Highly spectrum-efficient modulation techniques and other technology advances take hold in aerospace electronics

Advances in integration and technologies, such as LDMOS, and new, spectrally efficient modulation techniques, are making their way into aerospace electronics; reducing size, weight, and power requirements. This article explains a new quadrature phase shift keying technology, and a GPS translator technology.

By Ed Troy

There was a time when electronics for space and aerospace applications were very different from electronics for commercial applications. Aside from the obvious cost difference, electronics for aerospace applications were typically a few years behind electronics found in commercial applications. This was largely due to the fact that aerospace electronics had to be extremely reliable and, thus, only “tried and true” devices and technologies were used.

Unless a device or technology had years of history, its reliability was questioned. Thus, there always seemed to be a wide difference between commercial electronics and aerospace electronics.

Thanks largely to the cellular telephones, satellite television, and the popularity of GPS, today’s aerospace electronics are truly state-of-the-art, and as technologically current as any commercial or industrial electronics. When new technologies and techniques are introduced into truly massive markets, such as cellular and the others mentioned, the reliability of these new technologies are thoroughly tested and evaluated in a very short period of time.

In the early 1980s, conventional wisdom was that GPS would only be used in military systems, and perhaps commercial aviation, since they were the only two segments of the market that could afford the estimated $25,000 for even the least expensive receiver.

That all changed in the early 1990s when GPS receivers were slated to become the primary means of navigation for all segments of aviation, and when receivers could be purchased for the consumer market for prices ranging from a few hundred to a few thousand dollars. Today anyone can buy a GPS receiver for less than $100.

One of the primary drivers of this technology is the cellular market. Rapid advances in cost and size reductions have been made possible by the integration of large amounts of functionality into individual integrated circuits. A few years ago, if you wanted to design a receiver, you needed hundreds of parts, ranging from mixers and oscillators, to amplifiers and switches. Today, you can buy a complete receiver on a single integrated circuit. All that must be added is some peripheral components, such as capacitors, resistors, and inductors.

Interconnections

The increasing integration of functionality into increasingly complex and useful integrated circuits has had another advantage, however, that is critical to the aerospace electronics industry. Since one of the most common failure points in a circuit is the interconnections between components, if you reduce the total number of interconnects, you increase the reliability.

This fact is especially important when the systems are subjected to the extreme environments often seen by aerospace electronics. Since the overall mean time between failures (MTBF) is a function of the reliability of each

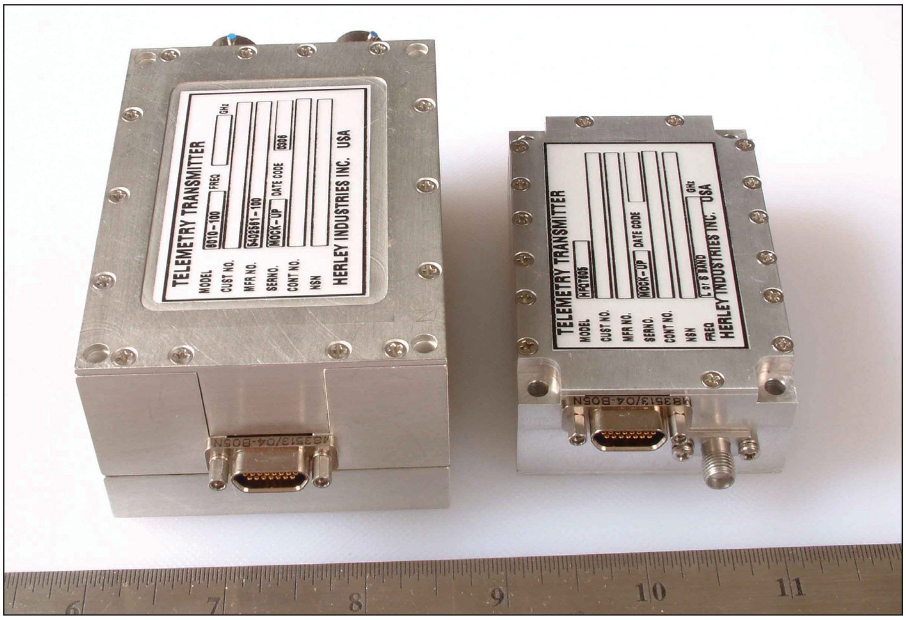

Figure 1: Old 10 W HFQT810, and new HFQT605 5 watt transmitter.

