

A MICRO ULTRA LOW POWER RF RADIO FOR NEURAL SIGNAL RECORDING

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Abstract: This paper reports the development of a small, light-weight and mini-battery operated low power radio transmitter for neural signal recording. This system allows recording of neural signal down to the level of 50 μ V. A micromachined electrode is used to obtain these signals. The neural signal is then amplified 10,000 times and transmitted to the receiver at 433 MHz. The manufactured radio system is 7 mm by 6 mm in size and 0.5 gram in weight, with a power consumption of 750 μ W. Radio functionality is tested and verified on locusts.

1 INTRODUCTION

Wireless recording of neural activity from the central and peripheral nervous systems has long been pursued by physiologists as a way to understand the operation of individual neurons, to decipher the relationship between the environment stimuli, nerve system response and the activities generated by the nerve signal (Akin, 1998). One of such research area is visually guided escape behaviors, which are critical to the survival of many animals.

In this design, we are required to detect the neural signals from main nerves of a locust. Therefore a small size, light weight and low power, cell battery based RF wireless telemetry system is needed. Unfortunately, the power consumption of available commercial radio chips is too large to be sustained by a small cell battery. In this design, we simplified the radio structure as much as possible to reduce power consumption. Firstly, a RF BJT oscillator is used to generate the carrier, instead of a Frequency Synthesizer. Secondly, AM modulation scheme is used instead of the typical FSK modulation in commercial radio chips. Thirdly, the whole system is analog. At last, a 30 AWG copper

wire with the length of 40mm is used as antenna with the radio transmitter working at 420 MHz.

After several experiments, it is verified that this design is small enough to be carried by a locust and light enough to allow the bug to jump as usual. The received signal provides strength and time information of the neural activities.

2 RADIO SYSTEM DESIGN

2.1 System Overview

The radio transmitter is divided into two functional parts: amplifier stage and transmitter stage. Detected neural signals are typically in the range of 50 to 150 micro volts. In order to process this signal, a high gain amplifier stage is used to amplify it 10,000 times. The amplified neural spikes are then sent to the transmitter stage for transmitting. Direct coupling is used between these two stages. The whole system runs on a 3 Volts cell battery and the power consumption is only 750 μ W in total. The complete system schematic is shown in Figure 1

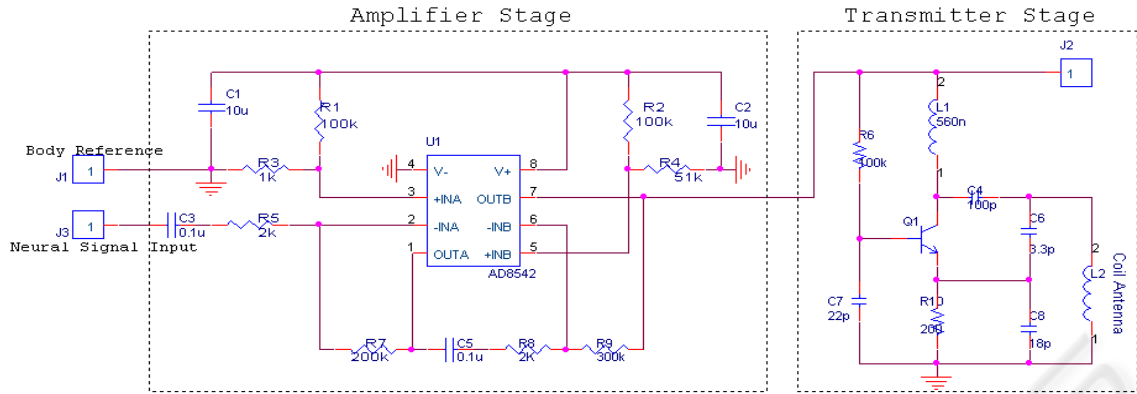


Figure 1: System Overview.

2.2 Transmitter Stage

For most neural experiments, researchers are mainly interested in the when this signal is generated and how many neural spikes are observed, other than their accurate amplitude value. Thus, simplifying the transmitter design has little influence on the research itself, but it can greatly reduce the power consumption, and reduce the size and weight of the system.

In our design, the transmitter is basically a 433 MHz BJT Colpitts oscillator. Colpitts Oscillator is well known for its simplicity and robustness. Figure 2 is the structure of our transmitter stage, which is a common-base (CB) Colpitts oscillator. In Figure 2 we can see that C1, C2 and L1 forms the positive feed back loop, and R1, L2 and R_F provide the DC bias for oscillation. C3 is the capacitor for common base structure.

Because of its wide application area, Colpitts oscillator is well studied. The oscillation frequency of this circuit can be calculated by equation (1).

$$f_0 = \frac{1}{2\pi \sqrt{L_1 \cdot \left(\frac{C_1 \cdot C_2}{C_1 + C_2} \right)}} \quad (1)$$

In this Colpitts oscillator application, the operation frequency is about 433 MHz. Therefore, several issues need to be taken care of. These issues will be discussed in the following subsections.

