Telemetry, Personal

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Some Considerations in the Design of

[1806] Personal Telemetry for Spacecraft

~~Although~~ One of the better known examples of biological telemetry has been the transmission of data from astronauts in orbit. This transmission was a relatively straight forward engineering problem which consisted of amplification of wired signals from transducers or electrodes to a level suitable for inclusion in the same telemetry data link used for operational engineering ~~and operation~~ data - Other than development of electrodes ~~for~~ suitable for pick up of signals from relatively immobile subjects there ~~was~~ has been little required to advance the state of the biomedical telemetry art, except of course the eye catching nature ~~& results~~ of the operation

Considerably more in the way of biomedical engineering will be required ~~in~~ for monitoring of astronauts in the next generation of large laboratory type vehicles. In these vehicles ~~one~~ relatively unrestrained subjects

~~for periods of 30 days & more~~

will live and work, and must be monitored for safety as well as studied in a variety of situations. ~~It is a~~ This must be accomplished for long periods of time, (30 days minimum,) c̄ maximum reliability + minimal interference to the subjects. Short range or personal telemetry is the only suitable technique for much ~~of this work~~ of this monitoring.
Space ~~is~~ is not available to describe all of the possible or even desirable types of telemetry systems that may be required. Rather, ~~an EKG +~~ various aspects of an EKG system will be described. The EKG may be considered the archtype of a biological signal and almost certainly will be ~~widely~~ extensively used for better or worse on all missions in the near future — (Introd?)

~~Too often the engineers~~

The electrocardiographic signal arises from the depolarization and repolarization of the heart muscles ~~during con~~ associated c̄ contraction. This electrochemical process is synchroni in the heart such that the signals may be considered to normally originate from three sequential rotating vectors in a volumed conductor, the body ~~the heart~~. The first of these vectors is ~~the~~ designated the P complex which begins the contraction cycle and is generated by the atria or two ~~upper portion~~ upper chambers of the heart. ~~This signal originates in~~ Three projections of a normal loop are shown in fig. 1 a. After a pause during which this event is coupled to all parts of the ventricles or larger lower chambers of the heart, their rapid depolarization ~~of th~~ produces the QRS loop or complex. This is shown in fig 1-b. The greater amplitude is ~~produced~~ caused by the ~~ret~~ larger muscle masses involved. Repolarization of these muscles produce the normal 3rd ~~complex~~ or T complex shown in fig 1 c. In normal practice the attenuated signal is recorded from the body's surface ~~at v~~ c conduction-ve electrodes. ~~The location on~~ Usually only two such electrodes are used at a time and the resulting scalar presentation is a function of the location of the electrodes (called a lead).

~~In~~ Fig. B2 shows a typical lead derived from the vector of Fig. 1 and taken between the right shoulder + left leg (lead II) c̄ ~~the~~ an ~~signal~~ amplitude calibration. One of the difficulties in handling this + ~~on~~ most other biological signal is their low frequency. ~~Although it is a relatively simple~~ In the handling of these frequencies one cannot simply rely on good engineering practice but must also be aware of the ~~use to which~~ way the signal will be used and even more aware of the established medical standards by which the signals will be interpreted. For example ~~it is a~~ fourier series + other analyses ~~a~~ are available for normal + abnormal EKG's and ~~they~~ the normally show a range of frequencies of — to — Hz. This data must be used c̄ caution however.

One of the increasingly common uses of the EKG is simply ~~to~~ for derivation of ~~the~~ ~~a~~ heart rate. ~~I~~ The QRS complex of the signal is the most suitable portion of the cycle for this derivation. ~~which consists of~~ Heart rate may be determined by simply detecting the QRS + then averaging the number of these complexes over some suitable time. An ~~alternative~~ alternative is to time the interval between these complexes + use this time value either directly or convert it to an instantaneous rate. ~~The~~ ~~It is ma~~ Where rate only is desired, great savings on information space may be effected by automatic signal analysis c recording/transmission of the resulting data. ¶ In this situation the telemetered transmission of only that ~~data~~ ~~use~~ signal component necessary of the QRS to detection of the rate ~~will~~ is desirable. ~~As well~~ ~~The~~ These frequency components of the QRS complex will depend ~~somewhat~~ on the individual & his physiological state &, the ~~electrode~~ ~~configuration~~ ~~or~~ lead chosen and the rate. ~~A~~, Each investigator usually has his own bandpass + ~~me~~ QRS detection methods but a frequency range of say 8 to 25 cycles is usually adequate to pass a ~~the~~ distorted QRS complex suitable for rate detection. ~~Method~~ Other components

(Amplitudes) (((

& movement & other electrode noise (artefacts)
of the EKG, exist predominantly below this frequency while signals from voluntary muscles (electromyographic signals - EMG) ~~range from~~ lie above this.

