MAGNETO-INDUCTIVE SKIN SENSOR FOR ROBOT COLLISION AVOIDANCE

(A NEW DEVELOPMENT)

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ANNUAL REPORT

CONTRACT
NAG 5 1053

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(NASA-CR-185402) MAGNETO-INDUCTIVE SKIN SENSOR FOR ROBOT COLLISION AVOIDANCE: A NEW DEVELOPMENT Annual Report (North Carolina Univ.) 12 p CSCL 14B
N89-25444
Unclas
G3/35 0217716

A New Development To Magneto-Inductive Skin Sensor For Robot collision Avoidance

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ABSTRACT

Safety is a primary concern for robots operating in space. The tri-mode sensor, being developed in-house at the NASA/Goddard Space Flight Center, addresses that concern by employing a collision avoidance/management skin around the robot arms. This RF-based skin sensor is at present dual mode (proximity and tactile). The third mode, pyroelectric, will complement the other two. The proximity mode permits the robot to sense an intruding object (including a human being), to range the object (in time to permit the robot to react) and to detect the edges of the object (with sufficient directionality and resolution to permit the robot to go around it). The tactile mode permits the robot to sense when it has contacted an object, where on the arm it has made contact and provides a three dimensional image of the shape of the contact impression. The pyroelectric mode will be added to the skin to permit the robot arms to detect the proximity of a hot object and to add sensing redundancy to the other two modes. This will be accomplished by adding a layer of pyroelectric material over the RF-based sensor which will "see through it". The sensing system will perform despite sun glint, temperature extremes and vacuum (conditions which predominate in space). Its RF field is sufficiently weak and low frequency that it will not disturb other instruments. And, since the RF field is sinusoidal, unfriendly EMI noise can be filtered out. Magnetic objects are easily identified. The sensing system would have difficulty detecting objects that are totally non-conducting and with a dielectric constant of one; but it is extremely unlikely such materials would exist in isolation on the Space Station or a space vehicle.

In this report the RF-modes of the sensing skin are presented. These modes employ a highly efficient magnetic material (amorphous metal) in a novel sensing technique. This results in a flexible sensor array which uses a primarily inductive configuration to permit both capacitive and magnetoinductive sensing of objects; thus optimizing performance in both the proximity and tactile modes with the same sensing skin. The fundamental operating principles, design particulars and theoretical models are provided to aid in the description and understanding of this sensor. Test results are also given.

I. INTRODUCTION

The objective is to develop a sensing skin that will prevent the robot arms from colliding with objects in space; particularly human beings. It is essential that this sensing system be able to function reliably in the extreme environment of space and that it not be disturbed by or create disturbances in neighboring NASA instruments. To date, this has been a vexing problem for NASA engineers. Our evidence indicates that an approach based on an array of low rf capacitors is promising. This approach will satisfy both the proximity and the tactile modes. A thin sheet of polyvinylidine fluoride (PVDF) will be added later to provide a temperature sinsing capability and complete the third mode.

II FUNCTIONAL REQUIREMENTS

At this point the functional requirements are general and address proving the suitability of the sensing principle for space use as a robot collision-avoidance sensor rather than worrying the details (such as out-gassing materials etc.). These are as follows:

1. The sensor should be able to detect a human at ranges of 12 in. (30.5 cm) to give the robot sufficient notice to stop.
2. The sensor should be able to detect the near-range of an object sufficient to avoid collisions and to find the object edges.
3. The sensor should be able to detect the edges of an object in the near-range sufficient to avoid robot collisions.
4. The sensor should be able to detect contact and where and how hard the contact is.
5. The sensor should be able to detect the presence, direction and temperature of hot objects.
6. The sensor should not interfere with other instruments nor permit itself to be interferred with.

