Design and construction of a system for wirelessly charging the battery of a robot

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Abstract: The purpose of this paper is to develop a check the technique designed for charging battery of robot Crawler during the pipeline inspection. The wireless energy transmission mechanism is composed of a transmitter, circular guided wave and a receiver. The system based on the principle of transfer of microwave energy inside- through - the pipeline. The idea is to use the pipeline as a waveguide to minimize the attenuation of energy as well as to maximize the power recovered to the level of horn conical antenna. We present and we studied the converting RF energy into DC electrical energy. This article represents an update on application areas and principles used and to show the utility of pipeline for transfer energy.

Key words: Robot Crawler, Magnetron, Horn antennas, circular waveguide, Pipeline, RF/DC Convertor.

1. Problematic

Pipelines are regularly inspected from the interior to detect defects, defaults, cracks and corrosion.
Such inspections require crawlers that work on battery power and need to be charged often. These charging operations represent a major time loss and cost to pipeline inspection and pipeline construction companies, and therefore to the whole gas and oil industry [1].
More information about these problematic indicates below:

- Pipeline construction projects: all over the world, hundreds of kilometers of pipelines are built every year. A few examples taken from Africa and the Middle East give an insight of the importance of this industry [2].

- Impact of crawler breakdowns: although pipeline inspection companies keep figures Confidential, experience shows that crawler breakdowns due to battery failures are common occurrences and cause significant losses [3].
For charging one battery of the robot crawler, need minimum 20W.

2. Introduction

In the oil & gas sector, the transport of hydrocarbon is done through steel tubes of different types and diameters both in field territory and maritime. These methods remain the most efficient and profitable.
This pipeline, which is an assembly of tubes, will submitted automatically to testing by non-destructive testing method (Gamma Ray, X-Ray, ultrasonic and eddy current technology) that allow us to verify and justify the quality of welds applied. Advanced techniques for this type of control is set to put robot crawler inside the section with a very advanced technology to help us diagnose the pipeline’s wall. However, during the inspection, the robot encounters a problem of autonomy (charge depleting).

3. Solution

We proposed product is a wireless charging device for pipeline crawlers that allow their batteries to be charged without being brought out of the pipeline. Inspections can then be performed quickly. It also solves the problem of discharged crawlers being blocked inside the pipeline while inspecting since charging can be made wirelessly.

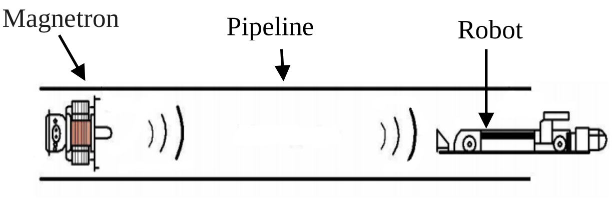


Fig.1. Wireless charging device for pipeline crawlers

4. Power emitter

Power wave's system respected all safety discipline in oil and gas industrial.

- Microwave beam.
- Retro directive beam control capability.
- Power level is well below international safety standard.

Attenuation of a wave function of frequency a guided wave.

The microwave source (Magnetron) is constituted of a microwave oven magnetron with electronics to control the output power. The output microwave power ranges from 10W to 80W at 2.45GHz. Direct connect the output of the microwave source to waveguide adapter. This adapter is connected to a waveguide circulator which protects the microwave source from reflected power. The circulator is connected to a tuning waveguide section to match the waveguide impedance to the antenna input impedance [4].The cavity magnetron is high-powered vacuum tube that generates microwaves using the interaction of a stream of electrons with a magnetic field [5].

As electrons sweep past these openings, they induce a resonant, high-frequency radio field in the cavity, which in turn causes the electrons to bunch into groups. The principle of microwave emitter is represented by the block diagram in Figure 2.

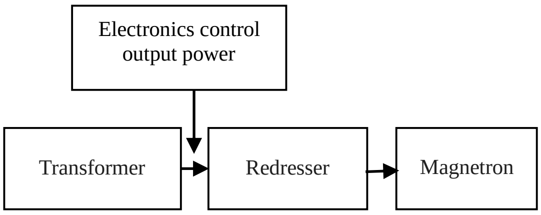


Fig.2. Structural diagram of microwave emitter

5. Pipeline guided wave

The idea is to use the pipeline as a waveguide. Waveguides are basically a device for transporting electromagnetic energy from one region to another. They are capable of directing power precisely to where it is needed, can handle large amounts of power and function as a high-pass filter [6] [7]. The waveguide acts as a high pass filter in that most of the energy above a certain frequency (figure 3) will pass through the waveguide, whereas most of the energy that is below the cutoff frequency will attenuated by the waveguide. Waveguides are often used at microwave frequencies (greater than 300 MHz, with 8 GHz and above being more common) [8].