However if the ~~full range of freq~~ EKG is to be used as a diagnostic or study tool no such limitation may be tolerated. Although there is little doubt that useful information ~~lies in the range~~ up to several hundred cycles per second may be present in some EKG's the ~~events of~~ conditions producing these high frequencies are unlikely to be present in astronauts and the state of the interpretative art is not sufficiently advanced to make use of these frequencies. The high frequencies may be safely ~~limed~~ limited to less than 100 ~~cps~~ Hz. while ~~the~~ in practice 50 Hz flat is more realistic & also more like the data most interpeters see. Although the P & T complexes are low in frequency the low frequency characteristics are in fact controlled by another phenomena. The region between the end of the S wave & beginning of the T, the S-T segment, is an ~~useful~~ indicator of pathological conditions. ~~For example~~ If the heart muscle receives insuffient blood this segment will be depressed below the iso-electric line. A depression of 1 mm. ~~is~~ or typically 5% ~~is~~ of the QRS wave amplitude is generally considered ~~very~~ pathological. Elevations ~~are~~ also signify extremely significant conditions. Although it may be argued that such conditions are unlikely to arise in astronauts it is important to insure that no possibility of error exists ~~and~~ through inadequate frequency response. The QRS is pulse like and ~~produces~~ may produce an undershoot or overshoot ~~in the~~ depending upon the lead & time constant. Worse this error may vary c̄ the position & state of the individual. Until there is ~~no~~ some way to differentiate between the S.T. depression from blood starved heart muscle & and that from an inadequate ~~RC~~ coupling capacitor it is best to avoid the danger entirely by the use of a 6 seconds or greater time constant(1). [(1) This is not based on engineering analysis but is based on a consensus of experience. ~~The~~ Dozens of papers ~~are~~ are in the literature on the discovery of abnormal S-T depression on other wise healthy individuals which ~~would have been avoided~~ who would have had normal EKG's c̄ larger coupling capacitors in their recording system]

Another ~~a~~ electronic-physiological interface problem is choice of the lead or electrode location. In clinical electrocardiography a large number of standardized leads ~~a~~ are recorded to ~~enable among other studies include~~ cover many facets of the signal including the ~~recog~~ approximate reconstruction of the vector. No such luxury is available, or for that matter needed, in the monitoring of ~~ats~~ subjects. ~~At l One or at the most two leads are~~ Currently two & in the future one lead will be used & these must supply the maximum amount of information consistent c̄ operational constraints which includes ~~active~~ vigorous movement. ~~a Every mos~~ There are many individual preferences but the lead location should 1) allow all complexes to be present at reasonable amplitude and 2) ~~allow~~ produce an ~~reasonable~~ optimum signal to noise ratio & 3) not interfere c̄ normal ~~movement~~ activity. By placing the electrodes ~~at~~ as near the heart as possible & along its longitudinal axis ~~the~~ all complexes are ~~opt~~ obtained at ~~thus~~ near their maximum level. In addition the electrodes should be ~~on an ll~~ unmoving to on an unmoving portion of the body & ~~away~~ as far removed as ~~po~~ far as possible from large muscle masses and their interfering EMG's. One such location is shown on ~~Fig~~ fig 3a c̄ its ~~associated~~ typical EKG signal. One electrode is placed over the sternal angle, a bony area near the top of the heart ~~wi~~ while the second is placed over a ~~rip~~ rib just ~~past~~ lateral to the point of maximum impulse which is near the apex of the heart. ~~This It is true there~~ There is the large pectoralis muscle ~~a b~~ between these points but this produces surprisingly little artefact even c̄ rigorous activity. ~~This~~ It might appear that the ~~lateral~~ side electrode is in a mechanically hazardous location but this ~~is~~ is not a problem in practice. Other ~~leads~~ commonly used leads are shown on Fig 3b c d c̄ their signal. ~~Th~~

