The AMA History Project Presents:
Autobiography of CARL E. SCHWAB

Born February 27, 1929 Began modeling in 1940

AMA #46891

Written & Submitted by CES (01/2000); Formatted & Edited by SS (08/2002), Reformatted by JS (01/2010)

Career:

- Developed the method of flying U-Control models with three lines
- Started work in 1951 with Hazeltime Corporation in Little Neck, New York
- Worked with Bob Petersen on developing a two-channel proportional with feedback servos
- Designed and built the Yellow Bird model
- Develop Blip Trim
- Develop Simpl-Simul
- Refined the design of a three-tone system in which the on/off ratio of each of the three tones would control each of the three flight channels
- Contributed to the development of MkI systems
- Built and perfected may different types of servos
- Developed the first upwards pulse system
- Developed Phase Reversal Modulation
- Helped develop reliable frequency-synthesized radio in the 1980s
- Experimented with Frame Validate
- Worked to develop an easier way to categorize batteries

Honors:

- 1998: Vintage Radio Controlled Society Hall of Fame
- 1998: Howard McEntee Award, presented at the WRAM show in New York

In Kansas

U-Control stunt; three-line system using equalized line tension

I was born on February 27, 1929 on a farm near the town of Madison, located in Southeastern Kansas, and spent the 1930s and 1940s there. In the depths of the Great Depression, the 10- and 25-cent Comet and Hi-Flyer kits were a great treat. By my high school years from 1943 to 1947, I had built many different rubber-powered Free Flight models; probably nearly every one in the old Comet line. I had seen only one model airplane engine – a Baby Cyclone. The guy who owned it couldn't get it to run, so I tried to help. We did manage to get it to run but not very reliably. My brother returned from serving as an U.S. Army paratrooper and we heard about someone flying U-Control in Emporia, about 30 miles away. We drove and did see Eldon Brazier fly a U-Control using a Bunch Tiger Aero. Eldon Brazier was an ex-U.S. Army P-38 pilot and attending Emporia State Teachers College under the GI Bill. He and his wife ran a small hobby shop as a side business and this is where my brother and I bought our first engine, a Herkimer OK Super 60. The first kit we bought was a deBolt biplane. The Super 60 was too large an engine so we bought a Delong 30. Everything was ignition at this point. This combination was flown quite a bit and lasted long enough that both of us mastered the basics of U-Control. At this point, my brother was accepted into Oklahoma A&M and headed for Stillwater, Oklahoma.

Dave Slagel had won U-Control stunt at the Nationals and plans for his model were in one of the magazines. I built it from scratch; it required the OK Super 60. Photo #1-1 shows me at age 16 with the model before painting. The control system used three lines with equal tension – the third for advancing the spark timing to control the power. Engines were now more plentiful and I acquired a Super Cyclone, an Arden 09, a Torpedo 29 and a McCoy 49.

While continuing to build I graduated high school and enrolled into Emporia State in a pre-engineering program. This meant I now lived in Emporia and could fly U-Control on the weekends with studying caught up. At this point, Fox was just introducing his 35; I got mine for $7.95 as an introductory price. It was a glow plug engine and this became the "just right" engine for stunt on 50-foot lines. For the 60 size engines, I used 65-foot lines with the added third line for engine speed control via moving the breaker points. I did not realize it at the time, but my method of equalizing the tension among all three lines was unique. Kit names I remember were *Brave*, *Squaw*, *Chief*, and *Over-Easy*.

A classmate, the late Bob Canaday, had interest in U-Control but continued his interest in Free Flight and I acquired interest enough in Free Flight to build two models – a Berkeley *Buccaneer D* and a *Playboy Senior*. The *Playboy Senior* used the Super Cyclone on ignition; the Buccaneer used the 49 McCoy also on ignition. At this point, I was reading about the Good brothers (Walter and William) and digesting whatever there was in magazines on the Radio Control subject. It seemed to me that the Buccaneer was a good candidate for Radio Control so I began to collect various components to attempt to build a single channel radio. Also, both Bob Canaday and I had now switched to Manhattan, Kansas, to Kansas State Engineering College having completed the pre-engineering curriculum.

Bob and I continued to fly U-Control at Manhattan and got to know a fellow by the name of Mat Benton who had enough money to buy a readymade Radio Control transmitter and receiver. He had a model called the Brigadier that used an O&R 19 with escapement. Most of the time the flight terminated in a long walk to retrieve the model and Bob and I did a quite a bit of that. Nonetheless, I become quite interested and continued reading whatever I could get my hands on about Radio Control. In time, from my saved up components, I built up a transmitter and a single tube (RK-61) receiver and installed a motor actuator into the Buccaneer. The transmitter was not crystal controlled, relatively low powered and thus it was necessary to keep the plane close in. Several short more or less successful flights were made.

My final semester and a half of college were hectic and so I didn't do much modeling. I knew I had a job offer in Little Neck, New York, but between working in a Radio and TV repair shop, logging hours for a private pilot license and school there wasn't much time. About this time, it was time to go to Little Neck, New York, and start the job offered by Hazeltine Corp. So on Labor Day 1951, I arrived by train, found a room and presented myself next day at the main entrance of Hazeltine on Little Neck Parkway. It wasn't until the next summer when I had a car that I was able to bring some of my modeling paraphernalia to New York.

1951 to 1954

Being employed and having a steady income made it possible to purchase model supplies as needed. By this time, I had made friends with other young engineers at Hazeltine and found a group renting a house and looking for one more way to split the rent. So in I moved and now I had some space to store things. Here on Long Island there were a myriad of places selling hobby supplies and I visited them all or so it seemed. U-Control was already being discouraged because of the noise and since I was an electronics engineer, it was natural to switch to Radio Control on a more or less steady basis.

By 1952, there were a number of articles stressing ways to improve performance of the various hard tube and soft tube (RK-61) receiver designs by adding a second stage. It was obvious I had to have a much better transmitter. My first design-from-scratch unit comprised a crystal-controlled MOPA design using 12AU7 tubes and mot-gen converter that brought 6 Vdc (from the car) up 135 Vdc. It could provide on/off carrier only or modulated carrier. This was assembled onto a 7x9 inch metal chassis and mounted against the inside end of a plywood box. The plywood box was about 18 inches high and arranged with a partition so that it could serve as a carrying box to and from the field. The antenna was three-section affair that could be assembled, plugged into the transmitter through an insulated hole in the top of the box and this whole thing set on the car hood. The control keying of the transmitter was done by a micro switch mounted in a handle and plugged into the 7x9 chassis through a cable and plug. This basic transmitter was used until 1958 or 1959 with some modifications in the 7x9 chassis and many different control arrangements including a joystick arrangement. With this better transmitter, I reworked the RK-61 one-tube receiver to work with the transmitter on 27.255 MHz. I then added a second tube, a 1AG4 that drove a second relay on tone. The plate relay in the RK-61 operated on carrier. In this manner, I had rudder control and throttle control with engine cut-off in case of equipment failure. I selected the Trixter Beam with its ample space inside the fuselage. By this time, I was married and we lived in an apartment in the Fresh Meadows area in Flushing. So the construction of the Beam was done on the living room floor on a surplus Navy blanket. Next problem was the engine; I needed something in the 19 range and didn't have one. After checking around, the Cameron 19 seemed the right choice. The cost was about $16 as I recall.

