Soil Erosion Prevention by Sustainable Phytoremediation Process using Solar Irrigation and Fertilization System

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Abstract-Soil and land degradation is considered for slope land such as riverbank or streambank and lands of high forced water runoff and rainfall causes severe soil erosion is the concern of this work. The major cause of runaway unprotected soil particles due to the natural reasons, thus making uneven soil plain surface scan be remedied by tree plantation or vegetation. A precision mirror-amplifier is designed for primarily sensing soil moisture and pH level to provide eventual environmental conditions needed for irrigation and fertilization for plants to grow healthy, which in turn reduces the soil erosion. Another special sensor designed and employed here that can monitor the degradation due to erosion and the system can determine the soil's critical limits. To design the system in an IC form, VLSI design MAGIC CAD tool is used to complete. Results from PSPICE has confirmed the proper performance of the IC and proved to be very applicable in the environment controlling systems. In this paper, design methods and results are presented for a sustainable cultivation technology to prevent soil erosion at slope land.

Index Terms- Land Degradation; Soil Erosion; Soil Moisture; Irrigation; pH Level; Slope Land; Mirror-Amplifier; VLSI.

I. INTRODUCTION

Land degradation is typically a more significant problem in areas with fragile ecosystems (deserts, semi-arid, volcanic islands, rainforests, etc.) and in places with heavy population loads where people are forced to over-use the same land with no alternatives. Degraded lands are also associated with areas where the land is the main resource for everything: human food, animal food, building materials, fuel, income generation, etc. These pressures create constant withdrawals that, if not reversed, lead to exhaustion of the land resource. Land degradation can be defined as reduction or loss of the biological or economic productivity of soil [1-3]. Among the several environmental damages caused by land degradation like (i) deforestation, (ii) erosion, (iii) loss of topsoil, (iv) siltation of streams and rivers, (v) reduced water infiltration, (vi) gradual drop in water table; this work is more concerned about erosion caused by wind and/or water. Figure 1 represents an impact caused by soil erosion.

1) Soil Erosion, Causes and Impacts

Erosion is the removal of soil particles from a site due to the forces of water, wind, and ice. Over time, these forces will slowly wear away or disintegrate the soil. Basically, erosion can be classified into two major types: (i) geological erosion, and (ii) man-made erosion. Geological erosion, which includes soil-forming as well as soil-removing, has contributed to the formation of soils and their distribution on the surface of the earth.

Figure 1. Showing the devastating impact of soil erosion reaching a life-threatening cataclysm.

Flowing water and wind is the most common causes of erosion, and it may occur in several ways. Erosion of streams in agricultural areas normally occurs as a result of one of three factors: (i) change in stream flow, (ii) water flowing over or through the streambank, and (iii) the discharge of concentrated runoff from other sources. As flow depths and velocities increase, the force of the water flowing against the streambank removes soil particles from the banks, and in many cases erosion causes banks to slump and fall into the flowing water. In extreme situations where high flows persist over long periods, banks may erode several feet annually. Rain falling on streambanks or runoff from adjacent fields that enters a stream by flowing over the streambanks can also erode soil from streambanks, particularly if banks are inadequately protected. Finally, water discharged into a stream from tributary drainage systems (such as waterways or tile lines) can also erode streambanks, particularly if the water is discharged in an area where the bank is unstable and highly erodible[4].Table 1 represents the factors that affect soil erosion by water [5]. Figure 2 and 3 are also representing the factors that influence the erosion[6].

Table 1. Factors that affects soil erosion by water.

Rainfall pattern	The more rainfall and the higher the "force" of the rain (called the intensity, i.e. the amount of rain which falls per minute), the more erosion will occur.
Slope steepness	The steeper the field, the higher the erosion risk.
Slope length	Erosion increases with slope length.
Soil type	Clayey soils show in general more resistance to erosion than sandy soils.
Erosion control structures	Well established and well maintained erosion control structures can be very effective. But when such structures are poorly established or poorly maintained it is possible that they accelerate erosion.
Cropping practices	Varying cropping practices have different effects on soil erosion.
Ground cover	The greater the groundcover the greater protection of the soil surface from the impact of rainfall.
Time	Soil erosion (as well as soil development) is a function of time.

So in a brief what contributes to erosion can be listed as: (i) removing vegetation, (ii) removing topsoil and organic matter, (iii) shaping the lay of the land, (iv) exposing subsoil to precipitation, (v) failure to cover bare soil areas, (vi) allowing gullies to form and grow larger, (vii) removing vegetation along stream banks [6].

Figure 2. Heavy rainfall, steep slopes, removal of most existing vegetation, and erodible soils result in higher soil losses from erosion. Source: Kentucky Erosion Prevention and Sediment Control Field Guide, U.S. Environmental Protection Agency (USEPA), 1987.

Figure 3. Lower rainfall amounts, flatter slopes, preserving existing vegetation, and less erodible soils result in lower soil losses from erosion. Source: same as figure 2.

As the overall effects of erosion are felt on farm by the loss of soil productivity as well as off farm when soil sediments enter the water system causing siltation and eventual flooding of lowlands. In term of on farm effects, the relationship between soil erosion and agricultural productivity relate to the altering of soils properties. Erosion can decrease rooting depth, soil fertility, organic matter in the soil and plant-available water reserves [7]. Thus, the exposed soil remaining will be less productive in a physical sense. These effects may be cumulative and not observed for a long period of time. Erosion may also affect yields by influencing not only the soil's properties but also the micro-climate, as well as the interaction between these two [7]. In contrast to natural erosion which happens slowly, human-induced erosion can happen fast with large amounts of soil being removed. If this happens, it can be a serious threat to agricultural production and the environment [8].