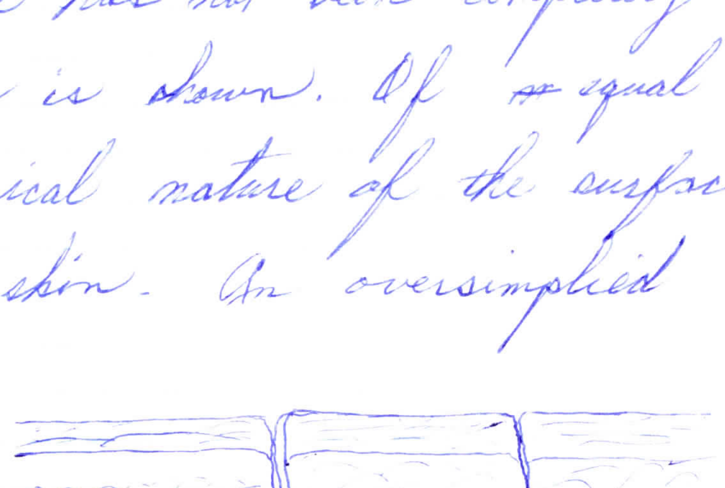
~~The~~ Most difficult of the entire problem is the true interface between body & electronic system, the electrode. ~~Small books~~ Volumes have been written on this and it still remains an enlightened (sometimes) art rather than a science. ~~a~~ Electrodes should

1) pick up a maximum of the desired signal c̄ a minimum of interference 2) cause no mechanical interference c̄ ~~the~~ normal activity 3) ~~last the provide the maximum to a min~~ produce no damage or discomfort to the subject 4) last ~~as long~~ the maximum time after an application 5) be simply & easily applied.

Item 1) usually ~~implies a low impedance coupling to the~~

The electrode consists of 1) some method of attachment to the skin 2) some electrical method of coupling the ~~skin~~ body surface to ~~the~~ 3) a conductor. The ~~bod~~ electrical analog of the signal source has not been completely described but one such analog is shown. Of ~~a~~ equal importance is the physical nature of the surface & sub-surface ~~of~~, i.e. the skin. An oversimplified view is shown in fig 4. ~~1 is~~ The uppermost layer is a dry ~~to~~ oily ~~surface~~ somewhat flaky surface of high electrical

1)



impeadance. Beneath this is a ~~lacy~~ layer of living cells which are continually regenerated from beneath & eventually become the dry upper layer. ~~Inside the cells~~ The ~~cells~~ living cells and their surrounding network of solid + liquid support ~~+ liquid food supplies may be considered to be~~ are of low impeadance. ~~This~~ The liquid ~~so~~ surrounding these cells ~~have~~ contain Na^+, Cl^-, Mg^{++}, CO_2^{--}, Ca^{++}, PO_4^{---} and other ions ~~...~~ c̄ the predominant ions being ~~Na^+, Cl^-~~ + concentrations shown in table 1 –

		Extra Cellular ~~Edema~~ Fluid	Sweat
P-720 White			
Stellen	pH	7.4	4.5 - 7.5
Smith	Na^+	135	<85
Biochem	Cl^-	105	<85
Meq/L	HCO_3^-	30	0-10

In addition the ~~s~~ living cells of the sebaceous & sweat glands pour out more or less sweat + oil depending upon location + condition. Absolute blockage of these glands will produce pathological derangements. The skin is of course subject to a wide variety of mechanical & chemical irritations especially on long continued contact.

~~Etc~~ The most common approach to

the establishment of an electrical contact between the conducting ~~living~~ regions + ~~a~~ ~~to~~ the amplifiers ~~in~~ ~~to~~ has been some variety of ionized paste. The most successful of the pastes to date contain some reasonable concentrations of the same ions in ~~solution~~ the body. ~~In~~ ~~addition~~ ~~The~~ "Wet" electrodes require some form ~~conto~~ ~~impermeable~~ impermeable containers to ~~be~~ prevent drying. The second interface between ~~the~~ paste & solid conductor is also of importance and the best results seem to range from a chlorided Ag to ~~pell~~ pressure formed solid pellets ~~of~~ containing ~~some~~ ~~of~~ the same materials as the paste. After application of such an electrode the electrode impedance & ~~at~~ movement artifacts decrease almost exponentially ~~to~~ during the first 8-10 ~~d~~ hours from 10-50 KΩ ~~after~~ ~~which~~ to a stable value of 5-10 Kohms equivalent resistive impedance. ~~is~~ ~~reached~~ (3). ~~Such~~ ~~electrode~~ ~~paste~~ ~~may~~ ~~be~~ ~~left~~ ~~in~~ ~~contact~~ ~~c~~ ~~the~~ ~~sk~~

