The FMA Flight System

New technologies for protecting RC aircraft

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Executive summary

Until now, no RC radio system has adequately addressed pilot concerns such as interference, loss of signal and loss of control. The evidence is clear: aircraft still crash. PPM receivers are essentially passive devices—unable to make decisions or take action in the event of a problem. PCM radios offer digital encoding and failsafe operation, but still have limited ability to prevent crashes. Although electronic technology has the potential to resolve many flying problems, its application to radio control systems has been slow.

In response to this situation, FMA, Inc. has designed, developed and brought to market a series of integrated airborne components that remove much of the risk from RC flying. Taking full advantage of state-of-the-art microcomputer technology, the new Flight System family provides a combination of features not available in any other RC systems:

- Preflight interference detection.
- Exceptional interference rejection.
- Servo failsafes.
- Flight stabilization.
- System data output (from the receiver, as well as PC-based software).

FMA's Flight System substantially improves the safety and reliability of RC aircraft operation by taking a comprehensive approach, starting before the airplane takes off, continuing during each flight, and even extending to post-flight review. For example, under worst case conditions—loss of signal, overwhelming interference or pilot error—Flight System components take control of the aircraft and put it into stable flight path.

Introduction

The crash. It's every RC pilot's worst nightmare: loss of control, damaged equipment, lost time and money, possible personal injury or property damage, visions of lawsuits, and severe embarrassment packed into a few terrifying seconds. Fly-aways are every bit as bad—they just take longer. With so much at stake, why has so little been done to prevent these all-to-common catastrophes?

Microelectronic technology is available for adding advanced analysis and decision-making power to receivers. Yet Pulse Position Modulation (PPM) receivers are still dumb devices that blindly pass pilot instructions through to the servos. In the face of interference or pilot error, a PPM receiver offers no solutions. Pulse Code Modulation (PCM) is an attempt to improve RC system performance. It uses digital techniques to minimize the effects of interference and to take over the servos when a clean signal isn't present. Yet aircraft with PCM radios still crash.

FMA, Inc. recognized these shortcomings in radio control systems. As the leading innovator in radio control electronics, the company decided to create a set of airborne components that would achieve several goals:

- Enable the pilot to detect radio interference that could endanger the aircraft.
- Eliminate random glitches that cause servo jitter.
- Operate reliably in the presence of strong on-channel and off-channel interference.
- If the transmitter signal is lost, or if there is overwhelming interference, take control of the aircraft and put it into a safe, predictable attitude.
- Help the pilot recover from an error.
- Provide useful information about radio system operation.
- Operate with off-the-shelf FM PPM transmitters.
- Operate with both digital and standard servos.
- Sell for substantially less than PCM components.

The result—FMA's Flight System—represents a major advance toward safe, reliable RC aircraft flying. The Flight System incorporates five key functions:

- **Interference Check**, a Flight System Receiver feature that determines the presence of a transmitter on your channel, as well interference from any source on any frequency, that affects receiver operation.
- **Digital Signature Recognition**, a powerful new technology that enables a Flight System Receiver to reject interference and to reconstruct corrupted frames.
- **Servo Failsafe**, which enables a Flight System Receiver to take control of the aircraft when a clean signal isn't present.
- **Flight Stabilization**, for returning the aircraft to a stable attitude when a clean signal isn't present (and also in the event of pilot error).
- **System status and performance data output**, which provides information about how your radio system operated during range checks and flights.

The Flight System product line seamlessly integrates these functions in several products:

- Flight System **Receivers** provide
  - Interference Check.
  - Digital Signature Recognition.
  - Servo Failsafe.
  - Direct system status and performance data output.

- Flight System **Co-Pilot** provides flight stabilization as requested by the Flight System Receiver or as needed by the pilot.

- **FS8 Co-Pilot** combines Flight System Receiver and Co-Pilot functions in a single platform.

- Flight System **Receiver Viewer Software** and **Co-Pilot Viewer Software** provide extended system status and performance data output.

This paper describes Flight System functions in detail, and shows how they work together to vastly improve RC aircraft reliability, safety and performance.

Interference Check

Until now, an RC pilot needed a frequency scanner to determine if a channel was in use. Still, a scanner can only search for on-channel interference, and can't detect interference from other sources or intermodulation effects.

Flight System Receivers address this problem with built-in Interference Checking. A Flight System Receiver not only checks for interference from another transmitter on the same channel, but also for interference on any frequency from any source that could endanger aircraft operation. Since interference checking takes place after signal conversion, the receiver even detects 2nd and 3rd order intermodulation products.

Interference checking is simple to use:

