TECHNOLOGY

Signal Advance, Inc.
2520 County Road #81
Rosharon, TX 77583

713 510 7445

www.signaladvance.com

Contents

THE TECHNOLOGY

In recent years, a physical phenomenon known as negative group delay (NGD) has been demonstrated in simple electronic circuits and shown to temporally advance the detection of analog waveforms. In a circuit exhibiting this property, the output signal is advanced in time relative to the input – the time delay through the circuit is, in effect, negative – so that the circuit's output precedes the complete detection of the input signal. Signal Advance, Inc. refers to this phenomenon, and its application, as Signal Advance (SA) technology. Successful development and implementation of SA technology carries important implications for interventional methodologies in cardiology and neurophysiology, as well as broader potential across a range of medical and non-medical applications.

Overview

Sensors detect physical or physiological properties – pressure, temperature, speed, or heart rate, for example – and convert them into analog electrical signals. These signals are typically digitized and processed to generate an output used for monitoring, intervention, process control, or similar functions. SA technology is designed to temporally advance the detection of analog electrical signals, thereby offsetting, and potentially eliminating, transmission and processing delays in responsive control or interventional systems. This capability may improve the performance of devices that process analog signals across a range of fields, including industrial process control, manufacturing automation, interventional medical devices, alarm and detection systems, transportation power-train and accident-avoidance control, and defense targeting and weaponry. Among the many potential application areas, medical intervention devices stand out as particularly promising: even a small increase in signal-detection speed, on the order of fractions of a second, could meaningfully affect the efficacy of such a device.

Signal Advance's proprietary circuitry operates on broadband analog signals within a specified frequency range and can be designed to minimize distortion between the circuit's output and its input. The Company has developed a number of prototype SA circuit designs operating across various frequency ranges; their transfer functions have been analyzed, their performance modeled, and the designs tested using a range of test signals.

Problem, Solution, and Value

In state-of-the-art interventional medical and industrial devices, time delays associated with analog signal detection and processing directly affect the likelihood of successful intervention. This is particularly true when containing or limiting a life-threatening patho-physiological event, such as cardiac ventricular fibrillation or an epileptic seizure: the earlier the intervention begins, the greater the likelihood of a successful outcome.

Hybrid predictive feedback and feed-forward control systems, commonly used to improve control-response performance, have inherent drawbacks. Approaches that rely on increasingly faster electronics can reduce these delays but can never eliminate them entirely, nor can they achieve a net temporal advance. SA technology is designed to achieve that advance by exploiting negative group delay – a counterintuitive, yet empirically verified, wave-propagation phenomenon in physics.

In most electronic circuits, the output signal is delayed relative to the input. In a circuit exhibiting negative group delay, however, the output signal is advanced in time relative to the input – hence the term Signal Advance. This temporal advance can potentially be used to offset signal-detection and processing delays.

Differentiation

Current approaches to improving the performance of signal-transmission and responsive systems generally rely on increasingly fast electronics together with hybrid predictive feedback and feed-forward control, typically implemented digitally, and may be adequate for many applications. SA technology, by contrast, achieves performance improvements through unique engineering grounded in physics and implemented in analog circuitry. By reducing or eliminating signal-detection and processing delays, this technology has the potential to improve performance across a wide variety of biomedical and industrial closed-loop intervention and control systems that rely on signal feedback. Success in this effort would have potential application across a broad range of systems that depend on the detection of analog signals, and could contribute to a new class of proactive, rather than reactive, intervention and control. SA technology can also be applied alongside these conventional methods to further improve system performance.

An Analogy

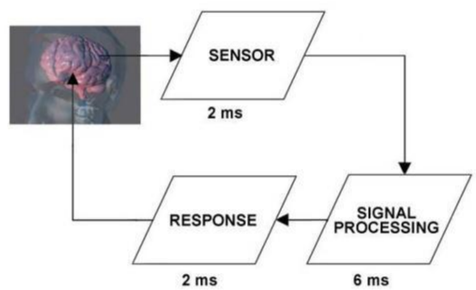
To illustrate temporally advanced signal detection, consider the hypothetical intervention scenario depicted at right. A man in a suit, carrying a briefcase, runs along the front of a wall, unaware that he is approaching the edge of a cliff.

Positioned near the end of the wall, and slightly behind it, is a second man whose task is to stop anyone from running off the cliff's edge. Because he is not permitted to stand in front of the wall, he can act only after the runner passes its end – he cannot see the runner coming until that moment.

In the illustration below, bright sunlight behind the runner casts a long shadow ahead of him. Because the guard can see this shadow before the runner himself comes into view, he detects the runner earlier, gaining additional time to react and improving his chance of a successful intervention.

