each block position correspond to Appendix 1.

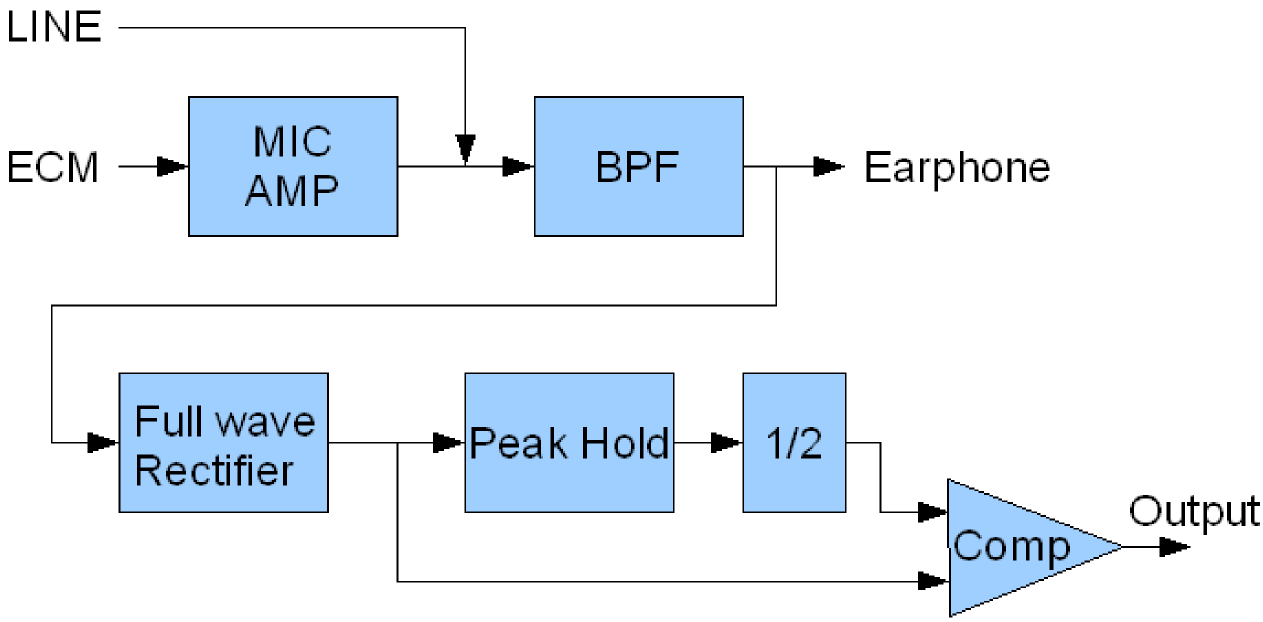


Figure 1. Block Diagram of Appendix 1

At first, analog circuit needs reference voltage. In this circuit, reference voltage generate with D101, D102 and D103 in Appendix 1.Each node has a tag (0.6V, 1.2V and 1.8V), name of tags are voltage (silicon diode voltage).

In Appendix 1, "1.2V" use for reference voltage for AC analog signal conditioning, it likes GND for AC signal.

A2-3 is ECM amplifier. You can use ECM for personal computer accessory. ECM amplifier has -46.5[V/V] of amplification. Minus sign is meaning of phase reverse (Inverting amplifier). This amplifier has BPF (Band Pass Filter) characteristics.

HPF (High Pass Filter) characteristic in BPF get from R101 and C101. Amplifier input resistance equal to R101, so C101 combination generate HPF characteristic. -3[dB] cut-off frequency (fc) determine by following equation:

$$fc = \frac{1}{2\pi \times C101 \times R101} \quad [\text{Hz}] \qquad (1.1)$$

In this case, C101=0.1E-6[F] and R101=4.3E3[ohm], therefor fc=370[Hz]

LPF (Low Pass Filter) characteristic in BPF get with C103 and R102 combination. -3[dB] fc determine by following equation:

$$fc = \frac{1}{2\pi \times C103 \times R102} \quad [\text{Hz}] \qquad (1.2)$$

In this case, C103=470E-12 and R102=200E3, therefor fc=1.7[kHz]

A2-3 is inverting amplifier. The reason of inverting amplifier come from LPF characteristic. When using non-inverting amplifier, 1[V/V] of amplification remain at high frequency (out of cut-off frequency). This mean out of cut-off frequency signal pass to output. Inverting amplifier has -6[dB/octave] in monotonic at high frequency. So inverting input amplifier is good choice. This is the reason of inverting amplifier.

Audio signal go into the active filter that consists of A1-1 and A1-2 and this filter consist of two BPFs. Difference between 1st.and 2nd. stage is amplification. 1st. stage has 1[V/V] and 2nd. stage has 4[V/V], so 4[V/V](＝1×4)for total amplification. Center frequency and Q of 1st and 2nd stages are the same (800[Hz] and 10). I used a book "Rapid Practical Design of Active Filters (John Wiley & Sons Inc.) " for the design.