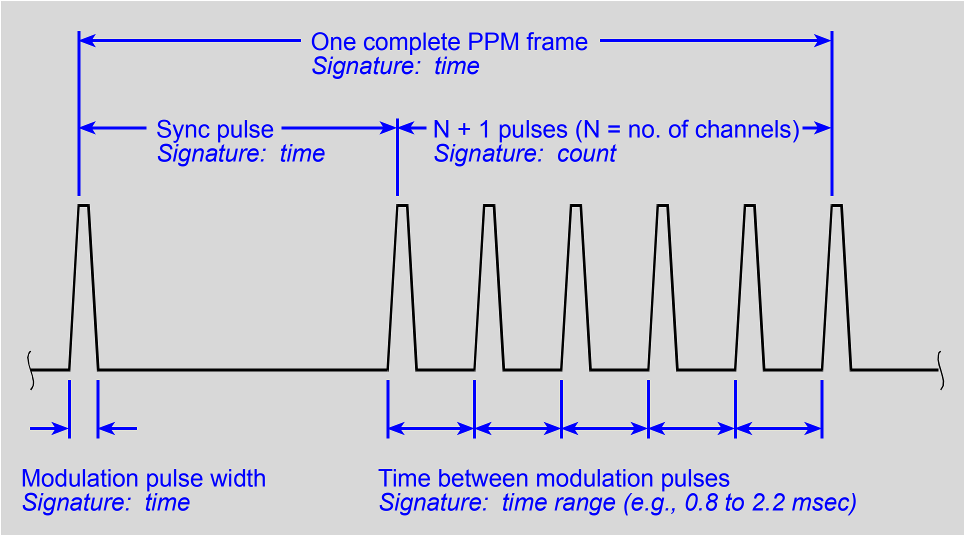
1. Turn on the Flight System Receiver, but leave your transmitter off.

2. Watch the LED on the Flight System Receiver:
   - If no interference is present, the LED blinks once.
   - If the receiver detects interference, the LED blinks continuously.

Digital Signature Recognition

Digital Signature Recognition (DSR) is an innovative approach for rejecting interference and recovering damaged frames. To understand how DSR works, it's important to first know about the signal it works with.

The Pulse Position Modulation (PPM) waveform output by a typical five-channel radio control transmitter is shown below.



As noted in the diagram, the waveform has several parameters that form a signature or "fingerprint" unique to each RC transmitter:

- Each frame is about 20 milliseconds long.
- The synchronization pause is 4 to 6 milliseconds long.
- There are always N+1 modulation pulses, where N is the number of control channels available in the transmitter.
- Each modulation pulse is 250 to 350 microseconds long.
- Pulses are between 0.8 milliseconds and 2.2 milliseconds apart. (This spacing varies according to transmitter stick and control positions, and is the source of the term "pulse position modulation.")

Additionally transmitters can be differentiated by frequency shift. Some transmitters (e.g., Futaba and Hitec) use negative shift, while others (e.g., JR and Airtronics) use positive shift.

These parameters vary from one transmitter model to the next, but they are fixed for a given transmitter. Digital Signature Recognition takes advantage of these facts to assure that every frame sent by the transmitter is faithfully reproduced at the Flight System Receiver's servo outputs. Here's how DSR works:

- DSR measures and stores your transmitter's unique signature.

- DSR then continuously checks the received signal against the stored signature.

- Then:
  - DSR rejects signals from sources other than your transmitter.
  - DSR reconstructs damaged frames using several proprietary error correction techniques.

Servo Failsafe

In the event of signal loss or overwhelming interference, Digital Signature Recognition triggers the Flight System Receiver to take corrective action. Under these conditions, the receiver takes control of the servos, and puts the aircraft into a predictable flight pattern. Each Flight System Receiver servo channel can be set to apply one of two options when corrective action is required:

- **Last Good Frame Hold.** Recall that DSR continuously compares frames against a known standard (the transmitter's normal waveform). After confirming a good frame, and applying the transmitter's instructions to the servos, the Flight System Receiver stores the frame in memory. If DSR concludes that the next frame is defective—and cannot be repaired—it pulls the last good frame from memory and applies it to the servos in place of the defective frame. The receiver continues applying the last good frame until DSR once again detects a clean frame.

  Random glitches, which show up as servo jitter, are the most common signal problem in radio control systems. By repairing bad frames or (in the worst case) using the last good frame, DSR in a Flight System Receiver eliminates nearly all servo jitter.

- **Servo Failsafe Preset Positions.** This option goes one step farther than Last Good Frame Hold by proactively moving servos to positions set by the pilot during radio system setup. Servo Failsafe Preset Positions, for example, can cut the throttle and put the plane into a gentle circle. Any channel in a Flight System Receiver can have a Servo Failsafe Preset Position (the simple setup procedure is described below).

When Digital Signature Recognition detects bad frames continuously for about 1 second, or if it detects no signal at all, the Flight System Receiver enters Failsafe Mode. Here's what happens in Failsafe Mode:

- For channels with Servo Failsafe Preset Positions, the receiver moves those servos to the preset positions.

- For channels without Servo Failsafe Preset Positions, the receiver applies Last Good Frame Hold.

Setting servo channels for failsafe operation takes only a short time. Failsafe positions are stored in the receiver (even when it is powered off), so you only need to repeat this procedure if you want different positions.

1. Enter Receiver Setup Mode: Turn on transmitter, then press and hold receiver setup button while turning on receiver.

   The receiver's LED "twinkles" in Setup Mode. Servos set for Last Good Frame move slowly, while servos set for Failsafe move to their failsafe positions (and don't move after that).

2. Set a servo channel for failsafe operation:
   a. Move the transmitter stick to the desired failsafe position
   b. Press the receiver's setup button
   c. Return the stick to neutral (or idle) before the LED turns on.

   Repeat for other channels. Channels in a mix are set at the same time. If not set for a failsafe position, a channel automatically goes to its last good frame position in the event of a problem.

Failsafe positions can be removed by pressing and holding the receiver's button for 2 seconds. This resets all channels to last good frame operation.

Flight Stabilization

FMA's Co-Pilot technology provides flight stabilization for the Flight System family. Introduced in 2002, the Co-Pilot add-on for all receivers has earned praise throughout the RC community. Instructors and beginners, for example, find Co-Pilot to be an ideal training companion. Experienced pilots use Co-Pilot to test new airplanes, as a takeoff and landing aid in windy conditions, and as a plane-saving backup when learning new aerobatic maneuvers.