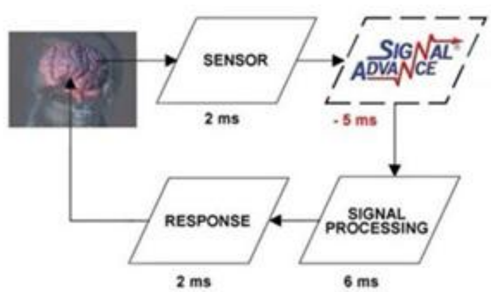
Implementation

The functional block diagram at right depicts a typical closed-loop control, or interventional, system. A sensor detects a physical parameter – in this example, a neural signal – and converts it into an analog electrical signal reflecting the parameter's value. The signal is then processed, and an appropriate feedback response is generated. Each step requires a finite amount of time: if signal detection takes 2 milliseconds, signal processing takes 6 milliseconds, and generating a response takes 2 milliseconds, the overall response time is 10 milliseconds.



Overall Response Time: (2ms + 6 ms + 2ms) = 10 ms

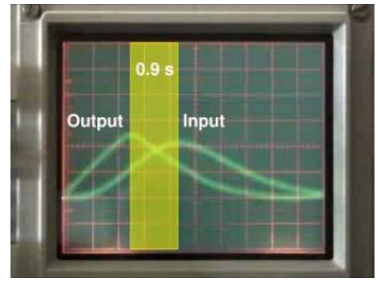
Incorporating SA technology into the same control system, and assuming a temporal advance of 5 milliseconds, would offset delays introduced by the other processing steps, potentially reducing the overall system response time by roughly half.



Overall Response Time: (2ms - 5 ms + 6 ms + 2ms) = 5 ms

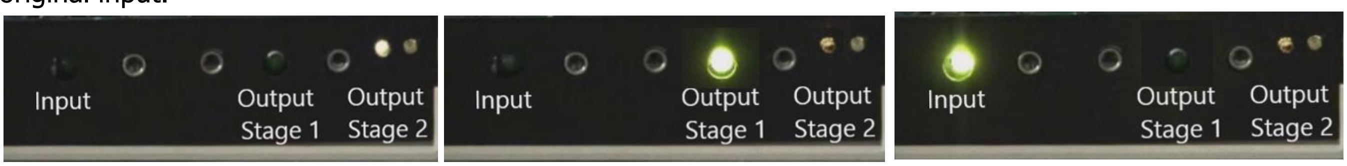
Visible Temporal Advance

An early two-stage SA circuit prototype was developed in which the temporal advance achieved by each stage was approximately 0.45 seconds, for a combined advance of roughly 0.9 seconds – slow enough to be observed with the naked eye. The circuit was tested using a Gaussian, or bell-shaped, pulse as the input signal.



The oscilloscope traces below show the temporally advanced output pulse, from the second SA circuit stage, relative to the input, using a timescale of 0.5 seconds per division. The temporal advance achieved was just under 0.5 seconds per stage, for an overall advance of nearly a second. Note the distortion evident in the output – a narrowing of pulse width and a skewing of shape – relative to the input.

Light-emitting diodes were connected to the signal input and to the outputs of the first and second SA circuit stages, as shown below, and were configured to illuminate when the signal reached its peak amplitude. In the recorded video, the output-stage-two LED illuminates first, followed by the output-stage-one LED, and finally the input LED – visually confirming that each successive stage advances the signal further ahead of the original input.



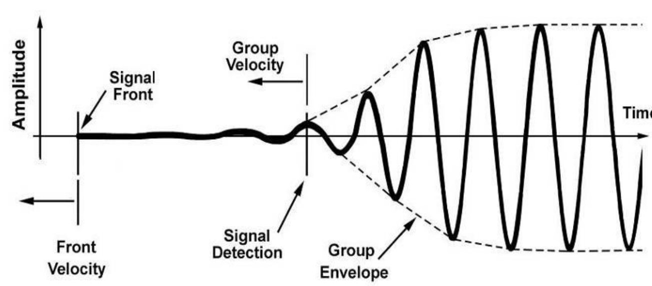
These preliminary results convincingly demonstrated that Signal Advance technology, grounded in negative group delay, can be implemented in electronic circuitry, and established two key findings:

1) SA circuit stages can be cascaded to increase the overall temporal advance achieved.
2) Signal conditioning is needed to reduce distortion introduced in the advanced output.