The better electrode pastes may be left in virtually

3) In my opinion the practice of decreasing this time by skin scraping or needle puncture cannot be justified.

a. Impedance is measured by shunting a high input Z amplifier c a resistance until the signal is reduced by 1/2 indefinitely s̄ difficulty.(4) Sweating appears ~~to~~ not to hurt or even to improve this type of ~~paste~~ electrode. ~~The~~ Holding the electrode in place is the real difficulty and to date no really satisfactory method is available. The best is probably a double sided ~~backed~~ adhesive paper, ~~dough~~ ~~donut~~ annular which ~~merely~~ sticks the electrode to the skin. A variety of adhesives are utilized including Eastman 910 cement but the ~~price to pay here~~ potential danger here is plugging of ~~the sweat~~ gland ducts & other skin irritations.

~~A complete electrode assembly is Several complete electrodes are shown in fig 5~~ A typical wet electrode is shown in the drawing of fig 5. A number of commercial electrodes that are variants of this scheme are available.

A somewhat utopean approach ~~to the electrod~~ to this problem are the "dry" electrodes in which one dons a vest or strap and the electrodes are in a prearranged location & function s̄ further ado. A wide ~~ver~~ variety of such electrodes have been tried

(4) length of time.

including ~~conductors~~ metal plates against the skin, metalized fabrics & ~~ags~~ (Hi meg), and a porous material impregnated c̄ an ionized, & deliquescent material such as LiCl. With a high input impedance amplifier these arrangements ~~work~~ function adequately on quiet subjects. With motion they are all ~~quit~~ quite noisy compared to even a modest liquid junction electrode. ~~There~~ In addition to high impedance, noise voltage generators are invariably present whenever any ~~motion~~ relative motion between electrode & skin occurs - ~~these~~ The homogenous contact afforded by the liquid junction plus ~~this~~ the reduction of relative motion avoids many of the generators. As the subjects sweat c̄ these dry electrodes i.e. they become wet or at least damp & their performance improves -

~~A third class of electrodes~~ Another variety of ~~wet electr~~ dry electrodes avoid some of the difficulty of relative motion by attachment of the electrode to the skin. The first of these is the ~~scaly~~ subcutaneous electrode, either a needle or a wire pulled through the skin. Their performance is good

but degrades c̄ time as ~~the~~ tissue reaction sets in.
More serious of course ~~is~~ are the possibility of infection (which is less than one might expect) and the psychological aspects. ~~Finally one techniq the only technique~~

~~Another~~ Other techniques consist of spraying a a suspension of fine metals on the skin in a rapid drying resinous carrier ~~of rapid~~ c̄ a tiny embedded conductor and the application of some form of semi-solid adhesive conductor. ~~The~~ One dry electrode electrode scheme which has potential makes use of a shielded FET electrometer follower c̄ purely capacitive coupling to the skin by a a small oxided metal plate.

At this time a good liquid junction electrode should last — days & may then be ~~so~~ packaged such that reapplication ~~to~~ in ~~a nearby area~~ an adjacent area ~~so~~ may be done in a matter of minutes. This is ~~far~~ far from ideal but ~~will~~ should be adequate as well as providing protection to the skin.

After the oftentimes black art of electrodes the engineering problems seem simple. For some reason no state of the art ~~tel~~ personal telemetry system has been produced and it is to be hoped that such a unit ~~for~~ will be produced to fill a long standing need in general as well as space medicine.

