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Enhanced capabilities for localization of interference sources

Frank Musmann
Dipl. Ing.

Project Manager and System Engineer
Aerodata AG
Hermann-Blenk-Straße 34-36
D-38108 Braunschweig, Germany
internet: http://www.aerodata.de
E-mail: musmann@aerodata.de

ABSTRACT
Signal interference or jamming of radio navigation frequencies, can reduce dramatically the performance of today's and tomorrow's navigation systems.
During flight inspection more and more often signal interference is identified as the cause for bad performance of a navigation aid. By adding direction finding equipment to a flight inspection system the task of detection and localization of interference sources can be started immediately after identification of its existence. The function for control of the direction finding equipment and the evaluation of the ascertained data can be integrated into the flight inspection system software. Graphical representation of cross bearings on moving map and automatic evaluation of coordinates make the localization of interference source a task that can easily be carried out by the flight inspection crew.

PURPOSE
This paper describes how automatic functions simplify the use of direction finding and spectrum analyzing equipment integrated in a modern automatic flight inspection system. These functions support automatic flying of interference search patterns and localization of signal interference sources. The system can further be used for localization of emergency locator transmitters for search and rescue purpose.

BACKGROUND
The purpose of flight inspection is to ensure sufficient coverage and accuracy of radio and satellite navigation aids. The common principle of all modern navigation aids is transmission on radio frequencies, where Radio Frequency Interference (RFI), unintentional or intentional, is always a concern. Vulnerable satellite navigation systems are facing a permanent increasing number of potential interference sources on ground. RFI is identified more and more often as reason for poor performance of navigation aids.
Normally, if RFI is identified during flight inspection, the task of the flight inspection crew ends. The flight inspection aircrafts returns to it's home base and another special equipped aircraft and special educated crew is brought in place for the complex task of locating the RFI source. The costly ferry flight time of these maneuvers can be saved by enabling the flight inspection crew to perform multi role tasks.
Locating interference sources can be performed by the same flight inspection crew if the flight inspection system provides special capabilities that simplify this complex task.
Today's modern automatic flight inspection systems (AFIS) come with 3-dimensonal position reference, ergonomic graphical user interface and full integration into the aircraft's EFIS, autopilot and intercom system. Such a system only needs a few enhancements to allow the normal flight inspection crew to execute interference localization.

SUBJECT
Special mission aircraft for interference localization typically have the following key components onboard:

a) Set of measurement antennas: e.g. direction finder antenna arrays and coupler
b) Audio Demodulator: for presenting interference signals on audio, typically included in Spectrum Analyzer
c) Audio Recorder
d) Spectrum Analyzer
e) Oscilloscope
f) Direction Finder (VHF, UHF; L-Band): for relative bearing to signal source
g) Recording System: e.g. Chart writer/Printer or digital recording of single spectrum analyzer or oscilloscope graphs.
h) Position Reference: normally GPS (useless if GPS signal is effected)
i) Special skilled flight crew: the flight crew is trained to fly special search patterns.
j) Special skilled system operator: the system operator controls all the equipment. He fuses together the various information e.g. by drawing direction finder bearings on a map.

Controlling all the different sensors causes a solid workload for the operator during interference searches.
A modern automatic flight inspection system (AFIS) comprises almost all of the above listed items. High Accurate Position Reference System, Spectrum Analyzer, Oscilloscope, Recording Media and Color Printer are standard equipment of flight inspection system. Further the flight crew and the flight inspector are well trained to perform special flight procedures. The missing items are the direction finding antenna arrays, coupler and the direction finder itself. The addition of a dedicated Search and Rescue direction finder allows further the flight inspection aircraft to monitor permanently emergency frequencies and contribute in SAR missions.
So why not include this missing direction finding equipment to a flight inspection system to include full interference localization capability to the flight inspection aircraft.
One remaining concern might be the skill of the flight inspector and the flight crew: would they be overcharged by the additional task of controlling all the equipment and evaluation of the obtained date for interference localization?
The answer to this question regarding the flight inspector can be: No, if the system provides a high level of automation for control of the equipment and visualization of automatic evaluated data.
But what about the flight crew: Do the pilots feel overloaded by flying the interference search patterns?
The answer to this question is: No, if the system is fully integrated into the aircrafts navigation and autopilot system and if the pilots are provided with detailed situational awareness information about the search patters to be flown.
Within the following an automatic flight inspection system (AFIS) with enhanced automatic functions for interference localization and integration into the aircrafts navigation autopilot system is described.