Wave Propagation Physics

Understanding this seemingly counterintuitive behavior requires recognizing that electromagnetic propagation is characterized by five distinct waveform velocities [Brillouin L, Wave Propagation and Group Velocity (Pure and Applied Physics), New York: Academic Press, 1960], described below:

- ***Phase velocity*** – the speed at which the phase of any single spectral-frequency component of the wave travels.
- ***Group velocity*** – the speed at which variations in the shape of the wave's amplitude, known as its modulation or envelope, propagate (see diagram below).
- ***Front velocity*** – the speed of an abrupt signal discontinuity, such as a signal turned sharply on or off. This is considered the very beginning of the signal in time and never exceeds c, the speed of light (see diagram at right).



- ***Energy velocity*** – the speed of energy transfer.
- ***Signal velocity*** – the speed of information transfer, which, depending on conditions, may be equivalent to one or more of the velocities described above.

The front velocity corresponds to the speed at which the first, often imperceptibly small, vibrations occur, while the signal velocity marks the arrival of the main signal, with intensities on the order of the input signal's magnitude. [Brillouin]

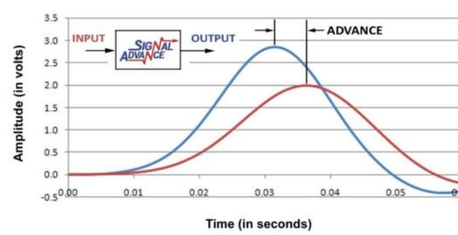
In most cases, the signal velocity is equivalent to both the group velocity and the energy velocity. While the front velocity cannot exceed the speed of light, in special cases – such as media or circuitry that amplifies the leading portion of a waveform while attenuating its trailing portion – the group velocity can, according to Brillouin, exceed the velocity of light c, and can even become infinite or negative. That is, detection of a pulsatile or extended-in-time waveform at a medium's output can precede the complete detection of that waveform at its input.

During the interval between the arrival of the wavefront (front velocity) and the detection of the group waveform, electromagnetic energy begins propagating through the medium, though its magnitude remains undetectable until the oscillations reach sufficient amplitude. These very early, very low-amplitude perturbations – termed "forerunners" by Brillouin – nonetheless contain sufficient information to reconstruct a temporally advanced signal. Signal Advance technology acts to temporally advance the wave envelope of an analog signal, resulting in its earlier detection.

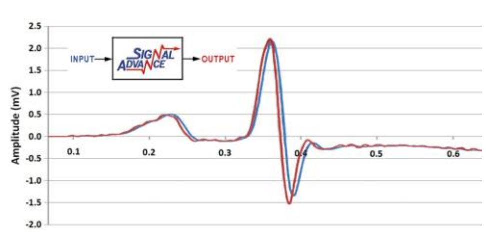
VALIDATION

Signal Advance's validation program is intended to substantiate the Company's core technical claims: that proprietary SA circuitry, operating on broadband analog signals within a specified frequency range, can be designed to produce minimal distortion between output and input, and that a range of prototype designs, spanning multiple frequency bands, have been analyzed, modeled, and tested against a variety of test signals. The sections below summarize the scientific, technological, and third-party validation obtained to date.

Scientific



During Dr. Hymel's doctoral studies, SA circuit designs developed specifically for electrocardiology – the electrical function of the heart – underwent rigorous refinement, testing, and evaluation. The research investigated the negative delay, or temporal advance, achieved with SA technology, analyzing both the magnitude of the advance and the fidelity of the temporally advanced output signals. Completed in 2010, the project exceeded its objectives, successfully demonstrating SA technology's ability to temporally advance a range of known constructed test signals, including pulses and sine waves, as well as human electrocardiographic (ECG) signals recorded from cardiac patients. The work formed the basis of a doctoral dissertation (Hymel CM, Application of Signal Advance Technology to Electrophysiology, University of Texas Health Science Center – Houston, Graduate School of Biomedical Sciences, August 2010); by December 31, 2017, the dissertation had been read more than 400 times, reflecting ongoing interest in the technology.



Technological

The results of this research were summarized in a peer-reviewed engineering article addressing the theoretical basis, practical implementation, and potential applications of SA technology, published as the feature article in IEEE Circuits and Systems Magazine, Third Quarter 2011 (Hymel, et al.).

Outside Recognition

In October 2011, the Company was awarded first place in the Goradia Innovation Prize competition ("Houston Technology Center Names 2011 Goradia Winners," Houston Business Journal, October 6, 2011).

Award selection was based on the soundness of the business plan, the commercial potential of the technology, the potential for regional job growth, and the likelihood of significant long-term success.

For his development work on Signal Advance technology, Dr. Chris M. Hymel, the Company's President and CEO, received the following recognition:

- The Oklahoma Bar Association's Intellectual Property Section named Dr. Hymel its 2012 Innovator of the Year.
- The State Bar of Texas Intellectual Property Section named Dr. Hymel its 2015 Inventor of the Year.

