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TELEDYNE TEST TOOLS

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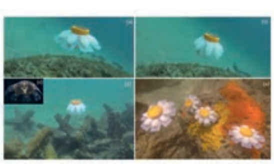

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- Efficient biomimetic ecological underwater robot

Regular column

- Robotics advancements are transforming many applications

Products

- Expanded automotive LED driver portfolio

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Cover supplied by TELEDYNE LECROY
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EPAPER AND THE 'STATE OF DISPLAY'

All engineers must find a balance between the pragmatic and the visionary to ground their ideas and troubleshoot them easily without compromising the functionality of the product. However, engineers could benefit from a little risk-taking when it comes to choosing materials for their products, especially in displays.

Challenging the Status Quo

Displays maker Plastic Logic recently surveyed engineers to identify the key trends when designing new products; the findings are outlined in the report called *'State of Display'*.

From the survey, it's obvious that when it comes to general product development, innovation of new features is considered crucial. Some 83% of the surveyed engineers considered it important, and 44% are actively required to innovate new features as part of their projects, confirming their requirement and obligation to put serious effort into the creative side of product development. As a result, their product can be differentiated from that of rivals and predecessors.

Sadly, this attitude doesn't seem to extend across all parts of product design. Despite a general positivity toward innovation, and 66% of respondents believing that the choice of display has a major effect on their final product's look, feel and functionality, only 20% conduct rigorous assessments of the display technology as part of their product design.

The surveyed engineers indicated their display materials of choice to be either LCD Graphical (35%) or OLEDs (27%). But, if products continue to use the same display materials, they will suffer from the same drawbacks, and fail to offer any differentiation or competitive edge.

On a positive note, however, engineers seem to acknowledge the drawbacks and limitations associated with these everyday displays.

Material World

The survey also found that those qualities liked in a display are also their weaknesses. Based on the survey, ruggedness (37%), outdoor readability (31%) and low power consumption (30%) are the three most critical display requirements, and are the most common issues for those working with glass displays like LCD Graphical or OLED.

Glass displays may be cheap and familiar, and provide high-quality images, but they also suffer from a number of issues that frustrate consumers: they are easy to break, inflexible, consume power at a high rate, and can be impossible to use under direct sunlight.

> **ePaper is highly resistant to scratches and impacts, and bends without snapping; it's easy to read under direct sunlight and boasts exceptionally low power consumption**

These weaknesses are leading to ePaper's emergence as an alternative material for displays. ePaper is highly resistant to scratches and impacts, and bends without snapping. It's easy to read under direct sunlight and has exceptionally low power consumption. For engineers looking to mitigate the weaknesses of the materials they are accustomed to, ePaper performs exceptionally well.

ePaper is also falling in price, since volume manufacturing has started to ramp up, buoyed by its use in a growing number of applications. Examples include Transport for London and DresdenElektronik's live-update bus timetables, OneBagTag's unique ePaper luggage tag, and Google and Levi's collaboration on fash-tech.

The areas where ePaper displays are being used are a testament to the creative potential of the material, and the unique set of qualities it brings to a product. ❖

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SCIENTISTS CREATE EFFICIENT BIOMIMETIC ECOLOGICAL UNDERWATER ROBOT

A team of US scientists from Florida Atlantic University (FAU) and the US Office of Naval Research have developed underwater robots to monitor and care for fragile parts of the oceans without damaging them. The robots belong to the biomimetic group, denoting synthetic methods which mimic biochemical processes. The underwater robots are designed to swim freely and through narrow openings, steering from side to side, mimicking the swimming of jellyfish. Previous robot jellyfish designs used a variety of different propulsion mechanisms, whereas this one uses hydraulic networks for propulsion.

"Biomimetic soft robots based on fish and other marine animals have gained popularity in the research community in the last few years. Jellyfish are excellent candidates because they are very efficient swimmers," said Dr Erik Engeberg, of FAU. "Their propulsive performance is due to the shape of their bodies, which can produce a combination of vortex, jet propulsion, rowing and suction-based locomotion."

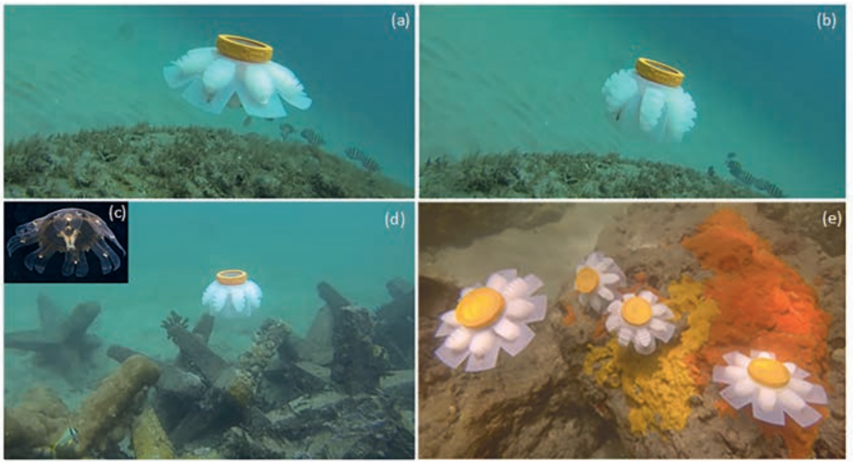
To allow the artificial jellyfish to steer, the team used two impeller pumps to inflate their eight tentacles. This design produced an open circuit of water flow, where water from the environment was pumped into the soft actuators to produce a swimming stroke. When the pumps were not powered, the elasticity of the tentacle silicon-rubber material constricted the actuators to push the water back into the environment during the relaxation phase. The elasticity is akin to that of real-life jellyfish after bell contractions. The design also removed the need for valves, reducing control complexity, space requirements and cost.

The team 3D-printed five different robot jellyfish, using silicon rubber for the actuators. Each jellyfish had a varying rubber hardness to test the effect it had on the propulsion efficiency.

"A main application of the robot is exploring and monitoring delicate ecosystems, so we chose soft hydraulic network actuators to prevent inadvertent damage. Additionally, live jellyfish have neutral buoyancy. To mimic this, we used water to inflate the hydraulic network actuators while swimming," said Dr Engeberg.

The team are now planning to incorporate environmental sensors like sonar into the robots' control algorithm, along with a navigational algorithm, to enable them to find gaps and determine if they can swim through them.

Biomimetic jellyfish robots



BRAINCHIP PLANS TO RELEASE ITS VERSION OF A NEURAL NETWORK CHIP NEXT YEAR

BrainChip Holdings, a small company listed on the Australian stock market, has disclosed the details of its neuromorphic system-on-a-chip (NSoC) chip called Akida, which will be ready for sampling late next year.

Its architecture mimics the biological processes of the brain, digitally. It contains data-to-spike converters, the 'neuron' fabric that does the computation and processing, some supervisory functions, I/Os for different type sensors, and more.

When signals arrive to the chip from sensors, be they analogue or digital, the architecture's layer of converters transforms them into 'spikes' (hence, "spiking neural networks", or SNNs), which then move forward through the network of logic gates ("hidden layer"). It is this progression of signals (spikes) through the network that makes it like that of the brain (or "neuromorphic"), and neither the traditional architectures (von Neumann, Harvard) nor convolutional neural networks (CNNs) work in the same manner.

"Spiking neural networks are considered the third generation of neural networks," said Peter van der Made, founder and CTO of BrainChip.

As these spikes move through the neural network, they are then either re-enforced or inhibited, based on the way the network has been trained or evolved. Multiple spike streams are handled simultaneously and asynchronously, leading to high-level parallelism at low power. The low power consumption is due to the chip using standard CMOS technology, but also because spikes are fired off only when there's change in information.

The BrainChip team claim this combination of low power and efficiency will make Akida appeal to sectors where number-crunching and trend-identifying are essential, such as in the financial business (parameter identification and analysis), automotive industry (object recognition and classification), and machine vision and cybersecurity, among others. However, the chip's accuracy so far is around 82%.

The Akida NSoC is designed for use as a standalone embedded accelerator or as a co-processor. Its neuron model contains some methodologies for supervised and unsupervised training. In the supervised mode, the initial layers of the network train themselves autonomously, whereas in the final fully-connected layers, labels can be applied, enabling the neural network to function as a classification network.

The Akida Development Environment is available now. The chip will be out late next year, expected to cost around $10.

Signal processing for digitisers – part 2

BY **OLIVER ROVINI** AND **GREG TATE**, SPECTRUM INSTRUMENTATION

Modular digitisers enable accurate, high-resolution data acquisition for quick transfer to a host computer. Signal processing functions, whether applied in the digitiser or the host computer, enhance the acquired data or extract useful information from a simple measurement.

Modern digitiser support software incorporates many signal processing features. These include waveform arithmetic, ensemble and boxcar averaging, Fast Fourier Transform (FFT), advanced filtering functions and histograms. This article, consisting of two parts, investigates all these functions and provides typical examples of common applications for these tools; this is part 2.

Weighting Functions

The theoretical Fourier transform assumes the input record is of infinite length, since a finite record length can introduce discontinuities at its edges, which introduces pseudo-frequencies in the spectral domain, distorting the real spectrum.

When the start and end phase of the signal differ, the signal frequency falls within two frequency bins, broadening the spectrum. The broadening of the spectral base, stretching out to many neighbouring bins, is termed leakage. Cures for this are to ensure that an integral number of periods is contained within the display grid, or that no discontinuities appear at the edges. Both approaches need very precise synchronisation between waveform signal frequency and digitiser sampling rate, and an exact setup of the acquisition length, which is normally only possible in the lab, and not with real-world signals.

Another method is to use a window function (weighting) to smooth the edges of the signal. To minimise these effects, a weighting function is applied to the acquired signal which forces the end points of the record to zero. Weighting functions have the effect of changing the shape of the spectral lines. One way of thinking about the FFT is that it synthesises a parallel bank of bandpass filters, spaced by the resolution bandwidth. The weighting function affects the shape of the filter frequency response. Figure 1 compares the spectral responses for four of the most commonly-used weighting functions, and Table 1 shows the key characteristics of each.

Ideally, the main lobe should be as narrow and flat as possible to represent the true spectral components, while all side lobes should be infinitely attenuated. The window type defines the bandwidth and shape of the equivalent filter to be used in the FFT processing.

Maximum side-lobe amplitudes of the spectral response are shown in Table 1. Minimum side-lobe levels help discriminate between closely-spaced spectral elements.

As mentioned previously, the FFT frequency axis is discrete, having bins spaced in multiples of the resolution bandwidth. If the input signal frequency falls between two adjacent bins, the energy is split between the bins, and the peak amplitude is reduced. This is called 'picket fence' effect or scalloping. Broadening the spectral response

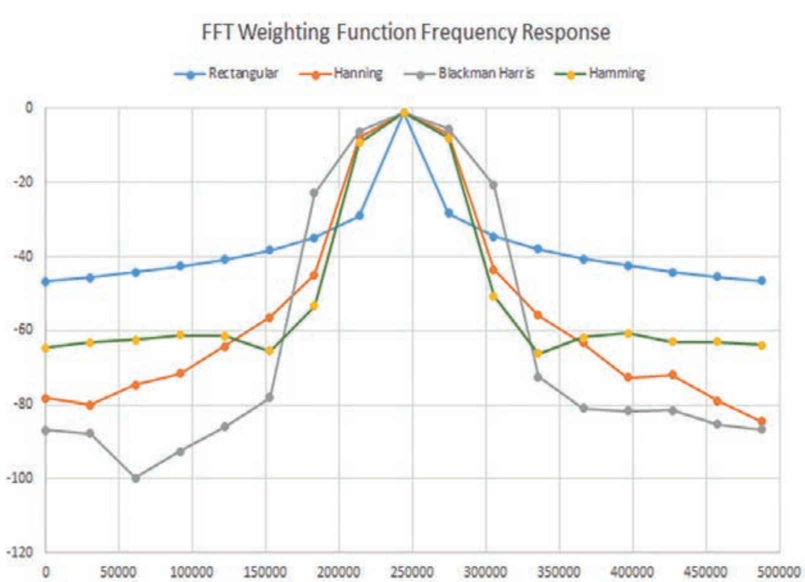


Figure 1: A comparison of the spectral shape for four most commonly used weighting functions including rectangular (no weighting), Hanning, Hamming and Blackman-Harris

decreases amplitude variation. The scallop loss column in Table 1 specifies the amplitude variation for each weighting function.

Weighting functions affect the bandwidth of the spectral response. Effective noise bandwidth (ENBW) specifies the change in bandwidth relative to that of rectangular weighting. Normalising the power spectrum to the measurement bandwidth (power spectral density) requires dividing the power spectrum by the ENBW, times the resolution bandwidth.

Coherent gain specifies the change in spectral amplitude for a given weighting function relative to rectangular weighting. This is a fixed gain over all frequencies and can easily be normalised.

The rectangular weighting function is the response of the acquired signal without any weighting at all. It has the narrowest bandwidth but exhibits rather high side-lobe levels. Because the amplitude response is uniform over all points in the acquired time-domain record, it is used for signals transient in nature (much shorter than the record length). It is also used when best frequency accuracy is required.

The Hanning and Hamming weighting functions have good, general-purpose responses, providing good frequency resolution along with reasonable side-lobe response.

Blackman-Harris is intended for the best amplitude accuracy and excellent side-lobe suppression.

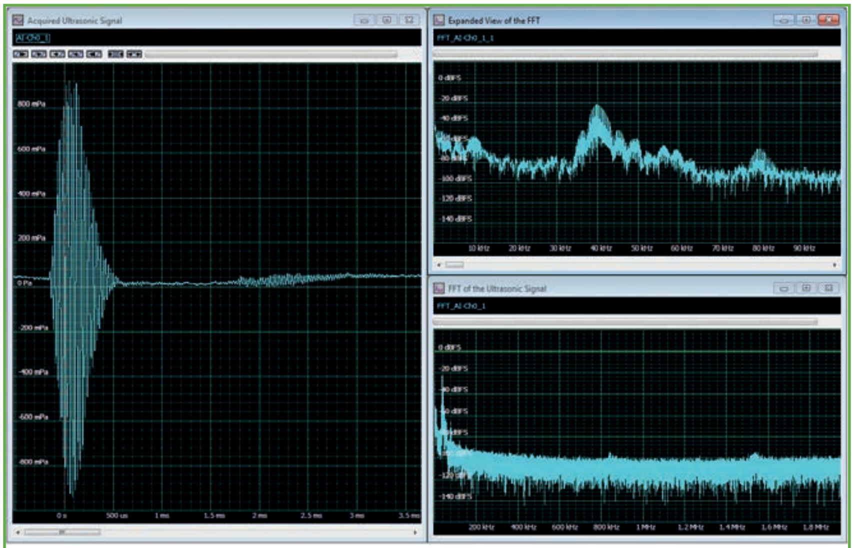


Figure 2: A 40kHz ultrasonic pulse (left)and its associated FFTs (lower right full spectrum, upper right zoom view) showing the principal spectral response at 40kHz along with undesired lower and higher frequency components

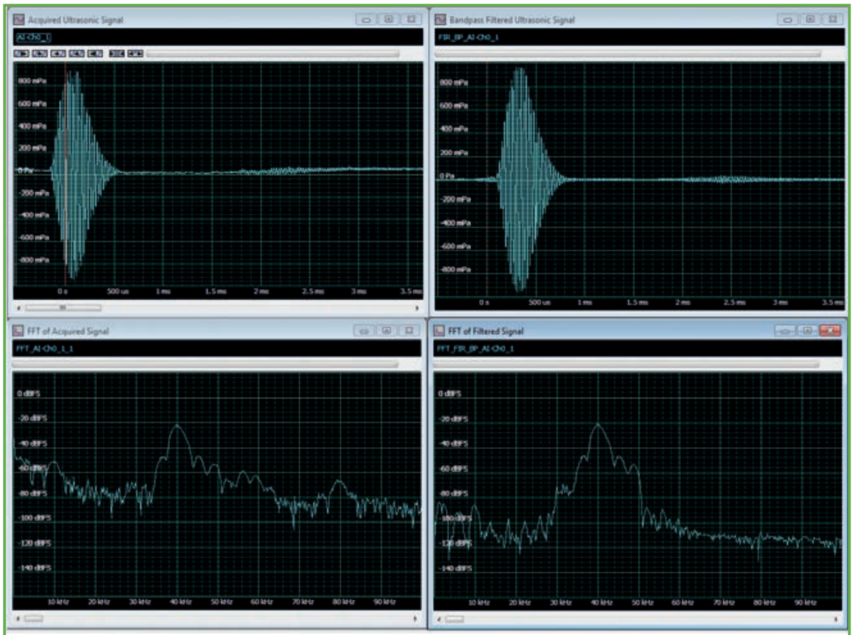


Figure 3: Showing the effects of applying a FIR bandpass filter with cut-off frequencies of 30-50kHz to the 40kHz ultrasonic signal. The raw waveform and its FFT are on the left side of the display, with the filtered signal and its FFT on the right. Note the flatness of the filtered baseline, the result of eliminating low-frequency pickup

FFT Application Example

Figure 2 shows a typical example where the FFT is useful. The signal from an ultrasonic range finder is acquired using a broadband instrumentation microphone and a 14-bit digitiser.

The acquired time-domain signal is in the left grid. The record includes 16,384 samples taken at a sample rate of 3.90625MHz; its duration is 4.2ms. The resultant FFT (right grids) has 8,192 bins spaced at a resolution bandwidth of 238Hz (the reciprocal of the 4.2ms record length) for a span of 1.95MHz (half the sampling rate). The spectrum in the lower right is the full span. The zoom view in the upper right shows only the first 100kHz, for a better view of the main spectral components.

