

## Recent Changes in the Signal System

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### Abstract

*Recent years have seen big improvements in signal systems, thanks to fast progress in communication technologies, artificial intelligence, and hardware capabilities. Signal systems are very important for modern technology. They are the basis for many different uses, including telecommunications, transportation, industrial automation, and medical diagnostics. Signal systems are all about making, sending, processing, and understanding signals, whether they are analogue or digital, so that information may be shared easily. As the need for quicker, more reliable, and smarter systems grows, both the theoretical and practical sides of signal processing have made great strides. This article talks about new things that have happened in several areas of signal systems such as digital signal processing (DSP), adaptive filtering, wireless communication protocols, and smart transportation systems. The focus is on how to combine machine learning methods for real-time signal analysis, improve spectral efficiency, and come up with new modulation and coding schemes. The study also talks about new technologies, like 5G and 6G signal systems, software-defined radios, and how quantum computing can be used in signal processing. These advancements not only improve the performance and dependability of contemporary signal systems but also create new opportunities for multidisciplinary research and industrial applications.*

**Keywords:** Adaptive systems, machine learning, communication technologies, software-defined systems, signal processing

### INTRODUCTION

Signal systems are the encompass various and technologies used to create, process, transmit, receive, and encode signals. They are important parts of many commercial products and are built into many systems used by the military, medical, and scientific organizations. Signal systems combine these functions to get certain jobs done. Their many uses also support technological progress across fields. So, improvements in signal system design have a big effect on modern civilization [1]. A signal system basically does the job of changing anything. It changes an input signal into an output signal so that the output is very close to a predefined intended signal. Four main parts make up a signal system: signal production, signal processing, signal transmission, and signal reception/encoding. These parts are employed repeatedly in different combinations of signal types. Additionally, modern digital signal systems now have digital signal processors (DSPs) that are tailored for specific tasks and the ability to communicate wirelessly. If any of these things change, the system can become a different kind of signal system. The hybrid signal system is the biggest part of the worldwide signal system market, showing that both digital signal systems and signal system components are still evolving. Signal systems have changed a lot since Samuel Morse's telegraph system in 1844. Now, they are made up of several ideas and sub-systems. The basic ideas behind signal systems were set in stone by the early 1980s, and these ideas were used in many real-world scenarios. Signals and Systems became a

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well-known class in schools for science and engineering, and this stayed the same until the early 2000s [2].

The basic parts of signal systems are signal generators, processors, transmitters, and receivers [2]. Signal generators make the initial messages or information that need to be sent. Signal processors do things, like amplify, modulate, filter, or mix the signals they find. Signal transmitters make it possible for signals to be sent over communication channels. Signal receivers take in the signals that are sent and do what is needed to get the information back so that it can be used later. These parts can be put together in different ways to make different kinds of signal systems such as analogue, digital, and hybrid. Signal systems combine both analogue and digital parts. They commonly change analogue signals into digital form for processing and then back to analogue for transmission or output. General-purpose signal systems often use hybrid setups, which take advantage of digital processing while still being able to work with analogue communication channels or devices. System design includes choosing and putting signal generators into place, as well as processing and sending signals. In field applications, it is helpful to have easy access to a portable signal generator. The goal of the design is to make a small, stable, and linear sine wave generator that uses conventional filter parts and has very little internal loss. This will allow for the creation of an amplitude-stable Wien-bridge oscillator [3]. Sinusoidal generators are commonly used to test electrical circuits, calibrate audio, and make tones. A simple way to make a variable frequency sinusoidal generator uses the output of a digital microcontroller and a low-pass smoothing circuit [4].

DSPs prepare raw signals for different output devices such as loudspeakers. This makes them useful in many industrial control systems. In the past, the switch from general-purpose microprocessors to dedicated DSP processors and Application Specific Integrated Circuits sped up the ability to process data in real time. The introduction of RAM-based Field Programmable Gate Arrays transformed DSP design even more by letting software algorithm authors put DSP algorithms directly into hardware using C/C++ flow. DSPs have a modified Harvard design, single-cycle multiply-accumulate operations, and single-cycle interrupt capabilities [5–9].

There are two basic ways to send signals: analogue and digital. Analogue transmission provides signals that are always on and represent information across a medium. It is an easy, direct, and cheap way to send services like voice, radio, TV, and monitoring. There are two main types of analogue transmission: satellite transmission and ground microwave transmission. Cable transmission, on the other hand, employs coaxial or optical fiber cable. In the last few decades, information and communication technology (ICT) has made a lot of progress, and new technologies now offer very high data rates. However, most data continue to embody analogue information. Digital technology has grown a lot. Sending information through electrical or electromagnetic signals within a system is what signal transmission is all about.

