PROJECT TITLE: *Interference free optical pick-up*

TEAM MEMBERS: ***Miha Leskovec, miha.leskovec@kate.si***

Urban Medič, urban_medic@hotmail.com

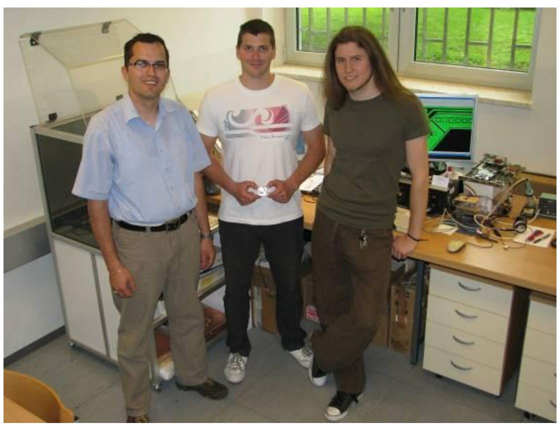
ADVISING PROFESSOR: doc. Dr. *Marko Jankovec, marko.jankovec@fe.uni-lj.si*

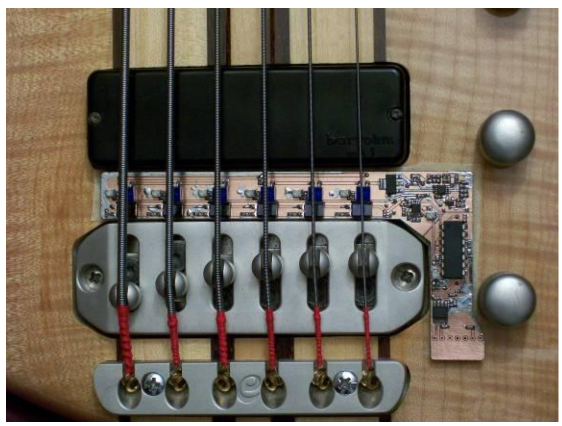
UNIVERSITY: *University of Ljubljana, Faculty of electrical engineering*

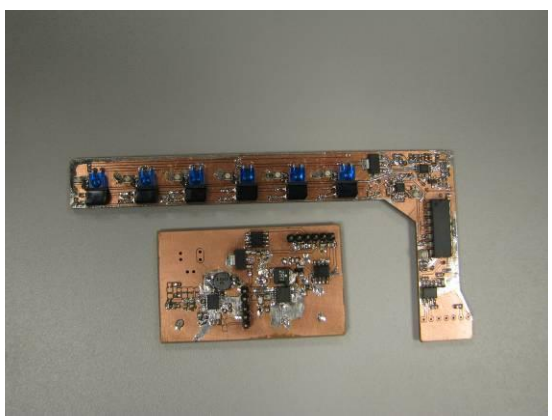
DATE: *25/June/2010*

TI PARTS USED IN PROJECT:

6× OPA354, http://focus.ti.com/docs/prod/folders/print/opa354.html
2× OPA2354, http://focus.ti.com/docs/prod/folders/print/opa2354.html
1× MPY634, http://focus.ti.com/docs/prod/folders/print/mpy634.html
1× OPA132, http://focus.ti.com/docs/prod/folders/print/opa132.html
1× TPS61175, http://focus.ti.com/docs/prod/folders/print/tps61175.html
1× BQ24103A, http://focus.ti.com/docs/prod/folders/print/bq24103a.html
2× TLE2425, http://focus.ti.com/docs/prod/folders/print/tle2425.html







PROJECT ABSTRACT

This paper describes the development of an optical bass guitar pick-up immune to ambient light. It explains the theoretical background of the lock-in method for demodulating AM signals and the benefits of a single IC vendor design. The main focus is in showcasing the variety of the Texas Instruments portfolio and support tools which help in designing a new product ready for the market in a really short time. The final product incorporates Li-Ion battery management, switch mode power supply, virtual ground ICs, LDO ICs, Operational amplifiers in various configurations and a precision analog multiplier.