The FFT allows better understanding of the elements that make up this signal. It is a transient signal with duration shorter than the acquired record length. In this case, rectangular weighting has been used. The primary signal is the 40kHz burst, which is clearly the frequency component with the highest

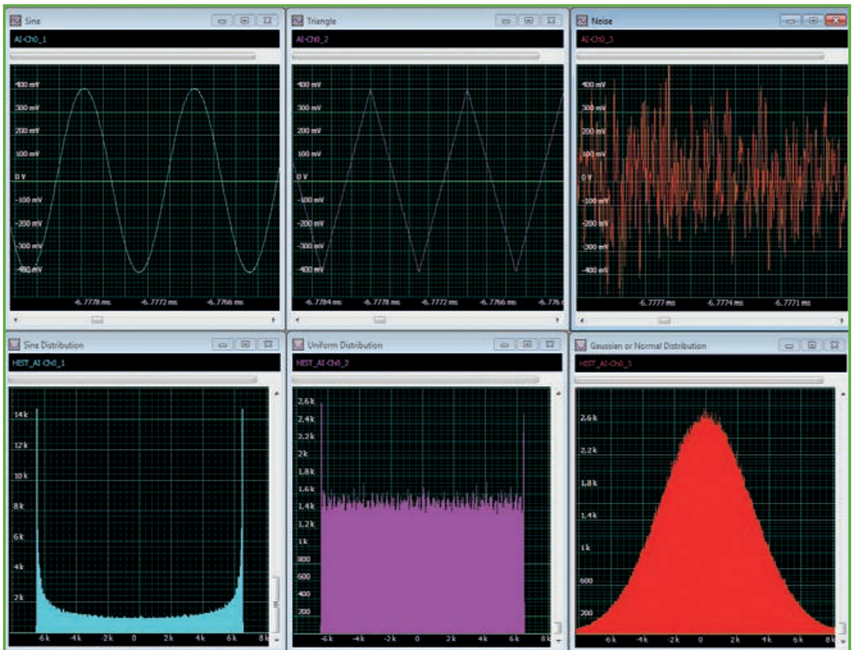


Figure 4: Some example of common waveforms including sine, triangle and noise, and their associated histograms

amplitude. There is an 80kHz signal, which is the second harmonic of the 40kHz component. Its amplitude is about 45dB below the 40kHz signal component. There are also many low-frequency components between 0Hz and 10kHz. The highest ones, those near DC, are ambient noise found in the room where the device was used.

The goal here is to be able to measure the time delay between the transmitted burst and the 40kHz reflection. To improve this measurement, we can remove the signal frequency components outside the 40kHz components range. This spectral view will be our guide in setting up a filter to remove the unwanted frequency components.

Filtering

The example shows finite impulse response (FIR) digital filters in lowpass, bandpass or highpass configuration. Filters can be created by entering the desired filter type, cut-off frequency or frequencies, and filter order. Alternatively, you can enter filter coefficients derived from another source. These filters can be applied to the acquired signal, and we can then compare the results with the raw or averaged acquisitions.

In Figure 3, a FIR bandpass filter with cut-off frequencies of 30 and 50kHz has been applied to the acquired signal. The upper left grid contains the raw waveform. Below that is the FFT of the raw signal that we have seen before. The upper right grid contains the bandpass filtered waveform. The FFT of the filtered signal is in the grid on the lower right. Note that the bandpass filter has eliminated the low-frequency pickup and the 80kHz second harmonic. The time-domain view of the filtered signal now has a flat baseline. The reflections are more clearly discernible, which is the goal of the processing. Again, the FFT provides great insight into the filtering process.

Histograms

So far, we have looked at data in both the time and frequency domains. Each of these views adds something to our understanding of the data being acquired. The data can also be viewed in the statistical domain, which deals with the probability that certain amplitude values occur. This is conveyed by the histogram of occurrence frequency versus amplitude value.

The histogram is a finite record length estimate of the signal's probability distribution. Some examples are shown in Figure 4, including sine, triangle and noise waveforms (top view) and their associated histogram distributions (bottom view). The horizontal axis of the histogram represents the amplitude of the signal, and the vertical the number of values in a small range of values (binning).

FFT WINDOW FILTER PARAMETERS

Window Type	Highest Side Lobe (dB)	Scallop Loss(dB)	ENBW (bins)	Coherent Gain (dB)
Rectangular	-13	3.92	1.0	0.0
Hanning	-32	1.42	1.5	-6.02
Hamming	-43	1.78	1.37	-5.35
Blackman-Harris	-67	1.13	1.71	-7.53

Table 1: Characteristics of the four most commonly used weighting functions

Each histogram distribution is distinct, and the difference is related to the signal characteristics. The distribution of the sine wave shows high peaks on either extreme and a saddle-shaped mid-region. The reason for this shaping is that the sinewave's rate of change varies through each cycle, fastest at zero crossing and slowest at peaks. If the sine is sampled at a uniform sampling rate, there will be more samples at the positive (right-most peak in the histograms) and negative (left-most) peaks, and the fewest samples at the zero crossing (in the centre of the histogram, horizontally).

The triangle wave has a constant slope, either positive or negative. The resulting histogram has a uniform distribution, except at the extremes. The peaks are there because the signal generator has limited bandwidth that rounds the peaks, and a greater number of samples are acquired at those points.

The histogram of the noise signal results in a Gaussian or normal distribution. The unique characteristic of the Gaussian distribution is that it is not bounded; other distributions have amplitude limits and a fixed horizontal range. The Gaussian distribution has 'tails' that theoretically extend to infinity (in the actual instruments the tails are limited by clipping in the analogue-to-digital converter).

So, histograms tell their own stories about acquired signals. They are good at showing up asymmetries (distortion) and low probability glitches in waveforms. Figure 5 shows a histogram of a sine wave with a glitch at the zero crossing. The histogram clearly shows significant peaks near the zero crossing that are not present in the sine histogram in Figure 4. ❖

See the first part of this column in the September issue

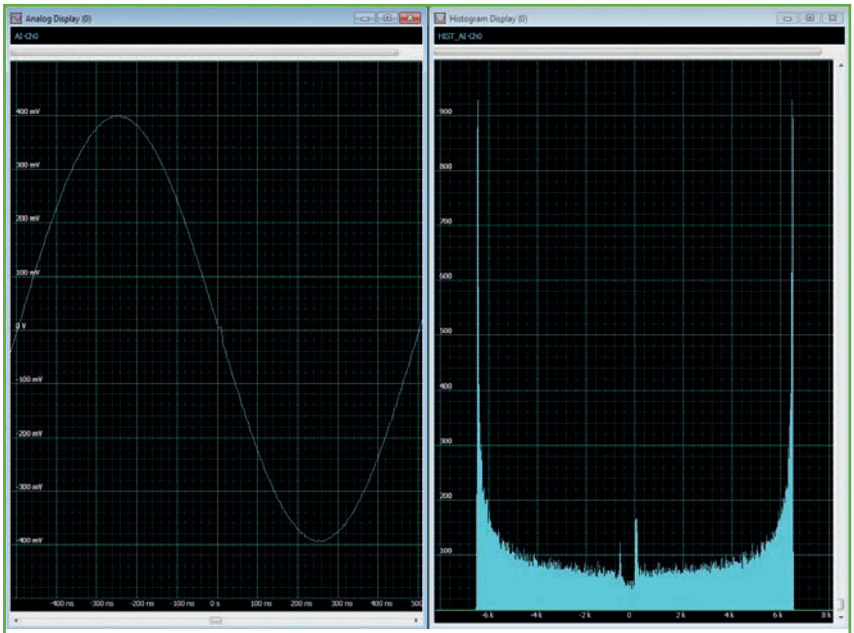
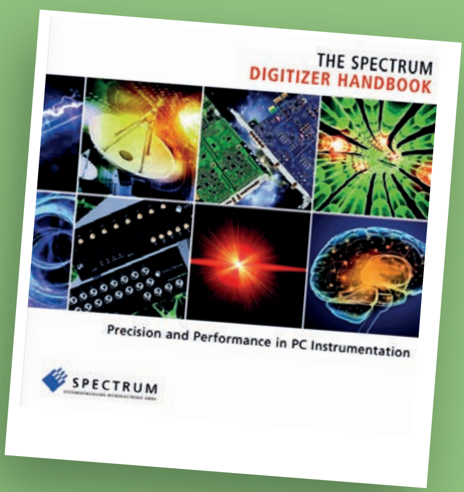


Figure 5: A sine wave exhibiting a zero crossing glitch and its associated histogram. Note the peaks near the centre of the histogram

FREE BOOKS

This article is adapted from *"The Digitizer Handbook – Precision and Performance in PC Instrumentation"* by Spectrum Instrumentation. To receive a free copy, go to https://spectrum-instrumentation.com/en/contact-us and tick the box marked "Please send me a copy of the Digitizer Handbook" , adding "EW" in the Comment section.



TELEDYNE LECROY INTRODUCES TELEDYNE TEST TOOLS BRAND

New range of test equipment serves diverse needs of designers, test engineers, and educators

Teledyne LeCroy announced the launch of Teledyne Test Tools, a branded portfolio that adds a comprehensive range of test equipment to the Teledyne LeCroy product offering. Teledyne Test Tools (T3) products complement and leverage Teledyne LeCroy's decades-long leadership in oscilloscope technology. The brand establishes a one-stop shop for test engineers, developers, and schools looking to satisfy ongoing testing, education, and electronics validation needs efficiently, reliably, and within budget.

Customer demand sparked the creation of the Teledyne Test Tools portfolio in collaboration with leading OEM technology partners; the brand will be supported by the Teledyne Sales and Customer Care organization. Under the Teledyne Test Tool brand, Teledyne LeCroy will develop a range of new test solutions and functionalities that support product-design needs across a range of industries such as mobile, automotive, communications, defense, and manufacturing.

"We are excited for the launch of Teledyne LeCroy's new branded test equipment portfolio that complements our oscilloscope technology and creates a one-stop shop for our customers' test solutions needs," said Roberto Petrillo, Worldwide VP of Teledyne Test Tool Development. "By leveraging our decades of market knowledge and strong customer relationships, the Teledyne Test Tool team will focus on speedily bringing new, innovative, and cost-effective test equipment solutions to market that meet the testing, education, and electronics validation needs of our customers' designers, engineers, and lecturers."

At launch the T3 portfolio will consist of the following products. Other instruments and tools will follow. More information is available at **http://teledynelecroy.com/testtools/**

Digital Oscilloscopes

T3DSO1000 Oscilloscopes feature two channel and four channel models. The scopes are available in 100 and 200 MHz models and incorporates two 1 GS/s ADCs and 14 Mpts memory modules. When all channels are enabled, each channel has sample rate of 500 MS/s and a standard record length of 7 Mpts. When only a single channel per ADC is active, the sample rate is 1 GS/s and the record length is 14 Mpts.

T3DSO2000 Oscilloscopes feature two channel and four channel models with analog bandwidth options from 100 MHz to 300 MHz. Each model offers a sample rate of 2 GS/s, and a maximum memory depth of 140 Mpts in half channel mode. The four channel models incorporate two 2 GS/s ADCs and two 140 Mpts memory modules. When all channels are enabled, each channel has 1 GS/s and a standard record length of 70 Mpts. When only a single channel per ADC is active, the maximum sample rate is 2 GS/s and the maximum record length is 140 Mpts.

Spectrum Analyzers

T3SA3000 Spectrum Analyzer range consists of models with frequency ranges from 9 kHz to 2.1 GHz or 9 kHz to 3.2 GHz. The displayed average noise level (Typ.) is -161 dBm/Hz, the offset phase noise (1 GHz, Typ.) is specified to be -98 dBc/Hz @10 kHz with a total amplitude accuracy of < 0.7 dB. The small footprint and easy user interface is augmented by a high-performance specification with many advanced measurement functions and capabilities. The high-performance Spectrum Analysis capability can be enhanced further with options to extend it's easurement Capability. Teledyne Test Tools spectrum analyzers offer comprehensive measurement capabilities even in the base units.

Function/Arbitrary Waveform Generators (AWG)

T3AFG5 and T3AFG10 series 5 MHz – 10 MHz 14-bit Function/ Arbitrary Waveform Generators are a new family of low cost, high performance, single channel Function/Arbitrary waveform generators offering a high level of functionality and an excellent specifi cation at a very competitive price point.

T3AFG range of generators are a series of single and dual-channel function/arbitrary waveform generators with specifications of up to 120 MHz maximum bandwidth, 1.2 GS/s maximum samplingrate and 14 or 16-bit vertical resolution. The proprietary TrueArb & EasyPulse techniques used on the higher bandwidth models helps to solve the weaknesses inherent in traditional DDS generators when generating arbitrary, square and pulse waveforms. With advantages above the T3AFG generators can provide users with a variety of high fi delity and low jitter signals, which can meet the growing requirements of complex and extensive applications.

HD Signal Generators

T3AWG3352-3252 are multifunctional 16-bit generators with 12 Vpp output voltage that combines many functions in one generator, including Arbitrary Function Generator, Arbitrary Waveform Generator and Digital Pattern Generator. These three-different functionalities are leveraging on the HW flexibility adopting two different technologies.

The Direct Digital Synthesizer (DDS) technology adopted when using the Function Generator (AFG) lets the user to change glitch free on-the-fly all the parameters preserving the waveform shape. All control and setting are always one touch away: swipe gesture to change the channel, the carrier selection and have access to the modulation parameters, swipe into the waveform gallery to import a signal at a glance and use the touch-friendly virtual numeric keyboard to change parameters values.

The variable clock, true-arbitrary technology adopted when using the Arbitrary Waveform / Digital Pattern Generator lets the user to create complex waveforms of analog and digital pattern, insert them is a sequence, apply loops, jumps and conditional branches. Digital output combined and synchronized with analog output signals represents an ideal tool to troubleshoot and validate digital design.

This disruptive and innovative hardware architecture provides the possibility to generate unmatched performances, versatile functionality, outstanding usability, making the T3AWG3352-3252 the ideal generator for today's and tomorrows test challenges.

Digital Multi Meters (DMM)

T3DMM4-5, T3DMM5-5, and 3DMM6-5 are 4½, 5½, and 6½ digit digital multimeters incorporating the latest 4.3" dual display

technology which can be configured to show data histograms, Data fluctuation Trends, Bar Graph, Statistics or the traditional Number mode, all in an easy to use interface. A great feature of the Teledyne Test Tools T3DMMs is it's ability to made highly accurate True RMS AC Voltage and Current measurements, meaning no loss of accuracy even when measuring complex voltage and current waveforms. The T3DMMs are especially well suited for the needs of the general purpose multifunctional environment, as well as supporting a full range of automatic measurements.

Programmable DC Power Supply

T3PS3000 is a Linear Programmable DC Power Supply with a 4.3" TFT display. It has three isolated outputs: two adjustable channels and one selectable channel from 2.5 V, 3.3 V, and 5 V with output short and overload protection for each channel. Support for series and parallel operation of the two main channels extends its flexibility beyond the standard specification. The T3PS3000 features include programmability via USB or LAN, a graphical display of power waveforms, and the high resolution numeric display of voltage and current. Typical users are Education, Production, and Design and Development.

Time Domain Reflectometers (TDR) up to 15 GHz

Today's modern fast bus speed designs make debugging signal integrity issues one of the most challenging tasks

for engineers to perform efficiently and precisely. For example, take high operating frequencies and mix that with anything that affects your signal's rise time, pulse width, timing, jitter or noise content and you increase the risk of impacting reliability at the system level. If you want to ensure signal integrity you need to understand and control impedance within the transmission environment the signals travel through and the ideal tool to pinpoint those impedance problems are TDR instruments. The Teledyne Test Tools SP-series combines high resolution with a rapid refresh rate, quick data acquisition rate, ultraportable design including a battery option all for a very attractive price. Use it out in the field and in the lab. ●

BY **DR MURAT UZAM**, ACADEMIC AND TECHNICAL AUTHOR, TURKEY

0-5V analogue input modules 3, 4 and 5

This column is dedicated to a project involving thirteen analogue input modules and seven analogue output modules for use with a 5V microcontroller through its ADC and DAC channels.

Previously, we covered the 0-5V analogue input modules 1 and 2, which accept DC input voltages from 0V to 6.26V and 12V, respectively. In this month's column, we will focus on 0-5V analogue input modules 3, 4 and 5, which accept up to 24V DC inputs.

0-5V Analogue Input Module 3

Figure 1 shows the 0-5V analogue input module 3, with its connections shown in Figure 2. In this design it is assumed that the input voltage range (V_{IN}) = 0-24V. When 0V – V_{IN} – 5V, V_{OUT} = V_{IN} (Figure 3). When 5.01V – V_{IN} – 24V, V_{OUT} will be equal to a value from 5.01V to 5.07V, due to the particular electrical properties of the LM358P-A used. Input voltages up to 24V do not damage the circuit, which outputs values between 5.01V and 5.07V.

This circuit is identical to 0-5V analogue input module 2 discussed last month, except for the 12V DC power. Here, the power supply is 24V, but for exact operation of the circuit refer to last month's article.

Table 1 shows some example input and output voltages for the 0-5V analogue input module 3, with a prototype circuit board shown in Figure 4.