2.2.1 Selection of Inductor L1

Three issues are important when deciding the L1 inductor value.

First, according to equation (1), the value of L1 is directly related to the oscillation frequency. For 433 MHz band operation, it is usually in the nano-Henry range.

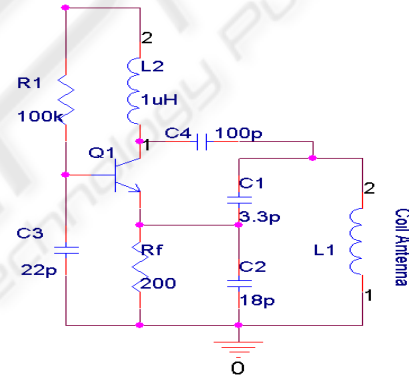


Figure 2: Transmitter Structure.

Second, the value of inductor L1 is also related to the quality factor of Oscillation. The relation is expressed in Equation (2).

$$Q \propto \frac{1}{r} \sqrt{\frac{L_1}{C_\Sigma}} \quad (2)$$

$$\text{Where } C_\Sigma = \frac{C_1 \cdot C_2}{C_1 + C_2} \quad (3)$$

And r is the serial resistance of L1.

In the oscillation loop, larger quality factor Q leads to more stable and accurate oscillation and lower power dissipation. From equation (2), for the same C_Σ , greater L1 and smaller r will contribute to a higher system quality factor. This indicates that we should choose a high Q inductor, whose r is

small. And the L_1 to C_Σ ratio should be large enough.

Finally, up limit does exist for the value of L_1 . Increase L_1 too much will decrease its self-resonant frequency and force the corresponding C_Σ decrease to the BJT's parasitic capacitance region, which may cause unstable oscillation (Razavi, 1998).

The selection of L_1 value is a compromise between these issues discussed above.

2.2.2 Selection of C1 and C2

According to the analysis in section 2.2.2, to achieve a higher quality factor, C1 and C2 should be as small as possible. On the other hand, however, C1 and C2 can not be too small. Because C1 is in parallel with the junction capacitance C_{CE} and C2 is in parallel with the junction capacitance C_{BE} , R_p is the equivalent resistance. Its relation to the loop is shown in equation (4). The equivalent oscillation loop is shown in Figure 3.

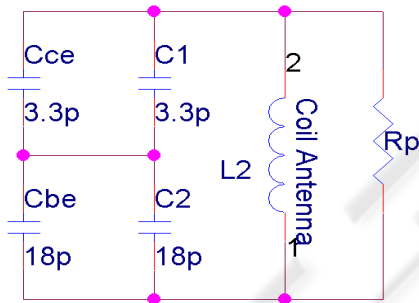


Figure 3: Equivalent Oscillation Loop.

Figure 3 tells us if C1 and C2 are too small, Cce and Cbe will dominate the oscillation frequency. Typically, C1 and C2 should be greater than Cce and Cbe. Therefore, C_Σ should lie in the range of 1 pf to 4 pf.

Also, known C_Σ , the value of C1 to C2 directly depends on their ratio, C1/C2. Again, compromise exists when selecting this ratio. Smaller C1/C2 ratio means larger loop quality factor but smaller positive feedback gain, while larger C1/C2 ratio gives greater feedback gain but lower quality factor (Razavi, 1998). In practice, experiment shows that 3.3pf and 18pf capacitor pair gives stable oscillation and makes it easy to start the oscillation. Now, we can modify equation (1) to obtain practical equation for oscillation frequency f_0 .

$$R_p = (1 + C_1 / C_2)^2 / g_m \tag{4}$$

$$f_0 = \frac{1}{2\pi \sqrt{L_1 \cdot \left(\frac{C'_1 \cdot C'_2}{C'_1 + C'_2} \right)}} \tag{5}$$

Where $C'_1 = \frac{C_1 \cdot C_{CE}}{C_1 + C_{CE}}$ (6)

And $C'_2 = \frac{C_2 \cdot C_{BE}}{C_2 + C_{BE}}$ (7)

2.2.3 Selection of Rf and R1

R_F is a DC negative feedback resistor, which helps stabilize the transistor current gain. R_1 is used to set up the collector I_C . However, R_F and R_1 are also the main power consumption components in this circuit. The power they consume can be estimated by equation (7) and (8).

$$P_{Rf} = I_C^2 * R_f \tag{7}$$

$$P_{R1} = I_B^2 * R_1 \tag{8}$$

Since I_C is usually large, R_F should be as small as possible. And because I_B is typical in uA range, thus P_{R1} is usual less than 50 uW. In practical design, for the purpose of low power consumption, we simultaneously decrease R_F and increase R_1 , the final power consumption of the oscillation is only 750 uW, compared to the typical 10 mW power consumption for a commercial transmitter, this is a great advantage.

