A BIOTELEMETRY UNIT FOR MONITORING NOCTURNAL BRUXISM

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ABSTRACT

This paper describes a biotelemetric application whereby information of tooth contact pressure from within the mouth of a human subject is transmitted to a bedside receiver where it is processed and used in the biofeedback treatment of nocturnal bruxism (grinding of the teeth). Bruxing information is encoded on a pulse width modulated 313 MHZ carrier. Issues that are addressed include miniaturization of the transmitter, minimization of power requirements, stabilization of carrier frequency, receiver selection, and the various problems associated with getting a radio frequency signal out of the mouth. Key words: Bruxism, biotelemetry, oral telemetry, biofeedback, pulse width modulation.

INTRODUCTION

Bruxism is the nonfunctional clenching or grinding of the teeth. Bruxism has been shown to cause or to contribute to occlusal tooth wear, increased tooth mobility, tooth loss, muscle pain and spasm, headaches and temporomandibular joint (TMJ) dysfunction [1]. Nocturnal bruxism is particularly serious and is difficult to treat since the sufferer is asleep and unaware of grinding behavior. This paper describes a radiotelemetry unit for use in a bruxism treatment apparatus. Bite pressure is encoded and telemetered out of the mouth to a bedside receiver unit. The bedside unit records bite pressure information and can turn on an alarm as part of a biofeedback treatment. Similar biofeedback approaches that have used electromyographic (EMG) monitoring of the masseter muscle instead of telemetry have proven successful in a clinical setting [2]. The advantage to the telemetric approach is the absence of wires attached to the patient.

The use of telemetry for transmitting biological data is well known (see [3],[4],[5] and the references therein) but most of these applications have addressed radio tagging or implanted biotelemetry units which generally have a quarter wave transmitting antenna and are not required to transmit continuously. Implanted units are generally surrounded by a stable environment. The application discussed in this paper has severe restrictions imposed on the transmitter with respect to size, power, and operation since it must be placed in the mouth. Because the tongue is a sensitive tactile organ, the transmitter must be smooth and compact. The tongue also affects transmitter performance because changes in its position and orientation cause shifts in the carrier frequency.

TRANSMITTER DESIGN

For this application a pressure transducer and radio transmitter are imbedded into a removable acrylic splint (night guard) which is worn by the patient during the night. Since a bruxing episode may be as short as 2 seconds, pressure information must be continually transmitted. The design requirements for the transmitter are the following, several of which are mutually conflicting:

1. must be small and nest into palate of a maxillary (upper) splint without compromising user comfort;

2. must work continuously for ten hours on a single rechargeable button cell;

3. must continuously encode bruxing information onto radio frequency carrier wave;

4. carrier wave must have sufficient signal strength to reliably transmit to a receiver located 1.5 meters away,

5. the carrier wave must have sufficient stability for reliable receiver lock.

In order to meet comfort requirements, the transmitter, including battery, must be small. Our first step in carrying out the transmitter design was to determine an acceptable power source. Although primary cells can provide a greater power density, the cell must be encapsulated into the splint and this does not allow for easy replacement. Accordingly, rechargeable cells were considered from a number of vendors. In the final analysis, the type ML1220 rechargeable lithium dioxide cell from Sanyo was chosen because of the higher voltage (3 volts) and higher energy density it provided. These cells measure 1.2 cm in diameter and 2 mm in thickness and have a rated capacity of 12 mA-hr. Although the lithium dioxide cell has a higher energy density, this type of cell cannot be deep cycled. This limits the usable storage for repeated charging/discharging to about 6 milliampere-hours with a life expectancy of about 200 cycles. For a ten hour discharge, the average current drain must be limited to 600 microamperes. To provide a margin of safety for a short charging time and long discharging time, our design was based on a 400 μA average. The recharging method was via two exposed terminals. An LED was added in series with one of these terminals to prevent external discharge. Also, since the acrylic splint is clear, the presence of an LED in the circuit allows the display of charging condition.