2) Soil Erosion, Causes and Impacts

Riverbank or streambank erosion protection can be done in several ways: (i) vegetation, (ii) windrows and trenches, (iii) sacks and blocks, (iv) gabions and mattresses, (v) articulated concrete mattresses, (vi) soil-cement, (vii) retaining walls. Besides that many other ways are possible to protect erosion. Among these ways, this work is concerned about vegetation, because it is the least expensive of riverbank protection measures, improves habitat, and aesthetically pleasing.

The vegetation process involves the deliberate planting of trees, shrubs, grasses etc., or retention of areas of natural vegetation (e.g. reforestation, contour hedgerows, natural vegetative strips) which: involve the use of perennial grasses/pasture legumes, shrubs or trees; are of long duration; often lead to a change in slope profile; are often zoned on the contour or at right angles to wind direction; are often spaced according to slope [8]. Figure 4 represents a typical vegetation process on slope land to protect from soil erosion process.

Figure 4. Slope land vegetation to protect soil erosion.

This work is more interested in vegetation process with a plant, locally known as Money Plant (in Figure 5). Scientific name of money plant is Epipremnum aureum which is a species of flowering plant in the family Araceae. Its native range extends from Northern Australia through Malaysia and Indochina into China, Japan and India. This is a root critter plant and often used in decorative displays in shopping centers, offices, and other public locations largely because it requires little care to grow; and this is the main reason of choosing it because it takes little care but with proper care it can grow vastly on long slope land to protect erosion.

Figure 5. Money Plants (Epipremnum aureum), an invasive root critter plant and also theygrow on ground soil has been proven for excellent protection against soil erosion.

II. Methods, Applications, Design and Materials

Keeping the soil covered with plant residues is the key to increasing soil organic matter and ultimately restoring degraded soils to the point that they can sustain crop production [1-3].

1)Erosion Control by Sustainable Irrigation

There is no doubt that plants can help slow down erosion. However, the soil on a steep slope is often missing nutrients for plants to grow. Water is also an issue on steep slopes because it moves downhill very quickly and does not soak into the soil. This makes it harder for plants to grow there. Keeping this in concern many technologies have been innovated to protect soil from erosion, and most of the technologies are pointed to the following 3 (three) goals. (i) Keeping the soil covered: bare soil is easily eroded by rainfall, especially on steeply sloped land. Mulching and the rotational/sequential planting of cover crops reduce soil erosion. Keeping the soil covered also shields it from harsh sunlight, moderating temperatures and thereby allowing soil organisms to thrive. (ii) Maximizing rain water efficiency/infiltration: rainwater harvesting strategies increase the percentage of rain water that percolates down into the soil, minimizing the amount of water lost to surface runoff. There are many techniques used separately or in combination to get this goal. Some of them include terracing, planting perennials along contours, and micro-catchments. (iii) Building soil and water conservation structures: these are physical barriers that prevent soil erosion on sloping land, protecting the soil resources of a farm or cropland. They can also be designed to capture water or increase infiltration, thereby lessening the negative impact of water on soil as well as increasing the availability of water for agricultural or other uses. While structures may have significant up-front cost associated with them, they can have immediate positive impact. They can be useful in stabilizing a severely damaged area, allowing subsequent erosion control strategies involving vegetation to succeed [1-3]. Figure 6depits a slope land vegetation process using Live Staking/Brush Mattress method [9].