For space use the system should have the following characteristics -

1) ~~Fidelity~~ Accurate transmission of the signal

2) Require no attention during use

3) Transmitter should function for 40 days continuously for current ~~missions~~ planned missions - 60-90 days is more realistic for future missions -

4) Rugged, reliable

5) Small size, weight

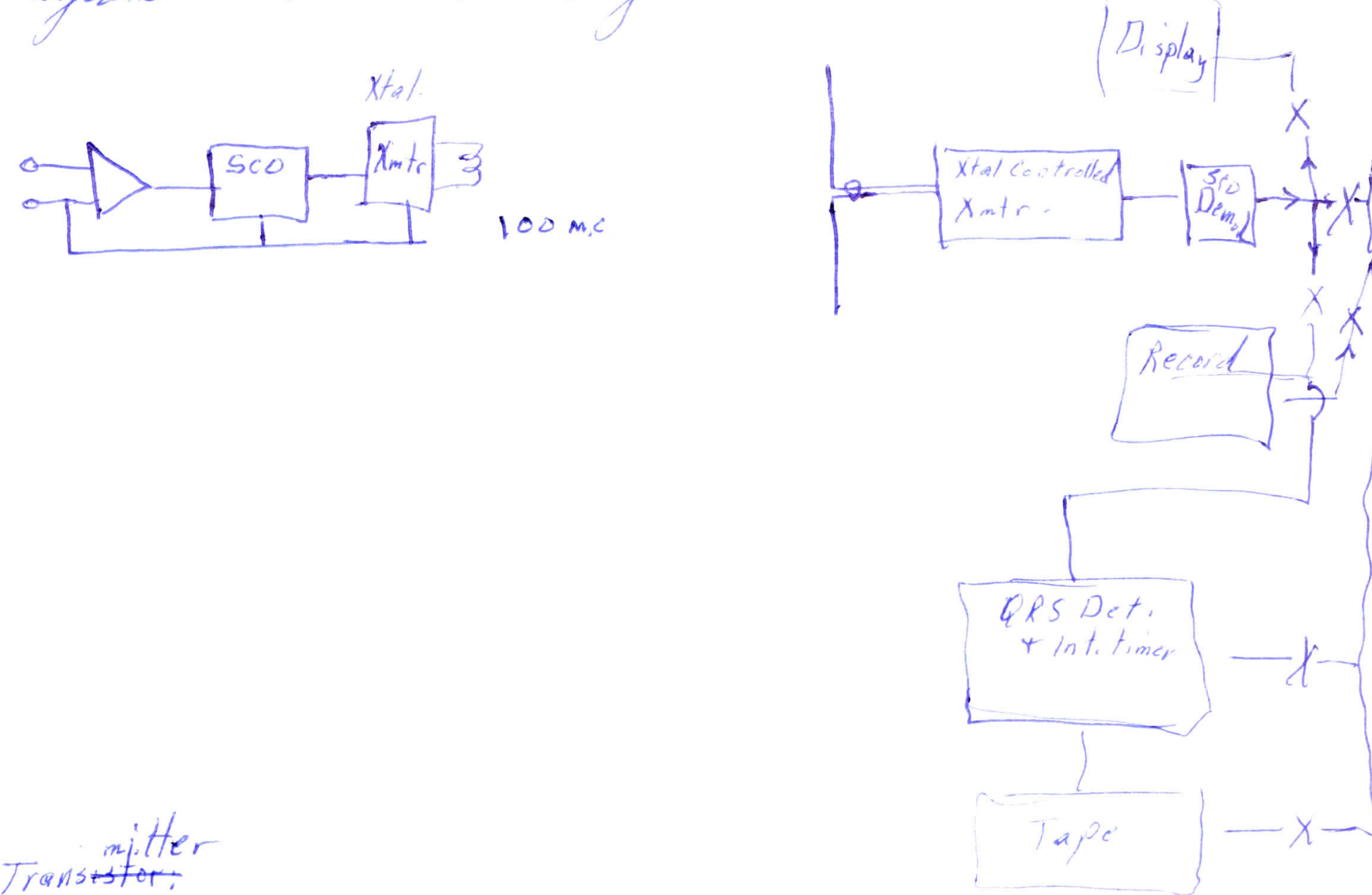
6) Compatible c̄ environmental requirements such as vibration, atmosphere, shock, outgassing

7) Offer no possibility of harm to the subject

8) Unit replacement rather than adjustment or attempted repair -

9) No interference c̄ other signals -

The block diagram of ~~so~~ a proposed EKG system is shown in Fig-6-



Trans~~istor~~mitter

The transmitter ~~should~~ consist of a miniature battery operated crystal controlled ~~monolithic pack~~ cast package c̄ integral electrodes and ~~a sec~~ only recessed ~~on~~ off-on switch and ~~of~~ depending upon the application a ~~calibrate control~~ manual ~~submerged~~ recessed calibrate switch. ~~Pd~~ Personal telemetry has grown up in the hands of ~~a few~~ dedicated experimenters *1 who are all too often used to adjustments, scopes & the like. There is no room for such in an astronauts schedule or for that matter doctors or nurses on earth. The ~~device~~ system must simply be go or no go c̄ every assurance that it will in fact go for its design period. If redundancy is required it should take the form of a complete transmitter or receiver rather than batteries or electrodes.

