# Distributed System of Radio Monitoring and Direction Finding

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## 1 ARC-POM Radio Monitoring System Structure

The general structural diagram of ARC-POM distributed system of radio monitoring and direction finding is given in Fig. 1. The main function of the system is radio monitoring in the operating frequency range, direction finding of radio signal sources (RSS), their position finding, radio control of the set channels and ranges. ARC-POM system provides:

- On-line search, detection and position finding of the radio signal sources
- Accumulation of information and keeping of sources database
- Technical analysis and measuring of radio signal modulation parameters
- Intercept and registration of informational messages
- Single channel and multi channel direction finding
- Simultaneous (synchronous) direction finding
- Estimation of electromagnetic field strength
- Other functions including record-keeping on loading the studied range.

ARC-POM system software supports a random number of stationary, semi-stationary and mobile direction finding stations. Mobile stations may be operated both under movement and stationary conditions.

All stationary stations of ARC-POM system are united into one network with TCP/IP protocol. Physically the connection to the remote stationary stations may be provided based on several standards, for example based on radio-Ethernet, using fiber-optic communication lines or cable channels.

ARC-POM system slave direction finding stations have communication means with the system main station. Data exchange between system stationary stations is carried out via high-speed radio channels, cable or fiber optic lines.

The communication system between ARC-POM system stations has two levels – software and hardware. The software level provides the unity of the interface of exchange between the applications operated on PCs included into the system. The hardware level determines the actual physical implementation of the communication channel between the system stations.

The interaction of the applications between each other is provided via a common component developed specially for ARC-POM and analogous systems. It is included in all the applications and implements the protocol of connection and disconnection, data exchange between the applications. The component is built above TCP/IP protocol allowing the applications to interact between each other in a standard manner not depending on their physical position. When working on one PC the component allows complete imitation of operation in the network without installation of network means and TCP/IP protocol due to using the files showed in memory for data exchange. System configuration setup (names, addresses, ports of the interacting applications) is done via ini-file allowing flexible reconfiguration of the system. Standardized exchange protocols of the upper level allow developing systems from the existing applications.

The configuration of radio network hardware depends on the number of system stationary stations and coverage area. A relatively simple system consisting of three stationary stations (one main and two slave) may use wireless “point-to-point” channels. In case of such communication organization two wireless network adapters are connected to control station PC. Each of these adapters allow the control stations PC to support the wireless connection to the direction finding stations PC equipped with analogous adapter. Direction (parabolic) antennas are used then at both main and remote stations. The advantages of this system are its relatively low price, low signal power due to the use of direction antennas at both ends of the communication channel. The disadvantages include the necessity to install two adapters at control station PC, irrational use of expensive radio frequency resource.

Taking into account the requirements of reliability, convenience, independency and scalability of network in the systems consisting of three and more stations, it is expedient to use “point-multipoint” communication organization with the basic station at the main stations and terminal stations at the rest. Modern equipment allows data transfer with the speed above 30 Mbps (without coding), with the communication range above 15 km under partial blockage conditions. In case of using “point-multipoint” channels the main station antenna shall be omnidirectional or sectoral requiring higher power of transmitting equipment.

One of the leading manufacturers of such equipment is Alvarion issuing the whole line of complexes for high-speed transfer of data operated in different frequency ranges 2.4, 3.5, 5, 10, 26 and 28 GHz: BreezeACCESS II, BreezeACCESS VL, BreezeACCESS OFDM, BreezeNET DS.11, WALKair 1000, WALKair 3000. Analogous products are manufactured by the following companies: Proxim, Marconi Communication GmbH, Wi-LAN, SR Telecom, Lucent Technologies and others.

The above high-speed systems are almost never applied for data exchange with the mobile station due to no line of sight and impossibility to use direction antennas, therefore low-speed radio communication systems are used in this case: autonomous narrow band radio systems for data transfer with the speed from 9600 to 40000 bps or cdma or gsm radio modems of cellular radio communication systems. For example as an option of organization of stable radio communication between the main stationary and mobile stations a ParagonPD+ base station may be sued for stationary stations and GeminiPD+ mobile modems for mobile stations. When using non-direction antennas required for operation of a mobile station in movement the range of coverage of such a system is similar to the line of sight distance. With a 30 m antenna at the stationary station and 3 m antenna at the mobile station the coverage of radio communication is about 20-30 km.

Many commercial and military radio stations have external models for digital data transfer. The examples include the Russian radio stations of Akveduk P168E family with integrated modems that can transfer digital data with the speed of up to 16000 bps. The range of specialized narrow band radio modems for the portable system is quite wide, for example IntegraTR or T-96SR radio modems are suitable for this purpose. In this case the typical distance between the stations is about 3-10 km depending on the power of the radio modems and usually limited by the line of sight between the stations.

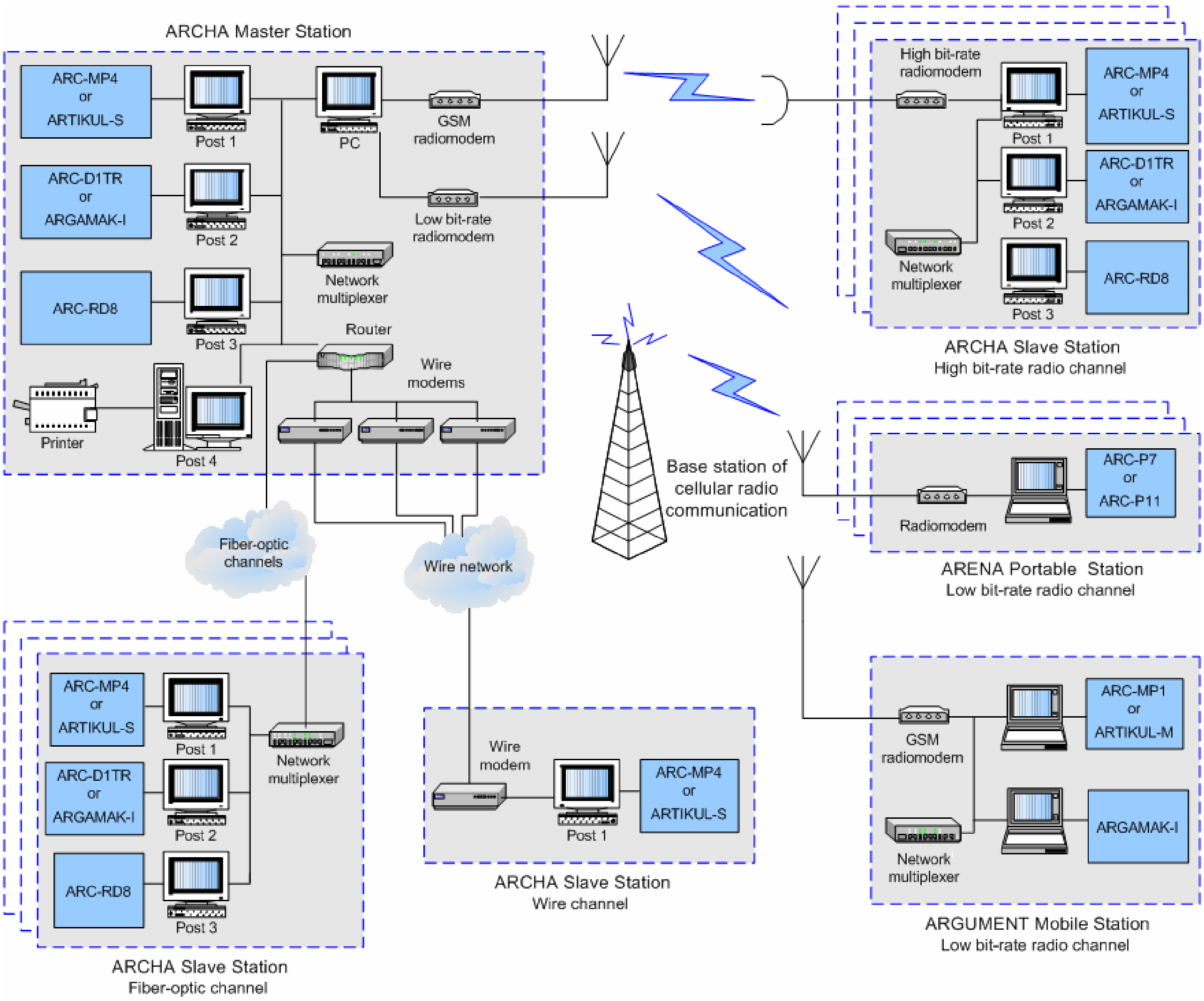


Fig. 1. General Structural Diagram of ARC-POM Distributed System of Radio Monitoring and Direction Finding

ARC-POM system may include several stationary, mobile and portable stations of radio monitoring and direction finding, as well as have additional manual direction finders.

ARCHA stationary station may be composed of the following:

- Station No. 1. ARTIKUL-S complex of radio monitoring and direction finding with stationary antenna system to be installed on a mast.
- Station No. 2. Panoramic radio receiver: Single channel ARGAMAK or multi channel ARC-RD8M or (if required to measure the radio facilities parameters) ARC-D1TR panoramic measuring radio receiver or ARGAMAK-I with measuring antenna set.
- Station No. 3. ARC-RD8 multi channel radio control complex.
- Station No. 4. ARC-KN1 or ARC-KN2 mapping and navigation equipment.
- Portable equipment for measuring and control of radio facilities parameters – ARC-NKZI portable complex on the basis of ARGAMAK-I panoramic measuring receiver.
- Portable equipment for RSS precise positioning in the area or in buildings – ARC-RP3, ARC-RP4 manual direction finders.
- Communication and data transfer facilities.
- System equipment.

In a minimum configuration each ARCHA station has only one station No. 1 combined with station No. 4.