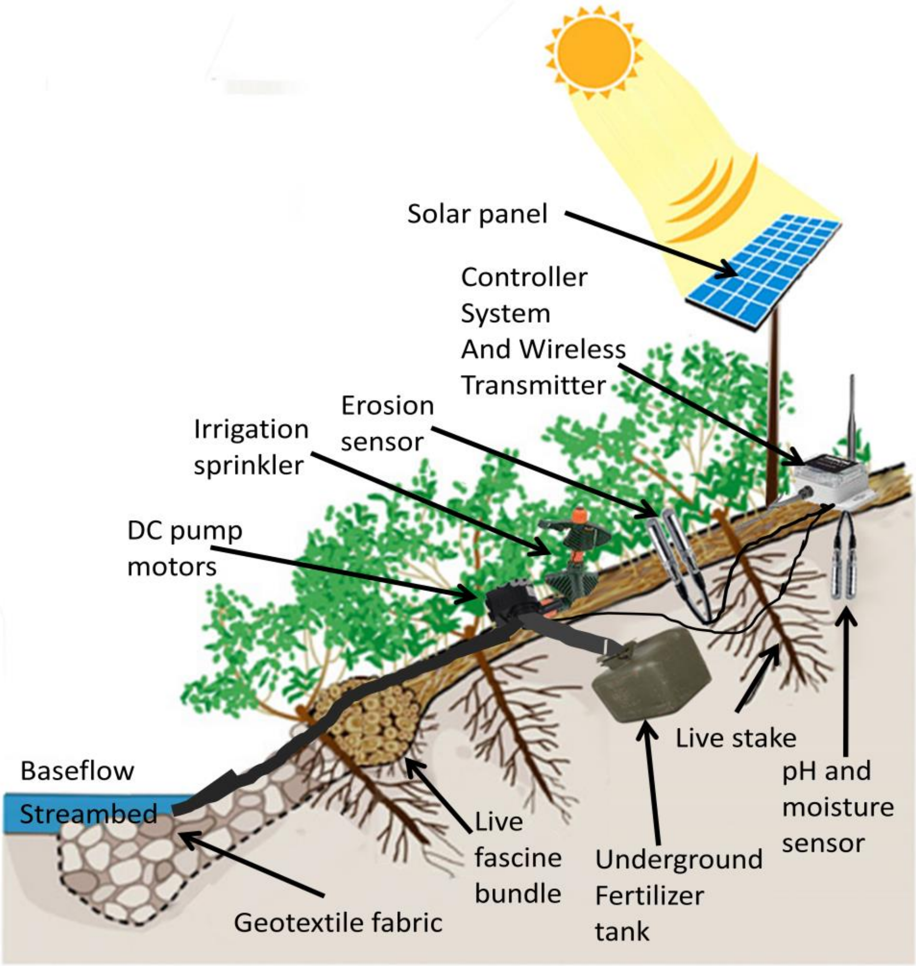

Figure 6. Illustration of an advanced system approach to slope land vegetation for preventing serious soil erosion. Source modified: Stream Corridor Restoration: Principles, Processes, and Practices 10/98 by FISRWG.

Soil and water conservation technology is developed from an understanding of the components of the Universal Soil-Loss Equation [10].The Universal soil loss equation is the most widely used method of predicting soil loss on sloping lands. This equation is given by the expression:

$$E = R.K.L.S.C.P$$

Where: E is mean annual soil loss (T/AC/YR), R is the rainfall erosivity index, K is the soil erodibility index, LS are the factors of slope length (L) and slope steepness (S) and are combined in a single index, C is the crop factor/nature of plant cover, P is the conservation practice factor used to manipulate the LS factor. If any of the factors listed above could be reduced to zero then soil loss and erosion will be reduced to zero. These factors are managed by soil management practices which decrease the effect of the impact of soil movement [8].

Keeping the other factors constant in the Universal Soil-Loss Equation, if C (crop factor) is reduced by increasing the vegetation with minimum crop stage, then E (mean annual soil loss) or erosion can be comparatively reduced.

Concluding here that this also indicates that all these factors are easily determined based on the land under consideration for particular land. Famers can easily find the best outcome of crops using the equation found from their experiments in a couple of seasons.

2) Application Based Design of Control System

This research works have been conducting to design an ultra low power IC which can sense several environmental conditions to provide eventual growth environments for the slope land vegetation process. According to this research the designed IC can be applied in controlling environments by setting two threshold windows: soil moisture threshold, pH threshold. And each threshold window will have three threshold levels: below threshold level, normal threshold level, and above threshold level. Depending on the threshold level the sensor circuit will make decision for the appropriate operations whether the irrigation and/or fertilization is needed.

The Figure 7 represents the block diagram of the system with the designed chip depicting the dashed block as a single chip where Fertilizer Control Module, pH Detection Module, and Irrigation Control Module is basically made of the mirror-amplifier circuit, which can also be called precision sensor. The external erosion detection module is feed to the Fertilizer Control Module.

The Motor Direction Control & Driver is basically an H-bridge made of very large size transistor, which drives the Fertilizer Pump Motor and leaves an opportunity to add a bi-rotational motor if needed. Irrigation Control Driver is also made of a large transistor to drive the Irrigation Motor. External Logic Control Unit is to be designed based on the electric parameters of a particular field with a particular necessity.

This concept is come up from the idea of optimal controlling of environmental conditions for any kind of plant growth, but precisely this research is being inspired on irrigation and fertilizer modules that are being found to be necessary for the vegetation process with Money Plant. But if the choice of plant gets changed based on the location of the riverbank or streambank, then additional modules can be used with the necessity.

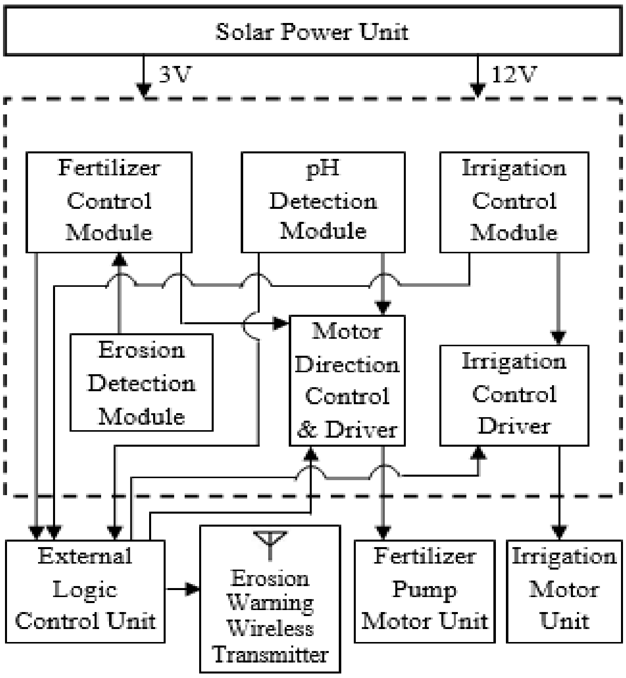

Figure 7. Block diagram of the system with the designed IC.