Signal transmitter systems are getting better, which means faster data rates and more reliable communication. Recent improvements in optical fiber technology, wireless communication, and 5G are making it possible to send data at much greater speeds with very little latency. Because of rising demand, services now need greater bandwidth, which means they need to use digital signal processing and transmission. There are two ways for signals to travel. Digitization gets rid of a lot of the difficulties that come with analogue transmissions like noise, distortion, and interference. This makes the signal-to-noise ratio (SNR) at the receiver end better.

## **DIFFERENT KINDS OF SIGNAL SYSTEMS**

Signal systems have become more advanced in recent years, and they are now used in a wide range of fields. So, choosing the right signal system is important for modern technology to work well. There are several different types of signal systems, including digital and hybrid. Analogue systems use physical values that can change constantly, including frequency, voltage, phase, or current, to represent information all the time. Digital signal systems, on the other hand, need all signal parts to be

digitized so that the signal and information can be shown in digital form. Hybrid systems use both analogue and digital signal systems [2].

### **Systems for Analogue Signals**

An analogue signal is a wave that changes over time and typically measures a physical quantity such as temperature or distance. External noise in the transmission medium might affect these signals, making the sound quality worse. To function, electrical transducers require electricity from an electrical source, and they typically generate a low-power signal. So, the electrical signals that are monitored need to be amplified to boost the power from the source signal. A dynamic microphone is an example of a transducer. It employs a magnet and coil to make a voltage that is proportional to the sound waves that hit the microphone. The source impedance of a dynamic microphone is around 50 ohms, and the amplitude is about 10 mV. The signal must be boosted to a power level of tens or hundreds of milliwatts to link these kinds of devices to a loudspeaker or phone system. An amplifier is an electronic circuit that makes electrical signals stronger.

### **Systems for Digital Signals**

As telecommunications and modern digital gadgets grow quickly, signal processing technology is getting more attention around the world. Fast changes in how different signals are sent and processed have a big impact on many areas of science and technology. Radio communication is a simple way to send signals. It needs sources that can give steady output power over a wide range of frequencies and variable phase. These are signal kinds that no oscillator at the receiver's end can directly produce. To get around this problem, systems generally move the needed frequency to the local oscillator and then modulate the signal with the stationary reference frequency. Digital systems are widely used in modern approaches to create the signals needed for these jobs. All modern signal processing systems use digital technologies.

A digital data processing system for measurement devices allows any station to send all the receivable frequency data for a specific repetition rate. Signal processing entails the digital reconstruction of images from projection data, typically consisting of many projections, utilizing various analytical approaches. Digital signal processing (DSP) systems create a continuous digital signal and do something with each sample. This lets them see a continuous audio signal as the separate samples that an A/D converter sends (which is thought of as an analog-to-digital conversion) [8].

As the need for high data rates, such as those in HDTV, grows beyond what traditional analogue technology can handle, the field of Digital Signal Processing (DSP) has made great strides, paving the way for new technologies and ways of doing things [9]. Recent technological advancements have facilitated the implementation of comprehensive systems within cost-effective DSP cards utilizing Floating Point DSPs. It is now possible to digitally create very high-rate PSK/FSK signals, including those at a frequency of about 900 MHz.

### **Systems for Hybrid Signals**

When signal systems are combined utilizing hybrid operation, new synergies that were not there before becoming possible. Until now, the two systems have competed to become separate paradigms since they were designed and worked in quite different ways. In the absence of direct evolutions, redesign emerged as the preferred alternative. Similarly, in signal systems, many methods were devised to integrate analogue and digital systems under a unified communication framework [10]. One way to do this is to send digital signals through regular analogue medium and analogue signals through digital media. However, these methods need signal transformations that have a big impact on how well the system works. A second method is to combine analogue and digital signals in the same medium by giving them separate channels at certain frequency bands and then optimizing the allocation based on the medium's properties. The Digital-Analog Hybrid System (D-AHS) is a third way to send signals at the same time in the same band. It combines two signals, one digital and one analogue, to make a final compound signal that may be sent across a common channel. This method is

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not just limited to frequency division. It can also use techniques, like single-sideband modulation and phase modulation for analogue signals, or OFDM and heterodyning for digital signals. It can also be used with new modulation methods, like amplitude variation, polar modulation, and phase-shift keying, along with the right analogue carriers, to make the compound signal.

