

Electronic Horn Based on MSP430 for Automotive Application

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ABSTRACT

This document describes the use of the MSP430 and TPS79801 in developing an electronic horn (E-Horn) for an automotive application. The MSP430 controls the switching frequency of the MOSFET. The frequency of switching can be calibrated thru 2 GPIO's of the MSP430 MCU. The TPS79801 powers up the entire electronic circuitry. Both MSP430 and TPS79801 are automotive Q1 qualified. The E-Horn developed is for 4 wheeler applications but can be easily tweaked for 2 wheeler automotive applications too. The design has been proven for 1 million cycles of Power ON and OFF for the required sound level (110 dB).

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1 System Requirements

The design requirements for this example are provided in [Table 1](#).

Table 1. Design Requirements

Parameter	Min	Typ	Max	Unit
Input voltage	10.5	12.0	13.5	V
Switching frequency	270	450	600	Hz
Sound level	97	105	115	dB
Operating temperature(°C)	-40	25	85	°C

2 Schematic

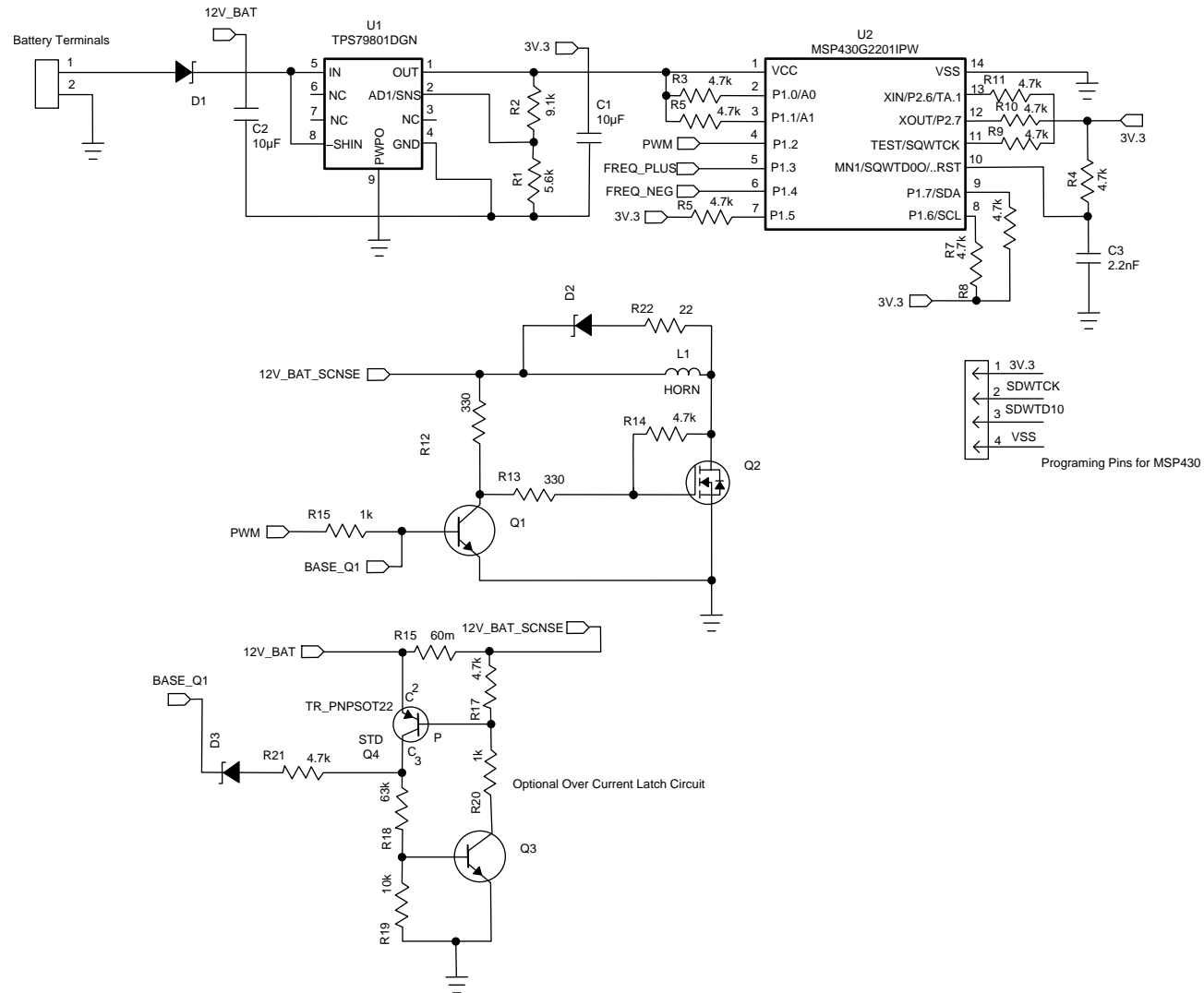


Figure 1. E-Horn Schematic

3 Design Procedure

3.1 Device Selection

Mechanical horns have a typical lifetime of 2 years and low cost. The most common reason for failure of mechanical horns has been the burning of the coil because of high current and the loss of resonance frequency point in tuning pot.