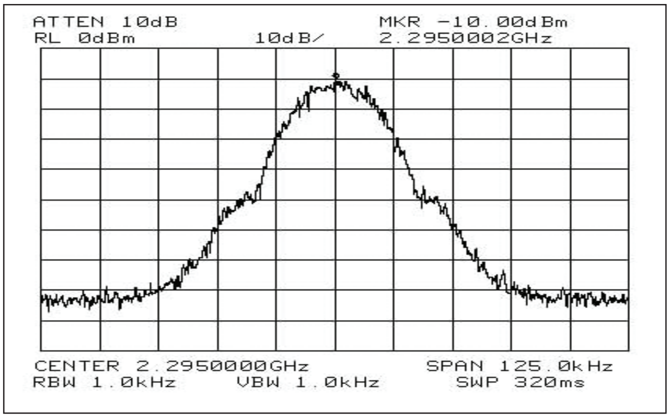

Figure 2: 25 kbps GMSK signal before nonlinear amplification.

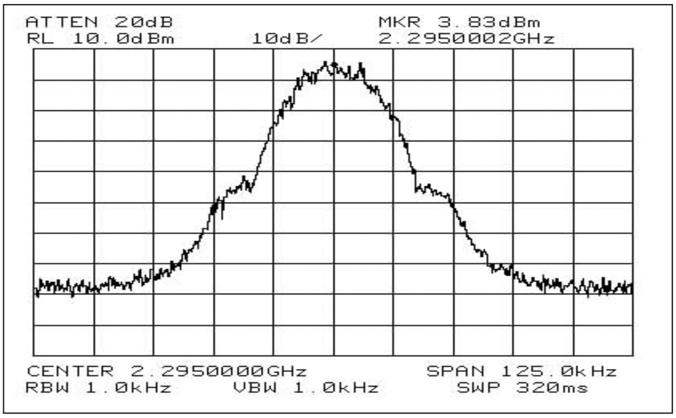

Figure 3: 25 kbps GMSK signal after nonlinear amplification.

of the individual components, if the overall number of components is reduced, the reliability increases. As you squeeze more and more functionality onto a given integrated circuit, you reduce the size and weight of the overall system. This, obviously, is an advantage for any electronic system that is destined for a space or aerospace platform.

There have been other significant changes in the space and aerospace electronics technologies, however, and they relate to advances in signal processing and modulation techniques. Again, much of this is related to advances brought about by cellular technologies, as well as the rising popularity of wireless computer networks.

One of the biggest problems for the cellular industry has been accommodating all of the users in a given geographical area with limited spectrum. In the wireless data industry, the problem is to provide more usable bandwidth. Just as cellular phones have evolved from simple FM radios using analog modulation techniques, to radios that use complex digital modulation techniques to squeeze more and more users into a given spectrum allocation, radios destined for space and aerospace applications have evolved in a similar fashion.

One excellent example that shows how significantly advanced modulation techniques can improve spectral efficiency is the Feher-patented quadrature phase shift keying (FQPSK)[1].

Using this technique, the spectral efficiency of a telemetry transmitter — used, for example, in an F/A-22 — can be doubled. This means that a transmission that had previously required 10 MHz of spectrum now only needs 5 MHz of spectrum[2,3].

