POWERWAVE NDT.

Wireless charging for pipeline crawler batteries

BY MOHAMED ZIAD CHAARI AND ORPHEUS HADDAD, JUNE 20, 2012

I. PROBLEM

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.

- Speed of inspection: the leading companies, such as TecniTesT, TechCorr, or Hainsco use robots that are capable of inspecting between 1 kilometer and 2 kilometers per day.

- 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.

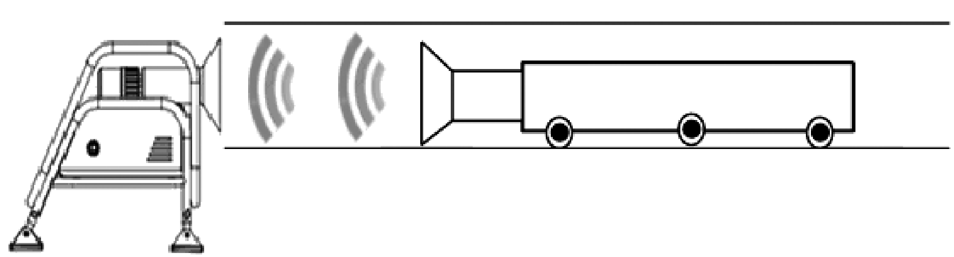
  In 2012, 340 kilometers will be built in Kenya, 395 in Nigeria, 310 in Rwanda, 230 in Uganda… In the Arab World, from 2012 to 2015, pipelines are scheduled to be built in Syria (140 km), Algeria (510 km), Egypt (491 km), Morocco (320 km), Kuwait (338 km)…

- 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.

II. SOLUTION

PowerWave's first 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.

As proved during the previous phases of "Stars of Science", PowerWave's device is capable of inspecting up to 6 kilometers per day. It also solves the problem of discharged crawlers being blocked inside the pipeline while inspecting since charging can be made wireless.



POWERWAVE'S wireless charging device for pipeline crawlers

III. Business Model

Key Partners

Who are our Key Partners?
Who are our key suppliers?
Which Key Resources are we acquiring from partners?
Which Key Activities do partners perform?

MOTIVATIONS FOR PARTNERSHIPS:
Optimization and economy
Reduction of risk and uncertainty
Acquisition of particular resources and activities

- Universities
  Technology improvement
- Part manufacturers
  Optimization and economy

Key Activities

What Key Activities do our Value Propositions require?
Our Distribution Channels?
Customer Relationships?
Revenue streams?

CATEGORIES
Production
Problem Solving
Platform/Network

- Research and development
- Efficient sales department
- Efficient maintenance service

Key Resources

What Key Resources do our Value Propositions require?
Our Distribution Channels? Customer Relationships?
Revenue Streams?

TYPES OF RESOURCES
Physical
Intellectual (brand patents, copyrights, data)
Human
Financial

- Intellectual - Engineering capabilities, patents
- Financial - $900,000 Investment
- Human - Labour

Value Propositions

What value do we deliver to the customer?
Which one of our customer's problems are we helping to solve?
What bundles of products and services are we offering to each Customer Segment?
Which customer needs are we satisfying?

CHARACTERISTICS
Newness
Performance
Customization
"Getting the Job Done"
Design
Brand/Status
Price
Cost Reduction
Risk Reduction
Accessibility
Convenience/Usability

Pipeline crawlers
- Newness
- Performance
- Cost and risk reduction

Nuclear industry
- Newness
- Safety

Customer Relationships

What type of relationship does each of our Customer Segments expect us to establish and maintain with them?
Which ones have we established?
How are they integrated with the rest of our business model?
How costly are they?

EXAMPLES
Personal assistance
Dedicated Personal Assistance
Self-Service
Automated Services
Communities
Co-creation

- Co-creation
- Personal assistance
- Training sessions

Channels

Through which Channels do our Customer Segments want to be reached?
How are we reaching them now?
How are our Channels integrated?
Which ones work best?
Which ones are most cost-efficient?
How are we integrating them with customer routines?

CHANNEL PHASES:
1. Awareness
2. Evaluation
3. Purchase
4. Delivery
5. After sales

- Fairs and exhibitions
- Invitations to bid
- Articles and ads in specialized publications

Customer Segments

For whom are we creating value?
Who are our most important customers?