0-5V Analogue Input Module 4

Figure 5 shows the schematic diagram of 0-5V analogue input module 4 to be used with an ADC input of a 5V microcontroller, with its connections to the MCU shown in Figure 6. Here it is assumed

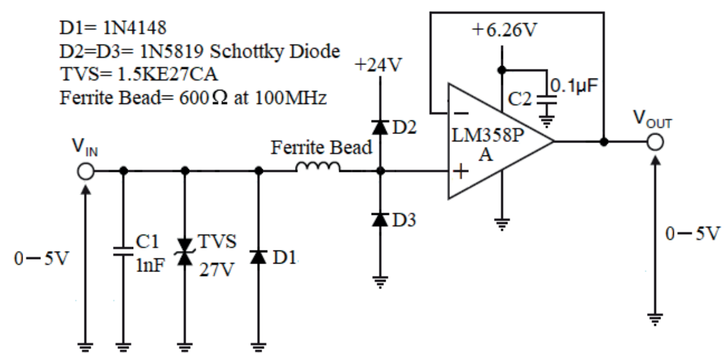


Figure 1: Schematic diagram of 0-5V analogue input module 3

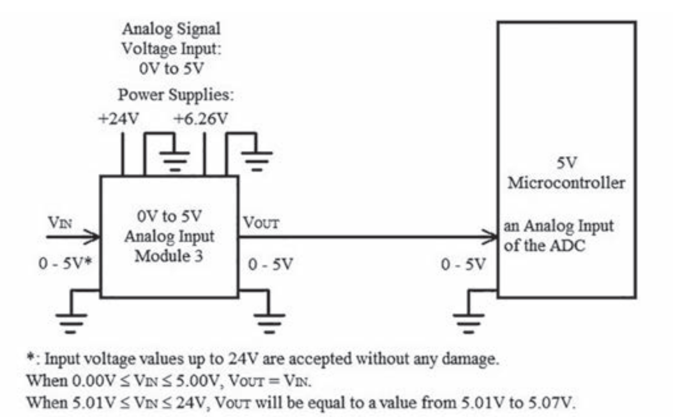


Figure 2: Connection of 0-5V analogue input module 3 to the analogue input of a 5V microcontroller

Figure 3: V_{OUT} vs V_{IN} for 0-5V analogue input module 3 shown in Figure 1

V_{IN}(V)	V_{OUT}(V)
24.00	5.0X
..	5.0X
20.00	5.0X
..	5.0X
10.00	5.0X
..	5.0X
5.00	5.00
..	..
4.00	4.00
..	..
3.00	3.00
..	..
2.50	2.50
..	..
2.00	2.00
..	..
1.00	1.00
..	..
0.00	0.00

Table 1: Example of input and output voltage values for 0-5V analogue input module 3. 5.0X is a value from 5.01V to 5.07V, due to the electrical properties of the LM358P-A used

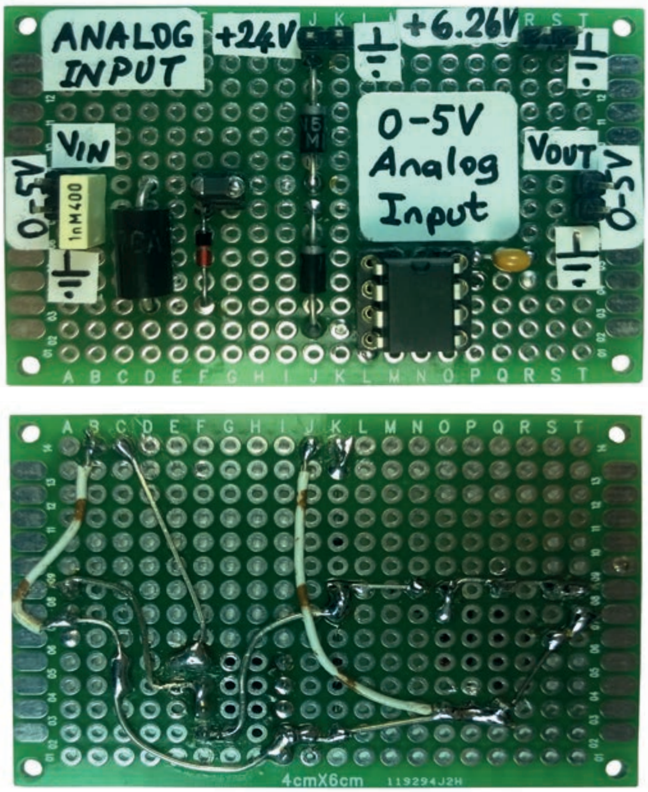


Figure 4: Top and bottom of the prototype circuit board of 0-5V analogue input module 3

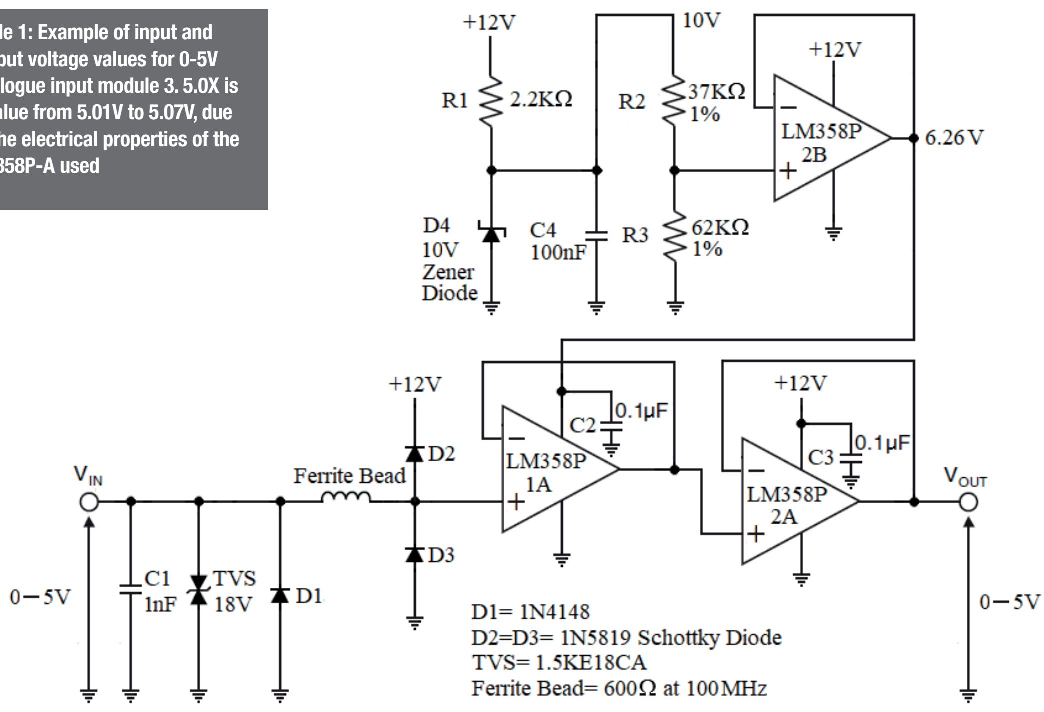


Figure 5: Schematic diagram of 0-5V analogue input module 4

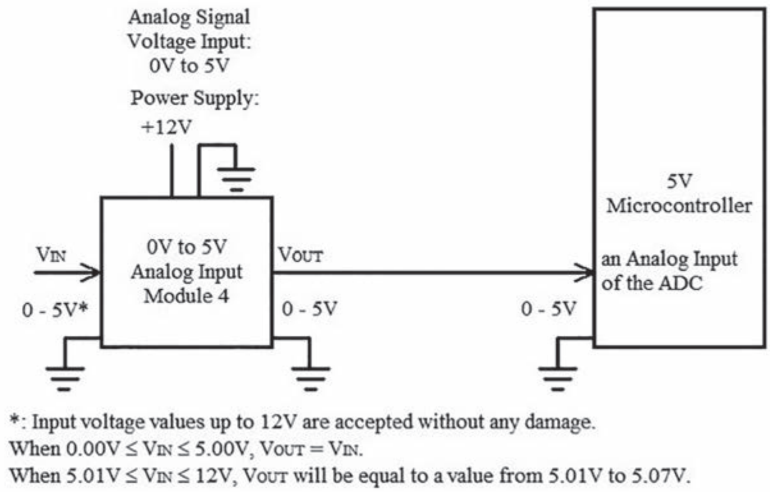


Figure 6: Connection of 0-5V analogue input module 4 to the analogue input of a 5V microcontroller

that the input voltage range (V_{IN}) = 0-12V. When 0.00V – V_{IN} – 5.00V, V_{OUT} = V_{IN}. When 5.01V – V_{IN} – 12V, V_{OUT} will be equal to a value between 5.01V and 5.07V, due to the electrical properties of the LM358Ps used. The relationship between V_{OUT} and V_{IN} is the same as in the 0-5V analogue input module 2.

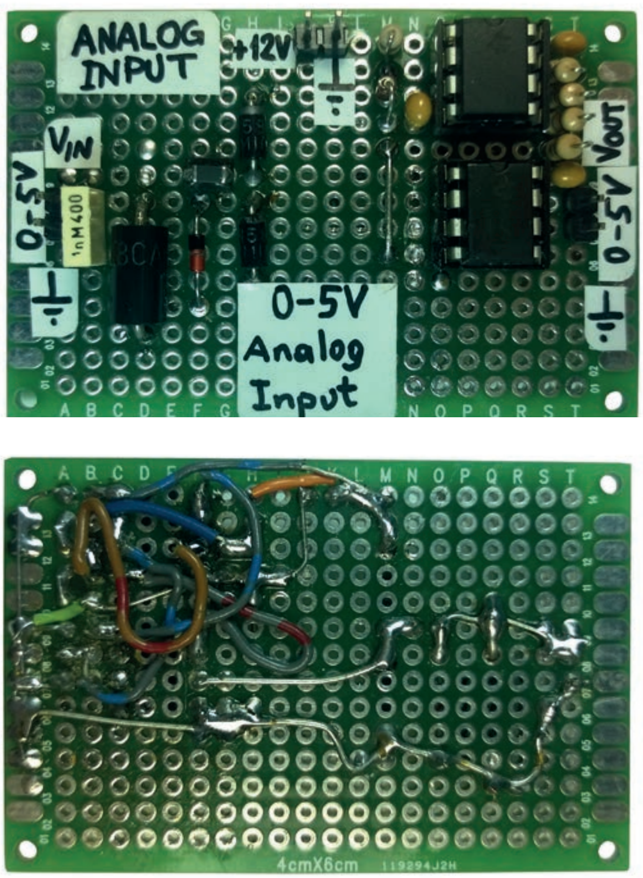


Figure 7: Top and bottom of the prototype circuit board of 0-5V analogue input module 4

Apart from the buffer amplifier LM358P-2A from which the output voltage V_{OUT} is obtained, the bottom part of the schematic diagram is identical to that of 0-5V analogue input module 2, explained in the last issue. The top part of the circuit generates the 6.26V reference voltage. R1, D4 (10V zener diode) and C4 provide a 10V reference voltage from a 12V power supply. This reference voltage is then divided using resistors R2 and R3 to obtain 6.26V, which in turn is connected to the non-inverting input of buffer amplifier LM358P-2B, whose output is fixed as 6.26V, capable of sourcing up to 20mA.

This module's prototype circuit board is shown in Figure 7.

An important implementation tip here is that, for proper operation, make sure that R3/(R2+R3) = 62.62%.

0-5V Analogue Input Module 5

Figure 8 shows the schematic diagram of 0-5V analogue input module 5 for use with the ADC input of a 5V microcontroller, with its connections shown in Figure 9. In this design, it is assumed that input voltage range (V_{IN}) = 0-24V. When 0.00V – V_{IN} – 5.00V, V_{OUT} = V_{IN}. When 5.01V – V_{IN} – 24V, V_{OUT} will be from 5.01V to 5.07V.

Except for the buffer amplifier LM358P-2A from which the output voltage V_{OUT} is obtained, the lower part of the schematic diagram is identical to that of 0-5V analogue input module 3. The top part of the circuit supplies the 6.26V reference voltage. R1, D4 (10V zener diode) and C4 provide a 10V reference voltage from 24V. Then, this 10V reference voltage is divided with R2 and R3 to obtain the 6.26V reference voltage, which is connected to the non-inverting input of the buffer amplifier LM358P-2B, whose output is fixed as 6.26V reference voltage, capable of sourcing up to 20mA.

The top and bottom of this module's prototype circuit board are shown in Figure 10.

As before, it's worth noting that, for proper operation of the circuit, R3/(R2+R3) = 62.62%. ❖

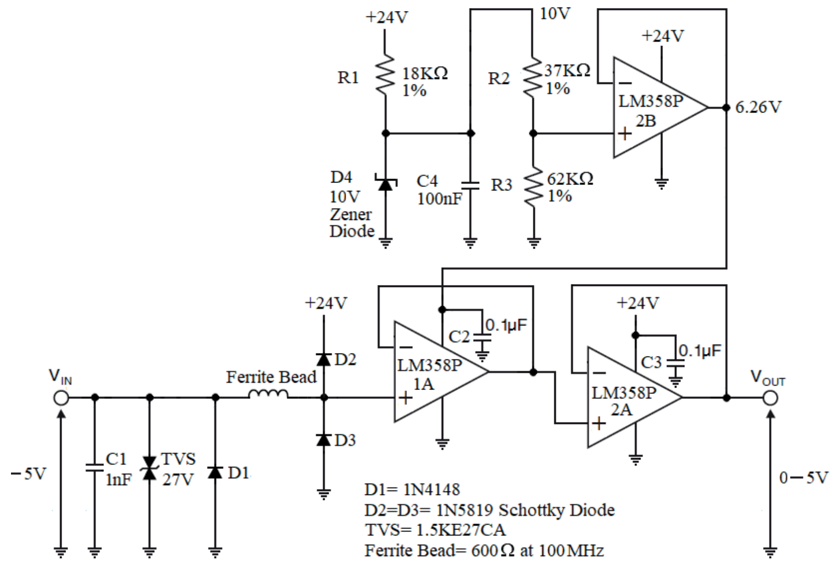


Figure 8: Schematic diagram of 0-5V analogue input module 5

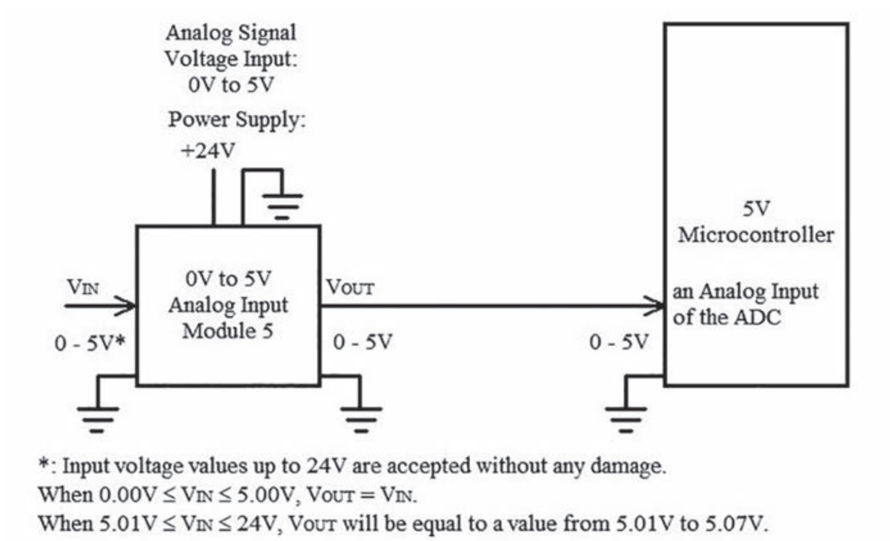


Figure 9: Connection of 0-5V analogue input module 5 to the analogue input of a 5V microcontroller

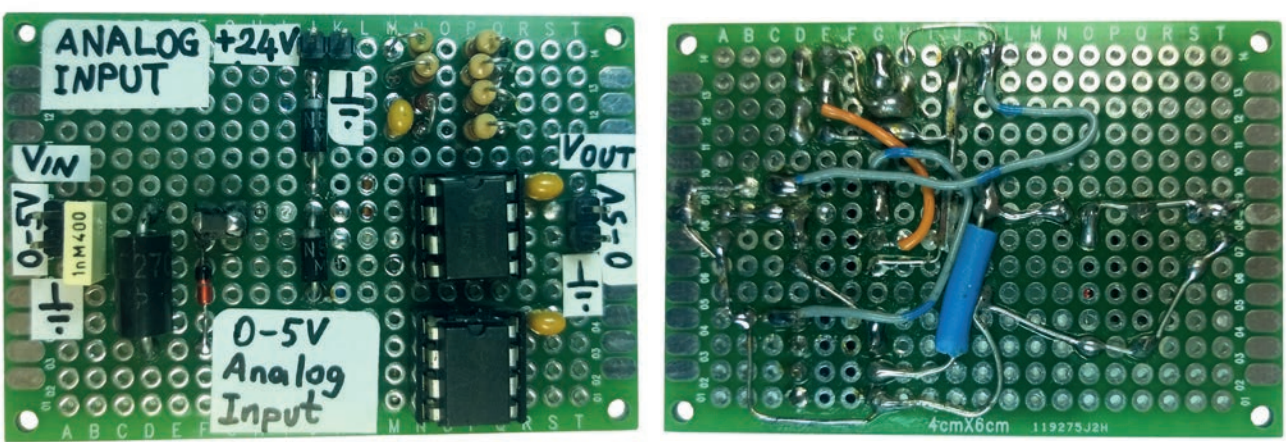


Figure 10: Top and bottom of the prototype circuit board of 0-5V analogue input module 5

Technology advancements in cobots are revolutionising manufacturing

BY MARK PATRICK, MOUSER ELECTRONICS

Modern industry is being transformed by a new generation of 'collaborative robots', or 'cobots', which typically work alongside people to provide additional strength, control, flexibility and safety. And given that cobots tend to cost less than traditional robots, many more companies can afford them, including for slower and smaller production runs.

Perceptive Technology

Underpinning the cobot are the sensors which enable it to be aware of its surroundings, for fast, accurate and safe operation. Sensors detect and measure a wide array of physical attributes, from distance to force, and from surface finishes to chemical composition. Machine vision also plays an important part, enabling cobots to spot and identify objects, orientations and more – in the visible spectrum and outside it. Motion-tracking capability and voice recognition can then make cobot control more intuitive, using gestures and spoken commands.

Data from these various sensors needs to be processed quickly, so the cobot can respond accordingly. This is where sensor-fusion algorithms come in, bringing together data from different sensors in different locations at different times.