III PRINCIPLES OF OPERATION

The general function of the robot skin is illustrated in fig. 1. A constant voltage source drives current through a resonant tank circuit in series with a resistor. The frequency of the signal is near resonance and is optimized for sensor sensitivity. The individual columns and rows of the array are mouned on the robot arm. These are individually and sequentially connected to the circuit, through a demultiplexer arrangement, at a point between the tank circuit and the resistor. The tank circuit and the resistor form a voltage divider with the sensor array poised between the two. The sensing element (column or row) of the sensor array is essentially a capacitive place at the potential of the circuit. When an object comes near the sensing plate(s), a leakage capacitive coupling to ground is formed, the balance of the voltage drivider is disturbed, and we observe this disturbance and intepret it as proximity sensing. Since we can individually scan rows and columns, we can locate the edges of the object and range it so provided it is either a conductor or dielectric. If the object touches a sensing element, the capacitive plate is pushed nearer the grounded robot arm and we observe a change in the potential on the thin conductor near the robot arm. We interpret this change as tactile sensing. Fig.2 shows the physical characteristics of the sensory array. Fig.3 shows the development of the equivalent circuit.

IV MODELLING

An electromagnetic sensor array located over an imperfectly conducting space can be modelled using the Dodd and Deeds theory1 and low frequency quasi-static theory. The quasi-static principle is applicable when the frequency is low and the driving signal is small. The voltage drop across the drive coil behaves as a charge conductor and current behaves in the similarity of drive signal. The a.c. characteristics of circuit is unperturbed but coupling characteristic only get changed - in proximity. Proximity of drive soil behaves quasi-static due to electrostatic flux present in the surroundings. The extension of quasi-static bus is also possible. The voltage occupies the extended surface and completely behaves as a changed surface. This peculiar quasi-static characteristic is used for skin sensor. Copper strips of 1" width are placed and glued horizontally and vertically in order to build array. Fig. photo of skin. Electro-static potential is brought to this array and coupling is experienced on resonant circuit. Movement of objects including human body is seen upto 1-2 feet range. It has directionality in coupling activity. The column or row in front of an object show more variation in output therefore array can be built ot and can be intefaced to a multiplexer for its data separation and position sensing of an object. The array and coil connections are shows in fig. 2. The mathematical expressions of electrical cuicuits are derived for both quasi-static and non-static behavior are presented in first semi-annual report.

V EXPERIMENTATION/CONCLUSIONS

The sensor was originally envisioned as an eddy current sensor with magnetoinductive coils mounted on the robot arm (see Fig. 4). Proximity sensing performace was both better and different than was expected. Experimentation revealed that it did sense inductively (using eddy currents from conductors and/or magnetic flux from ferromagnetic materials); but the dominant effect was quasistatic/capacitive. There was no evidence of sensing due to an antenna or radiation effect and this was to be expected considering the long wave length of the rf signal. A series of experiments was conducted over a period of several weeks to