ARGUMENT mobile station consists of the following:

- Station No. 1. ARTIKUL-M base complex with two antenna systems: AS-MP1 or AS-MP6 antenna system under radio transparent blister and AS-MP4 or AS-PP17 unfolded antenna system to be installed on a mast. Under field conditions the unfolded antenna system is located in the back of the car.
- Station No. 2. Panoramic radio receiver: single channel ARGAMAK or multi channel ARC-RD8M if required to measure radio facilities parameters – ARC-D1TR or ARGAMAK-I certified measuring panoramic radio receivers with ARC-KNV4 certified radio signal converter and measuring antenna on dielectric mast, installed on the car body or on the site near the car.
- Station No. 3. ARC-RD8 multi channel radio control complex.
- Station No. 4. ARC-KN1 mapping and navigation equipment.
- Portable equipment for measuring and control of radio facilities parameters – ARC-NKZI portable complex on the basis of ARGAMAK-I measuring panoramic receiver
- Portable equipment for RSS precise positioning in the area or in buildings – ARC-RP3, ARC-RP4 manual direction finders
- Communication and data transfer facilities
- System equipment.

In a minimum configuration the mobile station consists of station No. 1 combined with station No. 4.

All system stations may work both on individual tasks and in cooperation with each other.

Stationary stations installed on the dominant heights allow receiving precise bearings and locate RSS with the precision of several dozens or several hundreds of meters depending on the distance.

The mobile stations of ARC-POM increase the opportunities of the system. Fast RSS position finding correction and location of interference sources are possible with them. With the measuring receiver the mobile complex provides measurements of signal field strength in the area required for determining the coverage area, for checking RSS correspondence to the set parameters, for meeting the sanitary standards and assessment of electromagnetic compatibility of the radio station. A mobile station may be operated autonomously beyond the area of action of the stationary stations thus widening the operating area on the whole. Portable stations may be used under the conditions inaccessible for cars, manual direction finders are used for searching TSS inside buildings and structures.

Depending on the equipment included into the system there may be different types of distributed systems: ARC-POM1 consists of stationary and mobile stations, ARC-POM2 consists of mobile and portable stations and ARC-POM3 consists of portable stations.

Let's discuss the particularities of the operation of the distributed system based on the example of ARC-POM1 system currently operated in one of the big cities of Russia. This system is efficiently solving most of the problems faced by the radio frequency service.

## 2 ARC-POM1 System Implementation

Radio monitoring and direction finding system consists of the main station and three slave stationary stations each having ARTIKUL-S stationary unfolded radio direction finder. Besides the system has ARGUMENT mobile station equipped with ARTIKUL-M direction finder and ARGAMAK-I panoramic measuring receiver. The structural diagram of the system is given in Fig. 2.

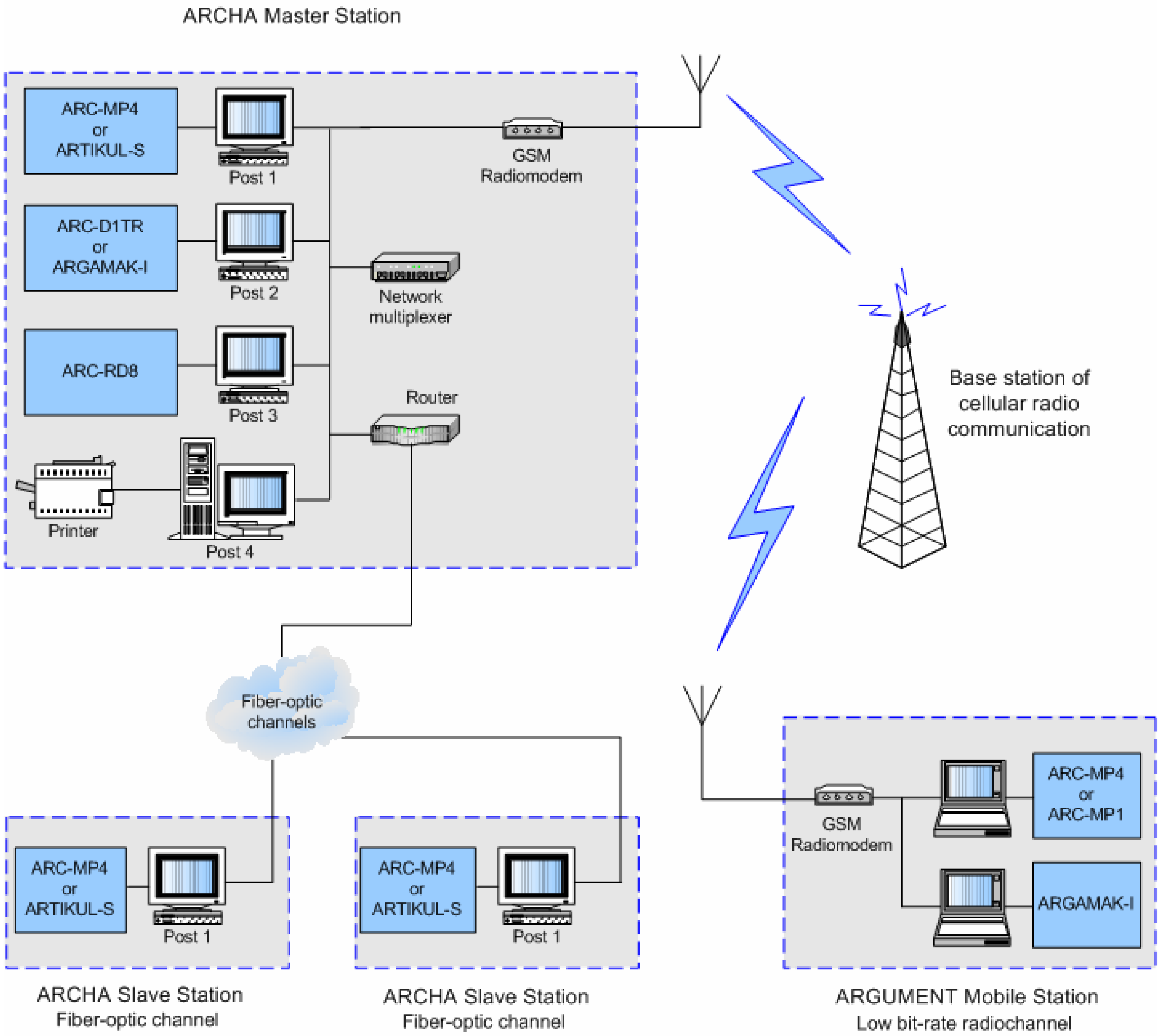


Fig. 2. Implemented ARC-POM1 System Structure. Slave station is combined with the main stations

The figure shows the case when the radio direction finder is located in the same building with the main control station. This allows using 100 Mbps internal local computer network for exchange between them thus partially reducing the traffic of the external fiber optic network that is used for controlling two other stations remote from the main one. Traffic reduction may be useful particularly when using rented fiber optic communication lines which cost depends on the transfer rate. Spectrum analysis rate of the equipment connected via 100 Mbps local network is about 2400 MHz/s.

The main control station may be moved to another building, for example to the central office of the radio control service. In this case the structural diagram of the system looks as shown in Fig. 3.

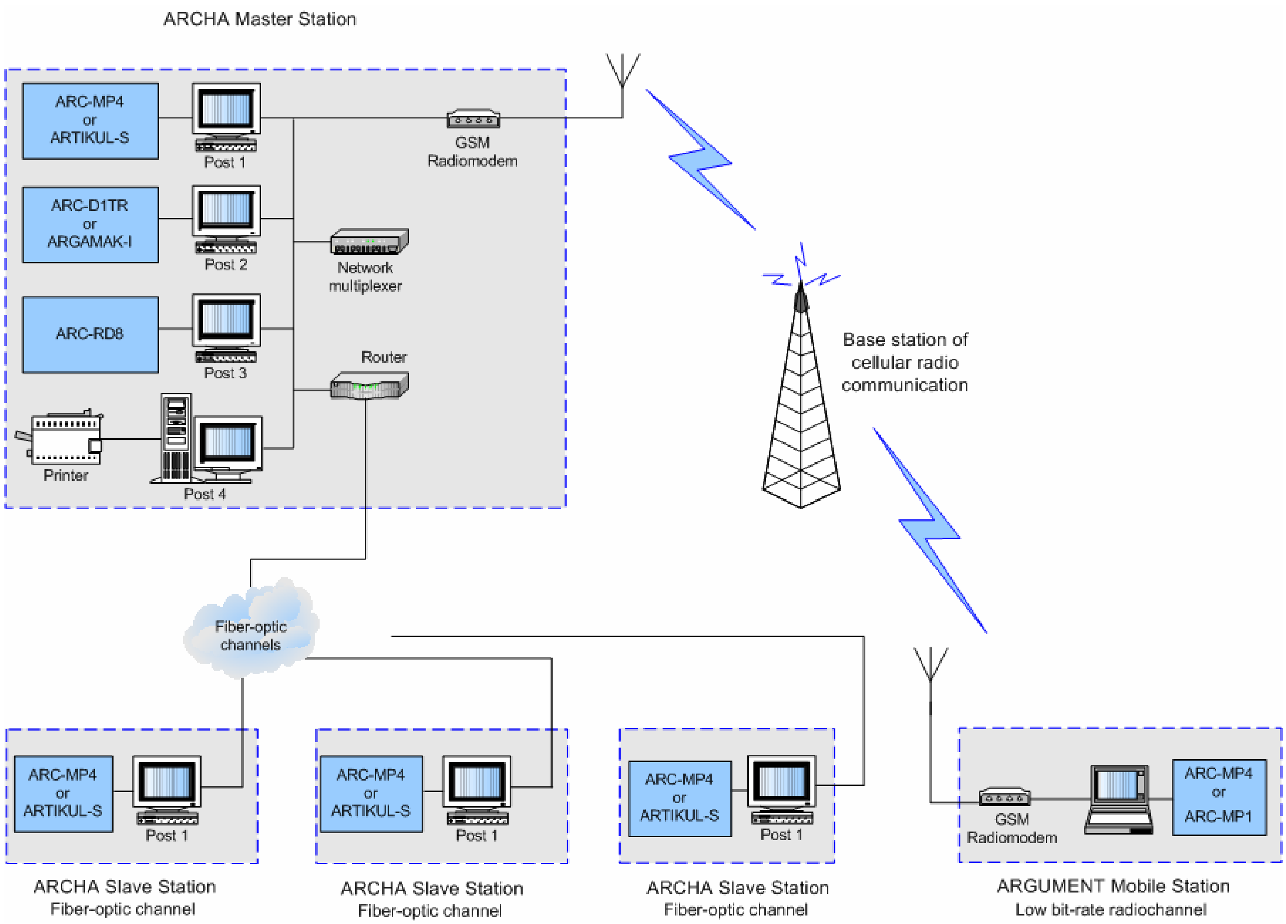


Fig. 3. Implemented ARC-POM1 System Structure. Main station is located in an individual building

In this case the acceptable transfer rate via the fiber optic network is about 10 Mbps while the values for slave stations remain satisfactory: Spectrum analysis at slave stations is decreased to 1200 – 1500 MHz/s.

