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By Steve Cerwin, WA5FRF

Amateur Television from Model Planes and Rockets

Install an ATV camera and transmitter in a model airplane or rocket and you'll see the world from a very different perspective!

Since I began flying radio controlled airplanes in 1980, I had wanted to include cameras and television equipment as payloads. Although I enjoyed early success with 35-mm photography, the television gear of that era was too bulky and expensive for my plane and pocketbook. Within the last five or so years, however, miniature TV cameras have become astonishingly small, lightweight, affordable and require only minimal power. And RF transmitter boards share similar characteristics. The availability of suitable components and the added attraction of contributing to an advanced middle school program brought my dream to reality nearly 20 years later.

Figure 1—The author with an ATV-equipped *Ugly Stick.*

An ATV frame capture from the *Butterfly.*

The Krueger School of Applied Technology (K-SAT) at Krueger Middle School in San Antonio, Texas, has a truly enlightened magnet program for sixth, seventh and eighth graders. Headed by Calvin Best, the program adds a heavy science and aerospace spin to all academic subjects. In addition to their normal classes, the students design and build model rockets and planes and are involved with the supervised flying of high-altitude rockets and radio-controlled model airplanes. The students also prepare for and obtain their ham licenses as part of the curriculum. My friend, Charles Thomas, WA3PAY, and I build and fly ATV-equipped RC airplanes for our own enjoyment, but derive as much or more satisfaction from sharing our experiences with the students. Charles and I serve as mentors for the K-SAT program.

Another K-SAT mentor, Bob Morris, is a retiree from the United States Geological Survey (USGS). Thanks to his efforts, we were invited to fly an airborne ATV system equipped with a GPS position overlay to survey the Texas flood plain areas affected by the October 1998 floods. This was done on a demonstration/volunteer basis in much the same way hams provide the National Weather Service with rainfall data. Using the camera-equipped planes we were able to fly over and videotape otherwise inaccessible creeks and riverbeds. The USGS used this data to assess water flow resistance and flood potential in times of high rain. The radio-controlled "camera planes" offered a low-cost and low-risk alternative to manned flight. The experiment turned out to be a highly successful and satisfying adventure.

Described below are some of the projects we have undertaken and shared with the school.

Airplane Platforms

The first (and the most versatile to date) airborne ATV transmitter was built as a completely self-contained unit that could be attached over the wing of any suitable model airplane with rubber bands. The original package contained a single forward-looking CCD camera, an 80-mW transmitter, a 12-V NiCd battery pack and an integral monopole antenna. The package measured 4 × 6 × 1.25 inches and weighed about 1.25 pounds. The inside of the plastic chassis was lined with copper foil tape to provide a lightweight shield for the electronics and a ground plane for the antenna. Subsequent revisions have included connections for a second, down-looking camera, a switch to select the look angle by remote control, and optical filters to improve the video quality. A photograph of the transmitter mounted atop a .40-sized *Ugly Stick* is shown in Figure 1.

The *Butterfly* motor glider has proven to be the most stable platform flown to date. The Butterfly sports a 99-inch wingspan and nearly 1000 square inches of wing area. It has been fitted with a .32-size engine to develop enough power to get the 1.25-pound camera package airborne with a short takeoff roll on a grass runway. The large size and inherent stability of this airframe makes it very easy for an experienced pilot to fly visually (looking at the airplane) or as a remotely piloted vehicle (RPV, looking at the video). As an RPV, the plane flies very much like a computerized flight simulator. In fact, when flying in this mode it's possible to inadvertently fly the plane out of range unless a safety pilot is present to tell the operator when to turn back toward the control transmitter. The frequencies and relative power levels of the control signal and ATV transmitter are calibrated to allow the ATV link to fail before the radio control link goes down. The rule of thumb is, if the picture starts getting fuzzy, it's time to head back!