Where a conventional robot typically follows pre-programmed instructions with limited (or no) regard for changes in its surroundings, cobots are different. First, instructing a cobot doesn't necessarily require complex programming. In some cases, all it needs is a person to guide the cobot's arms through the desired motion.

Cobots can also use artificial intelligence (AI) to respond ever more appropriately to the data they're collecting from sensors. This means they can analyse information, reason, solve challenges and learn how to respond to new situations, making decisions independently and interacting with people.

Making AI possible are fast processors and sophisticated software, giving cobots human-like attributes, making it easier and more intuitive for people to interact with them.

Different Actuators

Key to enabling cobots and people to work together are the machines' joints, which offer smooth, soft motions and forces. These mechanisms detect and respond to physical feedback, meaning they don't necessarily need high-precision drive mechanisms or motion sensors. Moreover, because of the cobot's different uses compared to traditional robots, it doesn't need the costly, high-force actuators or motor drives common in traditional robots.

Also, cobots' affordability, adaptability and ease of use mean they're within the reach of small- and medium-sized manufacturers. Many production machines require near-constant human tending – to load raw materials, keep an eye on the machine and unload its output, or for injection moulding, inspecting parts, or testing circuit boards.

Machine-tending is a widespread but

AI enables cobots to analyse information, reason, solve challenges and learn how to respond to new situations, making decisions independently and interacting with people

low-skilled job, and, where operators are repeatedly lifting heavy items, injuries aren't uncommon.

Cobots can be perfect for machine-tending, freeing human operators to do higher-skill work, such as quality control and repairs. Beside saving on labour costs, this can reduce injuries, minimise production downtime and lead to a more motivated workforce.

A related use for cobots is to assist humans with repetitive jobs, or those requiring high strength or long reach. Other examples include situations where different products on the line require different components in different places, i.e. where complete automation isn't necessarily feasible. For instance, a cobot could lift and approximately position a heavy component, with the human providing the necessary finesse at the end, either by hand, or by guiding the cobot.

Flexible, Collaborative Product Assembly

While a conventional pick-and-place robot needs to know exactly where to pick up and set down parts, a cobot's vision systems can enable it to work in environments where there isn't this level of precision. For example, a human operator may inspect,

> **Because of the cobot's different uses compared to traditional robots, it doesn't need costly, high-force actuators or motor drives common in traditional robots**

sort and pick out a part, then place it into approximately the right place on an unfinished product. The cobot would then align the part correctly and fasten it down. Situations in which this could be of value are many: the element may be too small for a human to align by sight, or its assembly might require the use of hazardous substances.

Where high-volume manufacturers can use robots to pack finished goods and load them onto pallets, those with smaller production runs may find this cost-prohibitive. Consequently, they've traditionally done this manually. Cobots change all of this. Manufacturers can program them to recognise and count products on conveyor belts, pack, label and load them into the right boxes. Importantly, the cobot can be reprogrammed relatively easily when product specifications or packing needs change.

Just the Beginning

These examples show the breadth of possibilities for cobots in manufacturing. The exciting thing is that as the enabling technologies develop further, cobots will become ever more useful and pervasive in industry. ❖

Intermediate voltage for increased power conversion efficiency

QUESTION:

How to increase the efficiency of a power converter with high voltage input and low voltage output?

ANSWER:

There are different solutions to convert a high input voltage to a low output voltage, such as, for example, 48V down to 3.3V. Typically, this is required in server applications for the information technology and telecommunications markets.

If a step-down converter (buck) is used for this single conversion step (Figure 1), there's the problem of small duty cycles. Typically, duty cycle is defined as the relationship between the on-time and the off-time of the main switch. However, a buck converter's duty cycle is defined by the following equation:

$$\text{Duty Cycle} = \frac{\text{Output Voltage}}{\text{Input Voltage}}$$

With input of 48V and output of 3.3V, the duty cycle is approximately 7%. This means that at a switching frequency of 1MHz (1000ns per switching period), the Q1 switch is turned on for only 70ns. Then, the Q1 switch is turned off for 930ns and Q2 is turned on.

For such a circuit, a switching regulator must be chosen that allows for a minimum on-time of 70ns or less. However, this brings another challenge. Usually, the very high power conversion efficiency of a buck regulator is reduced when operating at short duty cycles, because there's only a very short time available to store energy in the inductor. The inductor must provide power for a long period during the off-time, which leads to high peak currents in the circuit. To lower these currents, the inductance of L1 needs to be relatively large, because during the on-time a large voltage difference is applied across L1.

In the example we see about 44.7V across the inductor during the on-time, 48V on the switch-node side and 3.3V on the output side. The inductor current is calculated by:

$$i_L = \frac{1}{L}\int u_L dt$$

If there is a high voltage across the inductor, the current rises during a fixed time period and inductance much more than if there was a low voltage across the inductor. To reduce inductor peak currents, a higher inductance value needs to be selected, which then adds to the power losses. Under these voltage conditions, an efficient LTM8027 µModule regulator from

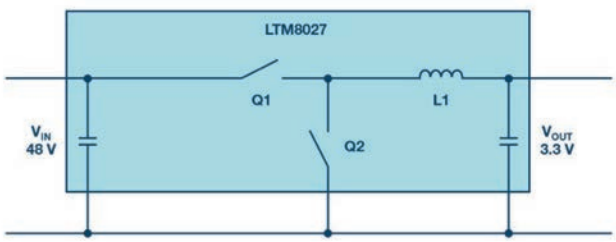


Figure 1: Single-step voltage conversion from 48V to 3.3V

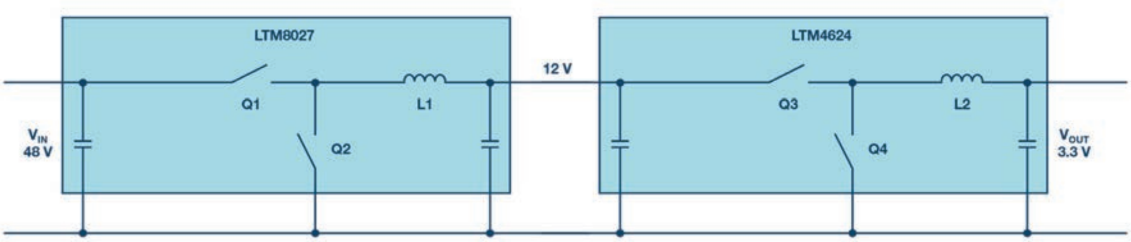
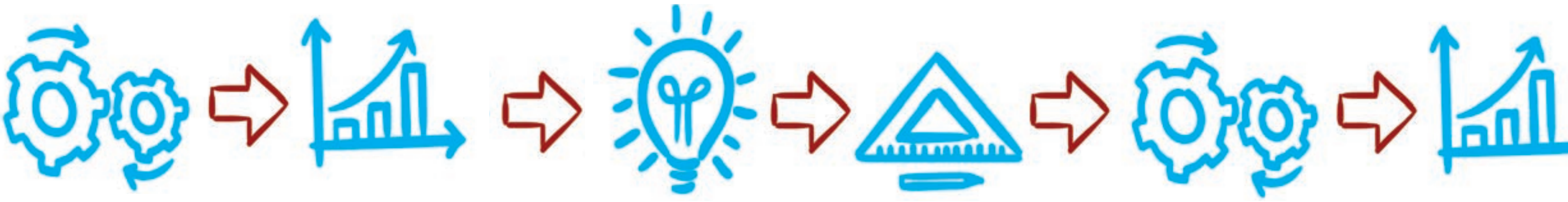


Figure 2: Voltage conversion from 48V down to 3.3V in two steps, including 12V intermediate voltage



BY FREDERIK DOSTAL, POWER MANAGEMENT TECHNICAL EXPERT, ANALOG DEVICES

Analog Devices achieves power efficiency of 80% at 4A output current.

Today, a very common and more efficient way to increase power efficiency is by generating an intermediate voltage. A cascaded setup with two highly efficient step-down (buck) regulators is shown in Figure 2. In the first step, the 48V is converted to 12V, then to 3.3V in a second conversion step. The LTM8027 µModule regulator has a total conversion efficiency of over 92% when going from 48V to 12V.

The second conversion step from 12V to 3.3V, performed by an LTM4624, has a conversion efficiency of 90%, yielding a total power conversion efficiency of 83% – 3% higher than the direct conversion in Figure 1. This can be quite surprising since all the power on the 3.3V output needed to run through two individual switching regulator circuits. The efficiency of the circuit in Figure 1 is lower due to the short duty-cycle and the resulting high inductor peak currents.

Other Aspects

When comparing single step-down architectures with intermediate-bus architectures, there are other aspects to consider besides power efficiency. However, this article is only intended to look at the important aspects of power conversion efficiency. One other solution to this basic problem is the new LTC7821, a hybrid step-down controller. It combines charge-pump action with step-down buck regulation, enabling the duty cycle to be $2 \times V_{IN}/V_{OUT}$ so that very high step-down ratios can be achieved at very high power-conversion efficiencies.

Generating intermediate voltage can be a quite useful way to increase the total conversion efficiency of a specific power supply. A lot of development goes into increasing the conversion efficiency in Figure 1 with such short duty cycles. For example, very fast GaN switches can be used, which reduce the switching losses and, as a result, increase the power conversion efficiency. However, such solutions are currently more expensive than cascaded solutions, such as that shown in Figure 2. ❖

Future-proofing energy solutions for medical devices

By Neil Oliver, technical marketing manager, and Michele Windsor, global marketing manager, Accutronics

The Internet of Things (IoT) is about sensor-laden devices in the home and office, but also in industry, medicine and even combat, among other places.

Batteries for Medicine

We are all aware how portable consumer electronic devices have changed our daily lives. It may be a cliché, but it's a fact that none of these devices would exist were it not for batteries powering them.

Some may shake their heads in disagreement when told that battery technology is keeping pace with technological developments since at first glance it may not seem so. However, even Gordon Moore himself would appreciate the technical challenges associated with providing a large amount of chemical energy in a small space, whilst ensuring it is safe, reliable, cost-effective and reusable.

Despite their technological advancements, it is still challenging to select the right battery to power the load.

"In the medical sector, we are seeing ventilators, infusion pumps, dialysis systems and anaesthesia machines move from mains AC power to portable battery power," said Johnathan Celso, applications engineer at Ultralife. "The increased need for portability in the medical field requires high-discharge batteries that can cope with continuous charge-and-discharge cycles efficiently and safely. This is where new chemistries such as lithium iron phosphate ($LiFePO_4$) are helping us create batteries that improve on traditional sealed lead acid (SLA) technology."

Greater Flexibility

Today, everyone expects portability in the quest for greater flexibility, operability and productivity, and the healthcare sector is no different – we are seeing a massive proliferation of battery-powered portable devices there too.

There are many reasons for equipping an existing medical device with a battery, but the most common is the need to carry it around for use when needed. Portability makes clinicians more efficient and helps prevent moving patients from their

Figure 1: Smart U1 for powering medical carts

beds – the greater flexibility and freedom means better care.

Other medical devices also need batteries, but not necessarily for portability. Patient lifts and acute ventilators are typical examples of transportable medical devices that use batteries and, for these applications, high voltage and discharge rate capabilities are the most important performance attributes. Here, medical device OEMs are moving away from the older nickel- and lead-based chemistries due to their low energy density and high environmental impact. The focus is now shifting to specialist Lithium-ion (Li-ion) chemistries that have emerged for high drain applications. Li-ion cathode chemistry that combines nickel, cobalt and manganese offers an enviable combination of performance traits such as capacity, power delivery and safety, making it ideal for demanding applications.

> **The relentless pursuit of smaller devices means that a cell produced in its millions last year may very well be obsolete and unobtainable next year**

Medical Device Life-Cycle

The rate of technological change in consumer electronics over the past decade is truly staggering. The difference is that the product life cycle of a mobile phone may be twelve to eighteen months, whereas that of medical equipment should exceed ten years.

Although only part of a medical device, the impact of component obsolescence – and in particular of cell supply – can't be ignored. Until the start of this century, battery manufacturers made cells to defined international mechanical standards, and device manufactures designed their devices around these cells.

The change occurred with the invention of Li-ion and Li-ion polymer cell technology and the new trend of vertically integrating batteries into device manufacturing. This shift has led to the development of customised cells, which in turn has offered medical device manufacturers the option to produce the ideal device for their customers, in accordance with their specifications. Yet the relentless pursuit of smaller devices means that a cell produced in the millions last year may very well be obsolete and unobtainable next year. For medical device OEMs this poses a real problem: how to use the latest battery technology and still be able to support devices for 10-15 years.

If early attention is given to possible future developments in cell technology, then it is possible to design a battery platform that can be continually upgraded over the product life-cycle.

Preparing for The Surgical Robot Boom

With greater investment from healthcare organisations, another discipline benefiting within this field is the surgical robot. The needs here, however, relate to these systems operating safely and reliably.

While they may sometimes feel like a new medical technology, surgical robots have been around for several decades. The first medical robot successfully conducted a neurosurgical biopsy in 1985, while the US Food and Drug Administration (FDA) approved its first surgical robot – the da Vinci – in the year 2000. However, it's only in the past few years that we've seen this technology really take off. In the UK, the number of surgical robots used in prostate cancer centres at NHS hospitals tripled between 2010 and 2017. The NHS subsequently invited companies to tender for a £300m surgical robot contract in January 2018, guaranteeing that the number of robot surgeons in the UK continues to grow in the coming years.

This same growth is happening across the world, and the popularity of the da Vinci system is an effective barometer

Figure 2: Surgical robots are growing in popularity

Figure 3: Batteries power medical devices that helps patients stay where they are

of a growing popularity. According to Intuitive Surgical, the company behind it, the da Vinci robot had sold 4,271 units globally as of September 30, 2017, more than half in the US.

As *The Economist* reported in 2017, many of Intuitive Surgical's patents are due to expire soon, leading to greater competition from startups and established companies. This is ideal for the prosperity of the robot market and will help improve the precision and effectiveness of complex, minimally-invasive surgeries. However, it does bring challenges with it. If new companies enter the surgical robot market, it is critical that their systems are designed to the same quality and safety standards as the ones produced by more-experienced companies. This means that design engineers working on the project must understand the importance of each component in the system, especially critical backup power components such as batteries.

Batteries for Medical Robots

Traditionally, robot systems have used sealed lead acid (SLA) batteries as a backup power source. This is because in hospital environments, with increasingly complex electrical requirements, AC power alone is not always reliable. The critical nature of the application means that even a momentary loss of power can have disastrous, even fatal, consequences.

However, the traditional SLA batteries used in robotic systems have drawbacks. They are bulky and unwieldy, offer relatively low energy density and require maintenance and servicing every two years. When you consider the associated costs, it makes for a relatively high total cost of ownership, which is understandably undesirable in the healthcare sector where a strong return on investment is important.

Fortunately, new movers into the surgical robot market can bypass these traditional problems by designing smart SLA replacement batteries. The role of design engineers in ensuring the safety of the next generation of surgical robots is to consider the proper critical backup power supply early in the process. By considering alternatives to traditional SLAs, design engineers can design their projects to outperform traditional systems for longer, while maximising patient safety.

How Smart Is Your Battery Charging?

In 1841, the average human life expectancy was 42 years. With significant improvements to medical knowledge and advancements in technology, this has now doubled, and medical device manufacturers are under intense pressures to develop products for the ageing population, at low cost but without compromising quality.

Despite the economic recession and depleting resources, the medical industry has experienced considerable growth since 2011, when the 'baby boomer' generation started turning 65, an age when people are becoming more susceptible to disease and disability. The World Health Organisation (WHO) estimates that by 2050 the number of 65-year-olds will significantly outnumber children aged five and under.

All these factors are driving the healthcare system and are a contributing factor to the market growth. In direct response to this increasing need for healthcare, more hospitals are digitising their processes and steering toward a data-driven healthcare system. This also includes more portable medical equipment so that patients can be treated at home to avoid straining hospital resources.

The growing movement toward on-the-go healthcare means that even complex medical devices can now be used away from hospitals and clinics. Although this reduces waiting times and increases the availability of hospital beds, most such devices were not designed for this type of use, leading to a gap between expectation and use. Poor quality or loss of power are two most prominent issues relating to batteries in healthcare. With portable devices in particular, many original equipment manufacturers (OEMs) struggle to guarantee their mobile devices can perform at the same level as their fixed counterparts.

Accuracy and Reliability

Today, it is fundamental that machines for dialysis or anaesthesia, for example, provide accurate charge status and are highly reliable, with predictable discharge profiles. This is especially important since a power failure in such instances could be fatal.

Another cause of power failure is the actual maintenance of the battery in the application itself. Although doctors from all specialties will be familiar with the use of electronic devices to monitor patient vitals and perform other tasks, most are not aware of how batteries are used within these devices. For example, remote patient-monitoring machines use backup batteries as a safety measure in the event of a mains power failure.

Many battery problems are the result of inadequate charging methods. Every time a battery is cycled, a small amount of active material is lost. This can be accelerated by deep discharging and rapid charging, which makes predictive maintenance even more challenging. As a result, highly-accurate fuel gauging has never been more important. Fuel gauges determine the amount of charge remaining in a battery, as well as how much longer it can continue to provide power and efficiently use all its available energy. And since portable devices are designed to be compact, OEMs must also integrate smaller batteries with increased capacity.

Intelligent Charging

As well as looking at the chemistry of a battery, healthcare professionals can ensure workflow efficiency and constant power to devices such as medical carts that allow for a battery hot-swap. Hot-swappable batteries eliminate any power-related downtime whilst ensuring maximum power availability. This is because when using a hot-swappable battery means there is no interruption of power when removing or charging the main power source, offering increased flexibility in low power situations.