Third Party Reviews

"… A NET PRESENT VALUE OF UP TO $10.4 MILLION … CONSERVATIVE VALUE FOR THE PATENT(S)." (for two biomedical applications), "…the patent is seminal in concept … there is no current competition."

Stephen P. Weeks, Ph.D. (Physics), First Principals, Inc.

"… truly 'pioneering' or 'landmark' invention …" " 'Excited'… my reaction to this technology and its future potential."

David G. Henry, Registered Patent Attorney, Law Professor

"… disruptive technology that forces rapid change in the field." "… early adopters gaining a significant commercial advantage ..."

Harold L. Russell, Ph.D., NeuroMedics Technology, Inc.

"The technology of Signal Advance may well be the key to such effective seizure suppression."

H. Martin Blacker, MD, Neurosurgeon

"Signal Advance technology … can revolutionize the non-pharmacological treatment of arrhythmias and epilepsy."

Hue-Teh Shih, MD, Electrocardiologist

INTELLECTUAL PROPERTY

The Company believes that Signal Advance's patent portfolio represents a new and unique application of the signal-advance concept to medical and other fields, and is therefore seminal in concept. To date, the Company has not identified any patents related to temporally advanced signal detection for improving the performance of control or responsive systems, nor any patents that would prevent Signal Advance from practicing its technology or that offer superior solutions to the problems it addresses.

Summary and Status

A patent titled "Utility and Method for the Application of Signal Advance Amplification to Analog Waveform or Signal Detection," describing the broad basis of the SA process and technology, was issued by the United States Patent and Trademark Office in 2014. International counterparts have since been issued in China (2013), Europe (2017, validated in India and Mexico), Mexico (2015), and India (2019); the European patent extends to France, Germany, Ireland, Italy, Spain, Sweden, and the United Kingdom. The Company has also registered the trademark Signal Advance.

The Company's overall patent strategy reflects the fact that SA technology must be tailored to the specific signal characteristics and requirements of each application, often requiring the development of unique circuitry and signal conditioning. This application-specific uniqueness in circuit design and parameter analysis supports novelty and non-obviousness in patent claim construction, and the underlying manipulation of negative group delay to achieve signal advance further supports non-obvious claims.

The Company expects each application of SA technology to warrant its own patent filing. Intellectual property covering various SA circuit configurations and signal-conditioning techniques – intended to improve the fidelity of temporally advanced signals, including technology developed through the Company's neural-training project – is currently being drafted. The methods used to analyze the specific characteristics of individual applications will be maintained as trade secrets; these need not be licensed and may be protected separately.

Searches of the patent and scientific literature have been conducted periodically since the Company's first patent filings in 2008. These analyses have distinguished among the relevant references and demonstrated that the prior art does not negate the utility or novelty of SA technology; no combination of the identified references has been found that would render the technology obvious to a person skilled in the art.

The Company's intellectual-property strategy includes adding multiple application-specific patents to its portfolio, each standing independently, such that an attack on any one patent would not affect the others. The Company will work with licensees to analyze market size and penetration in order to determine which international applications to file and prosecute.

Competition

Within the broader field of signal science and technology, detection, acquisition, and processing performance continue to improve through the use of increasingly fast electronics. Predictive feedback methods, which rely on historical input data, and feed-forward, or open-loop, control methods, which respond directly to changes in input rather than output, are also used to improve system performance; hybrid predictive methods combine elements of both and may draw on historical data as well.

These methods are widely used throughout the industry and, in some systems, may be adequate. Faster electronics can reduce response delays, but cannot eliminate them, let alone produce a net temporal advance. SA technology can be implemented alongside these other approaches to further improve performance.

SA technology offers distinct advantages over these methods: it has the potential to offset, or in some cases eliminate, response delays, and may even yield a net temporal advance. Because the technology is implemented using analog circuitry rather than digital processing, and analog circuitry generally operates at higher speeds than digital circuitry, it may also translate into lower component costs and increased reliability.

Given its distinct mode of operation, SA technology can be implemented alongside more conventional methods, potentially compounding the performance gains achieved.

The Company is not currently aware of other parties commercializing this specific technology. However, the Company's own success will likely invite competition as recognition and acceptance of SA technology grows – potentially including infringement by parties seeking to distinguish minor variations in the technology, as well as legal challenges from larger, better-capitalized firms capable of sustaining lengthy and costly litigation.

To date, searches and analyses of the patent and scientific literature have not revealed prior art that negates the utility or novelty of SA technology. Because SA circuitry must be precisely designed to accommodate the unique signal characteristics of each application, the Company believes that circuitry designed for particular applications will likely be separately patentable.