An example of how electronics for aerospace applications have gotten both smaller, lighter, and more spectrally efficient, is the comparison of Herley Industries Inc.'s (www.herley.com) HFQT810 synthesized variable rate FQPSK telemetry transmitter, and its newest FQPSK transmitter, the HFQT605. As shown in Figure 1, the new transmitter is significantly smaller than the old transmitter. The old transmitter was also 10 watts, while the new transmitter is 5 watts, but this is not the major reason for the significant size reduction.

Generally, QPSK is not considered to be a spectrally efficient method of modulation. This is especially true when the transmitter must use a nonlinear amplifier to save overall power. This is one reason why gaussian minimum shift keying (GMSK), and other forms of frequency modulation, are often preferred in applications, such as cell phones, where power is supplied from batteries, and the life of the battery is a critical consideration. Figure 2 shows a 25 kbps GMSK signal before being put through a nonlinear amplifier.

Figure 3 shows this same signal after being put through a nonlinear amplifier.

As you can see, there is very little spreading of the signal. This is because in the case of frequency modulation, the amplitude of the signal does not go through any major transitions. This cannot be said for most forms of phase shift keying.

Figure 4 shows a conventional QPSK signal before being sent through a nonlinear amplifier.

Already, you can see that it is not as spectrally efficient as the GMSK signal. And after that signal is sent through a nonlinear amplifier, the spectral efficiency degrades even further, as shown in Figure 5.

In the case of FQPSK, however, this spectral spreading problem does not exist. In fact, as shown in Figure 6 and Figure 7, respectively, the signal is even more spectrally efficient than GMSK, and there is no additional spreading after the signal is sent through a nonlinear amplifier.

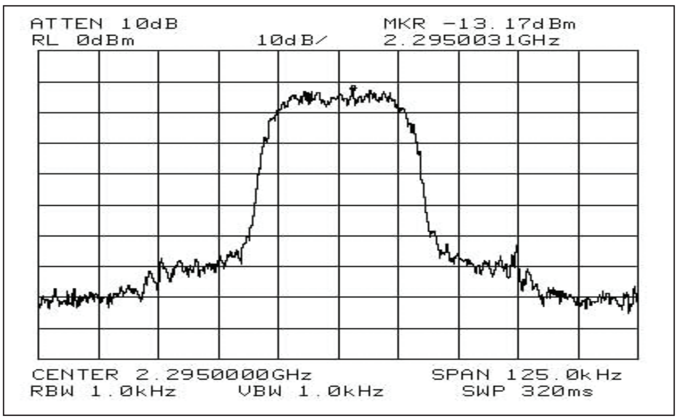

Figure 4: 25 kbps QPSK signal before nonlinear amplification.

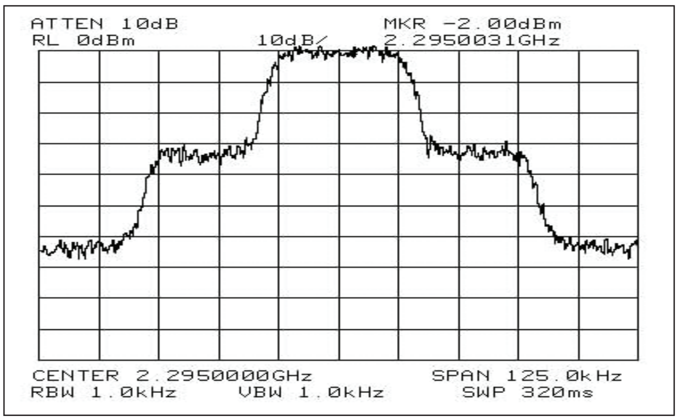

Figure 5: 25 kbps QPSK signal after nonlinear amplification.

