

AC 2008-1840: PERFORMANCE ANALYSIS OF 915 MHZ RFID SYSTEM OPERATING IN A FLUORESCENT LIGHTING ENVIRONMENT

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Performance Analysis of 915 MHz RFID System Operating in a Fluorescent Lighting Environment

Abstract

Radio Frequency Identification (RFID) has been widely utilized in retail stores and manufacturing environments, and sometimes without any consideration to environmental RF interference that can hinder its operation. Fluorescent lights, specifically the electronic ballast controlled, are found to be a common source of interference. They act as radio frequency (RF) signal reflectors which may introduce undesirable effects on the backscattered signals from RFID tags.

A project was conducted within the electronics engineering technology (EET) program as a partial requirement in the RF Effects and Measurements course. A 915 MHz RFID system was installed and operated, and its performance was investigated and analyzed in an environment abundant with electronic ballast controlled fluorescent lamps. It was found that the backscattered RF signals emanating from the fluorescent lamps interferes considerably with the tag-to-reader signal and hinders the ability of the reader to detect tag information.

This project- based approach introduced the students to state of art technology in RF wireless communication, provided a practical hands-on learning opportunity, and developed their ability to analyze and provide solutions for real life problems. The paper presents the experimental findings, their analysis, and the project educational outcomes.

Introduction

Projects investigating state of art technology are of vital importance for the graduating engineering technologists. In addition to the theoretical knowledge provided through the classical lectures and labs approach, these projects are valuable learning tools that provide a venue for the students to utilize their knowledge effectively, acquire in-depth understanding of the concepts, think critically, and independently analyze real life problems. In the Radio Frequency (RF) Effects and Measurements course two students were assigned a 3 week project as a partial course requirement. The aim was to investigate the performance and reliability of a Radio Frequency Identification (RFID) system operating in an environment abundant with electronic ballast driven fluorescent lamps. As a guideline the instructor introduced the group to the basic RFID concepts, the design concepts of the electronic ballast control of fluorescent lamps¹, and the results of previous research work^{2,3}. Their task was to carry out further analysis and investigation, based on the research results, verifying their work through practical implementation on an operating RFID system.

An Overview of RFID

Radio Frequency Identification has gained significant attention in the technology and business arenas. The two main system components are the RFID reader and RFID tags

which are attached to items to be identified (merchandise, people, pets, furniture, instruments etc.). An RFID system has a forward (reader-to-tag) RF link and reverse (tag-to-reader) RF link. These systems are widely utilized in retail stores and manufacturing environments, where fluorescent lights are commonly used. One widely-used system is the passive UHF 915 MHz RFID system. This system utilizes the radar backscatter principle to communicate back and forth between the reader and the tag, (see figure 1). The tag reflects part of the incident RF power, radiated by the reader, at the scatter aperture of the transponder antenna. The reflected power is modulated with transponder data, thus the term backscatter modulation³. It was found that the electronic ballast controlled fluorescent lamps can produce a similar backscatter signals to that of the tag-to-reader signal, and if this signal falls within the bandwidth of the modulated backscatter signal, it may significantly impede the reverse RF link from the tag to the reader².

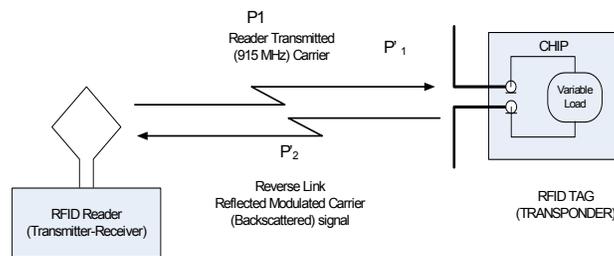


Figure 1 Modulated Backscatter Passive RFID System

In this project a circularly polarized reader antenna used to transmit UHF RFID frequencies of 915 MHz was operated in an environment with different electronic ballast controlled fluorescent lamps (FLs). The students used the knowledge and skills gained in previous labs to efficiently utilize high frequency generators and spectrum analyzers to perform precision RF spectral measurements, which were vital to project implementation. Based on the outcomes of previous research², they were tasked to perform further analysis of the backscattered signal from the FLs at different distances between the reader antenna and the FLs, and at various reader antenna/fluorescent lamp positional orientations. They were also required to apply the results to an operating RFID system and determine its reliability when exposed to the fluorescent lamps. In the following sections the experimental steps to implement the project and the technical results are presented, and the impact on student learning is reviewed.