Using four infrared temperature sensors, Co-Pilot monitors an aircraft's relationship to the Earth's horizon. In the infrared spectrum, the Earth is warm below the horizon, while the sky is cold above the horizon. A simple calibration adjusts Co-Pilot to the local environment. During a flight, Co-Pilot senses changes in the aircraft's attitude relative to the infrared horizon, and sends corrective signals to the aileron and elevator servos to keep the aircraft level. If an extra control channel is available, the pilot can turn Co-Pilot on and off, and adjust its sensitivity, from the ground.

Co-Pilot is recommended for the highest level of safety and crash prevention. And it is essential for aircraft with neutral stability, that is, planes that do not return to straight and level flight when the transmitter sticks are centered.

While a Flight System Receiver can apply servo presets in failsafe situations, these are not sufficient to put an airplane in a stable attitude. Under worst case signal conditions, the combination of a Flight System Receiver and Co-Pilot goes *beyond failsafe* to fly the plane into a stable and predictable flight path—giving the pilot time to find and correct the problem, and to warn spectators. An impressive illustration of this capability is described in "Worst case tests," later in this report.

System status and performance data output

It's unfortunate that radio control systems provide very little information to users. Besides reading the transmitter battery voltage meter and observing servo response to the sticks, pilots have no insight into radio system status and performance. Often, the only indication of a problem is that the plane crashes, leaving the pilot to wonder what went wrong.

FMA recognized that radio system operational information is vital for safe, reliable flying. To that end, Flight System Receivers include extensive data reporting capabilities. The most critical data can be read directly from the receiver. That data, as well as additional information, is available through PC-based software.

Direct data output from the receiver

Each Flight System Receiver has a single LED and pushbutton mounted on its circuit board. Using these simple components, the pilot can:

- Determine whether interference is present (as described in “Interference Check,” earlier in this report).
- Measure receiver battery voltage.
- Determine whether the receiver is in Setup Mode (for setting Servo Failsafe Presets) or Normal Mode (for range checking and flying).
- Determine how many times the receiver entered Failsafe Mode since it was turned on.
- Determine how many bad frames the receiver detected since it was turned on.

In most aircraft installations, the receiver is not readily accessible or visible without removing the wing. FMA provides an extension module, with an auxiliary LED and pushbutton, for mounting on the fuselage side. This enables the pilot to interact with the receiver from outside the aircraft.

Extended data output using software

Receiver Viewer Software included with Flight System Receivers—and Co-Pilot Viewer Software included with FS8 Co-Pilot—replicates the receiver’s direct data output and provides additional, real-time insight into the receiver’s operations. Although not required for Flight System Receiver set up and use, these Windows programs are excellent companion tools for their respective receivers. They can be used in the shop for testing, as well as at the field (when installed on a laptop computer) for preflight and post-flight checks.

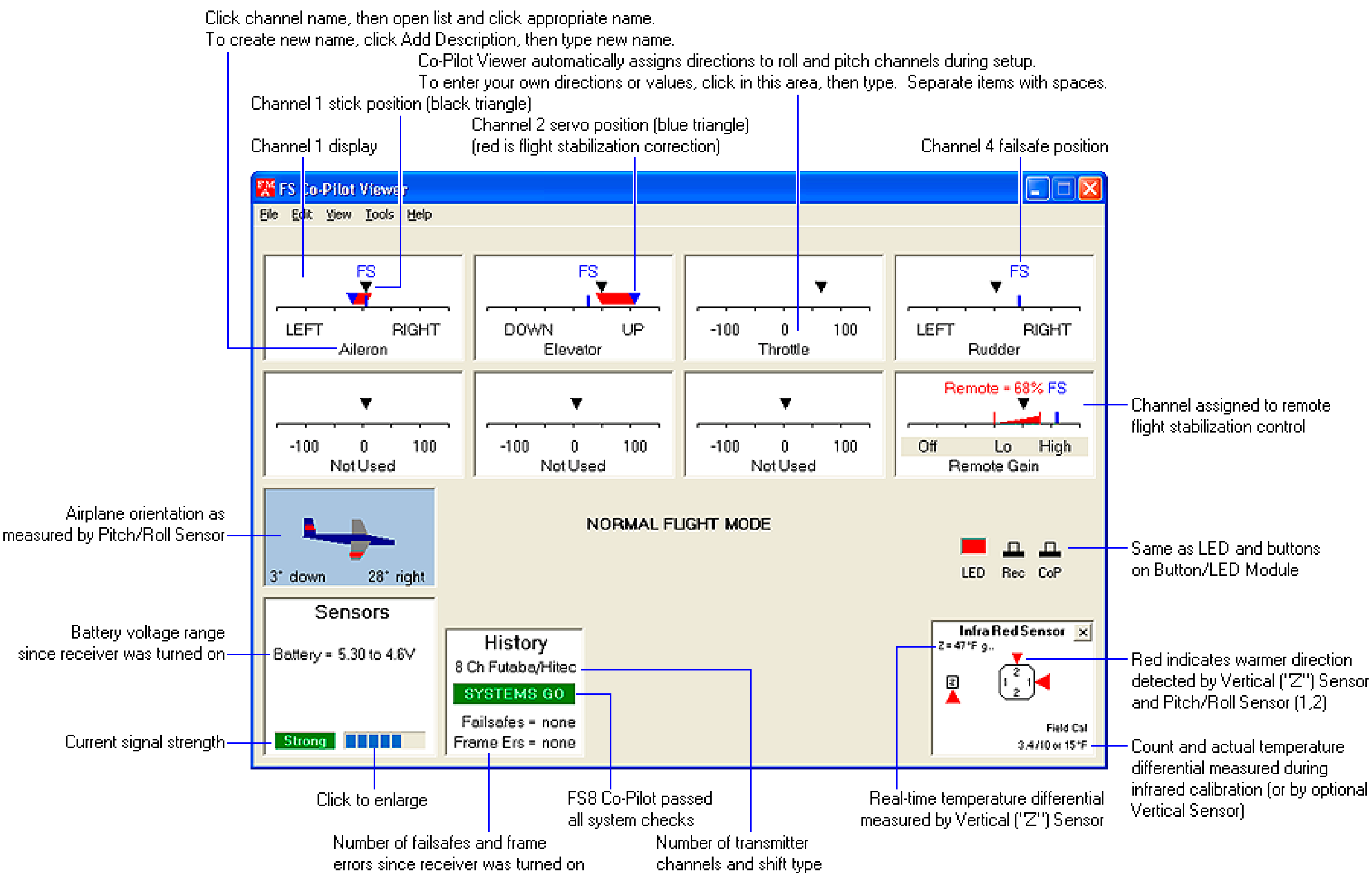
Besides a Windows PC and the Software, an FMA Serial Interface Module is all that is needed to view receiver data. The Serial Interface Module attaches to the receiver and plugs into the PC’s serial port.