Signal Amplifier

~~The~~ One of the advantages of personal telemetry systems is their inherently high ~~CM~~ equivalent C.M.R.R. ~~With the use of~~ If the size of a telemetry transmitter is held to reasonable proportions it behaves very much as ~~an~~ a ~~flat~~ perfectly isolated input. The only unbalance ~~arises~~ arises through ~~coupling~~ capacitive coupling of the ~~element~~ transmitter to nearby noise sources such as power mains and through ~~difference in coupling~~ capacitive pickup of the signal lead. A single ended amplifier easily yields ~~CT~~ equivalent CMRR of 10^6. With input levels of 1-2 mV there is no difficulty in achieving good signal to noise ratios even at the low frequencies encountered. The input ~~Z~~ impedance should be 100 X source impedance which means a maximum of

~~$10^2 \times 50 \times 10^3$~~ ~~ca~~ of about 5 megs. for reasonable electrodes. If "dry" electrodes are to be considered then ~~very high~~ ~~the use of the~~ full potential of FET inputs ~~should be consider~~ should be made. At this point in time FET input ~~should be consider~~ is the logical choice ~~especially~~ for the ~~and the p~~ only problems are biasing and the low maximum supply potentials available. Adequate R.F. bypassing (but not shielding) is essential here and throughout the circuit for ~~a~~ relatively high R.F. levels are present ~~at a not~~ between the transmitter and ~~a~~ subjects' body. This R.F. level varies c̄ movement. Without bypassing this varying R.F. level is detected and ~~is indistinguishable from other~~ has the same effect as motion artefact from the electrodes. ~~After a~~

S.C.O. ~~After raising the level to 10 × tens of millivolts~~ Although various forms of direct modulation schemes are possible a sub-carrier provides several advantages. Since economy is paramount here ~~some form of constant current charging~~ capacitor charge system one of the more economical & accurate systems consists of a constant-current (i.e. voltage independent) device which results in a linear ~~capacitive~~ charging voltage to some preset value where the capacitor is discharged ~~& the~~ rapidly & the cycle repeated. This results in a highly linear variation in frequency ~~over~~ as a function of modulating current. Such a system is shown in fig 6-