Mass Market
Niche Market
Segmented
Diversified
Multi-sided Platform

Step 1
Pipeline inspection companies, Pipeline crawler manufacturers

Step 2
Nuclear industry

Cost Structure

What are the most important costs inherent in our business model?
Which Key Resources are most expensive?
Which Key Activities are most expensive?

IS YOUR BUSINESS MORE:
Cost Driven (leanest cost structure, low price value proposition, maximum automation, extensive outsourcing)
Value Driven (focused on value creation, premium value proposition)

SAMPLE CHARACTERISTICS:
Fixed Costs (salaries, rents, utilities)
Variable costs
Economies of scale
Economies of scope

- Marketing
- Electrical components
- Manufacturing
- Reasearch and development

Revenue Streams

For what value are our customers really willing to pay?
For what do they currently pay?
How are they currently paying?
How would they prefer to pay?
How much does each Revenue Stream contribute to overall revenues?

TYPES:
Asset sale
Usage fee
Subscription Fees
Lending/Renting/Leasing
Licensing
Brokerage fees
Advertising

FIXED PRICING
List Price
Product feature dependent
Customer segment dependent
Volume dependent

DYNAMIC PRICING
Negotiation(bargaining)
Yield Management
Real-time-Market

- Product sale
- Maintenance contracts
- Warranty contracts

- Customer segment dependent
- Volume dependent
- Negotiation

IV. Underlying Technology

PowerWave's system uses **microwave technology**, which refers to technology for the transmission of signals at high frequencies. Microwaves are transmitted from an emitter to a receiver through a waveguide. The energy is then converted into direct current electricity thanks to a rectenna.

Signal transmission in microwave technology

V. Marketing & Sales

1. Marketing

Since PowerWave's innovation is dedicated to a very specific audience, it will be marketed mainly through fairs and exhibitions and specialized publications. The company will also respond to invitations to bid. Specialized scientific conferences will also help spread the word about the product.

The Abu Dhabi International Petroleum Exhibition and Conference (ADIPEC, visitors' details below) is the world's major oil and gas exhibition. PowerWave's wireless device will be presented there as well as in several other fairs and exhibitions such as the Australasian Oil & Gas Expo and the Shanghai International Petrochemical Technology & Equipment Exhibition.

Top 5 visitor job functions

- Engineering
- Sales
- General Manager
- Chairman/President/Director
- Managing Director

22% of ADIPEC visitors are senior level industry executives
Engineers represent 16% of our audience

Top 5 visitor company activities

- Oil
- Gas
- Engineering/Construction
- Petrochemicals
- Trader

'ADIPEC is the meeting place for the oil and gas industry' (95% survey respondents)

Top 5 visitor interests

- Products
- Pipes & Fittings
- Valves & Actuators
- Oil & Gas Storage & Transportation
- Drilling
- Production

A third of visitors arrange pre-planned meetings with potential suppliers of products/services they are interested in using MyADIPEC

Top visitor country attendance

- UAE
- Oman
- Iran
- UK
- India
- Kuwait
- US

The UAE accounts for 79% of attendees, however 2010 has seen an increase in attendance from 73%

27% of visitors have over $1mn budget to spend at ADIPEC: that is over 12,000 people and a combined buying power of $12 billion.