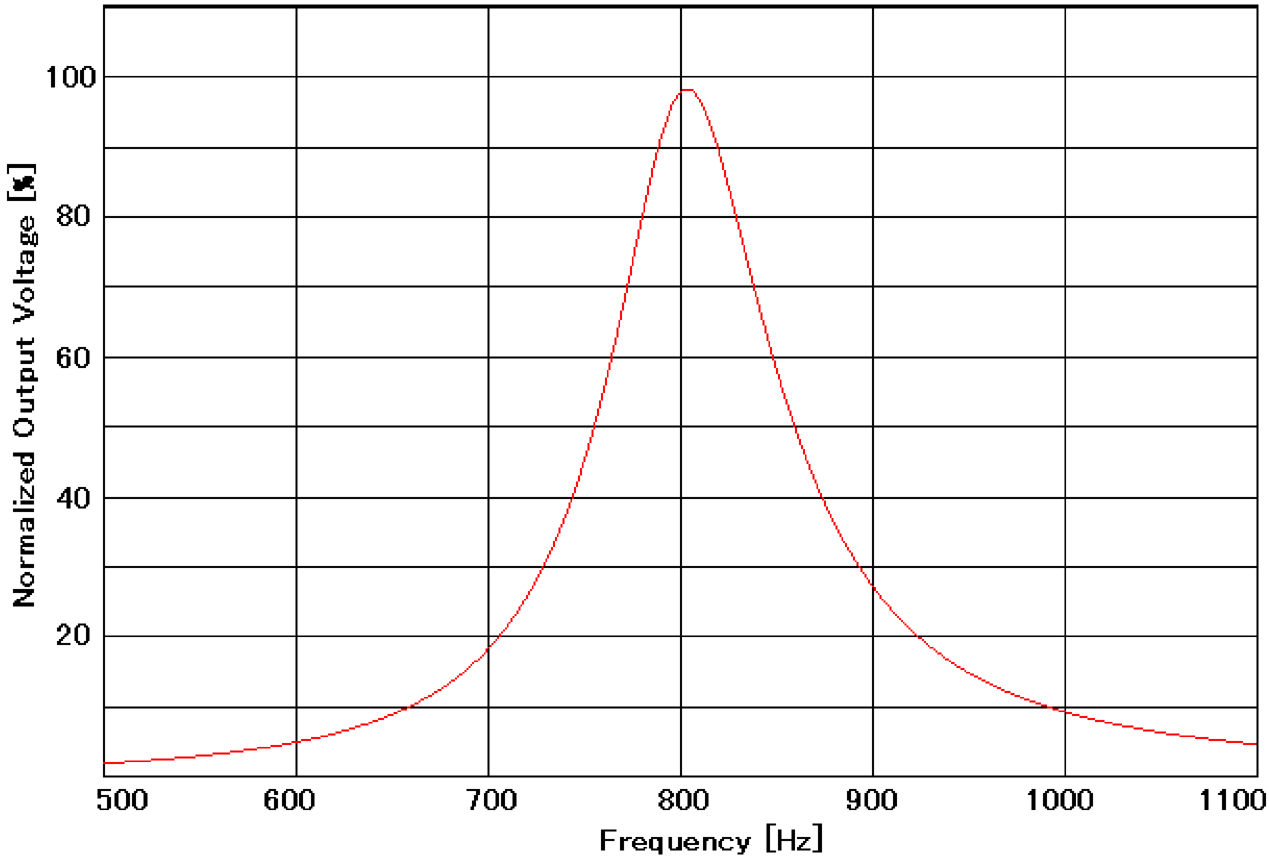


Figure 2. BPF Total Frequency Response

Figure 2 is calculated frequency response that including A1-1 and A1-2 stages (Not actual data). This calculation use nominal value of the parts (capacitors and resistors).

When BPF band width is too narrow, it will affect to high speed Morse code decoding. Because Morse code speed is proportional to band width. In my bench test, 63[wpm] is no problem to decode.

The unit of "wpm" mean words par minute, the word is "PARIS" and it has 50[dot] length ("dot" is period of Dot, Dash period is 3[dot] length). This is standardized measurement method. This document use this unit often and calls "PARIS speed", please remember this.

Filter output signal go into the full wave rectifier that consist of A1-4, A2-4 and TR101 (Explanation of earphone is later). Some Morse decoder uses PLL IC (ex. NE567) for this block.

That is one of easy way, however PLL has some peculiarities. Input signal amplitude dependency of Lock Range and various of Lock-in Time are for example.

Full wave rectifier doesn't have the same problem in basically. And this circuit works less than 10[mVrms] of small signal (NE567 needs >200[mVrms] of large signal). So this decoder doesn't have gain control because of wide dynamic rage (<10[mVrms] to 1[Vrms]) at rectifier input.

A2-4 work for comparator. The purpose of the comparator is detection of positive or negative cycle from reference voltage (voltage of Pin12). During positive cycle, A2-4 output become 0[V] and TR101 drain-source turn OFF. At this state, TR101 gate input voltage is the same as reference voltage (the same voltage as A2-4 Pin 12) because of D103 and D104 voltage drop. During negative cycle, A2-4 output become Vs (5[V] for nominal value) and TR101 drain-source turn ON.

Operation that included A1-4, A1-4 works +1[V/V] of amplifier during positive cycle, A1-4 works -1[V/V] of amplifier during negative cycle. Consequently, it works full wave rectifier.

The reason of "full wave" is getting accurate dot length particularly high speed Morse code. The period of Dot in high speed Morse code, number of cycle is not so large number. For example, when 60[wpm] of Morse code receive with 800[Hz] of tone signal. 60[wpm] is 3000[dot] length ($=PARIS\ Speed \times Dot\ length\ of\ PARIS = 60 \times 50$). From this number, time period of 1[dot] is 20[msec] ($=60 \div 3000$). One cycle period of 800[Hz] is 1.25[msec] ($=1/800$). So one dot consist of 16 cycles of 800[Hz] signal. When use half wave rectifier, we can get 16 cycles. When missed 1 cycle, we have 6.25[%] of error of Dot length, because Dot/Dash separator need accurate length signal. In full wave rectifier, we can get 32 cycles and it becomes more accurate. This is the reason of using full wave rectifier.

Next to the rectifier, C113 and R114+VR101-1 are ripple filter of the rectifier output. This is one of major reason of them. However there is another major reason. It is a tracking filter for base band signal. This filter is effective for smaller signal (similar level to noise). "Base band signal" mean Morse code signal.

Basically, Morse code is ON/OFF signal. This mean, spectrum of base band signal concentrate within 0 to 1/(2[dot] length)[Hz].

An idea of 1/(2[dot] length)

HH-bar (code of correction) is a good example. HH-bar consists of eight Dots and seven Spaces, this combination has highest frequency in Morse code. One cycle in this code is combination of one Dot + one Space and this is 2[dot] length. Frequency is a reciprocal number of this. At the spectrum, major energy contain within that frequency. This is the idea of 1/(2[dot] length).

Low level signal contains some noise, because signal level is close to noise level. C113 and R114+VR101-1 of Low Pass Filter is effective to noise reduction. Optimum cut-off frequency is depending on Morse code speed. So this decoder use tracking filter with dual ganged potentiometer. When you adjust speed to receiving signal, cut-off frequency adjust with automatically. Terminal 2 of VR101-1 in Appendix 1 has a broken line, it means dual ganged potentiometer.

TR102, TR103, TR104 and A1-3 are peak voltage hold circuit. TR102 and TR103 composes differential amplifier. TR104 charges C114 and voltage of C114 is TR103 base voltage. Overall operation of this circuit is negative feedback.

In the stable state, the voltage of TR102 and TR103 bases are the same, Ic (collector current) of TR102 and TR103 are the same also. TR104 sources TR103 base bias current (~150[nA] when assume hfe=200).

When TR102 base voltage increase (right after Mark coming), TR102 Ic increase and TR103 Ic decrease, voltage of VR102+R115 increase, TR104 Ic increase and C114 voltage (TR103 base voltage) increase with quickly. This operation stop when TR103 base voltage reach to TR102 base voltage.

When TR102 base voltage decrease (right after Space coming), circuit works opposite without C114 charge operation. TR104 turn OFF (Ic=0[A]). C114 sources TR103 base bias current (~300[nA]) and this current discharges C114 with slowly.

C114 voltage change quickly for increasing and slowly for decreasing, this is peak hold operation.

When you change time constant of peak hold circuit, I recommend to tune with C114.

R117 works for saving charge current. This is prevention for spike voltage caused charge.

In generally, use a current source at R116 position for getting accuracy. This circuit doesn't use it for saving count of parts. Accuracy is voltage difference between TR102 and TR103 bases dependency of TR102 input voltage. Actual error in the bench test was 6[%]. The meaning of this error is when TR102 base voltage change from 1.2[V] to 1.21[V] (10[mV] difference), there was 0.6[mV] of voltage difference between TR102 and TR103 bases. This is acceptable number in this application. I evaluated from 1.2 to 2.2[V] and 6[%] is the worst case.