THE BRUXISM SENSOR/TRANSDUCER

The transducer used to detect bruxing force is a force sensing resistor manufactured by Interlink Electronics, Inc. of Santa Barbara, California and portrayed in Figure 1. This sensor is less than .15 millimeters thick and is positioned on top of the splint surface and then covered with a thin layer of acrylic monomer. The acrylic encapsulation serves to distribute tooth contact force to the sensor while at the same time protecting the sensor from damage.

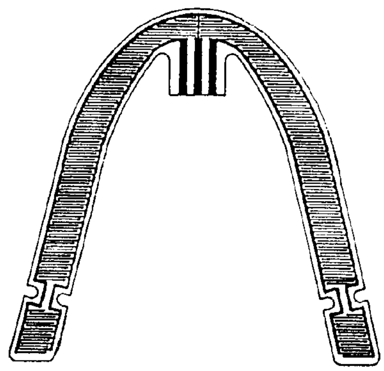

Figure 1 - The Bruxism Sensor

By electrically shorting the outside terminals of the bruxism sensor, both halves of the sensor are paralleled. The resistance between the center terminal and the shorted terminals is observed to decrease with increasing pressure. With no pressure, the resistance is greater than 1 MΩ. As pressure increases, the resistance of the sensor decreases to a minimum of about 1 KΩ. The relationship is not linear and when the sensor is encapsulated in an acrylic splint, the loading of the acrylic generally brings the baseline resistance down to about 20 - 30 KΩ. Hard to moderate clenches of the teeth will result in resistances in the range of 1.5 - 5 KΩ. The low resistance of the bruxism sensor led to some difficulty in encoding bruxing information into a telemetry signal since we had stringent limitations on power, requiring the use of high impedance circuits. We addressed this by using the modulator shown in Figure 2.

THE MODULATOR

The modulator is not only responsible for encoding the data but also performs the function of energy management and keying the transmitter. All of these functions are accomplished using a single package CMOS dual comparator. One comparator is used to generate a stable timebase of 10 Hz with a 50% duty cycle as observed at test point

TP1. Using high valued resistors and a relatively small capacitor keeps the physical size of the components small. Additionally, the high-ohmic value resistors also help minimize quiescent current. Unlike a conventional square-wave oscillator using a comparator, this circuit uses a

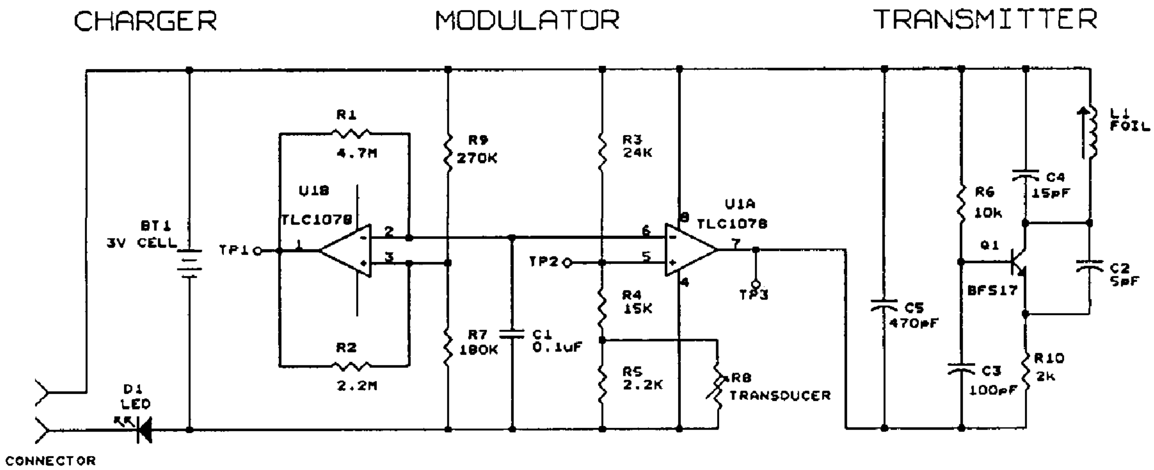

Figure 2 - Transmitter Assembly

minimum of hysteresis of approximately 4% of V_{DD}. This means that the peak-to-peak amplitude across the integrating capacitor is only about 4% Of V_{DD}. In doing this, two problems are solved. First, the waveform across the integrating capacitor is less concave and is more like the desired triangular linear charge/discharge ramp. Second, this small scale is used to measure the relatively low impedance of the pressure transducer as mentioned above.