To address both issues and increase the lifetime of the horn, a precise frequency control is needed. To generate a precise frequency we chose the MSP430 family MCU with precise factory-calibrated Digital Controlled Oscillator (DCO) acting as a clocking source for the MCU. Using this MCU also gives a unique advantage of frequency and solution scalability to multiple resonance frequencies making the same solution usable to low-, high-, and multi-tone horns. The low-cost target was met using the Value Line series of MSP430. The final part selected was MSP430G2201P14Q1.

To power up the MCU, a very reliable low dropout voltage regulator of 3.3 V was used. The TPS79801-Q1 has a wide input range up to 50 V, which suits 12-V automotive batteries as far as input transients and quiescent current is concerned. The thermal management of the LDO is supported by thermal PAD under the LDO. We chose TPS79801Q1.

3.2 Application Development

3.2.1 Switching Frequency Generation

The switching device, PMOSFET was fed with a PWM signal at resonance frequency generated by MSP430.

The on-board DCO is configured for 1 MHz using factory calibrated constants stored in information memory (256 bytes) of the MSP430, as mentioned below, using predefined macro.

```
BCSCTL1 = CALBC1_1MHZ;
DCOCTL  = CALDCO_1MHZ
```

MSP430G2201 has a Timer_A module which has 3 capture compare registers and 4 operating modes. The timer control registers were configured for OUTMODE_3 which is of SET/RESET mode. The PWM duty cycle by default is set to 70%. As shown in the schematic in [Figure 2](#), the level translator (PNP transistor) actually inverts the PWM waveform, hence only 30% of the duty cycle is fed to the gate of the MOSFET.

As shown below, the compare registers TACCR0 and TACCR1 are loaded with the default value. These default values are only loaded if the calibrated compare counter values are not present in the information memory of MCU.

```
void load_calib()
{
    char *Flash_ptr;           // Flash pointer
    unsigned int i;
    Flash_ptr = (char *)0x1040; // Initialize Flash pointer
    for (i = 0; i < 4; i++)
    {
        calib[i]=*Flash_ptr++; // Read flash to char array
    }
    TACCR0=CharToLong((unsigned char *)&calib[3]);
    if(TACCR0<1100 || TACCR0>8000 || TACCR0 == 65535)
    {
        TACCR0=2825;
        TACCR1=2110;
        value=TACCR0;
        LongToChar(value);
        write_calib();
    }
    TACCR1=(TACCR0*0.73); //Duty Cycle set to 27%
```

}

And in main function after initialization of clock:

```
load_calib();
TACCTL1 = OUTMOD_3;           // PWM 0.1 Set/Reset
TACTL   = TASSEL_2 + MC_1 + TACLK; //Up-Down Mode, SMCLK , Timer Clear
```

The PWM signal frequency tuning was done using 2 GPIO's of MSP430. Both the GPIO's were pulled up to +3.3 V (Vcc). Port 1 pins were used, as P1.3 for incrementing and P1.4 for decrementing the compare register 0 (TACCR0).

When the TACCR0 register changed, it was immediately updated in the information memory, so that the same can be loaded in the register at next power up.

```
void write_calib()
{
    char *Flash_ptr;           // Flash pointer
    unsigned int i;

    Flash_ptr = (char *)0x1040; // Initialize Flash pointer
    FCTL3 = FWKEY;             // Clear Lock bit
    FCTL1 = FWKEY + ERASE;     // Set Erase bit
    *Flash_ptr = 0;           // Dummy write to erase Flash seg
    FCTL1 = FWKEY + WRT;       // Set WRT bit for write operation
    for (i = 0; i < 4; i++)
    {
        *Flash_ptr++ = calib[i]; // Write value to flash
    }
    FCTL1 = FWKEY;             // Clear WRT bit
    FCTL3 = FWKEY + LOCK;      // Set LOCK bit
```

3.3 Addressing Thermal and Endurance Issues Through MSP430 Software

As mentioned above, thermal and heat management was one of the challenges which had to be faced and resolved. It was accomplished 2 ways; one by cutting off the MOSFET switching from MCU, and the other by locking the switching of MOSFET by analog circuitry.