Peak hold output signal (A1-3 output) go into comparator (A2-2). Between A1-3 and A2-2, there is voltage divider (R118 and R119). This divider generate a half voltage of peak hold output. This is threshold voltage for Mark and Space.

A2-2 is a comparator. Output assigned L (~0[V]) for the Mark and H (~5[V]) for the Space. This is compatible output to NE567 (PLL IC). So you can replace to NE567 easily. This comparator has 7.5[mV] of hysteresis for prevention of high speed switching with noise.

VR102 in the peak hold use for DC offset voltage adjustment. At No signal, A2-2 output should be H (Space state). But there is possibility of L that caused by DC offset voltage at peak hold, A1-3 and A2-2 when no adjustment circuit.

The right position of VR102 is near A2-2's H/L threshold and stable H state when no input signal. You can check this state with ON/OFF of LED1 in Appendix 2, it correspond to A2-2 output and LED should be OFF when no input signal. At this position, this decoder works highest sensitivity to input signal (Morse code). When use ECM, decoder works with whisper level.

BPF output (A1-2) connect to earphone jack. Earphone use for tuning of tone signal frequency (800[Hz]). From explanation so far, here is the final stage of tone signal. You can hear sound at this point and you can tune to the best position easily. When tone signal frequency meet to center frequency of the filter, tone signal volume go up. You can use regular magnetic earphone (~30[ohms] of impedance).

This Appendix 1 has many devices. But total power dissipation is similar to NE567 (less than 10[mA]). And if you already have Morse code decoder that used NE567 or signal compatible IC, you can replace to this circuit. I think performance of the decoder become good.

About Appendix 2,

Input and output,

Input is Morse code digital signal that regard L (~0[V]) as Mark and H (~5[V]) as Space.
Output is parallel coding Morse code that regard L (~0[V]) as Dot and H (~5[V]) as Dash.

Operation of the circuit

Mark/Space signal come from A2-2. A2-2 is operational amplifier output, so switching speed is too slow for digital devices. IC2-1 and IC2-2 shapes edge and generate inverting signal.

TR201 is variable current source. R203+VR101-2 determine source current. Voltage of R203+VR101-2 has constant value and it's 2 (silicon) diode voltage (~1.2[V] and 1 diode voltage canceled by TR201 V_{BE}). TR201 emitter current determine by 1.2/(R203+VR101-2) and this current is nearly equal to collector current of TR201. This current is nearly equal to D201 and R201 current. When we assume voltage of D201 equal to TR202 V_{BE}, voltage of R201 also equal to R202. So R202 current determine by V_{R201}/R202. This current (the same as TR202 emitter current) is nearly equal to TR202 collector current. The part of this is current mirror (R201, D201, R202 and TR201). Total circuit operation is, VR101-2 controls TR202 output current.

At this point, we can calculate TR202 output current (I) with the following equation :

$$I=\frac{\frac{1.8-TR201VBE}{R203+VR101}\times R201}{R202}=\frac{\frac{1.8-0.6}{2E3+VR101}\times 2E3}{75E3} \qquad (2.1)$$

From the equation 2.1, TR202 output current range is

$$I@10\text{kohm}=\frac{\frac{1.8-0.6}{2E3+10E3}\times 2E3}{75E3}=2.7E\text{-}6[A]$$

$$I@0\text{kohm}=\frac{\frac{1.8-0.6}{2E3+0}\times 2E3}{75E3}=16E\text{-}6[A]$$

R203 should use the same value as R114 (2[kohm]) for getting matching of both of circuit that connect to dual ganged potentiometer. When use smaller value for R114/R203, you will get widely speed range of Morse code, however noise reduction performance at R114 side will turn to worse when use the same value of C113.

About VR101, I recommend to use Logarithmic Taper Potentiometer that is the same characteristic as volume control in audio amplifier. I don't recommend linear taper for VR101. Table 1 is the reason.

% of Rotation	0	20	40	60	80	100
wpm @ Log	68	59	47	32	17	11
wpm @ Lin	68	43	24	16	13	11

Table 1. Linearity of potentiometer dependency

Table 1 indicates relation between % of potentiometer rotation and PARIS speed in this decoder (The basis data of "% of Rotation" got from Japanese Industrial Standards C 6444 2.2.5). Log (logarithmic taper) looks like linear characteristic. But Lin (linear taper) has big jump at 0% to 20% region, this is meaning of difficulty of adjustment at higher speed Morse code.

From Table 1, that also indicates wpm decrease when clockwise direction of the potentiometer. "Increase" is better of course, however we need anti-log taper. This is minor and expensive device. If you can get anti-log taper, it's much better. But you cannot solve this problem with change the connection of VR101 (swapping connection between terminal 1 and 3), if you do that, you will have huge jump (more than Linear taper) at high speed region.

TR202 output current charges C201 or C202+C203 depend on Mark/Space.

Functionality of current source and capacitor combination is an integrator. Integrator mean voltage of capacitor is in proportion to time. It also mean capacitor voltage go up monotonic with constant charge current. There is the following equation between capacitor voltage (V[V]), capacitance (C[F]), time (t[sec]) and charge current (I[A]) :

$$V = \frac{I \times t}{C}$$

IC1-1 and IC1-2 switch TR202 output current and it works complementary. C201 use for the Mark and C202+C203 use for the Space. C201, C202 and C203 are the same value (0.47uF) and charge current is also the same value. Consequently, the voltage increasing rate for C202+C203 is a half of C201. These capacitors discharge by 74HC07 through 390[ohms]. C201 discharge during Space period, C202+C203 discharge during Mark period.

The reason of the combination of C201 and C202+C203 is the following:

When decode Morse code, the Mark has Dot/Dash of two states. The Space has following three states, Dot/Dash separator (1[dot] length), characters separator (3[dot] length) and words separator (7[dot] length). These states detect by comparator in this decoder.

Comparator compare capacitor voltage and reference voltage (D101-D103). LMC660 use for comparator. Input common mode voltage range of LMC660 is 2.5[V]@Vs=5[V], this is 3 or 4 of silicon diodes voltage (0.6 to 0.7[V] for 1 diode voltage).

D101-D102 reference voltage connect to comparator, so reference voltage has meaning of "Threshold voltage" in other words. The plan of reference voltage is,

- 2[dot] length at Mark side use for threshold voltage of Dot and Dash
- 2[dot] length at Space side use for threshold voltage of the Dot/Dash separator and the characters separator
- 6[dot] length at Space side use for threshold voltage of the characters separator and the words separator

When assigned 1[dot] length to 1 diode voltage, 6[dot] length need 6 stacked diodes, this is not acceptable number from LMC660 input voltage range. This decoder uses two capacitors for Space side to reduce number of stacked diode, consequently, 2[dot] length assigned to 1 diode voltage at space side.

From above explanation, the assignment of A3-1, A3-3 and A3-4 are the following:

- A3-1 use for threshold voltage of Dot and Dash
- A3-3 use for threshold voltage of the dot/dash separator and the characters separator
- A3-4 use for threshold voltage of the characters separator and the words separator.