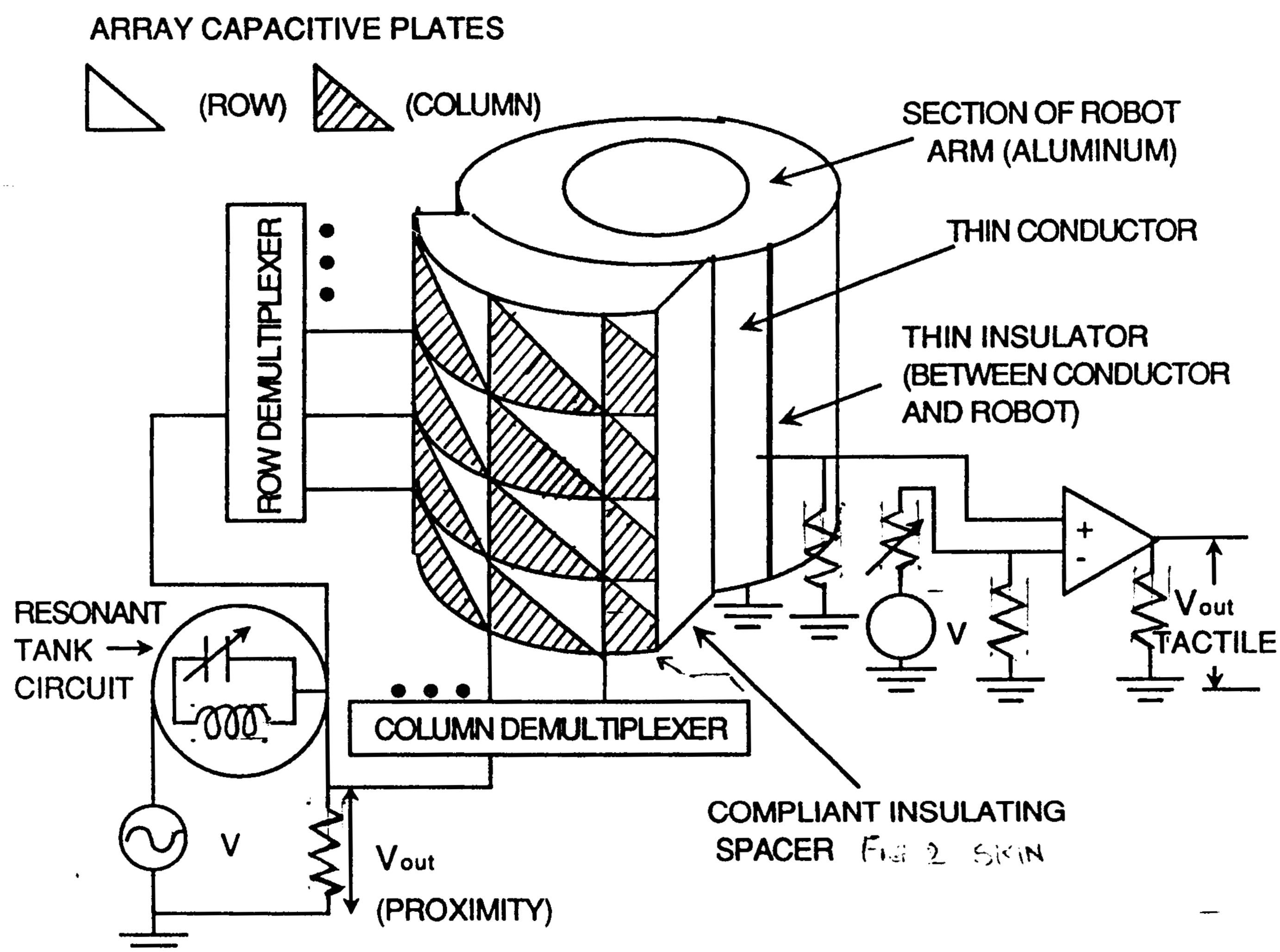


FIGURE 1. SENSOR CONCEPT (PROXIMITY/TACTILE)