The second comparator measures the small ratiometric change in a resistor-divider network due to the bruxism transducer, and changes state each time the voltage across the integrating capacitor swings through this point. This allows a linear change in duty cycle to be made without affecting the basic frequency. The output phase which is used to key the transmitter can be selected simply by swapping the inputs to the second comparator. By selecting a low duty-cycle during non-bruxing and a higher duty-cycle for bruxing events, minimal energy consumption is achieved.

THE TRANSMITTER

The choice of carrier frequency was made based upon considerations of interference from other sources and efficiency in getting a signal out of the mouth without exceeding our energy budget. Antenna limitations severely impact radiation efficiency since in the mouth there is very little space for a conventional antenna. Although at very high frequencies, strip or slot antennas can be used, tissue absorption increases with frequency and therefore such antennas are out of the question. Furthermore, the moist conductive tissue in the mouth functions somewhat like a Faraday cage. The various carrier frequency options that we considered were 49.86 MHZ, 183 MHZ and 313 MHZ. The 49.86 MHZ design had the advantage of being crystal controlled but because of antenna limitations, was too inefficient in transmission. The 183 MHZ design put us in the middle of VHF channel 8, a 6 MHZ band which is unallocated in the El Paso area (where this design work was done) and in the Pittsburgh area (where clinical trials on the bruxism treatment device were to take place). Although the 183 MHZ transmitter's radiated power was much higher than for the 49.86 MHZ design, our LC tank oscillator exhibited too much frequency drift for a narrow band receiver. This led us to a 313 MHZ design which had the advantage of higher antenna efficiency with a acceptable tissue absorption loss.

In order to achieve good efficiency, a single transistor oscillator/transmitter was designed. A single transistor design has the advantage that it minimizes the energy lost in transistor biasing but has the limitation that the oscillator cannot be isolated from the load presented by the antenna (commercially available surface mount inductors are too thick and thus chokes were not used in the transmitter). In the oral application under consideration, movements of the tongue in the vicinity of the oscillator cause a shift in frequency due to changes in load capacitance [5]. By layout geometry, proper biasing and feedback, this shift was limited to approximately 3 MHZ at a carrier frequency of 313 MHZ.

The transmitter oscillator (Figure 2) is a common-base LC oscillator with emitter feedback provided by C_2. The base is biased to a DC potential using R_6 and C together with R_{10} through the emitter-base junction. The power supply is bypassed by C_5 to have a low AC impedance. The frequency is determined by the LC network in the collector but is not isolated from either the feedback capacitance or from the internal capacitance of the transistor's reverse biased base-collector junction. Consequently, changes in bias voltage due to load or fluctuations in power supply voltage also change the frequency.

The transmitted signal is directly radiated by the tank inductor with no requirement for an additional antenna. The PC board was fabricated using copper coated kapton and is very thin with all electronic components surface mounted. By fabricating the inductor on the PC board the entire module is held to less than 2 mm in thickness. By component selection, the carrier frequency was deliberately set to be in the range of 290 MHZ to 305 MHZ. The frequency was then "fine tuned" by introducing a piece of insulated copper on top of the inductor and shifting its position until the desired carrier frequency was obtained. In doing this, the copper functioned as a paramagnetic slug which reduced the inductance and thus increased frequency.

