FIG 1 Two 19-inch instruments – the DF Converter R&S®ET 550 and the Digital Processing Unit R&S®EBD 660 – suffice to cover the entire VHF / UHF range. For expansion of this range from HF through to UHF, two DF converters and the R&S®EBD 660 are required.

Digital Broadband Search Direction Finders R&S DDF®0x A

Unrivalled performance and compact design

The new family of R&S DDF®0x A broadband search direction finders unites top-class RF engineering and the fastest digital signal processing components which yields an unrivalled combination of sophisticated performance and compact design.

Extremely fast and precise

The R&S DDF®0x A broadband search direction finders feature a high, occupancy-independent scanning speed of up to 20 GHz/s plus great reliability of bearings and a thoroughly object-oriented system interface. Whether they are used as stationary or mobile single workstations or as search and interrogation direction finders in complex radiomonitoring systems – they provide previously unheard-of potential for automatic operation. Three different configurations are available:

- **R&S DDF®01 A** HF range (0.3 MHz to 30 MHz)
- **R&S DDF®05 A** VHF / UHF range (20 MHz to 3000 MHz)
- **R&S DDF®06 A** HF to UHF range (0.3 MHz to 3000 MHz)

Design and function

Basically, each of the new direction finders consists of the Digital Processing Unit R&S®EBD 660 and one or two DF converters (FIG 1). The DF converter and digital processing unit constitute a fully coherent, three-path measuring system that is similar to a three-channel vector analyzer and divides the signals supplied by the antenna system into frequency channels using a filter bank and performs quasi-parallel calculation of the directions of incidence in up to 10 000 channels.

The DF converters filter the antenna signals and convert them to fixed intermediate frequencies with a bandwidth of up to 10 MHz. The DF Converter R&S®EH 110 is provided for the HF range, whereas the DF Converter R&S®ET550 handles the entire VHF/UHF range. The two converters feature excellent noise and linearity characteristics so that high-precision bearings are obtained even when adjacent-channel power is high. The third-order intercept of the HF Converter R&S®EH110 is 40 dBm and that of the R&S®ET550 typ. 20 dBm. These values are attained at a carrier offset of 30 kHz (HF) and 1 MHz (VHF/UHF) and are even significantly higher at larger carrier offsets.

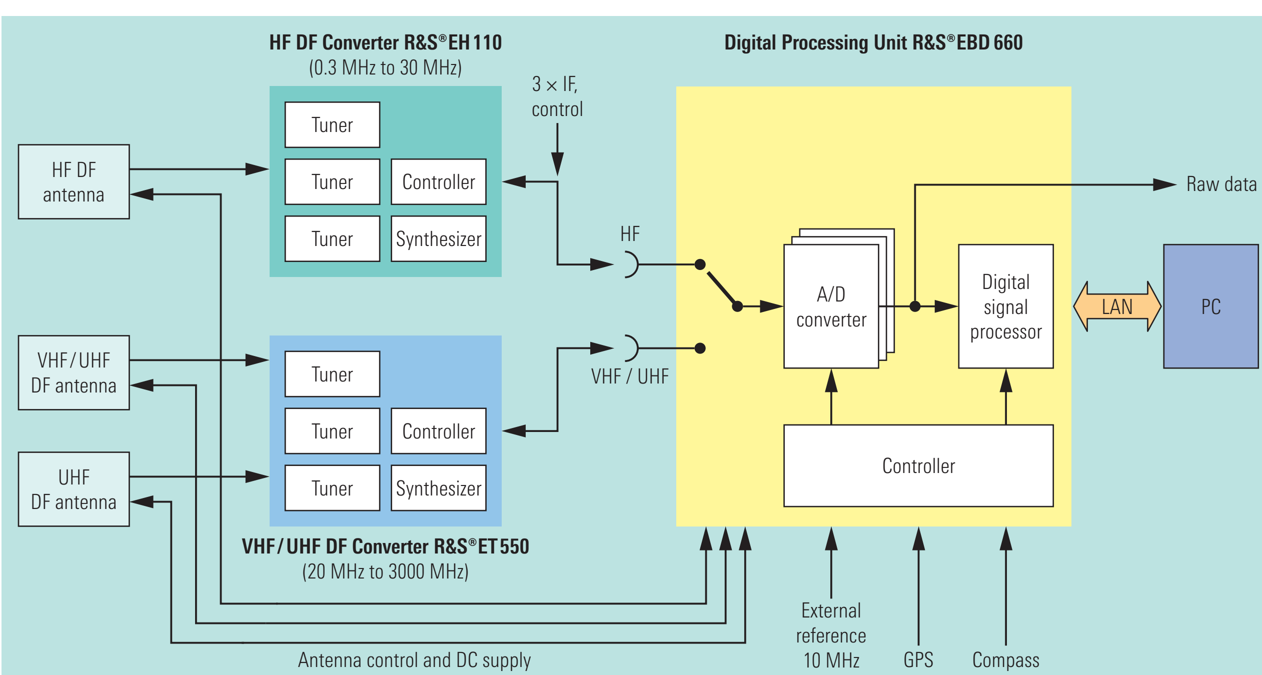
As phase noise is decisive for the permissible adjacent-channel power, the R&S®EH110 features –110 dBc/Hz (1 kHz frequency offset) and the R&S®ET550 an unrivalled –120 dBc/Hz (10 kHz).