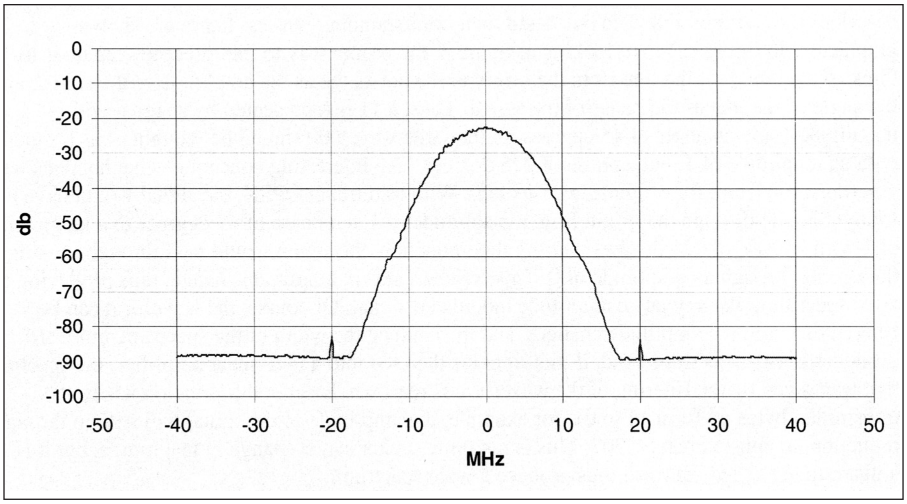

Figure 6: 20 Mbps FQPSK signal before nonlinear amplification.

Feher-patented quadrature phase shift keying (FQPSK)

This spectral efficiency is made possible by the modulation technique patented by Dr. Kamilo Feher known as *FQPSK*. In this technique, wavelets are used in a very clever way to ensure that the QPSK signal does not go through any amplitude transitions as the various bits of information are transmitted. In QPSK, information is transmitted two bits at a time. Table 1 describes the four possible data bytes and their corresponding phases.

These are shown graphically in Figure 8.

When looking at Figure 8, the proper way to interpret the graphic is to think of the length of the line from the origin to the dot as the as the amplitude of the signal, and the angle of the line as the phase of the signal.

Thus, a "11" is represented by a signal with magnitude 1 and an angle of 45 degrees. In the same way, a "00" should be thought of as a signal with an amplitude of 1, but a phase of 225 degrees.

I data	Q data	Phase
1	1	45
0	1	135
0	0	225
1	0	315

Table 1. The four possible data bytes used for QPSK, and their corresponding phases.[4]

The interesting concept is what happens when you transition from, for example, a "11" to a "00." With traditional QPSK, the signal would have to follow the line through the origin from a magnitude of 1 at a phase of 45 degrees, to a magnitude of 1 with a phase of 225 degrees.

During that transition, the signal would pass through the origin, thus going through an amplitude of 0. This creates a severe amplitude change, producing a wide spectrum, like any pulse amplitude modulated signal.

Of course, the waveform can be filtered to lessen the amplitude changes, and by doing so reduce the width of the spectrum, but it still produces a wide spectrum. And, if this signal is then fed into a nonlinear amplifier, the spectrum that was saved by the filtering of the waveform is regrown.

Even in the situation where the transmitted bytes go from "11" to "01", for example, the amplitude of the signal will still go through a reduction to approximately .707. This is not quite such a major change in magnitude, but it is still a magnitude change, and as a result, will produce a wide spectrum.

A further look at the graph in Figure 8, and a little imagination, might suggest a solution to the problem. What if the signal was encoded in such a way that the transmitted waveform could never transition through 0 amplitude?

This would prevent the pulse-like spreading created by a transition directly from, say, "11" to "00,", or "01" to "10." Furthermore, what if the waveform was forced to follow a circular trajectory from, for example, "11" to "01," or "10" to "11," as shown in Figure 9?

Now, there are no amplitude transitions, and, thus, no spectral spreading, or regrowth, after nonlinear amplification. It is, intuitively, relatively easy to see what has to be done in the case of transitioning from "11" to "01," or "10" to "11." What is not so intuitive, however, is how it gets from "11" to "00," or "01" to "10?" This is where wavelets come into play.