Integrating intelligent charging techniques and smart battery electronics can help those working in the medical sector maximise the runtime of their devices. Whether it's a battery or a charger powering an application like anaesthesia, endoscopy or cardio-pulmonary care machine, doctors no longer need to be afraid of their devices running out of power. ❖

SMARTER-POWERED MEDICAL CARTS

Medical-cart manufacturers and hospital equipment specifiers can now benefit from the latest lithium-iron-phosphate (LiFePO4) technology with Ultralife's URB12400-U1-SMB batteries, which have been qualified for use with medical-cart inverters from Tripp Lite and Ametek Powervar.

The 12.8V 38.4Ah (492Wh) URB12400-U1-SMB, also referred to as the 'Smart U1', was developed as a direct replacement for existing LiFePO4 batteries and SLA batteries currently used in medical carts. While SLA batteries are known to perform poorly in cyclic applications, Ultralife's Smart U1 battery can be fully charged and discharged over 2000 times, making it a 'fit and forget' proposition in many cases.

The battery's advanced LiFePO4 chemistry has been combined with Ultralife's Smart Circuit technology, which works in conjunction with the inverter for accurate real-time data, such as available capacity, remaining runtime and battery health. The battery also actively protects itself against abnormal use, so it cannot be accidentally over-charged or discharged.

The Smart U1 is certified to IEC 62133:2012, the pre-requisite safety standard for rechargeable batteries in many applications, including medical devices. It also meets the requirements of UN 38.3 (T1-T8) required for transportation.

MuSiC-based algorithm for on-demand heart rate estimation in medical devices

By Foroohar Foroozan, signal processing scientist, Analog Devices

Imagine a world where the word “hospital” is unheard of! This could be reality in a few decades’ time, when all health information will be recorded and monitored remotely via sensors. Homes will be equipped with various sensors to measure air quality, temperature, noise, light and air pressure, and, based on the home owners’ health information, systems will be adjusted to optimise their wellbeing.

As expected, heart rate (HR) monitoring will be a key parameter for those systems, and it is already found in many existing wearable devices. These devices measure photoplethysmography (PPG) signals, obtained by illuminating the human skin using LEDs, then photodiodes measure intensity changes of the blood flow using the reflected light.

The PPG signal morphology is like the arterial blood pressure (ABP) waveform, making it a signal of choice within the scientific community as a non-invasive HR monitoring tool. The periodicity of the PPG signal corresponds to the cardiac rhythm, helping estimate HR. However, this estimation can be degraded by poor blood perfusion, ambient light and, most significantly, motion artifacts (MA).

Many signal-processing techniques have been proposed to remove MA noise, which includes ADI’s motion-rejection and frequency-tracking algorithm, by using a three-axis acceleration sensor close to the PPG sensor.

This article focuses on adapting the multiple signal classification (MuSiC) frequency estimation algorithm for high precision, on-demand HR estimation with PPG signals from the wrist, using ADI’s healthcare watch platform; see Figure 1.

PPG Signals

As light is emitted by an LED, blood levels and tissues absorb various amounts of photons, varying the readout of the photodetector. As the photodetector measures the variations in blood pulsations, it outputs a current that’s amplified and filtered for further analysis.

Figure 2a shows a general PPG signal consisting of AC and DC components. The DC component detects the optical signal reflected from tissue, bone and muscle, and the average blood volume of both arterial and venous blood. On the other hand, the AC component indicates changes in blood volume that occur between the systolic and diastolic phases of the cardiac cycle, where the fundamental frequency of the AC component depends on the HR.

Figure 2b shows the PPG signal from the ADI ADPD107 multisensory watch, which measures multiple vital signs on the human wrist, including an electrocardiogram (ECG), electrodermal activity (EDA), accelerometer (ACC) and temperature sensors.

There are similarities between the PPG and ABP waveforms; the ABP waveform is created by blood being pumped out of the left ventricle. The main pressure travels down the systemic vascular network and reaches several sites, causing reflection due to significant changes in arterial resistance and compliance. The first site is the juncture between the thoracic and abdominal aorta, creating

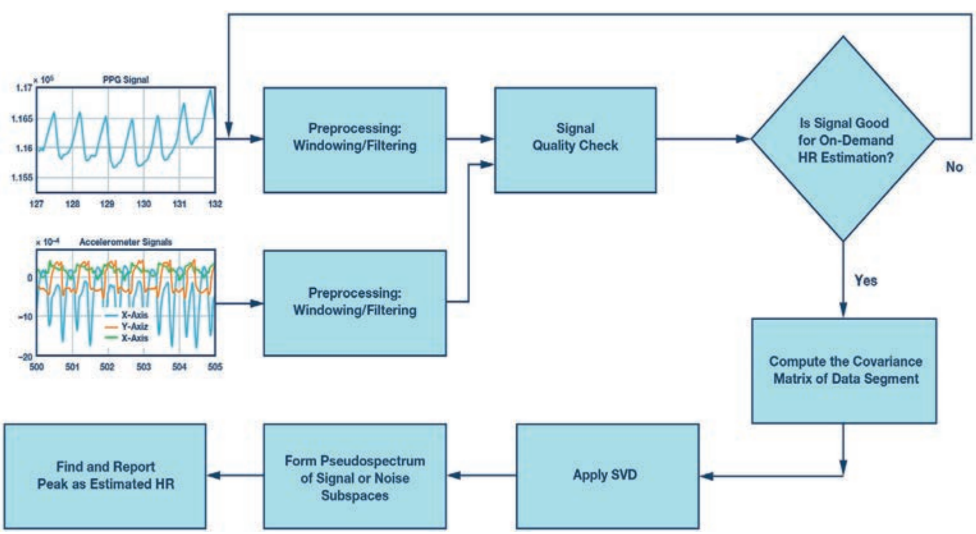


Figure 1: Healthcare platform based on the MuSiC algorithm

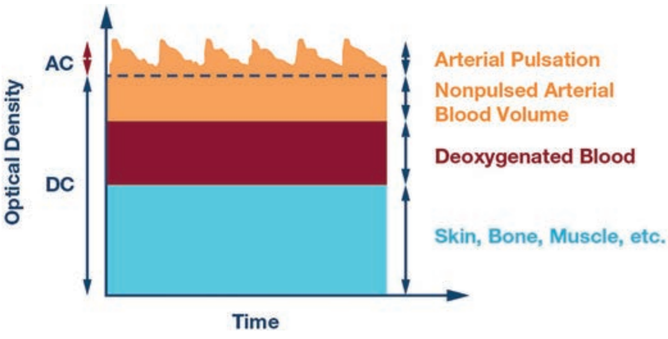


Figure 2a: Typical PPG signal with AC and DC parts

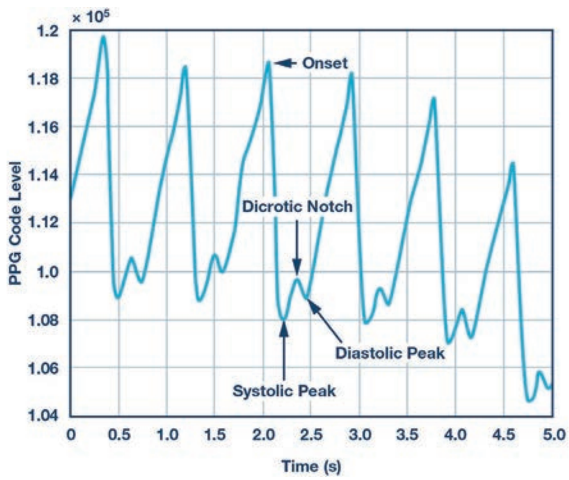


Figure 2b: A PPG signal from the ADI healthcare watch

the first reflection, commonly known as the late systolic wave. The second reflection site is the juncture between the abdominal aorta and common iliac arteries. The main wave is reflected again, which makes a small dip, called the dicrotic notch, observable between the first and second reflections. There are other additional minor reflections, which are smoothed in the PPG signals.

Preprocessing of PPG Signals

There's a susceptibility of the PPG signal to poor blood perfusion of the peripheral tissues and motion artifact. To minimise the influence of these factors in subsequent phases of the PPG analysis for HR estimation, a preprocessing stage is required. A bandpass filter is needed to remove both high frequency components (such as power sources) of the PPG signals, and low frequency components, such as changes in capillary density, venous blood volume, temperature variations.

Figure 3a shows a PPG signal after filtering. A set of signal quality metrics is used to find the first window suitable for the on-demand algorithm. The first check involves ACC data and the PPG signal to determine whether a segment of motion-free data can be detected, followed by measurement of the other signal quality metrics. Estimates from such a window of data are rejected by the on-demand algorithm if there is motion above a certain threshold of the absolute values of the ACC data in three directions.

The next signal quality check is based on certain autocorrelation having features of the data segment. One example of the autocorrelation of the filtered PPG signal is shown in Figure 3b. Autocorrelation of acceptable signal segments exhibits properties with at least one local peak and not more than a certain number of peaks corresponding to the highest possible HR, having the local peaks in a descending order with increasing lags, and a few others. Autocorrelation is only computed for lags that correspond to meaningful heart rates within a range, from 30bpm to 220bpm.

When enough data segments pass the quality checks consecutively, the second stage of the algorithm extracts the accurate HR using the MuSiC-based algorithm.

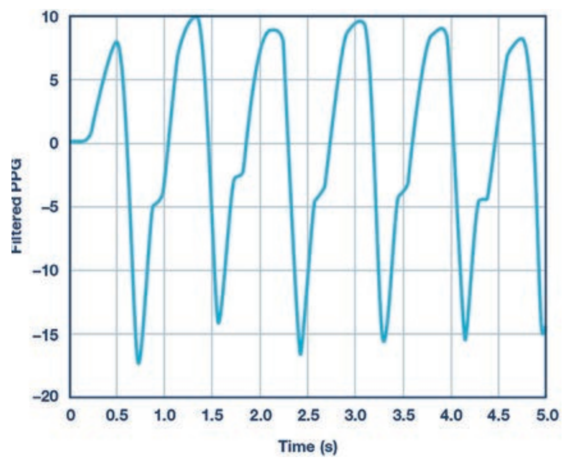


Figure 3a: Bandpass filtered PPG signal from Figure 1b

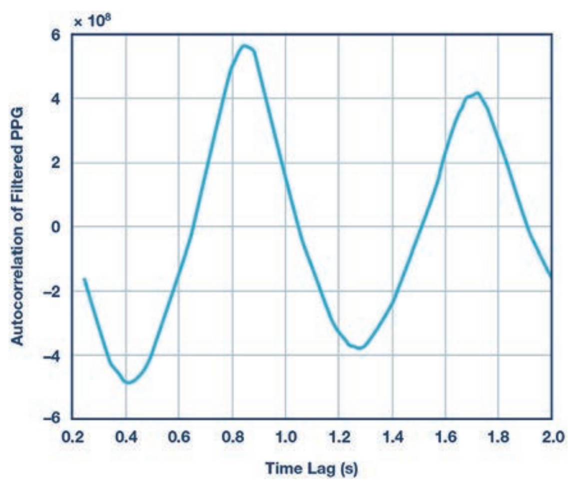


Figure 3b: Autocorrelation of the signal plot from Figure 2a

Metric	2 bpm Accuracy	5 bpm Accuracy	50th Percentile	75th Percentile
Accuracy (data1)	93.7%	95.2%	5.00 sec	5.00 sec
Accuracy (data2)	93.4%	94.1%	5.00 sec	5.00 sec

Table 1: Performance numbers for the MuSiC-based on-demand HR algorithm

On-Demand HR Estimation

MuSiC is a subspace-based method that uses a model of harmonic signals to estimate frequency with high precision. When it comes to the PPG signals corrupted with noise, the Fourier Transform (FT) approach may not do well, since we are seeking a high-resolution HR estimation algorithm. Also, FT distributes time-domain noise uniformly throughout the frequency domain, limiting the certainty of estimation, so it is difficult to observe a small peak near a large peak using FT. Therefore, in this study, we used the MuSiC-based algorithm for HR frequency estimation.

The key idea behind MuSiC is that the noise subspace is orthogonal to the signal subspace, so zeroes of the noise subspace will indicate signal frequencies. The following steps show a summary of this algorithm used for HR estimation:

1. Remove the mean and linear trend from the data;
2. Compute the data's covariance matrix;
3. Apply singular value decomposition (SVD) to the covariance matrix;
4. Compute the signal subspace order;
5. Form the pseudospectrum of the signal or noise subspaces;
6. Find the peaks of the MuSiC pseudospectrum, and use them as the HR estimate.

MuSiC applies a singular value decomposition and searches spectral peaks in the full range of frequencies.

Assume a window of length m of the filtered PPG signal, denoted as x_m and $m \le L$ (L is the total samples of the filtered PPG signal in a given window). The first step is to form the sample covariance matrix:

$$\hat{R} = \frac{1}{L-M}\sum_{m=1}^{M} x_m x_m^T$$

Then, an SVD is applied to the sample covariance matrix:

$$\hat{R} = U\Lambda V = U_s\Lambda U_s^T + U_n\Lambda U_n^T$$

where U is the left eigenvectors, Λ is the diagonal matrix of the eigenvalues and V is the right eigenvectors of the covariance matrix. The subscripts s and n stand for the signal and noise subspaces.

As mentioned earlier, the MuSiC-based algorithm is modified for HR estimation using prior knowledge that the signal has passed the quality checking stage, so that the only frequency content in the signal after the preprocessing step is the HR frequency.

Next, we form the signal and noise subspaces, assuming the model order only contains a single tone, as follows:

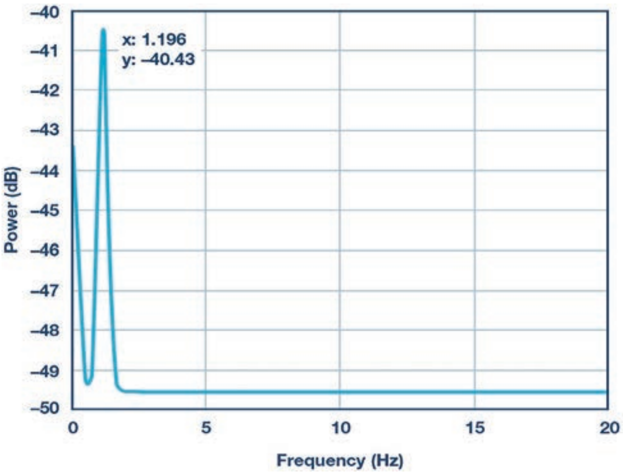


Figure 4: One sample of MuSiC-based estimation from the PPG data

$$U_s = U(1{:}\, p, :);\ U_n = U(p+1{:}\, end, :)$$

where p = 2 is the model number. Only frequencies within the meaningful HR limits are considered here, which significantly reduces computations and makes a real-time implementation for embedded algorithms feasible.

The search frequency vector is defined as:

$$(k) = [1, e^{-1\times\frac{2\pi j(k-1)}{L}}, e^{-2\times\frac{2\pi j(k-1)}{L}}, e^{-3\times\frac{2\pi j(k-1)}{L}}, \ldots\ e^{-(m-1)\times\frac{2\pi j(k-1)}{L}}]\,\hat{}\,T$$

where k is the frequency bin within the frequency range of interest for HR, and L is window length for the data in $x_m(t)$. Then, the following psesudospectrum takes the noise subspace eigenvectors to find the peaks of the MuSiC:

$$\Phi(k) = \frac{1}{a^H U_n U_n^H a}$$

The word psesudospectrum is used here because it indicates the presence of sinusoidal components in the studied signal, but it is not a true power spectral density. One sample result of the MuSiC-based algorithm on a five-second window of data is given in Figure 4, which shows a sharp peak at 1.96Hz, translating to HR of 117.6bmp.

HR Estimation Results

The performance of this algorithm was tested on a dataset comprising 1289 cases (data1), where at first the test subjects were asked to stand at rest. Table 1 shows the results of the MuSiC-based algorithm and indicates whether the estimated HR is within 2bpm and 5bpm of the reference (ECG), as well as the 50th percentile (median) and 75th percentile of the estimation times.

The second row of Table 1 shows the performance of the algorithm when there is a periodic motion (such as walking, jogging, running) over a dataset of 298 test cases (data2). The algorithm is successful if either the data is rejected as unreliable by sensing a motion or by accurately estimating the HR despite a motion. In terms of memory usage, assuming a buffer size of 500 (that is 5s at 100Hz), the total memory needed is around 3.4kB with 2.83 cycle per call for the frequency range of interest (30-220bpm). ❖

Power quality in hybrid operating theatres

By Steve Hughes, Managing Director, REO

"Hybrid operating rooms" may sound like something from a sci-fi novel, but they already exist, including at the St George's University Hospitals Trust in London.

These spaces combine the traditional operating theatre with high-end imaging systems such as magnetic resonance imaging (MRI), computed tomography (CT) scans or angiography systems.

Hybrid operating rooms are predominantly used by cardio-vascular disciplines, but as the demand for gentler surgery methods increases, we can expect more sub-disciplines to use them.

The World Health Organisation (WHO) predicts that by 2050 the worldwide population over the age of 60 will double, to two billion people. Driven by falling fertility rates and increased life expectancy, the number of old people will increase in the coming years, and, as we age, the more susceptible to illness and infection we become.

Today, chronic conditions like diabetes, cancer and cardio-vascular diseases count for an estimated 77% of the disease burden and 86% of the deaths across Europe. As such, an ageing population inevitably increases the volume of hospital admissions and practitioner appointments, placing significant pressure on the healthcare systems.

However, reduced patient operating times and inpatients stays in hospitals could soon become a reality with the wide adoption of hybrid operating theatres, expected to grow at a significant pace by 2023.

Previously, only mobile imaging equipment was based inside an operating room in the form of C-arms, ultrasound and endoscopy. However, the image quality from this equipment was often not high enough to base surgical decisions on. For example, mobile angiography systems have lower image quality due to lesser tube performance, and a low refresh rate, which is problematic for endovascular cases where surgeons need to see the smallest blood vessels.