### **NEW IDEAS IN SIGNAL PROCESSING**

Recent advances in signal processing are changing signal systems and making them work better in all kinds of applications. The rise of sensor-enabled systems and improvements in hardware and computing power are driving efforts around the world to create the next generation of measurement systems. To keep up with these trends, signal and data processing methods need to change to deal with the effects of sensors, the environment, or artefacts, and to allow for successful multisource, multidimensional data fusion and analysis [1]. Artificial intelligence is a key part of solving these problems. Intelligent radio signal-processing strategies provide superior solutions compared to traditional mathematical-model-based approaches, which often exhibit sluggish convergence, excessive complexity, limited scalability, and insufficient adaptation to dynamic settings [11]. The growth of the electronic world and the rise in linked devices mean that both the data and the signal processing strategies need to change to be able to analyze, extract, filter, and handle the information effectively to meet the needs of real-time communication and avoid data loss. Recent developments in signal processing concentrate on artificial intelligence and machine learning algorithms for the interpretation and analysis of diverse data sources and modalities, as well as the discovery of novel methods for real-time processing, dynamic denoising, dimensionality reduction, and the reconstruction of large datasets.

### **Uses of Machine Learning**

Machine learning uses models that have free variables as parameters and adaptive techniques that change the parameters based on certain principles. Using big, publicly available data sets and more powerful computers, it has been possible to train sophisticated models with millions of parameters on thousands of examples without overfitting [12]. Numerical studies demonstrate the efficacy of machine learning as a substitute for traditional communication strategies across diverse application contexts [13]. Notably, well-known modulation-clustering boundaries emerged as Bayesian optimal solutions within the categorical-generalized-normal framework, underscoring the method's capacity to discern near-optimal techniques without previous domain expertise. Machine learning can be used for things like estimating channels in MIMO and mmWave systems, opportunistic spectrum access, cooperative spectrum sensing, and distributed adaptive learning. Power control, interference management, device localization, navigation, positioning, network anomaly detection, spam filtering, phishing detection, and predicting how much power solar plants will produce are some other uses.

### **Methods for Processing in Real Time**

The Internet of Things (IoT) is the idea of having a lot of cheap, little sensing devices that are all connected to the internet. These devices often function in situations characterized by high noise levels, constrained processing capabilities, and restricted energy resources. New signal-processing techniques are needed to get around these limits and make smart sensing, autonomous operation, and dynamic (multi-hop) networking possible, according to [1]. One problem is to create signal-processing filters and dynamics that can get rid of unwanted parts of the signal, loosen stringent synchronization requirements, make up for mistakes, and tell the difference between phase, noise, contamination, and errors. This kind of help is necessary for IoT signal-processing algorithms and apps to work well. New methods are expected to include adaptive, event-driven sampling, adaptive filtering, low-cost facial and signature recognition, and recognizers built into sensor networks.

Real-time signal-processing techniques, multimodal data-fusion techniques, digital signal-processing architectures, multichannel acquisition systems, and data-conversion features make it possible to efficiently sort, filter, correlate, and understand large amounts of data that come from physical events. Analyzing data from several types of sensors is a promising way to improve situational awareness. Multi-sensor fusion combines data from different types of sensors that are all

witnessing the same thing and use advanced processing to find aspects that are important to the senses. An example is an IoT-enabled sensor system that combines data from coal mines and weather stations to make underground coal mining safer and better for the environment. IoT thus offers a platform for diverse data gathering and online integration in dangerous and complicated contexts.

### **IMPROVEMENTS IN SIGNAL TRANSMISSION**

There has been a lot of advancement in novel ways to send signals. Better optical fibers and better wireless networks have made it possible to send data faster and more reliably over large distances. Research into advanced signal processing techniques and machine-learning methodologies has led to major improvements in speech enhancement, picture reconstruction, and video tracking, among other things. Real-time signal processing approaches are becoming increasingly significant for monitoring and surveillance applications.

