



低空经济的安全保障： 复杂电磁环境下的频谱监测与干扰查找

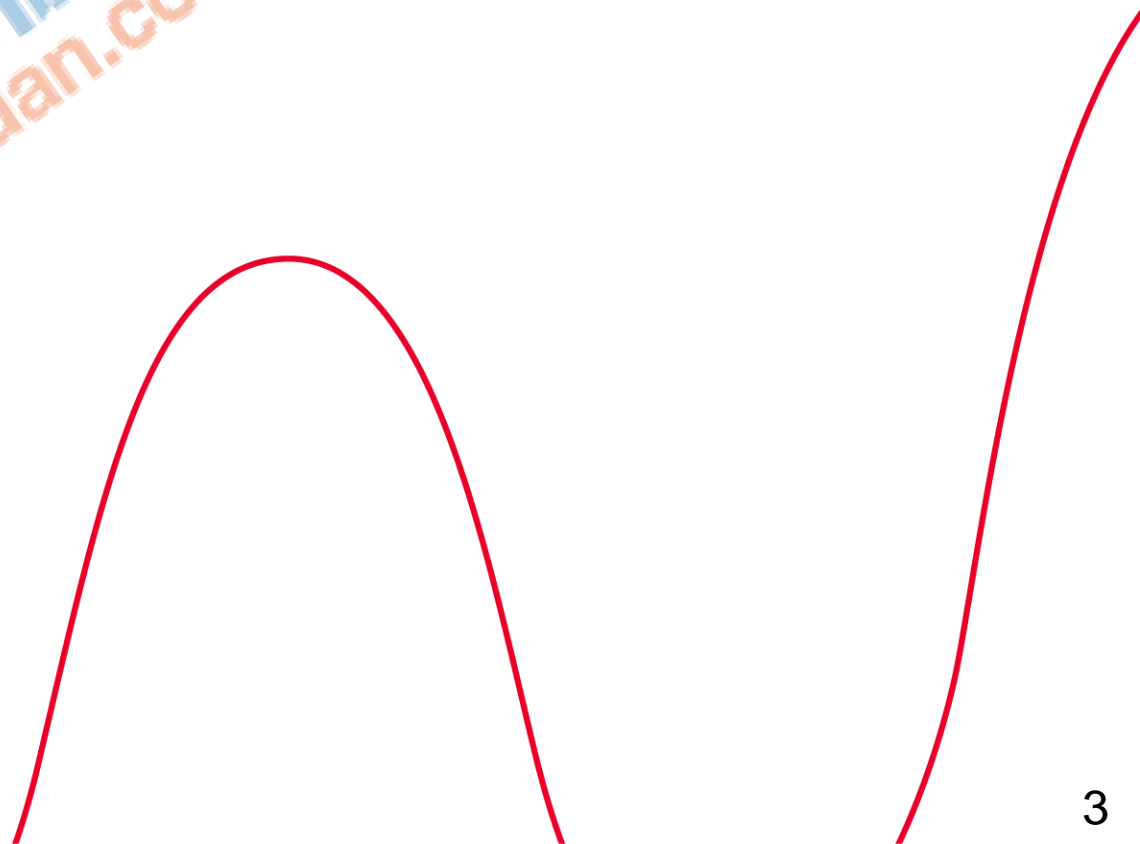
芮艳华 应用工程师
2024.07

日程安排

- 低空飞行器相关的无线电频谱技术
- Fieldfox 手持表
 - 实时频谱分析
 - OTA测试
 - 手动测向
 - 信道扫描
 - IQ数据记录
 - EMI预兼容测试
- KSMS频谱管理、信号监测软件
 - 频谱监测, 信号记录
 - 站点数据库支持
 - IQ流盘记录回放
 - 频谱数据记录回放
 - 频谱占用度测试



低空飞行器相关的无线电频谱技术



多种无线通信子系统应用于无人机和eVTOL

无人机相关

- 实时图像传输系统
- 实时控制数据传输系统
- 业务数据传输系统
- 基于GNSS的导航系统
- 基于微波毫米波雷达的避障系统



多种无线通信子系统应用于无人机和eVTOL

EVTOL 相关



- 飞行器与地面控制站，其他飞行器及空管的通信系统
- 数据链路，飞行器与地面控制站之间的数据链路系统
- 卫星通信系统
- 基于GNSS的导航系统

无人机探测和反制设备

无人机探测设备

- Ku波段雷达
- X波段雷达
- 探测距离1~8公里
- 重量 15kg ~35kg

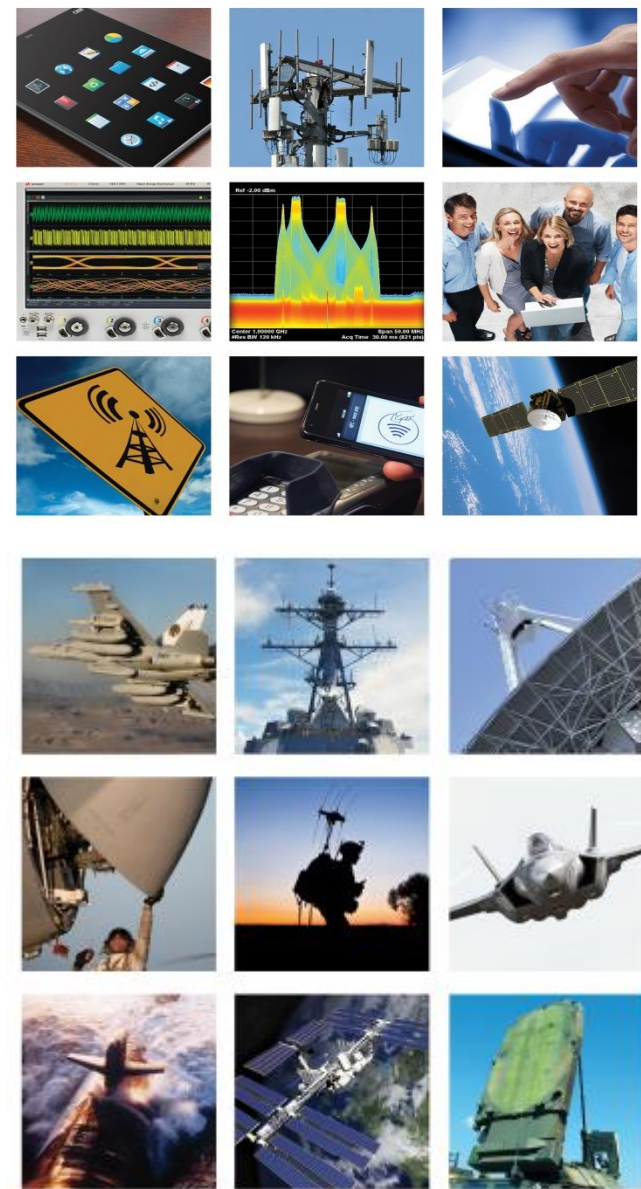


无人机反制设备

- 发射2.4GHz或者5.8GHz干扰信号
- 发射GNSS导航干扰信号

低空空域中存在的无线通信系统

- 无线网络 (Wireless Communication Network)
- 雷达 (Auto and Navigation)
- 卫星 (Satellite)
- 微波回传 (Microwave backhaul)
- 公共安全无线系统 (Public safety radio system)
- 列车控制 (Positive train control)
- 广播 (Broadcasting)
- 智能电网 (Smart grid)
- Wi-Fi 网络



低空空域的频谱环境



充满相互干扰！

低空频谱管理&信号监测方案的需求

便携,
更靠近发射源

测向/TDOA
干扰源定位

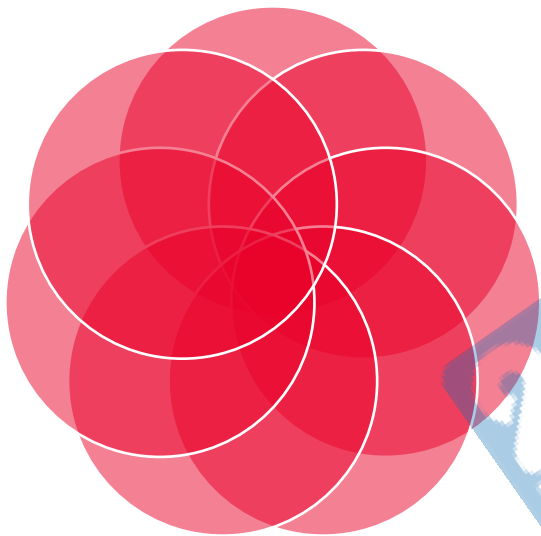
更高的频段, 更
宽的带宽

路测, 监测某个
航段是否有强干
扰信号

实时频谱分析,
查找瞬态信号

信号管理软件, 管理
协调多个站点

信号的记录与回放



Fieldfox手持表



21世纪电源网
21dianyuan.com

FieldFox N9912C – 单一型号, 无限可能



频率范围: 3 kHz to 4/6.5/10 GHz

实时频谱分析带宽: 10/40 MHz

器件测试

1. Cable and antenna test
2. TDR
3. VNA / Time domain
4. Vector voltmeter
5. Power meter
6. Tracking generator/pulse generator