To reduce the likelihood of the technology being co-opted by a market leader, the Company's defense against copying and infringement includes the following strategic elements:

- Each SAT application will be protected by its own patent or patents, such that multiple independent applications will not overlap or interfere with one another.
- An attack on any one patent or application area will not affect the others.
- Licensees will be required to participate in the defense of the patents they have licensed; a licensee that fails to do so will be subject to license termination.
- A licensing strategy will initially target smaller companies that are less likely to infringe or engage in litigation.
- Application-specific methods for developing SAT for particular sensors, signals, circuitry, and operational parameters will be maintained as trade secrets held by the Company.
- Patent, scientific, and trade publications will be monitored to identify infringement and competing developments.

These measures give the Company technical and legal advantages that potential infringers would have to overcome, at undue time and expense. Experience suggests that implementation of SAT can be more efficient with the Company's consulting support. Given the choice between infringing and implementing without assistance, or paying a license fee and receiving assistance, the Company believes most companies will choose the latter – reducing time to market, avoiding potential litigation expense, and limiting liability, all of which result in more cost-effective implementation.

Dr. Hymel, the Company's CEO and the inventor of SAT, has worked in this field for a number of years. His doctoral research stands as the seminal investigation of SAT's application to biomedical signals, specifically the human ECG, and the Company believes it is well positioned to be first to market with what it and others have described as a disruptive technology. Based on its multi-year head start, the Company believes it has established itself as a leader in the field, gaining a significant early competitive advantage.

APPLICATIONS

Sensors detect physical parameters and convert them into analog signals representing the property being measured. Inherent delays in signal detection and processing can reduce the effectiveness of the resulting control or intervention.

SA technology is designed to temporally advance analog signal detection, decreasing these delays and thereby improving overall system response time. Ideal applications are those in which a faster response time would meaningfully improve performance – typically responsive, closed-loop control or interventional systems.

SA technology can be applied to temporally advance both narrow- and broad-band signals, reducing or, potentially, eliminating detection and processing delays. Applied differentially, it could also help separate overlapping signal components in time, facilitating detection of otherwise masked signal components. In each case, SA technology is intended to serve as an adjunct to existing control strategies, further enhancing their performance.

The technology may apply to hundreds of sensors across a broad range of general categories, including:

Acoustic/Sound/Vibration	Angle/Rotation	Bioelectric signals
Chemical	Distance/Displacement	Electrical/Electro-Magnetic
Environment/Weather	Flow	Level/Density
Magnetic/Radio	Navigation	Position/Pressure/Force
Optical/Light/Imaging	Speed/Acceleration	Photoelectric Sensors
Proximity/Presence	Radiation/Subatomic Particles	Thermal/Temperature/Heat
(… and more)		

SA technology has potential applications across a broad range of signal detection and processing systems, spanning both industrial (non-medical) and medical markets. Representative examples include:

Medical:

- Cardiac rhythm management (CRM)
- Neurostimulation/neurotherapy
- Prosthetic, neural (brain/machine) interfaces
- Artifact detection/correction
- Gated imaging and radiotherapy

Industrial:

- Manufacturing automation/Process control
- Transportation(power-train/accident avoidance)
- Defense (weaponry/targeting)
- Energy (generation/distribution)

Medical Applications

In interventional medical devices and other closed-loop physiological systems, delays in signal detection, processing, and response can reduce overall performance. Certain patho-physiological events are candidates for temporally advanced waveform detection: for signals such as cardiac or brain activity, longer delay generally makes it more difficult to intervene early enough to contain or limit a pathological process such as cardiac fibrillation or an epileptic seizure. Signal Advance technology is being evaluated for potential application to early arrhythmia and seizure detection and intervention, among other uses.

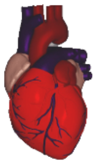
Signal Advance technology may be suited to medical instruments, treatment devices, and electrophysiological interfaces used in the detection, acquisition, and processing of band-limited analog waveforms produced by the body – for example, brainwaves such as the EEG and MEG, neuromuscular potentials such as the EMG, and cardiac rhythms such as the ECG.

Demonstrating reliable, temporally advanced detection of electrophysiological waveforms could, if validated, enable earlier intervention in a pathological event than is currently possible. Potential applications include cardiac rhythm management, neuromodulation and neurostimulation, neuroprosthetics and human-machine interfaces, neurotherapy, and physiologically gated imaging and radiation therapy. Signal Advance's initial research and development focus is the application of the technology to the detection of bioelectric signals for potential use in interventional medical applications.