Construction of the precision sensor mirror-amplifier circuit (in Figure 8) consists of two differential amplifiers creating mirror architecture as input stage and a NAND gate between them as output stage.

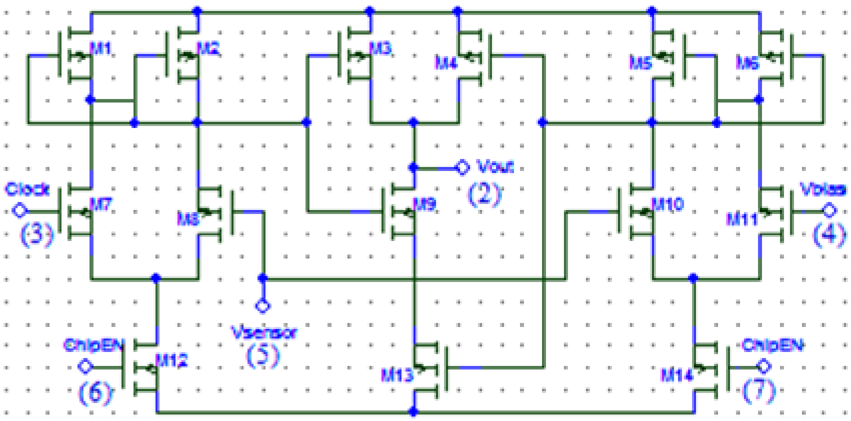

Figure 8. PSPICE schematic of the mirror-amplifier circuit for sensor.

The circuit contains total of 14 MOS transistors in which 6 of them are p-MOS (M1-M6), and rest 8 are n-MOS (M7-M14). The operation of the circuit is done by total of five input terminals; V_{sensor}, V_{bias} (or $E_{sensor1}$, Clock, and two ChipEN, and an output terminal V_{out}. The circuit is powered by ripple-free DC power of 3V from a solar power unit. In Figure 9 the Motor Direction Control & Driver is made of an H-bridge and an inverter coupled to its two inputs A and A-bar, those are built of very big size n-

MOS and p-MOS transistors to control and drive the fertilizer pump motor connected to the Fertilizer Tank underneath the field shown in Figure 6. The Irrigation Control Driver is made simply of an n-MOS transistor to drive a water pump. The justifications of these drivers are discussed in VLSI design and results sections. These two modules are power by ripple-free DC power of 12V from the solar power unit. Figure 9 shows the schematic diagram of an H-bridge.

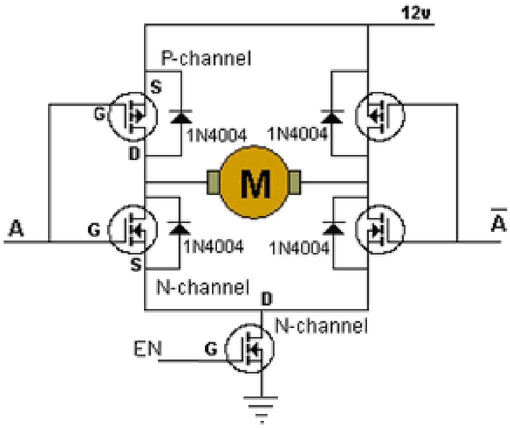

Figure 9. Schematic of the dynamic H-bridge circuit to control the directional operations of the bi-rotational DC motor.

3) VLSI Design of the IC

To have maintenance-free sustainable plants for many years, especially growing on the sloped land requires electronics with sensors that can perform complex decision making Logical Processes(mixed-signals) accurately. The system must maintain the programmed outcome, so plants on the field can stay healthy every season. This also requires carefully selecting the type of plants. For farming vegetations, it requires extra attention and reprogramming the system based on the type of plants grown, suitable for every season. An IC design is essential that implements the logical functions to determine the exact operations that can offer the sustainable health of plants and thus this phytoremediation process prevents erosion.

To design the system IC, based on precision sensor mirror-amplifier circuit and other modules in VLSI, MAGIC 7.5 is used with the process configuration of 0.5µm (SCN3M_SUBM.30). The circuit layout of the mirror-amplifier (in Fig.10) on silicon bar has area of 101λX48λ or 30.3µmX15µm using lambda=0.3µm CMOS design techniques, which is connected to the pin of 3V power supply. Lengths of all MOS transistors are same that is 2λ. For the input stage the ratio of p-MOS to n-MOS widths is 6:3 and for the input stage the ratio of p-MOS to n-MOS widths is 12:6. Three of the amplifiers placed in the IC with logical circuit configuration can control four modular functions previously shown in figure 7.