信号分析

7. Spectrum analysis
8. Real-time spectrum analysis
9. Time gating
10. Interference analysis
11. Channel scanner
12. Analog demodulation (AM/FM)
13. OTA LTE, 5G OTA
14. Pulse measurement with peak power sensor
15. Frequency counter
16. EMI pre-compliance test
17. EMF measurement
18. Direction Finding(DF)



功能

19. GNSS
20. DC voltage source
21. Secure erase
22. Mapping
23. Frequency extender

宽带毫米波 Fieldfox

多样的测量选件，满足信号监测需求

频率范围: 300kHz – 54GHz (110 GHz 通过混频器)
实时频谱分析带宽: 10/40/120MHz

器件测试

1. Cable and antenna test
2. TDR
3. VNA / Time domain
4. Noise figure
5. Vector voltmeter
6. Power meter
7. Extended range transmission analysis (ERTA)
8. Tracking generator

信号分析

9. Spectrum analysis
10. Real-time spectrum analysis
11. Time gating
12. Interference analysis
13. Channel scanner
14. Analog demodulation (AM/FM)
15. OTA LTE, 5G OTA
16. IQ analyzer, IQ streaming
17. Pulse measurement with peak power sensor
18. Frequency counter
19. Keysight VSA 89600 link
20. Phased array antenna control
21. EMI, EMF measurement
22. DF/TDOA



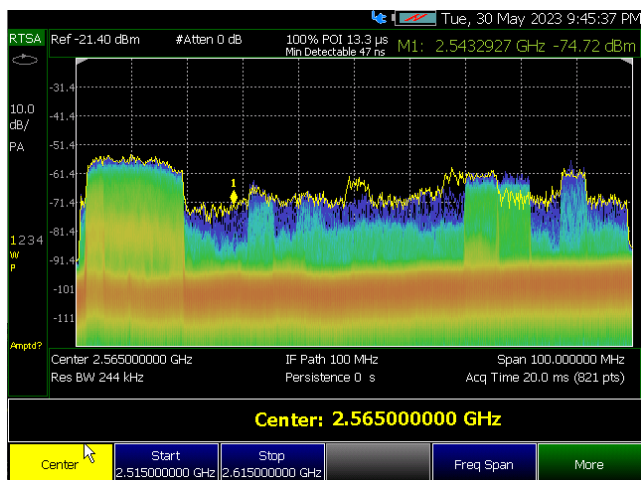
功能

23. GNSS
24. DC voltage source
25. Secure erase
26. Mapping
27. Frequency extender

瞬态信号、突发信号的查找与捕获

实时频谱分析

- 40 MHz 实时频谱分析带宽
- 6.12 us 100% 截获概率信号持续时间
- 11 ns 最短可捕获信号持续时间



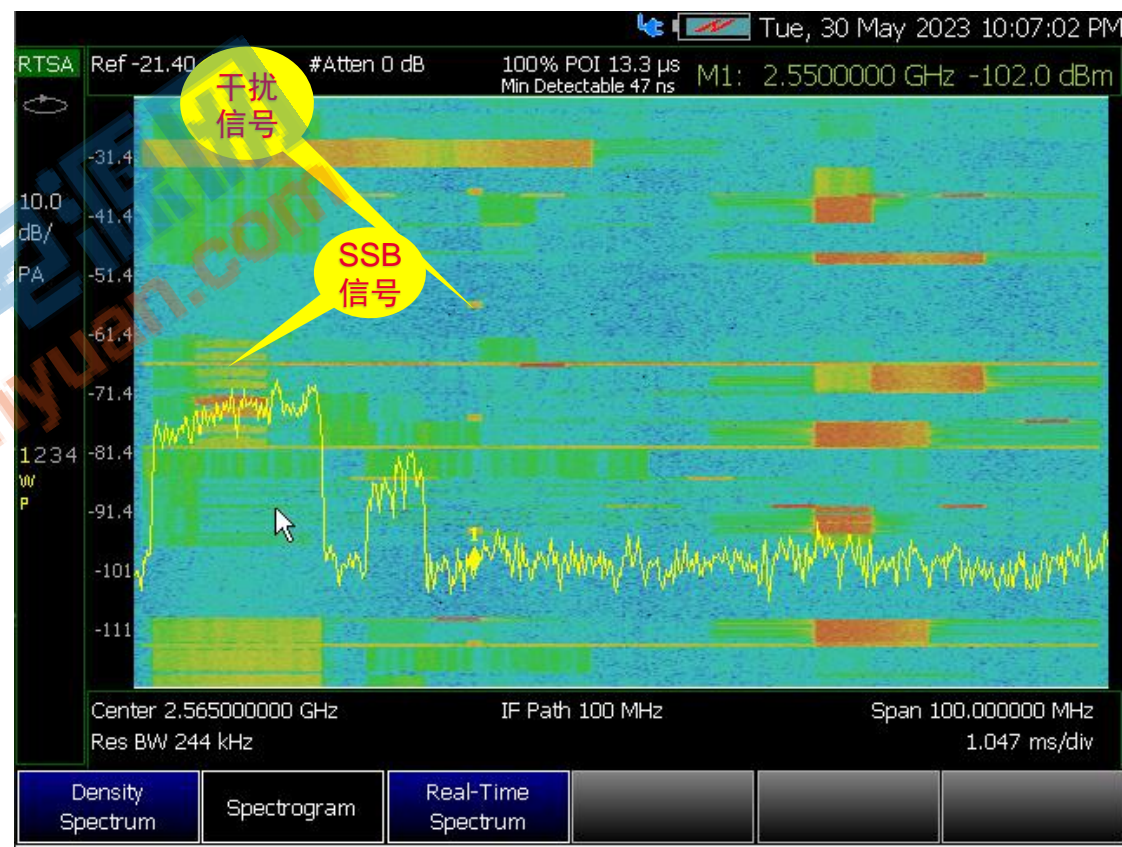
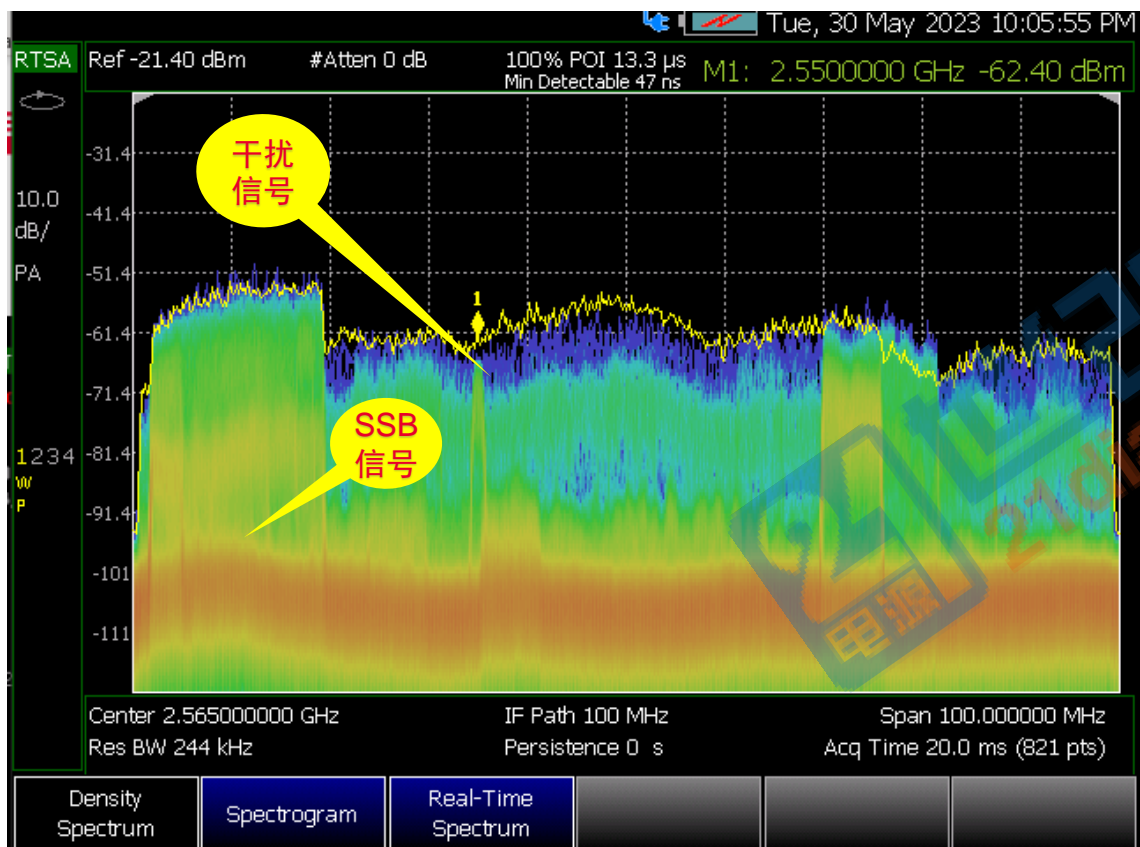
Density display: 2.565 GHz 5G NR spectrum