INDEX

1. INTRODUCTION AND MOTIVATION FOR PROJECT

The idea for the project came just before the competition was announced and it came as a prefect candidate to demonstrate that analog design still plays a major role in the era of the microprocessor. As a musician Urban came up with the idea to try and create a new pick-up for his Bass-guitar. We noticed that another company was already manufacturing a light-based pick-up that promised a big improvement over the widespread magnetic system that has been present for more than half a century. So we set up a proof of concept test rig and experimented with a DC driven IR transmitter and receiver module placed under the strings and found a lot of noise in the output from the ambient lighting. Instead of covering the pickup together with a substantial part of the strings as the existing company did we searched for a better solution to cancel the interference from ambient light based only on analog components.

2. THEORETICAL BACKGROUND

2.1 <u>Optical Principle:</u>

Picking-up the vibration of a string may be achieved by using different principles. For example by measuring the transversal velocity of the string (magnetic pickup) or the force on the bridge (piezzo pickup).

The optical pickup, in its basic design, converts the strings displacement into a voltage level. A vibrating string will thus form a resulting audio signal on the pickups output.

The physical interface of the pickup comprises a LED and a PIN photodiode. They are placed under the string as close as possible to each other, both facing the string. When the LED is driven by a constant DC current, the intensity of the light deflected from the string and picked up by the photodiode is in direct correlation with the perpendicular position of the string. We also aim to use sensors wider than the string to eliminate the effects of the parallel movement as this would result in a doubled frequency.

A transimpedance amplifier converts the current from the photodiode to a voltage signal. When the DC component is filtered out a sufficient gain can be achieved.

This setup works fine if no light interference in the frequency range of 20 Hz to 20 kHz falls onto the sensor. However - since the light of a network powered lamp fluctuates at double the network frequency, it creates an audible interference. Filtering this 100 Hz or 120 Hz frequency would also corrupt the guitars signal.

2.2 Lock-in method:

Using the same optical principle, when the LED is driven by a high frequency signal - say 500 kHz sine (the signal should obviously include an offset since the current driving the LED is only to be in one direction), the deflected light will now form the same sine wave that will be amplitude modulated by the strings position. This way we have applied a simple form of the lock-in method. The signal is then demodulated via an analog multiplier and a smoothing filter.

The lock-in method moves the interference from the audio specter to higher frequencies that can be filtered out by using a smoothing filter at the output.

2.3 Multiplying an AM signal with applied interference sine by the reference signal:

If the audio (string), reference (carrier) and interference (ambient light) signals are represented by:

$$U_A = \sin(\omega_a t + \varphi_a) = \sin(a)$$
$$U_R = \sin(\omega_0 t + \varphi_o) = \sin(r)$$
$$U_I = \sin(\omega_i t + \varphi_i) = \sin(i)$$

The amplitude modulated signal with the applied interference would be (discarding the exact amplitude of each):

$$U_X = (1 + \sin(a)) \cdot \sin(r) + \sin(i)$$

When this signal is multiplied by the reference signal we get:

$$U_X \cdot U_R = \sin^2(r) + \frac{1}{2}\sin(a) + \frac{1}{4}\left[\sin(2r - a) - \sin(2r + a)\right] + \sin(i) \cdot \sin(r) =$$
$$\sin^2(r) + \frac{1}{2}\sin(a) - \frac{1}{2}\cos(2r) \cdot \sin(a) + \sin(i) \cdot \sin(r)$$

All the signals except the ˝1/2 sin(a)˝ can now be filtered out via a low pass smoothing filter cutting above 20 kHz. We also need to filter out the DC component that derives from the squared sine.