After nearly wrecking the Beam trying to test glide I decided to try a low power test flight. It was successful and landed downwind a distance away without damage. I had not hooked up the second needle valve on the Cameron yet. Several successful flights followed. Most flights lasted about five to seven minutes depending how full the tank was, etc. After connecting the teeter-totter air bleed arrangement and the second needle valve, I now had high speed, low speed, and cut-off. This arrangement was flown dozens of flights during the summer of 1954.

By this point in time, I had met the late Bob Petersen. Bob was also an engineer at Hazeltine, but mostly I knew him from the flying field. He was having good success with a DeBolt Kitten powered with a 05 McCoy diesel. Again, it was escapements and being a ham operator, Bob operated on six meters. At the end of the summer, I added an escapement for elevator. I used a three-button system – one for rudder, one for elevator, and one for motor. My three-button system used an RK-61 as the superregen detector and two 1AG4s, each driving a Kurman relay.

The circuit separated two tones, one for rudder, and the other for elevator. Motor control was still by pulsing carrier off/on; still had the fail-safe motor cut off. By adjustment, it was possible to get the relays resonated closely enough that by using three tones, one could hold rudder (or elevator) and pulse the other or hold both. My three-button scheme used two handles; one with two buttons for rudder and throttle and the other with one-button for the elevator. For escapements, I used Bonner's with the mechanical slow down ratchet and also another arrangement I devised using the ED escapements with what I called “electrical slugging.” The ED was a standard, alternating two-position escapement with a current saving feature. By adding a capacitor and switch contacts I caused the escapement to pause a split second at the first position, long enough to pulse again to catch the second position. The additional contacts also caused the escapement to return to the reference position between commands. Using two of the ED escapements with the three-tone scheme, it was now possible to perform loops, stall turns, spins, Cuban 8s, Immelman turns, etc.

Petersen Years

Bob Petersen and myself, per happen stance, were assigned to the same project at Hazeltine providing ample opportunity to speculate what to do next in Radio Control. Neither of us was particularly interested in reeds and both of us thought that a two-channel true proportional with feedback servos could be done. We were well versed in the linearity characteristics (actually logarithmic) of the superegen receivers. We had devised a circuit based on the 1AG4 (and a couple of similar subminature tubes) that worked quite reliably over wide ranges of voltage. We had made measurements of dynamic range and knew in the log mode that the superegen receiver could handle 60+ db signal level range that meant we should be able to work with a 1,000 to one range ratio.

Pete and I had access to all kinds of test equipment and early on we made measurements on 2, 3, 4 tones for AM modulation into the superegen receiver and looked into intermodulation effects. It was from recollections of these measurements that I was able to do much of the later Quadruplex work. But it was from the results of these tests that Pete and I concluded that the waveform for the two-channel system would use a single rectangular waveform modulation with the first channel information carried in width ratio of the waveform and the second channel carried in the frequency of the waveform. The motor control would be by on/off keying the waveform modulation. The demodulators for the width ratio and the frequency were arranged so that without waveform drive they would return the servos to neutral. The motor control this time was a sequencing affair that, if pulsed, stepped through low, medium, and high throttle; if steady off the throttle moved to low motor. This was again a sort of fail-safe.

Pete built a Live Wire Cruiser and I built similar design from scratch, but somewhat larger than the Cruiser. Pete had obtained a pair of Schmidt servos that were used in the Schmidt five-reed system and added a potentiometer to the output. Since I didn't have access to the Schmidt servo, I decided to build the servos from scratch. Where Pete used Kurman relays, I used Sigma 4F. This combined with less backlash in the gear train made my servo resolution much better than Pete's. The penalty paid was in the weight of the overall system as installed in the fuselage. Because of the accessibility problems, Pete was having trouble getting all this inside the Live Wire Cruiser; my larger fuselage did improve accessibility. I arranged the entire receiver/servo/battery assembly on drop-in unit that could be removed and checked out on the bench outside the fuselage. Pete used a Fox 35 and this ultimately proved marginal enough on power that the plane required hand launching. I decided to use a McCoy 55 Sportster I had from U-Control. My design when finished was too big to hand launch and it was so heavy that I was concerned that the McCoy 55 would be marginal. I named it Yellow Bird.

Because of the lag in building Yellow Bird from scratch, Pet's Live Wire Cruiser was ready sooner. Pete probably had 10 to 20 flights on the Live Wire Cruiser before Yellow Bird was finished. The rough terrain was causing the Kurman relays to lose setting on landings. Once Yellow Bird was finished, we had to find a place where we could attempt a take-off. We finally decided to use an abandoned sand-mining pit northeast of Farmingdale, New York. Because of breaking and changing props we had one left, a 13x5 as I recall, that seemed to let the McCoy 55 generate about its best power. The wind direction was favorable so the first flight attempt was made. With the help of the wind, the run was about 100 feet and lift off was clean and gradual. At the point that the model was about 500 feet away and perhaps 100 feet high I started a left turn and low and behold, the response to rudder and elevator were crisp and positive. The 55 was not over-powering for sure, but it provided a reasonable rate of climb. The rest of the flight consisted of very smooth figure eights; Pete was delighted when he had a turn because figure eights were something the Live Wire Cruiser tended to wallow through. Since Pete had more proportional experience than I did, I asked if he wanted to land it. Pete's response was, “It's yours, your privilege to break it.” Because the crosswind leg had to be made close to standing trees, Pete posted himself to motion when I was too close to the tree line. With Pete in position, I made the downwind leg, turned to the crosswind leg then turned to final approach. The breeze was helping to settle the model with a good sink rate. The 55 ran out of fuel, so nothing to do but keep it coming straight ahead. The landing roll was probably 150 feet and stopped by the tailskid. With a sigh of relief, I headed out to bring the model back and only then did I realize that a number of people from the houses that surrounded the sand-pit had seen it and came down to have a look see. The wind had picked up to the point that no more attempts were made that day.

Pete and I were extremely pleased in the improvements in the servo response and also how the semi-symmetrical airfoil I used on Yellow Bird had worked out. Pete believed the wallowing of the Live Wire Cruiser was due to the flat bottom airfoil, which made it quite sensitive to gust effects. We continued to fly both models throughout the summer of 1956. Every flying session resulted in repairs and adjustments. As our proficiency improved, we could perform a number of maneuvers such as loops, rolls, spins, etc. Because of the airfoil and the dihedral, my model would fly inverted and in fact could do an outside loop (very carefully).

Pete was in the process of building a new wing for the Live Wire Cruiser when he decided to take a job offer he had from Stromberg-Carlson in San Diego, California. So in 1957 he loaded up the 1954 Chevy, rented a trailer, and drove the family to California. I continued to fly Yellow Bird during most of 1957 replacing the McCoy 55 with a Fox 59 to which I added a barrel type throttle similar to the Johnson Automix. I began thinking about improvements in the radio and also in the model with weight reduction in mind. When I look back, these were very rewarding years. Pete and I had a plan, executed it, and achieved good results.

