Microcomputer supported microwave transmitter and pseudo-monopulse receiver of GCS for UAV complex

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Abstract - **Paper presents microwave transmitter and pseudo-monopulse receiver supported by microprocessor developed and realized at Institute IMTEL as a part of telecommand-telemetry link for unmanned aerial vehicle (UAV) communication with ground control station (GCS). The role of described receiver is not only to receive signal from UAV's transmitter properly, but together with other parts of GCS and UAV telecommunication system to measure UAV-GCS distance and angular azimuthal error between boresight axe of GCS antenna system and actual position of UAV, thus forming autonomous measuring system of UAV position.**

Keywords - **microwave pseudo-monopulse receiver, microcomputer, unmanned aerial vehicle (UAV), autonomous position measuring system, intelligent interface**

I. INTRODUCTION

Global positioning systems that cover complete Earth exist nowadays and are commercially available to practically every potential user. However, in some cases still exists need for autonomous position measuring system for unmanned aerial vehicles (UAV) [1],[2]. This kind of position measuring system determines position in space of UAV only by use of parts of UAV system itself and not supported by anything out of it. Global systems are satellite based: GPS (USA), GLONASS (Russia), Galileo (European Union – under construction) or ground fixed reference stations based like: LORAN, Omega. Nowadays, a big number of UAV systems use GPS data for position determining and navigation because of low cost, small dimensions and weight and power supply of commercially available GPS receivers.

Still, some of UAV systems use autonomous position measuring system as an alternative way, or even as a main position determining system. Usually autonomous UAV position measuring system is referred to control station – whether it is at the ground, sea or in the air.

In the realized autonomous UAV position measuring system that is described in this paper polar coordinate system tied to ground control station (GCS) antenna system center as a reference point is used. It is field proven by test flights in the beginning with airborne communication part mounted on the top of automobile, then on the test helicopter and after proper functioning is approved airborne part is mounted in UAV and test flights are continued.

Autonomous UAV position determining system measures distance between GCS and UAV (so called slant distance-radius) applying the principle of secondary radar [3], while angular position in azimuth plane by use of monopulse receiver principle [4]. Radius is indirectly obtained by measurement of propagation time of emitted signals from GCS to UAV and vice versa. At the same time angular position of UAV is obtained by measuring azimuth error between GCS antenna system boresight axe and GCS-UAV direction of equal intensity signals. Angular position of UAV in elevation plane is obtained by finding ratio between UAV height above ground level and GCS-UAV radius length (sinus of elevation angle). UAV's height is obtained by barometric static air pressure measurement (absolute height above sea level). By these three parameters (radius, azimuth angle, elevation angle) UAV's position in space related to GCS as a center of spherical coordinate system is completely defined, and by referring to the geographical position of GCS consequently UAV's geographical position is also defined.

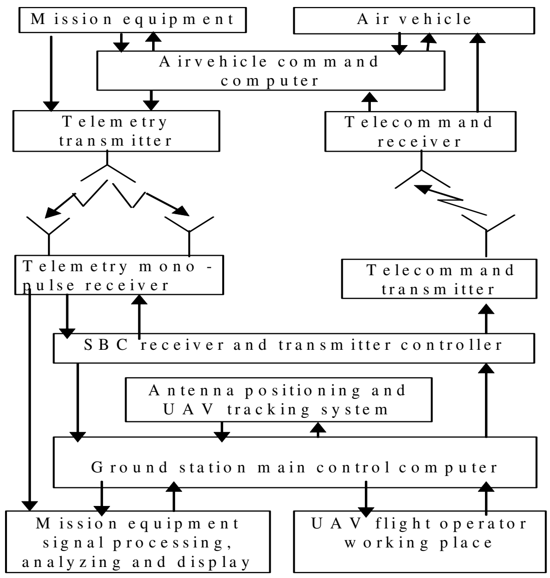

Fig. 1. Block diagram of UAV complex – airborne and ground part

The main reason for use of autonomous position (especially angular) measuring system in UAV systems is because of directional antenna system use for telemetry-telecommand links in GCS part of system. Use of directional antennas makes opportunity to obtain longer communication ranges keeping transmitted power the same. Due to unknown relative position (orientation) of UAV during flight omnidirectional antennas at UAV are preferred, though there are cases when

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both at the UAV and GCS directional antennas are used. It is common practice when very long transmitting ranges are requested because energy supply at the UAV is extremely restricted, having direct influence to ability of obtaining as long mission duration as possible. This implies basic conclusion that fundamental fulfilled condition for acceptable quality of UAV-GCS communication is that UAV during the mission have to be in the main lobe of GCS directional antenna system. Hence the importance of monopulse receiver role for the whole UAV's mission success is clear. In cases when monopulse receiver principle is not applied in two orthogonal planes as usual, but in one plane only (in this case azimuth), some authors use term pseudo-monopulse receiver.

