TRANSDUCERS AND ACTUATORS

AN IMPLANTABLE EMG SENSOR

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Introduction

In consequence of the poor selectivity of surface electrodes in detecting EMG activity in closely grouped muscles [1], control of prostheses by EMG has been restricted to a few special situations. The signal at any electrode site is usually composed of a dominant, and wanted, component from the nearest muscle(s), and an appreciable proportion of crosstalk coming from opposing or unrelated muscles, and therefore unwanted. Day-to-day variation of electrode site can further reduce selectivity.

The device to be described here has been designed for implanting inside individual muscles, so that the ratio between signal and crosstalk amplitudes will be increased, and it may then be possible to obtain usefully independent signals from muscles which are quite close together. Further, it may allow independent localised signals from small regions of large muscles to be obtained. Emgor (contracted from EMG sensor) is intended ultimately for use in control of prosthetic and orthotic equipment and is therefore designed to be permanently implantable.

Implant Circuit

The complete circuit contained in the implant is shown in Figure 1a. D_1 and D_2 are varactor diodes of equal capacitance, which form with inductor L a resonant LC loop, the capacitance being modulated by the EMG signal. The loop is balanced about the modulating terminals (ab) and the radio-frequency equivalent circuit is thus as shown in Figure 1b. Typically the resonant frequency lies between 1 and 3 MHz and Q is 30 to 40. The low-frequency equivalent circuit is as shown in Figure 1c. EMG is transmitted to the diodes over a flat passband covering the full EMG spectrum [2]. Typical lower and upper limits are 3 Hz and 15 kHz (−3db). The effective passband is determined rather by the monitoring circuit.

R_L is included to reduce the detuning effects caused by rectification of carrier signal, and C_B is to prevent such bias causing a direct current through the electrodes. R_S is intended to absorb variations in source resistance of the muscle, due to fibrosis around the electrodes. Inductor L is a centre-tapped winding of about sixty turns on a ferrite rod, 1 mm diameter x 7.9 mm long. The diodes are zeners, chosen for their very large capacitances of around 500 pF at

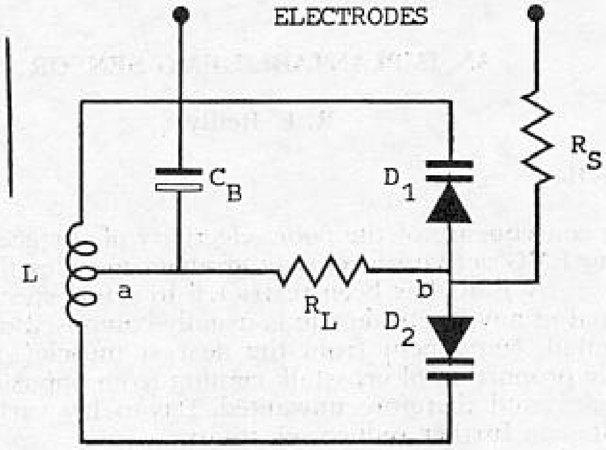
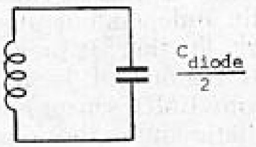


Fig. 1b. RF eguivalent circuit



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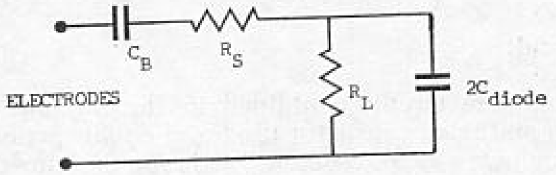

Fig. 1c. Lf eguivalent circuit

zero bias. The degree of modulation is approximately 250 Hz per millivolt of input signal, when the resonant frequency is 2 MHz.

Capsule

Figure 2 shows the completed implant, together with its internal components. The body is a cylindrical tube of high-purity alumina, a ceramic which is extremely strong, an excellent insulator, totally impermeable to moisture, and, on such information as is available, inert in the body [3]. The electrodes consist of platinum-iridium alloy caps bonded to the body with epoxy resin. The joints have a conical profile which allows a very snug fit, thus minimising any moisture penetration through the epoxy.