Spectrogram display: 2.565 GHz band

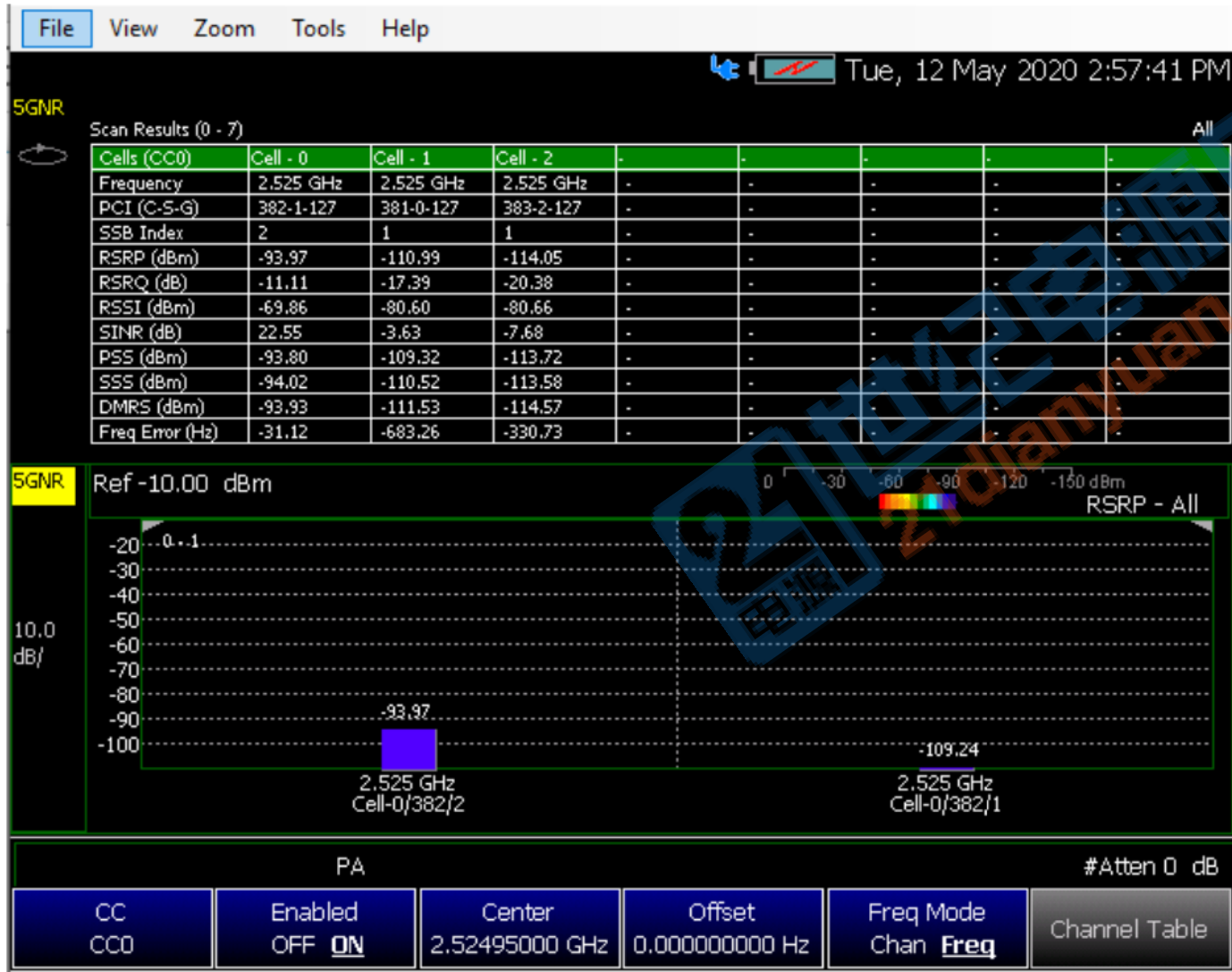


实时频谱查看掩藏在5G NR信号下的突发信号



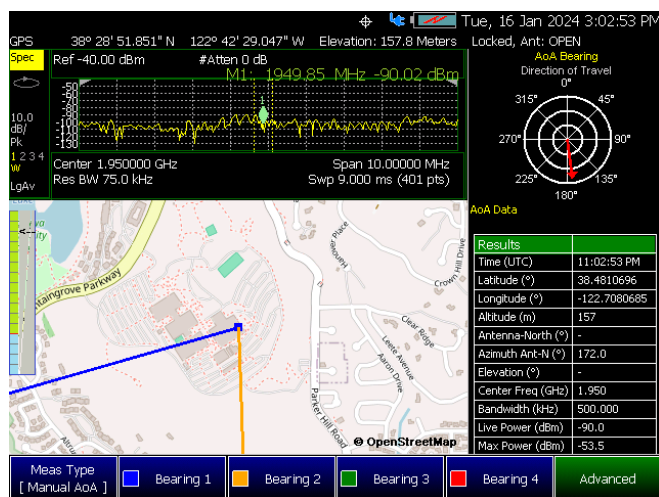
OTA 空口测量获取更多信号信息

5G NR OTA为例



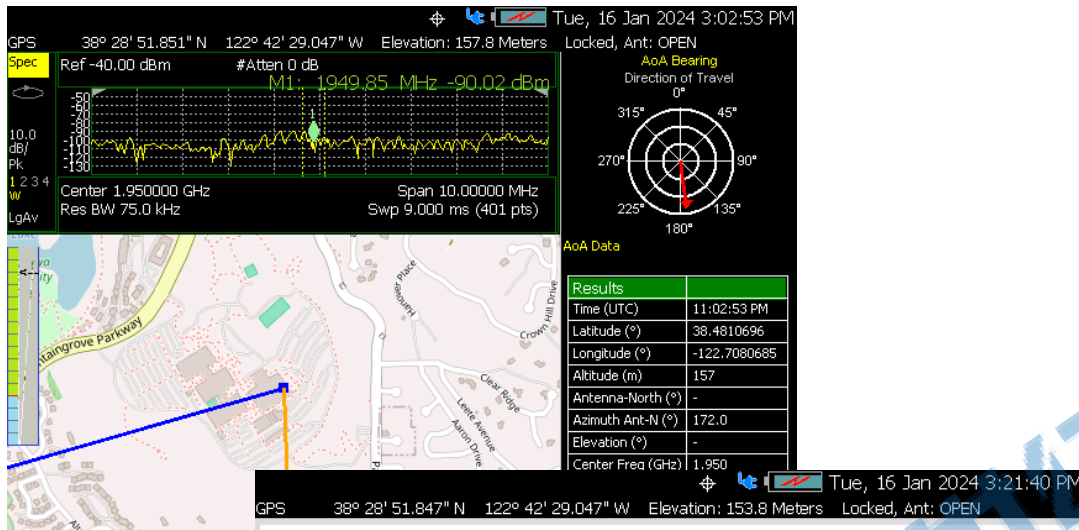
- PCI
- RSRP
- RSRQ
- PSS and SSS power
- SINR
- DMRS power and SINR
- SSB index (beam index)
- Frequency error
- EIRP
- SSB location/auto detection
- Top N cell scanning
- Top N component carrier scanning
- Demodulation bandwidth:100 MHz

手动测向干扰查找 – 选件 366



- Manual DF antenna: 85574A (20MHz to 8.5 GHz, optional to 9 kHz)
- Fieldfox option: 366
- Require SA or SA option and GPS option
- Triangulate emitter using directional antenna

手持DF天线 带数字罗盘



GPS 38° 28' 51.851" N 122° 42' 29.047" W Elevation: 157.8 Meters Locked, Ant: OPEN

Spec Ref -40.00 dBm #Atten 0 dB

M1: 1949.85 MHz -90.02 dBm

Center 1.950000 GHz Res BW 75.0 kHz Span 10.00000 MHz Swp 9.000 ms (401 pts)

AoA Bearing Direction of Travel 0°

AoA Data

Results	
Time (UTC)	11:02:53 PM
Latitude (°)	38.4810696
Longitude (°)	-122.7080685
Altitude (m)	157
Antenna-North (°)	-
Azimuth Ant-N (°)	172.0
Elevation (°)	-
Center Freq (GHz)	1.950

Meas Type [Manual AoA] Bearing 1

Electronic Compass Calibration

IMPORTANT! Make sure the Antenna is oriented on the horizontal plane.

IMPORTANT! Please keep the Origin at the same point in 3D space during ALL rotations. Antenna should move as little as possible away from this point.

NOTE: The armrest is not required to be attached for calibration.

Select **Start** to begin antenna calibration.

