Design An Antenna For Pacemaker Communication

Computer optimization helps develop an antenna that is small enough to fit on a pacemaker battery pack.

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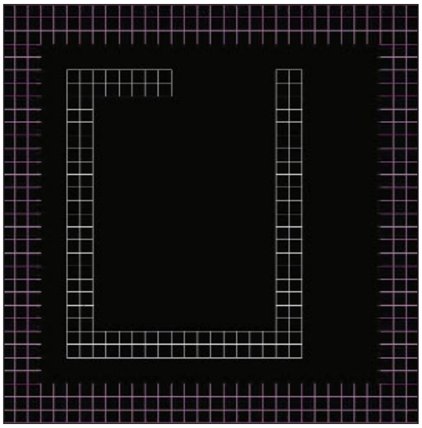
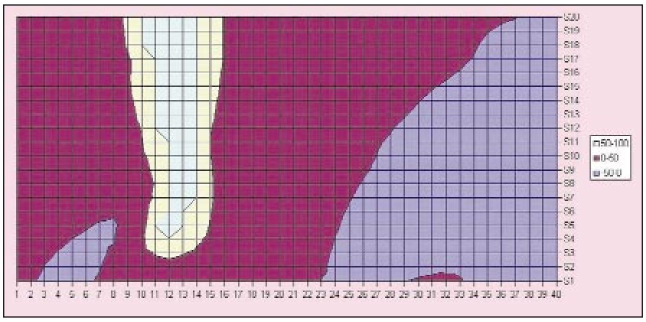
CARDIAC pacemakers are implanted inside the human body to monitor the heart's activity and take control when the heart rate falls below a programmed minimum, typically 60 beats per minute. Pacemakers are programmed with a pulse speed and stimulation waveform, and must be re-programmed to match the heart's changing condition. Pacemakers also collect useful diagnostic information, including the number of times the patient's heart requires excitation. Currently, the only way to re-program the pacemaker and collect diagnostic information from it is to use a large inductive coupler or to operate on the patient and remove the pacemaker from the body. In the latter case, the operation is performed infrequently–once every few years—to minimize trauma to the patient. It would be more desirable to download diagnostic information from the pacemaker and upload improved settings to it on a regular basis with a simple portable-communication device. This could be achieved by fitting a pacemaker with a miniature radio transceiver, allowing it to communicate with similarly equipped diagnostic, monitoring, and programming devices. The challenge is to design an antenna that is small enough to be unobtrusive in the body yet carry radio signals at a frequency that can penetrate body tissue. This article describes the design of a 2-in.^{2}, 433-MHz patch antenna that is small enough to fit on a standard-pacemaker battery pack. The design makes use of electromagnetic (EM) simulation software with an optimization engine.

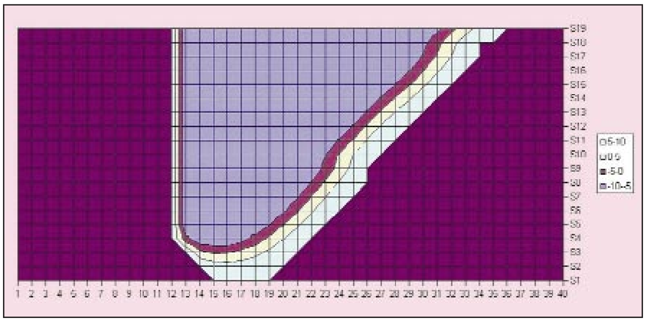

1. This antenna design length = 13 cells, which is an iSIGHT optimal design.

The first step in the design process was to find a frequency where radio signals could easily penetrate body tissue and communicate with external equipment, yet have a wavelength small enough to permit the use of a miniature, unobtrusive antenna, which is in itself small enough to fit on an existing pacemaker. For example, an antenna that is built to operate at an ultra high frequency of 2450 MHz would have a quarter wavelength of approximately 3 cm and could easily be manufactured small and unobtrusive. But at this frequency, radio signals can only penetrate a few centimeters of body tissue. On the other hand, radio signals at a frequency of 433 MHz would penetrate body tissue well enough to communicate with outside equipment, but antennas used at this frequency are normally 5 or 6 in. (12.7 or 15.24 cm) long. This type of antenna that is attached to a pacemaker would protrude into other parts of the body and risk infection or lung punctures. Nonetheless, the authors decided to develop a miniaturized 433-MHz antenna that could fit onto the battery pack of the pacemaker.