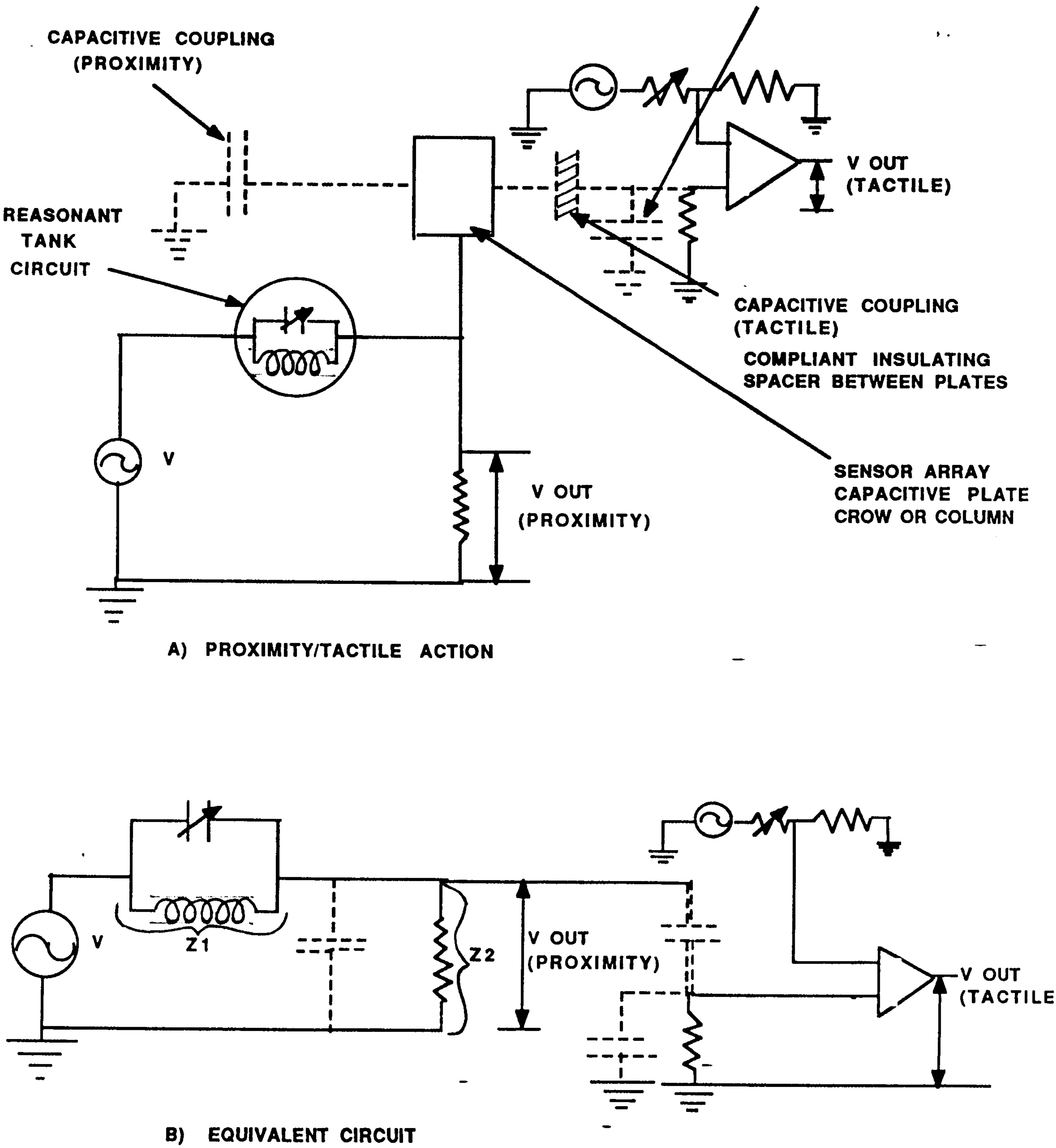


FIGURE 3. DEVELOPMENT OF EQUIVALENT