Start Preset Exit

85574A	Manual HH DF antenna
85574A option 100	20MHz to 8.5 GHz manual DF antenna
85574A option 209	Frequency extension 9kHz to 20MHz for option 100
Frequency	9kHz to 8.5 GHz
Gain	Up to 6 dB depending on the frequency
Low noise amplifier	8 to 18dB band dependent
Built in digital compass	3 degree / calibration and environment dependent
IP	56
User trigger	Manual trigger button on antenna

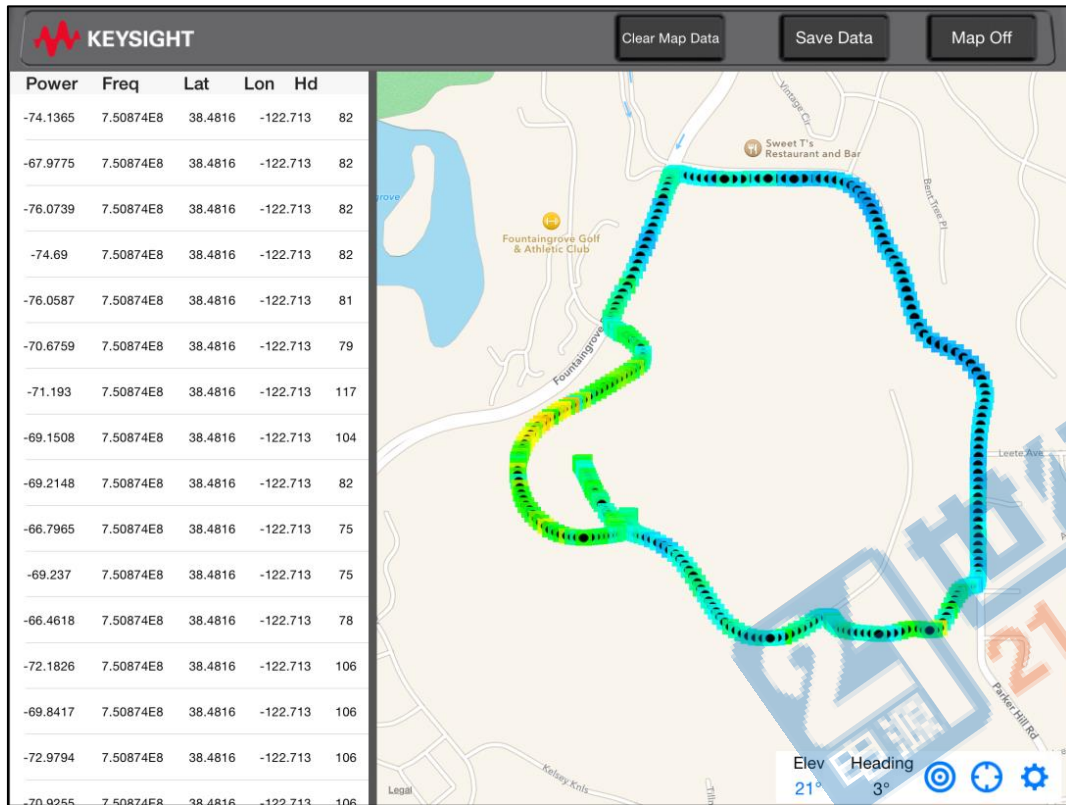
信道扫描 (Channel Scanner)



- Scan up to 20 channels, by range or by list
- Channel list can be saved and recalled
- Display types: Vertical /Horizontal bar chart, strip chart

- Record into CSV or KML file format
- Recalled CSV, and re-save it as KML
- Playback data

在地图上查看结果



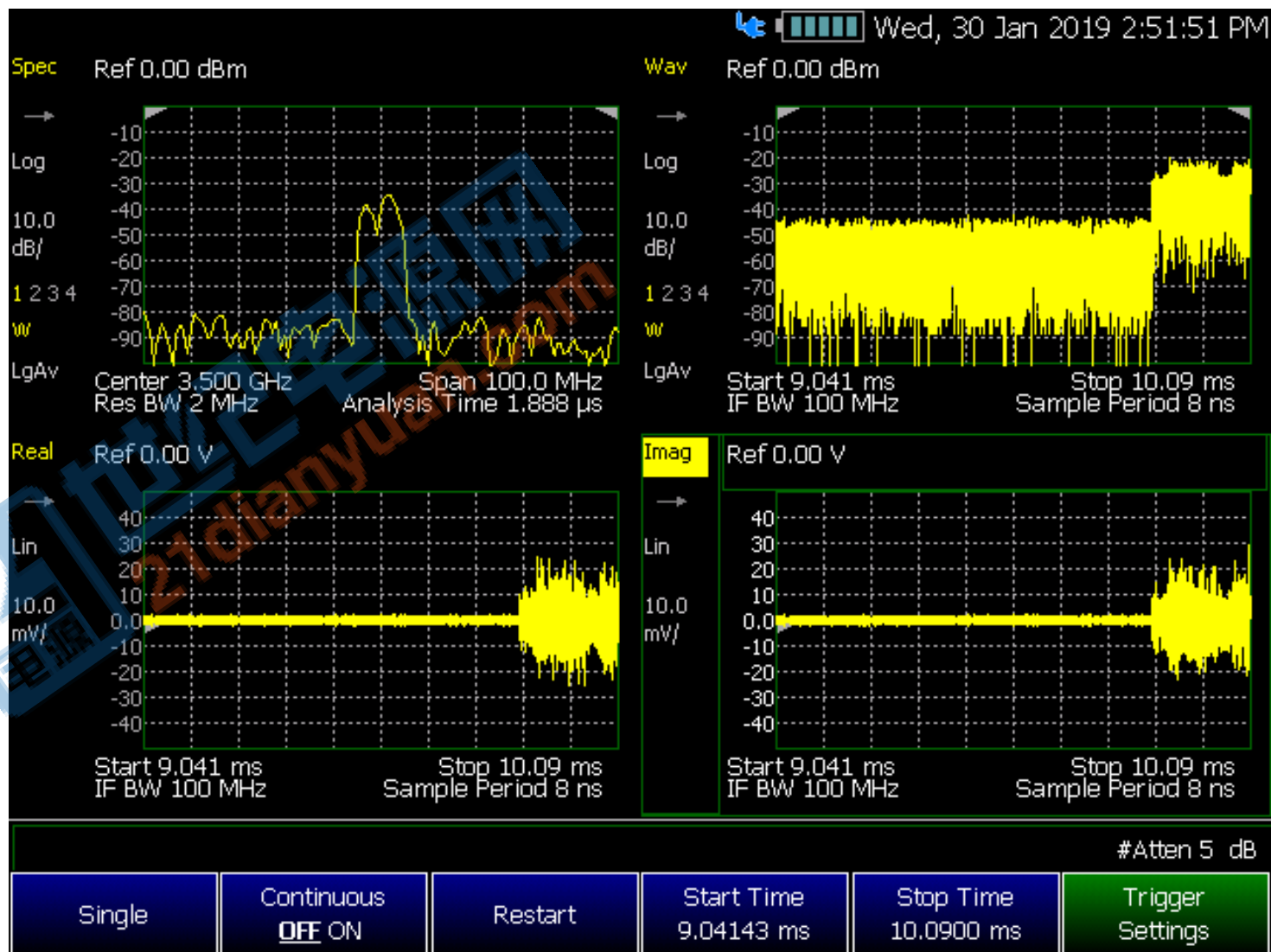
Google Earth

- Collect data in kml format
- View on the instrument or google earth

记录数据 把外场搬回办公室

IQ数据记录/频谱数据记录

- 仪表内置功能
- 10/40/120 MHz IQ数据记录
- 1 GB存储空间
- 14 bit ADC



多功能EMI 预兼容测试手持分析仪



- CISPR 带宽: 200Hz, 9kHz, 120kHz and 1MHz
- CISPR detectors (6dB bandwidth): peak, quasi-peak and EMI average
- CISPR 频段: A/B/C/D/E



- APD (Amplitude Probability Distribution)
- CCDF
 - Histogram
 - CISPR and MIL 461 6dB bandwidth