Most complex modulation schemes use an I/Q modulator to create the final signal. With the I/Q modulator, there are two waveforms that are multiplied together to produce the final waveform. These waveforms, like any other waveform, consist of magnitude and phase information. Looked at another way, at any given instant in time, these waveforms have a definite amplitude.

The final waveform has an amplitude that corresponds to the instantaneous product of the amplitudes of the I and Q waveforms. The *trick* used by FQPSK is to pick those waveforms so that at any given instant, the final, modulated waveform has a constant amplitude.

In other words, if the I channel waveform was at its maximum at one given instant, the Q channel waveform would be at its minimum at that moment. There are only 16 possible transitions for a byte consisting of two bits — "00" to "00," "00" to "01," "00" to "10," etc.

Because of this, a look-up table can be created that contains the 16 necessary waveforms for the I and Q channels. Then, depending on the data and the data transitions, the appropriate waveforms are selected and applied to the I and Q channels.

If these basis functions are properly cho-

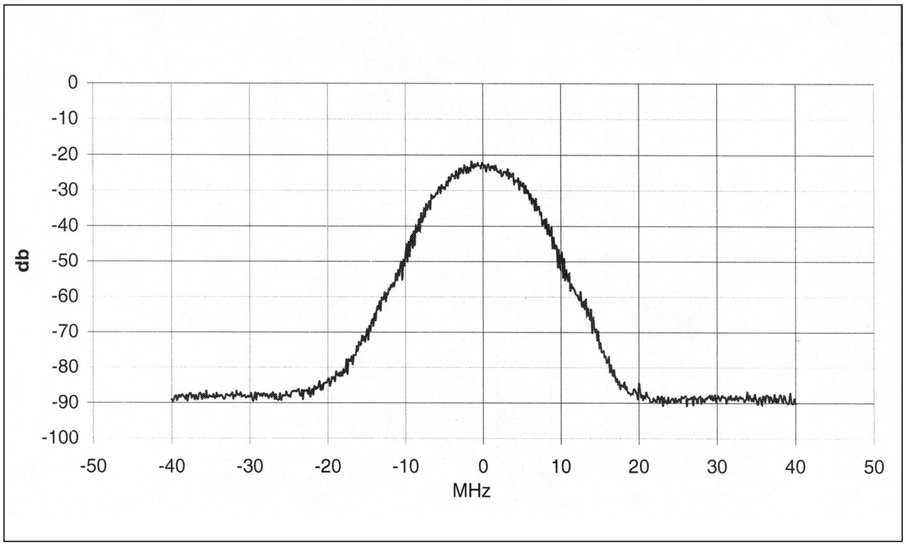

Figure 7 20 Mbps FQPSK signal after nonlinear amplification.

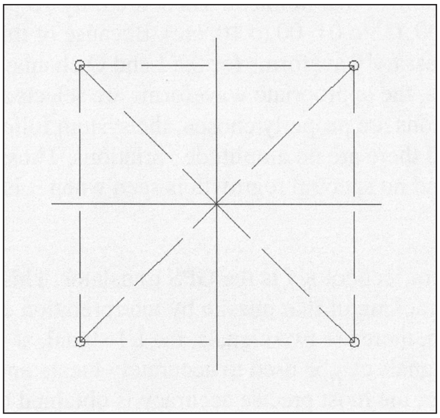

Figure 8: Simple QPSK constellation and transitions.

sen, the system follows an almost perfect circle , as shown in Figure 9, and there are no amplitude variations. Thus, the system uses a minimal amount of spectrum, and no spectral regrowth is seen when it is passed through nonlinear stages of amplification.

GPS translator

Another interesting use of technology is the GPS translator. This product is mounted on a missile, and allows for precise tracking of that missile by interpretation of the translated GPS signals.