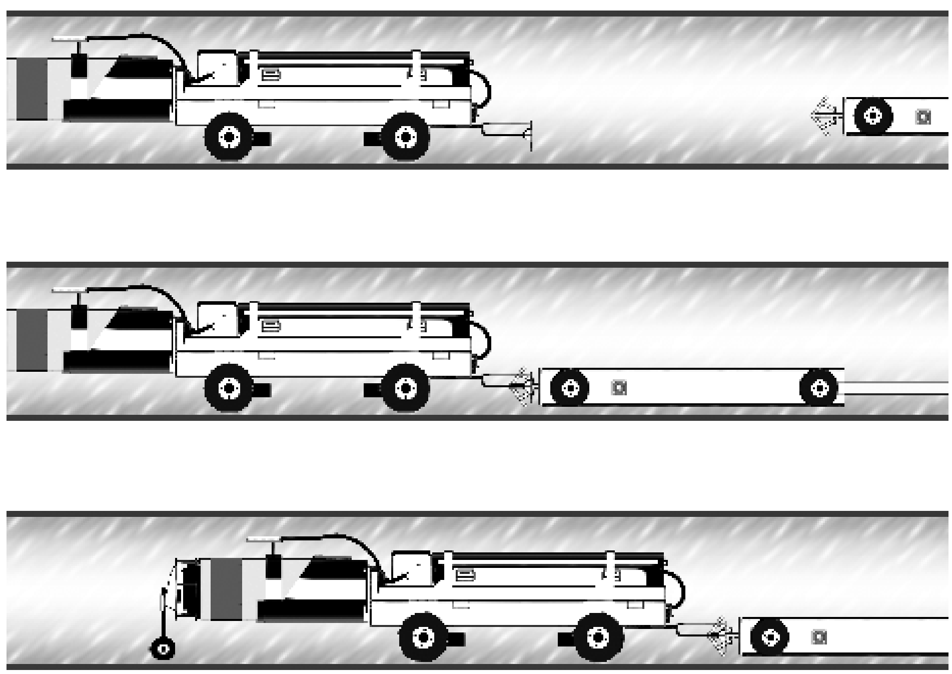
2. Sales

PowerWave intends to sell 200 pipeline crawler wireless charging units in 2012, and 390 units in 2013. Since less pipeline construction projects are scheduled for 2014, 2015 and 2016 according to the current estimates, a slight decrease in sales is expected to occur. Nevertheless, new devices developed for the nuclear industry, in addition to maintenance contracts will then create new revenues.

VI. Competition

PowerWave's product will be the first wireless device to solve the above-problem.

Nevertheless, another solution exists and consists in retrieving the crawler thanks to a retrieval unit that travels forward along the pipe, then winches the crawler out of the pipe.

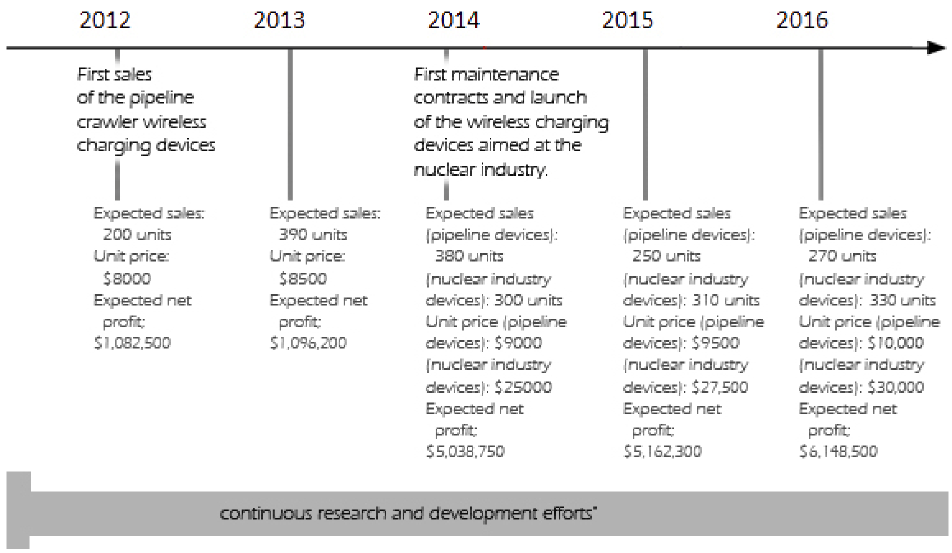


Solution provided by "XSPec Technology"

Competition may also exist between PowerWave's innovation and products being currently developed in research centers and soon released on the market.

VII. Status & Timeline

Thanks to the "Stars of Science" program, PowerWave's innovation is now ready to be produced and sold. The company hopes to start manufacturing and selling in 2012.



2012-2016 PowerWave's timeline

VIII. Summary & Call to Action

1. The first step in a long journey

PowerWaves' wireless charging system for pipeline crawlers, which is a major innovation in the oil and gas industry, is the first step towards developing wireless battery charging in other fields, such as the nuclear industry, and even for everyday use.

2. The Arab world in mind

Many oil and gas producing countries belong to the Arab world. PowerWave's technology will therefore have direct and positive impact on one of the region's main revenue sources.