In order to provide direction finding of the radio signal sources within the whole city with maximum accuracy it is expedient to position the stations in the corners of the equilateral triangle located on its borders. Fig. 4 shows location of slave stations. We can see that they form an irregular triangle with the legs 5.48 km, 2.92 km and 6.22 km due to the presence of high buildings accessible for installation of radio direction finders.

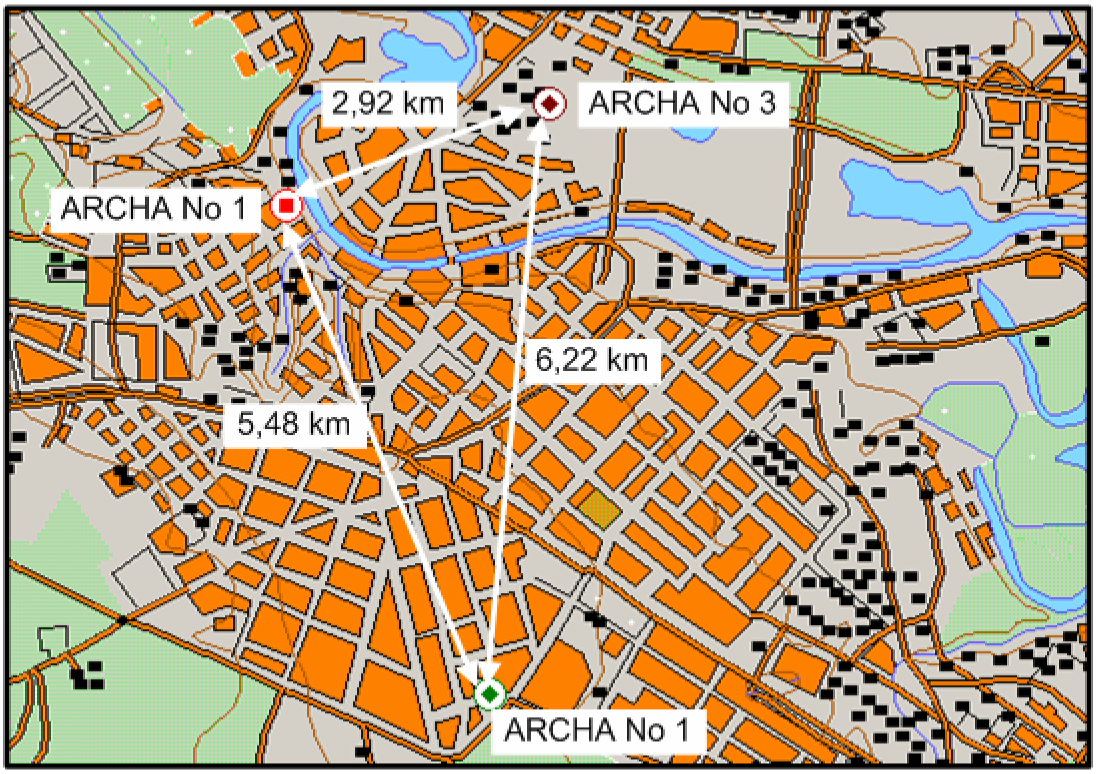


Fig. 4. ARCHA Stations Location

Fig. 7 – 10 show locations of antenna systems and equipment elements of the slave stations. ARTIKUL-S unfolded direction finders are designed to use lead-in cable up to several hundred meters long without any loss in direction finder sensitivity. This allows the analogue-digital processing unit, the PC, uninterruptible power supply and the equipment for data transfer to be located at any floor of the building.

Fig. 5. ARCHA No. 1 Slave Station

Fig. 6. ARCHA No. 1 station antenna system is located on 12 m telescopic mast

Fig. 7. Slave Station No. 2

Fig. 8. Slave station No. 2 equipment

Fig. 9. Slave Station No. 3

Fig. 10. Slave Station No. 3. Antenna system is located on the mast facility with flexible girders

The slave stations of the system are remotely controlled, located in small technical facilities and operated without servicing personnel. Fig. 8 shows the dislocation of the equipment on a non-attended slave station. ARTIKUL-S analogue-digital processing unit and a network power unit are located on the left by the wall, on the right there is the PC operating the controller-application.

Fig. 11 shows the working position of the operator of radio monitoring, direction finding and RSS positioning of ARCHA main station. Two PCs are used at the station, one for system station control, the other – for the electronic map.

Fig. 11. ARCHA Main Station. Radio Monitoring, Direction Finding and Positioning Station

2.1 ARTIKUL-S Unfolded Direction Finder for Stationary Stations

Radio direction finder consists of an antenna-radio receiving unit (ARRU), an analogue-digital processing unit (ADPU), a power unit and a PC. The radio direction finder applies correlative-interferometer method of direction finding. Operating frequency range is from 25 to 3000 MHz.

The functional diagram of the direction finder is given in Fig. 12.

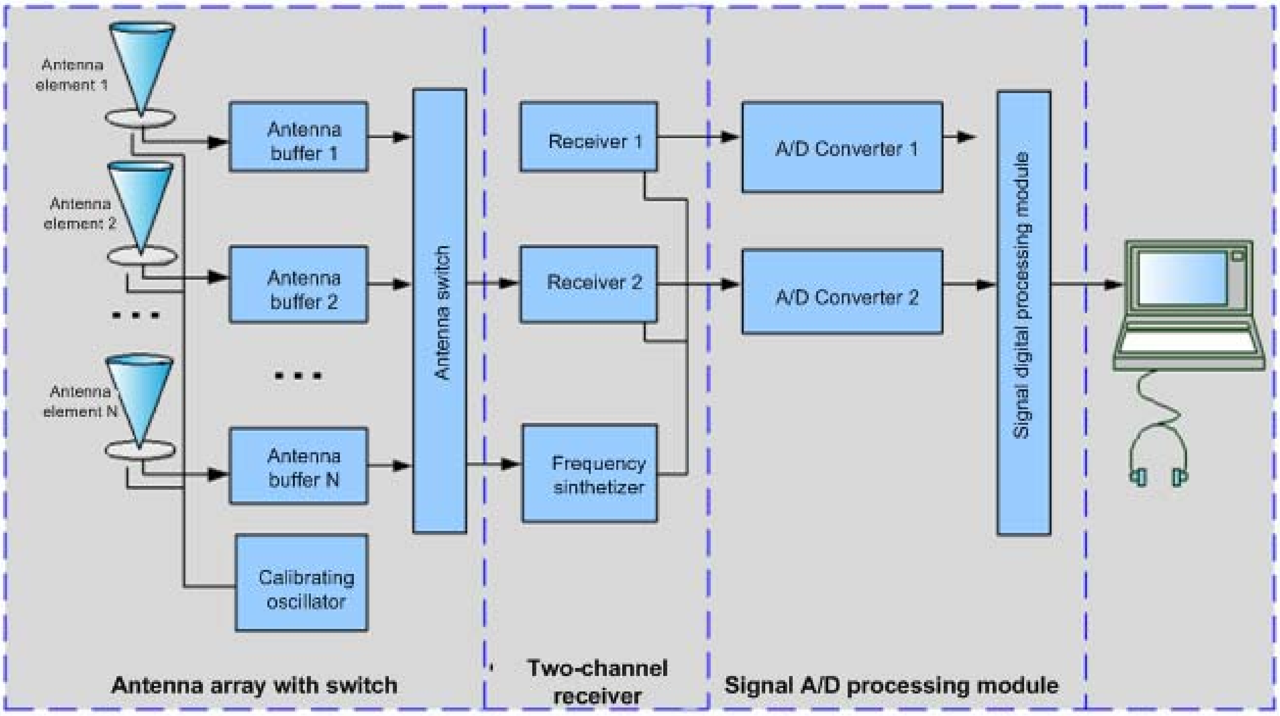


Fig.12. ARTIKUL-S Radio Direction Finder Functional Diagram

The antenna-radio receiving unit installed on a mast contains an antenna-switching unit and a tuner unit. The antenna-switching unit has two circle antenna arrays – first and second levels. The first level antenna array is operated in the range of 25-1000 MHz frequencies, the second level antenna array — 1000-3000 MHz.

First letter antenna elements are fixed on the extension cross beams, while the second letter antenna array is located below the plastic blister in the upper part of ARRU.

Antenna element hinging and extension cross beams make unfolding of the antenna system considerably faster. This includes installing ARRU seat on the top of the mast up to alignment of cross holes, fastening the antenna on the mast with a locking pin, turning antenna cross beams by 90 degrees until fixed in the unit bottom. Antenna elements always remain in vertical position.