Waveguides are wideband devices, and can carry (or transmit) either power or communication signals. Pipeline circular wav

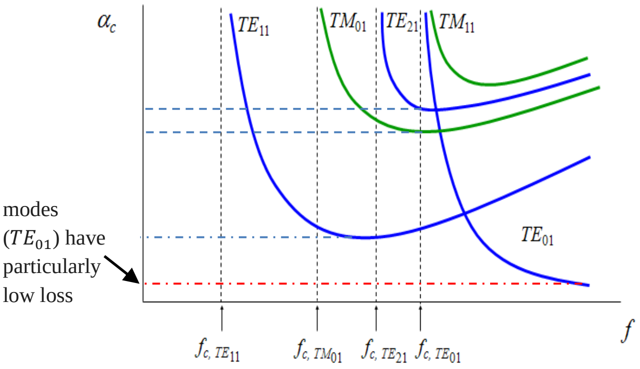


Fig.3 the higher order modes (TE_{01}) have particularly low loss

For a circular waveguide with diameter (a) and length (d), the mode of propagation with the lowest cut-off frequency is the TE_{11} mode, as illustrated in Figure 4b.

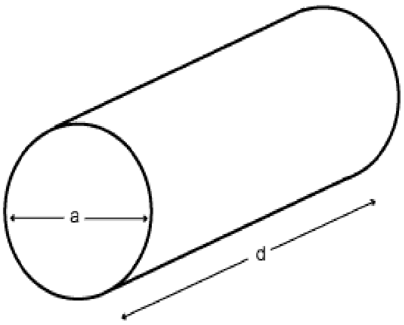


Fig.4.a. Pipeline circular waveguide geometry

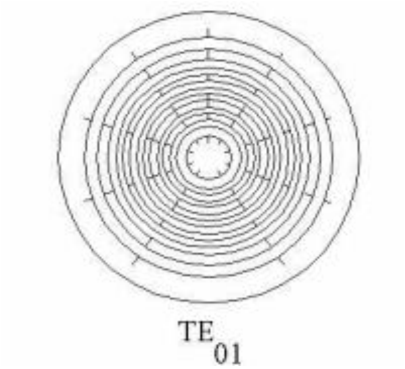


Fig. 4.b. *Field distribution of the higher order modes* TE_{01}

It is well known that the polarization of an electromagnetic wave (EM) is the orientation of its electric field $\vec{E}$ [9].

The polarization of the wave is called linear when the direction of electric field vector is constant. In this case, the field $\vec{E}$ still in the same plane. The electric field is represented by a vector perpendicular to the direction of propagation of the P wave (or Z). The magnetic field $\vec{B}$, too, is a vector perpendicular to the electric vector and perpendicular to the direction of propagation. Guided EM waves (which propagate in a coaxial cable) are not always transverse, that is to say that the electric and magnetic fields are not necessarily perpendicular to the propagation direction Z. A specific configuration of electric and magnetic fields of a wave propagating in a waveguide propagation mode is TE11 [10]. At a given frequency, there may be many modes propagating in a waveguide (TE, TE, and TEM). In a perfect guide, different modes cannot interact.

6. Behavior of a waveguide

The cutoff wavelength of a circular guide is 1.71 times the diameter of the waveguide [11]. Since the "a" dimension of a pipeline circular waveguide is approximately one half-wavelength at the cutoff frequency, or approximately1.17 times the "a" dimension of a circular waveguide.

The TE and TM modes stop growing below a frequency called f_c frequency. To determine if a mode is propagating in a waveguide, we must calculate its cutoff frequency f_c and compare it to the working frequency:

- If f exceeds f_c then that mode is propagated.
- If not there is a mitigation of energy.

The conditions of propagation of a guided wave are described below when:

- λ_0 represents the wavelength of an infinite medium having the properties within the guide.
- λg represents the guided wavelength inside the guide.
  $$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_r}} \quad (1)$$
- λc represents the cutoff wavelength.

$$\frac{1}{\lambda_0^2} - \frac{1}{\lambda_g^2} = \frac{1}{\lambda_c^2} \quad (2)$$

His propagation constant is given by,

$$\beta = k_c\sqrt{1-({}^{f}/_{f_c})^2} \quad (3)$$

Where k_c for the TE_{11} mode is,

$$k_c = \frac{3.682}{a} \quad (4)$$

Setting the term under the radical in Equation (4) to zero, the cut-off frequency as shown to be,

$$f_c = \frac{0.586 * v}{a} \quad (5)$$

Where V is the velocity of propagation in the waveguide dielectric ($3x10^8$ m/s in air).