1958 to 1961

More refinement of the two-channel proportional

A toy car manufactured in West Germany became available in the U.S. and had a very interesting motor made by Distler. This motor was quite efficient and had exceptionally low current drains compared to others available. The entire car was available for $5 so I bought several and disassembled the motor and gear reduction and experimented adapting these for the servo in the two-channel system. Philco was offering germanium power transistors that could handle the motor current reliably. My servo amplifier now consisted of the tube and the four transistors and produced a very good feedback servo. This servo for an analog servo was way ahead of its time. It was possible to cut down the volume and weight of the receiver drastically. I still used the drop-in unit idea, but now the unit weighed about two pounds including batteries. This system was installed in a Sterling Tri-Pacer kit and powered with a Fox 25. The system flew well although not very aerobatic. The throttle for the two-channel remained a sequencing arrangement with fail-safe. The drop-in unit idea was proving to be a problem in that it didn't fit many models, so my thoughts were turning to repackaging the system.

Blip Trim

The late Lee Berlette had a 10-reed Orbit system and was having good success with it. The Orbit was one of the first reed systems to offer simultaneous tone operation so that during rolls while the aileron was being held, elevator and rudder corrections were possible. The reeds were sufficiently reliable that several modelers were becoming quite expert. The systems usually had two servos mechanically connected to provide an elevator trim function. I devised a scheme I dubbed “blip trim” wherein three reeds were allocated to aileron and three to elevator. The control lever switch on the transmitter was modified so that for a partial deflection, the third reed was energized and its relay connected to defeat the centering contacts on the servo. Full deflection energized the appropriate reed and its relay for say up or down. To get partial deflection one blipped to full switch deflection and rested at the partial position. With this, it was possible to make great slow rolls without the constant pulsing. I modified Lee's Orbit and the idea worked very well. With solid simultaneous tone operation, one could become quite proficient.

Simpl-Simul

A scheme appeared in the magazines describing how one could obtain rudder and elevator control from a single Mighty Midget motor through a clever linkage. Actually, this scheme went by other names; one I recall was Gallopin’ Ghost. I had extra parts left from building the control box used with the two-channel proportional experiment. These were assembled to provide a width ratio varied from 15% to 85% with 50-50 the center and a repetition rate from two to 10 pulses per second and centered at 4.5 pps. The receiver used was the two-relay version, one tone operated and the other carrier operated. Throttle was the two-position, two-needle valve arrangement. The Beam was a trainer type model and not terribly aerobatic so I built another plane called the Arrow adding a semi-symmetrical airfoil and adding dihedral. From my experience with the Yellow Bird, the added dihedral improved steering by the rudder while inverted. At this point in time, most modelers did not realize that rudder did not reverse when inverted if there was sufficient dihedral and power. The Arrow was more aerobatic than the Beam for sure but not as good as Yellow Bird. But Simpl-Simul was simple and quite reliable and I did fly it a lot. But Simpl-Simul, as an idea, was kind of self limiting.

What had occurred to me at this point was the possibility related to Walt Good's TTPW. Walt's TTPW drove two relays in an independent manner; I had a two-tone receiver that could drive two relays independently. The concept was to use each of these independent channels, to convey pulse width and pulse rate information to drive two servo channels. In this way, the two-tone or a TTPW could become a four-channel system. Also at this time, I knew how to separate three or four tones in the output of a superegen receiver. But before pursuing these ideas, I needed to get a handheld transmitter.

Brown Box Handheld Unit

The so-called brown box transmitter was my first attempt to make a handheld unit for proportional control. The original system had a handheld control box but the main unit sat on the car hood and was connected to the car battery. Because I had access to 3A5 tubes that were surplus at Hazeltine, I began to think of a repackage design. Actual construction consisted of two, 7x12x2 metal chassis connected by ½-inch aluminum angles at the corners and painted brown. When joined by the angle brackets and stood on its bottom, the case was 12 inches high, 7 inches wide and 4 inches deep. The two aluminum angles at the top of the case were extended and pierced with a hole allowing a neck strap.

60-degree pots were now available. This was done by using silver paint to short out the resistance strip except for the 60-degree segment. This made it possible to make a joystick without using 4.5 to 1 gear ratio as I had done in the original stick control assembly. Simpler, lighter, better. This simple assembly was a vast improvement over the original and simple to make. This arrangement, with refinement, was used throughout all the Quadruplex transmitters only varying in how the third pot was mounted. The antenna used was a two-hole side mount style for AM car radios. Length was 56 inches as I recall. Spacing the two mounting holes about 5 inches apart, formed a convenient handle when carrying the unit. The transmitter was powered by dry batteries; three 45-volt series connected for +135 vdc for the plate supply and four D-cells parallel connected for the filament supply. These batteries were clamped with brackets in the other 7x12x2 chassis. Lee Berlette built an Astrohog and installed a three-channel proportional receiver with trimmable throttle. The system used two tones with width ratio for two-channel and collective rate for the third channel. Different servos were used including home builts, modified Bonner and DeBolt servos.

As far as contests were concerned, reeds were king. Several modelers were experimenting with proportional but nothing had emerged as dominant. The standard joke was that if you were interested in proportional, buy three systems; one to fly, one on the manufacturer's repair bench and one in transit to or from the manufacturer. Indeed some guys’ proportional radios went back to the manufacturer for repair for months at a time.

Dee Bee Years: How the association with Don Brown came about

I attended the final rounds of the 1961 Nationals (Nats) as a spectator. I watched Don Brown fly his final round and take second place. The system he was using was a Walt Good TTPW system with servos of his own manufacture. I had been reading about the direct pulse proportional systems and was very surprised at the performance. Don was obviously a very good pilot and it was apparent that direct pulse had promise. Because of the constant pulsing, these servos had infinite resolution, i.e., no dead band, but were force proportional rather than position proportional. The current drain was high but nickel-cadmium batteries were becoming available. Gould had introduced its 1200 mah C-cell size that could power three to four servos for at least five or six good length flights with safety margin. So at this point, I wrote Don a letter explaining my interest in his servo design and offered to provide a receiver design that would provide three pulse proportional channels with trimmable throttle. Because of Don's second place win at the Nats, he was member on the U.S. International Team; he was interested in the third channel. So we were off.

I immediately dived into refining the design of a three-tone system in which the on/off ratio of each of the three tones would control each of the three flight channels. Lee Berlette had a hand held version of the three-channel feedback system and we decided to modify that to pulse proportional. Also Andy Push was quite interested so I agreed to build a prototype system for him while I was building mine if he would scratch build a DBIV (Don Brown's design) for me. All these systems, including the one Don was building, were the so-called MkI versions. All were slightly different but all did use the Dee Bee servos. Both models and systems were flown extensively. By the 1962 Internationals all the prototype building and testing was complete. Don by this point was comfortable with the system technically and he and Chick McGee were interested in production and sale. We made an agreement that I would consult on technical problems and improvements in exchange for production equipment for my use and a small royalty. The first production units were called the MkII and were in the upright gray transmitter box as opposed to the horizontal box I had used on the MkI. Don had used the upright box because it was available from a commercial box manufacturer that didn't require any tooling or painting.