The Experimental Set-up

The system shown in figure 2 was constructed to measure and analyze the backscattered signals from the fluorescent lamps. An RF function generator (set to 915 MHz; 10 dBm) was connected to the “transmitter part” of an RFID transmitter/receiver antenna. Connecting a spectrum analyzer to the “receiver part” of the antenna allowed the viewing of the backscattered signal spectrum.

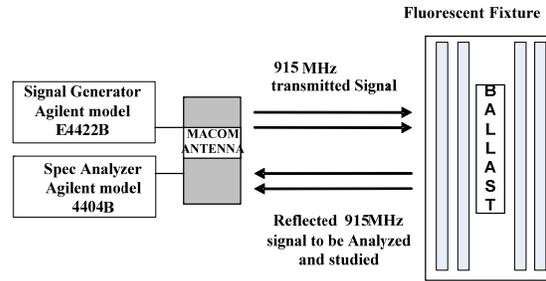


Figure 2 Experimental Set up

Experimental Procedure

Figure 3 shows two types of electronic ballast driven fluorescent lamps and the RFID reader used in the project. Figure 3a shows 3 fixtures (Set FLs1) each consisting of 2 FLs driven by ICN-2P32-SC electronic ballast. Figure 3b shows one fixture (Set FLs2); consisting of 4 FLs driven by ICN-4P32-SC electronic ballast.

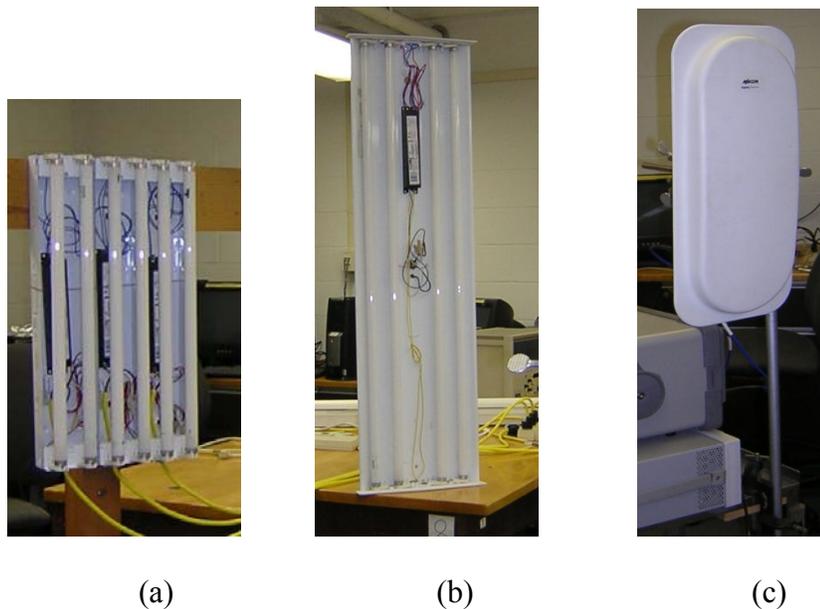


Figure 3 (a) Set FLs1, (b) Set FLs2, and (c) RFID Reader Antenna

First, the response using one fixture of the FLs1 ballast driven fluorescent lamps was analyzed using the experimental set up of figure 4b. Setting the fixture at “1 meter” from the antenna, and utilizing the measurements techniques in reference 2, a pair of prominent modulation sideband levels (at $915 \text{ MHz} \pm 83 \text{ kHz}$) were recorded in figure 5. The 83 kHz modulation sidebands are the backscattered signals caused by the *On/Off* switching of the fluorescent lamp². The switching phenomenon is due to the ionization and deionization process of the gasses in the lamp tube and closely resembles the backscatter behavior of the RFID tag signal^{2,3}. These measurements, shown in table 1, were repeated at various horizontal angles from the front of the antenna (assuming approximate symmetry). They show that when the FL fixture was in the back half-circle of the antenna, the position of lowest antenna directional gain as indicated by the

radiation pattern figure 4a, the sideband powers were at the noise floor level. As the fixture was placed closer to directly in front of the antenna, the position of maximum antenna directional gain, the sideband powers reached their maximum value of “-94 dBm”.