实时频谱分析

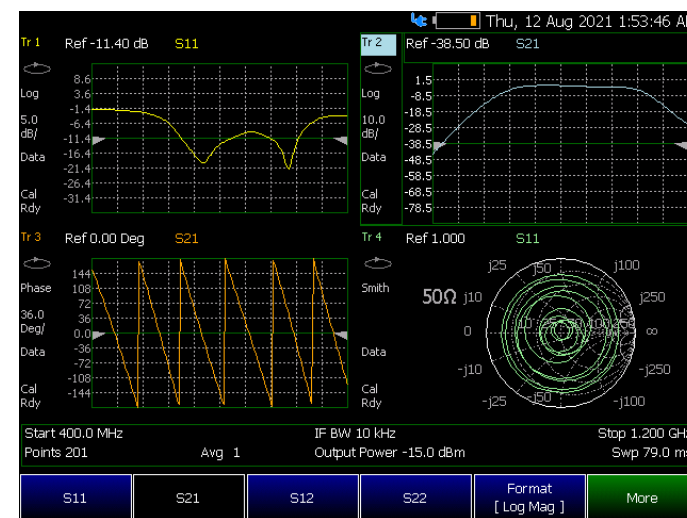
120MHz real time bandwidth

- POI: 5.5us
- Min. Det. Signal: 47ns
- Density, spectrogram and trace modes

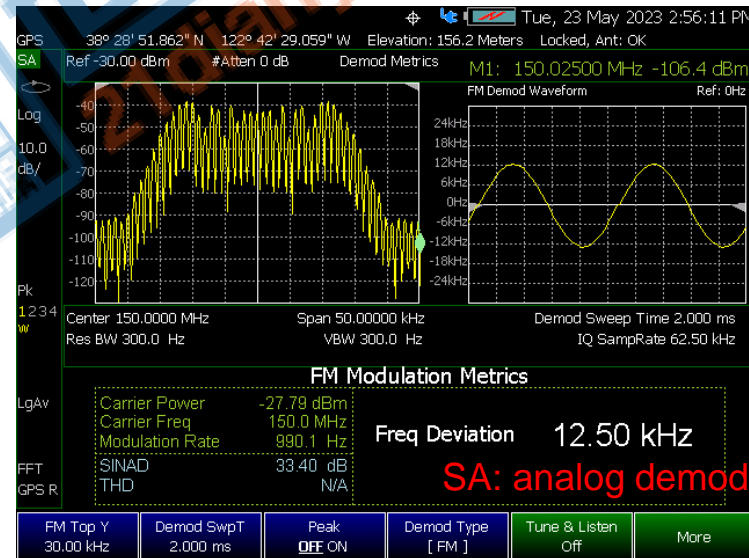
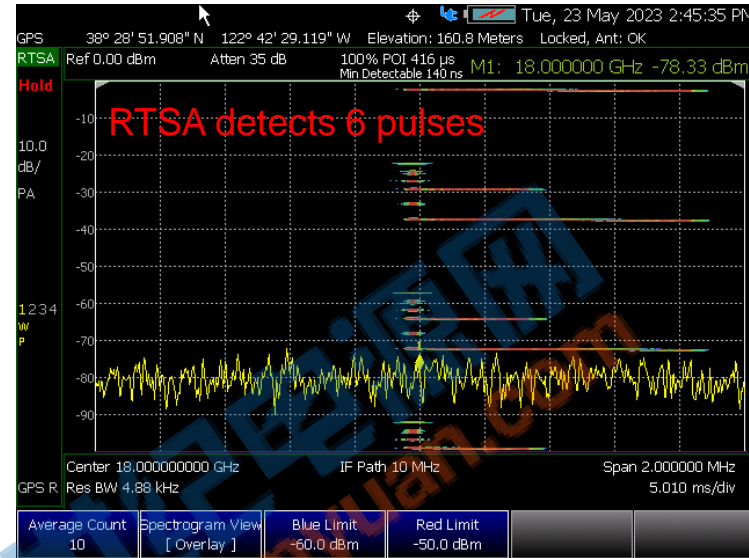
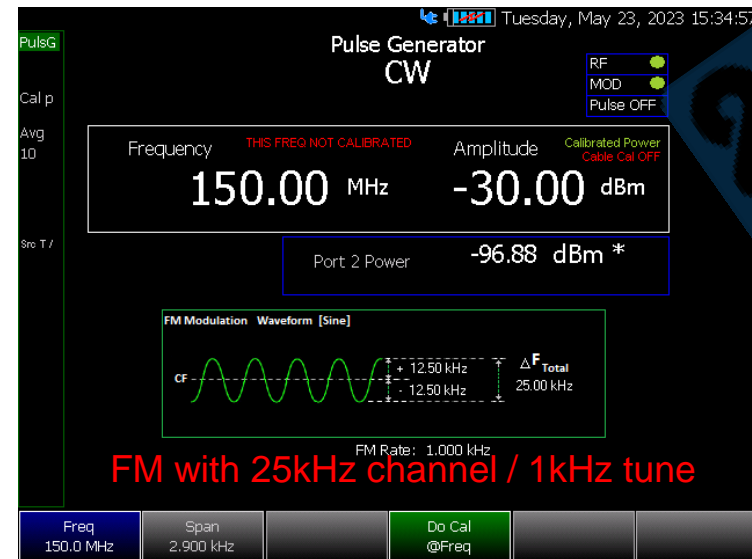
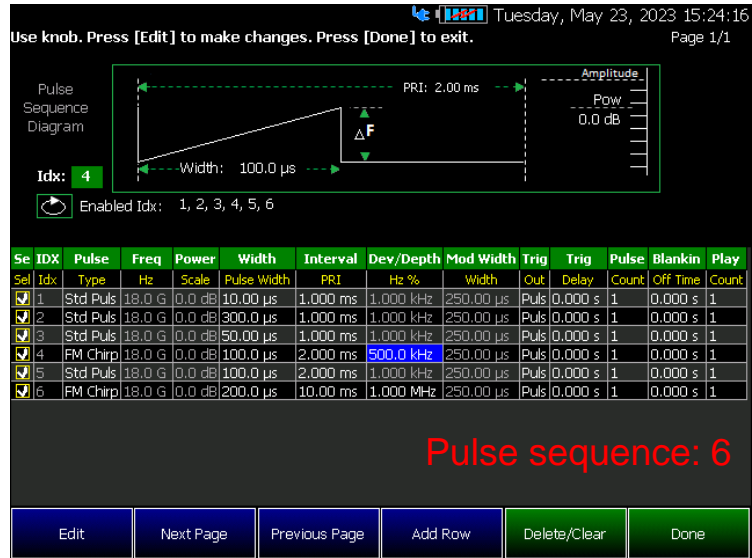


Full 2 port VNA

- 4 s parameters
- Magnitude and phase
- Group delay
- Impedance
- Smith Chart
- VSWR

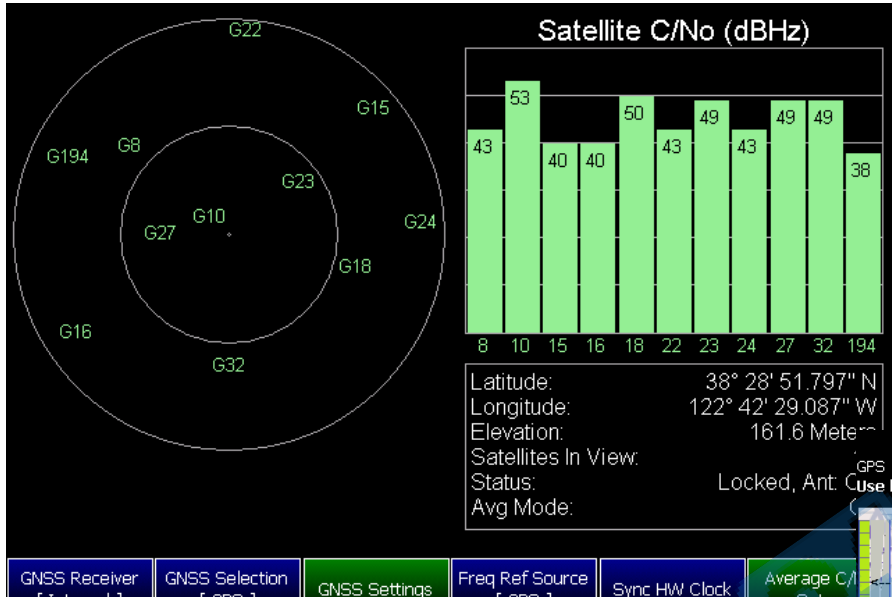


脉冲发生器

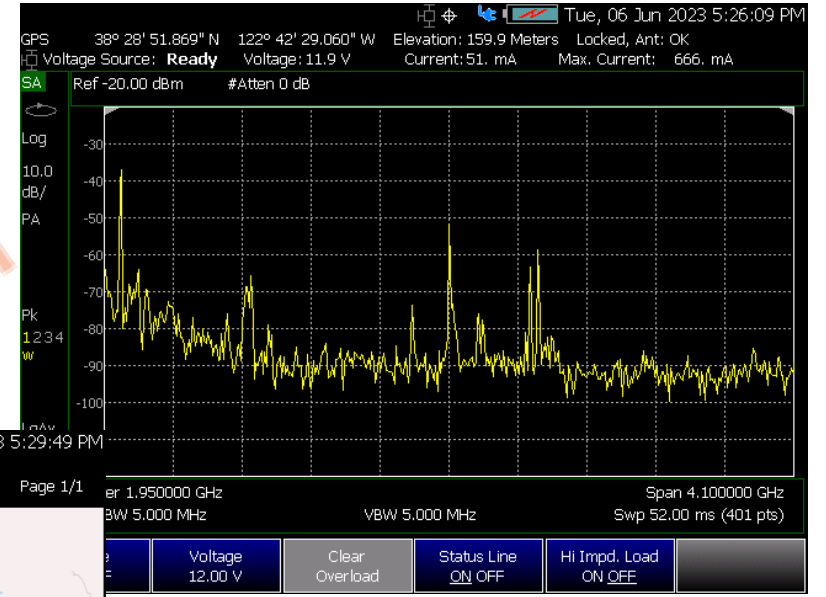


	Features
Frequency	100kHz to 50GHz
Output power	Calibrated with SA
Pulse width	> = 1us
Modulation	Pulse, chirp, triangle, FM and AM
Pulse sequence	On box and can be saved for future recall
FieldFox models	N995xA and N996xA