MkI and MkII Description

The RF section of the MkI and MkII were identical using a crystal oscillator driving a frequency doubling, 3V4 tetrode final; the remaining tubes were 3A5 tubes. One tube was used in blocking oscillator (BO) arrangement that generated a saw tooth wave. The return for the C charged negatively by the BO was a resistive network that comprised the control pots, 60-degree type and trim pots. Each of the wipers was connected to a half section of a 3A5, (the 3A5 was a dual triode) which had a Jaico (or equivalent) relay in its plate circuit. The saw tooth ran a nominal frequency of 10 pulses per second (was adjustable from about five to 15) so that now the relay received a rectangular current waveform whose ratio varied as a function of the control pot position. For aileron and elevator the ratio could be varied from zero to 100 percent, i.e., full on to full off. The rudder was limited 15 to 85 percent; zero and 100 percent were used for throttle change. A POD (pulse omission detector) was used to sense cessation of pulsing on the rudder channel and drove a trimmable throttle servo. This produced a fail-safe wherein the throttle closed, you got full left aileron and full up elevator. This was not a bad arrangement for most models flown at that time, they mushed around and, if high enough, would go into a spin and do little damage. It was certainly better than a fly away that did happen with reeds and consequent loss of expensive equipment. Fail-safe on an inverted pass was not good.

The receiver for both MkI and MkII equipment was the 1AG4 superegen. Tone separation was accomplished starting in the plate circuit of the 1AG4 with three toroidal transformers series connected and individually parallel resonated by caps. The secondary of each toroidal transformer was connected into an individual transistor amplifier whose collector had a matching toroidal transformer again resonated to the proper frequency. The secondary of this second toroidal transformer next drove another transistor with a Jaico relay in its collector. So now, voila, we had three relays in the receiver mimicking the relays in the transmitter. These relays now drove the Dee Bee servos for rudder, elevator, and aileron. The pulsing waveform on the rudder channel was capacitively coupled into a voltage doubler circuit, which drove the base of another transistor. This transistor was cut-off until rudder pulsing stopped in which case a relay in its collector would close transferring the rudder channel relay output to the throttle servo. A number of different servos were used for the throttle servo including a Dee Bee servo without the spring centering. The battery pack for the receiver consisted to four 1.2 Ah NiCad batteries with a pencil for the filament of the 1AG4. Eventually a dropping resistor, a ½-watt 68 ohm as I recall, drew the 50 ma from the rechargeable pack. A dc-dc converter developed 30 volts for the 1AG4 with a center tap at 15 vdc. The tone filter amplifiers worked between zero and +15 vdc while the relay drivers worked between +15 and +30 vdc.

The Spring-Centered Servo

The spring-centered servo was, at first a surprise to me, perhaps because of my experience with the feedback servos in Yellow Bird. Because of the air pressure on the control surface, significant blow back could take place. In spite of this apparent fact, the pilot had absolutely no problem flying smoothly. The dynamics of the situation was a stick deflection at the transmitter caused the flight surface to produce a deflecting force perpendicular to the control surface. In fact the spring restored servos tended to be force proportional rather position proportional as the feedback servos were. Don used the Mighty Midget motor and had devised a very clever centering spring. The initial spring rate near center was high and decreased as the physical deflection took place. The position that the servo took was a combination of this spring plus the blow back air load. The Mighty Midget stood up amazingly well, was inexpensive, and had replaceable brushes. The only noise suppression used on the Mighty Midget was a 100-ohm resistor strapped across the brush terminals, which served to hold the brushes securely in place. Except for physical size, the original Dee Bee servo worked quite well. While Don was busy manufacturing systems, I looked towards improvements. The principle concern was to eliminate the relays and to reduce the weight and size of the receiver. The receiver was 2.5x4.0x2 inches; the servos were 2.5x3.0x1.5 inches.

The first try towards eliminating the relays was to put a transistorized switcher inside each servo. I made this modification to my MkI system and gave it to Lee Berlette to fly. I did not try to reduce the receiver size at this point. The relays for aileron, elevator, and rudder were removed; the relay for throttle was retained. The throttle servo for that system was a Bonner Duramite. What was noticed was that the drop through transistors, about 0.6 volts, reduced the maximum available servo drive in full-on or full-off. One alternative was to increase the 4.8-volt center tapped to 7.2 center tapped. This now gave greater drive in full-on and full-off but pushed the weight of the system up; not what was wanted. Coincident with this experiment, Graupner, introduced a spring returned servo for reed systems. It was based upon Siemens/Falhauber motor, which was a refinement of the Distler car motor. Eventually this type of motor was referred to as the coreless motor. The spring centering used was a scissors spring, which did not have the correct restoring function but the weight and current drain of the servo were better than the Dee Bee Mighty Midget servo. The current drain, mechanical power using transistor switches with 4.8 vdc, center tapped, was OK. The weight was about 2/3 and mounting footprint about 1/4 of the Dee Bee servo. I worked out a spring arrangement that gave the correct restoring characteristic; this was used on the aileron and elevator. The scissor spring was retained on the rudder. These were test flown very successfully. They were a very good match to a Taurus with a 45 to 60 size engine; very smooth.

Superhet receivers were beginning to show up on five spot frequencies on 27 MHz in addition to the infamous 27.255 MHz. On six meters, we were successfully flying using 200khz separation with the superegen receivers. For the next iteration of the Dee Bee system, Don decided on the Mk21 designation because the flying system weight was 21 ounces; the case color was changed to red. The servo mounting board for the rudder and elevator spring servos was a PCB with the servo transistor switchers. The aileron servo, spring centered, was connected by plug to this PCB. The airborne system was getting smaller; installation was simple.

Return to Feedback Proportional

With a considerable number of MkII and Mk21 systems sold, Don had his hands full fixing, repairing, and answering questions. The equipment was reliable and most of the repair work came from pilot error problems. Several analog servos were being offered; most however had considerable “dead band.” The performance of these servos was enhanced if the error signal driving it had some kind of modulation on as well as the DC control signal. The was referred to as “dithering” and it did improve the small step resolution of the servo. The output of the Mk II and 21 equipments was a rectangular waveform with a peak-to-peak of 4.8 volts centered at 2.4 vdc. If the rate of the transmitter was raised to 15 pulses per second and this waveform put through a Radio Control filter, the output of the filter varied about the 2.4 reference and had a 15-hertz dither whose amplitude was determined by the value of the Radio Control product and markedly improved the servo performance. Space Control was around as was Klinetronics and ACL so I was looking to add the fourth proportional channel. I did add a fourth pulsed tone to the transmitter and added a fourth pair of toroids to the receiver. I contacted Don Steeb who was offering analog servos for Space Control and ACL; Don Brown contacted Bernie Murphy who was making Klinetronics servos. Both these servos were based upon the Siemens/Falhauber motor, which had the first gear pass inside the motor case. Everyone was promising smaller, lighter, simpler, systems so it seemed Dee Bee had to have a new system. The modified MkII worked well, but it was heavy and expensive to manufacture.