ARGAMAK DRR based tuner unit is located inside ARRU body. By placing the analogue part of the digital radio receiving unit (DRR) inside the ARRU the sensitivity of the direction finder is increased in the upper part of the operating frequency range due to the minimum length of high frequency cables. This also eliminates the antenna effect. Since IF signal from DRR input has relatively low frequency a lead-in cable up to several hundred meters long may be used.

Fig. 13. Folded ARRU

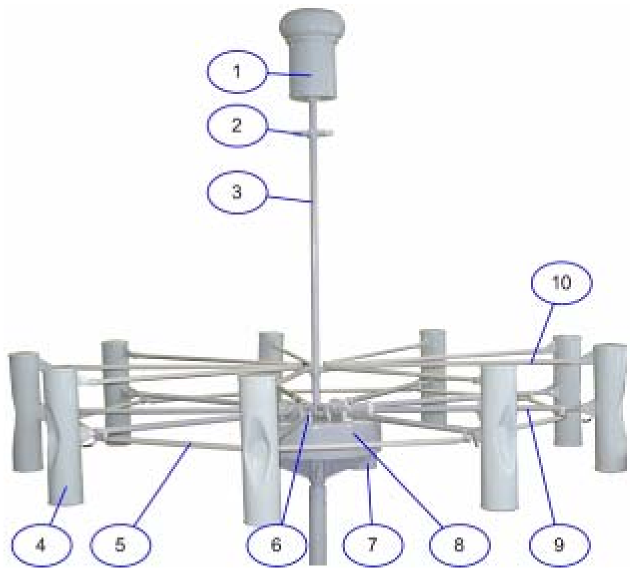


Fig. 14. Unfolded ARRU

Figures have the following meanings:

1 − 1000-3000 MHz range antenna system (upper level)

2 − a device for fixing antenna element cross beams when folded

3 − carrying axis

4 − 25-1000 MHz range antenna system element (lower level)

5 − distance rod

6 − a device for fixing antenna element cross beams when unfolded

7 − tuner unit cooling input channel

8 − ARRU base (tuner unit body)

9 − lower cross beam

10 −upper cross beam.

ARRU is operable in the wide range of ambient temperatures. Under minus degrees an integrated heater is automatically turned on in ARRU body, and under plus degrees - the venting system.

Filtered, amplified and transformed by tuners signals of two channels at 41.6 MHz intermediate frequency come to ADPU. The main elements of the unit are two-channel module of signal digital processing, designed on the basis of ARC-CO5 module and two-channel specialized ARC-C5 counter. The connection to the control PC is provided via USB 2.0 interface.

The analogue-digital processing unit of the direction finder is shown in Fig. 15.


Fig. 15. Analogue-Digital Processing Unit


Fig. 16. Network Power Unit

The main passport parameters of ARTIKUL-S direction finder are given in Table 1.

Table 1. ARTIKUL-S main technical specifications

| Parameter | Value |
|---|---|
| Panoramic Analysis and Fast Signal Search | |
| Operating frequency range, MHz | 25 - 3000 |
| Panoramic analysis speed in the operating range, MHz/s | |
| without ARC-C5 | 3200 |
| with ARC-C5 | 5000 |
| Intermodulation dynamic range (3rd and 2nd order),dB | 75 |
| Single Channel and Multi-Channel Direction Finding | |
| Direction finding method | Correlative Interferometer |
| Operating angle spectrum, deg. | 0 - 360 |
| Operating frequency range, MHz | 25 - 3000 |
| Multi-channel direction finding rate, min, MHz/s | 150 |
| Minimum duration of the bearing signal | |
| single | 30 ms |
| single (with ARC-C5) | 10 ms |
| repeated | 1 ms |
| Signal spectrum width of bearing RRS | Random |
| Field sensitivity for antenna system, depending on the operating frequencies subrange, µV/m | 2 - 25 |
| Instrument accuracy (RMS) for antenna system, depending on the operating frequencies subrange, deg. | 1 - 3 |
| Automated Radio Control | |
| Types of recorded data | Bearing, demodulated signal, spectrogram, time, digital signal at the intermediate frequency |
| Power supply voltage, AC, 50 (60) Hz frequency, V | 90 - 240 |
| Power consumption, VA | 110 max |
| ARRU weight, kg | 17 max |

| Parameter | Value |
|---|---|
| ADPU weight, kg | 3 max |

Fig. 17 shows the dependencies of root-mean-square deviation of direction finding from the frequency for the upper and lower letter determined in the course of manufacturer's testing of the series item of the direction finder. The general root-mean-square deviation for 25-3000 MHz frequency range was 1.1°.

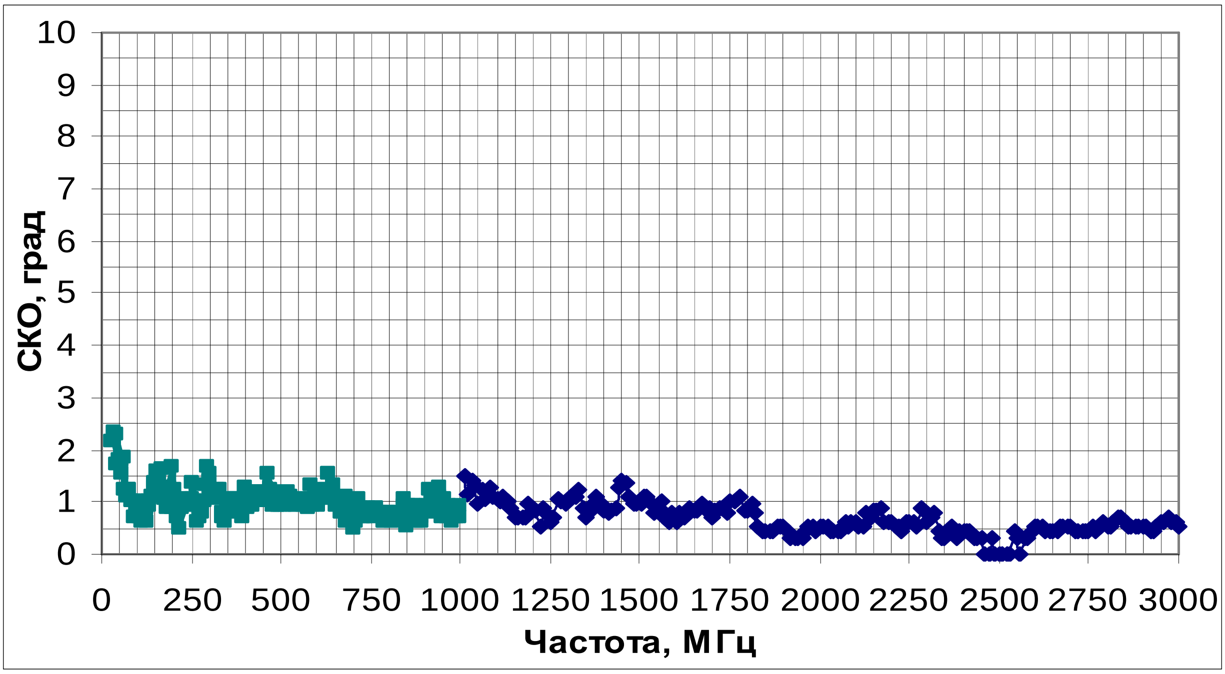


Fig. 17. RMSD of Direction Finding vs. ARTIKUL-S Direction Finder Frequency

Fig. 18 shows the dependency of the direction finding sensitivity on the frequency determined as a result of manufacturer's testing of the series item of ARTIKUL-S direction finder. We can see that direction finder sensitivity in the operating frequency range 25-3000 MHz may be from 0.5 to 9.8 μV/m.

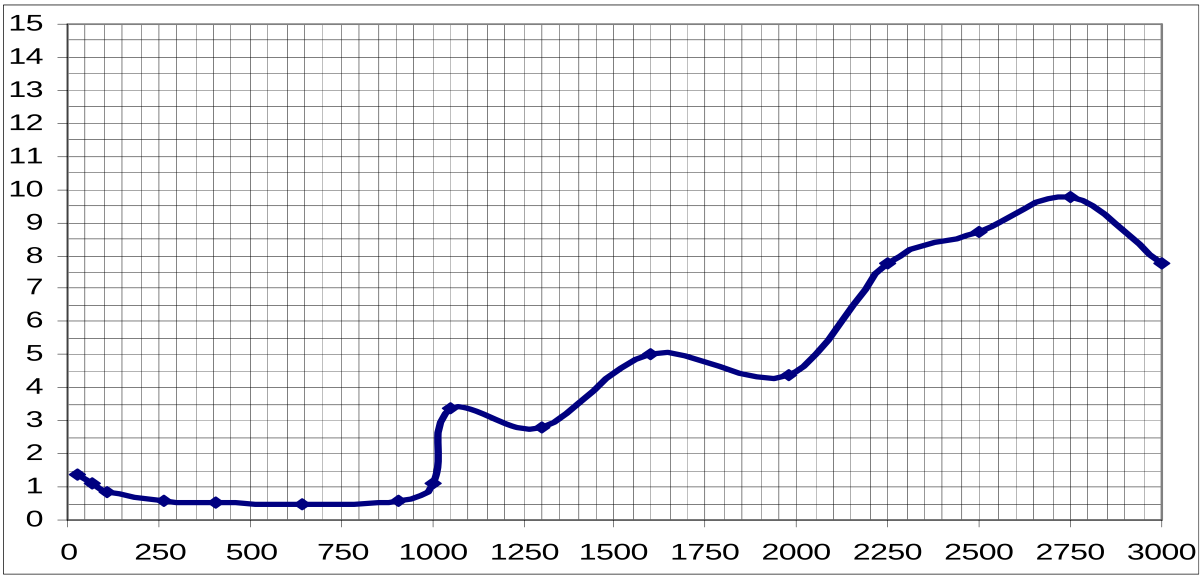


Fig. 18. Dependency of Field Direction Finding Sensitivity for ARTIKUL-S Direction Finder

## 2.2 ARTIKUL-M Mobile Direction Finder

ARTIKUL-M radio direction finder is operated at mobile direction finding stations. Similar to ARTIKUL-S it provides direction finding of the signals in 25 - 3000 MHz range. The antenna system consists of two antenna arrays. There are two variants of its design: removable AS-MK1M in the radio transparent blister allowing fast installation, as shown in Fig. 19, and AS-MK6 in a non-removable radio transparent blister being a part of ARGUMENT car structure, shown in Fig. 20.

