Rapid prototyping meets challenging schedule

Next Generation Satellite Communications
Airborne satellite communication systems require the greatest possible antenna positioning accuracy to prevent data loss and data leakage. This is no small challenge in unmanned airborne vehicles, which are constantly in motion and impose rigid constraints in terms of mass, power and volume. Astrium solved this problem with rapid control prototyping tools and support from dSPACE.
Antenna Control Unit
Building on a heritage of high-quality naval and airborne satellite communication terminals targeted for the defense industry, Astrium Ltd recently launched the first in its Air Patrol series. Covering a range of frequency bands from X to Ka, Air Patrol offers affordable, lightweight, robust and highly efficient satellite communications to a rapidly evolving unmanned airborne vehicle (UAV) market.
Astrium Ltd is responsible for the complete development life cycle of the antenna unit and the corresponding electronics line replaceable units (LRUs). Together, the LRUs and antenna unit perform the following tasks:

- Transmission and reception of radio frequency (RF) signals
- Up conversion and down conversion of frequencies
- Modulation and demodulation of data onto waveforms
- Control output and system monitoring (C&M)
- Antenna stabilization (to compensate for aircraft motion) and corrective motion (to point the antenna at the target satellite)

Antenna Pointing
RF transmissions typically follow a \( \sin(x)/x \) profile, where power peaks at the center of the beam and gradually reduces moving away from the center. The challenge for the ACU is to ensure that peak power is precisely directed towards a receiving antenna on a satellite in geostationary orbit 36,000 km away from the aircraft. To achieve this, typical pointing accuracies of a few tenths of a degree have to be maintained in the presence of aircraft motion.

Aircraft motion is sensed by an inertial navigation system (INS), a standard piece of avionics equipment for aircraft navigation, linked to the aircraft flight control computer through the Air Vehicle Bus (AVB). The ACU has a feed from the AVB, providing the antenna control algorithms with a measure of aircraft motion. The control algorithms induce corrective motion on the antenna to maintain accurate satellite pointing. Antenna motion is actuated by brushless DC motors on the azimuth and elevation.

Challenging Customer Requirements
UAV applications have to meet tough demands, such as harsh environmental conditions and constraints on mass and volume. Flight trials are expensive (due to factors such as airframe adaptation, installation, fuel, insurance and time), thus necessitating the use of numerical simulation as well as hardware-in-the-loop (HIL) tests. Many of the target UAV platforms are still under development, prompting a development methodology which eases the successive iteration of hardware interfaces. Demonstration of capability is important to potential customers. With rapid control prototyping, Astrium can present real hardware rather than mere paper designs.

Pointing Accuracy to a Few Tenths of a Degree
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Figure 1: Components of the Air Patrol terminal for precise antenna pointing.
antenna axes. Antenna position is sensed by absolute encoders on the same axes as the motors. This is fed back to the control algorithms on the ACU. A number of practical difficulties had to be overcome in the development of the ACU, such as noise, bias, quantization, transport delay, measurement bandwidth, actuation lag, saturation, friction, sampling effects, alignment errors, electromagnetic compatibility (EMC) and so on.

**Hardware-in-the-Loop Tests**

Rapid prototyping and HIL testing allowed an early evaluation of the non-linear effects described above, prompting corrective action where required. The HIL environment provided a means to evaluate the performance of individual pieces of equipment for their suitability in the Air Patrol application. It also provided a way to perform antenna system tests injecting test stimuli. This allowed a direct measurement of the frequency response of the real system, which in turn was used to validate linear models. HIL tests enabled the injection of real or simulated flight data from an aircraft INS, thus providing a simulation of the antenna’s pointing performance on a real flight. Setting up the HIL test environment forced an early configuration of the equipment software drivers, which has benefited latter stages of the project. Equipment communication issues were also resolved early in the project. Thanks to the rapid control prototyping methodology, it was possible to test the algorithms for antenna pointing at an early stage, using movable platforms such as ‘rocking beds’ and land vehicles. These also enabled antenna motion demonstrations for air shows and exhibitions. The process increased our confidence in the system design and, more importantly, increased the customer's confidence. A tangible shift in design reviews was perceived, from “can you build it” to more detailed questions which help to drive the product forwards.

**Wide Range of dSPACE Products for ACU Development**

dSPACE provided a seamless link from algorithm prototyping in Simulink® to deployment on real-time dSPACE hardware. The relative ease of accessing I/O on the dSPACE hardware enabled effort to be focused
on the core antenna pointing algorithms. Various pieces of dSPACE hardware were applied on Air Patrol. During the early phases, the DS1103 proved to be an excellent workhorse, with a wide range of I/O that suited our needs and initial limited budget. Several low-cost variants of the MicroAutoBox were deployed for marketing and functional test purposes. The DS1005 was used as the basis of a modular simulator, currently incorporating CAN, RS422, A2D and D2A boards. This solution is expandable to meet our future needs (such as Ethernet or 1553 I/O).