As shown in the example screen on the next page, Co-Pilot Viewer Software displays a wide range of information:

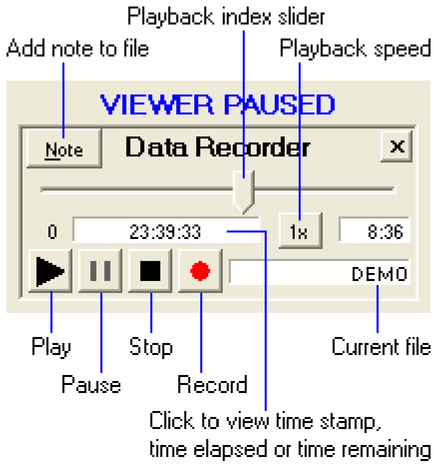
- Receiver mode.
- Number of transmitter channels and shift type.
- Stick positions for all channels.
- Servo positions for all channels, and amount of flight stabilization applied.
- Servo Failsafe Preset Positions.

- Transmitter signal strength (as measured at the most relevant place—the receiver).
- Instantaneous receiver battery voltage.
- Minimum receiver battery voltage since the receiver was turned on.
- Number of failsafes since the receiver was turned on.
- Number of bad frames since the receiver was turned on.
- Other receiver data.

Here's an example of data display in the Co-Pilot Viewer:

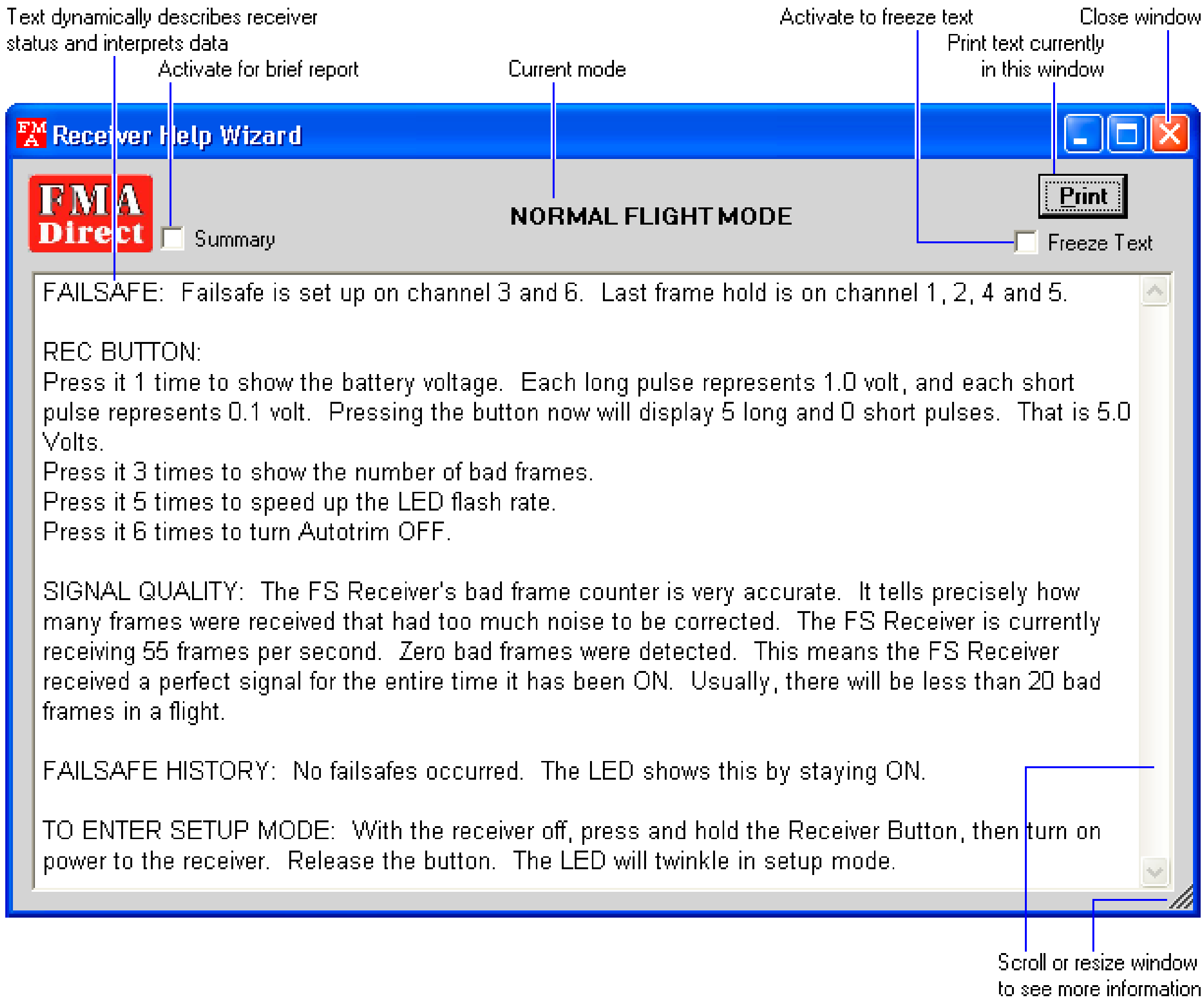


The Co-Pilot Viewer Software and Receiver Viewer Software can also record everything displayed on-screen, then play back the data for detailed analysis. Record and playback controls are shown below.



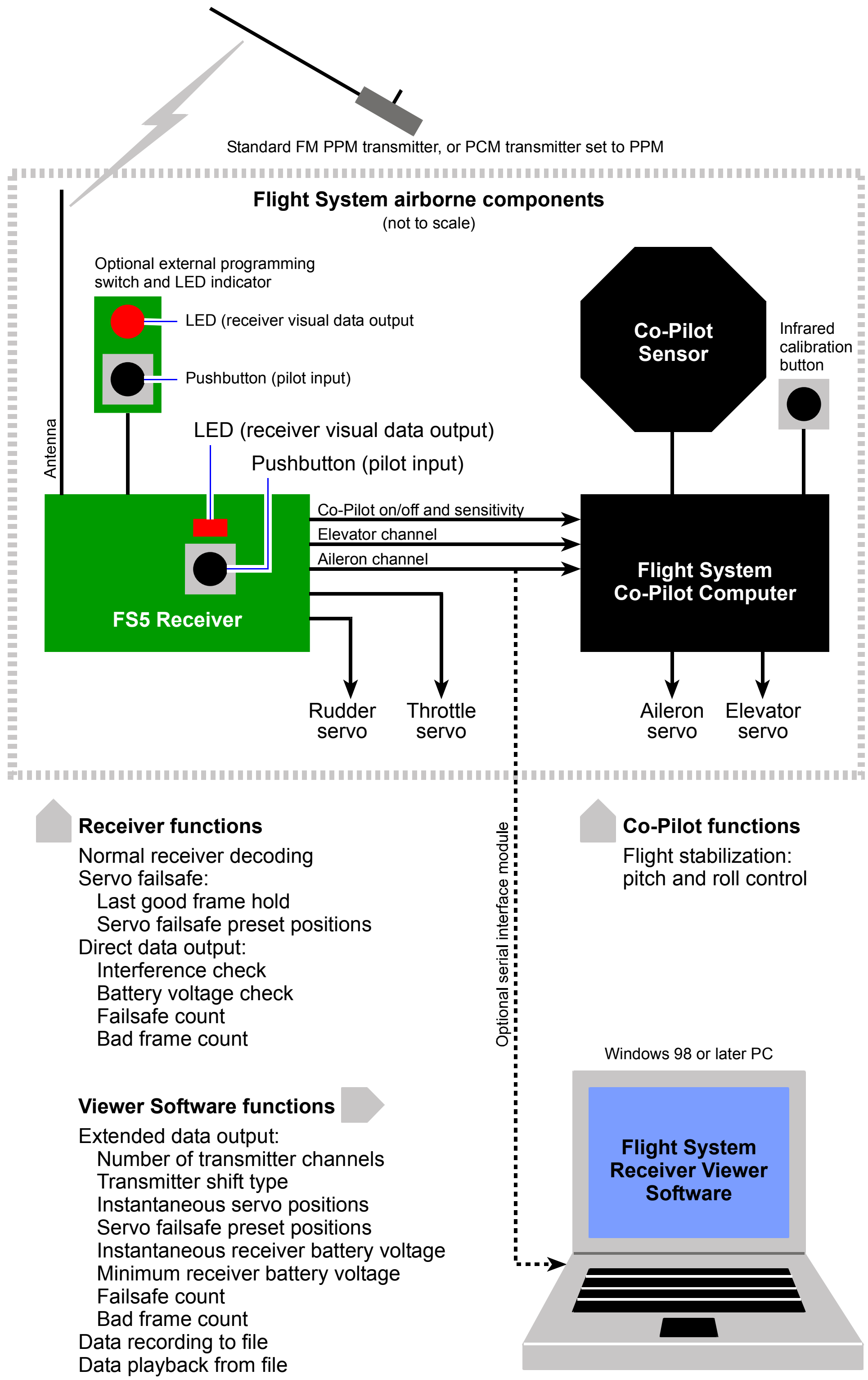
A prerecorded demonstration is provided with the software. This file was recorded by the Software while a Flight System Receiver was set up and tested using a standard FM PPM transmitter. During playback, the demo provides running commentary on what the technician was doing and how the receiver responded. The demo file introduces Software functions, as well as basic receiver functions.