For cutting it off thru MCU we used MSP430F2231P14Q1, which has an onboard ADC and temperature sensor. We used ADC and temperature sensor to measure the inside temperature of HORN and stopped the PWM wave output, as shown below.

```
unsigned char flag=0,STOPHORN=0;
/* ADC Configuration*/
ADC10CTL1 = INCH_10 + ADC10DIV_3; // Temp Sensor ADC10CLK/4
ADC10CTL0 = SREF_1 + ADC10SHT_3 + REFON + ADC10ON + ADC10IE;
ADC10CTL0 |= ENC + ADC10SC; // Sampling and conversion start
/* Initial Temperature Check*/
STOPHORN=1;
while(STOPHORN==1)
{
    P1REN|=BIT2;
    temp = ADC10MEM;
    IntDegC = ((temp - 673) * 423) / 1024;
    cntr++;
    if(cntr>0x0f0)
    {
        if(IntDegC<100)
        {
            STOPHORN=0;
        }
    }
}
```

```

        P1REN&=~BIT2;
    }
    cntr=0;
}
ADC10CTL0 |= ENC + ADC10SC; // Sampling and conversion start
}

```

Then in the main() function loop

```

/* Temperature Check*/
temp = ADC10MEM;
IntDegC = ((temp - 673) * 423) / 1024;
if(IntDegC>100)
{
    cntr++;
    cntr2=0;
}
else
{
    cntr++;
    cntr2=0;
}
if(cntr>0x0f0)
{
    /* STOP HORN*/
    TACCR0=0;
    TACCR1=0;
    P1REN|=BIT2;
    cntr=0;
    STOPHORN=1;
}
if(cntr2>0x0f0)
{
    /* START HORN*/
    TACCR0=TEMPTACCR0;
    TACCR1=TEMPTACCR1;
    cntr2=0;
    STOPHORN=0;
    P1REN&=~BIT2;
}
/* Temperature Check*/
if((STOPHORN==0) && (IntDegC>=70))
{
    deltatemp=(IntDegC-70);
    TACCR0=TEMPTACCR0+(deltatemp*0.90);
    TACCR1=(TACCR0*0.73);
}
else
{
    if(!STOPHORN)
    {
        TACCR0=TEMPTACCR0;
        TACCR1=TEMPTACCR1;
    }
}
ADC10CTL0 |= ENC + ADC10SC; // Sampling and conversion start

```

3.4 Addressing Cause of Thermal Issues due to Coil Heating and High-Voltage Stress on MOSFET

Driving high inductive loads at frequencies ranging in a few hundreds of Hz is not an easy task. This task becomes even more difficult when you are limited with a form factor of PCB and limited air flow because the PCB is enclosed in the horn. The inductive coil of the horn is driven by a low-side MOSFET at around 500 Hz with a duty cycle of 70%, in order to get the desired sound output. During off time, the MOSFET sees very high voltage spikes at its drain as a result of stored energy in an inductor. The voltage spikes can go as high as 800 V, depending on inductance, the type of winding, and the type of horn (with different current ratings).

This voltage stress on MOSFET can be kept under control by using the proper snubber circuit. By design equations of traditional RCD snubber, values of resistance and capacitance become unrealistic to accommodate in the given space. We have used one innovative technique here to use the MOSFET's gate to source threshold itself to control the voltage stress. In this case, MOSFET is used as a Zener by correlating its drain voltage and its gate to source threshold voltage. Refer to [Figure 2](#).