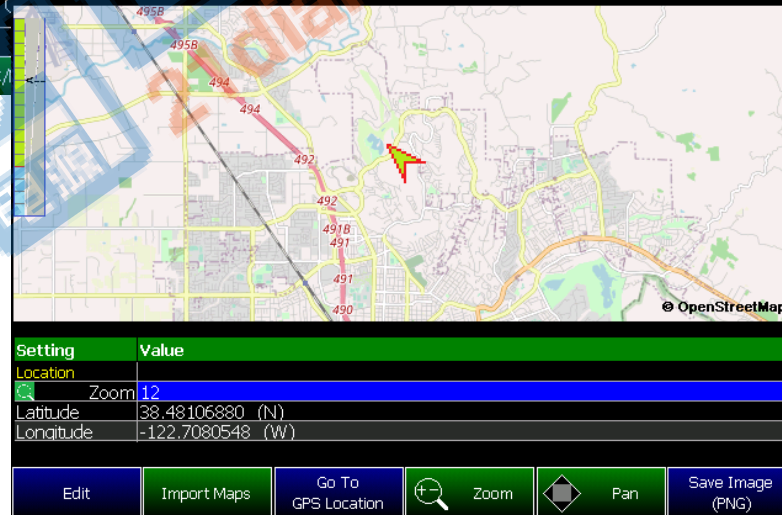
功能



GNSS /GPS



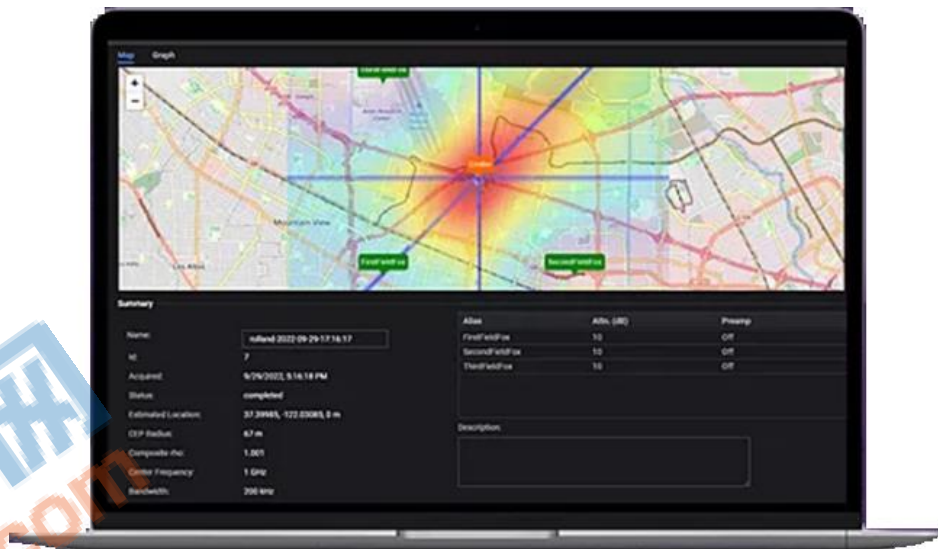
DC Voltage Source



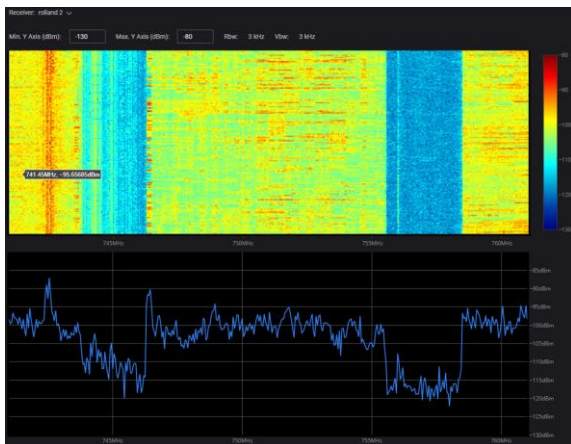
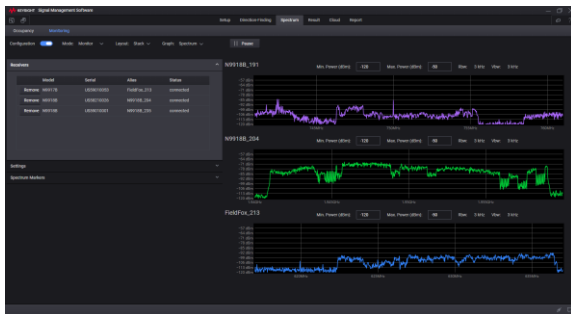
Map

FieldFox N9912C

KSMS 频谱管理、信号监测软件



移动频谱管理KSMS 使用FieldFox手持表



- Signal monitoring
- Spectrum occupancy report
- DF, TDOA
- Hybrid DF to combine TDOA and RSS
- Spectrum recording and playback
- I/Q streaming and playback
- PostgreSQL support

支持站点数据库导入

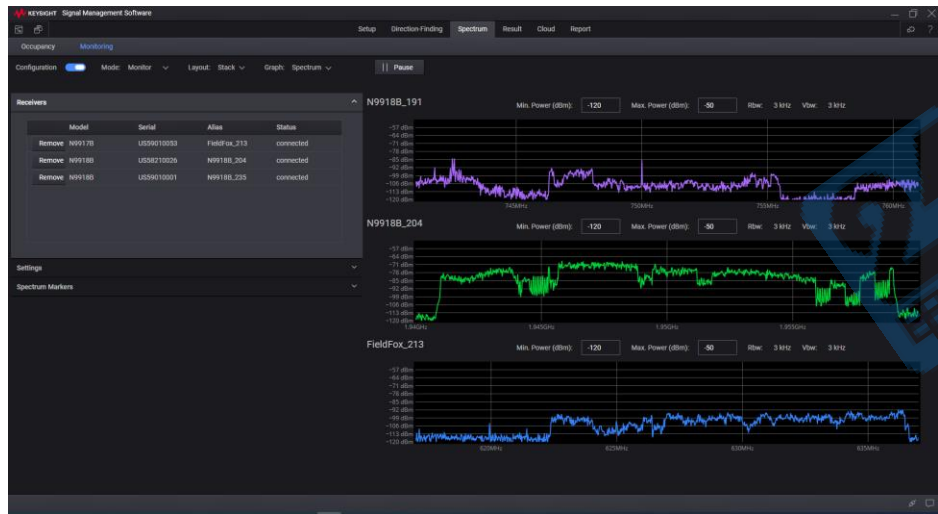
The screenshot displays the Keysight Spectrum Management Software interface. The top menu bar includes 'Receiver', 'Map', 'Setup', 'Directional-Finding', 'Spectrum', and 'Result'. The current view is 'Map', showing a map of North America with several colored markers (blue, green, yellow, orange) indicating site locations. The map includes latitude and longitude coordinates (Lat: 74.68325, Long: -128.84016) and a search bar for the 'Site Database' (abc). Below the map is a table of site data.

License No.	License Name	Transmit Freq.	Receive. Freq.	Location	Latitude	Longitude	Elevation
00709190171	TBayTel	887.5 MHz	842.5 MHz	COW1	48.474652778	-89.18644166	241
00709090042	TELUS Communicatic Inc.	2355 MHz	2310 MHz	45 Elan Boulevard Winnipeg Manitoba	49.89175	-97.06383055	234
00709190171	TBayTel	887.5 MHz	842.5 MHz	FWFN	48.3532	-89.2618	190
00709190171	TBayTel	887.5 MHz	842.5 MHz	CREEKSIDE	48.4404	-89.2752	242
00709190171	TBayTel	887.5 MHz	842.5 MHz	ACADEMY	48.4236	-89.2519	203
00709190171	TBayTel	887.5 MHz	842.5 MHz	DUNLOP	48.404275	-89.24819444	186
00709190171	TBayTel	887.5 MHz	842.5 MHz	George Wardrope Court	48.451	-89.2002	200
00709090044	Xplornet Communicatic Inc.	39637.5 MHz	38937.5 MHz	NW 3-3-23 W, Deloraine, MB	49.190502778	-100.5074416	497
00709090044	Xplornet Communicatic Inc.	38937.5 MHz	39637.5 MHz	SE 36-3-10 W, La Riviere, MB	49.251163889	-98.69133055	465
00709090044	Xplornet Communicatic Inc.	38937.5 MHz	39637.5 MHz	360 Main St, Manitou, MB	49.241922222	-98.53726944	489