The authors chose to pursue a particular type of antenna design known as a microstrip antenna, which



2. Real component of the impedance (note: 50 Ω is good) can be seen.



3. Imaginary component of the impedance (note: close to zero is good) is noted here.

excites an arbitrarily shaped conductor on a dielectric substrate with a backplane conductor. Since there is no analytical solution for designing an insulated and arbitrary-shaped microstrip antenna that is embeded in lossy media, the authors used EM finite-difference, time-domain (FDTD) software known as XFDTD from Remcom, Inc. (State College, PA) to evaluate the performance of specific designs. They selected FDTD software because it is capable of analyzing conductors, lossy dielectrics, magnetics, anisotropic materials, biological tissues, ferrites, as well as many other materials. Furthermore, as problems become electrically complex, the FDTD method quickly becomes more efficient in terms of computer time and memory than other methods since no direct-matrix solution is required. FDTD can provide results for a wide spectrum of frequencies from only one calculation using transient-pulse excitation and Fast Fourier transform (FFT) analysis.

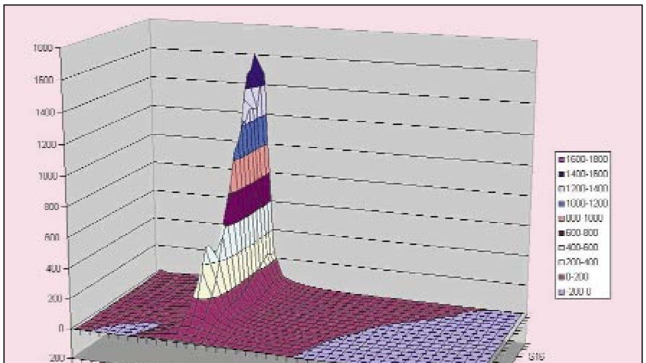
MANUAL SIMULATION

Even with the benefit of powerful simulation tools, the development of microstrip-antenna geometry meeting the stringent requirements of this application is a very difficult task. The authors gridded the microstrip antenna, cardiac pacemaker, and surrounding tissue with a 2-mm cell size. They created and analyzed 109 variations of this base model, primarily by varying the length of the patch, the location of the feed point, and the location of one or more grounding pins. After nine months of analysis, they finally developed two designs that met the requirements of the project—a U-shaped patch antenna and a spiral-shaped antenna.

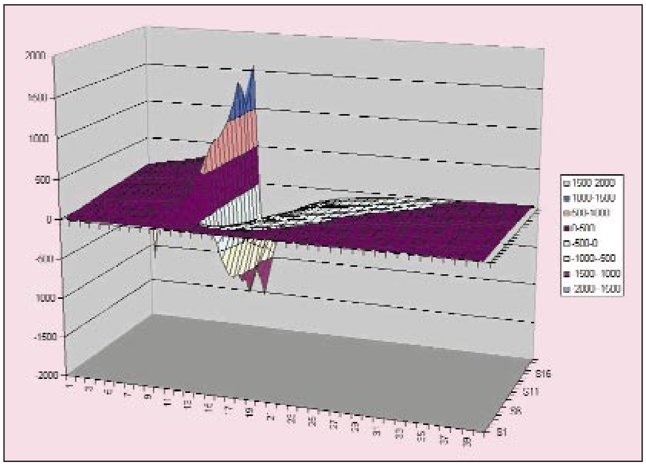
The work demonstrated the viability of the 433-MHz microstrip-antenna concept, but the authors recognized that the design would need to be re-engineered at least a few (and possibly many more) times to meet additional requirements that would arise as the project evolved. The authors did not feel the project could bear the time and expense of multiple iterations of the difficult manual-design process, so they employed an optimization software package called iSIGHT from Engineous Software, Inc. (Morrisville, NC). Essentially, iSIGHT replaces the manual, trial-and-error portion of the traditional design process with an automated, iterative procedure. The software automatically changes the input data, runs the XFDTD-analysis codes, assesses the output, and changes the input again based on instructions from an optimization algorithm chosen for the specific problem. The software optimizes the performance of the overall system while balancing conflicting design requirements and meeting all design constraints. It also provides graphical visualization of how the trade-offs in design parameters affect antenna performance.