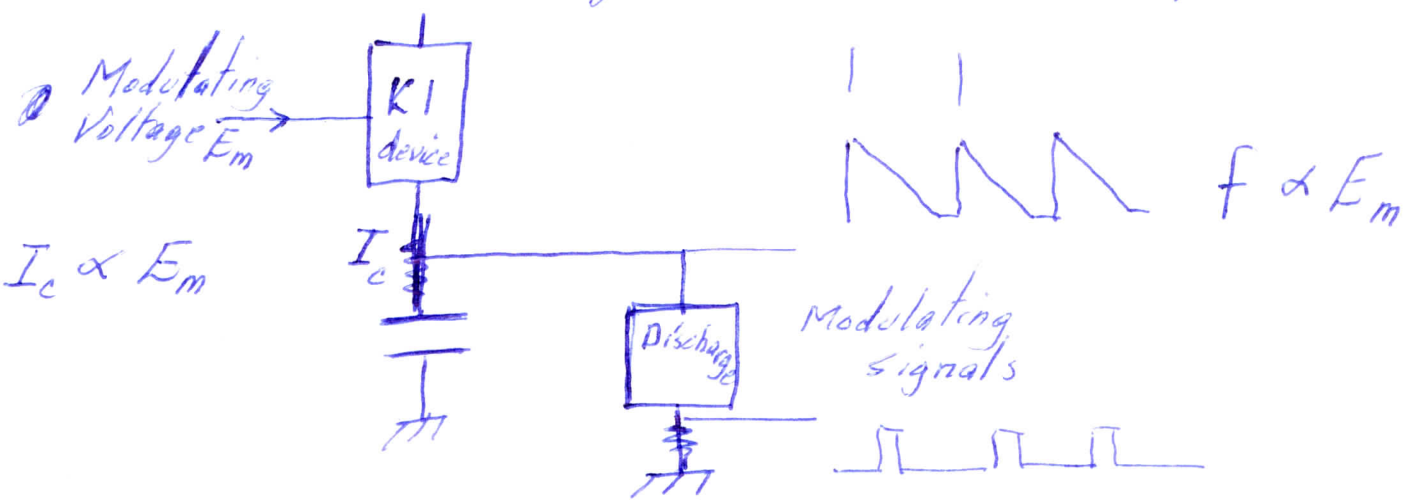


fig 6-

A transistor c̄ emitter degeneration c̄ the ~~capa~~ charging capacitor in the ~~em~~ collector ~~w/~~ & c̄ the modulating voltage applied to the base is one such arrangement. ~~Either~~ Degenerative ~~back to back~~ complementary ~~back to back~~ transistors may be used as a discharge device. Their discharge time may be varied & no current is drawn in the off period. A more stable & reliable temp. discharge circuit is a unijunction but some current is drawn during the on period. Further signal processing may be required before modulation

R.F. circuits -

A number of trade offs are possible here ~~including & this~~ the more important of which is choice of frequency and type of modulation. This ~~the~~ stage should be designed prior to the other stages for it will in large measure determine the overall performance. There is little justification for the use of a transmitting antenna over the short ranges involved since adequate radiation from a small tank coil may be obtained. ~~With these constraints~~ This radiation is enhanced by coupling to the subjects body. The ~~antenna~~ propagation problem has not been completely or adequately studied however ~~the~~ fig 7 shows a ~~plot~~ record of the field strength obtained at 100 mc. in a simulated ~~capsule~~ laboratory. from a telemetry transmitter radiating from 1/4" dia. x 1/2" long coil c volts R.F. on it.

Receiving antenna was a 1/2 dipole suspended vertically only a few inches from the chamber wall. Dead spots from interference or absorption were diligently searched for and only one was found & that was a region ~~of about DZ~~ so narrow that it was difficult to hold ~~just~~ near the entrance to the pilots compartment. However ~~once in th~~ even in the compartment c̄ a latticed metal door closed there was no difficulty. In some of the vehicles planned if the compartments are tightly bonded a multiple ~~or~~ receiving antenna ~~re~~ may be required - Unfortunately adequate data ~~on~~ at other frequencies is not available however operation 100 MC seems to present no problems, ~~As ffo~~

~~Mr D Modulation system~~ A variety of modulation systems are required & in spite of the necessity for crystal control my ~~no~~ personal choice is ~~an~~ a frequency shift two crystal ~~ckt~~ circuit using a single transistor & tank coil - Shifts ~~up to~~ greater than 1 MC are possible c̄ this arrangement. ~~A pos~~ ___ milliamps at 2.7 volts will produce ___ volts ~~og~~ across a ~~the~~ tank coil. ~~using~~ this oscillator is by far the largest power drain in the transmitter & will ~~allow~~ ~~dete~~ largely determine the requirements.

Consumptions of mW. are practical which allows a size of for Hg cells - ~~To demonstrate the~~ for days - To demonstrate the practicality of long ~~unattended~~ battery life a two year design based on the foregoing principals was supplied to ~~the [illegible]~~ a hospital which ~~has~~ routinely uses EKG in all surgical cases. ~~+ the +~~ This design has ~~[illegible]~~ been in use since ̄c the batteries, ~~simply change~~ two Mallory , ~~changed once every 3 months but otherwise left~~ simply installed + left on ~~[illegible]~~ ̄c a routine change every three months before end point -

Receiver - This should be a relatively straight forward design ̄c ~~good so~~ excellent AGC response & sensitivity for the signal levels are small & variable if maximum transmitter economy is to be effected - ~~Again~~ It should of course be crystal controlled & ~~[illegible]~~ size + power kept to a minimum to also allow telemetered monitoring in the capsules used for exit + re-entry -

Auxillary display equipment. With the possible exception of monitoring during unusual activity, EVA for example, or ~~for~~ during experiments it is hard to justify ~~display devices~~ monitoring devices more complex than a headphone jack at the receiver subcarrier level or if a QRS detector for rate ~~systems~~ is used a light which flashes c̄ every detected Q.R.S. Again the entire system must be made as ~~straight~~ simple to operate as say the voice communication system.

check - tissue &
Adhesives
Day