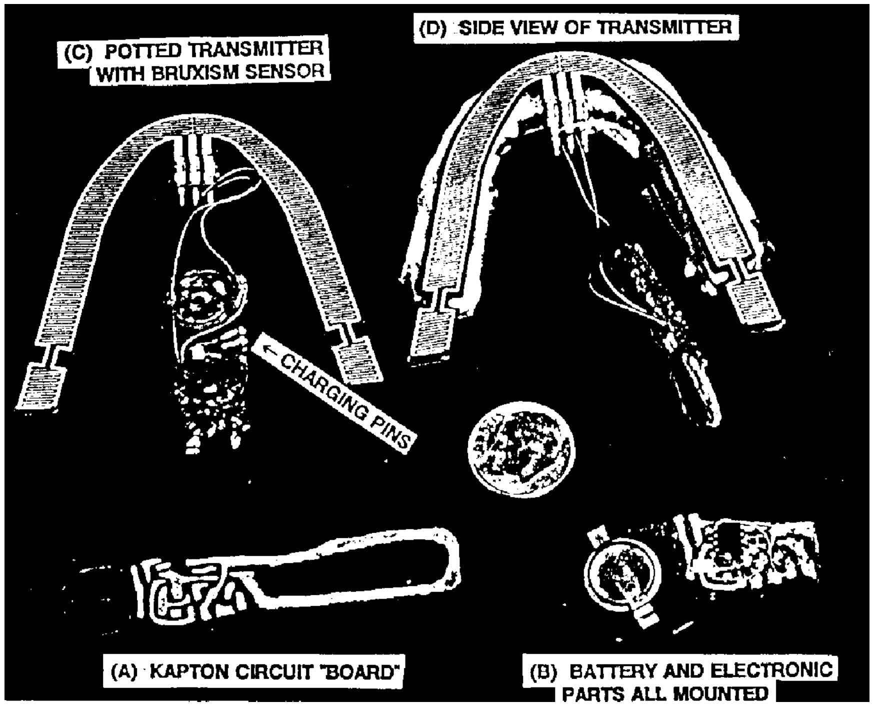

Figure 3 - Fabrication Details of the Telemetry Transmitter

THE RECEIVER

The receiver is a superregenerative direct-conversion unit with a bandwidth of about 6 MHZ. Employing this wide band receiver sidesteps problems with drift in the transmitter carrier frequency without requiring crystal control on the transmitter [6]. This receiver is shown in Figure 4.

The heart of the receiver is the oscillator tank formed by C_{12} in parallel with a tunable inductor. As Q_2 oscillates, its bias and loading is sensed through R_4 and amplified by the detector circuit using a dual op amp. This signal is then amplified by U1A and the resulting signal is squared up by the peak mean detector comprised of D_1 and U1B to yield a binary output. C_9 serves to hold the mean and provides the time constant for the detector. Because of RF quenching, this circuit has noise for output when no signal is received or when signal is being received after the time constant. This is due to the fact that after the time constant, a new mean is established and only a shift from this mean can be detected. This is why the circuit is excellent for picking up pulsed carriers but is not suitable for continuous wave. As long as transitions occur within the time constant of the detector, the logical transitions at the output will be clean and free of noise. A more detailed discussion of superregenerative receivers may be found in references [6] and [7].