CIRCUIT

NO = FIGURE 2

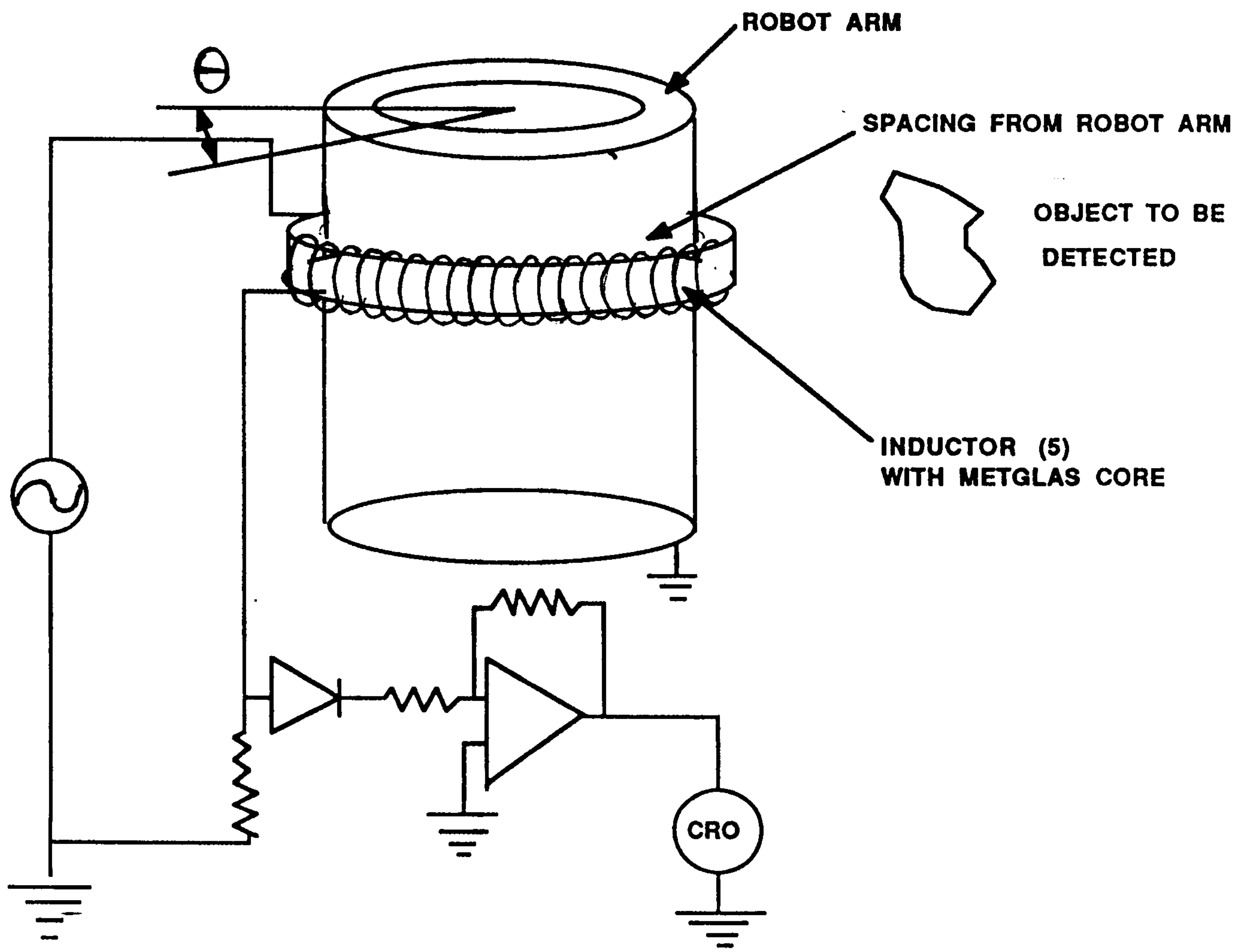