3. Highly targeted marketing plans

PowerWave's wireless charging system is dedicated to a very specific audience: pipeline inspection companies and pipeline construction projects. PowerWave's will therefore promote its innovation in the industry's fairs and exhibitions as well as in specialized publications. Moreover, the company will also respond to invitations to bid.

4. Sales expectations

PowerWave expects to sell 200 to 390 pipeline devices and 300 to 330 nuclear industry devices (starting 2014). Maintenance contracts will also increase the companies' income (see "Revenue Assumptions" for details).

5. Importance of Research & Development

PowerWave will operate in the wireless electricity field, which offers endless development opportunities. This is why the company will attach great importance to research and development, notably by forging close ties with universities and combining theoretical approach and practical application.

Wireless electricity is now in your hands.

WIRELESS POWER TRANSFER FOR CHARGING BATTERY OF ROBOT CRAWLER

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ABSTRACT

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.
Speed of inspection: the leading companies, such as TecniTesT, TechCorr, or Hainsco use robots that are capable of inspecting between 1 kilometer and 2 kilometers per day.
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.

I. INTRODUCTION

Wireless energy transfer is the process that takes place in any system where electrical energy is transmitted from a power source to an electrical load without interconnecting wires. Wireless transmission is useful in cases where instantaneous or continuous energy transfer is needed but interconnecting wires are inconvenient, hazardous, or impossible [1] [2]. Before discussing the presentation of different techniques allowing the transfer of energy without contact, seems necessary to examine the reasons and need this principle, as discussed below, has the disadvantage of a transfer yield enough poor in the state of the art today.
The absence of galvanic contact can be justified for categories of systems: [3][4][5]
• Systems for which energy storage is limited: electric vehicles, robots, parts of machine tools, portable household appliances[6].
• Systems in which it is impossible to establish a galvanic connection for reasons of Security: devices implanted in the human body, medical, domestic applications, high security, and nuclear field.
• Badge systems for authentication, electronic toll collection and security devices.

The aim of this paper is to describe wireless power for charging batteries of robot Crawler. The block diagram of the system is shown in fig. 1. It consists of two units: an implantable transmitter and an external receiver unit.

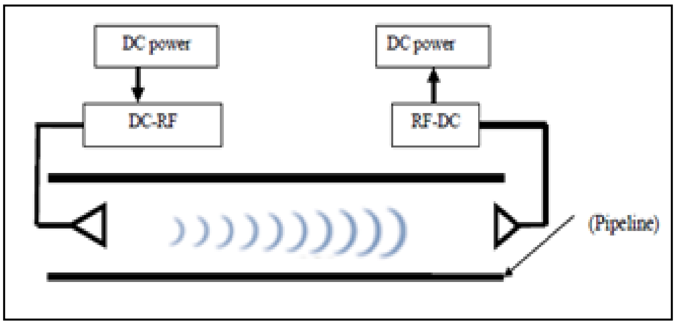

Fig.1 Block diagram of the wireless charging

II. THEORETICAL STUDY OF MICROWAVE EMITTER

A. Waveguide

The idea is to use the pipeline as a waveguide. Waveguides are basically a device for transporting electromagnetic energy from one region to another [7]. 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 [8] [9].
The waveguide acts as a high pass filter in that most of the energy above a certain frequency (the cutoff frequency) will pass through the waveguide, where as most of the energy that is below the cutoff frequency will be attenuated by the waveguide. Waveguides are often used at microwave frequencies (greater than 300 MHz, with 8 GHz and above being more common)[10].

Waveguides are wideband devices, and can carry (or transmit) either power or communication signals. Pipeline circular waveguide is shown in the following figure 3a.
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 3b.

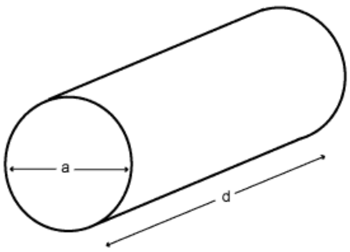

Fig.3a Pipeline circular waveguide geometry

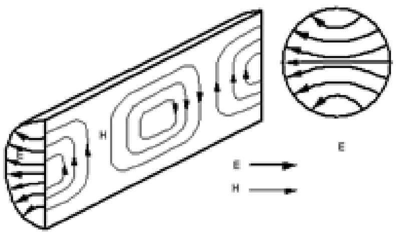

Fig.3b line field of TE11 mode

It is well known that the polarization of an electromagnetic wave (EM) is the orientation of its electric field $\vec{E}$. 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 called [11]. 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.