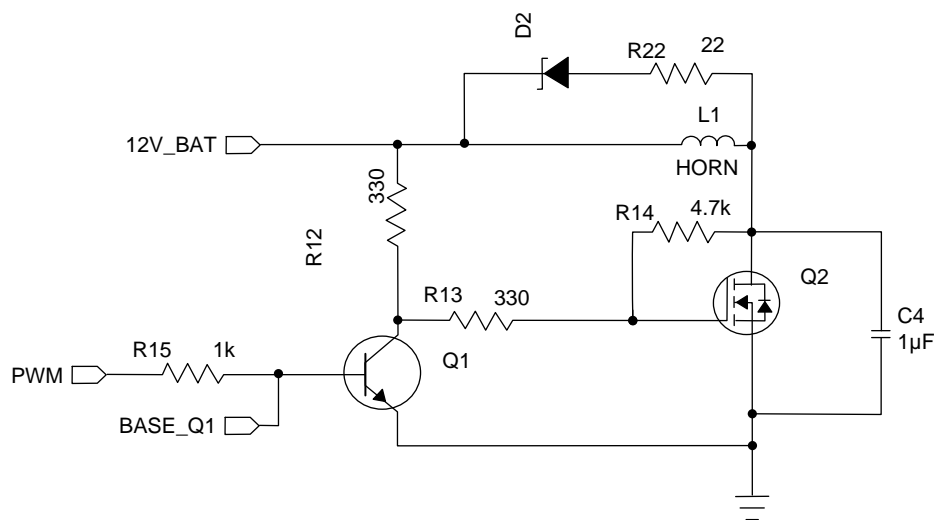


Figure 2. Driver Stage with MOSFET Used as Zener

In [Figure 2](#), 1 NPN transistor (Q1) will be OFF 70% of the time and ON for 30% of total time period, which in turn, drives the gate of Q2. Now MOSFET sees a very high spike, **V_{spike}**, when Q2 turns OFF. Now we can control this spike to our desired VDS threshold by keeping MOSFET on, unless our drain voltage reaches that value. This user-defined value can be adjusted by properly selecting resistors R13 and R14. Following a simple equation allows us to adjust this stress on MOSFET and select MOSFET with lower VDS rating and hence reducing cost.

When Q1 is ON then;

$$V_{GS}(Q2) = V_{DS} (Adj) \times R13 / (R13 + R14)$$

If the form factor of the PCB allows, a traditional RCD snubber can be used. The major reason for using MOSFET as zener clamp or RCD snubber is to control heating effect of the coil and increase the total number of ON-OFF cycles of the E-Horn.

4 Experimental Results

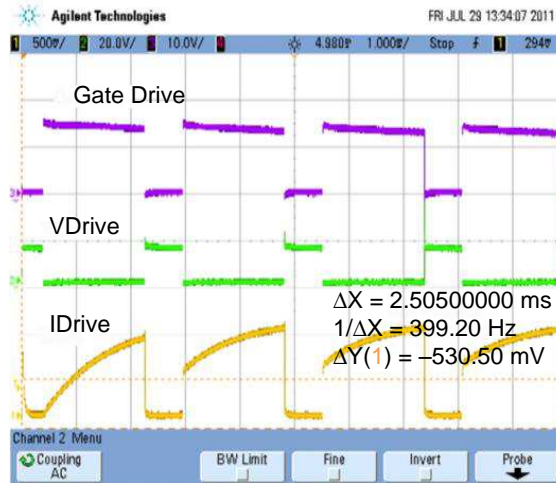


Figure 3. Drain Current (Channel.1), Drain Voltage(Channel.2) and Gate Drive(Channel.3) with Snubber Circuit. Sound Level-105 dB

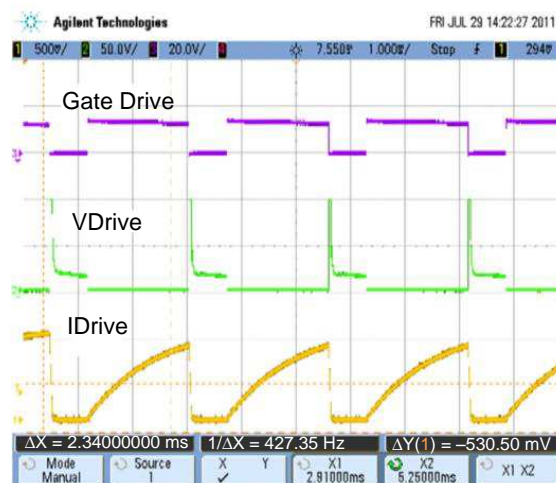


Figure 4. Drain Current (Channel.1), Drain Voltage(Channel.2) and Gate Drive(Channel.3) with Snubber Circuit. Sound Level-105 dB

5 Conclusion

Mechanical horns come with advantages of low cost and ease-of-manufacturing but they require frequent tuning, are prone to wear and tear and have warranty issues. Successful implementation of an electronic horn is done using TI's auto-qualified MSP430 and TPS79801-Q1 parts. Controller-based design gives advantages such as very-low frequency drift, easy scalability, programmable overtemperature and overcurrent protection and thus an enhanced warranty over the traditional analog-based solution. This design has been tested over 700 k cycles and special techniques have been used in firmware and hardware to limit temperature rise over the period and increase horn life. PCB form factor can be incorporated within the horn assembly or can be provided as a separate module based, on application.

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