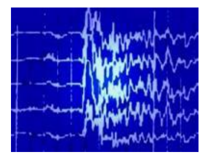
In real-time applications, Signal Advance technology may help offset signal-processing delays associated with extracting relevant features, potentially improving response time and overall system performance. Using multiple spectrally tuned bands of single-stage circuits in parallel, the technology has the potential to temporally shift overlapping signal elements – such as artifacts or noise – differentially, which may help unmask bioelectric signal components of interest based on their spectral content.

Potential biomedical applications include real-time artifact detection and correction, neural pacing and seizure suppression, neurofeedback and neurotherapy, brain-computer and neural interfaces, and electrocardiology. Signal Advance technology could also potentially assist physiologically gated diagnostic and therapeutic applications, such as medical imaging and radiotherapy, by advancing the detection of certain trigger signals; any resulting improvement in target and timing accuracy would need to be demonstrated experimentally.

Various sources of artifacts often produce unwanted signal components that overlap or mask the electrophysiological signals of interest. Much current artifact-detection and correction research focuses on reducing the computational load of existing artifact-rejection algorithms in order to reduce their processing time; a number of these techniques operate in the frequency domain over narrow spectral bands.

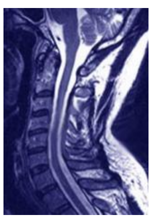


In electrocardiology, current cardiac-monitoring technology typically acquires multiple consecutive heartbeats to detect anomalous cardiac signals before generating a response, which is necessarily delayed – yet anti-tachycardia therapies are generally most effective when delivered soon after onset. Implantable cardioverter-defibrillators already use validated digital arrhythmia-discrimination algorithms, and any potential contribution from Signal Advance technology would be limited to a qualifying detection-timing component within that established framework, not a replacement for it. Signal components indicative of fibrillation or tachyarrhythmia (F-waves) can be masked by the larger ventricular QRST complex; temporally shifting the F-wave differentially could, if validated, facilitate its detection, which may be significant given the short time available to distinguish life-threatening ventricular fibrillation from other arrhythmias.



In epilepsy, seizures typically begin focally, in a small region of the brain, and can become generalized within a fraction of a second. The performance characteristics most critical to seizure suppression and neural pacing are high sensitivity, high specificity, and – most importantly – rapid detection. Earlier detection of epileptiform EEG activity and a faster overall response could potentially improve intervention efficacy.

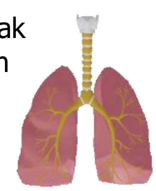
In gated imaging or radiotherapy, trigger signals are used to time image acquisition or radiation delivery to periods of minimal movement – between heartbeats or breaths – and to halt the process when unexpected movement is detected. Movement from respiration or heartbeat can otherwise produce imaging artifact,



reducing image quality and potentially requiring additional scans and increased patient exposure. In gated radiation therapy, unexpected respiratory or cardiac movement can result in unintended irradiation of normal tissue or reduced radiation to the targeted tissue. Commercial gating and motion-management systems already use predictive algorithms, including Kalman filtering and learned motion models, to anticipate respiratory and cardiac motion ahead of the triggering event; any potential contribution from Signal Advance technology would need to be evaluated against these existing predictive methods, not merely against an undelayed baseline.

Reduced response time or improved temporal separation of overlapping signals could, in some applications, support improved system performance, though any such benefit would need to be demonstrated for each specific application rather than assumed generally.

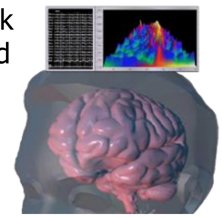
The signal characteristics of a given application determine its circuit-design requirements. For an ECG used in an implantable cardioverter-defibrillator, the frequency range of interest is often below 40 Hz, and waveshape is important for extracting specific signal features, so circuitry would be designed to provide constant advance and gain through 40 Hz in order to minimize distortion.



By contrast, for ECG-gated imaging or radiation therapy – where only detection of the QRS peak is required – waveshape is less critical, and some signal distortion may be acceptable in exchange for increased peak-detection temporal advance. Respiration rates are typically well under 60 breaths per minute (approximately 1 Hz), and motion of the lungs or other organs from respiration presents a movement profile similar to the respiratory cycle. This is a lower-confidence candidate application given the maturity of existing predictive respiratory-gating algorithms; circuitry could potentially be developed to temporally advance detection of respiratory-related signals, but any incremental benefit over current predictive-gating performance would need to be demonstrated experimentally before it could be considered a meaningful differentiator.

The processing demands associated with neural interfaces for prosthetic and robotic applications continue to limit cybernetic performance, as long time delays are associated with control and feedback loops.