With a smaller and fully symmetric shoulder wing, the *Ugly Stick* is fully aerobatic. The video from doing loops, rolls and spins is truly spectacular! It's like actually being in the plane, except you get to keep your lunch. The extra weight and drag from the ATV package, however, leads to longer takeoff rolls and screaming-hot landings. The camera package represents a larger fractional increase in weight for this airplane and maintaining sufficient airspeed is critical with the high wing loading. But even though it glides somewhat like a streamlined brick, it handles pretty well once you get used to the "heaviness" of the stick.

The *TH-60* has enough wing area (875 square inches) and power to easily carry the ATV package without strain. This airframe also provides superior wind penetration and crosswind landing characteristics as compared to the motor glider. Increasing the wing incidence one degree over stock and outfitting the airplane with fully functional flaps dramatically improved flight characteristics at minimum controllable airspeed and helped to slow the landings to more normal speeds. I've recently installed a second-generation ATV transmitter inside the TH-60 fuselage. Although the weight is still about the same, getting rid of the extra drag of the exterior ATV package yielded significant handling improvements. The forward-looking camera is mounted in a small box attached to the windshield and the down-looking camera looks through a hole in the bottom of the fuselage. As before, the look angle can be selected in flight. Microscope slides serve as windscreens to keep bugs and fuel spray off the camera optics. A future project will explore the use of a two-axis gyro to help stabilize flight in gusty winds.

Rocket Platforms

While the students at K-SAT build their three-foot-tall rockets, the adult kids build theirs. The big kids' "heavy lifters" stand 11 feet tall and carry an ATV transmitter with video overlays that display GPS position, speed, heading and altitude. Constructed under the expert guidance of Bill Wagner, these rockets require FAA coordination and need *lots* of empty land around them to fly. After months of rain delays, we finally got a chance to fly one of the big rockets in May 1999 at a 22,000-acre cattle ranch in southern Texas belonging to Rik Hoffman, K5SBU. The rocket carried a side-looking color camera and a 1.5-W ATV transmitter. After the pre-filed clearance was obtained from Houston center via cell phone, we started a quick countdown and hit the switch. The rocket leaped into the air atop a mountain of fire and roared away with Doppler-shifted thunder, ever decreasing in pitch as the rocket accelerated to 401 MPH. During its seven-second burn, the rocket consumed $360 of solid fuel at a rate of slightly more than $50 per second. The rocket then coasted straight up for another 23 seconds, reaching an altitude of 7000 feet.

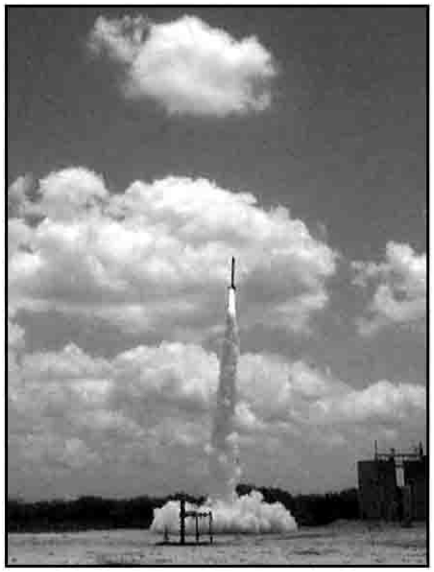


Figure 2—*Big Yeller* takes to the skies with GPS and ATV payloads.

The Hondo airport as seen from the TH-60.

Figure 3—Looking down the rocket fuselage at Hondo airport.

The ATV system worked flawlessly, providing spectacular video for the entire flight. The view was particularly impressive as the rocket approached, penetrated and ascended above a thin cloud deck at 3500 feet. As the rocket passed apogee and began to descend, the computerized altimeters sensed the increase in barometric pressure and deployed the parachutes. Five minutes later the rocket landed in a mesquite tree just over a mile from the launch pad. After touchdown, the ATV signal was still coming through, showing an excellent view of the thick underbrush and reporting its landing coordinates on the GPS data overlay. We punched the coordinates into a hand-held GPS unit and went right to the landing site. A photograph of the launch is shown in Figure 2.

A second rocket with its own ATV payoad was constructed, this time with a down-looking black-and-white camera. Both rockets were launched on December 4, 1999. You can see a view from one of the rockets in Figure 3.