Several methods use narrowband time series to send signals quickly and cheaply. These kinds of methods make a gearbox last longer by working below the noise level, which means they do not need more power to send. Satellite and terrestrial systems sometimes use spaced-signal transmissions, and most commercial platforms come with this feature. They use the entire signal bandwidth, from DC to the highest signal frequency, in the information content that limits the spectral transmit power to one section of the spectrum. The method gives the necessary coding gain without making the system cycle faster, and it is supported by well-designed spread-spectrum modulation to keep the low-rate time history within normal pulse structures. There are several distributed systems that are made just for sending warnings and data across low-rate analogue channels. These kinds of systems often need up to 14 analogue transmission channels. These channels are kept in garrisons for lengthy periods of time; thus, it is important to be able to maintain them with equipment that is easy to find. Modems and other terminal devices are part of equipment design. Microelectronic technology has made it possible to make modem systems simpler by turning some analogue functions into programmable logical circuits and microcontrollers. When these systems are modernized, they consider design approaches and development timetables [14, 15].

### **Technology for Optical Fiber**

Optical fiber technology is a big step forward in systems that send signals. Improvements in optical fiber technology have made transmission better and more reliable, allowing for high data rates, low signal loss, and low interference [16].

Fiber optic systems are now the main part of broadband networks around the world since they can send messages with a lot of bandwidth and very little delay. They may be used for both short- and long-distance communication, which is why they are the best way to send high-speed data. Wavelength-division multiplexing is used in many ways, which shows how important it is for improving the transmission capacity of current fiber optic communication networks. Future optical networks are projected to handle all data in the optical domain. This lets huge streams of data be switched, routed, and controlled at the speed of light.

This kind of technology is still getting a lot of study and development. Fiber optics naturally has properties that are quite useful for systems that send signals. It is very dependable, has minimal attenuation, makes communication safer, and does not have much electromagnetic interference. Ongoing research is focused on making the most of these favorable aspects to make fiber-optic communications more efficient, reliable, and capable, as well as to solve the problems that this type of transmission medium is now facing.

### **Improvements in Wireless Communication**

Wireless communications, which are a big part of our daily lives, keep getting better along with the technologies that go with them. Improving the efficiency of wireless transmission is still an important area of research. The transition from initial demonstrations of radio waves transmitting human speech

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to the prevalent use of wireless telephony and paging can be interpreted as a progression toward elevated data rates. Early cellular systems were mainly built to handle voice traffic. Second-generation (2G) networks added digital transmission methods, and third generation (3G) systems can handle both voice and data. The fourth and fifth generations (4G/5G) are not widely used yet, but they want to make it easier to send data [17].

### **STANDARDS AND PROTOCOLS FOR THE SIGNAL SYSTEM**

The International Electrotechnical Commission (IEC) and the International Union of Railways (UIC) oversee defining the main rules for railway signal systems. IEC 62290-1 gives general rules for train communication networks, and IEC 62290-2 gives more specific rules on how to put these into action. The European Railway Traffic Management System (ERTMS), which includes the European Train Control System (ETCS), is defined under UIC 71. The basic method for dividing up the railway infrastructure into occupation zones is transmission-based train control (TBTC) or moving block [18].

#### **Standards from IEEE**

Signal systems are made up of several parts that work together. These parts, which are usually set up in a sequence or in parallel, process signals in a set way.

Telecommunications, broadcasting, satellite communication, radar, measurement, control, audio, video, and data processing are just a few of the many things that applications can do. 1.1. IEEE Standards Previous standards in this category have a lot of problems, such as different methods, not enough uniformity, a limited range of coverage and guidelines, uncoordinated interfaces, reliance on instance-specific implementations, limited scope for coordination, evolving scope, selected focused areas instead of a comprehensive approach, and definitions that are unique to the company. IEEE standards deal with these problems by working with other relevant standards or recognized best practices in the same field. By using this method, they combine a flexible but consistent way of doing things that helps the complete development of system signal parameters, making it easier to integrate and work with other systems. By using the IEEE framework, designers have a strong structure that gives them broad, flexible guidance that can be used in many different sectors and situations. This helps make signal system development projects clearer, more consistent, and more interoperable [19].

#### **Suggestions from the ITU**

The United Nations' International Telecommunication Union (ITU) oversees problems that have to do with information and communication technologies. The ITU Radiocommunication Sector (ITU-R) sets standards and makes suggestions for radio, mobile, broadcast, space, fixed, and other types of telecommunications. ITU-R recommendations cover a lot of technical and operational areas, like how to plan and run transmitting stations, how to measure things, how well equipment works, international agreements on sharing frequencies, and limits on emissions, to stop harmful interference between radio-communication services that are using the same or nearby frequency bands.