The core of each R&S DDF®0xA is the **Digital Processing Unit R&S®EBD660** (FIG 2). It contains three parallel measurement paths with highly linear A/D converters at 14 bit resolution. The high sampling rates of the A/D converters and the resulting high decimation gain in the case of filtering plus the analog control circuit yield an excellent dynamic range: At a resolution bandwidth of 1 kHz, for example, it is more than 140 dB. Decimation is followed by the main filtering process that takes place in a digital filter bank. The use of prime FFT made it possible to implement the channel spacings usual with receivers without suffering any loss in speed (100/50/25/20/12.5/8.33/5/2/1 kHz in the VHF/UHF range; 20/10/5/2/1/0.5/0.2/0.1 kHz in the HF range). Many manufacturers, however, use the simpler Radix2 FFT method. This type of FFT only permits channel spacings of 1/2/4/8 kHz, for example, which do not coincide with the channel spacings used in practice and thus make it difficult to hit the channel precisely.

Filtering in the R&S DDF®0xA yields the complex amplitudes of up to 10000 channels at a time. These amplitudes are averaged if there are bottlenecks in data traffic to the PC and in order to achieve higher sensitivity. They are provided with the amplitude and phase correction values for the balance of the receivers and distributed to 16 signal processors for DF value calculation. The DF values plus the level values and the time stamps inserted before filtering are transferred to the communication processor that makes the information available to the control and display PC or the system network via an Ethernet interface at a data rate of 100 Mbit/s (FIG 2). This ensures an unvaryingly high scanning speed even in the case of very high channel occupancy. In the fixed frequency mode, the filtered data stream of the reference path is routed to a separate processor where the center channel is demodulated using a demodulation bandwidth that can be selected independently of the DF bandwidth.

The **DF methods** implemented as standard are based on the algorithms for the advanced principle of the correlative interferometer and for the tried-and-tested Watson-Watt method; the evaluation method is automatically selected depending on the connected antenna and the set frequency range. The Watson-Watt method is especially used in the HF range when space is at a premium, such as in vehicular applications in conjunction with the Antenna

FIG 2 **Basic configuration of the Broadband Search Direction Finder R&S DDF®06A for the frequency range 0.3 MHz to 3000 MHz.**



R&S®ADD119 and for semi-mobile HF applications. The correlative interferometer has become the standard DF method of today. In contrast to the Watson-Watt method, it provides high bearing accuracy even in environments with interference by obstacles and at low signal levels. The correlation algorithm employed as standard in the new direction finders uses nine spatial sampling values of the incoming waves obtained by 9-element circular antenna arrays in time multiplex in three parallel paths. This dimensioning makes for the following:

- Excellent bearing accuracy with a low number of antennas, especially in difficult environments (i.e. multiple-wave fields)
- Low expenditure on instrumentation (including reduction of parameters involved such as dimensions, weight, number of antenna cables, current drain, purchase price)
- Short measuring times owing to state-of-the-art DSP technology

Operating modes

The Direction Finders R&S DDF®0xA can operate in three different modes: SCAN, SEARCH and FFM (fixed frequency mode).

In the **SCAN mode**, the channels of a frequency range of up to 10 MHz (realtime bandwidth in the VHF/UHF range) are simultaneously detected and DFed. After the measurement has been completed, the measurement window is shifted by the realtime bandwidth by retuning the DF converter, and a new measurement is performed.