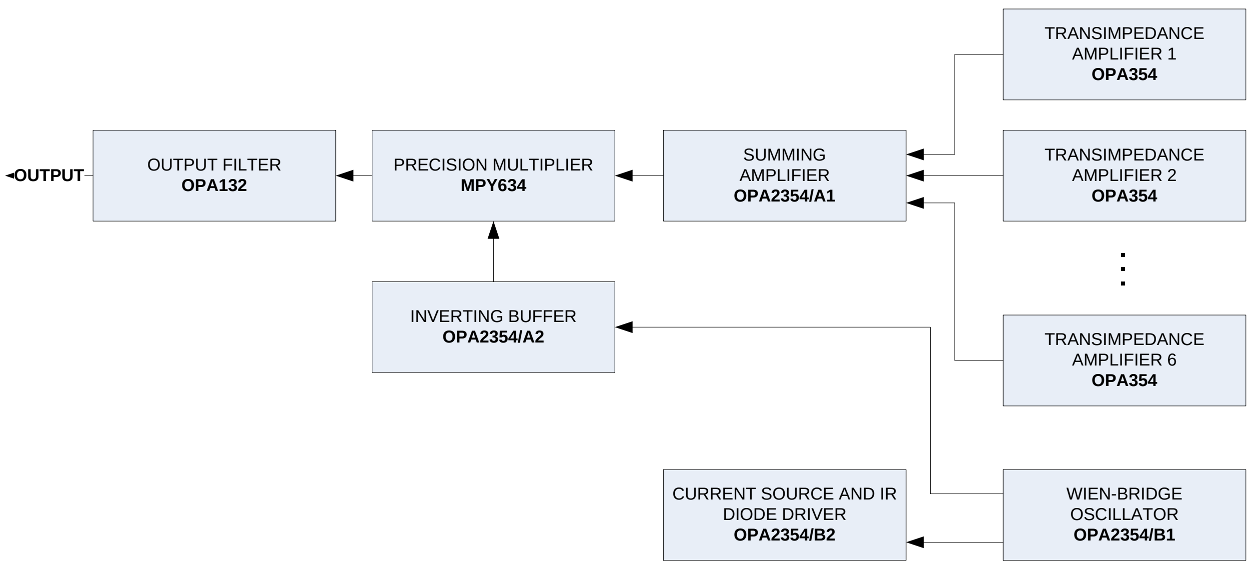
3. IMPLEMENTATION

The system consists of two separate sections:

- Analog audio section
- Power supply

Our main focus was on the audio section which will determine the quality of the end product and also showcases the new idea behind this project.

3.1 Analog audio section:



Picture 1: **Analog audio section block diagram**

3.1.1 TRANSIMPEDANCE AMPLIFIER

A lot of trial in designing a transimpedance amplifier has been done in Tina-TI simulation environment. The OPA354 has been chosen for its FET-input with low current and voltage noise as well as for its high speed capability at a relatively small quiescent current. Low current noise is very important in transimpedance amplifiers and the low quiescent current makes for a longer battery life.

Before amplifying the signal we eliminate the DC component. We have reached up to 100 dB transimpedance gain at 1 MHz in simulation. An 80 dB gain turned out to be sufficient in our design so the feedback resistor is of 10 kOhm and parallel to it there is a 1 pF capacitor to compensate for the PIN photodiode capacitance. One LED, photodiode, and amplifier is used for each of the strings.

3.1.2 SUMMING AMPLIFIER, OSCIALLATOR, CURRENT SOURCE AND INVERTING BUFFER:

In addition of the versatility of the test rigs we gained from the wide bandwidth of the OPA354 and OPA2354, the small IC packages enabled us to adapt the outline of the system so that it can be retrofitted on the instrument without interfering with the ergonomics of the guitar and so enabling an easier package design and wider marketing options.