Cameras and Optics

Small CCD cameras are still evolving. Our first ATV transmitter used a single board black-and-white camera with a pinhole lens and required 9-V dc at 100 mA. Our first color camera ran on 10.5 V, had three PC boards and required 300 mA. Our present camera is a much smaller single-board color model that requires 10 V at 100 mA. A series string of 1N4001 rectifier diodes is used to drop the 12-V ATV transmitter battery voltage to about 10 V dc. The cameras were obtained from Supercircuits (see the Equipment Suppliers sidebar) in Austin, Texas.

Cameras are available with pinhole or multielement lenses. Both give a 70 to 90° field of view, with the wider view preferred for airborne operations. The multielement lenses have less barrel distortion than the pinhole versions, but are physically larger. The apparent curvature of the earth evident in some of the aerial views isn't real—it's caused by the barrel distortion of the camera lens.

The picture quality obtainable from outdoor operations can be improved by adding filters in front of the camera lens. Most CCD cameras are set up for low-light performance and suffer from overexposure in bright sunshine. The symptoms can include blank-out or streaking if the sun comes into the field of view, sluggish AGC response and excessive contrast, causing loss of ground detail below a bright sky. This can be fixed by adding a neutral-density filter to the front of the lens. Values between ND 0.5 and ND 1.5 work well. The wing-mounted ATV package was modified to include a 37-mm screw-in adapter to accept one or more photographic filters. Infrared and ultraviolet (haze) filters can improve color balance.

Another parameter affected by light level is shutter speed, the primary exposure control of a CCD camera. Without neutral-density filters, the shutter speeds can be faster than a ten-thousandth of a second. This is fast enough to stop the prop of a 12,000-RPM engine if the camera is looking through the prop arc. The resulting stroboscopic effect is fascinating to some and downright annoying to others. Adding the neutral-density filter starves the camera for light and it responds by slowing its shutter speed. This causes the prop to blur or even disappear if the prop is dark in color, giving a more pleasing frontal view. The present external ATV package uses one or two neutral-density filters screwed onto the chassis ahead of the camera lens.

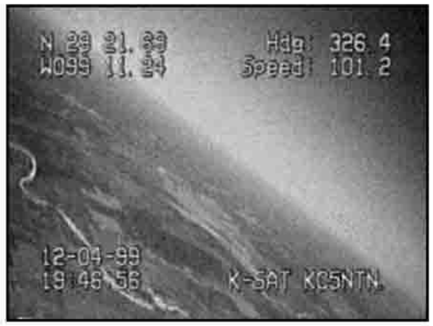
Frequency Selection

Several factors influence the choice of operating frequency for the ATV transmitter. These include range, efficiency and receiver complexity. ATV frequency bands include 70 cm, 33 cm and 24 cm, and 2.4 GHz and above. It takes four times as much power to get the same signal at 900 MHz as it does at 450 MHz. Transmitters are also more efficient at 450 MHz, meaning smaller and less massive batteries can be used on the already overburdened RC aircraft. Also, it just happens that cable TV channels 58 through 60 fall completely within the 70-cm band (427.25, 433.25 and 439.25 MHz, respectively). This means that a cable-ready TV or VCR can be used as a receiver without any additional electronics. Transmitter suppliers are well aware of this fact and offer transmitter boards already tuned to these frequencies. These factors make 70 cm our hands-down favorite for airborne ATV activities.

Interference to and from other amateur services (FM repeaters and satellite operations) isn't really an issue because the airborne packages typically use only 80 to 200 mW and are flown for short durations from (necessarily) remote locations. Maximum range, even with a beam for a receiving antenna, is only a few miles.

Antennas

Our antennas are designed to maximize range and minimize interference between co-located functions. In the airplanes, this is the ATV transmitter and the flight pack receiver. In the rocket, it is the ATV transmitter and the GPS receiver. An additional goal is to provide uniform coverage with minimal dropouts in the coverage pattern.



The view from the K-SAT rocket at 7000 feet.