The **SEARCH mode** is equivalent to frequency scanning. When a signal has been detected, the direction finder dwells on this signal for a preselectable time; the bearings are presented in the same way as in FFM.

In **FFM** only one frequency channel is investigated. To obtain an optimal dynamic range, the bandwidths of the analog prefiltering circuit can be reduced to 20 kHz in the HF range and to 120 kHz in the VHF/UHF range. In addition to direction finding, an IF spectrum with a user-selectable width of 1 MHz, 5 MHz or 10 MHz is calculated for easy selection of the signal to be detected and demodulated.

Three different types of squelch-controlled averaging are available in FFM:

- **NORMal** (signals above the selected threshold are averaged for a selectable period of time; after this period has elapsed or the signal has dropped below the threshold, the averaging memory is cleared)
- **GATE** (same as NORM, except the averaging memory is not cleared after the signal has dropped below the threshold, which is important in the case of pulsed signals or modulation gaps)
- **CONTinuous** (averaging takes place irrespective of the set threshold)

Optimized operation

As a rule, an external PC is used to operate the new direction finders and to display the results. A fast Ethernet system interface connects the PC and the direction finder. The user interface supplied (FIG 3), which runs under Windows 2000/XP, is similar to the sophisticated user interfaces of the R&S DDF®0xM und R&S DDF®0xS direction finders. It has been further enhanced as follows:

- Enlarged measurement windows
- Operating elements that are always required are permanently visible and conveniently arranged
- Numerous possibilities for visualizing measurement results in all modes

System compatibility ensured

The new direction finders are outfitted with a fast Ethernet system interface. The software interface for controlling the direction finder is based on CORBA (common object request broker architecture), a platform-independent component model. For maximum speed the result data is output via TCP/IP as standard. Owing to these features and the comprehensive interface documentation, only a minimum of effort is required to integrate the direction finder into complex systems – even systems with customer-specific software.

As regards system applications, it is particularly important that the time information can be precisely allocated to the measurement results. With the R&S DDF®0xA, time allocation takes place directly after A/D conversion so that the delays of the digital filters are of no importance. The GPS seconds pulse should preferably be used as the time standard if maximum accuracy requirements are to be met. Precise time information and strictly deterministic scanning sequences in the direction finder's DSP network are moreover the prerequisites for the synchronous operation of several direction finders (option R&S DDF®-TS), e.g. for locating frequency-agile transmitters with the R&S®ScanLoc radiolocation software from Rohde&Schwarz.

Interfaces for compasses, GPS and external frequency standard are of course available. At the customer's request, the direction finder can be equipped with a raw-data interface (option R&S DDF®-DR) that stores the baseband data of all three receive paths to an external medium.