In a normal GPS system, there are two signals, the L1 signal, at 1575.42 MHz, and the L2 signal, at 1227.6 MHz. These signals can be used to accurately locate an object in latitude, longitude, and altitude. However, the most precise accuracy is obtained by using differential GPS.

In differential GPS, the signals from a GPS constellation is monitored at a known (accurately surveyed) location. Under the assumption that another GPS receiver is receiving signals from the same constellation of GPS satellites, and that it is within a few hundred miles of the reference station, the precise location of that other GPS receiver can be determined by subtracting out the errors in latitude, longitude, and altitude that are being measured by the reference receiver. (After all, they are both receiving the same signals and those signals are passing through a similar electromagnetic path, and thus they should have virtually identical errors.)

The GPS translator works by taking the GPS signals received by the missile, and frequency shifting those signals to a standard telemetry band. Then, that data is transmitted to the tracking station in real time. There, it can be stored for later analysis, as well as compared with GPS data received by the reference station, to produce a real-time, highly accurate position for the missile.

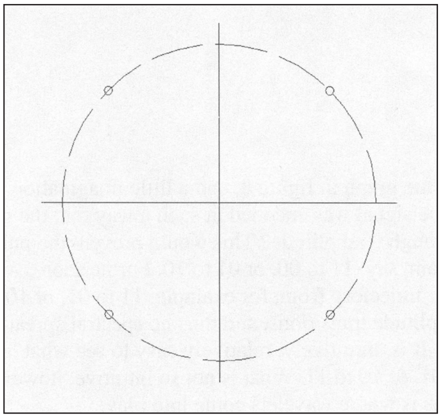

Figure 9: FQPSK constellation and transitions.

While this sounds almost trivial, it is extremely complex. For one thing, GPS signals are spread-spectrum signals, and they are widely spread. In fact, they are spread so widely that a GPS signal is well below the level of the background thermal noise.

GPS signals only become visible and useful after they are de-spread. This means that the system must be designed in such a way that virtually no extra noise is added to the signal. The more noise the system adds, the more difficult it becomes to eventually de-spread the signal and determine useful position information.

Also, if the highest degree of accuracy is to be obtained, the precise phase characteristics of the signal must be preserved. This further complicates the translator system.

Other complications include the fat that the missile is a highly dynamic vehicle. For this reason, multiple GPS antennas must be placed onto the missile and the various signals from these antennas must be multiplexed and inserted into the data stream.

In the case of the Herley Industries GPS translator system, there are four antennas that get multiplexed into three data channels, and these three data channels are then translated into a telemetry band, amplified, and send to the tracking station for analysis.

These two systems demonstrate the cutting edge of aerospace electronics. They make extensive use of the latest technologies in the areas of laterally diffused metal oxide semiconductors (LDMOS) devices, integrated subcircuits, and modern ceramic and saw filter technologies, as well as the one of the most spectrally efficient modulation techniques available today to systems where power efficiency is a critical concern.

Both of these systems demonstrate the rapid migration and adoption of technologies and techniques that were made possible, in large part, by the technological advances brought about by the cellular and wireless data markets.

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References

1. Feher Patented FQPSK-GMSK, patented under one or more of: U.S. PAT. Numbers 4567602, 5784402, 5491457, 4644565. CANADIAN PAT. Numbers: 1211517, 1130871, 1265851

2. Air Force Flight Test Center, public affairs department press release, “Air Force Develops Telemetry Capability for DoD Training Ranges,” February 28, 2003.

3. Dr. Kamilo Feher, “FQPSK Doubles Spectral Efficiency of Telemetry; Advances and Initial Air to Ground Flight Tests,” *Proceedings of International Telemetering Conference*, ITC 1998, San Diego, Calif.

4. Eugene Law, *Modulation Methods with Improved Bandwidth Efficiency*, Update to IRIG 106, Chapter 2, paragraph 2.4.5.1.2.

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