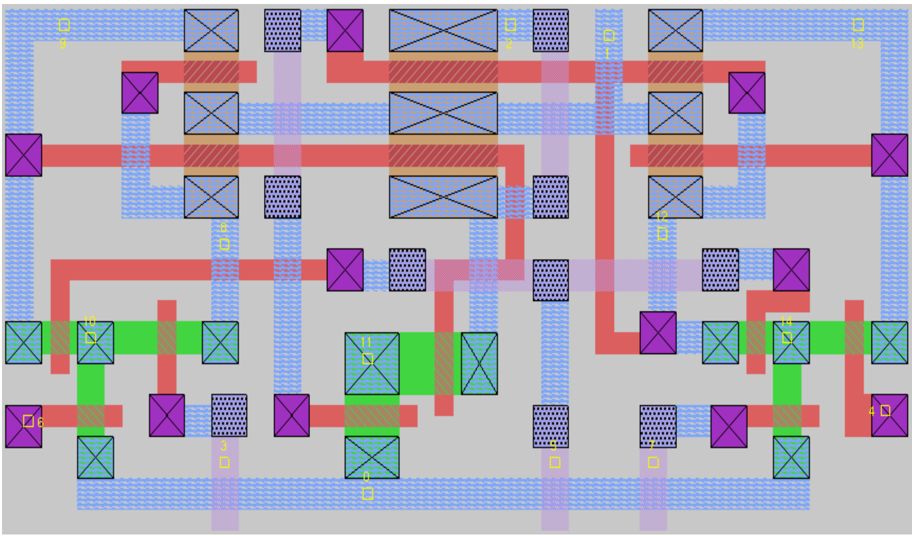

Figure 10. Physical layout for one of the mixed-signal mirror-amplifier in IC.

The circuit layout of the Motor Direction Control & Driver module (in Figure 11) has the area of 102λX220λ or 31.6µmX66µm on the silicon bar, which is connected to the pin of 12V power supply. Length of all MOS power transistors is the same i.e. 2λ and the ratio of p-MOS to n-MOS widths is 200:100 so that the module can drain enough high current to drive a motor.

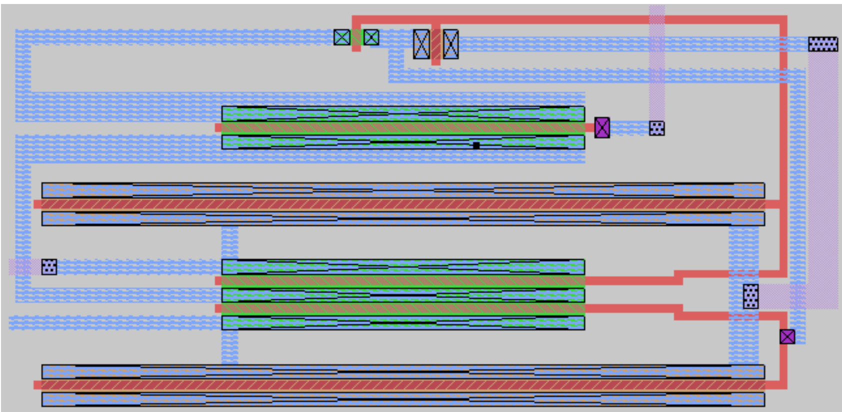

Figure 11. CMOS dynamic motor direction control driver is comprised of an H-bridge (lower) and an inverter (upper).

The complete IC is designed with a pad frame of 32 pads (in Figure 12). Total area of the chip layout including pads is 990λX1014λ or 297µmX304.2µm. Also the packaging of the chip is shown in Figure 13 with a 32-pin open cavity plastic package served by MOSIS, which has cavity area of 3.3mmX3.3mm. The pin configuration of the IC is given in Table 2, and specification of the package is given in Table 3. Three of the

Table 2. Pin configuration of the designed IC.

Modules	Circuits	Pin Name	Pin #
Fertilizer Control Module	Mirror- amplifier	Vdd (3V) GND EN1 EN2 Clock $E_{sensor1}$ $V_{sensor2}$ V_{out}	31 30 1 4 2 5 3 12; to driver's i/p A
pH level Detection Module	Mirror- amplifier	Vdd (3V) GND EN1 EN2 Clock B_{bias} V_{sensor} V_{out}	31 30 28 25 29 26 24 27
Irrigation Control Module	Mirror- amplifier	Vdd (3V) GND EN1 EN2 Clock B_{bias} V_{sensor} V_{out}	31 30 19 22 20 23 21 to driver's i/p
Motor Direction Control & Driver	H-bridge with an Inverter coupled	Vdd (12V) GND A A-bar Motor i/p #1 Motor i/p #2 EN	32, 17 30 12 13 14 15 18
Irrigation Control Driver	n-MOS	Vdd (12V) V_{out}	32, 17 16

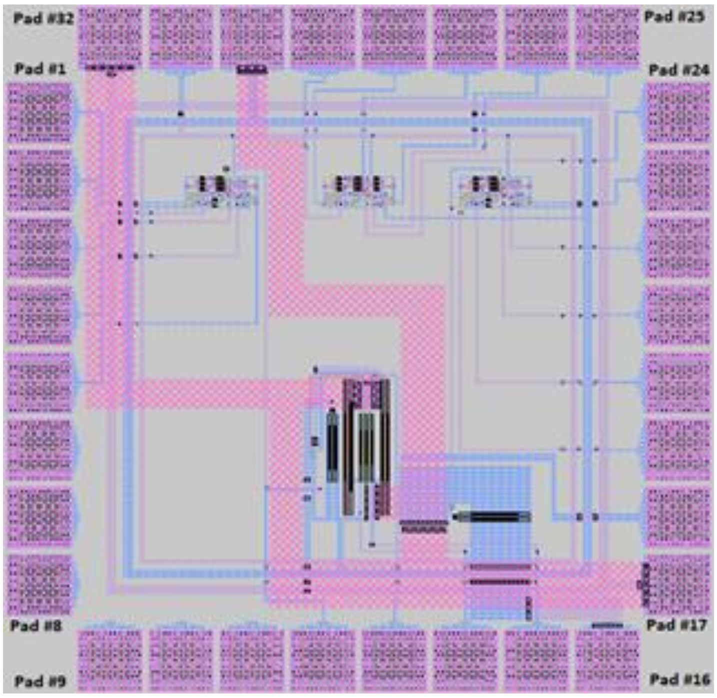

Figure 12. The complete IC layout comprised of four controlling segments and two driver segments with 32 pads.