B. Behavior of a waveguide

The cutoff wavelength of a circular guide is 1.71 times the diameter of the waveguide [12]. 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 propagation in a waveguide, calculate its cutoff frequency f_c and compare it to the working frequency

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

A waveguide behaves like a high-pass filter as illustrated in Figure 4.

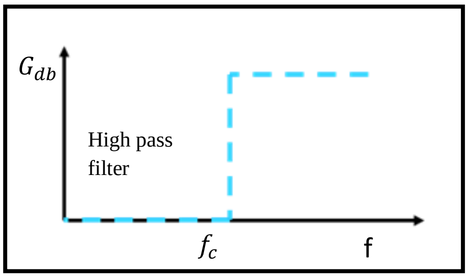

Fig.4 Attenuation of a wave function of frequency a waveguide

The conditions of propagation of a guided wave

- λ0 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 is shown to be,

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

Where $\boldsymbol{V}$ is the velocity of propagation in the waveguide dielectric ($3\text{x}10^8$ m/s in air).

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

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

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

$$\text{Attenuation in } db = 20 \log e^{-|\beta| d} = 8.7|\beta| d \qquad (7)$$

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

$$attenuation\ in\ db = 32\ \frac{d}{a}\sqrt{1-({}^{f}/_{f_c})^2} \qquad (8)$$

C. Microwave emitter

The microwave source (Magnetron) consists of a microwave oven magnetron with electronics to control the output power. The output microwave power ranges from 10 W to 80 W at 2.45 GHz. 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 [13]. The cavity magnetron is a high-powered vacuum tube generates microwaves using the interaction of a stream of electrons with a magnetic field. The 'resonant' cavity magnetron variant of the earlier magnetron tube was invented by Randall and boot in 1940 [14].

All cavity magnetrons consist of a hot cathode with a high (continuous or pulsed) negative potential by a high-voltage, direct-current power supply [15]. The cathode is built into the center of an evacuated, lobed, circular chamber. A magnetic field parallel to the filament is imposed by a permanent magnet. The magnetic field causes the electrons, attracted to the (relatively) positive outer part of the chamber, to spiral outward in a circular path rather than moving directly to this anode. Spaced around the rim of the chamber are cylindrical cavities. The cavities are open along their length and connect the common cavity space. 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. A portion of this field is extracted with a short antenna that is connected to a waveguide (a metal tube usually of rectangular cross section).
The principle of microwave emitter is represented by the block diagram in Fig 5.

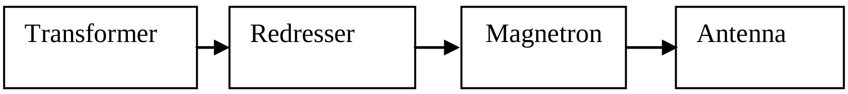

Fig 5.Structural diagram of microwave emitter

III. 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 antenna microstrip.

A. Theoretical design of 2.45 GHz antenna

Design process has strated with the design of a microstrip patch antenna operating at 2.45GHz. Width of the antenna is calculated using

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\ \sqrt{\frac{2}{\varepsilon_r+1}} \qquad (9)$$

Where $\mu_0$the permeability of free space is, ε_0 is the relative permittivity of free space, f_c is the radiation frequency and ε_r is the permittivity of the substrate used in the antenna. In this design, epoxy which has a relative permittivity of 4.32 Farads/m2 is used as the substrate [16]. For the 2.45GHz case, the width is calculated using values μ_0=1.22222*10-6 Weber/(Amps*m),f_r=2.45GHz and h=1.6 mm, and the result is found to found to be 29.27mm. then the length of the antenna is calculated as

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{eff}}\ \sqrt{\mu_0\varepsilon_0}} \qquad (10)$$

Where

$$\Delta L = 0.412 * h * \frac{(\varepsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}+0.8)} \qquad (11)$$

And

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\, {}^{h}/_{W}\right]^{-1/2} \qquad (12)$$