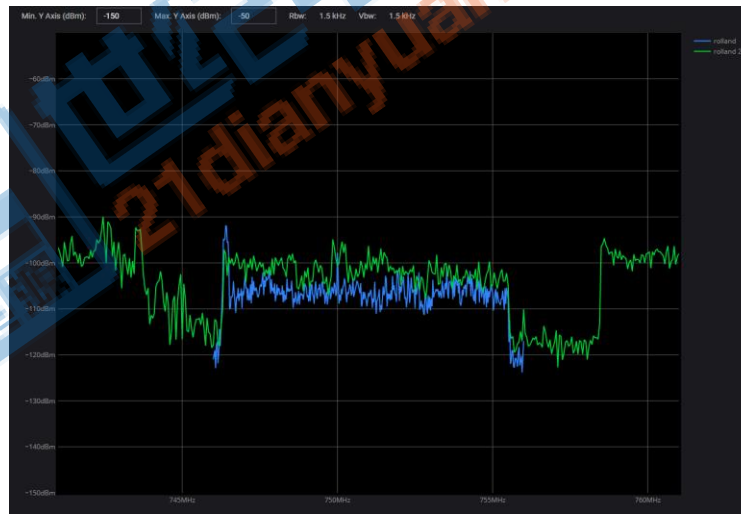
- CSV file
- Import any site data base with database header mapping template, a text file to map database keywords to KSMS import

信号监测

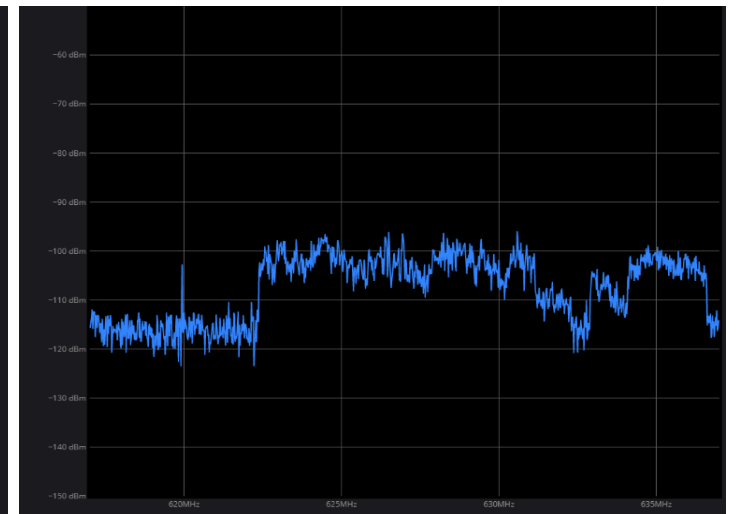
- 查看来自多个Fieldfox的频谱
 - 不同位置，相同频段
 - 相同位置，不同频段
- 支持Frequency Offset的设置，用于卫星多路信号的监测
- 来自不同接收机的频谱数据，可以在单个窗口显示，多个窗口显示，也可以在单个窗口重叠显示



Multi- receiver stack mode display

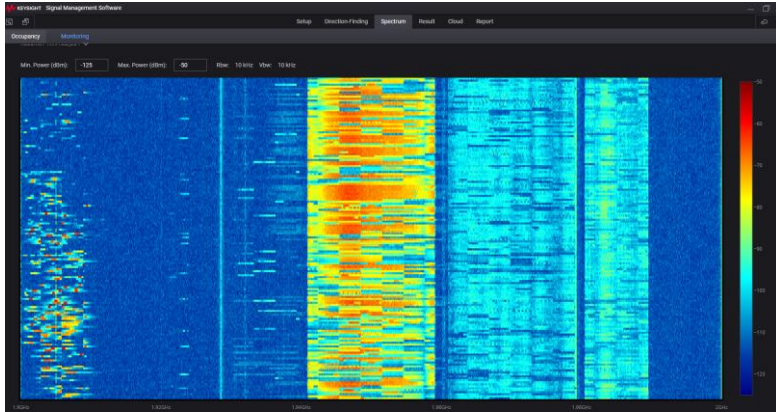


Spectrum overlay



Single receiver spectrum

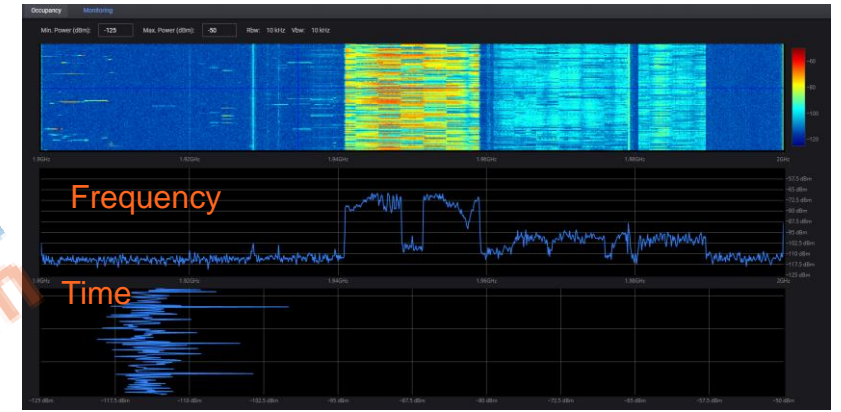
瀑布图



Single receiver spectrogram



Multi-receiver spectrogram

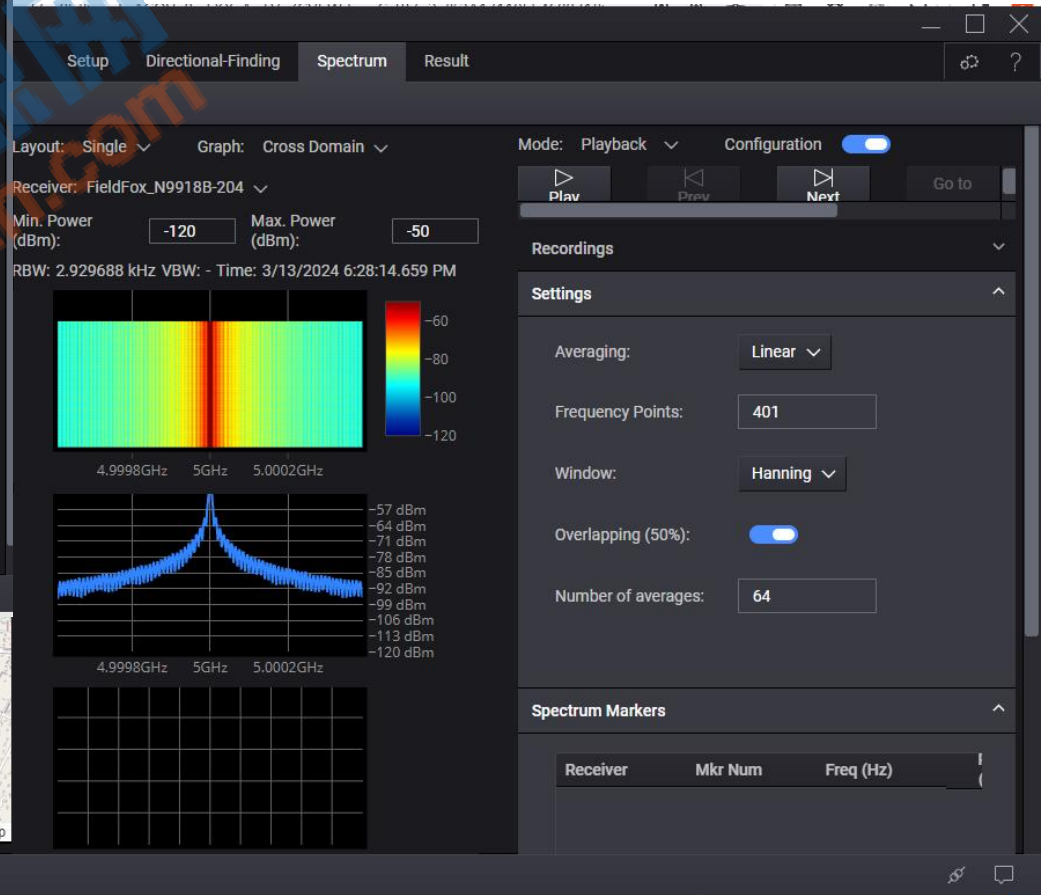
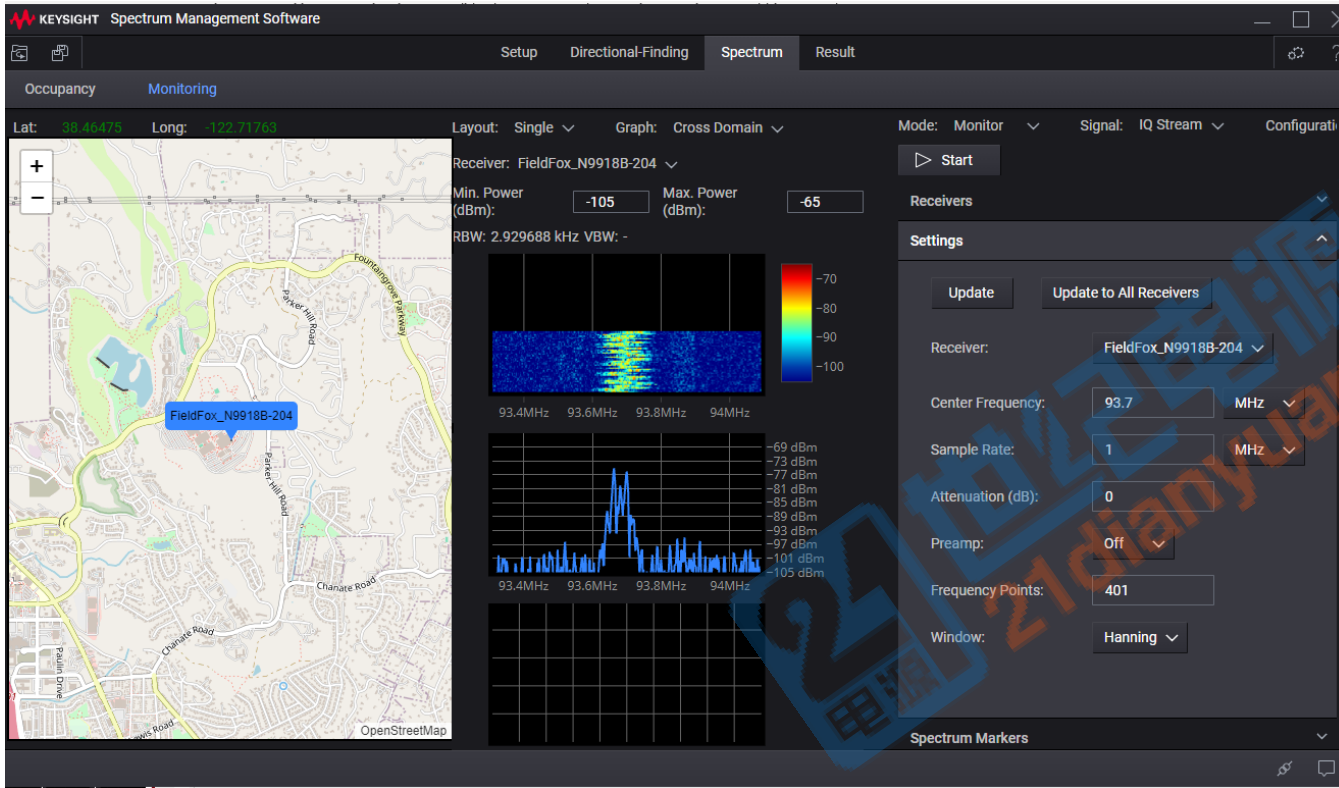