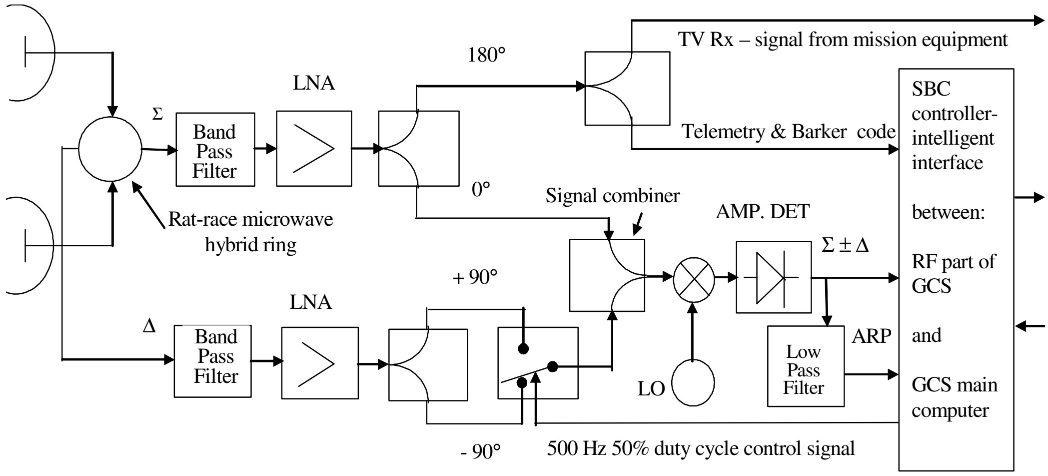

Fig. 2. Realized monopulse receiver without reference chanel

II. Realized UAV Complex

Block diagram of realized UAV complex consists of one GCS and one UAV (figure 1). Air vehicle is airplane of classical configuration, wingspan of 4 meters, tricycle lending gear, requesting smooth terrain for take-off and landing. Cruising speed of UAV is about 100 km/h, maximal speed about 125 km/h and endurance is more than 1,5 hour. Propulsion is by two-stroke one cylinder petrol engine.

As electronic equipment at the UAV there are: telecommand receiver and actuators, air computer, mission equipment – day light TV camera and low light level camera, telemetry transmitter, antennas and set of sensors for flight and air frame status data. Signals from Pitot tube for air-speed measurement, barometer for height measurement, termopairs for motor cylinder head and exaust gases temperature measurement, air temperature, temperature in electronic compartment, fuel quantity, revolutions per minute of propeller and accumulator voltage are collected and inserted in telemetry message that UAV transmits towards GCS receiver together with mission equipment signal.

GCS is modular, easy to transport and use, consisting of modified radio-control for RC planes, telecommand transmitter, telemetry and mission equipment signal receiver, GCS main computer for virtual cockpit and digital terrain map display and monitor for mission equipment signal display (TV picture). Also received signal archiving device and antenna systems (transmitting and receiving) positioning, as well as power supply equipment are parts of GCS.

III. GCS-UAV Communication System

Block diagram of GCS-UAV communication system is depicted at figure 2. It is important to stress mutual coupling of functions between various systems in GCS-UAV complex to proper functioning of the complex as a whole.

Communication part at GCS consists of transmitter, transmitting antenna system, receiver antenna system and receiver. Transmitting and receiving antenna systems are mounted on common antenna positioning system, having possibility of azimuth and elevation axial rotation. Transmitter, receiver and antenna position controller are interfaced to main GCS computer, that also supports man-machine communication with UAV's operator in GCS. The main part of this interface is single board computer system that will be presented in this paper, and it is part of communication system of GCS.

Communication system part at the UAV consists of telecommand receiving antenna, telecommand receiver, telemetry and mission signal equipment transmitter and transmitting antenna.

IV. Single Board Computer Functions

The role of this SBC is to properly interface digital command data obtained from main GCS computer to GCS telecommand link transmitter concerning data level, timing etc, to properly interface telemetry data obtained from GCS receiver to GCS main computer and to fulfill all measurement procedures necessary for obtaining data about UAV's position: distance between GCS and UAV [5], azimuth error between GCS receiving antenna boresight axe and direction of arrival of receiving telemetry signal from UAV [6] and other receiving signal parameters if possible (signal intensity).