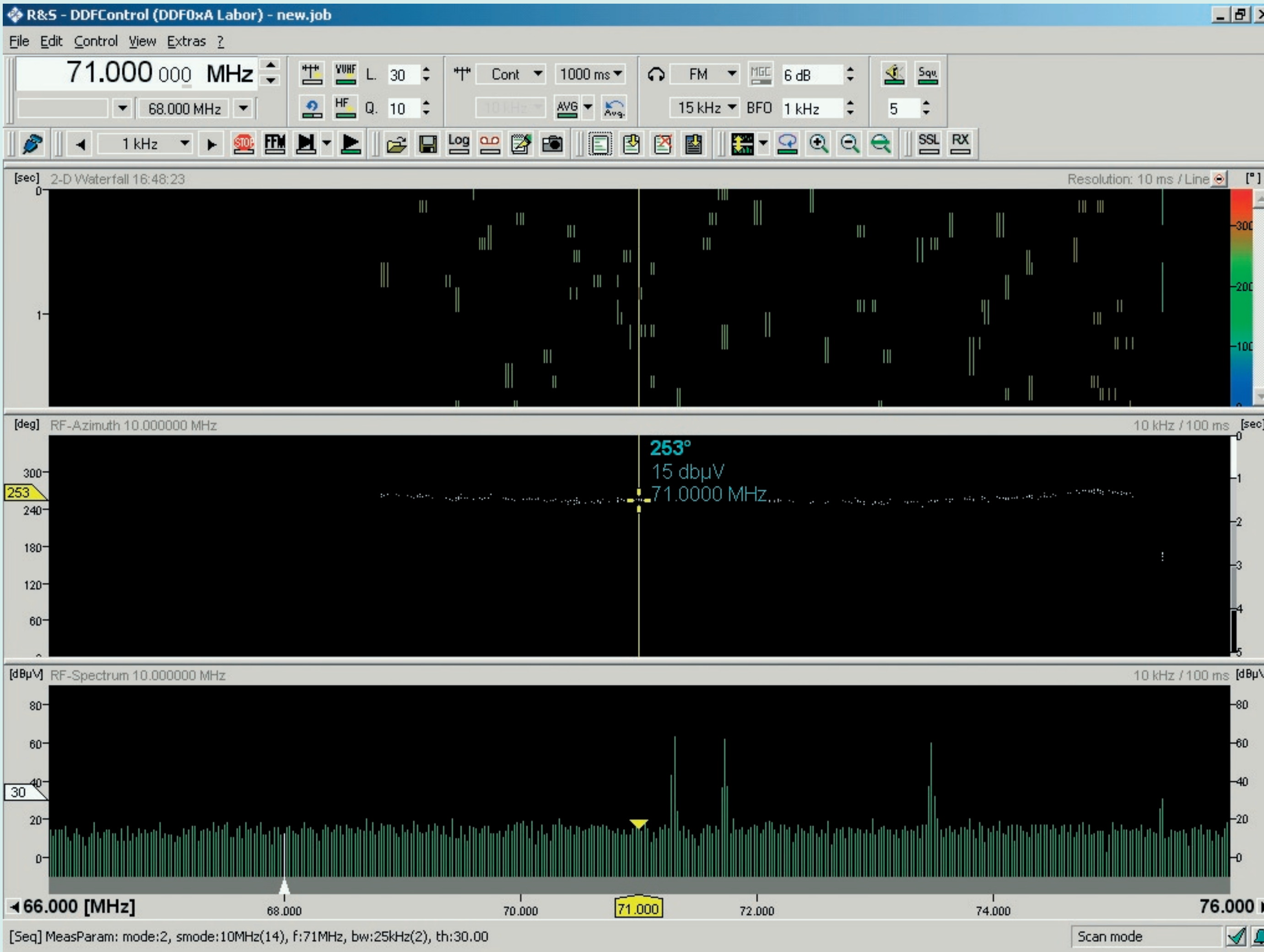


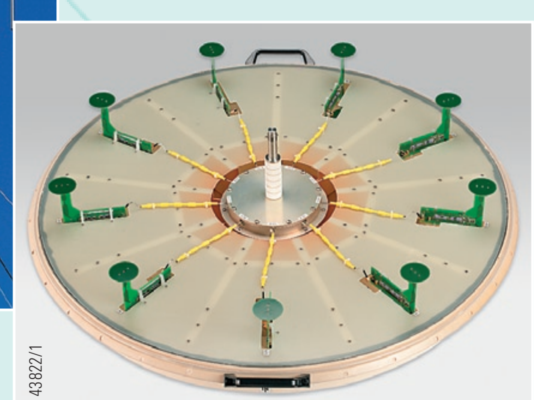
FIG 3 User interface of the Broadband Search Direction Finder R&S DDF®0xA in SCAN mode (span 10 MHz). The screenshot shows a frequency hopper with 6 MHz hop width. The measurement windows for azimuth versus frequency, azimuth versus frequency and time as well as level versus frequency are displayed.

Antennas for the new direction finders

The antennas for the Direction Finder Families R&S DDF®0xM and R&S DDF®0xS can be used with the new R&S DDF®0xA direction finders without any restrictions. The wide range of mobile and stationary antennas for the frequency range from 300 kHz to 3 GHz allows a custom solution to be configured for every application (FIG 4). The VHF/UHF DF Antenna R&S®ADD150 has been modified to provide about 10 dB higher sensitivity in the frequency range from 20 MHz to 100 MHz (FIG 5).

FIG 4 DF antenna system for 20 MHz to 3000 MHz in stationary use.

FIG 5 VHF/UHF DF antenna (without top cover) for 20 MHz to 1300 MHz with improved sensitivity in the range 20 MHz to 100 MHz.