Figure 1: Enhanced AFIS

General Functions
A general function of an AFIS is centralized and automatic control of various sensors via one easy to use Graphical User Interface (GUI).

Figure 2: Flight Inspection System GUI

Another key function is the highly accurate reference position determination and digital recording of sensor data. Some AFIS provide Hybrid Reference Positioning which fuses the data of a variety of sensors with different measurement principles. Typical sensors of such a hybrid position reference are: PDGPS, INS, Barometric Pressure, Multi DME or Camera Update. Such hybrid position reference system work independent from GPS which is important for localization of GPS jammers.
The hybrid reference position is permanently recorded together with the data of all involved sensors to allow replay analysis with geo-reference.

Spectrum Analyzer / Oscilloscope
A digital Frequency Spectrum Analyzer (FSA) as well as a digital Oscilloscope (OSC) are standard equipment of modern AFIS.

Figure 3: Console with FSA and Oscilloscope

Both the FSA and the OSC are automatic fully remote controlled during normal flight inspection operation and perform automatic measurement programs according to the navigation aids under inspection. The FSA is automatically connected to the best suitable antenna for the measurement. An integrated compact antenna switch unit controlled by the AFIS performs this task fully automatically.: e.g. for detecting GPS interference from ground a downward facing GPS antenna installed under the fuselage is connected to the FSA. By this interference is detected immediately during the flight inspection task.

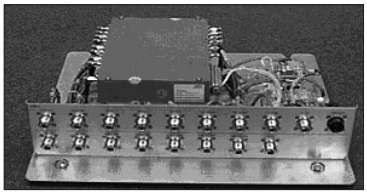

Figure 4: Integrated Antenna Switching Unit

The data of each measurement graph, without any action of the flight inspector is recorded in a common recording file together with the normal flight inspection data of the AFIS. This allows further to evaluate all FSA and OSC graphics during a time synchronized replay of recorded AFIS data. If interference is suspected by just clicking a button the video signals of the FSA or OSC are routed to one of the two flight inspection displays in front of the flight inspector. This allows real time monitoring of FSA and OSC graphs while sitting in normal working position without inconvenient contortions.
The carrier frequency of the interference can easily be detected using the marker functions of the FSA.

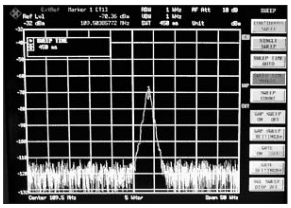

Figure 5: FSA Carrier Frequency Measurement

The frequency determined by the FSA marker (either by automatic function or manually) can directly be commanded to be used by the Direction Finder via the GUI of the AFIS.
The AM/FM demodulator of the FSA allows further to listen to the modulation of the interference source via the AFIS Audio System.
The visualization of the modulation on FSA and OSC allows easy identification of the source by the signal's "footprint".
Via the Audio Control Panel of the AFIS the flight inspector can select among a variety of audio sources: audio signals of flight inspection receivers like NAV, DME, VHF/UHF-COM as well as the audio output of the FSA AM/FM demodulator:

Figure 6: Audio Control Panel

Whatever the flight inspector has selected on the Audio Control Panel is digitally recorded in the common flight inspection recording file and can be further analyzed by replay.
By just listening to the AM/FM demodulator quite often the interference source can be identified e.g. as a local radio station or can at least be identified to be voice, data or just noise.

Direction Finding Equipment
For interference localization a remote controlled direction finder (DF) is integrated to the flight inspection equipment. The DF is tuned by the AFIS according to the interference frequency as determined with the marker function of the FSA.

Figure 7: Remote Controlled Direction Finder

The DF is connected to antenna arrays for operation in different frequency bands: VHF, UHF and L-Band.

Figure 8: DF VHF/UHF Antenna Array

The antenna array with integrated antenna couplers is mounted under the fuselage to provide best reception to signals from ground.
A Direction Finder Control window in the AFIS GUI provides further remote control functions for DF.