We used the OPA2354 for the Wien-bridge oscillator (selecting the frequency is described in the experimental part) connected to the op. amp. driving the MOS-FET used as the current source for the LEDs. OPA2354 is also used as the inverting summing amplifier which adds another 20 dB gain to the sum and for the reference signal inverting buffer. These two signals are then multiplied by the analog multiplier.

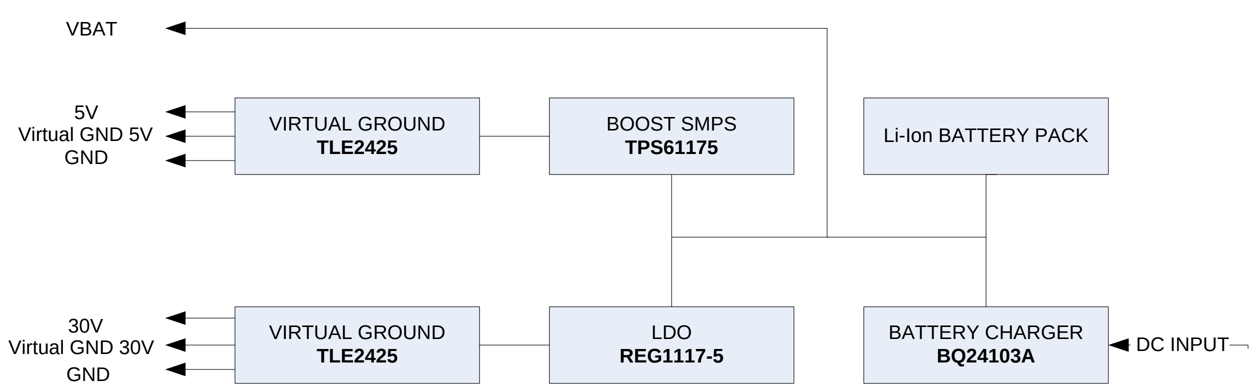
3.1.3 PRECISION ANALOG MULTIPLIER:

The multiplier is the central component for applying the lock-in method and so enabled us to test our new concept. Its variety of configurations let us experiment with different attenuations and bandwidths. This way we managed to optimize the system for the best results. The only drawback is the DIL package that enlarged the product. We have ended up using the unity gain circuit at most.

3.1.4 OUTPUT FILTER:

Thanks to the superior audio quality of the Burr-Brown family of operational amplifiers we were able to achieve very good results in our listening tests.

3.2 Power supply:



Picture 2: **Power supply block diagram**

3.2.1 BATTERY CHARGER:

For the battery charger we chose the BQ24103A for its small size, considerable power capabilities and all-in-one solution far battery management. Its high switching frequency and integrated zener diode reduced the space needed on the board while maintaining high charging currents. While charging the battery the charger also supplies the complete circuit with power, this way the battery can be charged while the system is running.

3.2.2 BOOST SMPS:

This power supply powers the multiplier and needs to increase the voltage from 6.4V on the battery to 30V for symmetrical 15V power rails. Once again the power pad package made the difference in the space needed as there was no need for an additional external switch. The high switching frequency kept the inductor small and its wide input range meant that it could also run on a single cell battery pack design. For the design we used the SwitcherPRO software which with the integrated libraries made the designing process and choosing components very easy and quick.