Positions of the components inside the capsule are indicated in the photograph. The inductor is placed centrally to avoid shorted-turn damping by the electrodes. At one end is placed the diode-resistor network, built on a printed-circuit panel. Tantalum electrolytic capacitor C_B is at the other end, beside its electrode. The circuit is assembled in a combined jig and mould, where it is encapsulated in a cylinder of silicone rubber. The device is completed by bonding this cylinder into the alumina body, making electrode connections, and finally bonding the electrodes to the body under end pressure. Overall dimensions are 3.2 mm. diameter x 20 mm. long; volume is 160 mm^3, and mass is 1.0 g.

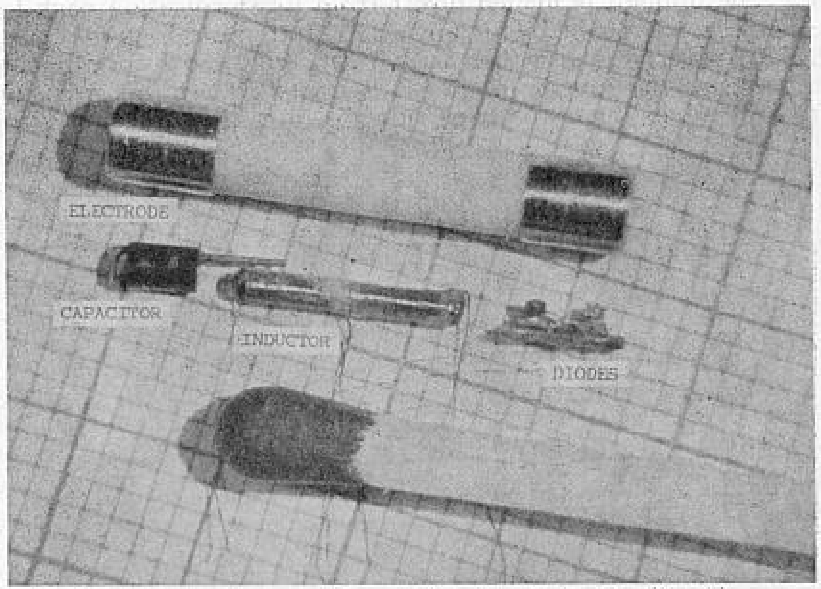

Fig. 2. Internal components and completed capsule. Small grid sq; uares are 1 mm.

The cylindrical shape has the following useful features. It provides a suitable spacing of electrodes with minimum volume of capsule, and it can lie parallel to the muscle fibres, unobtrusively, so any discomfort is likely to be minimal and only temporary. Also, in a limb, the magnetic axis will then be parallel to the limb axis, which is convenient for the design of probe coils. The shape lends itself to the possibility of implantation through a cannula; and finally the capsule is quite simple to make.

Sterilisation and Implantation

The completed capsule is cleaned by soaking in dilute nitric acid, then in Decon 75, a surface active agent. It is then sealed into polythene bags, and sterilised by gamma radiation. This method ensures that in the unlikely even of a capsule breaking in service, there will be no infection hazard.

Briefly, the implantation procedure is as follows. A trocar, with nylon cannula fitted over it, is introduced into the muscle through a small skin incision. The trocar is used to part the tissues at the selected site, then withdrawn, the nylon cannula being left in place. The implant is loaded direct from its sterilisation pack into the cannula, and pushed with a nylon rod into position in the muscle (Fig. 3). The cannula is then withdrawn, followed by the pushing rod, to leave the Emgor in site. It is hoped to use this procedure with only a local anaesthetic on human subjects.

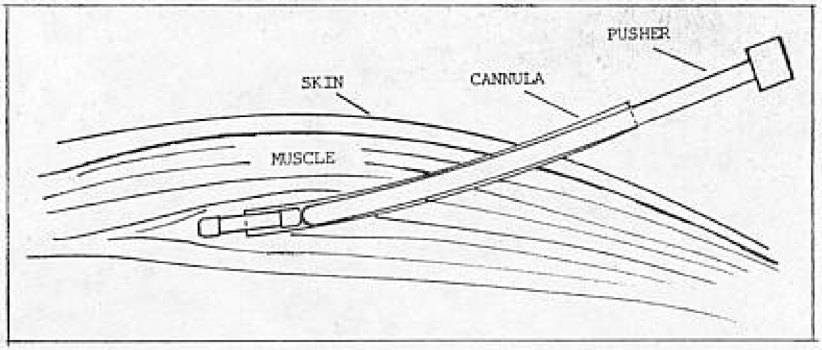

Fig. 3. Method of implanting Emgor in muscle.