Below the cutoff frequency, the magnitude of the field in the waveguide decays exponentially,

E (Z)= $E_0 e^{-|\beta|Z}$ (6)

The total attenuation of the field traveling a distance, d, expressed in dB is then,

Attenuation in:

$$dB = 20\log e^{-|\beta|d} = 8.7|\beta|d \quad (7)$$

Or, combining Equations (5), (6) and (7),

$$Attenuation\ in\ = 32\,\frac{d}{a}\sqrt{1-({}^{f}/_{f_c})^2}\ \mathrm{dB} \quad (8)$$

A raduis ofa circulair waveguide (pipeline) is a=10.16 cm.

Filled with air ($\varepsilon_{r=}1$, $\theta_r = 1\ H.m^{-1}$) is used at a frequency of 2.45 GHZ

For the $TE_{01} mode$;

7. Mathematical equation:

A/ The cutoff frequency;

$$f_C^{TE_{01}} = \frac{X_{01}}{2.a.\pi\sqrt{\mu_0\varepsilon_0}} \tag{9}$$

$$f_C^{TE_{01}} = \frac{3.8318}{2.a.\pi\sqrt{4\,\pi\,10^{-7}}8.85\,10^{-12}} \tag{10}$$

$$f_C^{TE_{01}} = 1.8\,GHZ$$

B/ The guide wavelength;

$$\lambda_g = \frac{\lambda}{\sqrt{1-(\frac{f_c}{f})^2}} \tag{11}$$

$$\lambda = \frac{c}{f} \tag{12}$$

$$\lambda = \frac{3.10^8}{30.10^9} = 0.010m$$

$$\lambda_g = \frac{0.010}{\sqrt{1-(\frac{1.8}{30})^2}} = 0.01m$$

C/ The phase propagation constant of the TE_{01} mode is:

$$\beta_z = \frac{2\pi}{\lambda}\sqrt{1-(\frac{f_c}{f})^2} \tag{13}$$

$$\beta_z = \frac{2\pi}{0.01}\sqrt{1-(\frac{1.8}{30})^2}$$

$$\beta_z = 627.16\,rad/m$$

D/ The wave impedance of the TE_{01} mode is

$$z_{01} = \frac{\eta}{\sqrt{1-(\frac{f_c}{f})^2}} = \frac{120\,\pi}{\sqrt{1-(\frac{1.8}{30})^2}} \tag{14}$$

$$z_{01} = 378.5\,\Omega$$

E/ The cutoff wave number of the TE_{01} mode is;

$$Kc_{TE01} = (\frac{\rho'_{01}}{D/_2}) \tag{15}$$

$$Kc_{TE01} = \frac{3.8318}{0.1016} = 37.714$$

F/ The Phase velocity;

$$\vartheta p_{TE01} = \frac{2\pi}{\lambda((\frac{2\pi}{\lambda_0})^2-(\frac{\rho'_{nm}}{D/_2})^2)^{\frac{1}{2}}}.C \tag{16}$$

$$Kc_{TE01} = 3.01\,10^8\,\frac{m}{s}$$

G/ The group velocity;

$$\vartheta p_{TE_{01}} = \frac{\lambda*\{\left(\frac{2\pi}{\lambda_0}\right)^2-\left(\frac{\rho'_{01}}{\frac{D}{2}}\right)^2\}^{0.5}}{2\pi} \tag{17}$$

$$Kc_{TE01} = 2.98\,10^8\,m/s$$

H/ The relation by ϑ_g and ϑ_p;

$$\vartheta_g * \vartheta_p = c^2 \tag{18}$$

$$3.01\,10^8 * 2.98\,10^8 = 8.9\,10^{16}$$

8. Attenuation in loss waveguide

The propagation wave in an ideal waveguide suffers no attenuation as the travel down the waveguide.