At this point, you can calculate Morse code speed range from explanation so far. Calculation factor at mark side, 1 diode voltage (0.6[V]) assigned to 1[dot] length, capacitance is 0.47[uF], TR202 output current range is 2.7[uA] to 16[uA]. Time period of 1[dot] length is,

$$Dot\ period = \frac{C \times V}{I} \qquad (2.2)$$

$$Dot\ period\ @2.7\text{uA} = \frac{0.47\text{E-}6 \times 0.6}{2.7\text{E-}6} = 104\text{E-}3[sec]$$

$$Dot\ period\ @16\text{uA} = \frac{0.47\text{E-}6 \times 0.6}{16\text{E-}6} = 17.6\text{E-}3[sec]$$

Convert to PARIS speed [wpm],

$$PARIS\ speed = \frac{60\text{second}}{Dot\ period \times Length\ of\ PARIS} \qquad (2.3)$$

$$PARIS\ speed\ @2.7\text{uA} = \frac{60}{104\text{E-}3 \times 50} = 12[wpm]$$

$$PARIS\ speed\ @16\text{uA} = \frac{60}{17.6\text{E-}3 \times 50} = 68[wpm]$$

Table 1 calculated from this. And when you mark PARIS speed to potentiometer, you can use this calculation.

When you mark SPEED with degrees, you have to know TR202 output current. TP1 and TP2 (voltage drop of R203) use for this purpose. You can calculate output current from voltage difference of R202. However you should care input impedance of voltage meter, I recommend to use >1[Mohm] of input impedance for this measurement. Almost all digital multimeter satisfy this condition, but some analog multimeter has low input impedance (ex.20[kohm]).

LED201 and LED202 use for clue when adjust VR101 (Speed control). LED201 indicates receiving signal, it light during Mark. LED202 indicates mark exceeded 2[dot] length. When adjust LED202 lights only Dash period, it is the right position.

C201, C202 and C203, I recommend to use film capacitor and better than 5% tolerance. 0.47[uF] film capacitor is slightly minor device and it is a slightly larger size (depend on maximum voltage). When you cannot get 0.47[uF], you can redesign that use smaller capacitors (ex.0.1[uF]). But you should care leakage current that connect to the current source (TR202), because output current reduce in proportion to capacitance. In generally, leakage current of semiconductor depend on temperature. For example, PN junction reverse current is two times of leakage current generate every 10 degree Celsius go up. 0.47[uF] is trade-off from this.

Why both of circuits (VR101-1 and VR101-2) tracks?

At first, VR101-2 side. From the equation 2.3 that including equations 2.1 and 2.2, a variable in PARIS speed is "2E3[ohm]+VR101" in the equation 2.1 only, because other factors are constant values. The following equation is PARIS speed that described 2E3[ohm]+VR101 and Cons for constant value:

$$PARIS\ speed = \frac{Cons}{2\text{E}3 + VR101} \qquad (2.4)$$

At VR101-1 side, this is CR filter. The model of this circuit operation is similar to CR circuit charge/discharge by square wave. At this model, we can use CR time constant model. CR time constant should decide by minimum period of Mark and Space (This decoder uses ~2.6CR of time constant). Period of Dot is minimum length. We can describe it that using equation 2.3 with replace from Dot period to 2.6CR as the following,

$$PARIS\ speed = \frac{60}{2.6\mathrm{CR} \times 50}$$

At here, replace R to 2E3[ohm]+VR101 and also replace $60/(2.6\mathrm{C}\times 50)$ to Cons, the equation is,

$$PARIS\ speed = \frac{Cons}{2\mathrm{E}3 + VR101} \qquad (2.5)$$

Equations 2.4 and 2.5 is the same style. This mean, the equation 2.4 proportion to the equation 2.5. Therefore both of circuits tracks.

Now we got all of digital control signals.

IC2-3 output (inverting signal of A3-1 output) is Morse code that's cording L (~0[V]) correspond to Dot and H (~5[V]) correspond to Dash. This signal go into 10bit length of shift register that consist of IC3-1, IC3-2 and IC4. Shift register memorized IC2-3 output at every end of Mark signal.

The point of shift register is the reset state. Reset signal generate by A3-3 (end of character). When reset signal coming, IC3-1 Q output turn to H (~5[V]) and the other stages Q outputs turn to L (~0[V]). When describe reset state with binary code (add "b" letter) with H=1 and L=0,

00 0000 0001b

In binary expression, the first stage is positioned 2^0 (Least Significant Bit).

The reason of this reset state is recognition of the head bit. If 00 0000 0000b use for the reset state and Morse code "e" received, shift register will take 00 0000 0000b. This is the same when "i", "s" and "h" received, because these Morse codes also consist of Dots. This mean we cannot separate these Morse codes. When use 00 0000 0001b for the reset state and "e" received, shift register will be 00 0000 0010b. In other case , "i" coming, shift register will be 00 0000 0100b. We can separate all of Morse code with additional head bit. This is the reason of the reset state.

IC5 and IC6 are D-flipflop and memorize shift register output at each end of characters. The clock signal for IC5 and IC6 and shift register is the same source (A3-3 output). The difference is IC2-5 propagation delay.(~20nsec). So it should connect with short wire.

IC5 and IC6 reset by IC3-4 (end of word). This is prevention to remain previous character right after new word coming. From this prevention, 00 0000 0000b transfer to next stage (Display block). In this decoder, there is 00 0000 0000b assigned LED, so this assigned LED should mask (shield of light).

About Appendix 3

Input and output,

Input signals are parallel Morse code D9-D0 (including head recognition bit) and Blank signal.

Output is LED matrix. Each LED has each assigned character, corresponding LED lights by D9-D0 signal.

Operation of the circuit,

This is display circuit block that using LED matrix module. This decoder uses 128 LEDs (One module consist of 64 LEDs and 2 modules used). If you build this module with discrete LEDs or bulbs, this decoder need 51peices for English.

The reason of using LED matrix is cheapness. And I use Japanese also. Japanese has 50 characters. I purchased 100[yen] for 1 module (100[yen], yen is Japanese currency unit and it is approximately 1US Dollar or 1Euro). Photo 2 is the purchased module and Appendix 5 is inside circuit of the module. Dimension of the module is H:D:W=10.3 : 37.6 : 37.6[mm]. Separation of each LED is 4.7[mm] and diameter of each LED is 3.7[mm].