In the past, a patient would be wheeled out of the sterile operating-theatre environment and taken to the imaging department. In a hybrid operating theatre, however, an intraoperative 3D imaging system can be used to continuously

Figure 1: MRI scanning

guide the surgeon. This follows the trend of minimally-invasive surgery (MIS), where doctors reduce the trauma involved in surgery by minimising the size and frequency of incisions. For example, surgeons now can perform vascular surgery for aortic aneurysms without opening the chest or abdomen. Reduced trauma reduces the risk of complications, lowers patient recovery time and shortens the average length of hospital stays after a procedure.

In emergency situations, patients with severe bleeding need immediate care to avoid life-threatening blood loss. Hybrid operating rooms allow doctors to perform open and endovascular treatment without having to reposition the patient, which could result in further injury. So, for example, in the event of a patient experiencing tension on the brain due to a severe haemorrhage, doctors can relieve the tension and coil an aneurysm in the same room.

Electrical Considerations

Most hospitals in the UK typically follow procedures to reduce interference caused by medical equipment and comply with regulations such as the European standard EN60601, which outlines the basic requirements for medical equipment in hospitals. Even with these standards in place, extra precautions should be taken, especially with the proliferation of hybrid operating rooms.

"These are complex projects with high-end equipment and interdisciplinary collaborations," says Jane Whittaker, angiography business manager at Siemens Healthcare. "There can be an increased number of people working within this environment, as well as a wide range of equipment required for the procedure. From our experience, the most successful installations are a result of careful planning and strong communication between all stakeholders, throughout the project."

An important point that all parties should consider is power quality and the problems that can occur with so many different electrical requirements in a single room. With imaging systems and traditional monitors in an operating room, design engineers must consider the additional power quality implications, compared to a traditional operating room.

To protect patients, hospital managers must consider all equipment used in their hospitals. MRI scanners, for example, emit large amounts of electromagnetic radiation, and, without taking the necessary steps to ensure radiofrequency shielding, the electromagnetic radiation could cause interference to nearby medical devices. If the levels of electromagnetic energy exceed the electromagnetic resistance a device has been designed and tested for, then this can result in electromagnetic interference (EMI). Hybrid operating rooms are susceptible to problems like EMI because of the high usage and range of power electronics based medical equipment in one room.

If unaddressed, EMI causes electrical harmonics, spikes and fluctuations in power, which can interfere with the mains network, causing intermittent faults, short circuits or even a complete power outage. This can impact the data collected by medical equipment and the way devices interact with each other. If decisions are made on potentially incorrect data from the equipment, this could prove harmful for the patient.

For critical systems taking measurements or displaying essential images, any electrical interference in the mains supply could also affect equipment performance. This can accelerate the wear of components, increasing the chances of device failure and putting patients at risk.

> **Hybrid operating rooms are susceptible to issues like EMI because of the high usage and range of power-electronics-based medical equipment in one room**

When designing electrical equipment for use in hybrid operating rooms, engineers must therefore incorporate components to reduce the effect of electrical interference.

An important way to do this is by using isolating transformers such as REO's REOMED range. The wide REOMED portfolio includes radio frequency interference (RFI) filters, surge protection and protection against half-wave loss. These products are specially engineered to go above and beyond the required medical standards such as the EN 60 601-1 standard.

Transforming Power

When isolation transformers are used in operating theatres, they allow safe galvanic separation between the primary and secondary circuits. This limits interference from other devices nearby, as well as protecting equipment from poor power quality.

Traditionally, some engineers are put off by electrical transformers for medical environments, as they tend to have quite high electrical losses. This reduces energy efficiency, which could invalidate the cost savings made by reducing patient costs with hybrid operating theatres. However, REO UK's REOMED transformers have been shown to deliver a 45% reduction in electrical losses compared to conventional electrical transformers.

While hybrid operating rooms present a wealth of new possibilities for healthcare, they bring challenges of equipment safety, power quality and system continuity. It is vital that design engineers consider the implications for power quality in this new type of environment.

Wide Adoption

The concept of hybrid operating rooms was first introduced in the 1990s. Since then, their adoption has been slow, but now that technology has advanced, we can soon expect at least one hybrid operating room per hospital. This will significantly help complex surgical procedures, patient treatment and recovery, and overall costs. ❖

Protecting medical devices from hackers

By Scott Jones, Managing Director, Embedded Security, Maxim Integrated

From toys to refrigerators to cars, the connected devices in our lives are increasing in volume, and medical devices are no exception. While intelligence and connectivity bring great convenience in monitoring patients' wellbeing, they can also bring malicious attacks.

Many pundits have already raised the red flag on medical devices as the next potential security concern. A hacked security camera or even a toy can expose users to privacy breaches, and this is very worrisome. Imagine the ramifications if a cybercriminal gained control of something like a pacemaker or an insulin pump! Such incidents have already come to light:

- In 2007, the cardiologist of former US Vice President Dick Cheney requested the manufacturer of Cheney's implanted heart defibrillator to disable the wireless feature to prevent hacking.
- In September 2017, the Industrial Control Systems Cyber Emergency Response Team (ICS-CERT), which is part of the US Department of Homeland Security, reported a security flaw in syringe infusion pumps discovered by an independent security researcher, where a hacker could potentially change the quantities of medication administered to a patient.
- Another device manufacturer is dealing with lawsuits related to vulnerabilities in its implantable cardiac defibrillators and pacemakers, some of which have been recalled.
- There are reports that British and Belgian researchers have uncovered security flaws in the proprietary communication protocols of ten implantable cardiac defibrillators on the market.

Taking Steps

These are just a few examples highlighting the risks for the industry. A Ponemon Institute study released in May 2017, called *"Medical Device Security: An Industry Under Attack and Unprepared to Defend"*, reported that while 67% of medical device makers anticipate an attack on their devices over the next year, only 17% of them were taking significant steps to prevent such an incident.

Another alarming finding of the study is that only one-third of device makers surveyed reported that their organisations encrypt traffic among Internet of Things (IoT) devices and only 29% of healthcare delivery organisations use encryption to protect data transmitted from medical devices. In fact, only about one third of those surveyed were even aware of potential adverse effects on patients stemming from insecure medical devices.

> **The cardiologist of former US Vice President Dick Cheney requested the manufacturer of Cheney's implanted heart defibrillator to disable the wireless feature to prevent hacking**

When it comes to implementing security, there are persistent myths that may be preventing developers from proactively protecting their devices. Many believe that implementing security is expensive, time-consuming and difficult. These beliefs prevent device developers from acting in the first place. When you take a closer look at the techniques and technologies available now, however, it's quite clear how easy it can be to strongly protect medical devices from cybercriminals.

With features such as wireless connectivity, health-monitoring sensors and near-field communication (NFC) integrated into medical devices, healthcare professionals can easily keep tabs on their patients, wherever they are. Patients can also conveniently track their own wellbeing. There are implantable medical devices that monitor health parameters and deliver medication;

connected devices that track adherence to prescribed treatments; ingestible sensors that also monitor adherence; and many more. These smart, connected devices are continually collecting and sending data wirelessly to medical professionals, enabling a more proactive, coordinated approach to care and streamlining medical costs. And with the connected technology, medical care is expanding to people with impaired mobility.

Risk Scenarios for Medical Endpoints

In its report *"Internet of Medical Things, Forecast to 2021"*, Frost & Sullivan projects that the number of IoMT devices could grow to 30 billion by 2020, from 4.5 billion in 2015.

If not secure, any of these devices could be a target for a hacker, and what if a cybercriminal uses the hacked device to gain entry into, say, a hospital's network, stealing sensitive data to file false medical insurance claims or purchase pharmaceuticals? For the device manufacturer, a breach could open the door to theft of intellectual property (IP) and lost revenue if, say, the attacker creates counterfeit versions of devices. Medical endpoints, including tools, sensors and consumables, face these potential risk scenarios:

- Introduction of a virus or harmful configuration data;
- Re-use of limited-life endpoint peripherals beyond their targeted lifecycle, creating unsafe situations;
- Counterfeiting, where fake devices and sensor endpoints have falsified or altered the data produced by a real one.

Regulatory agencies worldwide are sounding an alarm to device developers. The US Food and Drug Administration (FDA), for example, encourages what it calls a "total product lifecycle approach" when it comes to securing medical devices. Security should be built in as soon as the product design phase begins; there should be a plan to manage any risks that might emerge, as well as one that outlines ways to reduce the likelihood of future risks, according to the FDA.

The European Union Agency for Network and Information Security (ENISA) cites these FDA medical device cybersecurity measures for guidance. In Asia, the China Food and Drug Administration (CFDA) has called on medical device developers to assess security of each device in question in the context in which it will be used, and take appropriate risk-control measures. *I Am The Cavalry*, a grassroots organisation formed in 2013 to focus on issues where computer security intersects public safety and human life, has issued a Hippocratic Oath for Connected Medical Devices. This oath urges stakeholders to support a set of principles:

- Cyber safety by design;
- Disclosure of potential safety or security issues to third parties;
- Evidence capture, preservation and analysis to learn from safety investigations;
- Safeguarding critical elements of care delivery in adverse conditions;
- Prompt, agile and secure updates.

The oath was developed collaboratively with cybersecurity researchers and those working within the healthcare ecosystem. Its aim is to preserve patient safety and trust in the process of care delivery.

Techniques for Safeguarding Medical Devices

So what kind of risk-control measures are suitable for medical devices? Software-based security is considered cost-effective and relatively easy to use; however, it is also easy to modify and readily susceptible to malware. Hardware-based security has proven itself far stronger, as it's difficult to alter the physical layer. Secure ICs with a root of trust are particularly robust. For example, with a microcontroller, the root of trust could be startup code stored in internal immutable ROM, used to verify and authenticate an application's software signature when the microcontroller is powered on; the root of trust cannot be modified. By implementing hardware-based root of trust from the bottom up, developers can close off more potential entry points into their design. In fact, it really is the only solution that guards against attacks that attempt to breach the casing of an electronic device.

Next-generation hardware security based on physically unclonable function (PUF) technology provides an even stronger level of protection. PUF circuitry uses the random electrical properties of IC devices, producing a unique and repeatable root cryptographic key for each IC. Even though different ICs may share the same mask and manufacturing process, each IC is slightly different based on normal manufacturing variability. By tapping into this variability, PUF circuits can extract secret information that is unique to each chip. Gate delay, the power-on state of SRAM and random mismatch of analogue circuits are among the many physical characteristics that can be used to derive the secret code. The key is generated only when needed through analysis of a variety of PUF elements, and it is never stored anywhere on the chip. As such, a device featuring this technology cannot succumb to an invasive attack. Even when attacked via techniques like de-processing or micro-probing, this will change the circuit's electrical characteristics to a point that further attack is prevented.

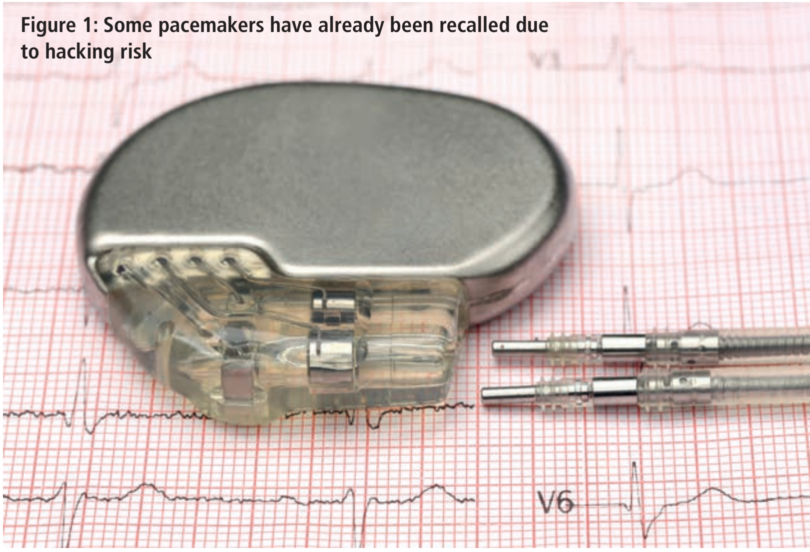
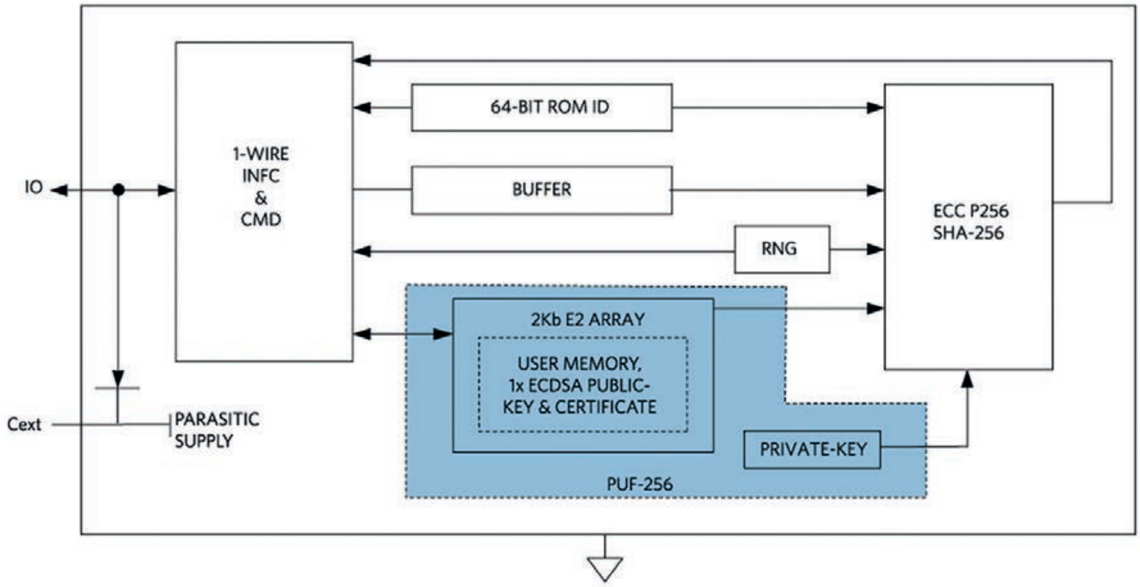


Figure 1: Some pacemakers have already been recalled due to hacking risk

Figure 2: Block diagram of a secure authenticator with PUF technology, the DS28E38 from Maxim



Sub-$1 secure authenticators with PUF technology are now available. With fixed-function operation and no device-level programming, these authenticators can easily be integrated into an embedded design.

Secure Authentication Prevents Counterfeiting

Secure authentication technology provides many benefits, including traceability, usage and secure monitoring, and safeguards against counterfeiting. For example, consider a connected blood glucose meter, from which data is transferred to a smartphone and then to a patient's record at a medical facility. Authentication provides traceability by verifying that the data came from a specific device.

As an example of secure monitoring, consider a medical consumable. Secure authentication can verify the consumable and provide authenticated usage information back to a central processing site for transfer to a patient's record. Many medical devices are designed for single use only. Challenge-and-response authentication can be implemented to ensure that the tool, like a surgical instrument, is both authentic and hasn't been used before.

Challenge-and-response authentication is considered a robust methodology for our digital world, much more secure than password-based authentication, as passwords can easily be intercepted. Challenge-response authentication can be due to symmetric or asymmetric cryptography. In symmetric cryptography-based authentication, the host and the device to be authenticated have a shared secret key. The host sends a challenge in the form of a random number to the device. The device then computes a digital signature as a function of the secret and the challenge, sending it back to the host, which runs the same computation, comparing the results. If there's a match, the device is authenticated.

Secure hash functions, such as SHA-256, provide the mathematics to ensure a device will be able to prove its secret without disclosing it; see Table 1 for an overview of some popular cryptographic algorithms supported by secure authenticators.

In asymmetric cryptography, there's a private key and a public key. Only the device to be authenticated knows the private key. The public key can be shared with any entity that seeks to authenticate the device. Here, the host sends a challenge to the device, which computes a signature based on this challenge and its private key, and sends the result back to the host. The host then uses the public key to verify the signature. The function used here to compute the signature must have certain mathematical properties, which are commonly used functions for asymmetric cryptography are RSA and ECDSA. Embedded security ICs that support SHA-256 and ECDSA can be integrated into a medical device design, for protection from the ground up.

Added Security

While secure microcontrollers and authenticators and other embedded security ICs can protect the medical device designs themselves, other measures can further safeguard the IoMT from malicious attacks. Separating the medical network of devices from the network for PCs, laptops and databases can hamper attempts to break into a compromised device. This way, if a connected medical device gets hacked, the attack won't fully unfold.

It's also important to protect the software applications that run on connected medical devices, preventing copying, tampering or the insertion of malicious code.

Strong authorisation protocols are another essential tactic to minimise the chances of a device getting hacked.

By designing embedded security ICs into medical devices from the very beginning, developers can prevent costly problems later on. ❖

Algorithm	NIST Standard
SHA-256 MAC	FIPS 180
SHA-256 HMAC	FIPS 198
ECDSA-P256	FIPS 186
ECDH-P256	SP 800-56A

Table 1: Popular cryptographic algorithms supported by secure authenticators

High-performance security design for IoT medical devices

By Maurizio di Paolo, technical writer based in Italy

The Internet of Things (IoT) has created a new ecosystem of connected electronic devices that communicate with each other to provide customised functionality in many fields, including medicine. But as with other IoT devices, in medical ones the most significant challenges are in securing confidential information from unauthorised access. Hacker attacks are a serious threat, making an unsecure design a strong limitation for an IoT node or device. This requires a great deal of mathematics and microelectronic solutions, with cryptographic algorithms integrated into the systems.

Enormous Data Exchange

The amount of data IoT devices can generate is staggering. A US Federal Trade Commission report called "*Internet of Things: Privacy & Security in a Connected World*" found that just 10,000 families can generate terabytes of data, attracting hackers to all that sensitive information. When this is multiplied by millions of hyper-connected devices that use different technologies, the enormity of the challenge becomes very uncomfortable, indeed.