A unique Help Wizard describes (in plain English) exactly what the receiver is doing, interprets receiver data and provides instructions. Here's an example of Help Wizard commentary:

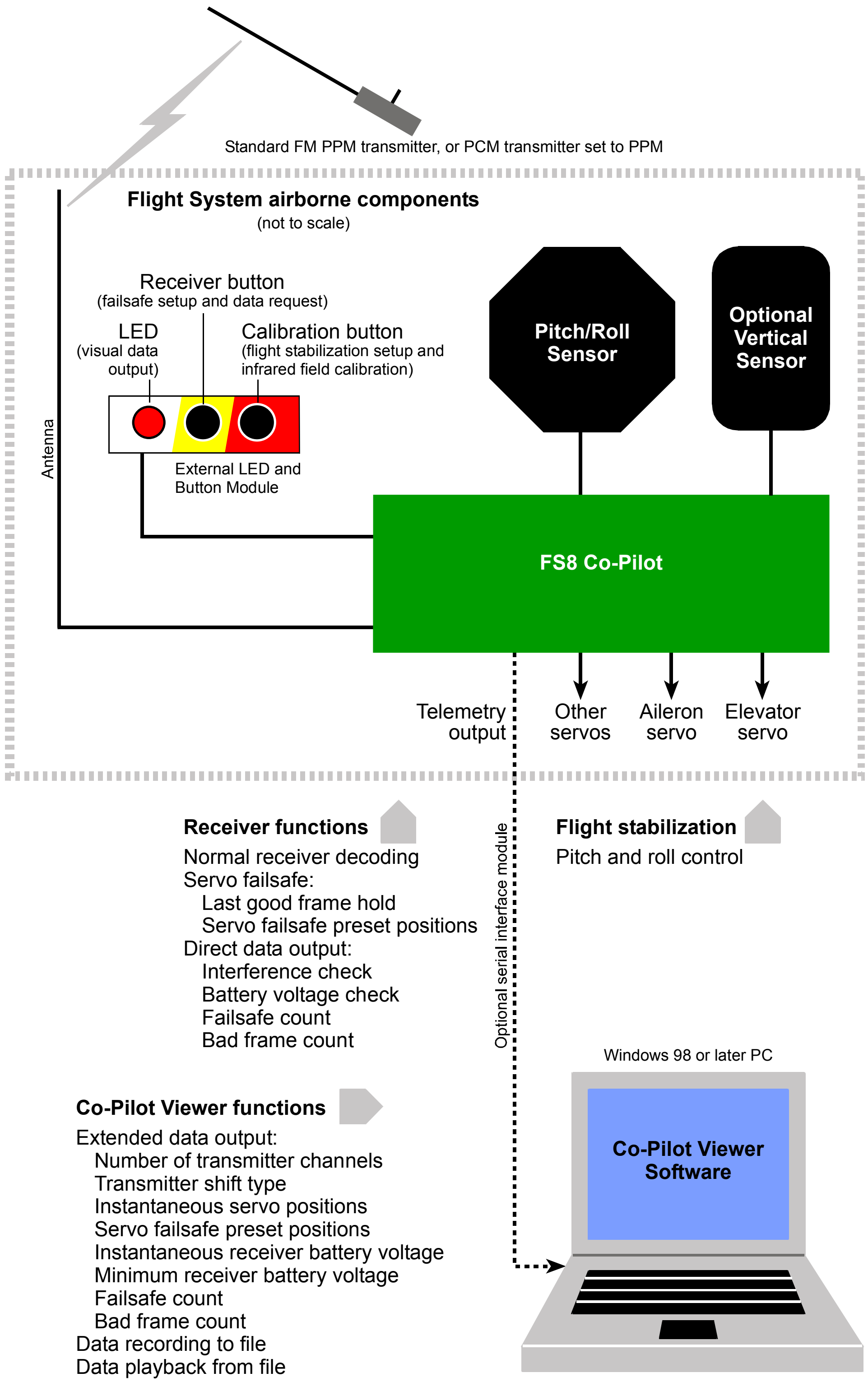


System configuration

The diagram below shows how the FS5 Receiver and FS Co-Pilot are connected in a typical installation.



The next diagram shows a typical FS8 Co-Pilot installation:



Helicopter applications

While this report has focused on Flight System use in airplanes, the components work equally well in RC helicopters. Interference check, Digital Signature Recognition, servo failsafe, flight stabilization and radio system data readout are all available in helicopter installations and provide benefits corresponding to fixed wing applications. Flight System components are compatible with helicopter configurations of FM PPM transmitters.

Flight System products

Core components

Product	Description	Availability
FS5 Receiver	5 channels, FM, PPM Failsafe operation 72 MHz (for aircraft use) Universal shift, dual conversion 1.67" x 0.80" x 0.58", 0.4 oz. Works with digital and standard servos Uses FMA Fortress or Quantum series crystals	Available now
FS8 Co-Pilot	8 channels, FM, PPM Failsafe operation plus flight stabilization 72 MHz (for aircraft use) Universal shift, dual conversion Size and weight to be determined Works with digital and standard servos Uses FMA Fortress or Quantum series crystals	Available now
Co-Pilot	Flight stabilization for any receiver 4 infrared sensors Surface inputs: roll and pitch Control input: remote on/off or sensitivity adjust Surface outputs: roll (or yaw) and pitch Switchable elevon mixer and servo reversing Sensor: 1.35" x 1.35" x 0.53" Computer: 1.5" x 0.89" x 0.60" 1.00 oz. (combined weight) 5 mA power consumption	Available now

Software

Included with receivers, but also available separately.