Figure 4—The circularly-polarized ATV antenna on the rocket payload bulkhead.

The best airplane ATV antennas have been simple vertical ground-planes or vertical dipoles. For short-range flights the receive antenna was a simple quarter-wavelength vertical mounted on my car with a mag-mount. For longer-range airplane flights and for rocket flights, a 10-element beam (a KLM 440-10x) was connected to the receiver. The airplane's flight pack receiver uses a standard trailing-wire antenna supplied by the manufacturer. The control receiver and antenna are configured for horizontal polarization and are mounted as far away from the ATV antenna as possible.

The rocket payload contains two antennas: one for the ATV transmitter and one for the GPS receiver. The 70-cm ATV antenna is a circularly polarized turnstile mounted on the wooden bulkhead separating the payload section from the booster. A photograph of the antenna is shown in Figure 4. When worked against a horizontally polarized beam on the ground, good signals—without dropouts—were obtained from the spinning rocket (as it ascended overhead and as it drifted upside down to the landing site a mile from the launch site).

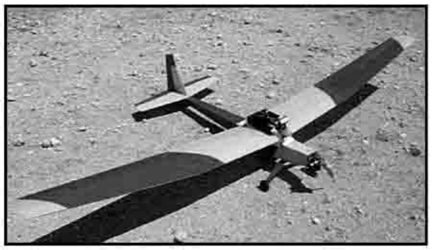
The GPS antenna was glued to the outside of the rocket. A folded dipole design was selected for simplicity, conformal mounting and frequency selectivity. The folded dipole was placed on the rocket as far away from the ATV antenna as possible. Tuned for 1570 MHz and fed with a half-wave coaxial balun, it provided good rejection of the 427-MHz ATV signal. The antenna was capacitively coupled to the coaxial feed line to keep from shorting out the preamplifier bias voltage placed on the coax by the GPS receiver. Excellent GPS coverage was obtained during the flight.

If the ATV transmitter is connected to the antenna with a coaxial feed line, a balun will prevent the feed line from becoming a part of the antenna. This will eliminate feed line radiation (which can distort the radiation pattern), keep the ATV RF away from sensitive onboard receivers and facilitate tuning the antenna. Choke, ferrite bead, sleeve and current transformers are good balun candidates. I've had excellent results with a simple choke balun formed by coiling the RG-174 feed line at the antenna feed point. This eliminates unwanted feed line radiation and decouples the feed line from the antenna, significantly improving the SWR.

Operational Considerations

One safety issue that must be addressed for safe RC aircraft operation is eliminating interference from the ATV transmitter to the flight-control receiver. Both use a 60-Hz frame rate, and ATV signals can cause serious interference to the flight pack receiver and subsequent loss of aircraft control. Although the control frequency is at 72 MHz (or at 6 meters for hams), receiver "desensing" can occur if the ATV signal enters the receiver through the antenna, servo or battery leads. I took several steps to eliminate this problem. First, the TV camera and the ATV transmitter were mounted in a shielded enclosure. Copper foil tape makes an excellent lightweight shield when applied to plastic and balsa enclosures. The antennas for the ATV transmitter and flight pack receiver were placed as far apart as possible and cross-polarized (ATV vertical and flight pack horizontal). A balun was used in the ATV antenna coax to eliminate unwanted feed-line radiation. To eliminate conducted interference, separate batteries were used for the flight pack and the ATV package, and the direct connection between the flight receiver and the ATV package was decoupled by inserting a 1-k ohm resistor in series with the signal and the ground wire.

With the ATV package mounted atop the TH-60, I couldn't eliminate all of the interference until I decoupled the leads from the aileron servos by winding them around a ferrite toroid. Ferrite beads and toroids can be effective only if they are suitable for use at 450 MHz. Most are not, and the manufacturer's data sheets should be consulted when selecting the correct ferrite cores for various frequencies.



The elegant Butterfly with its ATV package attached.

The ATV-equipped Tower TH60 ready for takeoff.

The KSAT rocket and launch team.