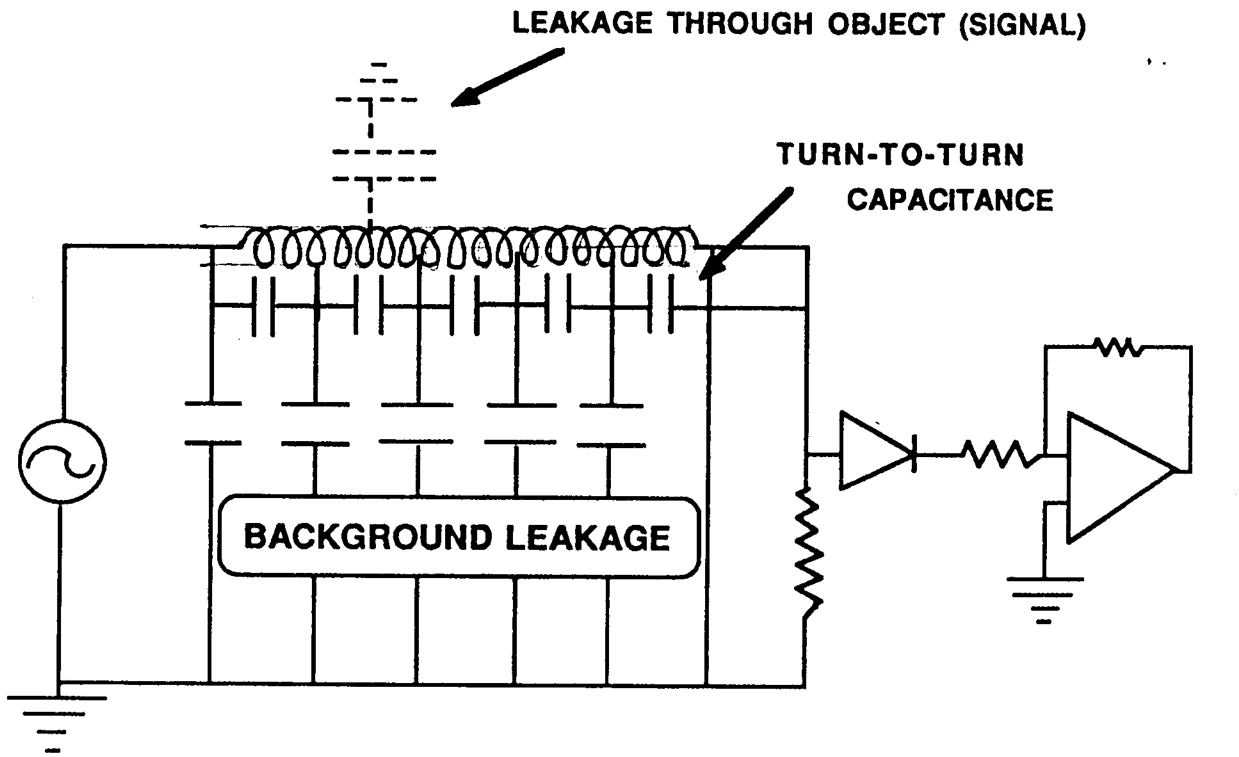
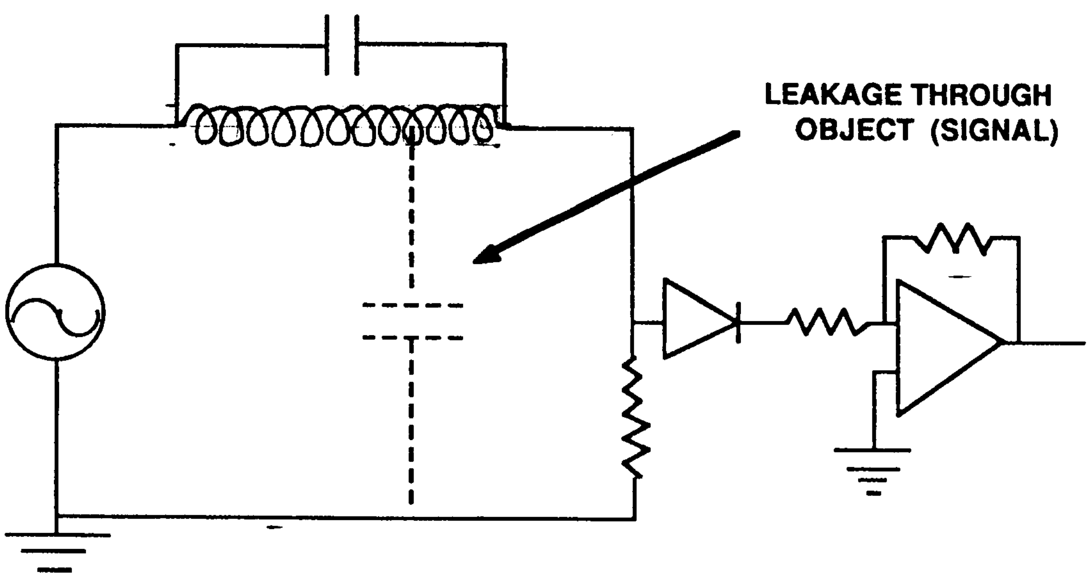