Product	Description	Availability
Receiver Viewer Software	Provided on CD-ROM with FS5 Receiver Runs on Windows 98 or later PC	Available now
Co-Pilot Viewer Software	Provided on CD-ROM with FS8 Co-Pilot Runs on Windows 98 or later PC	Available now

Options and accessories

Product	Description	Availability
External Programming Switch and LED Indicator	For FS5 Receiver Interact with receiver from outside fuselage Pushbutton switch High intensity red LED 0.84" x 0.34" x 0.88" Cable plugs into Flight System Receiver	Available now
Optional Vertical Sensor	For FS8 Co-Pilot Simplifies infrared calibration for large aircraft Enables stabilization to roll aircraft from inverted 1.2" x 0.81" x 0.42"	Available now
Optional Heli LED/Button Module	Low profile replacement for stock FS8 Co-Pilot LED/Button Module	Available now
Serial Interface Module	Connects Flight System Receiver to PC 1.24" x 1.22" x 0.60" Standard 9-pin serial connector for PC Standard universal connector for receiver	Available now

FMA offers Flight System products individually, and in combination packages.

Worst case tests

The following tests were carried out by FMA personnel and replicated by independent pilots. They confirm the ability of Flight System components to prevent crashes under the most extreme conditions.

> **CAUTION:** These tests were carried out at closed and carefully supervised flying fields. **Do not try these tests yourself.** FMA strongly advises against flying two or more RC aircraft on the same frequency at the same time. FMA also strongly advises against turning off a transmitter when it is controlling an aircraft in flight. FMA does not accept responsibility for such actions.

Signature discrimination test

An airplane was equipped with a Flight System Receiver. Using Transmitter A, the airplane was flown to the highest altitude at which it could still be clearly seen.

1. Transmitter B, on the same frequency and with its antenna collapsed to half its normal length, was turned on. The receiver ignored Transmitter B and responded only to Transmitter A.

2. Transmitter B's antenna was fully extended. The receiver continued to respond only to Transmitter A.

3. The airplane was flown through a series of common maneuvers with both transmitters operating. As expected, some bad frames occurred during the flight (as revealed by post-flight analysis using the Receiver Viewer Software), but control of the airplane was not degraded.

Complete loss of signal test

An airplane having neutral aerodynamics was equipped with a Flight System Receiver and Co-Pilot. Servo Failsafe Preset Positions were established as follows:

- Ailerons: neutral.
- Elevator: slight up.
- Throttle: about 1/4.
- Rudder: moderate right turn.

1. The airplane was flown to a safe height and put into inverted attitude at full throttle.

2. The transmitter was turned off.

3. In less than one second, Co-Pilot returned the airplane to normal attitude, while the Flight System Receiver reduced engine speed and put the plane into a right turn.

4. The airplane circled and descended slowly for several minutes.

5. Before the plane reached the ground the transmitter was turned on and the pilot again took control of the airplane. (Unless the airplane had encountered tree or other obstacles, a landing under these conditions should incur minimal damage to the model or property.)

If this were an actual loss-of-control incident, the pilot would have time to:

- Make certain the transmitter is still on and check its battery voltage.
- Find out whether someone else is transmitting on the same frequency, or locate other sources of interference.
- Take any corrective action.
- Warn spectators.

And all this can be done without the distraction of watching the plane crash.

Conclusions

FMA, Inc. has introduced a system of integrated components that sets a new standard for radio control safety and reliability. Development began with a set of design goals addressing various shortcomings in existing PPM and PCM radio systems. The resulting Flight System product line—built around Flight System Receivers and Co-Pilot Flight Stabilization—offers innovative features not available in any other RC radio system.

Flight System functions are actively involved in aircraft protections throughout the entire flight cycle, from preflight checking to post-flight review. Most importantly, when an aircraft is flying, the Flight System maintains control even under worst case conditions.

Appendix A: Test flying an FMA Flight System

Now that you are familiar with Flight System concepts, it's time to see how easy it is to set up and use this groundbreaking radio control system.

Set up your airplane with the following radio components:

- Your PPM transmitter.
- FS5 Receiver and FMA crystal to match your transmitter's frequency.
- Flight System Co-Pilot.
- Your servos, battery and switch harness.

After assuring everything works correctly, perform some one-time setups:

1. Set the Servo Failsafe Preset Positions for critical controls. For example:
   - Ailerons: neutral.
   - Elevator: slight up.
   - Throttle: about 1/4.
   - Rudder: moderate right turn.
   - Co-Pilot: on.
2. Configure Co-Pilot according to instructions in the Co-Pilot user guide.