Performance and safety requirements vary widely from one application to another, and the success of smart homes, connected devices and cars, as well as industrial equipment, depends on the trust of users in robust and easy-to-use solutions with security features for absolute protection. The higher the volume of sensitive data transferred over the IoT and the IIoT, the higher the risk of data falsification, manipulation, theft and misuse.

This applies across all sectors, including medicine. The demand for improved, efficient health and medical services is worldwide, and technology takes centre stage. Wireless communication, micro- and nanoelectronics, battery power for devices, and more, are being harnessed to bring on earlier and more efficient treatment of patients, eventually shifting the way healthcare works, from diagnosis to prevention. But it is these same requirements, regulatory compliance and now security that also present challenges for developing and testing the newly-created, connected medical devices.

Security First

Many IoT devices use low-end microcontrollers (MCUs) with limited processing power and memory. Some devices have no user interface, and many are designed by OEMs with little or no Internet security. This leads to one of the most significant challenges to today's IoT, enabling robust security for low-end devices.

Security features are primarily based on some core elements, including stable cryptographic cyphers, such as the Advanced Encryption Standard (AES), Secure Hash Algorithm (SHA), RSA (Rivest-Shamir-Adleman) and Elliptic-Curve Cryptography (ECC) public key.

SHA-1 is a hash algorithm, i.e. a one-way function, that is extremely difficult to invert. SHA-1 was designed by the US National Security

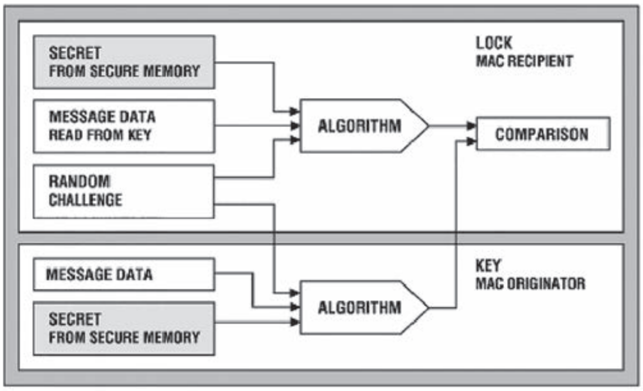


Figure 1: SHA-1 block diagram

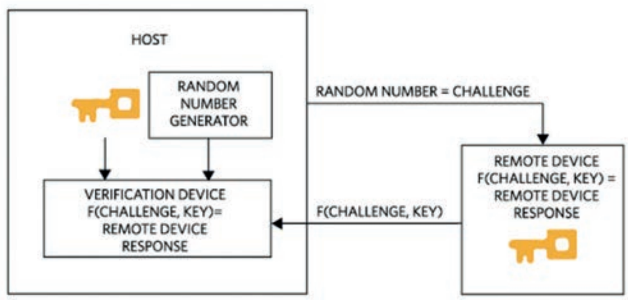


Figure 2: Authentication based on symmetric cryptography

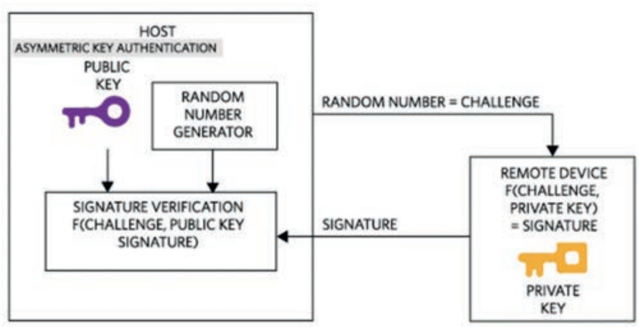


Figure 3: Authentication based on asymmetric cryptography

Agency (NSA) and published by the National Institute of Standards and Technology (NIST) as a Federal Information Processing Standard (FIPS). It's been widely used in applications for secure authentications, since it consists of a very complex set of functions that result in a unidirectional hash; see Figure 1.

Public-key cryptosystems verify the integrity and authenticity of the digital content (integrity refers to the digital content not changing since its creation, and authenticity indicates that an identified entity has released that content). These two fundamental characteristics are provided by the digital signature system to confirm that the digital content can be trusted.

A decisive way to perform authentication in the digital world is the challenge-response method, which can be symmetric or asymmetric. Symmetric authentication is based on a shared secret, as shown in Figure 2.

The authentication based on asymmetric cryptography, instead, consists of two keys: private and public. The private key is known only by the device to be authenticated, whereas the public key can be revealed to any entity that wants to authenticate the device; see Figure 3.

Authentication ICs are configurable, fixed-functionality devices that provide a more efficient way of implementing challenge-response authentication, along with a compact set of cryptographic operations for active authentication. The SHA-256 safe authenticators use a 256-bit secret. The secure authenticator is a 1-wire slave with a unique 64-bit ROM ID that serves as a data element for authentication calculations.

Encryption MCUs

Microcontrollers support both symmetric and asymmetric encryption for digital signature and authentication, as well as cryptographic algorithms. They are equipped with hardware accelerators for SHA, RSA, ECDSA and AES, as well as with a complete encryption library that provides a turnkey API aligned to standards.

MAXQ1061 from Maxim Integrated (Figure 4) is a coprocessor that not only allows authentication but also manages the most critical steps of the TLS/SSL standard secure communication protocol over IP. Some solutions, such as MAX32626, have a hardware protection unit that supports AES authentication, and hardware for encryption, with integrated secure boot-up.

Modern MCUs have begun to include hardware accelerators, typically in the form of specialised peripherals, to simplify and speed up the processing, storage or transmission of sensitive data. For example, the Microchip PIC32MZ family (including PIC32MZ1024ECH100-I / PT) has a 'crypto engine' that accelerates common cryptographic functions. Cryptographic processors are managed by a finite state machine using local storage of data packets. Atmel ATSHA204A-SSHDA-B, for example, provides secure authentication and validation for both host and client operations. And CC3100 and CC3200 SimpleLink Wi-Fi devices from Texas Instruments offer an on-chip TLS stack with highly abstract and easy-to-use APIs, and integrated cryptographic hardware accelerators that

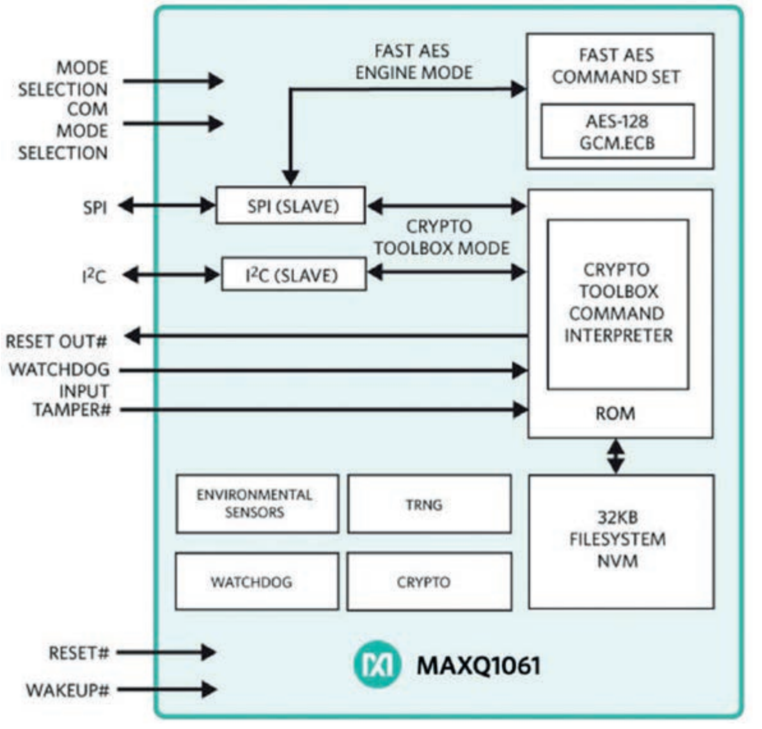


Figure 4: MAXQ1061 block diagram

quickly and efficiently perform complex computational tasks.

Some solutions implement a so-called "message digest that guarantees the integrity of the digital content". This is a secure hash algorithm such as SHA-1, SHA-256 or SHA-3. A digest message is like a super-cyclic redundancy check (CRC), but it produces more outgoing bytes; for example, the SHA-256 algorithm produces a 32-byte output.

Maxim Integrated sells a series of devices that use a hardware implementation of SHA-256 to transfer data securely through a standard 1-wire interface. DS24L65 converts a standard I²C interface into a secure 1-wire that can then connect to a variety of 1-wire

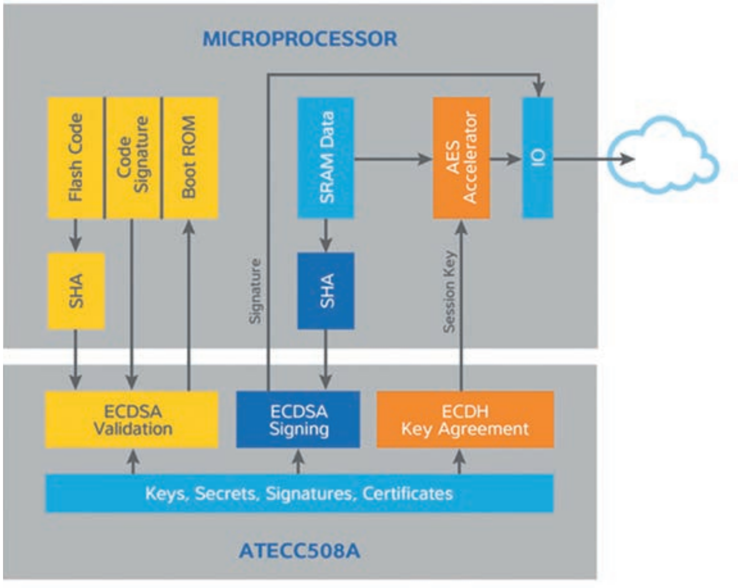


Figure 5: ATECC508A block diagram

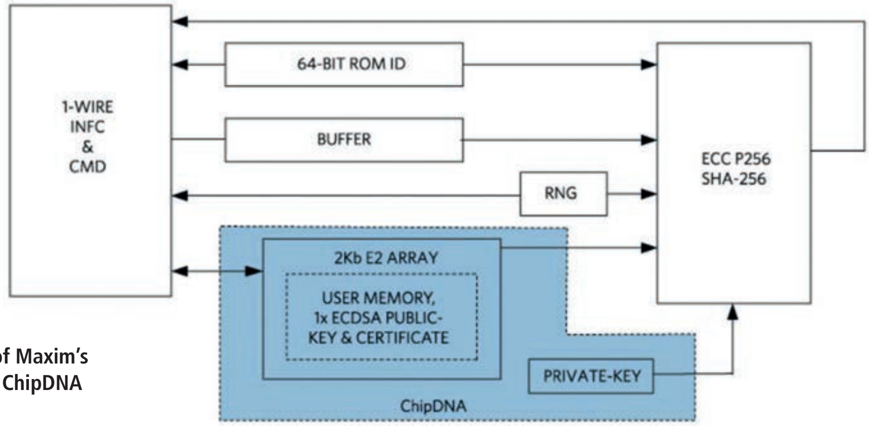


Figure 6: Block diagram of Maxim's DeepCover solution with ChipDNA technology

peripherals, such as the Maxim DS28EL22, with an on-chip SHA-256, 2kbit EEPROM and a unique 64-bit ID.

Equally, the Kinetis K6x NXP family of devices provides hardware acceleration for several standards, including AES and SHA. This coprocessor can run independent of the CPU and uses a memory interface mapped so commands and data can be stored in a cryptographic accelerator unit (CAU).

Elliptic-Curve Cryptography

In recent years, the ECC algorithm has widely spread across the security industry. There are several types of this scheme:

- **Elliptic curve digital algorithm (ECDSA):** a digital signature algorithm primarily used to authenticate digital content and identify that content's author.
- **Elliptic curve integrated encryption scheme (ECIES):** a hybrid encryption scheme that provides semantic security. System security is based on the Diffie-Hellman problem.
- **Elliptical curve Diffie-Hellman (ECDH):** allows two parts, each with public-private key pairs, to share a secret on an insecure channel.

The elliptical curve uses less computational resources than other versions, and has a reduced footprint. A secure application of RSA requires at least 2048 bits of security; RSA keys need 256 bytes. The equivalent ECC keys are only 224 bits long and the keys 28 bytes. There are two ECC from the Atmel CryptoAuthentication (Microchip) family of high-security hardware authentication devices: ATECC508A and ATECC108A. The ATECC508A is an ECDH encryption device for digital systems, specifically IoT nodes used in domotics (from the Latin word "domus" that means house, a combination of information technology, electronics and communications that makes a home "smart"), and medical, mobile and other applications; see Figure 5.

IC Security

Secure device authentication and enhanced encryption ensure the platforms are reliable. Maxim's DeepCover safety ICs with ChipDNA technology provide adequate protection against invasive physical attacks. In addition to silicon, drivers and middleware, communication stacks and support are offered for rapid time-to-market development.

ChipDNA technology involves a physically unresolved (PUF) function that provides protection against invasive physical attacks, implementing advanced physical security to provide maximum low-cost IP protection, as well as clone prevention and device authentication.

In the ChipDNA authenticators, the PUF circuit is based on random analogue characteristics of the device's silicon to produce cryptographic keys, making it immune to all known invasive attack instruments and capabilities. In addition to security benefits, the ChipDNA simplifies or eliminates the need for secure IC key management; see Figure 6.

Attempts to probe or observe the ChipDNA modify the characteristics of the underlying circuit, preventing discovery of the unique value used by the chip's cryptographic functions. Likewise, more exhaustive reverse-engineering attempts are thwarted because of the factory conditioning required to make the ChipDNA circuit operational.

The unique key is generated by the ChipDNA circuit only when needed for encryption and is then instantly deleted. More important, the ChipDNA key never resides statically in registers or memory.

DS28E38 uses ChipDNA technology to cryptographically protect all data stored on the device. The device provides a set of cryptographic tools derived from integrated blocks, including an asymmetric hardware engine (ECC-P256), a random number generator compatible with FIPS/NIST (TRNG), 2kb of protected EEPROM, a counter and a unique 64-bit identification number (ROM ID).

Into Medicine

Health and wellness are one of the fastest growing applications for wearable IoT devices. Diabetes management is more efficient with wearable IoT devices, and soon many blood-related measurements will be possible through non-invasive means, using advanced detection applications.

Access to all of an individual's personal health data is a major impetus to better health, but managing that access will be fundamental to personal privacy.

Security at both device and network level is essential for the operation of "objects". This does not require a revolutionary approach, but rather an evolution of measures that have shown success in computer networks adapted to the challenges of the embedded world. Many integrated-processor providers – NXP, Maxim, Microchip, STMicroelectronics, Texas Instruments and others – have included dedicated encryption/decryption engines and random number generators on their ICs already, at the ready to protect the new generation of connected devices. ❖

Salinity and sugar sensing using microstrip technology

By Md. Naimur Rahman and Mohammad Tariqul Islam, Universiti Kebangsaan, Malaysia, and Md. Samsuzzaman, Patuakhali Science and Technology University, Bangladesh

Conditions like diabetes, stroke, kidney failure among others are on the increase, partly because of modern-day high intake of salt and sugar.

To monitor these in the food and beverage industry, as well as medicine and even agriculture, there are various ways to measure salt and sugar content. The open-ended coaxial probe is one of them, which measures the dielectric properties of food and liquids; however, this process is time-consuming and complex, and system development is costly.

Another measurement method, based on microstrip technology, is considered simple and cost-effective. Dielectric-based sensors read the dielectric and physical properties of a material; they can also sense moisture, temperature, bulk density, and other parameters.

Microstrip Patch Antenna as a Sensor

A fringing field that originates from an antenna patch and affects the substrate causes electromagnetic radiation, affecting the permittivity of the substrate and hence the performance of the patch sensor. A coaxial or probe feed is directly attached to the patch to reduce this radiation, allowing the antenna to operate in a large bandwidth. The performance of a microstrip patch antenna depends on several factors, including its size and shape, with the size changing the resonance frequency of the antenna.

In this project, the sensor measures the reflection coefficient of the sensing antenna within different concentrated salt and sugar solutions. The dielectric properties change due to the bond between dissolved ions and water molecules when salt or sugar are added to the water. This change reduces the polarisation of water and decreases the dielectric constant. The effective dielectric constant also decreases, given the reduction in dielectric constant. Hence, the load impedance increases and, consequently, the reflection coefficient decreases.

Antenna Design

The antenna consists of a tuning-fork-shaped patch with a slotted ground plane. The patch of the antenna is printed on one part of a Rogers RT/duroid 5880 substrate with relative permittivity of 2.2 and 0.0009 loss tangent.

A microstrip feed line with length F_L and width F_W is printed on a similar part of the substrate, acting as the radiating component. The slotted partial ground plane is printed on the other side of the substrate.