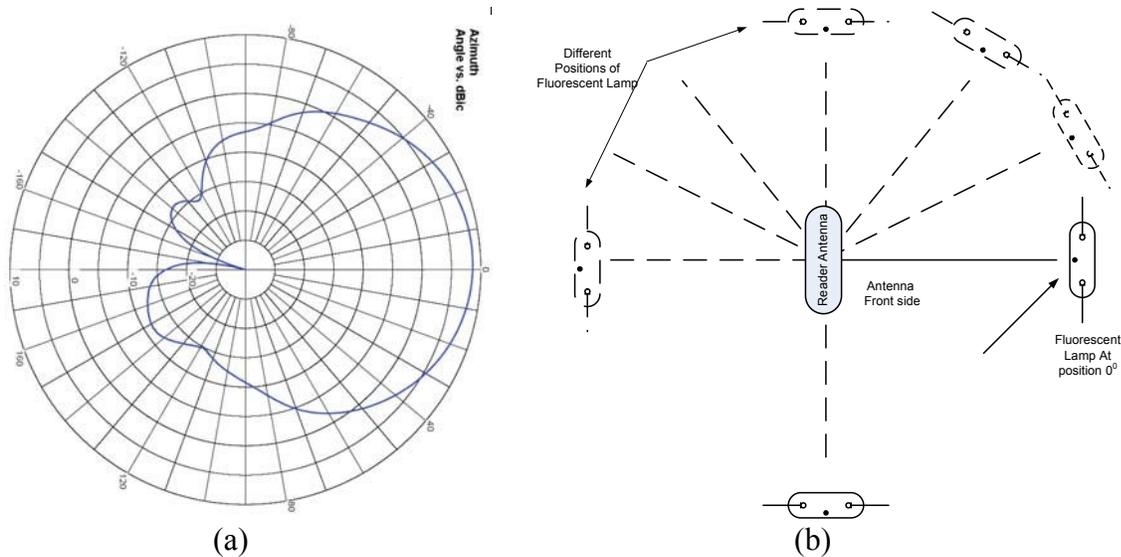


Figure 4a the antenna radiation pattern, 4b. Horizontal orientation of lamp around the antenna

Note: after expanding the spectrum of the first sideband, the individual components of the sideband can be seen, (refer to figure 6). Notice how the peaks differ by 120 Hz, twice the frequency of the standard 60 Hz power used to power the ballast electronic circuit, which is a similar result to what was obtained and explained in reference 2.

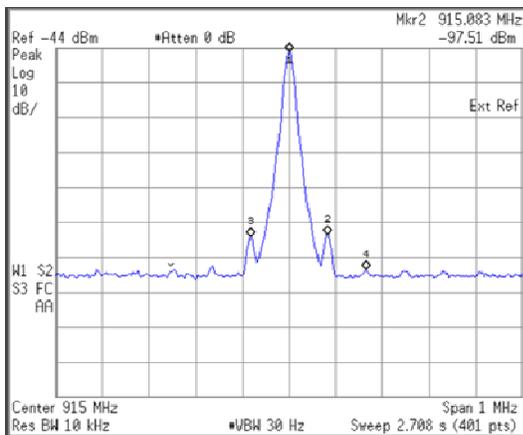


Figure 5 Received power with one lamp operating 1 meter away (facing antenna)

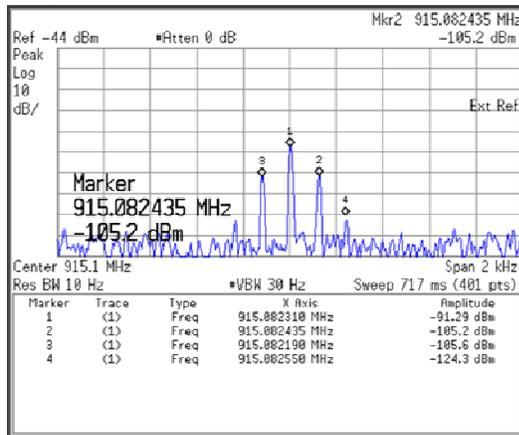


Figure 6 Expanded view of the first sideband

Table 1

Distance of 1 meter	
Angle from front of antenna	Measured first sideband power (dBm)
0°	-94
30°	-97
60°	-103
90°	-107
90°~180°	-108 (noise floor level)

A second set of measurements was taken by angling the vertical position of the antenna at a distance 1 meter from the FL, (see figure 7).