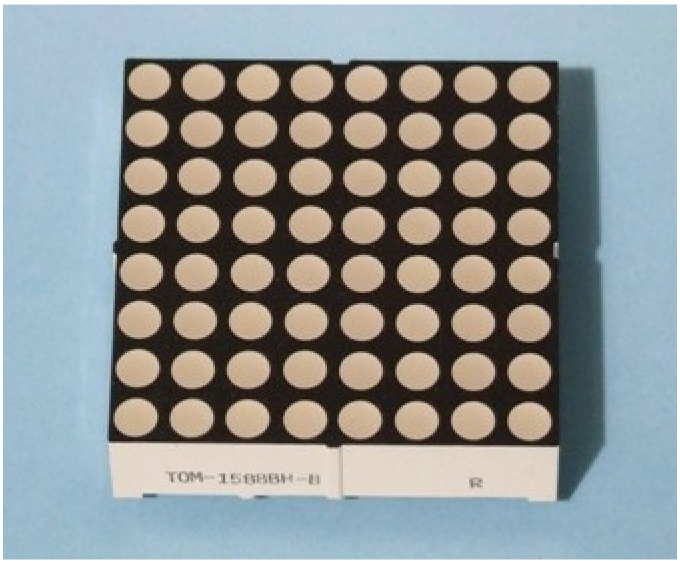


Photo 2. LED Module

Operation of the circuit is,
D9 to D0 signals come from IC5 and IC6 and Blank signal come from IC2-4. D5-D0 of six bits signal go into IC7 and IC8, these signals are select signal in binary. These ICs has 8 outputs and selected output turn to L (~0[V]).

IC 12 and IC13, these are inverters. Selected output of IC12 or IC13 turn to H (~5[V]) and this is LED drive voltage. So IC12 and IC13 output connect to anode of LED matrix module.

IC11-1 and IC11-2 generate select signal of IC12 and IC13. When more than 6[bit] length of Morse code received (9[bit] is maximum length Morse code, it is SOS-bar), the head bit position within D6 to D9. In this state, IC11-1 output turn to L (~0[V]) and IC11-2 output turn to H (~5[V]). Subsequently, IC13 output will be enable and IC12 output will be disable. When less than 5[bit] length of Morse code received, IC12 is enable and IC13 is disable.

IC7 output connect to IC9 and IC10, these are buffer and open drain output. In generally, LED is very weak to reverse voltage, when pass several micro amps of reverse current , LED will have damage permanently. From this reason, it should drive open collector or open drain type of output devices.

From this operation, one LED light that determined by D9 to D0.

Blank signal disables IC7 and 8, LED turn off as the result.

Table 2 and Table 3 are LED assigned map for English.
Number at lowest position in each box is address of LED in octal, so it has "o" letter. R7-R0 and C7-C0 is the same signal as Appendix 3 and Appendix 5.

"(Mask)" in the box of R0 & C0 in Table 2 mean shield of the light. This LED lights when A3-4 active (end of word). I recommend to shield this LED. One of method of the shield is aluminum foil paste on the LED, I use this method.

	C0	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*
R0	(Mask) 00o	01o	**E** 02o	**T** 03o	**I** 04o	**A** 05o	**N** 06o	**M** 07o
R1	**S** 10o	**U** 11o	**R** 12o	**W** 13o	**D** 14o	**K** 15o	**G** 16o	**O** 17o
R2	**H** 20o	**V** 21o	**F** 22o	23o	**L** 24o	25o	**P** 26o	**J** 27o
R3	**B** 30o	**X** ***1** 31o	**C** 32o	**Y** 33o	**Z** 34o	**Q** 35o	36o	37o
R4	**5** 40o	**4** 41o	42o	**3** 43o	44o	45o	46o	**2** 47o
R5	**AS**-bar 50o	51o	**AR**-bar + 52o	53o	54o	55o	56o	**1** 57o
R6	**6** 60o	**BT**-bar = 61o	/ 62o	63o	64o	65o	**KN**-bar **(** 66o	67o
R7	**7** 70o	71o	72o	73o	**8** 74o	75o	**9** 76o	**0** 77o

Table 2 Lower side LED matrix module assignment map

*1: Mark of multiplication

	C0	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*
R0	**HH**-bar 00o	01o	02o	03o	04o	**VA**-bar 05o	06o	07o
R1	10o	11o	12o	13o	**?** 14o	15o	16o	17o
R2	20o	21o	**"** 22o	23o	24o	**,** 25o	26o	27o
R3	30o	31o	32o	33o	34o	35o	36o	37o
R4	40o	**-** 41o	42o	43o	44o	45o	46o	47o
R5	50o	51o	52o	53o	54o	**)** 55o	56o	57o
R6	60o	61o	62o	**.** 63o	64o	65o	66o	67o
R7	**SOS**-bar ***2** 70o	71o	72o	73o	74o	75o	76o	77o

Table 3 Upper side LED matrix module assignment map

*2: Mark of division

About Appendix 4

Input and output,

Inputs are AC power line and battery.

Output is +4.7[V]DC (nominal voltage when use AC power line) power supply for internal circuit. Difference of 0.3[V] between 5[V] and 4.7[V] is voltage drop at D404 (Schottky diode).

Operation of the circuit,

This is power supply block. You can use AC power line and battery. When connect to AC line, power supply switch to AC line automatically.

T1 output is 6.3[V] 0.18[A] (1.134[VA]) of small transformer. Total power supply current of the decoder is ~25[mA] maximum and ~10[mA] at standby. This transformer is smallest one that I could get. So you don't need satisfying 6.3[V] 0.18[A]. I believe 6.3 to 24[V] of smallest transformer is better choice. 24[V] of headroom come from absolute maximum rating of 78L05.

I recommend to use 78L05 (regulator IC) for IC14. The reason of this is D404's forward current in absolute maximum rating (=300[mA] for peak current). 78L05 has 100[mA] of output current limiter.

About a battery, you can use 4.5[V] to 6[V] battery for nominal voltage. Power supply voltage range is 4[V] to 7[V]. I confirmed functionality at 3.6[V] for lowest operation voltage in my bench test. 7[V] of headroom decided from absolute maximum rating of 74HC devices. So you can use four 1.2[V] or 1.5[V] batteries.