Advanced prosthetic and brain-computer-interface systems already rely on low-latency embedded digital signal processing to decode neural activity, and this remains a competitive and rapidly advancing field. Signal Advance technology is not intended to replace this digital decoding pipeline; if validated, its potential contribution would be limited to a qualifying signal-detection component upstream of existing processing, and would need to be demonstrated as a meaningful improvement over current digital approaches to be commercially relevant.



In neurofeedback therapy, EEG signals are detected and interpreted to control the feedback provided to the patient – a form of operant conditioning. Reducing feedback delay could potentially improve the efficacy and efficiency of neurotherapy generally. Most neurofeedback systems operate on EEG signals with spectral content well under 100 Hz, which may make them suitable candidates for evaluation of Signal Advance technology.

These examples illustrate that circuit design must be tailored to each specific application, weighing trade-offs among the temporal advance achieved, the minimum spectral range required, and tolerance for signal distortion. For Signal Advance technology to be of practical use in electrophysiological applications, the temporal advance achieved must provide a usable offset to signal-processing delay, or provide a means to separate masked or overlapping signal components in real time based on spectral content. In near-term applications, the temporally advanced output signal should closely represent the input signal so that current detection, feature-extraction, and signal-processing methods can still be applied.

Early experimental results suggest that overall temporal advance may be increased by cascading multiple circuit stages, provided that signal distortion and any introduced artifacts are minimized through appropriate filtering and signal conditioning; further validation would be required to confirm this approach across additional applications.

<u>Industrial Applications</u>

Signal Advance has identified categories of physical analog signal sensors that may be suited to signal-detection temporal advancement, along with a range of potential licensing targets. Industrial applications and markets span a wide range of commercial, industrial, military, and transportation areas, including industrial process control, alarm and detection systems, vehicular and flight control, chemical processing, manufacturing and production, and military targeting and weaponry.

In industrial process control, physical parameters such as temperature, pressure, and flow provide input data for closed-loop control systems that act to optimize production yields. In the petrochemical industry – for example, in distillation – transient response times are measured in seconds to minutes, making these processes potential candidates for the application of Signal Advance technology, though the achievable benefit would depend on the extent to which sensor-signal delay, rather than valve, actuator, or process dynamics, limits the overall control loop.

In refining, closed-loop response time is often limited primarily by valve and actuator dynamics and process residence time rather than by sensor-signal delay, so any benefit from Signal Advance technology in this application would likely be incremental and application-specific rather than a primary performance driver. Where sensor-related delay is a meaningful component of the loop, faster closed-loop response could still provide better disturbance rejection, and even modest gains in yield, energy use, or safety could have economic value given the scale of refining operations; this remains a candidate for evaluation rather than a demonstrated benefit.

Compressors run most efficiently when operating near their stability limits, or stall margins, relying on real-time pressure, temperature, and flow measurement to determine the operating point and surge margin. Modern compressor control systems already use high-rate digital sensing and spectral analysis of pressure fluctuations to detect surge precursors, and these digital approaches are mature and widely deployed. Signal Advance technology is not intended to replace these systems; if validated, its potential value would be as a complementary analog front-end that could further reduce the delay between a detectable pressure-signal change and the point at which existing digital control logic acts on it, potentially widening the effective surge margin. In high-performance aircraft engine control systems, real-time detection of inlet airflow distortion is used for high-speed engine control to increase engine stability, reduce stall margins, improve performance, and lower fuel consumption; these systems already rely on extensively validated digital control architectures, and any new analog front-end technology would need to operate alongside – not replace – those systems, and would face substantial certification and qualification requirements before adoption.

With gas-turbine engines more broadly, improved flow control – including faster closed-loop fuel-flow control, compressor operation closer to its stall boundary, fuel/air mixing control, and turbine-temperature-based air cooling – are areas where a demonstrated reduction in sensor-related delay could complement existing digital control strategies, though the achievable improvement would likely represent a small fraction of overall system response time given the mechanical, thermal, and aerodynamic dynamics involved.

In transportation more generally, Signal Advance technology could potentially improve crash avoidance, safety and security, drivetrain performance, and overall vehicular control. Engine combustion control is a lower-confidence candidate application: modern engine control units already operate at very high loop rates, and combustion timing is generally dominated by fuel-injection dynamics and combustion chemistry rather than sensor-signal delay, so any benefit from Signal Advance technology in this specific application would likely be marginal and would require application-specific evaluation to confirm.

In defense systems, feedback delay reduces response effectiveness. Modern targeting systems already use sophisticated digital sensor fusion and predictive tracking algorithms; any potential contribution from Signal Advance technology would be limited to reducing a qualifying sensor-detection component of the overall response time, and would need to be demonstrated as a meaningful improvement over these existing digital approaches before it could be considered a differentiator in target acquisition and tracking accuracy.