The CL-5: The New System

The general concept of “0 frequency IF” seemed attractive, i.e., each servo would control the frequency of a tone that would match one of the tones sent by the transmitter. The frequency of the tone was controlled by a joystick pot in the transmitter; the pot in the servo would control the frequency of an identical circuit in the receiver/servo and drive until they matched in frequency and phase. This would produce an exceptionally tight servo with frequency and phase matching. The big gain was the number of toroids per channel was one and now Q was no longer a problem. At this point, I was still thinking of using the pot in the servo to control the frequency of the oscillating transistor. Further simplifications were to result.

In the course of developing the PLL, I worked on isolating the oscillator to prevent “entraining”; the acid test for this was to observe the phase detector (which drove the servomotor) on a scope with the oscillator free running. To perform this test, one carefully tuned the LO through the input frequency and measured the frequency range over which the LO would "entrain.” Suddenly the light lit! Why not build a frequency discriminator using this entraining to produce an error signal that could drive any analog servo. This was an almost trivial modification to the breadboard setup; everything got simpler and standard servos such as Bernie Murphy's worked well. Using one servo that I could pass around to the various detector outputs it was apparent it worked well.

Don was extremely anxious to push to the feedback servo system; people were deviling him about when they could get one. I put myself to the task of making a transistorized transmitter in the RF sections. This was finished to working breadboard in about a month. Meanwhile Don had redone the transmitter case and worked up the mechanics of a single stick transmitter. The CL-5 actually had four tones; the fifth function, which was an electric nose wheel brake circuit, was coordinated with the low throttle control. This worked out well in that fail-safe was neutral on aileron, elevator, rudder, and low throttle. In order that the servos would have a fixed center and fixed end-to-end travel it was necessary that the amplitude of the input sine wave be constant. From Panter's work, it was apparent that the ratios of the fundamental signal levels remained unchanged after the composite had passed through hard limiting. The limiting guaranteed that the summed energy would remain constant. Thus, the receiver path consisted of a superhet receiver followed by a limiter whose output drove the four tone discriminators. The penalty of the limiting was the generation of intermod products. The effect of these intermod components, when close to a specific channel tone frequency, was to cause an oscillation at the beat rate with an amplitude related to the ratio of the beat tone amplitude compared to the tone signal amplitude. As Don was building systems to sell, he accumulated a lot data that showed what combination of tones produced beats into which channel. Early on he had noted that not all systems had the beats (or lumps as he called them) at the same tone combinations. A big improvement came by making the limiting softer symmetrical. Using Don's data we were able to find channel tone ranges that worked extremely well except for very unusual combinations like 1/2 throttle, 2/3 right rudder, full left aileron and 1/2 down elevator. It got to be a game to try to find these lumps; they were that elusive. The intermod products were present in the MkI, II, 21, but because the tone frequency was fixed, the intermod frequencies were fixed as well. Only much later did I realize the significance of this fact.

In the CL-5 temperature, effects were present and I spent considerable time tracking down the causes. A small amount was due to the residual coefficient difference between the polycarbonate cap and the toroid. The more bothersome temperature problem was caused by the germanium transistors used in the Bright switches used as synchronous phase detectors. At 100 degrees F and above, the leakage current reduced the slope of the servo command signal so that the max throw in each direction reduced. We received almost no complaints about this effect so a fix seemed unwarranted.

Other factors regarding the competitiveness of the CL-5 were its weight and number of channels. It was obvious that PPM had a weight advantage and as time went on interference problems with PPM would be solved or at least improved. Bonner had introduced his Digimite 8 system that did provide up to eight channels. Although Dee Bee was selling a number of radios, it was apparent that the CL-5 wouldn't go much further and be competitive. Don decided that a better investment was in the equipment to manufacturer the ARF (almost ready to fly) kits. He continued to service the installed base of MkI, II, 21 and CL-5s and a few years later remarked how remarkably loyal the user group had been.

This for all practical purposes ended the Dee Bee years of producing radios.

The CL-5A and the CL-4

In the course of working with Don, I had gotten to know Austin Leftwich and he and a friend, Walt Maidl, were interested in making control systems for their own use. Austin owned a Kraft four-channel digital at this point and was having fair success but mixed in with unexplained “funnies” The general impression was that analog proportional was more resistant to interference than was digital. This impression always struck me as odd because, the so-called digital, was really pulse position analog and the word digital just sounded good. It wasn't until the advent of PCM that digital radios were truly digital. At this point, there were several speculated refinements in the CL-5 that Austin and Walt were interested in trying. Also they were interested in a different version of the single stick transmitter eliminating the knob on the top of the single stick for rudder control.

To reduce the temperature effects of the CL-5, the CL-5A and the CL-4 were designed with silicon transistors in the demodulating circuitry; also the Ls and Cs were switched to Siemens pot cores and polystyrene caps. At this time, the receiver was a superhet using germanium transistors but was working quite well without temperature problems of any kind.

The servo oscillation or “lumping,” as Austin, Don and Walt called it, was caused by intermodulation distortion producing beats that could fall almost exactly on the channel tone frequency. I spent more time figuring out the best adjustment procedure in setting the four tones in frequency range, transmitter modulation level and limiting characteristic in the receiver and had a good degree of success making the lumps undetectable.

The CL-4 was an attempt to shrink the receiver and by dropping the electric brake arrangement, expanding the tone range used for throttle. The size was reduced to 2 x 2.5 x 1.25 inches; which was comparable to any of the digitals appearing. With Austin and Walt's help, we worked up an alternative single stick arrangement that moved the rudder from the top of the stick to the top of the case. The left hand now operated rudder by the thumb and throttle by the first or second finger. I used this arrangement for two iterations of transmitters before going to the two-stick arrangement now nearly universal. Although the performance of the CL-4 was quite good and its interference resistance excellent, it still remained that it could not be produced competitively and that adding any more channels was not in the cards. So only three CL-4s were built and I turned my thoughts to how to do a digital. By this point, a number of digital servos were being manufactured and were available so my concentration was on the receiver/decoder and modulation techniques.

Upwards Pulse Digital

It now became apparent that adding more channels would come by way of some form of TDM, (time division multiplex). Even with the now realized improvements, the intermod products from multiple tones would present a limitation at four to five channels unless a very linear transmission media was used (wide band FM for example) and the weight would be a problem unless the Ls and Cs could be eliminated. Various schemes had been devised to send the tones serially and the demodulators arranged to sample and hold on only its correct tone. Sampey used such an approach as did Space Control. Both of these systems had severe temperature drift effects.

The PPM digital system, by placing a feedback one-shot in the servo, was achieving what I had sought in the predecessor scheme to the CL-5, i.e., each servo position controlling the phase and frequency of the demodulator in a PLL manner. The modulation of the digital was simply keyed off carrier. Early on various schemes were tried but the one that worked the best was a nominal 1.5 millisecond space between and a 0.3 millisecond off time. Since the actual channel information was in the space duration between the lead edges of the pulse it was not clear why the carrier wasn't turned on during the pulse rather than turned off. When I queried some of the people as to why the choice, it was apparent they didn't really have a reason except that it was simple and others were doing it that way. It seemed if the pulse were turned on rather than off, then the same range performance should result with a large reduction in transmitter average power. The only real thing the carrier was doing in the downwards modulation was to make the AGC dead simple and to make meeting the FCC requirements straightforward. Despite the large carrier term, many of the early digitals splattered badly into adjacent channels. This meant if upwards pulse were to work the radiated spectrum had to be shaped. But the question of “Why send the carrier?” persisted and led to upwards pulse modulation experiments. I might add others must have asked the same question for some years later another upwards modulated digital radio called Variant was manufactured by a company in Connecticut.