Two loss mechanisms exist in a realistic waveguide:

- Conductor loss
- Dielectric loss

The overall attention constant α ($in\ units\ of\ \frac{Np}{m}$) for a realistic waveguide can be written in terms of the two loss components as

$$\alpha_{01} = \alpha_{c_{01}} + \alpha_{d_{01}} \tag{19}$$

Where

α_c: $conductor\ loss$

α_d: Dielectric loss

8.1 Circular waveguide attenuation

An air filled low carbon steel waveguide (API 5L Gr B)

D= 8’’=8 $* 2.54 = 20.32\,cm = 0.2032m$

A=0.1016$m = 10.16cm$

$\sigma_c = 9.25\,10^6\,S$

$\mu_r = 10000\,H.m^{-1}$

The loss in $^{dB}/_{m}$ for the TE_{01} $mode$:

A/ The cutoff frequency

$$f_C^{TE_{01}} = \frac{X_{01}}{2.a.\pi\sqrt{\mu_0\varepsilon_0}} \tag{20}$$

$$f_C^{TE_{01}} = 1.8\,Ghz$$

B/ Skin effect

$$\delta = \frac{1}{\sqrt{\pi\,f\,\mu_0\mu_n\sigma_c}} = 9.68\,nm \tag{21}$$

C/ resistance

$$R_s = \frac{1}{\sigma_c \delta} = 11.14\ \Omega \tag{22}$$

D/ Impedance

$$\eta_{TE\ 01} = \frac{\eta'}{\sqrt{1-(\frac{f_{c01}}{f})^2}} \tag{23}$$

$$\eta' = \sqrt{\frac{\mu}{\varepsilon}} = 377\Omega \tag{24}$$

$$\eta_{TE\ 01} = \frac{\eta'}{\sqrt{1-(\frac{f_{c01}}{f})^2}} = 378.53\ \Omega$$

E/ Attenuation constants due to conductor loss are given by $(\boldsymbol{TE_{01}})$

$$\alpha_{C01}^{TE} = \frac{R_S}{a\,\eta'\sqrt{1-(\frac{f_c}{f})^2}} * \{\left(\frac{f_c}{f}\right)^2 + \frac{m^2}{(\gamma'_{mn})^2 - m^2}\} \tag{25}$$

$$\alpha_{C01}^{TE} = 0.00105\ Np/m$$

$$\alpha_{L01}^{TE} = 0.00918\ dB/m\ = 9.884\ dB/km$$

The attenuation constant due to dielectric loss is given by $10\log\left(\frac{P_r}{P_e}\right) = -9.884$ (26)

8.2 Simulation used the MATLAB software

For approving our idea also our calculation use MATLAB platform to check all equations and check the influence of distance on the attenuation. First simulations present the curve of energy attenuation Vs distance.

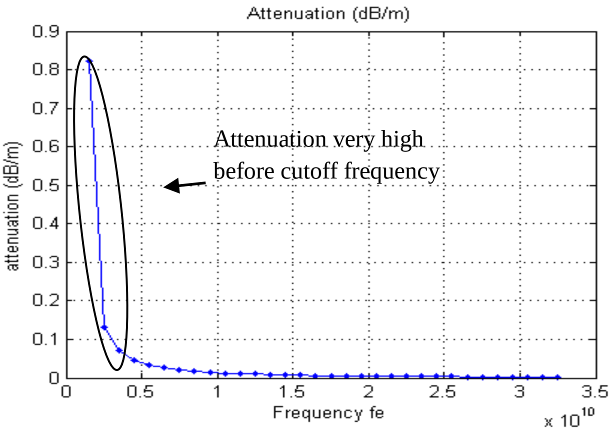


Fig.5. Attenuation of a wave function of frequency a waveguide

Second simulations present if frequency more range than cutoff frequency, the power in receiver will be increase.

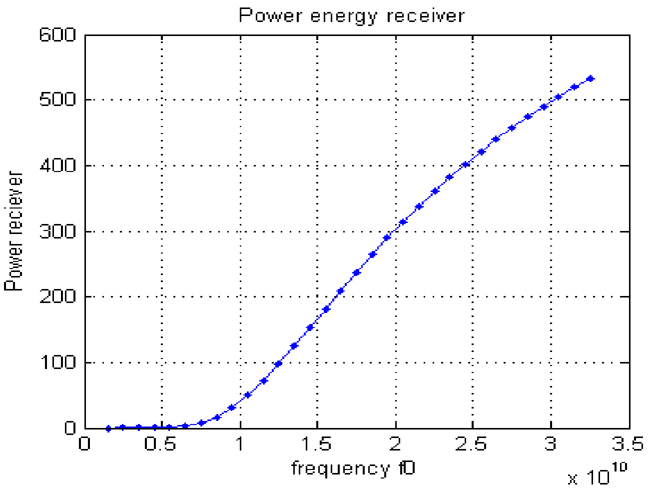


Fig.6. The relation between cutoff frequency and diameter of oil pipeline

9. Theoretical Study of Convertor RF/DC

A rectifying antenna called a rectenna receives the transmitted power and converts the microwave power to direct current (DC) power. The rectifier is a GaAs Schottky barrier diode that is impedance matched to the dipoles by a low pass filter. The rectifying diodes are connected to Horn antennas shown in Figure 7 [12].