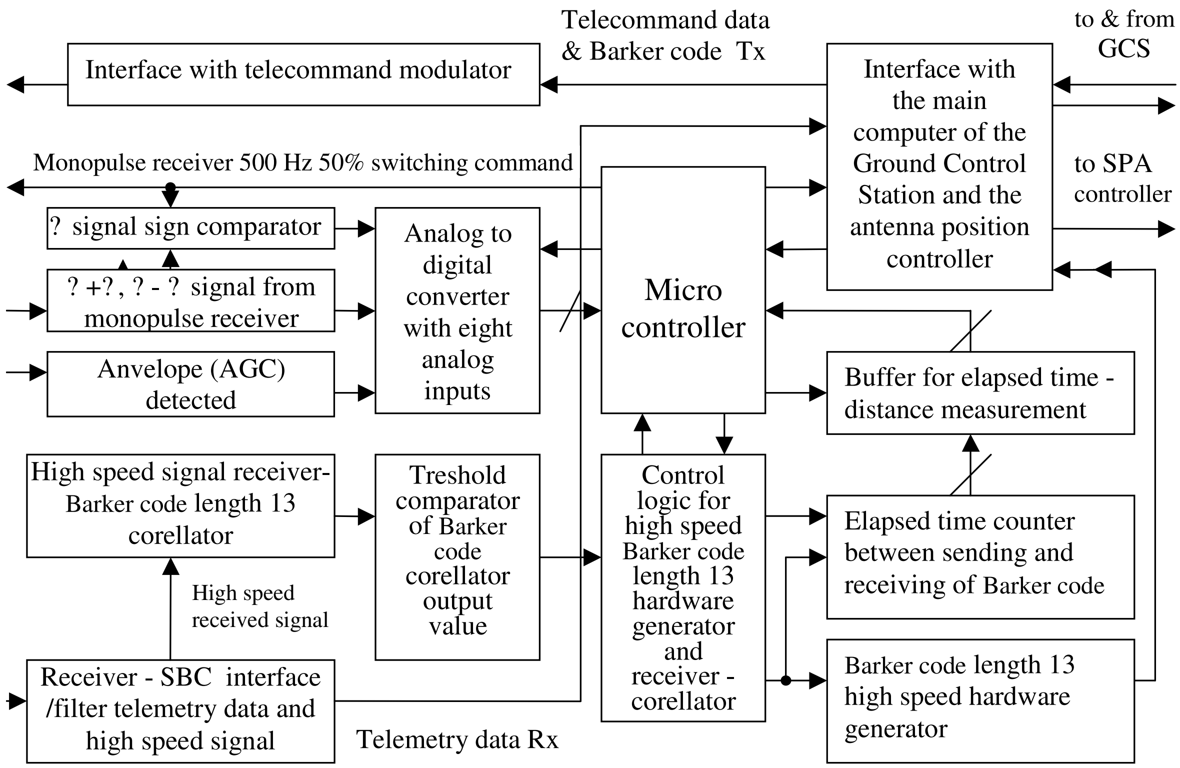

Fig. 3. Block diagram of microcontroller based single board computer for GCS communication system

SBC's activity is synchronized with the main computer activity, i.e. periodical transmitting of command data message – string of bytes with predefined format. When command string starts microcontroller directs it towards modulator. At the same moment microcontroller preloads – initiates hardware realized Barker code generator which is specialized periphery of microcontroller and then waits to detect end of command string. When end of command message is detected microcontroller issues command to open receiver and waits till end of receiving message is detected, at the same time starting time out counter. Time out counter threshold is so adjusted that is bigger than the longest ever needed time for telecommand – telemetry signal propagation along both directions together. If time-out happens and telemetry signal is not detected, unsuccessful communication is flagged-marked and another attempt is tried to accomplish communication. There are two kinds of flags-no signal at all and poor quality of received signal.

If the number of successive attempts without established communication is achieved above threshold, main GCS computer is alarmed and it commands position system controller to start acquisition of signal trying to establish communication. At the beginning search for telemetry signal starts at the angular position at which communication disappeared. Initial sweeping angle calculation is realized by applying worst case design approach: UAV trajectory is perpendicular to UAV-GCS direction (tangential moving), UAV is moving with maximal speed perpendicularly to last detected distance of UAV, and it lasts during the time equal to elapsed time from break of communication. Sweeping angle by azimuth is increased each time when attempt to establish communication fails.