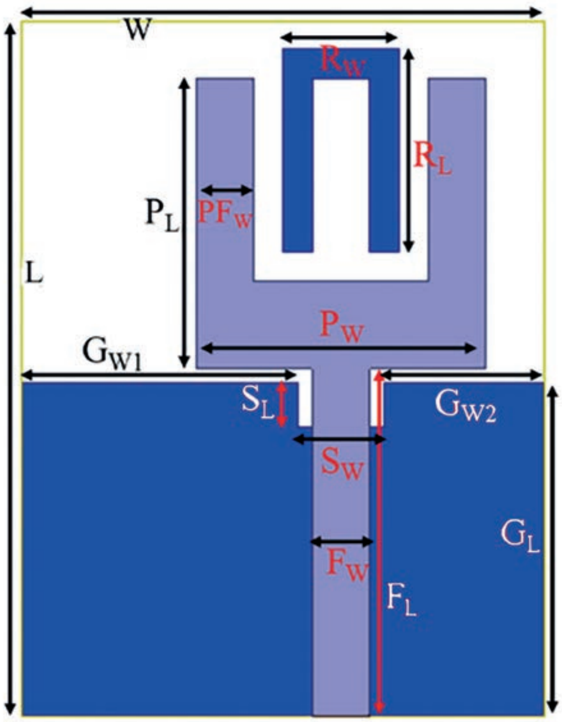


Figure 1: Antenna structure

The antenna parameters are: L= 24mm, W= 18mm, G_L= 11.5mm, G_{W1}= 9.5mm, G_{W2}= 5.5mm, S_L= 1.5mm, S_W= 3mm, F_L= 12mm, F_W= 2mm, P_L = 10mm, P_W = 10mm, P_{FW} = 2mm, R_L= 7mm, R_W = 4mm; Figure 1 shows its geometry and configuration.

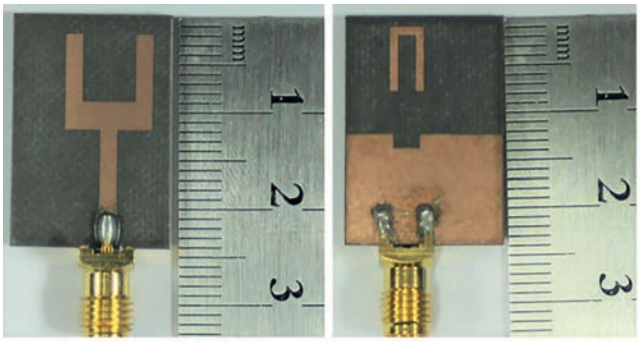


Figure 2: The fabricated antenna: (a) top; (b) bottom

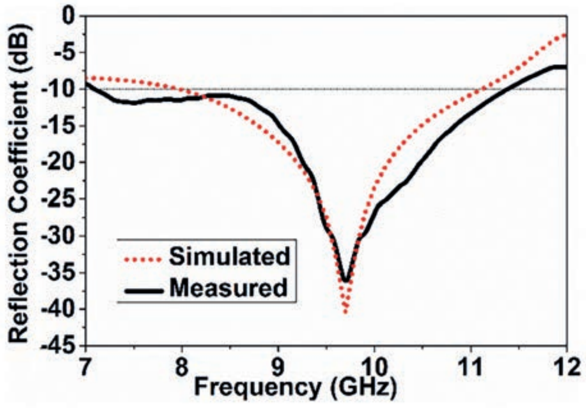


Figure 3: Simulated and measured reflection coefficients of the antenna

Salt (NaCl) and sugar ($C_{12}H_{22}O_{11}$) are crystalline compounds. For our experiment, each was added individually to water to make 20%, 40%, 60% and 80% salt and sugar solutions.

Antenna Performance

The presented antenna has been simulated with the finite-element method-based High-Frequency Structural Simulator (HFSS) and prototyped on a printed circuit board for practical experiments. To measure the antenna's parameters, we used the N5227A PNA Microwave Network Analyser (10MHz-67GHz). The antenna prototype is shown in Figure 2.

Figure 3 shows the antenna's reflection coefficients. In the simulation, the antenna covers bandwidth from 8.0GHz to 11.0GHz with 10dB return loss, whereas in the measurement, the antenna covers the bandwidth from 7.10GHz to 11.30GHz. In both the resonant frequency is 9.70GHz.

Sensor Applications

For the practical experiment of the antenna as a sensing device (Figure 4), the reflection coefficient of the antenna was measured in free space, as well as with the different concentrations of salt and sugar; see Figures 5 and 6. It can be seen that the reflection

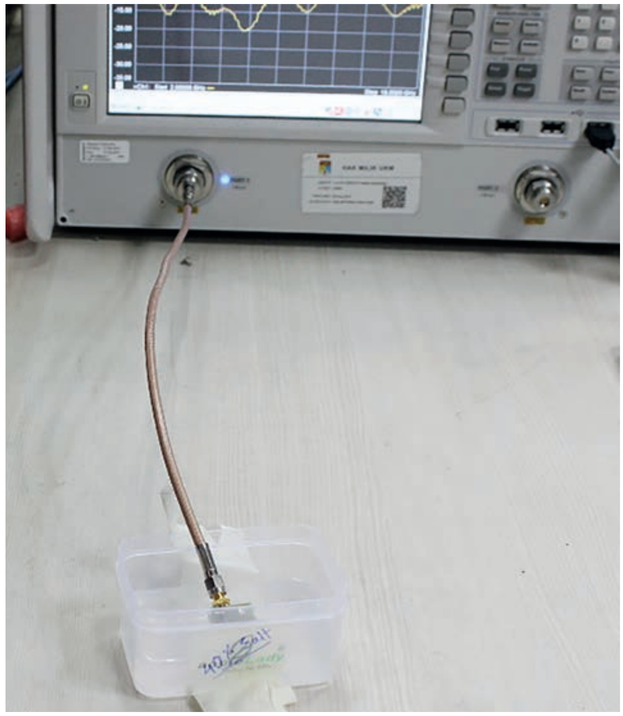


Figure 4: Antenna sensor measurement system

coefficients decrease with the increase in percentage of salt and sugar in the water at the resonant frequency of 9.70GHz. This is because when the salt and sugar content increase, the free water molecules decrease, leading to mismatch impedance reduction, and the reflection coefficient decreases. As the free water molecules decrease, the dielectric constant of the solution also decreases. The reduction of permittivity of the solution reduces the effective dielectric constant of the solution, lowering the load impedance.

This microstrip-technology-based measurement system can be used in the food and beverage industry to detect salt and sugar content in produce, and also in the medical and pharmaceutical fields. ❖

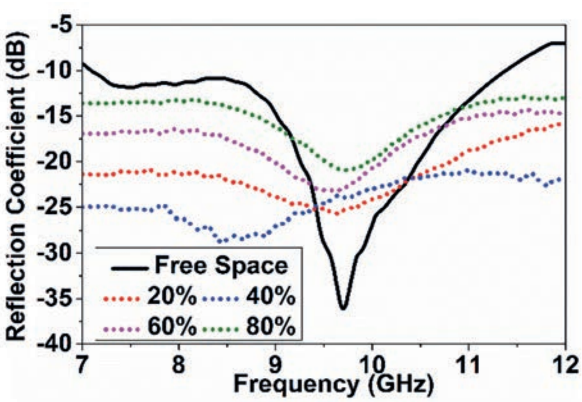


Figure 5: Reflection coefficient variation with different concentrations of salt

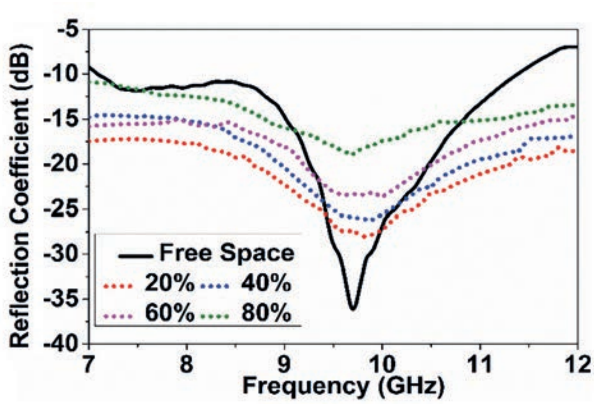


Figure 6: Reflection coefficient variation with different concentrations of sugar

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electronica 2018

Electronica, the largest electronics event in Europe, opens its doors November 13-16, in Messe Munchen, Germany.

This year, the show will be opened by US social theorist, Jeremy Rifkin, known not only for identifying current developments in the economy and society from an early stage, but also for his work on the global networking of industrial and social processes in the "Supergrid". His works "The End of Work", "The Third Industrial Revolution" and "The Zero Marginal Cost Society", will be the inspiration for his keynote speech the evening of Monday, November 12, before opening the new Electronica Experience with a talk on Tuesday, November 13.

Energy

Electronica's focus this year is on smart energy systems, automotive electronics, medical systems, artificial intelligence (AI), robots and digital security.

Energy systems in Europe are undergoing a transition, with the switch to sustainable generation bringing about increasing decentralisation, impacting the entire value chain. Smart energy is the umbrella term for a wide range of technologies in this area relating to energy storage, consumption control and energy conversion. This year Electronica focuses on "Connecting everything – smart, safe & secure". In addition to showcasing products and services from a wide range of sectors, all with some connection to this broad topic, the "Power Electronics Forum" will cover power electronics, smart grid and energy storage.

Medical Electronics Conference (eMEC) – the Debut

In 2018, Electronica will shine its spotlight on medical electronics for the very first time when the field has its own dedicated conference (November 15, at ICM – International Congress Center München). The event will include doctors and electronics engineers discussing the future of the medical sector. Issues covered will include smart medical devices, cloud computing, data security and sovereignty, blockchain technology, collaborative robots, smart contracts, usability, artificial intelligence, telemedicine and Medicine 4.0.

AI and Robots

Electronica will also extensively focus on AI and robots.

In June 2018, Electronica commissioned market research to question 7,000 consumers about AI. Over 80% of respondents said they would like easier lives through electronic devices and aids.

However, many have very different views on what AI, robotics and digitalisation should and shouldn't do. For example, 71% of consumers think that, even in the future, electronic devices should only assist humans, and that human thought processes should not be replaced by artificial intelligence.

A Large Networking Range

For more inspiration and business opportunities, there will also be the Electronica Experience and North by North East (NxNE), as well as IMPACT – Design for a Cause. It will feature engineering associations Hackster and Element14 among others for a look into the future influences of electronics on communications, the environment, medicine and other. There will pitches, presentations and discussion panels.

ALLEGRO MICROSYSTEMS EXPANDS AUTOMOTIVE LED DRIVERS PORTFOLIO

Allegro MicroSystems has released its latest addition to the family of 62xx/808xx LED drivers for lighting, the ALT80802. It addresses a key market trend of 3-4 white LEDs (WLEDs) in a single string powered from 12V battery input, very desirable for fog, backup, DRL, side mirror and other automotive lighting applications. The device provides 2MHz operation, enhanced PWM dimming capability performance, fault protection and reduced external component count. The ALT80802 can be operated in buck mode up to 2A, to drive 1-2 WLEDs from the battery or up to 12 WLEDs from a pre-boost supply.

The ALT80802 is a high-frequency switching regulator that provides constant output current to drive high-power LEDs. It is developed to aid in EMC/EMI design by frequency dithering, soft freewheel diode turn-off, and well-controlled switch node slew rates.

www.allegromicro.com

MOUSER'S PRIZE DRAW DEVKIT GIVEAWAY AND ELECTRONICA EXHIBITION

Mouser Electronics will exhibit at Electronica, the world's leading trade fair and conference for electronics, in Munich, November 13-16, 2018. As in previous years, Mouser is partnering with TTI under the slogan "From Design Chain to Supply Chain … Your Complete Distribution Solution".

Before Electronica, however, Mouser is running an online contest where designers can win a high-level development kit of their choosing:

- ON Semiconductor – IoT development kit bundle;
- Texas Instruments – mm wave sensor evaluation module;
- Intel – RealSense depth camera D400 series;
- Infineon – Aurix application kit TC 297 TFT;
- Linear Technology/ADI – DC 1962C starter kit;
- Cypress – CY8CKIT-062-WiFi-BT PSoC 6 WiFi-BT Pioneer kit;
- Panasonic – Pan 1760A evaluation kit;
- NXP – i.MX 8MQuad evaluation kit (MCIMX8M-EVK);
- STMicroelectronics P-L496G-CELL01/2 STM32 Discovery Packs;
- Maxim – Health band.

Visitors to Mouser's booth at Electronica, in Hall C3, Stand 550, will be offered a free cup of coffee and the chance to test their luck at the "Spin to Win" game, with over 1500 DevKits up for grabs over the course of the four-day event.

MOUSER ELECTRONICS.

https://www.mouser.com/electronica/

RIGOL HAS A NEW HIGH-PERFORMANCE OSCILLOSCOPE FAMILY

Rigol Technologies introduces four new high-end oscilloscopes with a large 10.1" touch-colour display.

The MSO/DS7000 is a versatile mixed-signal high-performance oscilloscope that incorporates many of the latest Rigol own-designed ChipSet ASIC technology and integrated processes. With bandwidths of 100-500MHz (bandwidth upgrade), sample rates up to 10GS/s and with four analogue and 16 digital channels, the MSO/DS7000 series fits many application areas, including research and development, education, production and quality control, as well as the markets for communications, automotive, aerospace, industrial and power electronics, and many more.

This product family's memory depth is up to 500 million points, and waveform capture rate up to 600,000wfms/s, allowing the user to capture, display and evaluate fast signal sequences based on the new UltraVison II Chip Set technology for fastest analysis (decoding).

www.rigol.eu

WIDE-RANGING FAMILY OF 8GHZ SOLID-STATE RF PXI SWITCHES

Pickering Interfaces launched a 13-model family of 8GHz solid-state RF PXI switches, including SPDT, SP4T, SP6T, SP8T, SP16T and 4x4 matrix devices. Its series 40-88xA high-performance switch family now covers 10MHz to 8GHz in the modular PXI format for easy system integration.

Targeting the telecoms and semiconductor test industries, and compatible with a wide range of platforms, including PXI, PXIe Hybrid and Pickering USB/LXI chassis, all the new units feature automatic termination of unused switch channels, up to +36dBm input power handling and excellent RF performance characteristics. Single, dual, quad, hex and octal versions are available on some family members.

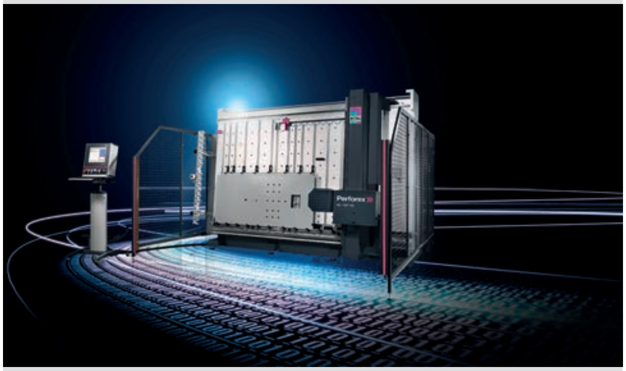
Solid state switches ensure a long service life with no wear out mechanism, and can sustain frequent hot switching without performance degradation. Pickering offers a wide range of units to meet the customer's exact requirements.

www.pickeringtest.com

RITTAL INVITES CUSTOMERS TO TRY THE PERFOREX SOLUTION AT ITS DEMO CENTRE

Customers are invited by Rittal to see a working demonstration model of the Perforex, in its new working demonstration centre in Rotherham, the UK. Rittal Perforex machining centres are designed to automate the creation of bore holes, cut-outs and threads in mounting plates, enclosure doors and side panels. It means that the time-consuming and mechanical processing steps required for the preparation of enclosure panels can now be accomplished in a single work step to an extremely high level of accuracy. The work can be simply programmed into the Perforex to be repeated multiple times for fast, effective batch processing.

Customers can bring examples of their own enclosure modification projects using Rittal AE enclosures and compare the quality of finish they're currently achieving as well as the time a job takes with that delivered by the Perforex.



www.rittal.co.uk

SIGLENT TECHNOLOGIES STRENGTHENS ITS EUROPEAN OPERATIONS

Continuing with its growth and to strengthen its relationship with its customers, Siglent is expanding its European operations. As a result, it is bringing Thomas Rottach on board as its first Sales and Marketing Manager for the new Siglent Technologies Europe. Rottach has over 15 years of experience in the Test and Measurement industry.

"The customer stands at the centre of the Siglent world. Our focus is to partner with our customers to solve their most challenging test issues on time and on budget," said Rottach.

Siglent Technologies established its first European office in 2014. Now, Siglent will move its EU head office from Hamburg to Munich.

The company will also exhibit at Electronica 2018 in Munich (Hall A3, Booth 648), showing its complete, existing portfolio and previewing new instruments, to be released soon.

SIGLENT®

www.siglenteu.com

FREE ESD SURVEY FROM INELCO HUNTER

Did you know that to feel a static discharge it must be about 2000V? However, a component can be damaged by as little as 100V, which means it's very easy for damage to occur without even noticing when it happens.

Inelco Hunter offers an ESD survey which covers many aspects of your static control processes, including:

- Sampling of select areas in your facility, including SMT lines, soldering stations, functional test and shipping/receiving.
- Assessment report including numeric findings, gaps between the program and industry standards EN 61340-5-1 and IPC-A-610E, references to best practice, and recommendations for improvements.

The free assessment is carried out by trained members of the Inelco Hunter team and the company's experienced ESD supplier, Desco, the largest ESD manufacturer in the world.

A wide range of static control products are also available.

www.inelcohunter.co.uk

FIRST CONGATEC SMARC 2.0 MODULE WITH NXP I.MX8 PROCESSOR

Congatec has announced the conga-SMX8, the company's first SMARC 2.0 Computer-on-Module based on the 64-bit NXP i.MX8 multi-core ARM processor family.

The ARM Cortex-A53/A72 based conga-SMX8 represents the new flagship module for ultra-low-power embedded computer designs, offering the recent best-in-class ARM processor with excellent performance, flexible graphics and numerous embedded features for all kinds of IIoT applications. It provides high-performance multi-core computing along with extended graphics capabilities for up to three independent 1080p displays or a single 4K screen. Further benefits of this native industrial-grade platform include hardware-based real-time and hypervisor support along with broad scalability, as well as resistance against harsh environments and extended temperature ranges. All these features make the SMARC 2.0 module meet the recent performance and feature set needs for low-power embedded, industrial and IoT, as well as the mobility sector.

www.congatec.com