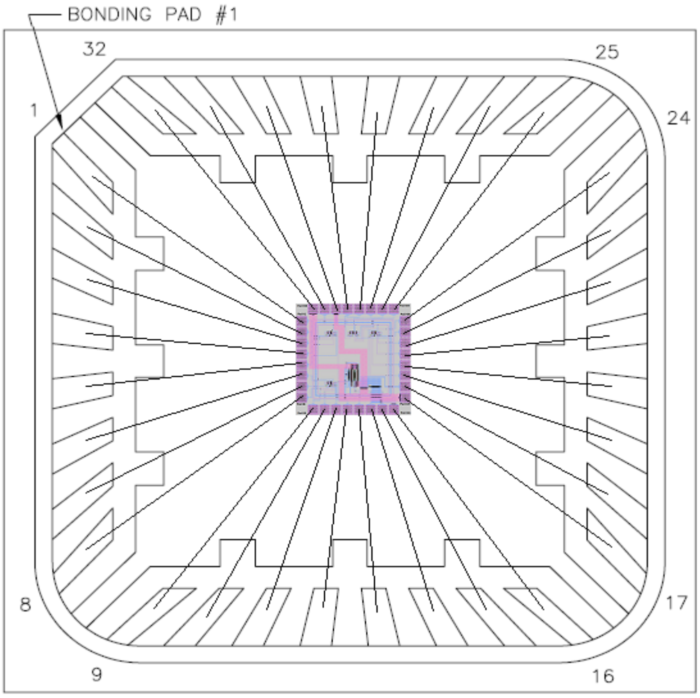

Figure 13. Bonding diagram of the chip in SEMPAC package.

Table3. Specifications of the chosen IC package.

Package part number	OCP_QFN_5X5_32A
Package manufacturer	SEMPAC
Package size	5mmX5mmX0.8mm
Die placement cavity	3.3mmX3.3mm
Pins	32

III. Results and Discussion

Figure 14 represents the result of the designed precision sensor circuit using MAGIC extraction tool and PSPICE, which is done in two steps. In the 1st step, Output is taken with respect to node 4 (V_{bias}) with 0.4V DC (below threshold) supply at node 5 (V_{sensor}) and 0V to 1.5V clock pulse at node 3 (Clock). In this case output toggles and get steady at 1.4V giving a power dissipation of 1.66 milliwatts. It is found that Hysteresis at threshold voltage level causes dynamic power loss [11]. This design has flexibility of voltages to bias CMOS circuitry. So the pin configuration is changed to get desired response. In the 2nd step, output is taken with respect to node 5 (V_{sensor}) with 1.4V DC supply at node 4 (V_{bias}) that is got in the 1st step. Clock pulse is still 0V to 1.5V. In this case output toggles and get steady at 0.18V. Power dissipation is found to be 4.39 nanowatts in this case. Thus the system is improved for our desired operation with nano-power dissipation.