Monitoring Probe

Communication with the implanted Emgor is by inductive coupling via an external probe coil placed close to the implant site, the particular arrangement depending on the site in question. Most attention has been given to a cylindrical configuration, appropriate to a limb site. Here the probe, a two-terminal inductor with specially-distributed winding [4], can be conveniently incorporated into the socket fitting over an amputation stump which contains the implants (Fig. 4). Magnetic coupling coefficient proves to be around .01 to .02 and fairly independent of Emgor position within the coil volume. It is considered implicit that in this kind of site a number of Emgors will be monitored with a single probe coil.

Monitoring System

A monitoring circuit which is particularly appropriate to the limb site has been developed. In it the probe coil forms the tank inductor in an LC oscillator (Fig. 5), whose natural frequency is the same as that of the implanted Emgor. At this condition the modulating EMG signal on the varactor diodes has greatest control of the oscillator frequency. The EMG signal is then derived from the carrier by a normal FM discriminator and amplified by a low frequency amplifier. The circuit is quite simple, and has only two stages which have to be tuned to a particular Emgor frequency; thus it will detect modulation from only one Emgor at a time, when there are several present (as in Fig. 4) with different resonant frequencies. It is proposed then to use time division multiplexing to sample the signals from all Emgors, via the same probe coil, by tuning to each one in sequence.

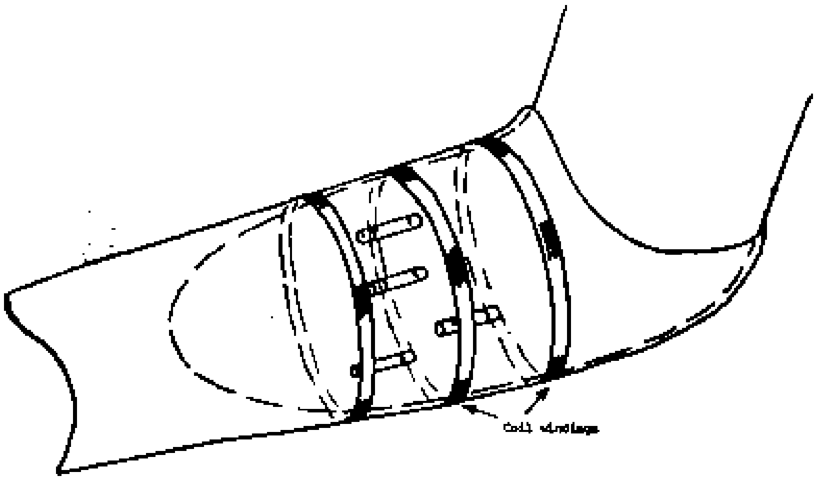

Fig. 4. Probe coil built into socket to communicate with implants in stump.

Presence of some objects in the vicinity of the probe coil could detune the oscillator from the Emgor frequency, and therefore cause the signal to be lost. To counter this the coil is fully screened electrostatically, but by virtue of its role it must have an open magnetic field. The circuit therefore includes a feedback loop to keep the oscillator tuned to the stable frequency of the discriminator, which is fully screened and protected. Feedback is applied to the oscillator by means of the varactor V in Figure 5, which forms part of the tank circuit. Bandwidth of the feedback loop is limited to the range of DC to about 20 Hz by the low pass filter R_F and C_F, so that the desired FM due to the EMG signal is not cancelled. For a system described by Figure 5, using a probe coil design as illustrated in Figure 4, the following are some measured characteristics:

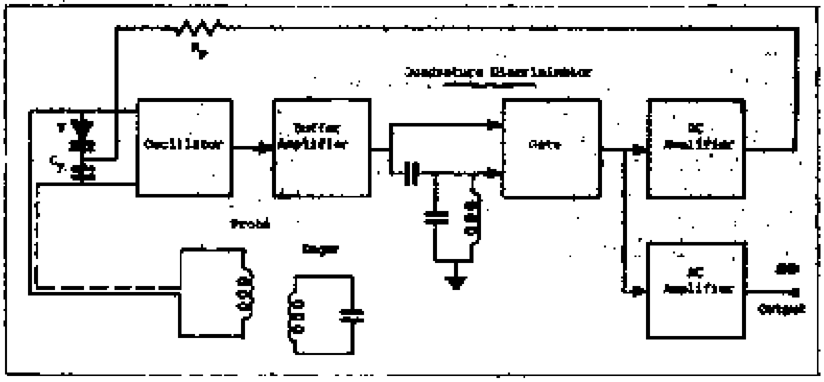

Fig. 5. Diagram of external monitoring circuit

Coil Diameter:	7.5 cm.
Length of coil:	6 cm.
Coupling coefficient:	.015
Voltage gain:	1,000
Noise level referred to input of Emgor:	10 µV RMS
Carrier frequency:	2 MHz
Power consumption:	30 mW

A simpler and more compact version of this monitoring circuit is now being constructed using recently-introduced low-cost integrated circuits.