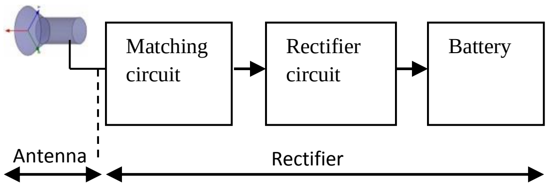


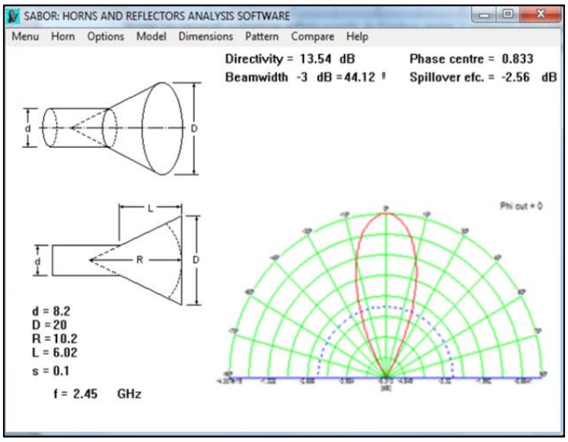
Fig.7. Block diagram of a conventional Rectenna.

9.1 Conical Horn antenna design

Antenna design is important in the proposed rectenna. The antenna absorbs the incident microwave power, and the rectifier converts it into a useful electric power. In this paper, in order to reduce the size of the rectenna, we propose to combine the BPF and the antenna into a single unit.

The horn antenna design was relatively simple. Once you meet the physical constraints of the E and H plane of the aperture then you can use plane geometry and symmetry to get the rest of the dimensions [13].

Antenna characteristics of gain beam with, efficiency, polarization, and impedance was determinate by SABOR HORNAS simulator.



Directivity = 13.54 dB
Beamwidth -3 dB =44.12 º
Phase centre = 0.833
Spillover efc. = -2.56 dB

d = 8.2
D = 20
R = 10.2
L = 6.02
s = 0.1

f = 2.45 GHz

Fig.8. Simulation of the horn antenna with SABOR HORNAS

Antenna construction for easy application and specialized performance is shown in Figure 8.

9.2 Rectifier circuit

The rectifier circuit composed by two parts first the matching circuit and the RF-DC convertor.

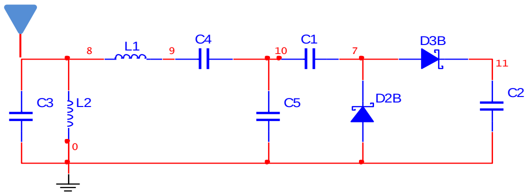


Fig.9. Rectifier topology

9.3 Matching circuit

The major integration issue with inputting the antenna directly into the rectification circuit is matching the impedances on the transmission line coming off of the receiving antenna.

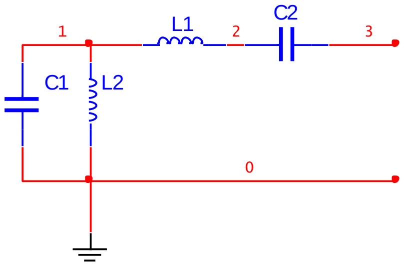


Fig.10. Matching circuit

9.4. Design Rectanna a multistage voltage multiplier using ADS

The purpose of the RF-DC converter is to take the incoming microwave signal from the antenna and rectify it into a DC voltage that could be used to power the circuit [14]. The components used for this purpose are rectifying schottky diodes (BAT-63) [15] and capacitors. By simulating, this circuit a 12 V DC are generate. Figure 11 shows the transient response of this circuit.