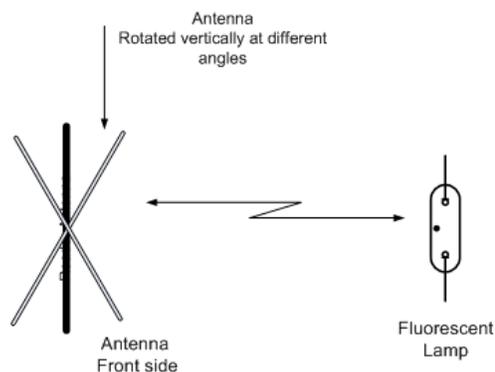


Figure 7 Vertical angular rotation of antenna

Results are tabulated in table 2 below. (Note that measurements were taken in the lab, therefore there is some error in the precision due to reflections from walls, cabinets, etc.)

Table 2

Distance of 1 meter	
Angle of antenna	Measured first sideband power (dBm)
0° (directly facing lamp)	-92
30°	-95
60°	-106
90°	-107
90°~180°	-108 (noise floor level)

As expected, the greatest received power in the sideband is when the antenna directly faces the lamp.

A third set of measurements were taken of the lamp and antenna directly facing each other at various distances. The data in figure 8 shows the reduction in the FL backscattered radiated power as distance increases, which is a familiar characteristic of RF signal propagation.

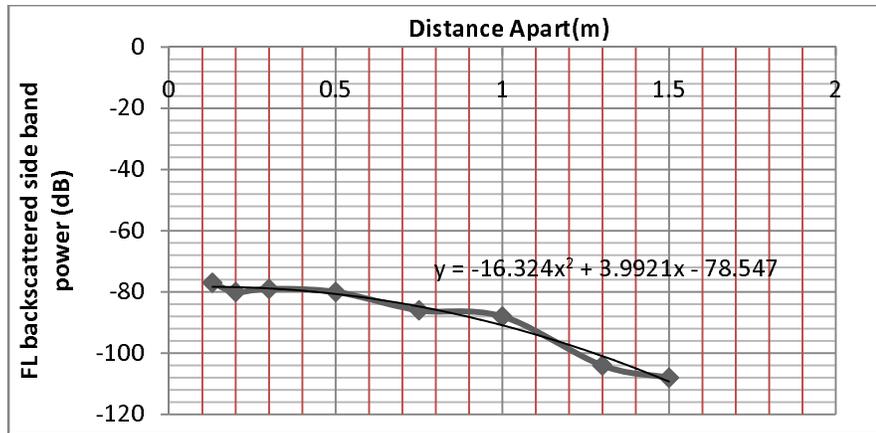


Figure 8 FL Backscattered sideband power vs. distance apart

Multiple Lamp Measurements

The experimental set up is shown in figure 9, with the function generator set at 915 MHz 10 dBm RF output:

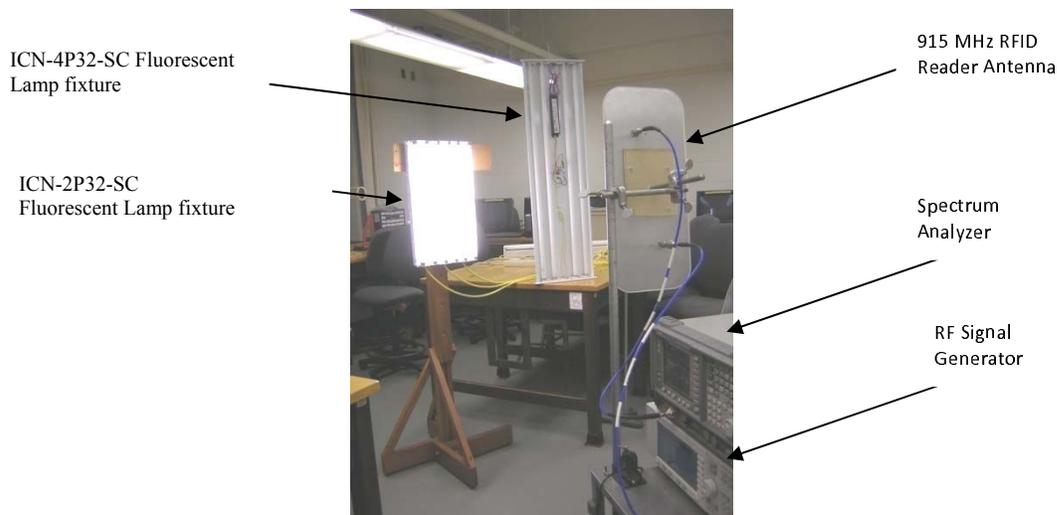


Figure 9 Two set of electronic FLs, (Note the ceiling FL is an old 60 Hz power line ballast FL which doesn't produce frequencies within RFID backscattered spectrum)

Measurements taken using multiple lamps in the FLs1 fixture showed that:

- With one fixture *ON* at 1 meter, the reflected sidebands power was -86 dBm.
- With two fixtures *ON* at 1 m, -84 dBm;
- With three fixtures *ON* at 1m: -82 dBm.

Each lamp fixture increased the power of the backscattered signal by 2 dB which is equivalent to absolute power gain of 1.6. Using a different fixture (FLs2) with different ballast, 4P32, more measurements were taken, and the results showed that:

- At 0.5 m, the received sideband powers were -81 dBm. At 1 m, the power was “-88 dBm”. The important observation here is that the sidebands frequency has changed from 83 kHz to 90 kHz.
- With both the 2P32 and the 4P32 lamps on, initial analysis showed that the received power looked surprisingly the same. However, upon closer spectral analysis two “first” sidebands peak were observed, one for the 83 kHz 2P32 ballast and another for the 90 kHz 4P32 ballast.
- The significance of this is that if the two ballasts are used in near proximity of the RFID system, even more tag frequencies could be blocked out due to the increased bandwidth of received backscattered interference.

Effects on an Operating RFID system

The above measurements do not mean much until they are compared to the receiving capabilities of an RFID system. Since the RFID system is designed to detect backscattered tag signals as low as the -100 dBm range³, the effects of the fluorescent lamps become very strong possibility. However, it is almost impossible to state whether or not the lamps will have significant effects until simulations are done with an operating RFID system. Some points to ponder before introducing the fluorescent lamps into the RFID system are:

- Do the lamps block out only a select few tags such as those only operating at that exact same frequency of the reflected power from the lamps?
- Is the reflected power from the lamps large enough to block out the signal transmitted by the tag, or can the reader still recognize the tag?
- Is there a location where the lamps could be placed to guarantee no interference?

The results of placing the ICN-2P32-SC lamps near the RFID system were actually rather surprising. An RFID system was set and operated using different types of tags. A testing environment was created by placing the lamps about 2.5 meters from the reader and about 20° off the maximum directional gain position (refer to figure 10). Figure 11 shows the two tags used together with the operating RFID system. They are ALN 9540 and ALN-9534; both are of the latest generation of RFID tags EPC-Class 1 Gen 2⁴.

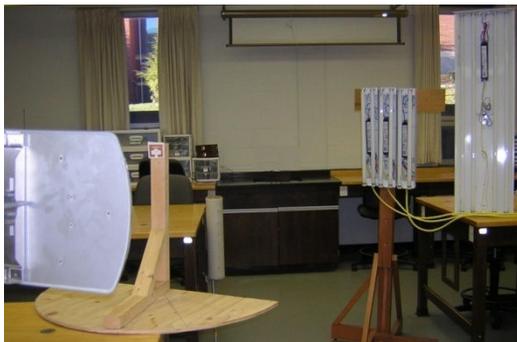


Figure 10 Operating RFID system with electronic Ballast driven Fluorescent lamps

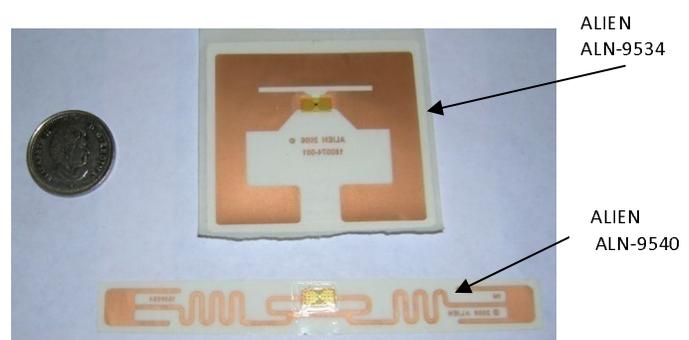


Figure 11 EPC-Class 1 Gen2 tags

Experimental results showed that:

- By holding the ALN-9540 tag at about 2.5 meters from the reader where it can still be read effectively, and then switching on the 2 fixtures the received signal from the tag was completely blocked.
- With the ALN-9540 tag at 0.8 m from the reader, with the lights *ON* at 2.5 m, the reader still would *not see the tag most of the time*.
- Using the ALN-9534 tag at 0.8 m from the reader, with the lights *ON* at 2.5 m, the reader would *not see the tag at all*. This may be due lower sensitivity of the 9534 compared to 9540, refer to reference 4.
- This seems rather surprising since the measured first sideband power reflected from the FL, at 1.5 meter, was already down to the -100 dBm range (noise floor). So, with FLs at a distance of 2.5 meters, the received power would be even less, (see figure 8). However, this low level interference was enough to significantly reduce reliability and the readability of the tag information.

Before the fluorescent lamps were implemented into the RFID system, the students felt that the FLs would have minimal effect on the RFID tags' readability since the reflected received power was measured as very close to the noise floor on the spectrum analyzer at a distance of 1.5m. However, the lamps when used in combination with an operating RFID system caused considerable decrease in the reliability of the reader to detect the tag information.

Lessons Learned

This project was conducted during the last 3 weeks of the RF effects and measurement course and under the supervision and guidance of the instructor. It aimed at training the students to analyze, optimize, and propose an engineering solution for a problem that may hinder the operation of a new evolving state-of-the-art technology system. The students effectively utilized their theoretical and practical knowledge to analyze the existing problem. They gained hands-on experience in effective utilization of RF instruments to acquire reliable measurements. They learned how RFID systems work, and how a seemingly simple operational configuration (RFID within range of fluorescent lamps) may cause considerable effects on the reliability of the system. It made the students think like engineering technologists, they did not only learn how a sophisticated system operated but they also learned how to analyze problems associated with RF systems operations, signals, and their effects. The knowledge gained and in depth understanding could not possibly be attained in a two hour lectures and two hour lab course.

Conclusion

Only after operating the lamps in conjunction with the RFID system can better conclusions be made. Using the results witnessed by having a fluorescent lamp nearby (2.5 meters), it is concluded that **electronic ballast-operated fluorescent lamps may indeed greatly decrease the reliability of the RFID system**. Even with the lamps behind the reader, reflective materials in the vicinity may cause this interference to reflect back into the reader and impede its reliability (this was also proven experimentally).

Basically, the only way to truly tell if the RFID system will work with various lamps is to actually test it on site. Since the reflections and positions of the lamps could greatly change the readability for certain settings, it cannot be concluded that the system will or will not work with a specific array of electronic-ballast fluorescent lamps. However, it is worth noting that the standard (non-electronic ballast) fluorescent lamps did not noticeably hinder the readability of the tags in the RFID system, as was not the case with the electronic ballasts.

At the end of the projects the students' comments indicated that:

- The project was very interesting and informative, other than the repetitive measurements which were boring.
- The actual simulation with an operating RFID system dictated the effects of the fluorescent lamps.
- The project made them think of what is going on in the real world of RF engineering.
- The project trained them how to identify a real life engineering problem and think how to fix it.
- For such a project, more structure needs to be created and more guidelines provided.
- It definitely needs further tests and analysis.

From the group discussions and comments it is concluded that the students have learned to identify an existing problem using precision measurements techniques, analyze and critique the results, think critically, and suggest possible remedies.

References

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2. Ibrahim G., Sensenig J., Effect of Fluorescent Lights on the RFID Systems operating in Backscatter mode, ASEE 2007 annual conference Proceedings.
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4. Alien Technology ALN-9540 & ALN-9543 Product Overview, www.alientechnology.com