FIGURE 4. EXPERIMENTAL SETUP



A. DISTRIBUTED COMPONENTS



B. LUMPED COMPONENTS

FIGURE 5. EQUIVALENT CIRCUIT OF EXPERIMENT

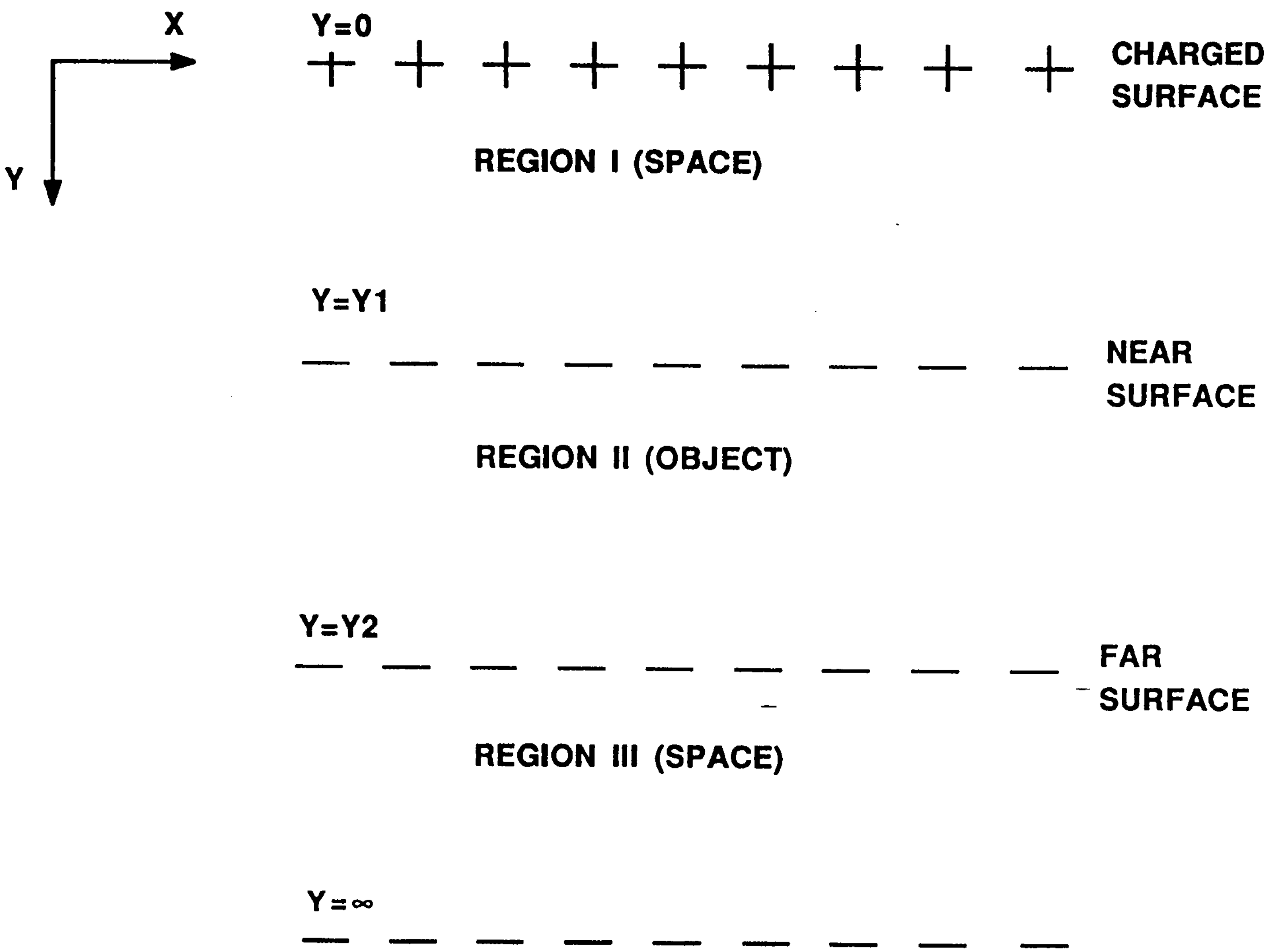


FIGURE 6. PROXIMITY SENSING

arrive at the conclusions described above. However, it is felt that the results of the single set of experiments described below gives a good summation of the phenomenon which makes the sensor work and its potential capabilities.