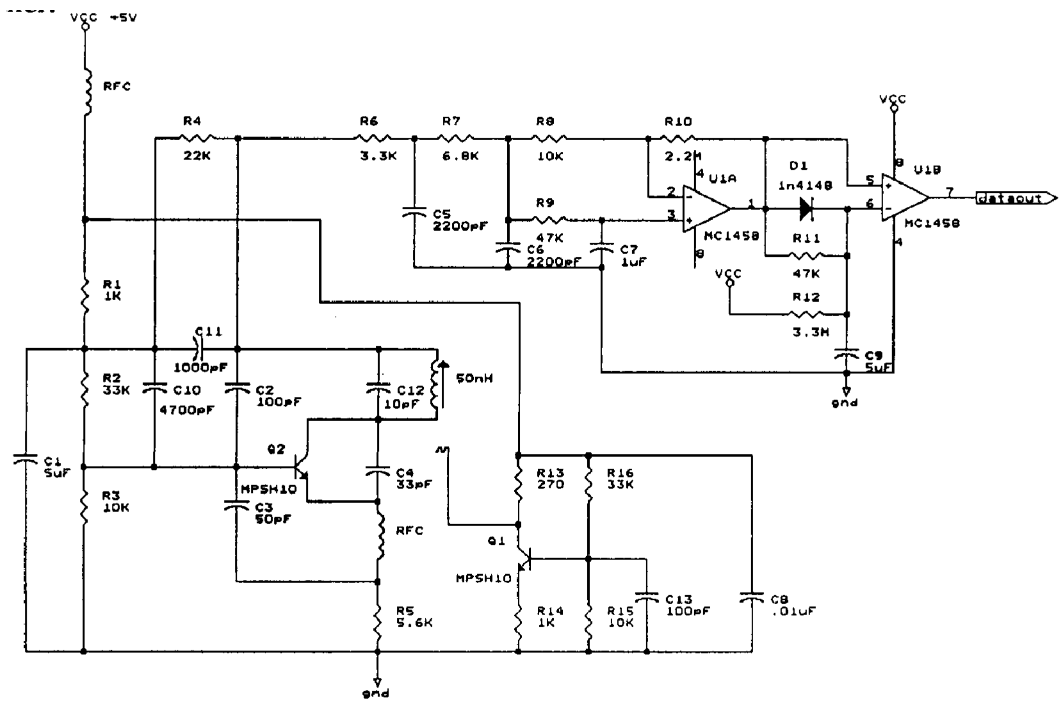

Figure 4 - The Receiver

Through tuning of the single adjustable coil, the receiver can be adjusted from about 280 MHZ to as high as 330 MHZ. The design is simple but a price is paid for this simplicity. Since the receivers are actually oscillators, they radiate RF energy around the receiving frequency. This means that if two or more units are operated in tandem, they must either be tuned to frequencies at least ten MHZ apart or they must be physically separated by about 5 meters. Otherwise they will interfere with each other.

USE OF TELEMETRY IN BIOFEEDBACK

The telemetry transmitter/receiver described in this paper is but one part of an overall treatment apparatus currently in use in a pilot study at the University of Pittsburgh School of Dental Medicine. In the test set-up, dental patients are fitted with a dental splint into which a transmitter, battery and bruxism sensor is encapsulated. The telemetry receiver unit is attached to the headboard of the patient's bed at home. A three conductor cable connects the receiver to a data processing/logging module which is located remotely. The three wires connecting the two units represent power, ground and digital pulse width information. The data processing/logging module is built around an IBM XT compatible motherboard with real time clock and 720K floppy disk drive for program and data storage. The disk drive is internal and is not accessible to the patient. When the module is turned on, it automatically downloads a program that governs operation. The module monitors the signal line from the receiver and filters it for noise. The resulting signal is then converted to a decimal level that is proportional to force as derived from duty cycle. The levels range from 00 (no force) to 99 (high force).

The data processing/logging unit is programmed once by the dentist at the time that the patient is fitted with a splint. The only variable that needs to be programmed is the force threshold corresponding to a bruxing event. This must be programmed by the dentist for each individual because the way that the sensor is built into the splint affects the amount of force that the sensor detects. In addition, all patients are different and their biting habits and forces will vary.

For each minute during the night, the receiver unit will record the maximum pressure from the bruxism sensor that occurred during that minute. At any time that a biting pressure in excess of the predetermined threshold is sensed, the alarm is set off. The alarm consists of a blinking yellow strobe light in combination with a shrieking audio piezoalarm. This combination of audio/visual stimulus is designed to be obnoxious since the purpose of the alarm is to awaken the patient as soon as possible. Preliminary studies with patients at the University of Pittsburgh suggest that the splint with transmitter will be well tolerated and the entire apparatus will be user friendly and enjoys good patient acceptance and compliance. The pilot study on efficacy in treating bruxism is still in progress.

CONCLUSION

This paper described a telemetry unit for use in studies on the biofeedback treatment of nocturnal bruxism. The apparatus developed is designed not only for a clinical and diagnostic setting but as a first step toward a commercially available treatment device designed for home use. Transmitting and receiving a signal from inside the mouth presented a number of challenges. The telemetry unit that was designed is small and low power and accurately encodes and transmits information on bruxing force to a receiver located 1.5 meters away for more than ten hours on a single battery charge. The transmitter design is easily assembled and exhibits consistent performance from unit to unit. The receiver is wideband and can tolerate up to 6 MHZ of drift in the carrier (solving the carrier drift problem at the transmitter due to tongue movement). Signal conditioning is performed on the received signal by a computer controlled unit so that filtering can be implemented and false triggering avoided. The telemetry unit described in this paper is not limited to the monitoring of bruxism but could be easily modified to log data on any measurable variable within the mouth such as pH and temperature.

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