Communication is established when monopulse receiver SBC detects good telemetry message. At that moment microprocessor starts hardware generator transmitting of Barker code train of pulses, starting at the same moment hardware quartz stabilized counter-timer that measures the time interval with resolution of 20ns. Barker code sequence has length of 13 bits and is well known for its property of clearly defined correlation peak value during one bit above all other values of correlation of this sequence (figure 3). Hardware generator and time counter are used because wanted time resolution is not possible to obtain using microprocessor only.

Transmitted Barker code is received by UAV's receiver of telecommands, regenerated and retranslated through telemetry link towards GCS receiving system. Counter-timer counts until receiving corellator gives value of correlation of 13 bits long Barker code and received signal above threshold. In that moment timer counting stops and interrupt to microprocessor is generated. Microprocessor loads value of counter in input buffer, and restarts the whole procedure, repeating it predefined number of times.

At the same time microprocessor generates symmetric train of command pulses to monopulse receiver. The role of this pulse train is to generate alternate commands to microwave switch in monopulse receiver [6] that alternatively enables synchronous detection of signals $\sum+\Delta$ and $\sum-\Delta$ in baseband.

After analog to digital conversion of these detected signals, appropriate numerical values of their values are fed to microcontroler. Finding sum and difference of these two signals by arithmetic operations in microcontroller numerical equivalents of original microwave intensities of signals are obtained. Symbols $\sum$ and Δ designate amplitude of receiving microwave telemetry signal sum and difference respectively at the appropriate outputs of rat-race modul of monopulse receiver (figures 2, 3). Signal designated by Δ under fulfilled circumstances corresponds to angular error in azimuth plane, as it is known from theory of monopulse receiver. Knowing data of angular position of antenna positioner and angular error, absolute position in azimuth plane of UAV is obtained. Comparing phase of command signal to monopulse receiver and measured Δ signal, antenna position error orientation is obtained, i.e. whether UAV is left or right (positive or negative error) from azimuth boresight axe of antenna system.

During the whole time interval between successive telecommand – telemetry message rounds is used for repetitive measurements of distance and angular position of UAV. The resultant measurement of one period (round) is obtained by averaging of successive measurement values in one round. Resultant measurements are fed to main computer of GCS and to controller of GCS antenna positioner.

Antenna position controller task is to track UAV's actual trajectory minimizing azimuth angular error [7]. Keeping angular error close enough to zero enables UAV to be in the main lobe of the GCS antenna system and thus to have the best possible quality of telemetry – telecommand signal, avoiding break of communication. Due to applied antenna construction (planar array of radiating elements) antenna diagram in elevation plane is like fan-stacked beams about 2 degrees wide in azimuth and 30 degrees wide in elevation plane. Because of that it is important to realize good tracking in azimuth plane only.

UAV by itself is subjected to its local disturbances influencing position (orientation) change in pitch, rotation and roll (all three axes of UAV's space orientation) due to unpredictable wind gusts, changing angles of pitch, rotation and roll (all three axes of UAV's space orientation) in spite of continual efforts to stabilize flight. Because of impossibility to obtain smooth flight trajectory, omnidirectional antenna at UAV is used as a simple solution. The cost of this choice is necessity of bigger transmitting power of telemetry signal, lowering of GCS telemetry receiver's signal threshold or increasing GCS receiving antenna gain to compensate lack of UAV antenna gain. This implies significant increasing of necessary energy of electrical supply of UAV vehicle, independently whether its electrical equipment is powered by accumulator (battery) or by electrical generator driven by internal combustion motor for airplane propulsion.

Increased weight has as a consequence shortened autonomy (and consequently shorter duration of useful part of mission) compared to directional antenna use at UAV and also growing cost of airvehicle as a flying platform itself. At the other side, use of directional antenna is not only much more complicated and expensive to realize, but also unreliable in functioning and maintenance due to rotary joints for microwave frequencies. So engineering trade-off in decision making is what we had to do also in this case.

V. Conclusion

Microcomputer with specialized peripheries realized on single board as a integral unit of ground control station communication system part that supports functioning of microwave telecommand transmitter and telemetry and signal mission signal receiver is developed and realized in Institute IMTEL. Single (azimuth) plane monopulse receiver operation is applied (called by some authors pseudo – monopulse receiver because of lack of other spatial plane – elevation channel receiver) for angular position in azimuth plane measurement and also secondary radar principle for slant distance measurement.

It is successfully field tested and proven in UAV complex as a part of the ground control station communication system. Proper functioning of this SBC enables autonomous determining of UAV's position in space and tracking of its movement along trajectory during mission, thus enabling communication between UAV and GCS. Further improvements of the system are under way.

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