Animal Trials

Implantations in animals are being undertaken with the hope of resolving the following questions:

1) Whether the implant will remain in its original site, and if not, how to ensure this.

2) Whether it will continue to function over a long period without failure through fluid leakage or breakage.

3) Whether formation of scar tissue around the electrodes is likely to affect the characteristics of the transmitted EMG signal.

Experience so far is limited to a single implantation, in the gastrocnemius muscle of a goat, chosen because it is similar in size to the human, and is fairly active.The implant was inserted through a cannula as outlined above, and no attempt was made to secure it in position. The animal has shown no signs of discomfort or other ill effects. It can be reported that this unit continues to function, and that there has been no noticeable change in amplitude of signal, sixteen months after implantation. Oscillograms of the signals obtained from this implant, at low levels of contraction, are presented in Figure 6. Its location has been checked from time to time by monitoring through a special probe coil, and it is estimated that any movement cannot have exceeded 2 cm since implantation. This accuracy of measurement is not however sufficient for some purposes, notably in connection with detection of single motor unit impulses, and an improved locating method is planned.

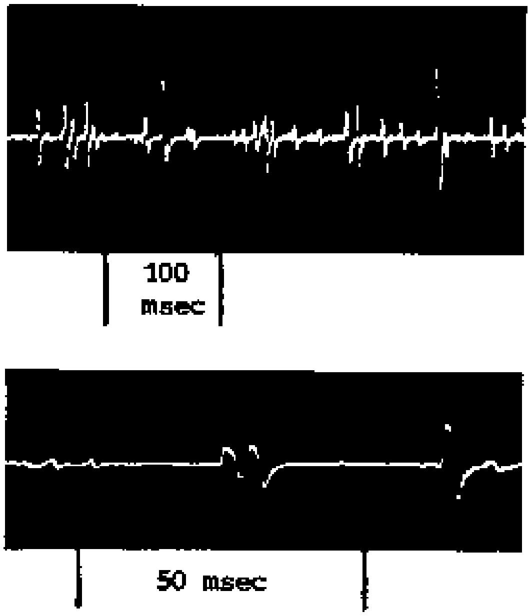

Fig. 6. Electromyograms obtained from goat 16 months after implantation.

Some further implantations in animals are anticipated before trial in human volunteers.

Applications

To take first the case considered above (Fig. 4), it may be possible to achieve by this technique sufficiently low crosstalk among the closely-grouped forearm muscles to allow the amputee two or three degrees of freedom in his artificial hand. Moreover, each muscle might take a role closely resembling its natural one. This amounts to an extension of the work with surface electrodes reported by Germans [5]. The wearer would normally be ambulant, and so a compact, unobtrusive electronic system with low standby power consumption is a major priority.

Another potential field of application is in persons with severe paralysis, e. g. from a high-level spinal injury. Emgors might be implanted in neck and shoulder muscles to exert control over paralysed arms, by means of powered splints [6]. There may be scope here were to develop skill, already reported, in contracting separate small regions of muscles selectively [7], as a means of increasing the number of control sites. Further, with Emgor it may be feasible to apply the ability to contract single motor units individually, which demands implanted electrodes. There is need here for a very stable electrode site, in order that waveform and amplitude of impulses remain constant [7]. Control of assistive equipment by this means may be difficult, but still worthwhile to the very severely disabled. The user would be confined to a wheelchair, and there would therefore be no practical limit to complexity or power consumption of the electronic system.

A further possibility lies in connection with functional electrical stimulation, where signals derived from EMG sensors implanted in active muscles may be used to control stimulation of paralysed muscles, as proposed in other contributions to this Symposium.

Conclusion

Basic development of an implantable EMG sensor has been carried out to the stage that it now seems likely to be viable for long-term use. An external monitoring circuit has also been produced, which is no more complex than the electronics which would be associated with surface electrodes. Further implantation in animals is planned, to establish statistical support, and implantation in humans will soon be undertaken, to begin study of its potential clinical value to limb-disabled patients.

A fuller description of some aspects can be found in an earlier paper [8]; projects having similar aims to this one are described in References 9 and 10.

Acknowledgements

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