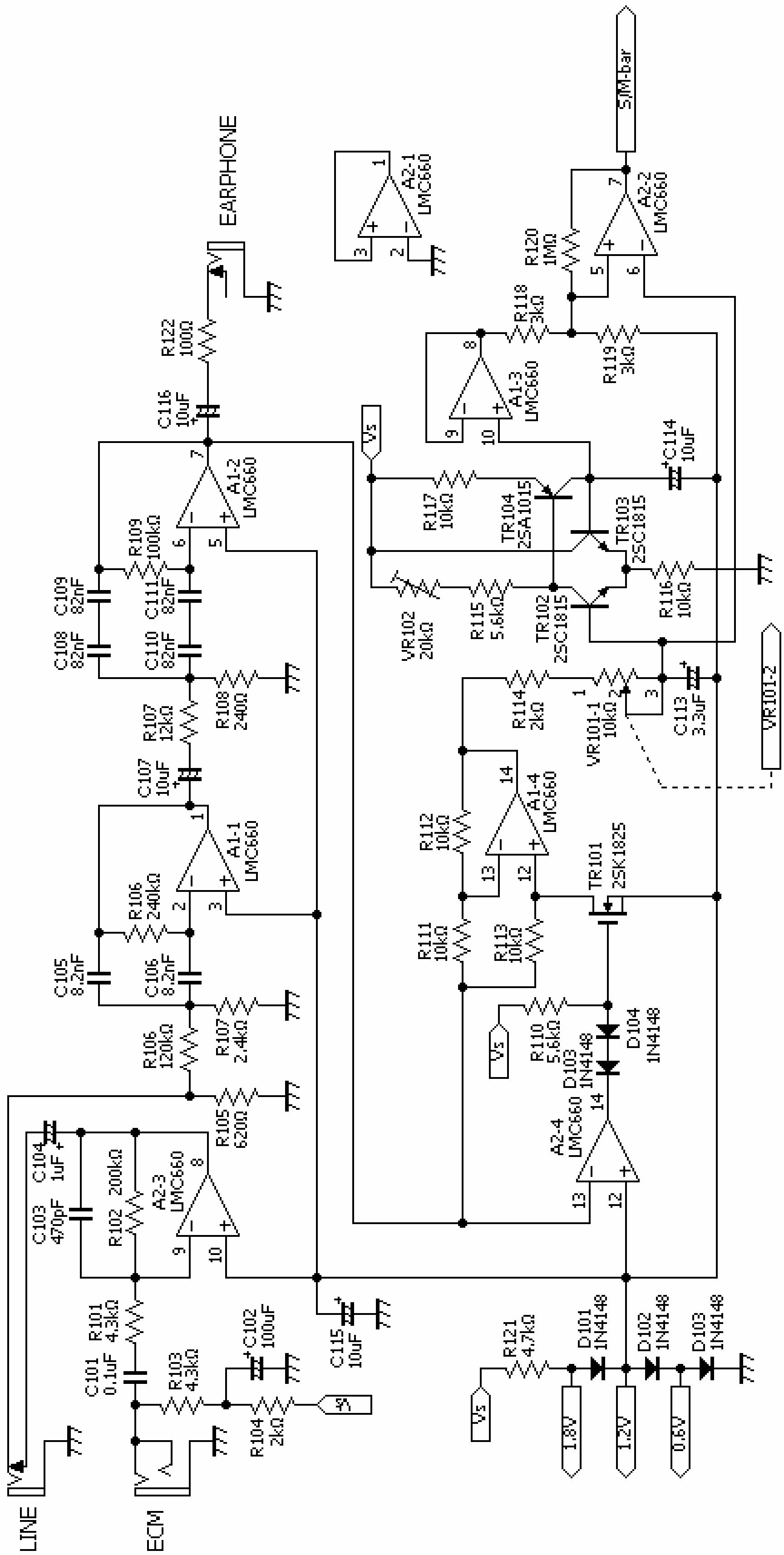
CAUTION

This circuit include AC power circuit. There is possibility of serious **HEALTH DAMAGE**. If you don't have experience of AC power circuit or you don't have knowledge for AC power circuit or you don't have expert adviser, I do NOT recommend to try AC power circuit building and I recommend using battery only.

In this case, you can remove AC power circuit with the following method :

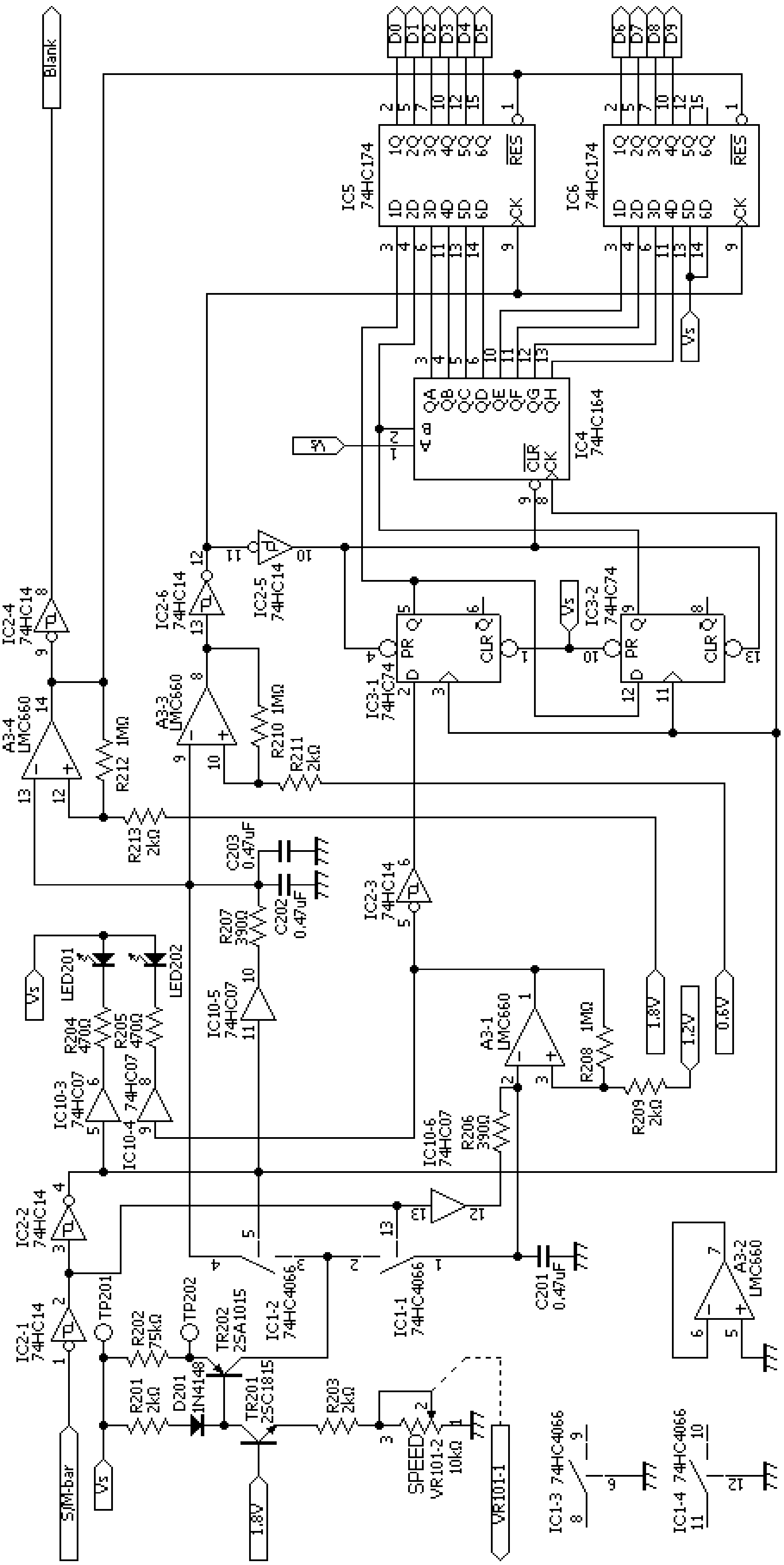
Connect battery and "Vs" in Appendix 4 directly through SW1 and remove all of AC power circuit and switching circuit (that consist of TR401 - TR403 and peripheral resisters of them) including D403 and D404.