AGC Studies and Servo Motor Interference

The first upwards pulse system was made by gutting a CL-4 prototype. The mechanical parts from the transmitter were used; the RF board saved, and the encoder removed. I then added a 1/2-shot string to develop the pulse frame in a variable frame rate arrangement. My reason for using the variable frame idea was that the synch interval was fixed at 4.5 milliseconds and I felt would make achieving good AGC performance straightforward. The modulation to the RF section was a simple transistor switch affair using an L and C pulse-forming network. This provided a nicely shaped pulse of about 18-volts peak amplitude to the RF output stage. This resulted in an RF power during pulse about three to six db greater than the downwards modulated digitals.

The superhet from the CL-4 was used directly except for the AGC arrangement. The AGC was developed by peak rectifying the detected pulse. Because of the low duty factor of the pulse, the discharge constant for the AGC had to be several times the 1.5 milliseconds. Typically, I used a time constant of 20-40 milliseconds and for the normal range variations that was fast enough. This later proved to be a problem particularly with helicopters where blade modulation caused unwanted received pulse amplitude variation causing decoder synch problems. Range of the system was excellent and it operated side by side with downwards digitals on adjacent channels causing no interference and receiving no interference. That was the very good news; but one other aspect was annoying. Servo motor brush noise; the servomotors required chokes in the motor leads.

At this point Austin and I made a trip to Cincinnati, Ohio, during the Toledo show to visit with John Maloney to see if he had any interest in manufacturing the upwards pulse modulated version. Maloney expressed interest and provided MAN 2-3-4 kits that I would assemble; one with upwards and the other with downwards and World Engines would compare. If upwards showed advantage World Engines would produce the radio. I did assemble the two MAN 2-3-4 kits and shipped them to World Engines. Austin and I now had a good source for servo parts and mechanical parts to put together systems for our own use.

At this point Walt Maidl was being reassigned at work so he no more time and lost interest in the project. Austin was offered a position in Honeywell Corporate in Cleveland, Ohio. He hated to leave Harrisburg, Pennsylvania, but decided he had to take the offer to survive in Honeywell. I modified Austin's old Kraft to add a fifth channel and installed chokes in all the servo leads. Austin was quite pleased and used the system in competition for several years.

World Engines, John Maloney, and Jim Lanterman

At the first meeting with John Maloney I do not think Jim Lanterman was yet an employee. Jack Port had been the electronics brain behind Controllaire but passed away very suddenly. Port had designed a digital radio but it suffered a number of problems that collectively gave it a bad reputation. John was smart enough to know he had to replace Jack Port; Jim Lanterman grew into that replacement. Jim learned the radio design business OJT (On the Job Training) and his first assignment was to try to fix the many problems people were turning up building the MAN 2-3-4 kits. It was at this juncture that Maloney changed the name from Controllaire to World Engines and started the expansion into imported engines, model kits, etc.

As Jim Lanterman worked on the various problems in the MAN 2-3-4 kit design, I consulted and offered advice. The side-by-side testing of the two MAN 2-3-4 kits clearly demonstrated that for the same peak RF power, Upwards was 3-6 db poorer in regards to motor noise. But using chokes in the servo wiring made the performance very good. In tests of AGC operation the Upwards was much poorer than Downwards. It also showed that most Downwards systems had unnecessarily slow AGC operation, which hurt them in helicopter operation. Because of the interest in helicopters the issue of better and better AGC operation kept surfacing. Other manufacturers were going to various FM systems that had no AGC and employed limiters in its place. At this point it occurred to me that a log receiver should work well with AM downwards modulation and would not require AGC. Jim did design a receiver that was essentially a log receiver; it had no AGC. It was successful for helicopter control and was used in the Blue Max and in one of the Expert series of receivers. Jim continued with various decoder arrangements and evolved the 4017 decoder, which is about the best ever produced. Eliminating the requirement for AGC was of continuing interest because of the growing popularity of helicopters; this caused me to think about alternatives such as phase reversal modulation.

Phase Reversal Modulation (PRM) Experiment

The idea of PRM was that rather than turn the carrier off during the pulse, the carrier would simply be reversed in phase and continued during the pulse. The upshot of this was twofold; (1) a limiter could be used, i.e., no AGC, (2) the sideband energy was four times or six dB greater than downwards modulation. The second point meant that the receiver four times less sensitive to interference. This concept was reduced to practice in late 1975 and beginning in early 1976. I modified a World Engines Expert radio to use PRM. This experimental system was flown for hundreds of flights and worked so well that, in reflection, it is not quite certain why it wasn't produced as the next step in the Expert Series. World Engines at this time was enjoying good sales of its Downwards modulated systems and together with Dave Brown's success in the contest circuit there wasn't any reason to change. Also early FM systems were suffering various problems so it was not certain which avenue World Engines should pursue. Almost coincident with the FM issue was the issue of single versus double conversion receivers. Kraft and most of the other manufacturers were puzzling what was the next move as was World Engines. To further complicate matters the frequency synthesizer technology was developed to the point that it needed attention.

Frequency Synthesizers

After the AMA successfully lobbied the FCC for the 50 channels in the 72-73 MHz band it became apparent that rather than stock all the 50 possible crystals a synthesizer might be used. The phase-in plan called operation of the even numbered channels up to 1991 and then to include the odd number channels as well. Starting about 1980 I prototyped units using Motorola chips for the most part and did build both fixed prescaler and duo modulus prescaler versions. Kraft had attempted to sell a frequency-synthesized radio in the early 1980s just before he sold the business. The unit got very mixed reviews and had the reputation of being bad news in the hands of the wrong modeler. What Jim and I did evolve was the concept of frequency key pairs; one for the transmitter and one for the receiver. These keys were plugged into a socket mounted on the transmitter case and a socket mounted on the fuselage side. Frequency channel was clearly marked on the key plug.

Double Conversion and Hi-IF Receivers

If the standard 455 KHz IF is used then the image is only 910 KHz away and without better RF section selectively the image can be a problem. As a matter of fact when 72 MHz operation first became available, some manufacturers did not realize that if high side or low side were used exclusively, an in-band image problem would occur. If the lowest frequency, 72.010 MHz was used then for high side LO the image was 72.920 MHz, which was dead between channels 56 and 57. World Engines recognized this and used split LO assignments, i.e., channels one through 33 were low side LO and channels 34 through 60 were high side LO. For all practical purposes now the image was outside the 72-73 MHz Radio Control band. To further attenuate this near image frequency I suggested to Jim that we use a series LC trap at the image frequency and them parallel resonate this combination for our signal frequency. This worked well and made an excellent, inexpensive receiver.