In setting up the optimization problem, the authors created an interface between iSIGHT and XFDTD. This process was as simple as selecting the right parameters in the input and output files of XFDTD. The variables that they allowed iSIGHT to control were the length of the spiral antenna and the locations of the source and the ground pins. They set a maximum length of 40 cm and a maximum distance from source to ground of 20 cm. In this case, they fixed the shape of the antenna to a spiral. iSIGHT was given the latitude of selecting a design shape, which at the total length of 40 cm, was a spiral configuration and at minimal length, was an inverted L-shaped configuration. The design that iSIGHT selected was slightly longer than a full U-shaped configuration (Fig. 1).

iSIGHT is also capable of optimizing the shape of the antenna, and the authors plan to use this feature on future designs. The output variables that the program used to evaluate the performance of each design iteration were the real and imaginary values of the antenna impedance. For a matched resonant antenna, the real



4. The real feasible values between + or –50 are feasible, while values higher than 50 set to 50.



5. Imaginary feasible values between + or –10 are feasible, and values higher than 10 set to 10.

value of impedance must be as close as possible to 50 Ω and the imaginary value must be as close as possible to 0 Ω at the design frequency of 433 MHz.

They configured iSIGHT to use a genetic algorithm to seek out the optimized design. Genetic algorithms are based on two assumptions—the best solutions will be found in the regions of parameter space containing relatively high proportions of good solutions, and these regions can be explored by genetic operators of selection, crossover, and mutation. Genetic algorithms start with a population of design variables that are manipulated with genetic operators to create a new set or generation of designs. Each population of designs is evaluated and a new population of designs is selected based on a survival-of-the-fittest scheme. It is worth noting that the software package provides an optimization advisor that guides the user toward the best of several available techniques for a particular problem.

The next step was simply turning on the optimization engine. Using the genetic algorithm, iSIGHT proceeded to create and analyze approximately 100 to 300 different designs, depending on the initial design location. The genetic algorithm was used to explore the design space until a feasible design was found which satisfied the design constraints. There were only a handful of designs that were feasible solutions—those where the impedance was approximately 50 Ω. Evaluation of the analysis results later revealed one of the challenges of hand-optimizing this design problem. The design space is very "bumpy"—relatively small changes in the design variables create large changes in the output variables in some regions of the design space. In other regions of the design space, large changes make very little difference (Figs. 2 and 3). For example, the final optimized design selected by the software had a real impedance value of 52.99 Ω and an imaginary value of 11.41 Ω. Yet, an adjacent design had a real impedance of 90.38 Ω and an imaginary impedance of −3.57 Ω. Figure 4 is a design-space map showing regions of feasible designs for real impedance values. Figure 5 shows the same for imaginary impedance values.

The solutions developed by the optimization engine and the authors turned out to be quite similar. This is to be expected, since the design goals and the variable parameters were the same in both cases. The design generated by iSIGHT had slightly better gain. But the truly remarkable difference was the amount of time that was required to produce the designs. The human designers took nine months to find an acceptable design, while the optimization engine took only one week to find the optimum design. The actual improvement was even greater considering the fact that only two days were required to set up the optimization problem—the rest of the time the computer ran by itself without requiring any manual intervention.

The antenna was built and tested using a network analyzer and spectrum analyzer. Raw ground beef was used in order to simulate human chest-cavity tissue. The measurement of the prototypes matched the simulation results, except that they operated at a lower frequency. This difference was attributed to the fact that the prototype was constructed from a different material than that used in the analysis. Work is continuing at Utah State to validate the design and adapt it to several different pacemaker designs. The end result is intended not to commercialize the device, but rather to validate the technology and encourage its implementation by pacemaker manufacturers.●●