These examples illustrate a few of the industrial applications that may benefit from Signal Advance technology, pending validation. If realized, improvements would likely take the form of operating-efficiency gains, performance and yield improvements, or accident-prevention benefits, rather than a fundamental change in how these systems operate.

Cybersecurity

Overview

Signal Advance's cybersecurity work is built around Analog Guard®, its mixed-signal, physical-layer, hardware-rooted encryption platform, owned by Analog Guard, Inc., a wholly-owned subsidiary formed January 1, 2026. Where conventional encryption operates on digital data in software, Analog Guard performs its transformation on the analog signal itself, giving it a fundamentally different security model and failure mode than software-based cryptography. Analog Guard builds on Signal Advance's core Negative Group Delay signal-processing work but addresses a different problem than the applications discussed elsewhere in this document: rather than temporally advancing detection of a physical signal, it applies a key-controlled transformation intended to protect that signal's information content.

The Mixed-Signal/Physical-Layer Mechanism

Analog Guard converts digitally represented information into controlled analog signal states, applies a key-controlled nonlinear transformation, and returns the protected signal to digital form for storage or transmission. Authorized recovery uses a matched inverse process keyed to the same transformation parameters. A mismatched key is designed to produce output approximating random data rather than a partially decoded signal, which is intended to distinguish this approach from conventional digital encryption operating entirely in the software domain. This mechanism remains subject to continued development, independent testing, and validation.

Development Status

The Analog Guard program has moved beyond concept and simulation into hardware prototyping. Validated models have been translated into circuit designs and schematics, with printed-circuit-board layouts in progress and nearing completion as of this writing. Current engineering work is focused on fabricating and testing physical encryption and decryption hardware, confirming matched-key recovery in hardware, and correlating bench performance against the simulation record. As with Signal Advance's other applications, commercial deployment would require further validation, hardware qualification, and, depending on the application, applicable certification and compliance review.

Patent Portfolio

The Analog Guard portfolio is anchored by a foundational U.S. patent, U.S. Patent No. 12,126,720 (filed March 29, 2024; issued October 22, 2024), which establishes matched-key nonlinear analog modulation for encrypting and recovering analog or digitally encoded signals. Two continuation patents extend this foundation: U.S. Patent No. 12,689,512 (filed October 21, 2024; issued July 21, 2026), which adds claim coverage for key-controlled modification of a message or reference signal and its recovery using the corresponding analog key, and U.S. Patent No. 12,615,149 (filed October 21, 2024; issued April 28, 2026), which extends the platform to multi-key, cascaded nonlinear circuits with processor and synchronization-controller coverage. A continuation-in-part application, U.S. Application No. 19/220,451 (filed May 28, 2025; allowed July 27, 2026, with 30 claims), adds key-controlled mixed-signal encryption and decryption with dynamic transfer-function control and variable-resolution encoding. International counterparts of the foundational family have been filed under the Patent Cooperation Treaty (PCT/US2024/022278 and PCT/US2026/030207), with national-stage filings pursued in China, Germany, and India.

The portfolio also includes four U.S. provisional applications, filed in 2026 to establish priority for expansion areas the Company is continuing to develop: physics-based evaluation of live signal generation consistency; physical-layer cryptographic security primitives for hardware-enforced control of blockchain and distributed-ledger operations; an out-of-band, hardware-enforced governance system for artificial intelligence using temporally advanced present-state authority signals; and a distributed analog reconstruction-key (DARK) system for synchronized orchestration of analog encryption-state waveforms. As provisional filings, these applications establish an early priority date but have not been examined, and any resulting non-provisional claims, along with their ultimate scope, remain to be determined.

Commercial Positioning

Analog Guard is positioned as a complementary, physical-layer security measure rather than a replacement for existing digital encryption standards. Potential applications span enterprise data protection, data storage and endpoint security, embedded systems and industrial equipment, semiconductor and OEM integration, artificial intelligence and data-center infrastructure, and defense, aerospace, and critical-infrastructure systems, subject to continued development, independent testing, and validation. The Company's provisional patent filings also point toward two earlier-stage areas of exploration: hardware-enforced security controls for blockchain and distributed-ledger applications, and hardware-enforced governance mechanisms for artificial intelligence systems using temporally advanced signals. These represent priority-stage concepts rather than validated applications, and their development would be subject to the same testing and validation standards applied elsewhere in the Analog Guard program. Additional detail regarding Analog Guard's potential markets and licensing opportunities is available on the Company's website.