All dSPACE hardware is controlled and monitored via the experiment software dSPACE ControlDesk®. Astrium benefits from the ease of accessing all intermediate variables and parameters in the Simulink model as well as the real-time graphical plotting functionality. The next step is to target production hardware, which has been developed in parallel with the antenna pointing algorithms. Without the use of rapid prototyping target hardware (such as the hardware offered by dSPACE), it would have been necessary to wait for the completion of production hardware development before being able to test the algorithms in a real environment.

To avoid the need for a detailed specification and handcoding of the algorithms, code is autogenerated using TargetLink. This offers a consistent environment for algorithm development, testing and deployment to production hardware. It has completely eliminated algorithmic errors due to misinterpretation of requirements by giving the algorithm developer ownership of the source Simulink model, which also forms the source of the autogenerated code.

The autocode generation process does not eliminate the need for input from software engineers. Some collaboration is needed between the systems and software teams to agree and define the interfaces with the autogenerated code. Furthermore, I/O drivers and the scheduler are best handcoded or taken from the target hardware board support package.

**Why We Chose dSPACE**
dSPACE tools have proved invaluable in the rapid prototyping of the Air Patrol ACU. It is difficult to imagine a quicker route to prototyping a real-time embedded con-
control application. It has promoted an early understanding of the interface issues and performance capabilities of the antenna system hardware elements. TargetLink completes the software development cycle, allowing production-standard software deployment to production hardware. The verification of the generated code is assisted by in-built features such as model-in-the-loop simulation, software-in-the-loop simulation and a profiler tool, which tracks the timing of tasks and events during run time. When required, dSPACE engineers have proven extremely knowledgeable and keen to assist in the successful delivery of the Air Patrol product.

Next Steps
Given the ease of adaptation to different applications, our existing dSPACE hardware will continue to provide useful prototyping and test equipment for years to come. Assisted by dSPACE engineers, we are continuing to develop our understanding of TargetLink capabilities as our autocode requirements evolve with project needs. A crucial step will be proving compliance to the DO178B standard. We are confident that TargetLink will accommodate our future requirements.  

Ed Hagger  
Astrium, Secure Satcom Systems

Figure 3: Typical configuration of dSPACE hardware for testing.

Summary
For smooth radio communications between UAVs, satellites and ground stations, reliable antenna pointing is essential, and it must remain within a tolerance of a few tenths of a degree regardless of aircraft motion. Flight motion is captured by means of an inertial navigation system (INS) and used to compute the commands to the motors that position the antennas. Various disturbance factors have to be taken into account: noise, alignment errors, actuation lag, EMC, sampling effects, etc. In the laboratory, either real or simulated flight data was fed in to simulate the continuous antenna pointing process that occurs in real flight. All the components involved were tested and evaluated with the aid of the dSPACE hardware and software. Finally, the production code for the antenna ECU was generated by means of TargetLink, the production code generator from dSPACE. The dSPACE tools enabled early, realistic evaluation with tangible hardware and contributed decisively to the punctual completion of the system.
Mitsubishi Heavy Industries is researching further optimization of combustion engines with a variable valve test system and engine valve control (EVC) system employing high-speed hydraulic actuators. The EVC system permits any desired valve lift pattern, ensuring highly flexible operation and high engine speeds. A DS1006-based dSPACE multiprocessor real-time system is being used as the experimental control unit.

Variable Valve Control
Variable valve systems are already in use in many mass-production engines. To improve engine efficiency even further, research is underway on the control of intake air volume with inlet valves, elimination of engine knock, and internal exhaust gas recirculation control. Variable valve control can be implemented by various processes, each of which provides a different degree of variability. To achieve further optimizations in the engines of the future, a high degree of freedom is desired in the variable valve system in terms of not only valve open and close timing, lift, operating angle and inlet-exhaust valve overlap, but also in the ability to vary the valve profile itself.

Electric and Hydraulic Actuators
Variable valve controls use either solenoids or hydraulic actuators. Solenoid actuators provide excellent response, but are characterized by small output forces and do not support continuous position control. They are therefore mostly used only for ON/OFF control and are not suited to precise reproduction of lift patterns. In contrast, hydraulic actuators provide high output forces and are readily controlled, but they are generally less responsive and cannot handle high engine speeds. Mitsubishi Heavy Industries have now poured their years of experience in the field of hydraulic control into developing a small, fast hydraulic actuator to be used in an EVC system.

Structure of the EVC System
The EVC system consists of hydraulic actuators (figure 1) driving the valves and fitted to the cylinder head, servo valves to control the flow and direction of the high-pressure hydraulic fluid, sensors and control equipment to control actuator position, a hydraulic pump, and ancillary equipment (figure 2).