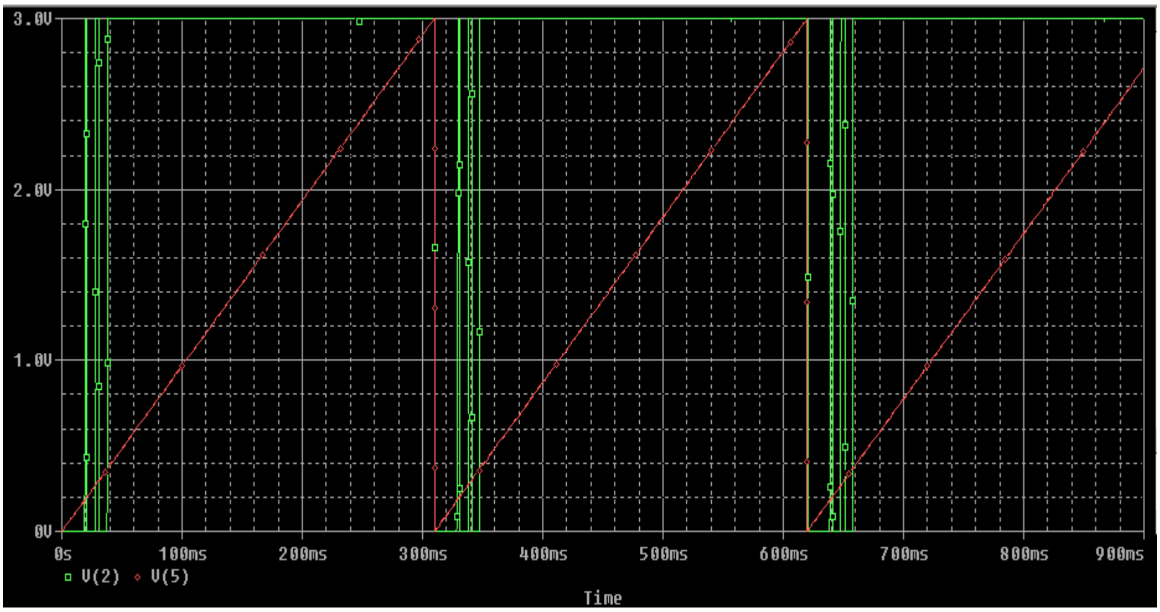

Figure 14. Plot of the PSPICE results of the VLSI sensor circuit in the IC

Now V_{bias} can be set depending on the moisture level conditions of the slope land. The V_{sensor} senses moisture levels accurately, all the time for the IC to activate water hoses to increase moisture level of the field as necessary. Similarly, V_{bias} can be set for sunlight conditions for each type of betel plants based on light conditions in a particular field. Sunlight shutters are controlled by sensor signal to V_{sensor} of the chip. As a result, the system applies power to electric motor to control shutter position. Thus the perfect sun lighting condition is created for the field throughout the year. Figure 15 shows the setup test result of the CMOS based H-bridge.

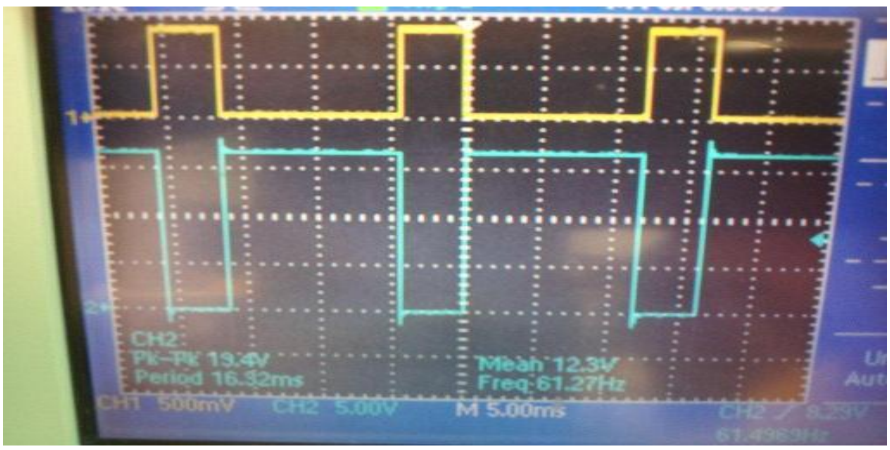

Figure 15. Voltage across the motor shown in blue and the control signal is shown in yellow.

Figure16 shows the experimental setup of the moisture sensor. The designed chip can be attached to a soil moisture and pH probes (in Figure 17) which is placed in the root zone of the slope land vegetation field allows it to be watered enough to get the moisture and pH level detected with very high precision level by electrically controlled water valves and hoses. Soil moisture and pH probes will pass electrical signals corresponding to the moisture and pH level; as a result when moisture level and/or pH level gets below the set threshold window, the chip generates logic HIGH signal and passes it through the drivers to drive the corresponding pumps for opening the electrical valves. The chip keeps turning on the electrically operated valves of watering and fertilizing hoses (running to various parts of the vegetation field) until the moisture level and pH level gets eventually normal for the field.The entire logic flow chart is presented in the Figure 18.

Figure 16. An experimental setup of the moisture sensor.

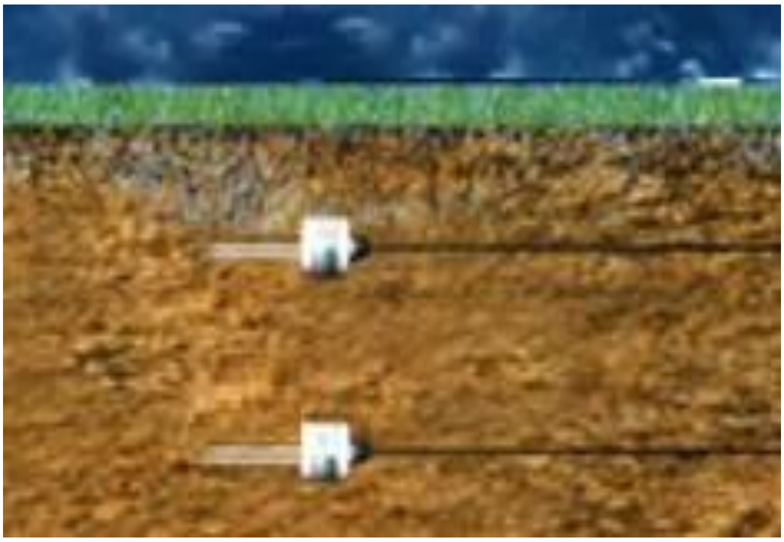

Figure 17. An underground vertical-reference soil/pH moisture sensor probes.

