DEVELOPMENT of a
MYOELECTRICALLY-CONTROLLED
PROSTHESIS

When muscles contract they produce minute
electrical potentials that usually exist for a
few milliseconds. The potentials produced by the
voluntarily-controlled muscles of an amputee
should, in concept, be ideal control signals for
prostheses. A prosthesis that responds to muscle
contraction in the same way that the replaced part
of the body responded could be used "naturally"
with a minimum of retraining.

Muscle EMF's are called myoelectric (or "action")
potentials (myo is derived from the Greek myos
for muscle). Electrical volume conduction of these
potentials through body tissue and fluids results
in potential differences that can be sensed on the
skin. Myoelectric potentials measured on the skin
are much attenuated relative to the amplitude of
the "signals" at their point of origin in the muscle.
They are composite signals from many muscle
fibers. Surface electrodes in contact with (but
not penetrating) the skin are used for prosthesis
control despite the smallness of the signal and its
composite nature because of the formidable
problems encountered in the use of percutaneous
electrodes for any length of time.

The myoelectric signals acquired on the skin
cannot be precisely described because they are
affected by many factors. Among these are: (1)
muscle type, function, and condition (including
fatigue); (2) characteristics of the tissue, bone,
and skin that lie between the muscle and the
electrodes; (3) electrode material, surface texture,
geometry, and spacing; and (4) the location of the
electrode relative to the muscle. However, some
characteristics of the myoelectric signal acquired
on the skin are typical. These are: (1) the signal is
an AC voltage that is roughly proportional (in
amplitude) to the force developed by the muscles
that generate it; and (2) the power spectrum is
such that the major portion of the power lies be­
tween 30 and 500 Hz. Signal amplitudes on the
order of 100 microvolts RMS are typical for healthy
muscles developing modest tension. Paralyzed
muscles often produce myoelectric voltages, but
their amplitude is much lower than for healthy
muscles. Some prostheses that are controlled by
myoelectric potentials are unsatisfactory because
of difficulties encountered in obtaining signals that
are both sufficiently large in amplitude and rela­
tively free of noise and "crosstalk." Crosstalk
results when unwanted signals produced by antag­
onist (and other) muscles are sensed along with the
desired signals.

An electrically powered artificial hand and con­

trol system has been designed and fabricated at
the Applied Physics Laboratory. This closed-loop
system (Fig. 1) comprises a servo operated hand,
signal acquisition electrodes, signal amplifiers, a
servo amplifier, power control circuits, and a
battery pack power supply.

The APL system differs from open-loop systems
that are presently in use in that electrodes are
placed at only one site. Problems from signal crosstalk between different electrode sites are thus completely obviated. This system duplicates the operating characteristics of a voluntary opening hook. Cosmetically, the artificial hand is far superior to the hook. Problems attendant to harnessing and control cable routing are minimized. The servo control system is designed so that the hand opens in approximate proportion to the amplitude of the myoelectric control signal. Other single site closed-loop prosthetic systems that are now in use or being developed require that the user deliberately sequence or control the system to control the position of the fingers. Such mode switching is not required with the prosthesis developed at APL, and in this respect it more closely duplicates the action of the natural hand it replaces.

![Fig. 1—Myoelectrically controlled artificial hand.](image)

The hand, shown in Fig. 1, is driven by a small motor inside a metal shell. The shell is from an Army Prosthetics Research Laboratory—Sierra mechanical hand from which the internal mechanism and the actuated fingers and thumb have been removed. A gear reduction and lead screw mechanism designed at APL operates the thumb in opposition to the fore and middle fingers. The operating fingers are made of silicone rubber that is cast on "skeletons" made of aluminum. The hand is relatively rugged. Because of the silicone rubber, it is superior to cast plastic hands for picking up objects of small diameter. The resiliency of the silicone rubber also minimizes loss of grip resulting from structural deformation of the fingers. The hand is covered with a realistic looking cosmetic glove.

A block diagram of the system is shown in Fig. 2. The myoelectric signal is acquired by stainless steel button electrodes that are held in contact with the forearm. The electrodes can be placed in close proximity to either the flexor or extensor muscles that control the fingers. One integrated circuit operational amplifier is used in the preamplifier. The circuit has a gain of approximately 2000. The output signal from the preamplifier is amplified by an additional stage before it is detected. Over the operating range of the system, the dc output of the detector is roughly proportional to the amplitude of the input signal.

The output of the detector is applied to a servo amplifier that controls an electric drive motor in the hand. With the muscles relaxed, and minimum control signal, the hand is in its closed position. With the muscles tensed, the electrodes pick up a control signal. As the control signal increases, the servo amplifier drives the motor, opening the hand. The hand continues to open until the voltage on the wiper of a potentiometer driven by the lead screw follower in the hand is equal to the control signal. The hand is servo controlled for all positions between closed and full open.

The power control circuits operate from the error signal in the servo amplifier. If the hand closes fully or is stalled when it grasps an object, power is automatically disconnected from the servo amplifier. It is these power control circuits that enable the hand to operate like the voluntary opening hook. Additionally, power consumption is greatly reduced. This is very important in systems that must operate from portable power sources.

![Fig. 2—Block diagram of servo-controlled prosthesis.](image)