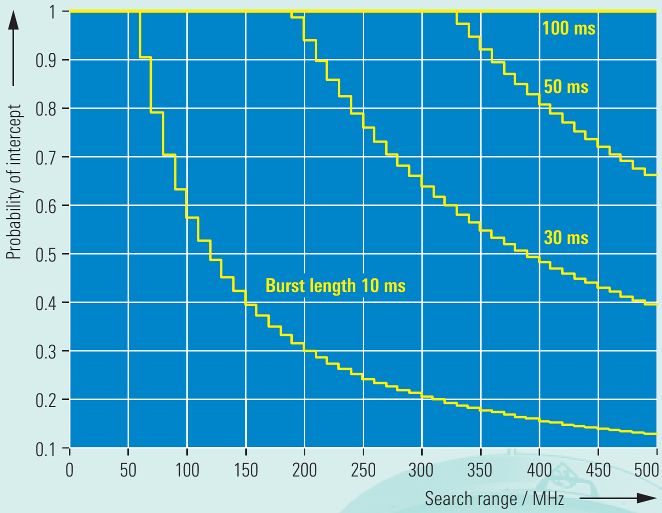


FIG 6
Probability of intercept for a single burst depending on the search range at a resolution bandwidth of 50 kHz (correlation method).

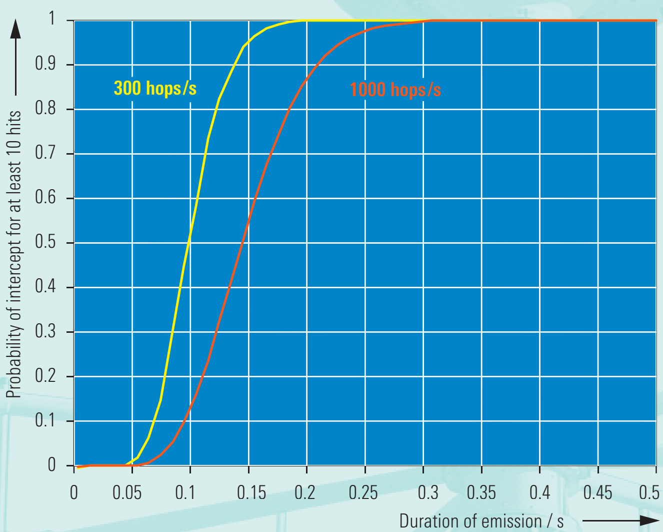


FIG 7
Probability of intercept of frequency-hopping signals in the VHF/UHF range as a function of the duration of the emission for a 60 MHz search range of the R&S DDF®05A direction finder and with at least 10 hits (direction finding with correlation antenna). The hopping range of the emitter and the overlapping range were also assumed to be 60 MHz. The resolution bandwidth is 50 kHz.

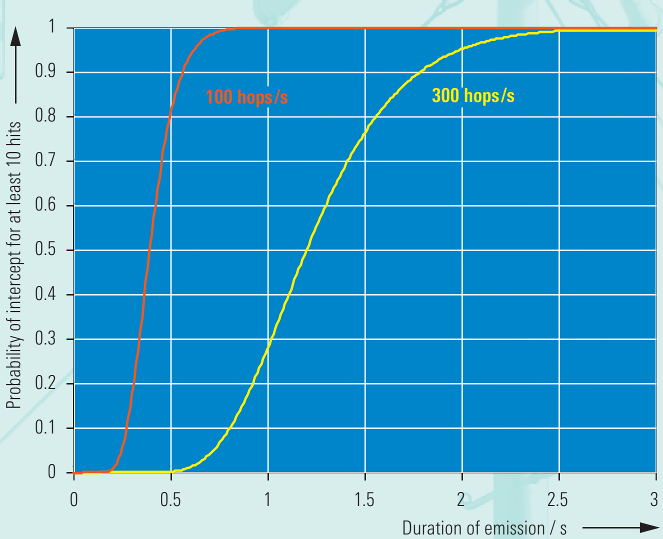


FIG 8
Probability of intercept of frequency-hopping signals in the HF range for at least 10 hits as a function of the duration of the emission (Watson-Watt evaluation). The hopping range and the search range were assumed to be 2 MHz, and the overlapping range is 1 MHz. The resolution bandwidth is 1 kHz.

An essential criterion of system compatibility is the efficiency of data reduction. As standard, the direction finder provides azimuth, level and quality filters in order to suppress irrelevant signals.

Detection of time-compressed and spread-spectrum signals

The ideal search direction finder is able to securely detect short-term signals of unknown center frequency and bandwidth in the relevant frequency range and to take the bearings with high precision.