Figure 9: DF Control Window

The DF outputs are relative or absolute bearings to the signal source with an accuracy of up to 0,5° RMS.
The bearing provided by the DF together with the data of the hybrid reference position is used by AFIS to compute the location of the signal source. At least two bearings from different aircraft positions allow the AFIS to determine the signal source's position in WGS84 coordinates. The more bearings from different positions are used for this computation the more precise the signal source can be located by the AFIS.
The determined cross bearings are visualized on the AFIS screens as well as in the cockpit by a new developed Special Mission Moving Map. Visualization of the special mission moving map in the cockpit is provided via a new developed Cockpit Information Display.
Depending on the estimated position of the signal source optimized and continuously improved search flight patterns are created by the AFIS. They are displayed on the AFIS screens, and on the aircraft's EFIS as flight plan to guide the pilots. This synthetic created flight plan is also displayed on the Cockpit Information Display by the Special Mission Moving Map software. The autopilot of the aircraft can be coupled to these AFIS generated flight guidance signal to steer the aircraft along these special mission flight profiles fully automatically.

Special Mission Moving Map

A Special Mission Moving Map "AeroMap" supports situational awareness. The moving map software allows to display various symbols as overlay to any kind of digital map with geo-reference. Different scales are also supported as heading up and north up mode.
Typical maps are e.g.: aeronautical map, topographical map or nautical map depending on the operational area. The map can be changed during operation by just a press of a button.

Figure 10: Moving Map with Map and Overlays

For focusing on the information provided by overlays only, the map in the background can be switched off.

Figure 11: Moving Map with Overlays only

Typical symbols are displayed for the following layer:
- Aircraft symbol, with position and heading
- Aircraft track line
- AFIS generated flight plan with waypoints for optimized search patterns
- AFIS triggered DF - Cross Bearings
- Calculated position of signal source

Other layers are available for:
- ADS-B or TCAS detected targets
- Radar detected targets
- Search and Rescue (SAR) direction finder cross bearings

This Special Mission Moving Map software is displayed on the AFIS screens as well as on the Cockpit Information Display.

Cockpit Information Display

For visualization of an AFIS generated map with overlays during normal flight inspection and interference search a Cockpit Information Display has been developed.

Figure 12: Cockpit Information Display

The Cockpit Information Display provides individual control buttons for the pilots to adjust the map regarding Zoom, Heading/North up mode and switching on/off layers.

Note:
The Cockpit Information Display is not for primary Navigation. Mission Safety must be maintained by other means of navigation.

This display obtains mission data from the AFIS via Ethernet/LAN. It is fully qualified for installation in cockpit instrument panel. The Cockpit Information Display is installed at a position being in view and reach of both pilots. The following picture shows a typical installation in a Beech King Air B300 with Collins Pro Line 21 avionic

Figure 13: Beech B300 Pro Line 21 Installation

EFIS/Autopilot Integration

For supporting the pilots during normal flight inspection but also during interference localization flights the AFIS provides flight guidance on the aircraft's Electronic Flight Instrument System (EFIS).

Figure 14: AFIS guidance on cockpit EFIS

Figure 15: AFIS controlled EFIS indicators

The AFIS can be selected by the pilots as additional navigation source. The guidance provided by the AFIS controls the following indicator of the EFIS:
- Desired Track Pointer
- Course Deviation Indication
- Vertical Deviation Indication
- Ground Speed
- Distance to Go
- AFIS generated flight plan

The autopilot of the special mission aircraft can also be coupled to the AFIS generated flight guidance for automatic flying of interference search patterns.

CONCLUSIONS

If the AFIS provides features and a high level of automation for the task of localization of radio frequency interference sources, it can easily be carried out by the flight inspection aircraft and a trained crew.

The described features make the flight inspection aircraft and its crew multi role on flight inspection missions as well as for interference investigation and Search and Rescue (SAR) purpose.
The flight inspection aircraft with it's AFIS for this purpose should provide the following features:
- Common User interface for control of the involved measurement equipment, like Frequency Spectrum Analyzer, Oscilloscope, Direction Finder
- Time synchronized recording of FSA and OSC graphs together with DF data and other flight inspection sensor data
- Analysis and recording of audio signals
- Automatic Antenna Switching for Spectrum Analyzer
- Automatic DF control according to FSA determined interference carrier frequency
- Automatic AFIS computation of interference location by cross bearing
- Comfortable visualization of DF- Cross Bearings on moving map on AFIS screen and in cockpit
- Automatic generation of flight plan according to search pattern
- Visualization of AFIS flight plan in the cockpit
- Providing AFIS flight guidance on EFIS
- Support of automatic flying of AFIS generated interference search patterns.

REFERENCE

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