Fig. 19. AS-MP1 Antenna System of ARTIKUL-M Direction Finder Installed on a Car Roof

Fig. 20. ARGUMENT Mobile Station with ARTIKUL-M Radio Direction Finder with ARC-MP6 Antenna System

AS-MK6 antenna array is shown in Fig. 21. It also consists of two levels of active antenna elements designed for operation at the frequencies up to 1000 MHz and above 1000 MHz.

Fig. 21. AS-MK6 Antenna Array

The structural diagram of the mobile direction finder is the same as of the stationary direction finder given in Fig. 12. Direction finder's heart is a two-channel digital radio receiver based on ARGAMAK (DRR).

Small size of the two-channel radio receiver of the direction finder allows placing it under the ceiling clothing of the operator's room near the antenna switch and antenna elements as shown in Fig. 22. This ensures the maximum sensitivity of the direction finder particularly in frequency ranges of 900 MHz and higher.

ARTIKUL-M mobile direction finder uses the same analogue-digital processing unit as ARTIKUL-S. The unit is located to the left of the operator's chair under the table of the first working position, as shown in Fig. 23.

Fig. 22. Two-Channel Tuner and Antenna Switch under the Ceiling Clothing of ARGUMENT Station

Fig. 23. ADPU under the Table of the Working Position of Station No. 1 Operator

Main passport parameters of ARTIKUL-S direction finder are given in Table 1. The exception if the root-mean-square deviation of direction finding which is a little higher in case of the mobile direction finder due to the location of the antenna system directly on the car body. The general root-mean-square deviation of direction finding is 2.5° maximum.

Fig. 24 shows the working position of the mobile direction finder operator. Two PCs are connected via a local network. One PC is used for operation of SMO-PPK application controlling ARTIKUL-M equipment, the second PC is used for SMO-KN mapping application. Parallel operation of these two applications on one PC is also possible but this would affect the speed of direction finder operation and the convenience of operator's work.

Fig. 24. The Working Position of the Operator of the Station for Detection, Technical Analysis and Direction Finding of the Mobile Station

## 2.3 Narrow Band Radio Channel for Data Exchange with the Mobile Station

It is expedient to use high-speed communication lines for connection of mobile stations, but as a rule in reality we have to use narrow band radio channels with maximum throughput 30 Kbps since it is quite difficult to use the existing high-speed data transfer systems in mobile systems due to no line of sight between the main and the mobile stations and the impossibility to use direction antennas when moving. Narrow band data transfer radio systems with data transfer rate from 9600 to 40000 bps or radio modems of cellular systems of radio communication are usually used for connection with mobile stations.

In the given system the area of ARC-POM3 system operation is within GSM cellular radio coverage and therefore GSM radio channel is used for data transfer between the main stationary and mobile stations. This solution has the following advantages:

- No need for getting the permits to use the radio frequency range and buying expensive autonomous radio modems
- Very small weight and size of the radio equipment
- Range of operation depends on the cellular communication system coverage area.

There are also some disadvantages:

- Necessity to pay for the services of the cellular communication operator
- Dependency of ARC-POM3 system on the operability of the cellular system and its coverage area.

GSM radio modems Siemens MC35i are used for data transfer. GSM modem exterior is shown in Fig. 25.


Fig. 25 . Location of GSM Radio Modem, Interface Unit and Power Panel of Working Position No. 1

Despite high potential of GPRS (General Packet Radio Service) technology the circuit switch mode was used for data transfer. One of GPRS disadvantages is unstable stat transfer rate depending on the loading of the cellular network. In practice data transfer rate usually fluctuates within 900 – 700 bps, and sometimes goes down to zero. Besides the server is required with a known network address to connect the stations via TCP/IP protocol. Therefore the system uses on-line circuit switch mode of “point-to-point” type between two radio modems. The transfer rate in this case is equal to the voice channel throughput of 9600 bps.

## 2.4 Software Modes

One and the same software package is used at all ARC-POM system stations. As minimum it consists of three customized software packages SMO-PPK, SMO-KN.

SMO-PPK Package (customized software for panoramic and direction finding complex) contains SMO-PPK application and controller applications (drivers). The package provides system management, fulfilling of all typical functions of radio monitoring, including single-channel and multi-channel direction finding.

SMO-KN Package (mapping and navigation) is designed for work with electronic terrain map, it provides bearing and automatic detection of RSS location based on direction finding data received from SMO-PPK application or entered manually.

In addition the software set may include SMO-ASPD post-processing and analysis application (customized spectrum and bearing data analysis software package) and SMO-STA radio signal technical analysis application (customized signal technical analysis software package.)

Any page can be operated autonomously or in a system under the main station control. Presence of the operator is required at the station when operated in autonomous mode. When operated in a system the following options are possible:

1) The stationary station is the main one, while the mobile station is operated in a system as slave

2) The main station is the mobile station.

The difference between these options is this: in the former case the main station is connected to the stationary slave stations by high throughput communication channels, data from the mobile station are transferred by a low-bit-rate channel. In the latter case the same low-bit-rate channel is used for data transfer from the whole system. In spite of all the measures to compress and minimize the transferred data in the second case, some modes are operated much slower, while others are not actually implemented, for example transfer of sound files or time samples. However the main modes remain the same.

When operated under the main station control controller applications are launched at slave stations providing remote control from the main station. Slave stations may exchange the data with the main station only, thus implementing the “star” topology.

SMO-PPK customized software package operated on the main station PC has the necessary functions of controlling the radio equipment slave stations. For SMO-PPK application the slave stations are remote controllers each having its own number. For example if there three slave stations in the system the controllers will have numbers from zero to two.

The main station operator sets the operation mode, for example, **Spectrum**, **Search**, **Background Scanning**, **Scanning**, **Bearing**, **Multi-Channel Direction Finding**, **Electronic Map**, etc. The purpose and opportunities of these modes have been discussed in, therefore here we will focus on the particularities of their operation in the multi-position system only.

In **Spectrum** mode the main station PC displays the spectrum panorama from the chosen controller. Another controller may be selected by pressing the button with the corresponding number. Fig. 26 shows SMO-PPK window in case of the spectrum displayed from controller No. 2.

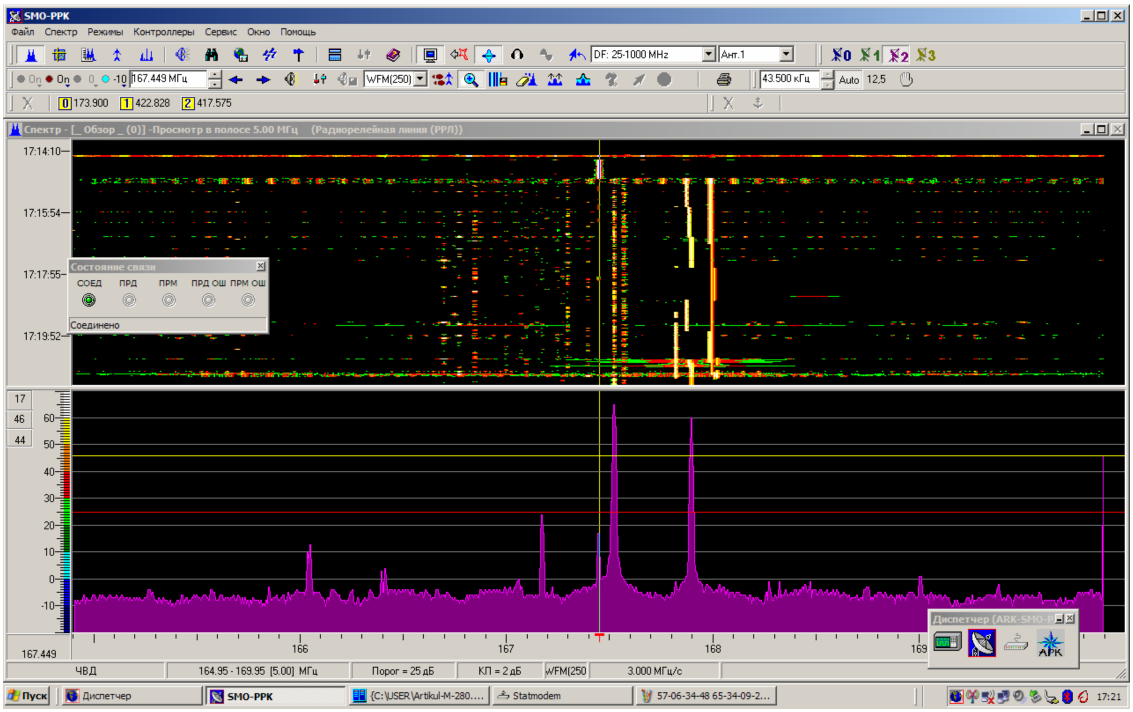


Fig. 26. **Spectrum** Mode. Controller No. 2 is Chosen. Mobile Station is the Main One

In **Search** mode the stations are detected along the spectrum panorama received from the chosen controller in accordance with the selected search algorithm. In parallel with **Search** mode the mode of **Background Scanning** may be turned on. This mode provides automatic single or repeated scanning of the detected frequency by all system controllers. Each of them gives the answers set by the operator, for example bearing values, spectrum diagrams, signal time samples for technical analysis, signal demodulated files. The answers are saved in the database.