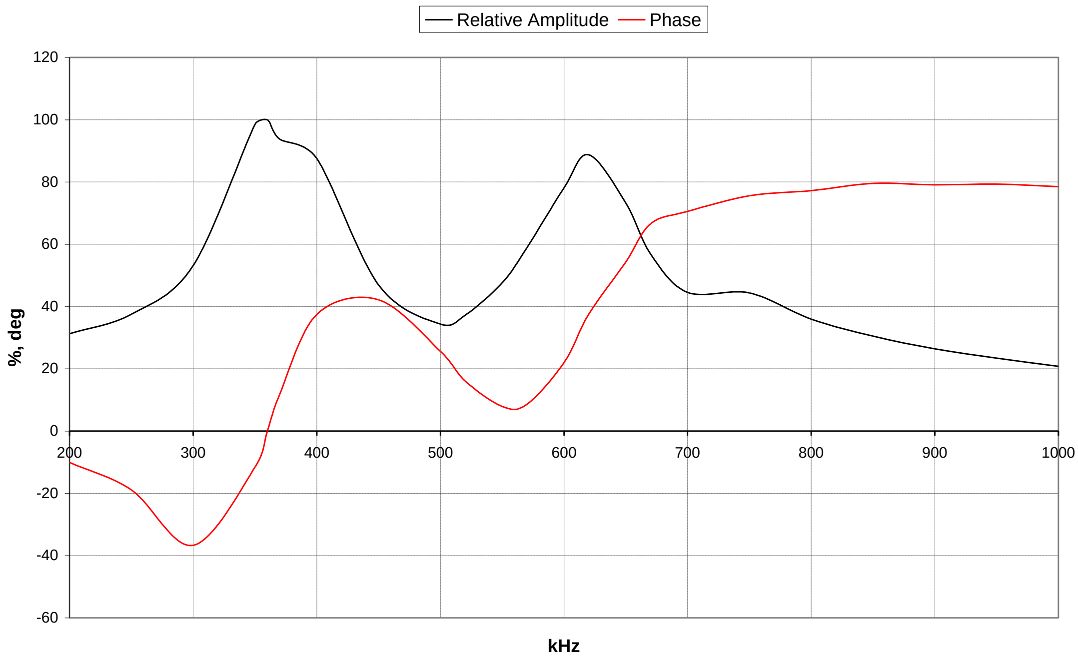
3.2.3 VIRTUAL GROUND:

Since the whole circuit is battery powered the symmetrical power lines had to be made virtually from non symmetrical power rails. For this purpose the TLE2425 was used as it offers a very stable and easy to use solution for a wide range of input voltages. This solution reduces the need for extra precision resistors which are expensive and take up space on the board.

4. EXPERIMENTAL RESULTS

In order to effectively use the multiplication as the demodulation method, the phase shift between the two signals has to be minimized.

Graph 1 shows the measured frequency response (amplitude and phase) of the "transceiver" i.e. the current driven LED and the photodiode with the transimpedance amplifier. The amplitude of the current driving the LED is 20 mA and its offset is 25 mA.



Graph 1: **Transceiver frequency response**

Most of the responses fluctuations originate from the photodiode. The continuous drop above 800 kHz however is caused by the capacitance in the transimpedace amplifier feedback loop.

Based on these measurements we have selected 360 kHz as the carrier frequency because the phase shift at this frequency is practically zero.

At the output of the multiplier the most obvious signal is the double carrier frequency sine that is now considered noise for any further audio equipment. The displacement of the string however is now noticeable as the added low frequency offset of this signal. Since the high frequency noise amplitude is around 500mV and the offset change over the expected string displacement is around 10mV we can conclude that at least 4^{th} order low pass filter is required. Also a gain of about 40 dB for the audio band should be achieved through the filtering process.

5. SUMMARY AND CONCLUSIONS

After testing the system on a bass guitar we can conclude that the system works as requested and does not obstruct the guitar player. The only thing that has not been tested is the duration of the battery as it has not discharged in the time needed for testing. In the listening test the wider bandwidth of this design made a noticeable impression. The system as a whole is nearly ready for its first public debut and we hope that you and the public will like it.

6. FUTURE PLANS

The options for future research are quite vast. In addition to further improving the output smoothing filter we intent to increase the modulation factor of the signal being multiplied. In theory we should be able to achieve this by deducting the reference sign from the AM carrier and further amplifying the carrier. We also plan to make a wireless version with the new CC8520 RF SoC and build a test rig for measuring the linearity of the optical transceivers. TI support and development tools as well as the wide variety of ICs should be of significant help in the future design and improvement of this product.