To boost sales John felt World Engines needed to offer a double conversion receiver and he had made arrangements with Hitec in Korea to import such a receiver. The rationale for double conversion is that the high frequency first IF solves the image problem and the low frequency second IF permits good adjacent channel selectivity. Double conversion in solving the image problem typically uses 10.7 MHz for the first IF causing the image to be 21.4 MHz removed. The second IF is typically 455 KHz. The image for the 455 KHz IF, 910 KHz away, is above or below 10.7 MHz depending the Second LO frequency. Early designs of double conversion receivers, including Hitec's, turned out to be subject to third order intermodulation effects (3OI) and I spent considerable time with Jim Lanterman diagnosing the problem. What was necessary was to prevent either the first mixer or the second mixer being over driven by adjacent channel signals. In the double conversion receiver this meant careful balance of AGC/limiter action and narrowing the bandwidth of the 10.7 MHz pass band between the first and second mixers. I became convinced that RF attenuation under AGC control, combined with low gain between the first and second mixer followed by limiting was the way to go for FM receiver. One offshoot was the introduction of the 10.7 MHz crystal filter into the Hitec receiver design that combined with the other fixes virtually eliminated the 3OI problem.

While this was going on I was looking into a single conversion receiver using a 10.7 MHz IF only. To do this I relied on a monolithic crystal filter at 10.7 MHz for adjacent channel rejection and I used an RF attenuating AGC ahead of the first and only mixer. I built several breadboards of these receivers for AM, FM and PRM. The Signetics chips provided and RSI (receiver signal indication) that was an excellent log receiver output. I test flew a sample AM receiver for some time with excellent results. FM and PRM detection was a different problem and early versions used a VCXO in a PLL, (voltage controlled crystal controlled oscillator in a phase locked loop), for the demodulation. Unfortunately since two crystals were required for the FM and PRM detection, the approximate parts count and parts cost were similar to the double conversion. For this reason neither of these systems saw production by World Engines.

Phase Reversal and FM Comparisons

Alluded to earlier was the fact that PRM and FM are constant carrier amplitude systems and thus can function behind a limiter circuit. The advantage to the limiter is reduction to amplitude fluctuations caused by multipaths between the transmitter and receiver antenna. An advantage of PRM is that the frequency of the carrier is easily crystal controlled and the sideband energy is six dB greater than Downwards Pulse AM. The comparison with FM is more complex but by using computer programs for FFTs (Fast Fourier Transforms) I found that the PRM was closely equivalent to FM for a modulation index of 1-1.5. In the rush to meet the narrow band channel assignments many manufacturers were adjusting the modulation index to lower than one, which was equivalent to an AM system with less than 100% modulation. Another aspect with FM is that all Radio Control systems directly modulated the channel crystal. This puts a restriction on the crystal source and it makes temperature control of the crystal circuit more difficult. I am convinced that PRM is a better way to go both from cost and overall performance standpoint.

At this point I began to consider PRM with the alternate reversals spanning the period between the pulses rather than just during the period of the pulse. The advantage is that this puts the same energy into the sidebands but packs these sidebands closer to the carrier. The result is a better narrow band approach. It further developed that this allows easy detection of the PRM without the need of the VCXO. This means less parts cost without any sacrifice in performance. Also re-visited at this time was the “injection locked” FM discriminator. This makes it possible to build a very narrow percentage bandwidth discriminator without resorting to high Q resonators. It does require a temperature stable LC combination but by separation of the peaks of the discriminator about 20 KHz sufficient sensitivity can be produced and temperature variation is acceptable. Note here the pass band on the receive end is determined by the crystal filter; the pass band of the discriminator can move up or down due to temperature by using capacitor coupling to the video circuits. This allows a single conversion high IF system with only one crystal; very cost effective.

Frame Validate Concept

By the early 1980s a few companies were offering the first PCM digitals. These systems were the first truly digitals in that they encoded the control position to a binary format and proceeded to send the strings of 0s and 1s to the receiver. To help sell these early systems the idea of programmable fail-safe control positions was promoted. Actually some systems offered hold last position for a presettable time then to fail-safe reference positions. The hold last position combined with a parity check was a useful feature when the receiver experienced intermittent interference on channel. The fail-safe reference position sounded great but much as Bonner's Digimite 8, it caused more trouble than it eliminated.

Early in the experiments with PPM digital the thought had occurred to me that if one could count the number of pulses in a frame then interference could be detected. The reasoning was that interference in order to screw up the receiver decoder had to show up as another pulse causing the decoder to miss count. Adding or missing a pulse in a frame will cause one or more servos to receive full defection commands. Some argued that interference could move the position of the pulse but this is not valid because that presupposes a joint occurrence of a canceling and in interfering pulse in the same frame; extremely unlikely.

I performed experiments that showed that if an interfering extra pulse got through the decoder and to a servo(s) then you needed up to five good frames to get the servo(s) back to correct position. Conversely if you prevented the defective frame reaching the decoder it only caused a missed update to the servo and nothing else. I further showed that you could lose half of the updates to the servo and although sluggish it was still flyable. So we had the makings of a good idea; store a frame for one period (about .02 seconds) and if it validated only then pass it to the servo decoder. Essentially this provided a hold last position type of fail-soft. This was Frame Validate.

All of my experiments with Frame Validate were performed by using a second PCB the same size as the Expert receiver board and using two Expert receiver cases glued back to back. This was convenient and expedited testing. I also had laid out a PCB for a single conversion, high IF, AM receiver deck this combined with the Frame Validate was flown extensively. Had it not been for the death of John and subsequent failure of World Engines this was the next design ready for prime time. Had it gone into production it would have been offered in AM, FM and PRM versions all with Frame Validate. Frame Validate would have been reduced to a single ASIC and the receiver all put on a single PCB.

Four-Wire Frame Validate Servo

Experimentally I had determined that if the servo motor bridge (part of the servo electronics) was gated off at the end of the corrupted frame and re-energized at the completion of a good frame then the benefits of Frame Validate could be retained. In order that the drive to the motor bridge be correct it was necessary that the front end circuits of the servo electronics be powered. In effect we needed two Vccs for the servo, one switched and the other on steadily. It turned out that some of the servo amplifier chips for different reasons while not having separate Vccs, did have separate ground returns for the front-end circuits and the power bridge. It becomes a simple matter to insert an N-channel FET in series with the bridge ground return and provide a gate signal from the Frame Valid detector. The N-channel FET now had to be in servo case and additional wire was needed to convey the gate signal from the Frame Validate detector. This became another good news/bad news situation. The bad news was that the servos were no longer standard because of the fourth wire. The good news was that the servos were quieter because we no longer needed the CCD delay circuits. The four-wire servos worked normally using three-wire drive.

Hobby Lobby Association

In the late 1980s I developed an interest in the status of electric-powered flight. In fact just prior to John Maloney being diagnosed terminally ill, Jim Lanterman and I discussed possible products that World Engines might sell and/or manufacturer. My interest was stirred because it appeared the battery technology, driven by the hand tool market, was making good progress. It seemed to me that the technical data available for motors and batteries was either too superficial and mostly hype and mirrors, or so complex as to be incomprehensible by the average modeler. I knew that theoretically it should be possible to build speed controllers for PM DC motors that had near 100% efficiency. From experiments performed on Futaba frame rate controller, although it did not get hot itself, its efficiency was only about 50% at half voltage condition. After puzzling as to the mechanism of the loss I concluded that the rms value of the current in the motor armature was much greater than the average DC value. The lost power was appearing as additional heat in the motor winding resistance. The solution for bringing the rms and average value of the armature current to the same value was to use a higher switching rate. This would place a requirement for better power commutation diodes; that was OK they would help the efficiency. I sat about to design a better mousetrap.