**Scanning** mode is similar to **Background Scanning** mode. The difference is that in this case scanning is done by the frequency list set by the operator.

**Bearing** mode. In this mode signal bearing is performed at the chosen frequency by all the system controllers, the spectrum is displayed from the selected controller. SMO-PPK application window in **Bearing** mode is shown in Fig. 27.

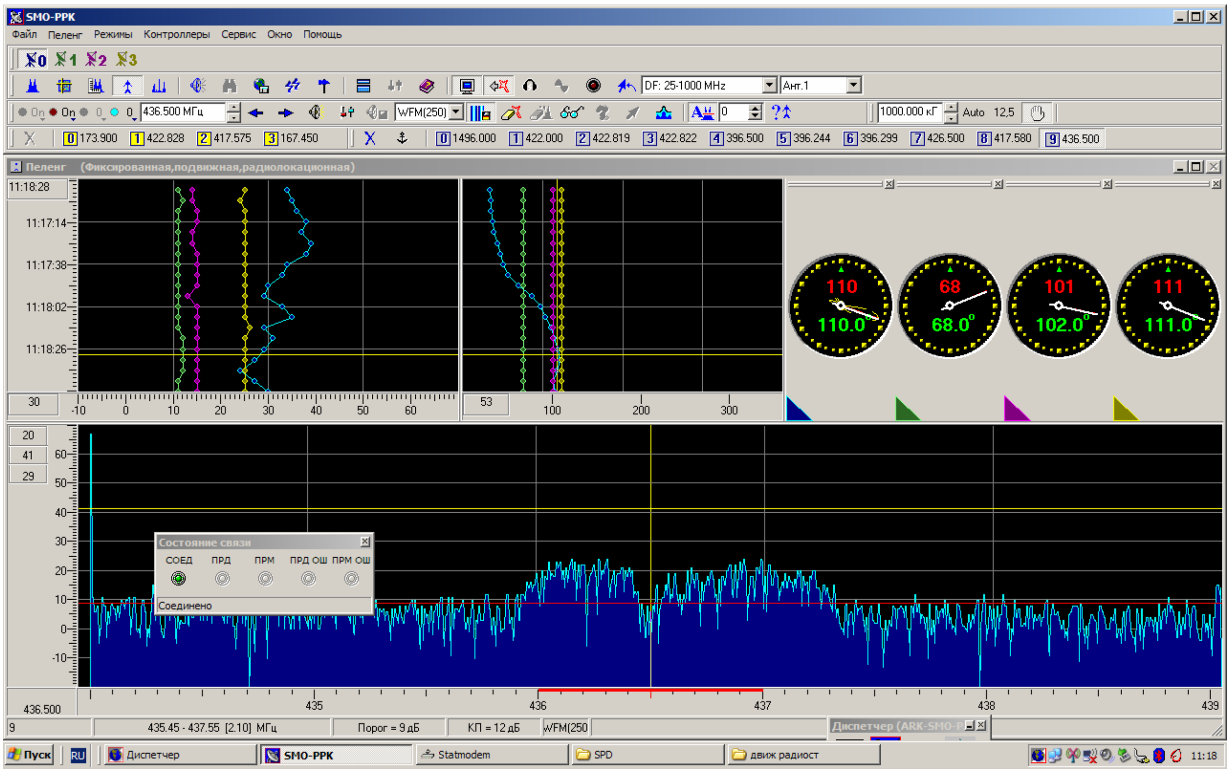


Fig. 27. **Bearing** Mode

The figure shows the case of bearing the radio-relay station signal at 436.5 MHz frequency. Bearing is performed by 1 MHz signal bandwidth. In the right part of the application window four dials are displayed related to (from left to right): Mobile direction finder (a dial with blue corner), ARCHA No. 1 station (a dial with green corner), ARCHA No. 2 station (a dial with red corner) and ARCHA No. 3 station (a dial with yellow corner.) In diagrams the amplitude and bearings histories for all the stations are displayed to the left of the dials (from left to right). The current signal spectrum received by the mobile direction finder is shown below in the diagram. We can see that amplitude histories and bearing histories from the stationary direction finders are virtually straight lines evidencing stable source bearing. At the same time the amplitude and bearings from the mobile direction finder is changing since when moving the signal is fluctuating due to the changes in propagation conditions.

In **Multi-Channel Direction Finding** provides direction finding of all the stations in the selected frequency range or ranges.

**Electronic Map** mode. In **Background Scanning, Scanning, Bearing, Multi-Channel Direction Finding** bearing, bandwidth and amplitude values for the bearing signals are transferred to SMO-KN application electronic map. Fig. 28 shows SMO-KN application window. The yellow circle shows the location of the radio signal source and the circle with a blue mark - the mobile direction finder. The route of the mobile direction finder movement is displayed in the map with a yellow line. The coordinates of radio signal sources are calculated for all frequencies selected by the operator.

Automatic calculation of the sources coordinates is done based on maximum likelihood method, which is based on determining the maximum likelihood function by solving a system of non-linear equations taking into account the mutual geometrical location of the stations with direction finders and RSS, difference in distances from the stations to the sources, as well as root-mean-square deviation of bearings.

The **Electronic Map** mode provides for displaying the route of movement of radio signal sources based on the bearing results. There is also the mode of automatic streamline detection of radio signal source coordinates based on bearing values transferred to the map. The values of frequencies, bearings, bandwidths, signal amplitudes, sources coordinates are saved in databases.

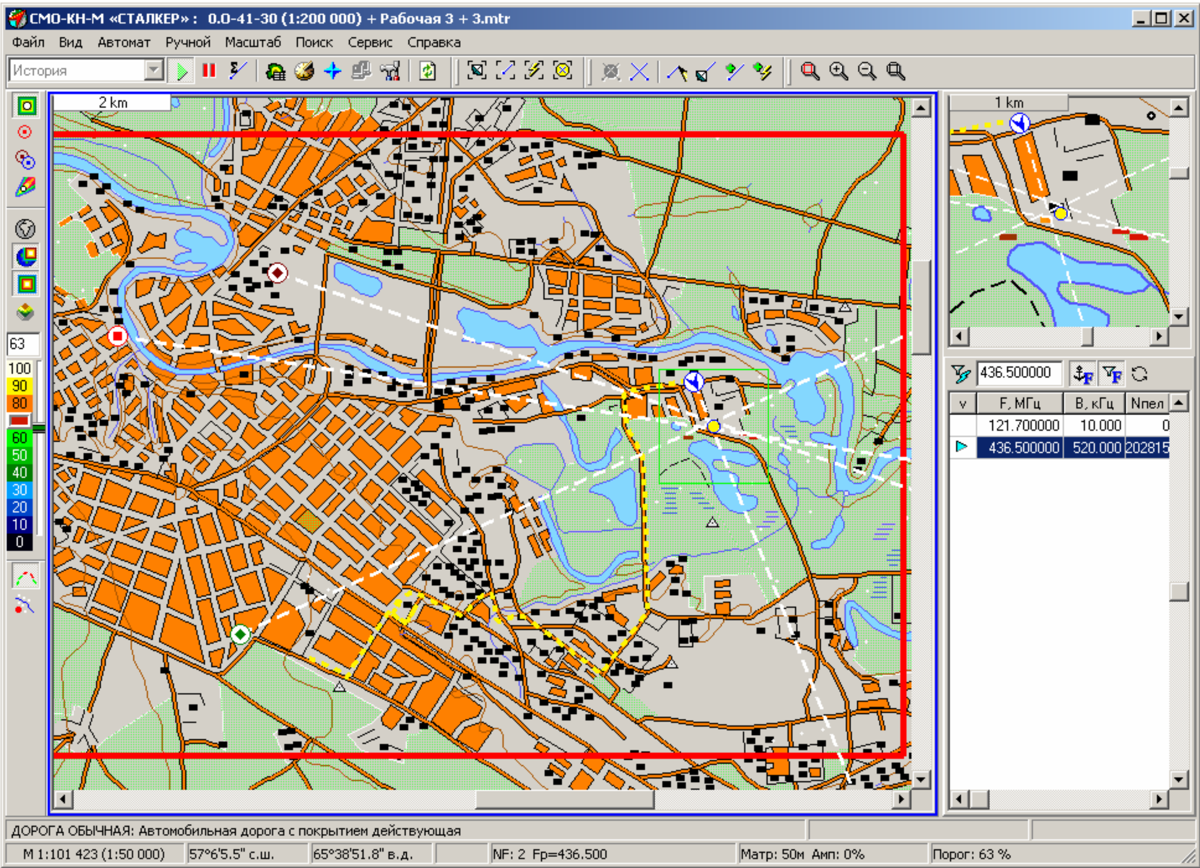


Fig. 28. SMO-KN Application Window in Mode of Simultaneous Bearing of Radio Signal Source by All System Stations

In practice under urban conditions bearing of radio signal sources by a single mobile station is quite complex due to multi-path propagation of radio waves with possible no line of sight area. Stationary direction finders with antennas up above are capable of bearing weak signals that cannot be received by the mobile direction finder with the antenna system located 2-3 meters above ground. Thus combined operation of a mobile direction finder with stationary stations makes search of radio signal sources much faster. The actual task of the mobile station is specification of the source location, i.e. going to the area of its location using the coordinates received from the stationary system and determining the source location in direct vicinity, often in the line of sight conditions.