March/22/2009

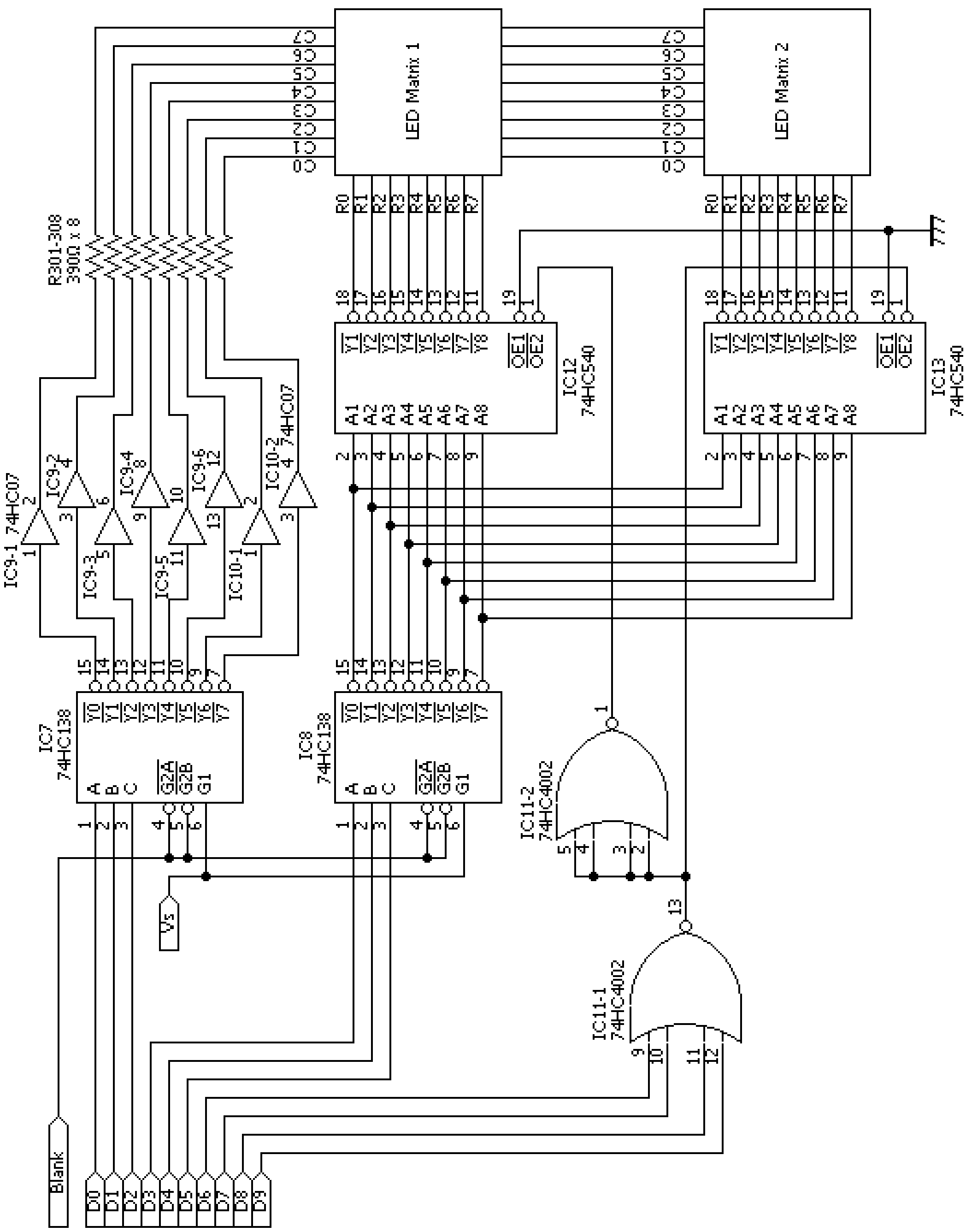


LINE
ECM
EARPHONE
S/M-bar
VR101-2
Vs
1.8V
1.2V
0.6V
A1-1 LMC660
A1-2 LMC660
A1-3 LMC660
A1-4 LMC660
A2-1 LMC660
A2-2 LMC660
A2-3 LMC660
A2-4 LMC660
TR101 2SK1825
TR102 2SC1815
TR103 2SC1815
TR104 2SA1015
D101 1N4148
D102 1N4148
D103 1N4148
D104 1N4148
VR101-1 10kΩ
VR102 20kΩ
R101 4.3kΩ
R102 200kΩ
R103 4.3kΩ
R104 2kΩ
R105 620Ω
R106 120kΩ
R107 2.4kΩ
R106 240kΩ
R107 12kΩ
R108 240Ω
R109 100kΩ
R110 5.6kΩ
R111 10kΩ
R112 10kΩ
R113 10kΩ
R114 2kΩ
R115 5.6kΩ
R116 10kΩ
R117 10kΩ
R118 3kΩ
R119 3kΩ
R120 1MΩ
R121 4.7kΩ
R122 100Ω
C101 0.1uF
C102 100uF
C103 470pF
C104 1uF
C105 8.2nF
C106 8.2nF
C107 10uF
C108 82nF
C109 82nF
C110 82nF
C111 82nF
C113 3.3uF
C114 10uF
C115 10uF
C116 10uF