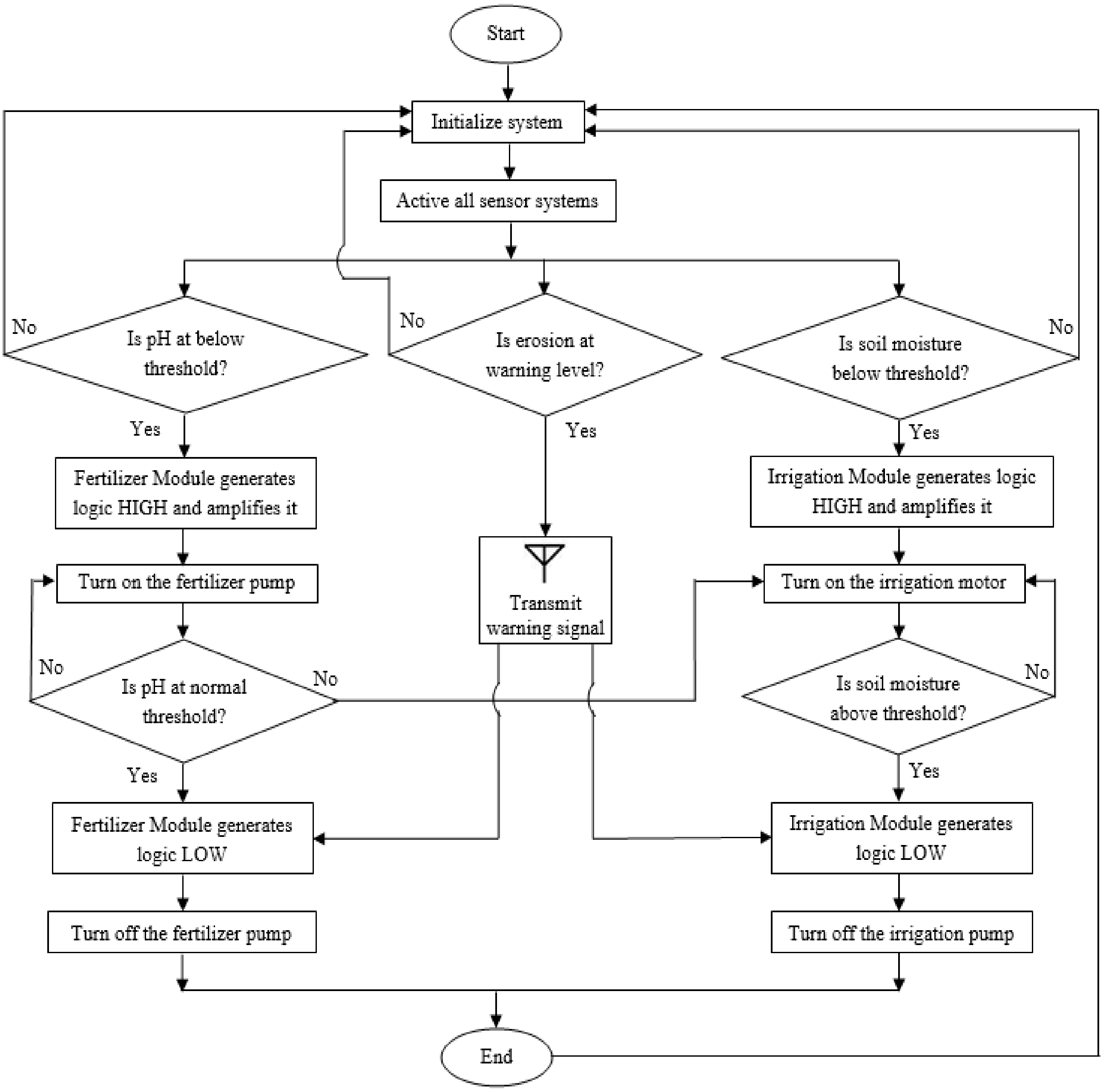

Figure 18. Logical flow-chart of the entire control system by the designed chip

IV. CONCLUSION

The UNCCD estimates that over 250 million people are affected by land degradation, and about 1 billion people in over 100 countries are at risk. According to the WMO, 33% of the world's land surface is vulnerable to land degradation. Breaking that down further, they estimate that 46% of the land in Africa is vulnerable, with Sub-Saharan Africa being the most vulnerable; 25% of Asian lands are vulnerable. [1-3]. In addition, soil erosion is one of the major factors regarding this risk which can be significantly reduced by vegetation process with proper care by controlling the environmental conditions. Towards that a solar powered complete system is designed which is composed of an IC based on pre-designed mirror-amplifier with two separate control segments for different controlling parameters, depending on the necessity of different cases, including the precision irrigation modules and fertilizer modules for the vegetation process with Money Plant at slope land. The chip designed in CMOS 0.5µm fabrication process has the total layout area of 297µmX304.2µm. Using this IC with sensors, the controlling system can satisfy the controlling with a number of advantages including greater precision, more efficient use of water and fertilizer, and reduction in human errors. With the application of this research, farmers can maximize the vegetation process by growing healthy plants on the slope lands. This is a multi-level beneficial process where both farmers and duellers can eliminate the risks of soil erosion and landslides.

ACKNOWLEDGMENT

This research work has been completed as joined engineering efforts by authors that started in late 2010. The concept and IC design in this research work was completed outside any academia or institutional involvements. Finally, the field application system was completed at CRG in 2013. Later, eight of the soil moisture sensors and cluster control electronics were let borrow to

help MeMDRL-UTSA in 2013 for a short project and the system was used successfully to study effects on Tomato plants grown in captivity in Botanical Environmental Lab. This Tomato plants' project was not in anyway related to this work of CRG.

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His personal interests include research on plants for improving their growth and yield by precision electronics. Recently, he has designed and published a novel technique to monitor plant's health which indicates heartbeat-like pulses, titled as 'Plant's Healthbeat'. This technology has been submitted for full patent disclosure. He is also working on various sensor designs, amplifiers and control systems for bio-systems and biomed applications. His other interests include micro-power bio-energy harvesting and sustainable energy control systems for real-time applications.

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