2.3 Amplifier Stage

Figure 6 is the structure for amplifier stage. It consists of two JFET operational amplifiers. Each stage runs on a single power supply and has a gain of 100. To save power, an OPA with only 40 uA current consumption at 2V is used. Important design rules about amplifier stage are explored below.

2.3.1 Power Line Decoupling

In practical application, the battery has non-zero internal impedance, which induces AC voltage on the power line.

If not carefully decoupled, the AC voltage on the power becomes an input to amplifier stage. This will cause the amplifier stage self-oscillate. Also, smaller R_{20} and R_{19} (as shown in Fig 4) value may be necessary to further ensure no self-oscillation will occur.

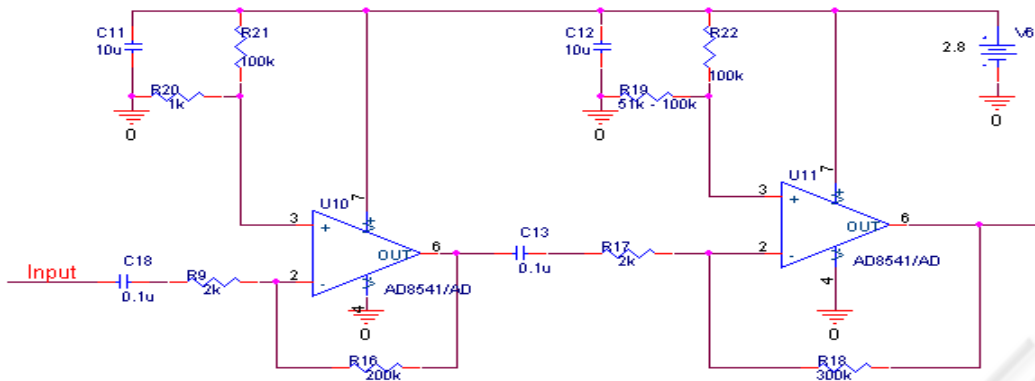


Figure 4: Amplifier Stage Structure.

2.3.2 Direct Coupling

In this design, we can use the DC bias component of the OPA as the power supply voltage V_{CC} for the next transmitter stage. Therefore, a direct coupling is used between amplifier stage and transmitter stage.

When no neural signal input appears, the output voltage of the amplifier should be half of the battery voltage. That is the V_{CC} power supply for the next transmitter stage.

When neural signal is connected to the amplifier input, the amplified signal of interest will directly couples to transmitter, that is add to V_{CC}

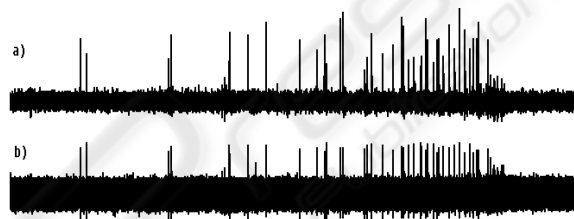


Figure 6: a) neural spikes measured on the transmitter side b) neural spikes observed on the receiver side oscilloscope.

3 EXPERIMENT RESULTS

Figure 5 shows the radio installed on a locust. A pair of micromachined electrode is used to collect neural signal from the locust. Figure 6 demonstrates the neural spikes collected and observed at the receiver side oscilloscope.

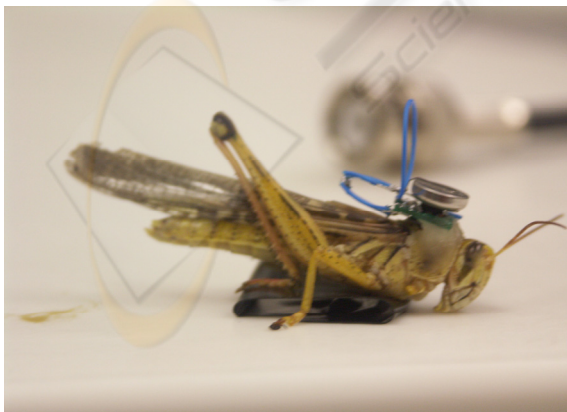


Figure 5: Locust with micro radio installed.

4 CONCLUSIONS

This paper discusses a design scheme of a single BJT transistor oscillator based RF Radio for neural signal recording. Comparing to other radio existing, this design has two important advantages. First, it is an ultra low power radio, with a power consumption of only 750 uW, only 7.5% of the available commercial transceiver chips. This feature makes it possible to be powered by a tiny watch battery. Second, this radio is small and light, it is only 7 mm by 6 mm in size and 0.5 gram in weight. These two advantages make this radio especially suitable for wireless recording tasks performed on small animals, insect, such as locusts and pigeons. The communication range of this radio is up to 20 feet.

REFERENCES

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