## 2.5 Check of Maximum Range of Direction Finding

Field sensitivity of the direction finder is set by the passport parameters and results of field testing, but in practice the question often arises: “What will be the distance for bearing, for example a 5 W radio signal source?" Precise answer depends on the given conditions of radio wave propagation, but even testing results may describe the operational capabilities of the system.

The following experiment was carried out when commissioning ARC-POM1 system. Argument mobile station of direction finding was the main one and managed the whole system operation. It had a portable Motorola GP-344 radio station on board with a standard antenna. Passport power of the radio station was 4 W, signal frequency 417.5 MHz. Radio station exterior is shown in Fig. 29. Argument station moved away from the city, the distance to the stationary direction finders was controlled using the navigation system. When stopped the radio station was put out into the car window and turned on for transmitting. Each stationary station carried out direction finding of the radio station, the bearing values were recorded, signal-noise ratio was determined based on the spectrum. Test results are summarized in the table and shown in Fig. 30 - 33.

As it has been expected the bearing signal level went down with the increasing distance (see Table 2.) Signal-noise ratio at the first stop was 4 dB lower at station No. 2 than at station No. 3, although the car was closer to station No. 2. The same rule was true for other stops as well. It is possible that the lower value of signal-noise ratio in the bearing signal bandwidth is caused by low location of the antenna system at station No. 2 above the building roof.

At the sixth stop when the distance from the car to station No. 2 was about 28 km bearing by this station was finished. Two other stations continued bearing with the distance from them being 22.45 and 27.25 km correspondingly. It is known that the maximum range of radio wave propagation above the plain ground surface in decimeter wave ranges is approximately equal to $d = 3{,}57(\sqrt{h_1} + \sqrt{h_2})$, where $h_1$ and $h_2$ are antenna system height above the ground level. Taking the radio direction finder antenna height as 50 m and the radio station height as 2.5 m we will have the maximum distance of 30.8 km. Thus the maximum distance of 27.25 km when bearing is still possible is close to the maximum propagation range evidencing high operational sensitivity of the radio direction finders.

Table 2.

| Station | Stop Number | Station to Car Distance, km | Signal-Noise Ratio, dB | Bearing |
|---|---|---|---|---|
| No. 1 | 1 | 1.78 | 31 | Yes |
| No. 2 | | 6.97 | 8 | Yes |
| No. 3 | | 7.35 | 12 | Yes |
| No. 1 | 2 | 5.29 | 19 | Yes |
| No. 2 | | 10.55 | 3 | Yes |
| No. 3 | | 10.25 | 20 | Yes |
| No. 1 | 3 | 9.39 | 12 | Yes |
| No. 2 | | 14.56 | 2 | Yes |
| No. 3 | | 13.92 | 8 | Yes |
| No. 1 | 4 | 13.67 | 11 | Yes |
| No. 2 | | 18.95 | 3 | Yes |
| No. 3 | | 18.31 | 8 | Yes |
| No. 1 | 5 | 18.13 | 11 | Yes |
| No. 2 | | 23.42 | 2 | Yes |

| | | | | |
|---|---|---|---|---|
| No. 3 | | 22.86 | 10 | Yes |
| No. 1 | 6 | 22.42 | 8 | Yes |
| No. 2 | | 27.95 | - | No |
| No. 3 | | 27.25 | 4 | Yes |


Fig. 29. Motorola Gp-344 Portable Communication Radio Station ,4 W

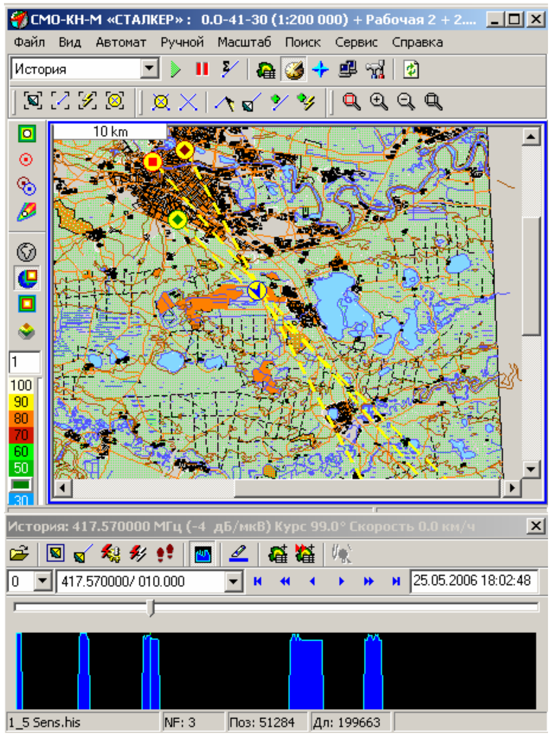


Fig. 30. Stop 2. Distance from Archa No. 3 to the car is 10.25 km

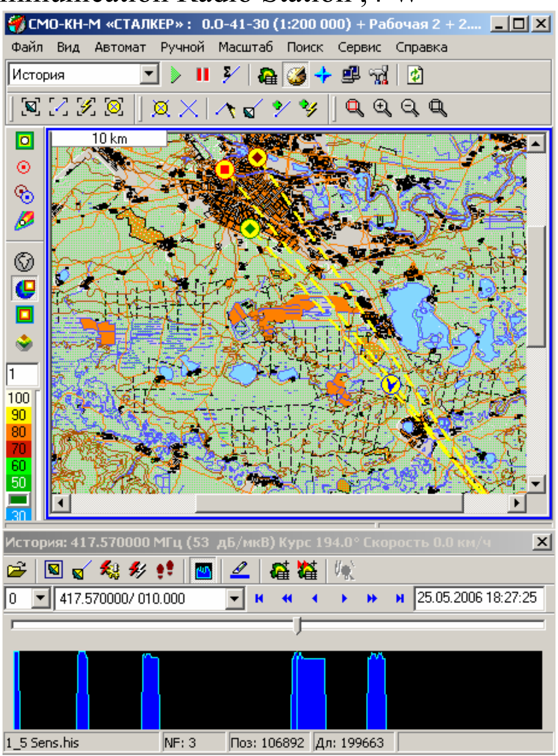


Fig. 31. Stop 5. Distance from Archa No. 3 to the car is 22.86 km

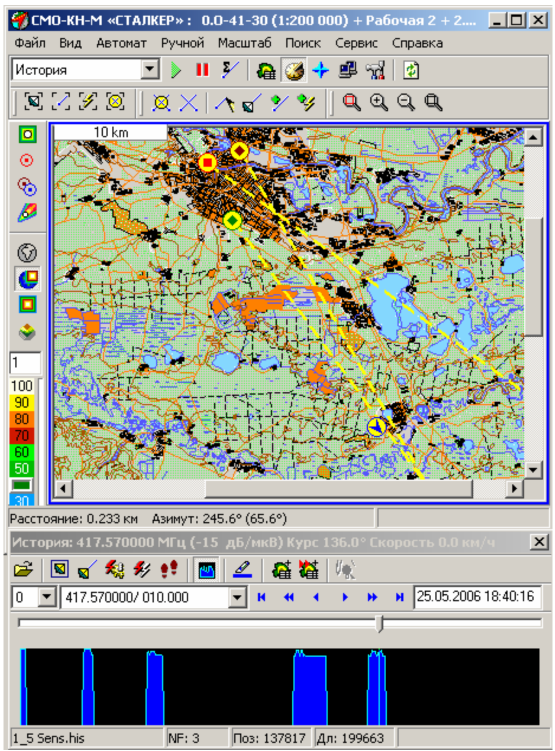


Fig. 32. Distance from Archa No. 3 to the car is 27.25 km

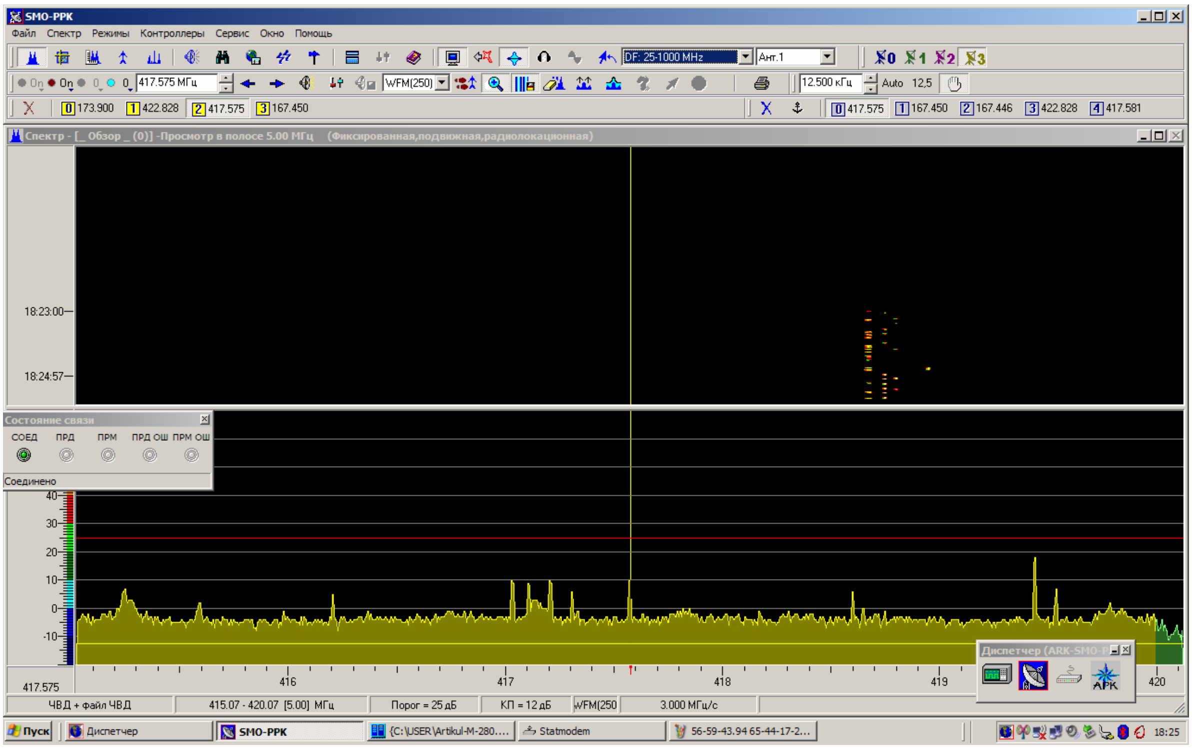


Fig. 33. Stop 5. Bearing Signal Spectrum

## 2.6 Features of Radio Signal Sources Bearing by a Mobile Station in an Autonomous Mode

There are several methods used in ARGUMENT mobile stations for sources positioning:

- Step by step method
- Quasi-stationary method
- Method of calculation of the source coordinates in movement.