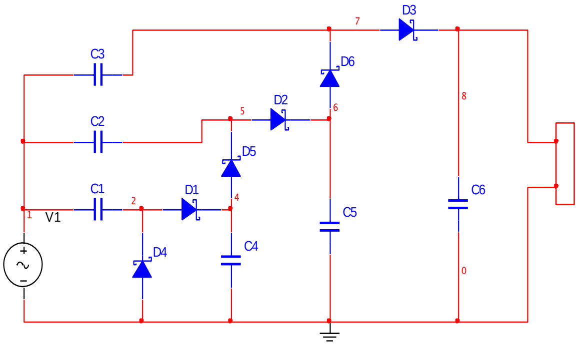


Fig.11. RF-DC converter schematic of the voltage double rectifier circuit.

This design is based on the principles behind diodes and capacitors, and their behaviors when configured into a charge pump circuit. Charge pumps work in stages that progressively increase the output voltage in a DC form.

A rectification circuit will be designed, built, and tested that converts the input AC signals into a DC signal.

The rectification circuit will be optimized to have the highest efficiency possible to increase overall system performance.

The rectification system consists of a many stage charge pump utilizing Schottky diodes.

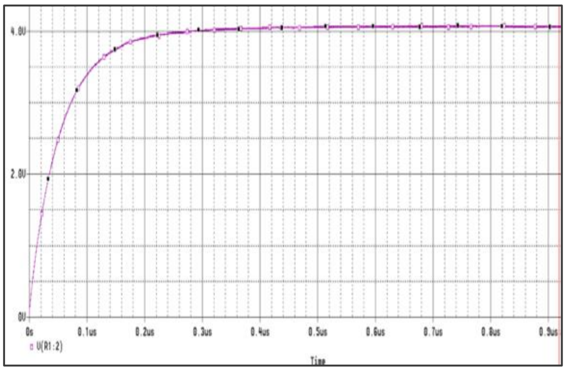


Fig.12. Measured RF-to-DC conversion efficiency and DC output voltage versus RF input power

The proposed RF-DC converter circuit is simply a voltage multiplier that rectifies the signal using BAT 63 schottky diodes that can operate at a very high frequency up to 2.5 GHz, plus they are fast and have a low forward voltage. The next step was to bread board this test circuit using components that are available in the electronic Lab.
Figure 13 below is a photograph of the test circuit built on the bread board.

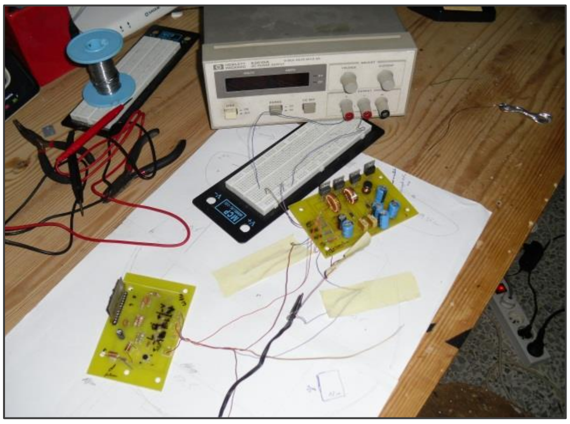


Fig.13. The final testing process was to build the circuit on a printed circuit board.

The first few attempts used surface mount components to minimize overall board size because they will connect with the robot crawler. Figure 14 below is a photograph of the microwave receiver.

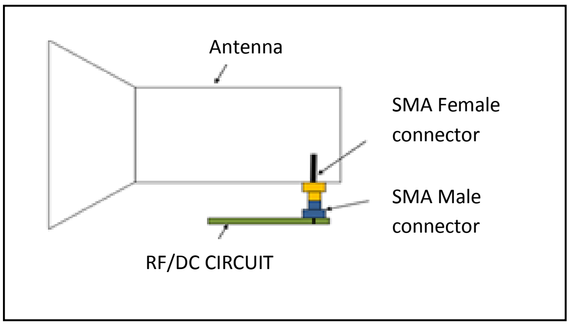


Fig.14. Photograph of connection between rectifier circuit and Horn antenna.

10. Test Plan

As a result, the following test plan includes a detailed overview of all stages of testing that were conducted for both primary subsystems. Moreover, a detailed plan for how to begin testing and the integration of the secondary subsystem is overviewed, as well.

Fig.16. Check our system inside pipeline

11. Conclusion

This paper presents the system for charging battery of crawler wirelessly. It is to study and model the problems that have an influence on the functioning of a robot at the time of pipeline inspection. Has been studied, simulated and implemented a wireless charging system, knowing that the pipeline is considered as a guided wave which improves the performance of our system.

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