### **EFFECTS OF 5G ON SIGNAL SYSTEMS**

The arrival of fifth-generation cellular communication and networking (5G) has made big improvements possible in the field of signal systems. 5G communication systems have been able to improve data speeds and lower latency by several orders of magnitude thanks to new technologies like massive multiple-input multiple-output (MIMO) and millimeter-wave (mmWave). As a result, these advancements open the door to revolutionary uses in a wide range of signal fields such as communications, radar, imaging, and healthcare. Signal systems have greatly benefited from recent experimental improvements in 5G technology [20], which are the basis of signal sciences.

#### **Faster Data Rates**

The rising need for wireless data rates has pushed researchers to look for new technologies that would allow for ultra-high data-rate communication. The goal for the 5G period is data speeds of 5 to 20 Gbps. For the sixth generation (6G) wireless system and beyond, the goal is 20 to 40 Gbps. These

systems will work with the growing digital economy, connected intelligence, and the metaverse. The Shannon–Hartley theorem says that to speed up the rate at which data can be sent, you need either a bigger bandwidth or a higher SNR. To get larger symbol rates, you need a wider bandwidth, which is usually more available at higher carrier frequencies with stronger atmospheric attenuation. For long-distance transmission with high data rates, it is good that the atmospheric attenuation peaks can be avoided. For short-distance communication, meanwhile, larger attenuation from absorption peaks is good for large-scale frequency reuse. In the microwave frequencies from 6 to 42 GHz, there is only around 10 GHz of bandwidth available, which makes it very hard to get the fastest data rate. The millimeter-wave bands, like the E-band, D-band, and G-band, on the other hand, have larger bandwidths that can support wireless communication at speeds of up to tens of Gbps. When the waveguide bands are fully used, the rules for giving out bands beyond 275 GHz can be ignored, which could lead to even faster data rates. Using InP-HEMT technology, highly integrated transceivers with bandwidths of more than 40 GHz have been shown to work in the D-band, G-band, and even at 300 GHz. Wideband modulators and demodulators are still hard to find, as shown by the 40 Gbps DQPSK modem. Using high-order modulations to make the spectrum more efficient can also speed up the data rate for a given bandwidth. But making high SNR millimeter-wave signals and demodulating them in real time is still hard [21, 22].

### **Communication with Low Latency**

Systems that use fast synchronization with orthogonal preambles and channel estimation with the least mean-squared error get very low latencies, in the microsecond range. You can get similar latencies by using optimized software design for transmission and reception chains on general-purpose processor systems. Most wireless systems send data in frames that last a set amount of time, usually between a few milliseconds and a few seconds. The Universal Mobile Telecommunications System (UMTS) uses radio frames that are 10 ms long, while the Worldwide Interoperability for Microwave Access (WiMAX) standard uses frames that are 5 ms long. Since most communication happens in frames, it is quite important to know the basic latency limits in this situation. Many modern applications have very strict latency requirements. For example, in a cloud radio access network's downlink structure, partial detection of frames must happen in about 100  $\mu$ s [23]. This is used in real-time machine-type communication systems. Moreover, current projects in the European Train Control System require ultra-low latency communication for directed control of train lines, which is not possible with the existing UMTS radio standards. Ultra-low latency short-range communications are an important technique for making communication protocols between moving units that are only a few meters apart more reliable and rapid [24]. In mission-critical financing processes, it is frequently essential to connect two stock exchanges situated in distinct geographical areas of a city, ensuring end-to-end latency remains below 1 ms. Likewise, in the context of collision-free vehicle-to-vehicle alerts, the transmission of ultra-low latency messages is a fundamental requirement [25].

### **CONCLUSION**

A signal system has four parts: a signal generator, a signal processor, a signal transmitter, and a signal receiver. People employ a lot of analogues, digital, and hybrid signal systems. There has been a lot of advancements in optical fiber communication, satellite communication, and 5G mobile communication. Optical fiber communication has a lot of advantages such as a wide communication bandwidth and a high transmission capacity. One satellite can cover a lot of ground at a big angle via satellite communication. It has the benefits of being able to communicate well over vast distances. 5G mobile communication has the benefits of a high peak rate, a lot of bandwidth, minimal latency, and many connections. As the need for communication bandwidth and capacity grows, new signal processing and transmission technologies for the above communication techniques keep coming out. Higher-speed transmission technology is becoming the trend in the world of optical fiber communication. The integration of machine learning with real-time optical signal processing technologies has caused a big change in the field of optical fiber communications in the last few years. However, in real life, signal systems often have difficulties with interference that make communication much worse. Also, adding new technology to signal systems has caused some security issues. Consequently, the investigation of signal security has emerged as a significant area of study.

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