An experimentor stood out of the range of the sensor and then moved his hand nearer for one set of measurements. The experimentor was isolated from gound. For the second set of measurements, a small, gounded, conducting cylinder was moved near the sensor and for the third set of measurements, the small cylinder was ungrounded. Table 1, below, shows uncalibrated measurements. They were measured using distances off a meter stick and estimated readings off a CRO. These were sufficient at the time to establish the dominant sensing phenomenon and to get an estimate of its performance potential. Some initial conclusions are as follows: 1. The sensor can detect a human at ranges in excess of 12 in (30.5 cm). Thus it can detect an object which is a poor conductor; but has a high dielectric constant (81) and is a large charge source. Clearly the sensor has potential as a safety device for humans in space and clearly its means of sensing is capacitive; not inductive. 2. The sensor detects grounded small cylinders much better than ungrounded; but the capacitive effect is. Therefore we can again see that the capacitive effect is dominant; particularly at long ranges. And, we can see that a relatively small diameter conductor, if grounded, or connectyed to a large charge source can easily be detected at relatively long ranges. This also shows the sensor's potential as a safety device in space. Measurements taken approaching the coil 1.5 in (3.8 cm0 above its centerline show the readings dropping off considerably at short ranges so we can see the systems' potential as a near-range edge detector. Variations in the azimuth field results which are similar to those given at zero azimuthal angle.

Closer examination of the experimental setup shown in fig.4 indicated we received our best performance at 80 Khz and this turned out to be near a high "Q" resonance. We were dealing with a tuned circuit and not merely an inductor. The equivalent circuit, therefore, is as shown in fig. 5 and the measurements and mathematics supports this interpretation. Why not, then, take the coil off the robot arm, and create the same effect using a remote tuned circuit with capacitive plates on the arm? This reconfiguration was tried and it worked. The equivalent circuit developed in fig.3 and the capacitive plates on the arm shown in fig.2. reflect this conclusion. We are now experimenting with eliminating the metglas coil and replacing it with some off-the shelf very high "Q" oscillators operating near resonance, and stabilizing them with phase-locked loops, where appropriate. Variable frequency oscillators will also be employed, a beat signal will be developed and the frequency of this beat signal will contain the necessary detection information. This should improve many performance parameters of the sensor range, sensitivity, stability, and resistance to effects of external noise.

Tactile sensing has always worked exceedingly well and has required very little development. Essentially, pressing on a capacitive plate pushes it closer to the grounded robot arm and this is detected immediately.

Table f = 80 KHz. Azimuth = 0^{o}

Elevation above coil centerline = 0 in, 0 cm.

Distance from coil to object		OBJECT		
in	cm	Ungrounded Human	Grounded Al cylinder 2.75 in dia.x 4.5 in long	Ungrounded Al cylinder 2.7 in dia. x 4.5 in long
1	2.5	1.9 v	0.52 v	0.39 v
2	5	360 mv	250 mv	60 mv
3	8	150 mv	110 mv	40 mv
6	15	17.5 mv	17.5 mv (est)	2.5 mv
9	23	7.1 mv	7.5 mv	----
12	31	4.4 mv	5 mv	-----
18	46	8.0 mv	------	-----

VI. FUTURE PLANS

We next plan to put a sample of the skin on a PUMA 560 arm and demonstrate its detection capability (proximity and tactile). Following this the heat detecting film, Polyvinylidine-Flouride (PVDF), will be placed outside of the rf dual mode system and the capacitive effect will perform as if the PVDF will complete the tri-mode sensor hardware. The software and detection and collision avoidance algorithms will represent, however, on a new phase in the development and this will be an extensive one.

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