While optimized DF methods and antenna arrays as well as excellent noise and linearity specifications ensure high bearing accuracy even under difficult conditions, short measurement times and the number of simultaneously processed frequency channels make it possible to detect short-term signals even without previous knowledge (e.g. of frequency range, bandwidth, time of emission) and to gain significant information from the collected data through high measurement precision.

Since information is transmitted in ever wider frequency bands, modern search direction finders must be able to monitor a large number of channels in the frequency ranges of interest in parallel and to detect and DF the signals almost simultaneously. The new Direction Finders R&S DDF®0xA can detect and average signals and take bearings in a maximum of 10000 channels in parallel. This means that frequency bands of up to 10 MHz (VHF/UHF range) with a resolution of 1 kHz are processed simultaneously. To handle wider frequency ranges, the 10 MHz window is shifted step by step at high speed in the SCAN mode. The processing speed is independent of channel occupancy.

Search direction finders from Rohde & Schwarz – a long-standing tradition

As early as1989, Rohde & Schwarz launched the world's first integrated search direction finder: the Integrated Broadband Signal Interception and Direction Finding System R&S®PA 2000 which used a fast-switching, conventional scanning receiver. It was followed by the Digital Scanning Direction Finder R&S DDF®0xS (1994) which was the first to make intensive use of digital signal processing and especially of fast Fourier transform (FFT).

An essential innovation compared to the previous generation of digital multichannel direction finders is the capability for threshold-controlled averaging of the three measurement channels in the SCAN mode. This feature improves sensitivity if signals are detected multiple times because of their duration or their repeated occurrence, but does not reduce the probability of single events being intercepted. In addition, it prevents signal loss even if the speed of the subsequent data processing circuit is low.

Interception of burst transmissions

For a burst to be intercepted, its duration must be at least as long as the required measurement time of the direction finder. With the R&S DDF®05A, it is only 0.5 ms at a resolution bandwidth of 50 kHz, for example, and with correlative evaluation. Other essential influencing quantities are the following:

- Frequency range in which the burst can occur (= search range of the direction finder or number of channels)
- Duration of burst

As the R&S DDF®05A processes a 10 MHz wide band in a single measurement, search ranges of up to 10 MHz and bursts with a duration of at least twice the measurement time can be detected, i.e. the probability of intercept is 100%. Shorter measurement times or larger search ranges reduce the probability of intercept. FIG 6 illustrates the probability of intercept for bursts of differing length as a function of the search range.

Interception of frequency-hopping (FH) signals

An FH emitter outputs a burst sequence where the frequency channel of each individual burst is selected according to a random sequence. The following parameters are decisive for intercepting such signals by means of a direction finder:

- Hopping range of the FH emitter (number of channels)
- Search range of the direction finder (number of channels)
- Overlapping between hopping range of emitter and search range of direction finder
- Entire duration of the emission
- Length of time the FH emitter dwells on a frequency channel
- Measurement time of the direction finder
- Specified number of hits (i.e. detection and direction finding of single bursts) for secure interception

As an example of the performance of the VHF Direction Finder R&S DDF®05A, FIG 7 shows the probability of intercept of FH emitters with different hopping rates (=1/dwell time per hop), and FIG 8 illustrates the situation for the HF range if the Antenna R&S®ADD119 is used (Watson-Watt evaluation).

Interception of DSSS signals

DSSS (direct sequence spread spectrum) signals are difficult to intercept because of their low spectral power density. If the cooperative receiver has a system gain of 17 dB due to despreading (corresponds to a spreading factor of about 50) and a signal-to-noise (S/N) ratio of 15 dB before demodulation, for example, a non-cooperative receiver at the same distance from the emitter and with identical antenna gain would have to perform detection and direction finding at an S/N ratio of –2 dB.

The R&S DDF®0xA direction finders feature high system gain in the correlation mode and are therefore able to take precise bearings even at very low S/N ratios. The high system gain is obtained by averaging and generating synthetic directional antenna patterns when the antenna signals are correlated with the comparative data. To successfully process DSSS signals, it is therefore necessary to select an antenna with a diameter that is large in comparison to the wavelength and to perform as much averaging as possible.

Franz Demmel, Ulrich Unselt

More information and data sheet at www.rohde-schwarz.com (search term: DDF)