Cross domain spectrogram

- Top: spectrogram
- Middle: spectrum trace at marker or current record
- Bottom: time domain display at marker frequency

IQ 数据流盘, 记录和回放

- stream data from 4 Rx at same time;
- Save it as SDF file for Keysight VSA software
- Vita49 support
- Playback with FFT overlapping, average and at various of frequency points



频谱轨迹数据记录和回放 Fieldfox记录频谱数据导入

Record spectrum with limit line trigger

Recordings

Session Prefix: AutoSession37

Cancel Import Selected

	Start Date	State No.	Center Freq.	Span	No. Points	Rbw
<input checked="" type="checkbox"/>	12/1/2023 4:50:27.432 PM	0	751 MHz	100 MHz	1001	10 kHz
<input type="checkbox"/>	12/1/2023 4:54:45.391 PM	1	751 MHz	20 MHz	1001	10 kHz
<input type="checkbox"/>	12/1/2023 4:54:52.794 PM	2	153 MHz	20 MHz	1001	10 kHz

Recording File Path: C:\Users\zhang\Documents\KSMS user\AutoSession37

Receiver: N9917B, US59010053

Imported & Importing Recordings

Session Name	Imported Frames	Total Frames	Status	Action	M
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KEYSIGHT Spectrum Management Software

Setup Directional-Finding Spectrum Result

Occupancy Monitoring

Lat: 38.46848 Long: -122.70513

Layout: Single Graph: Cross Domain

Min. Power (dBm): -120 Max. Power (dBm): -50

RBW: 10 kHz VBW: 10 kHz Time: 12/1/2023 4:50:32.269 PM

720MHz 740MHz 760MHz 780MHz 800MHz

720MHz 740MHz 760MHz 780MHz 800MHz

-57 dBm
-64 dBm
-71 dBm
-78 dBm
-85 dBm
-92 dBm
-99 dBm
-106 dBm
-113 dBm
-120 dBm

Playback with location and run data analysis

压缩的瀑布图展示 用于能量检测

Settings

Recording Date Time Range: 10/4/2023: 12:01:40 PM -> 12:11:41 PM

Start Date Time: 10/04/2023 12:01:40 PM

End Date Time: 10/04/2023 12:11:41 PM

Spectrogram Row Mode: Fixed Number of Rows

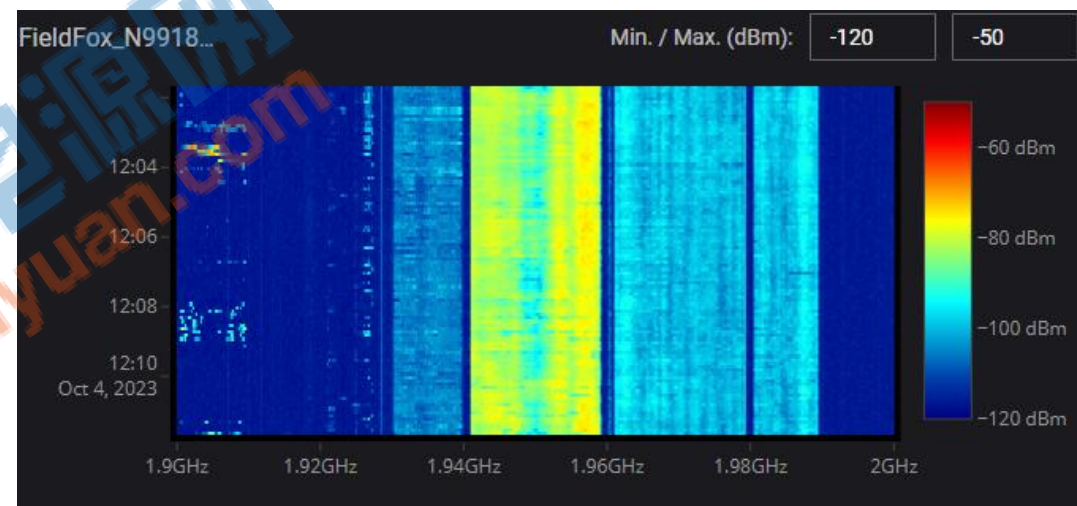
100 Rows

Compression Algorithm: Peak Hold

- ✓ Peak Hold
- Linear Average
- % Of Measurements Over Threshold

Start Compression

Name:



频谱占用度测试

Channel	Name	Frequency (MHz)	Bandwidth (MHz)	Threshold (dBm)	Total Samples	Active Samples	Occupancy Rate	Occupancy Time
1	Verizon	751	10	-80	524	520	99.24%	00:02:53
2	ATT	1950	20	-80	524	524	100.00%	00:02:54
3	Tmobile	629.55	15	-80	524	524	100.00%	00:02:54

Name	Date	Status
SpecOcc-2023-01-11	1/12/2023, 5:04:31 PM	completed
SpecOcc-2022-11-28	11/28/2022, 3:39:27 PM	completed
SpecOcc-2022-11-28	11/28/2022, 3:37:41 PM	completed
SpecOcc-2022-11-28	11/28/2022, 3:34:40 PM	completed

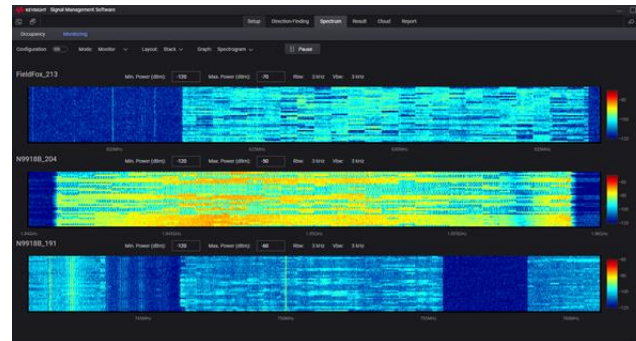
Channel	Name	Frequency (MHz)	Bandwidth (MHz)	Threshold (dBm)	Total Samples	Active Samples	Occupancy Rate	Occupancy Time
1	Verizon	751	10	-80	1786	1771	99.16%	00:09:50
2	ATT	1950	20	-80	1786	1786	100.00%	00:09:55
3	Tmobile	629.55	15	-80	1786	1786	100.00%	00:09:55

- Monitor spectrum utilization rate
- Ad hoc and long-term spectrum activity monitoring
- Reports active samples, occupancy rate and occupancy time
- Daily collection scheduler
- Results can be exported to csv file

总结

保障低空经济安全

- Fieldfox 手持表
 - 4/6.5/9/14/18/26.5/32/44/50/54 GHz 频率范围
 - 120 MHz实时分析带宽
 - 手动DF
 - 支持OTA测试
 - IQ/频谱数据记录回放
 - GNSS卫星及C/No显示
- KSMS频谱管理软件
 - 频谱监测
 - 站点信息导入
 - 频谱占用度长时间监测和汇报
 - IQ数据流盘回放
 - 频谱长时间记录与回放
 - DF测向定位



Thank you