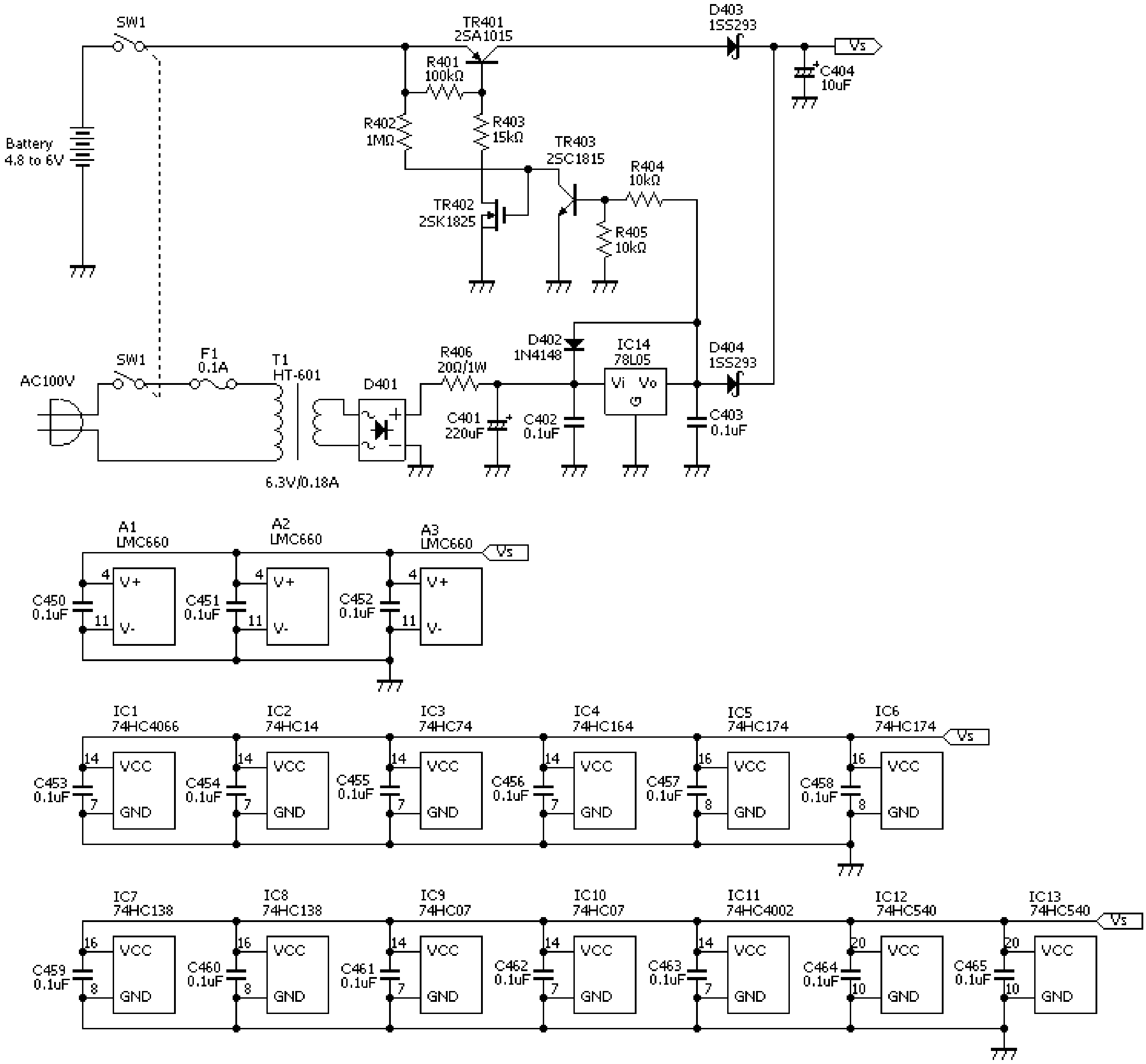
Appendix 1


Blank
D0 D1 D2 D3 D4 D5
D6 D7 D8 D9
IC5 74HC174
IC6 74HC174
IC4 74HC164
IC3-1 74HC74
IC3-2 74HC74
IC2-1 74HC14
IC2-2 74HC14
IC2-3 74HC14
IC2-4 74HC14
IC2-5 74HC14
IC2-6 74HC14
A3-1 LMC660
A3-2 LMC660
A3-3 LMC660
A3-4 LMC660
IC10-3 74HC07
IC10-4 74HC07
IC10-5 74HC07
IC10-6 74HC07
IC1-1 74HC4066
IC1-2 74HC4066
IC1-3 74HC4066
IC1-4 74HC4066
R201 2kΩ
R202 75kΩ
R203 2kΩ
R204 470Ω
R205 470Ω
R206 390Ω
R207 390Ω
R208 1MΩ
R209 2kΩ
R210 1MΩ
R211 2kΩ
R212 1MΩ
R213 2kΩ
C201 0.47uF
C202 0.47uF
C203 0.47uF
LED201
LED202
D201 1N4148
TR201 2SC1815
TR202 2SA1015
TP201
TP202
SPEED VR101-2 10kΩ
VR101-1
S/M-bar
Vs
1.8V
1.2V
0.6V

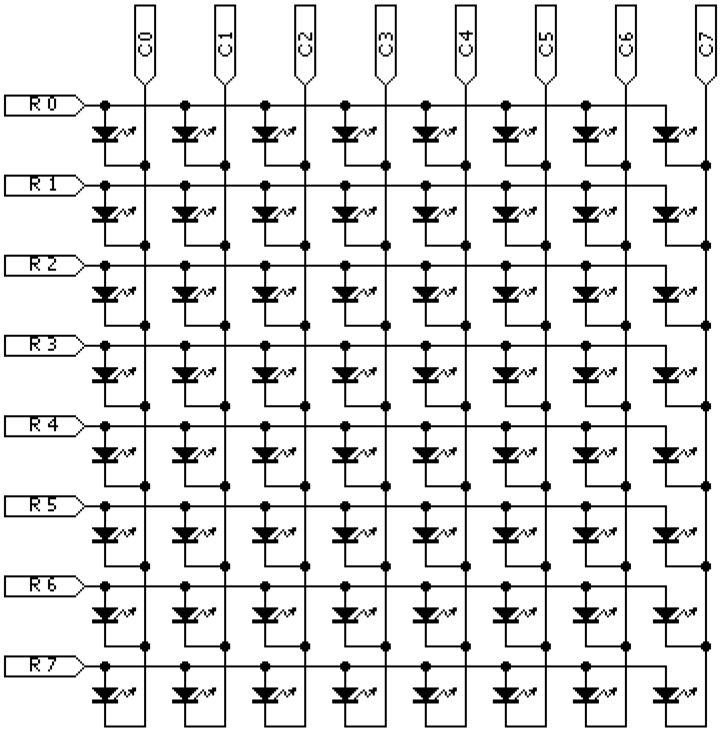
Appendix 2


LED Matrix 1
LED Matrix 2
R301-308
390Ω x 8
IC9-1 74HC07
IC10-2 74HC07
IC7
74HC138
IC8
74HC138
IC12
74HC540
IC13
74HC540
IC11-2
74HC4002
IC11-1
74HC4002
Vs
Blank
D0
D1
D2
D3
D4
D5
D6
D7
D8
D9

Appendix 3


SW1
Battery
4.8 to 6V
TR401
2SA1015
R401
100kΩ
R402
1MΩ
R403
15kΩ
TR402
2SK1825
TR403
2SC1815
R404
10kΩ
R405
10kΩ
D403
1SS293
Vs
C404
10uF
AC100V
SW1
F1
0.1A
T1
HT-601
6.3V/0.18A
D401
R406
20Ω/1W
C401
220uF
C402
0.1uF
D402
1N4148
IC14
78L05
Vi
Vo
G
C403
0.1uF
D404
1SS293
A1
LMC660
A2
LMC660
A3
LMC660
Vs
V+
V-
C450
0.1uF
C451
0.1uF
C452
0.1uF
IC1
74HC4066
IC2
74HC14
IC3
74HC74
IC4
74HC164
IC5
74HC174
IC6
74HC174
VCC
GND
C453
0.1uF
C454
0.1uF
C455
0.1uF
C456
0.1uF
C457
0.1uF
C458
0.1uF
IC7
74HC138
IC8
74HC138
IC9
74HC07
IC10
74HC07
IC11
74HC4002
IC12
74HC540
IC13
74HC540
C459
0.1uF
C460
0.1uF
C461
0.1uF
C462
0.1uF
C463
0.1uF
C464
0.1uF
C465
0.1uF

Appendix 4



Appendix 5