Is the effective permittivity. In the effective permittivity calculation h is the thickness of the substrate and it is assumed to be much smaller than the thickness of the antenna [17] . For the 2450MHz design calculation, length of the antenna is found to be 33.24 mm. After calculating the dimensions of the patch, design process continued with the matching of the radiation resistance of the antenna 50Ω. For matching, inset feeding technique is used. Position of the inset feed point is calculated as follows:

$$y_0 = \frac{L}{\pi}\arccos\left(\frac{R_{in}}{R_{in0}}\right)^{1/2} \qquad (13)$$

In the above formula, R_{in0} is the resonant input resistance of the antenna before the application of inset feeding and R_{in} is the required input resistance which is 50 Ω for this case [18]. The result of the calculation on the position of the inset feed point came out to be y_0=12.45 mm.

After the calculation of the above metrics of the antenna, the antenna is simulated in 'Agilent Advanced Design System' software and S11 parameter of the antenna is given on the below plot within a frequency range of 1.0 to 4.0 GHz.

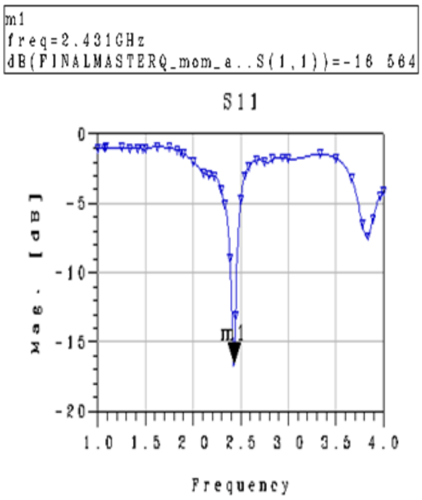

Fig.6. S11 plot for simulation of 2450MHz patch

The current distribution at 2.45GHz is given below

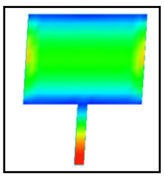

Fig.7. Current distribution at 2.45GHz

C. Calculation of the ground plane dimensions

The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. It has been shown by [19] that similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery. Hence, for this design, the ground plane dimensions would be given as:

$$L\,g = 6h + L \tag{14}$$

$$W\,g = 6h + W \tag{15}$$

Hence, the calculated *Lg* and *Wg* are 42.84 mm and 42.87 mm respectively.

D. Design, Simulation and Tests Microstrip Patch Antenna arrays

After performing the measurements with a single patch, we now simulate an array antenna with n stages to improve gain and directivity.
Determine the geometry of the network is to network the primary radiating elements along a particular geometric arrangement to best meet the requirements in terms of gain, maximum size and radiation patterns.
The objective here is to choose the total number of elements and the spacing between them (not the network) to achieve desired levels of gain.
The distance between elements will be determined according to the constraints but also to gain size imposed by the specifications.
To better understand the principle, we will work primarily on a sample of two patches and another example with four patches spaced by 0.7 λ.

E. Patch array antenna

The antenna with two patches notch is adapting the supply line is shown in figure 8.

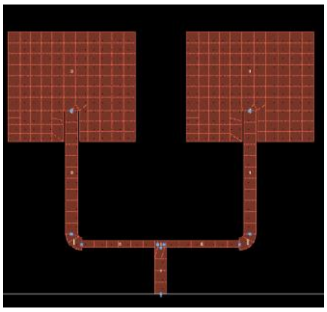

Fig.8. Layout of 2 element patch array antenna

We modify the parameters of an antenna array with two patchs and are simulated in Momentum, for an adjustment of approximately -19.00 dB.

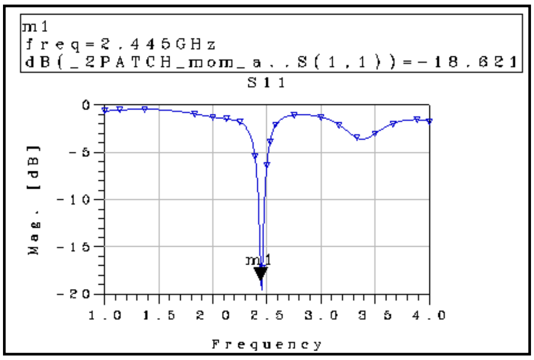

Fig.9. S11 plot for simulation of 2450MHz patch

Following this amendment, the antenna parameters have become more significant as shown in Table 1 Indeed, the value of the radiated power is 980 mw, the gain value reaches 3.41 dB and the directivity is about 7.03 dB for the frequency 2.45 GHz.