Before the flight

At the field, perform preflight checks:

1. With your transmitter off, turn on the Flight System Receiver to determine whether interference is present (the receiver detects both on-channel and off-channel interference). If there is no interference, proceed.
2. Turn on your transmitter. The receiver measures and stores your transmitter's unique signature.
3. While moving the transmitter sticks (which applies a load to the receiver battery), press the receiver's button one time, then read the battery voltage on the LED (1 long blink = 1 volt, 1 short blink = 0.1 volt).
4. Test failsafe operation: turn off the transmitter. Servos with failsafe presets should move to those positions. Other servos should hold steady.
5. Perform a range check as described in the Receiver user guide, but keep your transmitter on. When you return to the plane, observe the receiver's LED:
   - If the LED is blinking, the receiver entered Failsafe Mode during the test. This is a critical situation—find and correct the problem before proceeding.
   - Press the receiver's button three times, and read (on the LED) the number of bad frames that occurred during the test (1 long blink = 10 bad frames, 1 short blink = 1 bad frame). A few bad frames is common.
6. Calibrate Co-Pilot for current conditions (usually, you only need to do this once per flying session).

7. Carry out your other routine preflight checks.

Notice that you have verified radio system operation more thoroughly than you could with a frequency scanner, signal strength meter and extended scale voltmeter. Comprehensive preflight checking like this isn't available on any other radio system.

During the flight

Now you're ready to fly. While the plane is airborne, here's what the Flight System does:

- Eliminates random glitches. You won't even know they happen.
- Ignores signals on your channel, as well as any other interference.
- Takes over if there is loss of signal or extreme interference
  - The receiver moves servos to their failsafe presets (or to their last good frame positions).
  - Co-Pilot puts the plane in a stable attitude.

  This gives you time to find and (if possible) eliminate the problem, and to warn spectators. Worst case, your airplane descends slowly instead of drilling into the ground or flying away.
- Takes over in the event of pilot error. Just let go of the sticks, and Co-Pilot puts the plane in a stable attitude.

No other radio, even the most expensive PCM "failsafe" model, provides this level of safety and protection against crashes.

After the flight

Once the plane is back in the pits, keep the transmitter on so you can find out how the radio system performed:

1. The LED blinks the number of times the Flight System Receiver went into Failsafe Mode. If it's not blinking, the system performed perfectly.
2. Press the receiver button three times, then read the number of bad frames received during the flight. (A dozen or two bad frames is normal, and indicates the radio system is performing very well. It takes at least 50 *consecutive* bad frames to cause a failsafe condition.)
3. While moving the transmitter sticks, press the receiver button once to read post-flight battery voltage.
4. Finally, turn off the receiver to reset the failsafe and bad frame counts for the next flight.

Tip: If a crystal is available, you can use a Flight System Receiver to check for interference on any channel. Other pilots will appreciate this courtesy. Install a crystal for the suspect channel, then fly the aircraft to altitude (where interference is more likely than on the ground). After landing, check the Receiver's bad frame and failsafe counts to determine the extent of interference.

Appendix B: PPM versus PCM

In Pulse Position Modulation (PPM), each servo position is encoded by a specific pulse width. Pulse width for one channel ranges from 1 to 2 milliseconds. A 6 channel transmitter will generate 7 pulses in the output signal. The receiver knows what pulse is servo 1 because it follows a long sync pulse that lasts about 5 milliseconds.

A glitch occurs when a stray pulse is introduced to the signal. Suppose a stray 0.1 millisecond pulse occurs in the channel 4 pulse. Servos 1-3 would be positioned correctly, while servo 4 would move to an incorrect position. The glitch gets worse when the receiver shifts channels 4, 5 and 6 down one position because of an extra pulse. The position of channel 5 is now given to servo 6, while servo 6 goes to the empty slot for servo 7. After a single glitch, correct servo positions are restored in the next frame. The 1/50th second wait for the next frame causes little movement of a servo. Since glitches are random, the odds are greater for glitches on the servos connected to higher channel numbers. That is why important control surfaces are on channels 1 and 2.

Standard PPM receivers have some tolerance for noise. Most of the time, only half the servos receive a big glitch. Smaller glitches will not shift the servos at all. When just one servo shakes a little, a small glitch delayed the pulse on its channel.

In Pulse Code Modulation (PCM), transmitter control positions are converted to 10-bit binary numbers before transmission. Each channel requires 10 pulses to represent the numeric position. A glitch in this data stream could dramatically change the positions of all servos on channels following the glitch. However, to keep the numbers readable by the receiver, the transmitter calculates and sends a cyclic redundancy check (CRC) number. The CRC number is recalculated in the receiver to determine whether the binary string was received correctly. If one or more bits are corrupted, the entire frame is thrown out. This is known as error detection. The PCM receiver then waits for the next clean frame before updating the servos. In a PCM radio system, moderate noise can corrupt several frames in a row.

Individual pulses are much shorter in PCM because there are so many of them. The higher number of pulses per frame slows down the frame rate. A 6 channel PCM frame will have at least 72 pulses in a frame. One delayed or changed pulse among the 72 will corrupt the entire frame. This is why PCM receivers can lose control and go into failsafe mode. To make things better, some PCM transmitters break up a 6 channel frame into two frames of 3 channels each. This way, only half the channels will be affected by a discarded frame.

When it comes to glitches, PCM receivers are better then PPM receivers because they catch all glitches. The CRC will never let a glitch through to the servos. On the down side, a PCM receiver will discard an entire 5-channel frame if it finds 1 bad bit among the 50 data bits. In comparison, if a standard PPM receiver encounters 1 bad pulse in 50, it still has four good 5-channel frames to work with.

In brief, Flight System Receivers combine the advantages PCM (error detection and high noise tolerance) and the advantages of PPM (faster and more tolerant of glitches) to create a higher level in receiver performance. They also incorporate many new features, as described in the body of this paper.