Equipment Suppliers

Supercircuits
One Supercircuits Plaza
Leander, TX 78261
800-335-9777
http://www.supercircuits.com
(cameras and transmitters)

Edmund Industrial Optics
101 East Gloucester Pike
Barrington, NJ 08007
800-363-1992
http://www.edmundoptics.com
(cameras and optics)

PC Electronics
2522 Paxson Ln
Arcadia, CA 91007
http://www.hamtv.com
(transmitters, GPS overlay boards and cameras)

Tower Hobbies
PO Box 9078
Champaign, IL 61826
http://www.towerhobbies.com
(model aircraft and supplies)

These steps were sufficient to guarantee no loss in control range for my RC aircraft. More stubborn cases may require shielding the receiver, decoupling each servo lead with feed-through capacitors or chokes where the lead enters the shielded receiver compartment and inserting a low-pass filter in series with the antenna lead. Before flying with ATV gear, carefully "range test" the system on the ground with the engine turned off. A typical test involves removing or collapsing the transmit antenna and backing away from the aircraft while observing the control surfaces. Tests should be performed with the ATV transmitter *on* and *off* to make sure that the maximum control range has not been compromised.

We installed the ATV gear only on aircraft that had already been proven flightworthy. After installation, the center of gravity was carefully checked to ensure that the additional gear was at the correct location as indicated on the airplane plans. The greater wing loading caused longer takeoff and landing rolls, higher stall speeds, sluggish climb performance and a degraded glide ratio. Rudder trim became very important and it was necessary to add more rudder for coordinated turns. The TH-60 flew best when the control transmitter was set up to automatically mix rudder deflection with the ailerons.

If the camera is mounted behind the engine, fuel spray can become a problem. A microscope slide or neutral-density filter makes an excellent windscreen to protect the camera lens, but it can become fogged in only a few minutes if the fuel spray is excessive. Exhaust is the main culprit, and the muffler should be positioned on the opposite side of the airplane from the camera. To keep fuel spray off the microscope slide window on the bottom of the TH-60's fuselage, I had to install a triangular baffle ahead of the window. Significant fuel spray can also come from the carburetor. This can be reduced by installing an air filter. Engines that use crankshaft bushings instead of sealed bearings spray fuel from the front of the engine. Cowling the engine or using a ball bearing engine will fix this problem.

We discovered that the computerized altimeters used to deploy the parachutes on the rockets were susceptible to interference from the 2-meter hand-helds we used to coordinate launch activities. Chute-deployment failure and pre-launch chute deployment were problems before we caught on to what was going on. We lost our first two ATV rockets to this problem, even though both rockets contained redundant altimeters. Fortunately, the rockets came down in the (planned) remote area, and the crash was a non-event. The rockets and all onboard equipment were a total (and spectacular) loss. In the future, the altimeters will be shielded and all connecting wires will be shielded and decoupled with bypass capacitors and ferrite chokes. All hand-helds will be kept at least 50 feet from the launch site. Careful checks will be made to ensure that the 70-cm ATV transmitter can't cause similar problems. Additionally, we will be installing simple backup timers to deploy the chutes if the altimeters are unable to function for any reason.

Precautions

I don't want this to sound too much like "don't try this at home," but in reality, flying model aircraft and rockets can be dangerous and should be undertaken only by qualified individuals. Both possess sufficient speed and energy to cause injury, death or extensive property damage. Model airplane engines and propellers can cause serious hand injuries. Flying RC aircraft is a difficult skill that is within the reach of most individuals, but may take years to master. Launching model rockets that weigh more than 1500 grams or carry more than 125 grams of propellant is subject to FAA regulation. Additional restrictions apply: See FAR Part 101 of the Code of Federal Regulations for more detail. Rocket components and chemicals for larger motors are available only to individuals certified by Tripoli Rocket Association or The National Rocket Association.

This article is meant to share experiences and prompt a discussion of the technical issues involving airborne ATV experimentation. It should not be construed as a "how-to" cookbook. This activity involves risks, and individuals participating in this activity do so at their own risk.

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