Besides, combined methods when two or three of the above are operated simultaneously are also possible.

Step by step method is based on the movement of the direction finder to the radio signal source location area along the bearing direction. As the distance to the source decreases the bearing signal amplitude increases that is an additional sign that the direction finder is moving in the correct direction. Single-channel source bearing mode is usually used under the step by step method.

Quasi-stationary method is based on receiving several bearings from fixed points located at a significant distance from the object. At that a location is chosen for the mobile direction finder away from the systematic interference sources — high buildings, electric power lines, tram railway, metal fences and similar facilities. It is quite expedient to locate the direction finder at some dominant elevation. The mode of bearing accumulation and histogram building is turned on. Bearings are accumulated for some period of time. The bearings direction is mapped based on one or several bearing histogram maximums. Then the direction finder is moved to the next position and the bearing procedure is repeated. RSS location is calculated based on bearing mapping from several stationary positions. The positions and bearings used for calculation may be chosen by the operator from the data base, if necessary. Quasi-stationary method allows using for direction finding a remote bearing antenna system unfolded on a mast which provides greater radius of coverage area and has higher sensitivity and bearing precision than an antenna on a car roof.

The advantages of the quasi-stationary method include clearness of the results, the possibility to work at considerable distance from the sources making the bearing procedure more easily concealed. The disadvantages are the necessity to choose "good" positions for source bearing and unfolding the antenna system on a mast, usually requiring much time, as well as the probability of receiving erroneous bearings due to the influence of objects around.

As the mobile station is moving along the route the constant bearing of the radio signal sources is performed and all the bearings accumulated from the start of the session are used for source location calculation. In the course of work session as bearings are accumulated the source coordinates are specified.

SMO-KN software package has several algorithms for RSS coordinates calculation:

- Matrix algorithm
- Maximum likelihood method
- Cluster algorithm
- Amplitude-goniometric method.

The simplest one is matrix method. It uses the grid (matrix) covering the operating area in the map. The grid is viewed as a raster, bearings are mapped using raster algorithm and summarized by the amplitude in the grid cells. As a result we get a three-dimensional surface formed by the bearing lines, which amplitude will be higher in those cells where the bearings are more often overlapping and bearing signal has higher value. It is most probable that the source is located within the cell with the most accumulated amplitude.

Cluster algorithm is a further modification of the matrix algorithm. It also uses a matrix grid covering the operating area in the map. However the grid cells accumulate not the bearing lines, but bearing lines cross points — triangulate task solutions. As a result we get a three-dimensional surface formed with the bearing cross points. The amplitude will be higher in those grid cells where the bearings cross each other more often. The disadvantage of the cluster method is great amount of calculations, its advantage is the possibility to locate the random number of radio signal sources operating at one frequency.

Starting from 2006 a new algorithm of radio signal source coordinate calculation under movement has been included unto SMO-KN application – amplitude-goniometric method. The method is based on bearings calculation and assessment of the strength of the electromagnetic field from the radio signal source. Its main advantages are the possibility to position the radio signal source when the bearing base is small, for example, when the mobile station is moving to the source clear display of the sector or area of the most probable location of the source even under strong interference conditions. Fig. 34 and 35 show SMO-KN windows corresponding to the case when the mobile station is determining the coordinates of the radio signal source at 436.5 MHz frequency. As we can see from the very beginning of the station movement the electronic map shows the sector of the most probable source location. Then as the car moves the sector becomes a closed are, the calculated point (yellow circle in the map) moves closer to the point of the actual location of the source (see Fig. 28.)

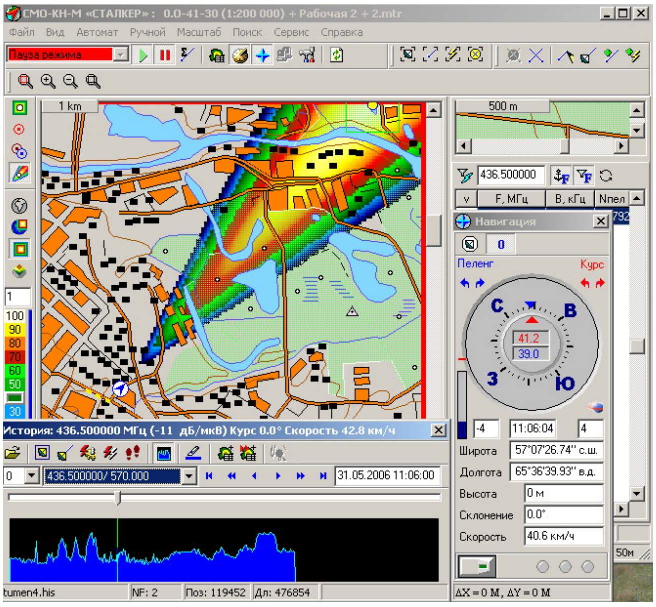

Fig. 34. Amplitude-Goniometric Method. Beginning of Source Coordinates Detection

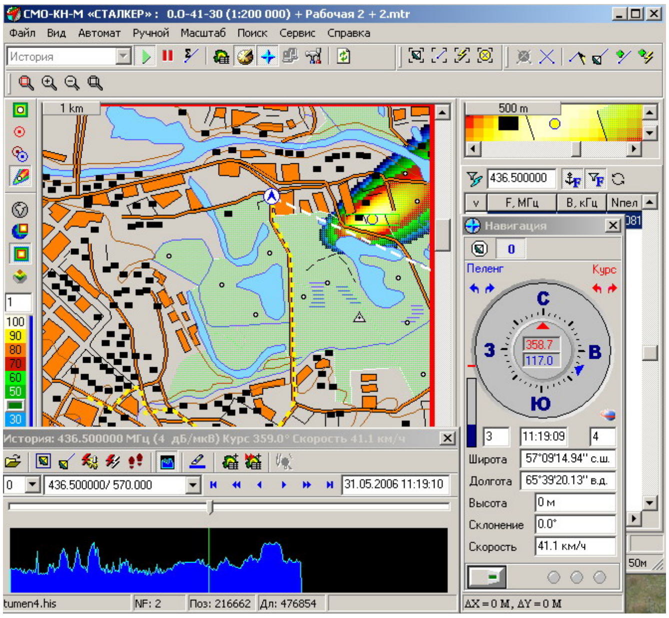

Fig. 35. Amplitude-Goniometric Method. The process of Source Coordinates Detection is Close to its End

This method is highly efficient in detecting the sources positioning and is quite convenient for bearing the radio signal sources by a single station under movement, particularly in urban conditions.

Constant direction finding of sources when moving along the route in urban conditions gives a great number of false bearings. If the car speed is fixed high bearing rate provides decreasing the probability of loosing “good” route sections where bearing values are close to true ones. ARTIKUL-M equipment is capable of calculating over 20 bearing per second and when using an additional specialized calculator ARC-S5 – up to 100 bearing per second. This means that if the car moves with average speed of 40 km/h bearings will be calculated each 0.1 -0.75 m. The advantages of the method of calculation of sources coordinates under movement include the possibility to operate the system in an automatic mode without the operator, high concealment of the station operation, constant bearing calculation, allowing locating the sources that are seldom on air.

## Conclusion

This paper deals with the composition, structure, management organization and functions of the equipment and software of ARC-POM multi-position systems. It has been shown that these systems may be developed based on three types of stations: stationary, mobile and portable unfolded.

The operability of the multi-position system depends on one factor - reliable system of data transfer. For data exchange between the stationary stations it is expedient to use high-bit-rate channels and for organization of communication with mobile and unfolded stations – low-bit-rate systems. In the latter case depending on the system requirements and purpose autonomous narrow-band radio modems or cellular system radio modems may be used. Slave stations of the system are operated in remote control mode.

The system equipment has unified structure. Its heart is ARGAMAK portable digital panoramic radio receiver. Its technical parameters ensure system efficiency on the whole. Despite the fact that some devices are portable ARC-POM system has high rate of review and direction finding, considerable sensitivity and wide dynamic range.

Unified radio equipment of ARC-POM system allows using a unified software set at all stations. This makes system station installation faster, operators training easier and work simpler. ARC-POM software package implements all the necessary functions of direction finding, positioning, parameters measuring of RSS with random broadcast types, supports remote control of system stations via both high-bit-rate and low-bit-rate communication channels. In the latter case the amount of transferred data is decreased by compressing.

The system software package implements the complete set of functions allowing fulfilling most of the radio monitoring tasks. Processing and saving of considerable bulks of information received from the station distributed along the territory, work with mapping, spectrum, time data in real time mode and post-processing, as well as friendly interface ensure efficient use of ARC-POM system for radio control purposes.

System operation may be controlled from the stationary main stations or from the mobile stations. At the same time the mobile station may fulfill the tasks independently from the network of stationary direction finders with the preferable algorithm of radio signal source positioning being the amplitude-goniometric method. This method combines calculation efficiency, clearness of result displaying and simple use in direction finding under movement.