Table.1. Antenna parameters on two patchs

Power radiated (watts)	0.001002481897	
Effective angle (degrees)	133.95	
Directivity (dB)	7.303799412	
Gain (dB)	3.416765875	
Maximum Intensity (Watts/Steradian)	0.0004287919428	
Angle of U Max (theta, phi)	6.00	0
E(theta) Max (mag, phase)	0.5683881473	69.37493878
E(phi) Max (mag,phase)	0.003578448581	48.09058443
E(x) Max (mag,phase)	0.5652744576	69.37493878
E(y) Max (mag,phase)	0.003578448581	48.09058443
E(z) Max (mag,phase)	0.05941273958	-110.6250612

OK

F. Simulation and realization of an array antenna with four floors

After performing simulations with a single patch and two patches we will now simulate an antenna with four patches to improve gain and directivity, as illustrated in figure 10.

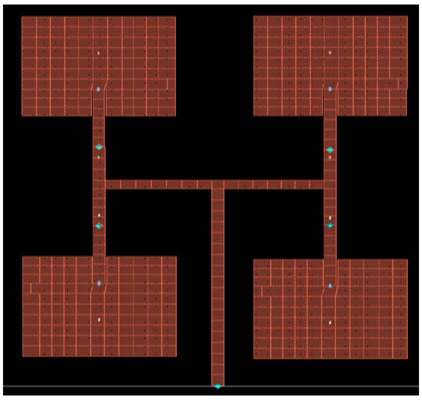

Fig.10. Layout of 4 element patch array antenna

We note that the reflection coefficient S11 at the antenna input passed to -16 dB as shown in figure 11.

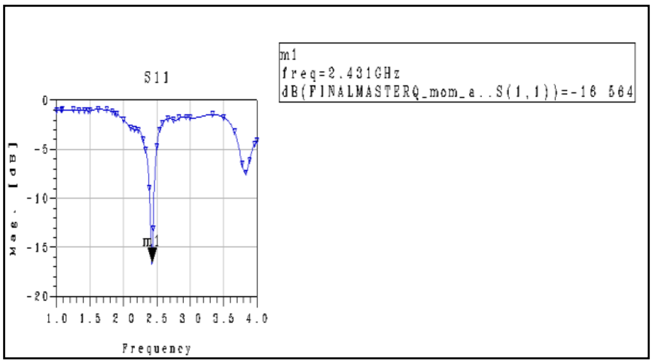

Fig.11. S11 plot for simulation of 2450MHz patch

Following this amendment, the antenna parameters have become more significant as shown in Table 2. Indeed, the value of the radiated power is 980 mW, the gain value reaches 5dB and the directivity is about 9 dB for the frequency 2.45GHz.

Table.2. Antenna parameters on two floors

Power radiated (watts)	0.000980119722	
Effective angle (degrees)	92.36	
Directivity (dB)	8.91859586	
Gain (dB)	5.068379448	
Maximum Intensity (Watts/Steradian)	0.0006080353796	
Angle of U Max (theta, phi)	45.00	0
E(theta) Max (mag, phase)	0.6768522114	-85.32015515
E(phi) Max (mag,phase)	0.001366164805	75.83294448
E(x) Max (mag,phase)	0.4786067885	-85.32015515
E(y) Max (mag,phase)	0.001366164805	75.83294448
E(z) Max (mag,phase)	0.4786067885	94.67984485

OK

IV. Conclusion

This paper presents the system for charging battery of crawler. It is to study and model the problems that have an influence on the functioning of a robot at the time of the inspection of a pipeline. Has been studied, simulated and implemented a wireless charging system, knowing that the pipeline is considered as a waveguide which improves the performance of our system. Future work we can imagine the possibility to charge batteries other remote inspection equipment to improve their performance and also to accelerate the work by minimizing the time of inspection. There will also be evaluating the device made by making measurements at different power issued and different length of the pipeline.

Figure 12. Photograph of me system and invention

V. ACKNOWLEDGMENTS

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