High Efficiency Controller

Through a series of experiments I had concluded I could operate at about 6,000 Hertz; at this frequency the inductance of the motor smoothed the current and, further, I could provide the necessary drive voltage to the gates of the power FETs. I had surveyed available sources and had settled on Motorola partly because samples were readily available. Motorola had a good Schottky barrier diode specced at current levels suitable for the commutation diode(s).

The drive voltage to the gates of the power FETs was a 6,000-Hertz rectangular waveform with the on-off ratio adjustable from 0-100%. I devised a decoder circuit that converted the 1.0-2.0 milliseconds control signal from a standard digital receiver into the 0-100% duty factor drive waveform for the power FETs. Although many of the commercial controllers drove the gate signal to the power FETs from 4.8 vdc, I concluded from the spec sheets that I needed to double this to 9.6 vdc. Therefore I added a voltage doubler circuit and added that voltage to the regulated 4.8 vdc. This works very well.

BEC or battery elimination circuit was another element I added. This had been done on many controllers particularly those for the Radio Control cars. I opted for a different approach; I used a very small (50 mah cells) four-cell pack that was voltage charged by the regulator for the speed controller and then pumps back to supply the receiver and servos for a limited time after the motor pack is drained. This works extremely well not only extending the time for a go-around but also acting as a DC capacitor providing peak currents for the servos without the controller BEC regulator providing the servo current surges.

As I developed the circuit I added more power FETs and more commutation diodes. Principally this was to improve the efficiency and spread out the dissipation area for the ohmic loss heat. With three power FETs in parallel and four Schottky diodes in parallel I achieved better than 90% efficiency at half pack voltage and 25 amps supplied to the motor.

Opto coupling was incorporated into the design as an option. It requires the use of a 4.8 vdc flight pack to supply the receiver and servos; the 4.8 vdc for the electronics following the opto coupler is supplied from a 7805/6 regulator from the motor power pack. The idea of using the opto coupler is to separate the grounds of the receiver and the high power ground of the power FETs. To achieve RF isolation, one must route the wiring for the motor/controller/ motor battery pack separately from the wiring harness for the receiver and servos. It does not appear too necessary to do this unless you are using the 15 to 35 cells and motor currents in the order of 50 amps. Several of the controllers were constructed and used; I have spent some time trying to get manufacturers to use the ideas with some success.

Electric Motor Measurement and Cataloging

In college I had done so well in DC Machinery I was given and A+ and allowed to skip the final exam so I had a very comfortable feeling working with DC motors. In looking at the various sources of supply for the electric motors I looked at Hobby Lobby's catalog and noticed Jim Martin's efforts at trying to categorize the motors in some more meaningful way rather than the vague 05, 15, etc., that had been promoted by Bob Boucher of Astro motors. For my own edification I really wanted to know how much power was generated by a specific motor/battery/prop combination and at what efficiency.

Jim Martin for his part had made a thrust measurement rig and was categorizing various motor/battery/prop combinations by ounces of static thrust. I introduced him to the half free shaft speed/maximum power out concept. Further, we developed a straightforward procedure to compute the power output in watts. Jim proceeded in successive issues of the catalog to list the motors in ascending maximum power output capability. Jim tested and rated some near 100 combinations of motor/battery/prop; two items came to the surface. One was a simple safety issue; as the motors became larger and the output approached 1000 watts, the thrust rig was not adequate. A second item was measurement of the free shaft speed. Because of the variation of battery pack voltage at lower currents and the particular pack peak charge condition, accurate speed measurements were difficult. Another occasional complaint was that our 50% efficiency included the losses of the battery and the motor to represent the maximum power available from that motor/battery combination. Some motor manufacturers protested that the battery losses should not be included; it reduced the apparent maximum power available from their motor.

Two-Point Method of Measure

Collecting the data for the catalog chart required several steps. First, you had to select the motor and determine the appropriate number of cells. Second, you either calculated or measured the free shaft speed. Third, you had to select the prop that came closest to the half-free shaft speed, note its pitch and diameter, and record the measured rpm and the current draw. Having done this you then measured the thrust in the test set up. This was a time consuming effort and because of the previously mentioned stalling effects of the props, the selection was rather restricted.

In my work in my basement, I had evolved a set-up that provided a variable voltage source and I had been paying more attention to the no load current of the motors. When I performed a load test, I put on what I thought was an appropriate propeller simply adjusted the voltage to the motor until I achieved either the desired rpm or the desired current. With this set up I could make accurate measurement of the Krpv, rpm per volt. By not having to connect up a particular string of batteries and search for the right propeller, the testing was speeded up considerably. Further it occurred that by measuring the Rpm, current and terminal voltage of the motor/prop at two separated voltage conditions I had two equations written in terms of 1/Krpv and Rmot. Knowing these two parameters for the motor made it is possible to calculate all the entries for the catalog.

Two Pitch Hub

Variable pitch props had been experimentally tried but not commercially successful. The idea is simple, by adjusting the pitch to prevent the motor speed dropping below half-free shaft speed. Because the torque output of the motor is Tpa x Ia if the pitch reduction is torque controlled, then this also limits the maximum current drawn by the motor. The advantage of using a torque controlled pitch is that take-off acceleration is excellent and as the model achieves speed, the rpm increases until such point that the current reduces, the torque reduces and the pitch increases. Samples of such a prop hub have been assembled and are now offered for sale by Hobby Lobby.

Conclusion

I continue my interest in Radio Control and particularly enjoy the electric-powered activities because of the intellectual challenge. My wife Rose and our three children have resided on Long Island the past 45 years. For relaxation, we enjoy sailing, traveling, and the three granddaughters. My son, Lewis, is an accomplished Radio Control modeler with interests in Quickie 500 racing, collecting, and restoring old model engines. Living on Long Island, I have witnessed the loss of many flying sites because of noise, and hence, my modeling interests more recently have been geared toward electric powering. I consult with Jim Martin of Hobby Lobby on many technical questions regarding motor power rating, battery performance, and electronic speed control (ESC) capability. I was selected as a test driver for the GM IMPACT electric vehicle test program in April of 1995 and thoroughly enjoyed the experience. The versatility of electric propulsion is amazing.

(signed) Carl E. Schwab
January 5, 2000

Carl at age 16 holding an early U-Control model powered by an OK Super 60 using the three-line equalized tension system.

Two of the MkI prototypes. Left is Andy Push's design and right is Carl's DBIV.

Production version of MKII Quadruplex.

2000: Carl's passport photo

c. 1967: Carl with Kwik-Fli and an alternate single stick configuration transmitter with CL-5A or CI-4.

AMA History Project
National Model Aviation Museum
5151 E. Memorial Dr.
Muncie IN 47302
(765) 287-1256, ext. 511
historyproject@modelaircraft.org

ACADEMY OF MODEL AERONAUTICS
Bringing Modelers Together