KEYSIGHT

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

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低空飞行器相关的无线电频谱技术

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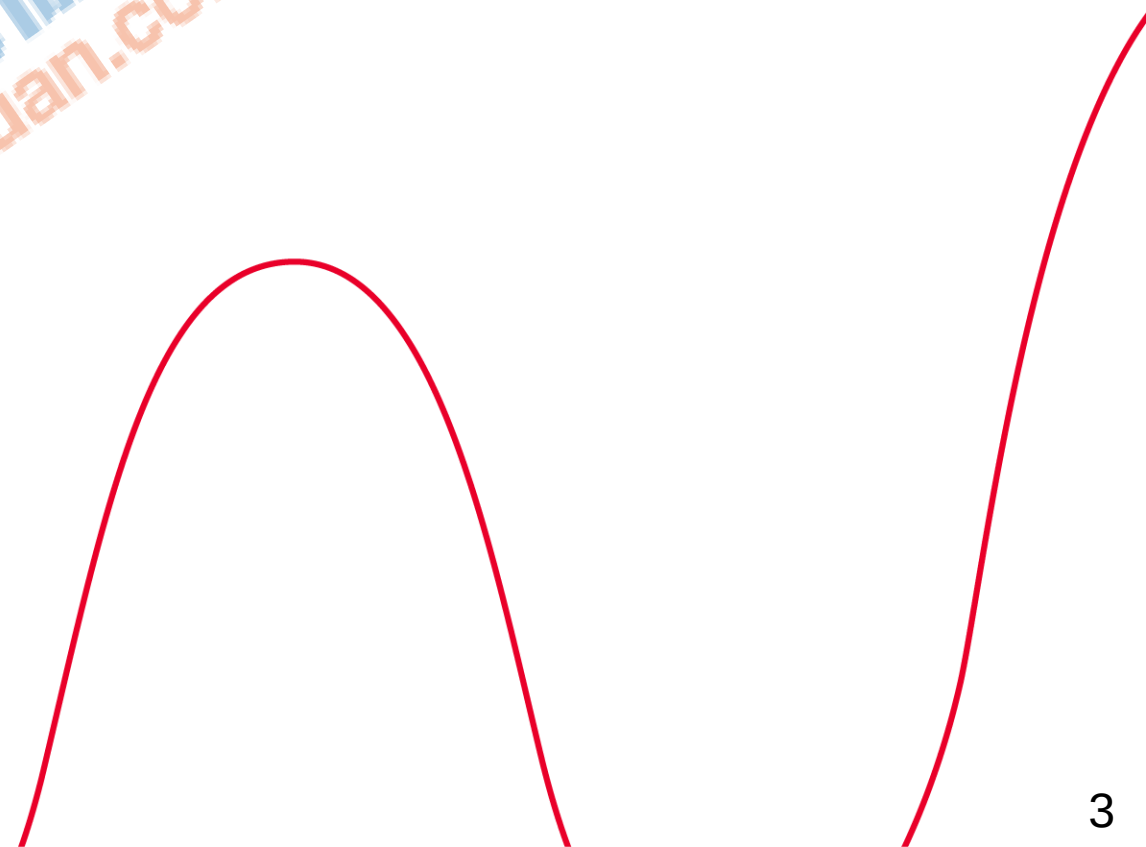

多种无线通信子系统应用于无人机和eVTOL

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

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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

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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

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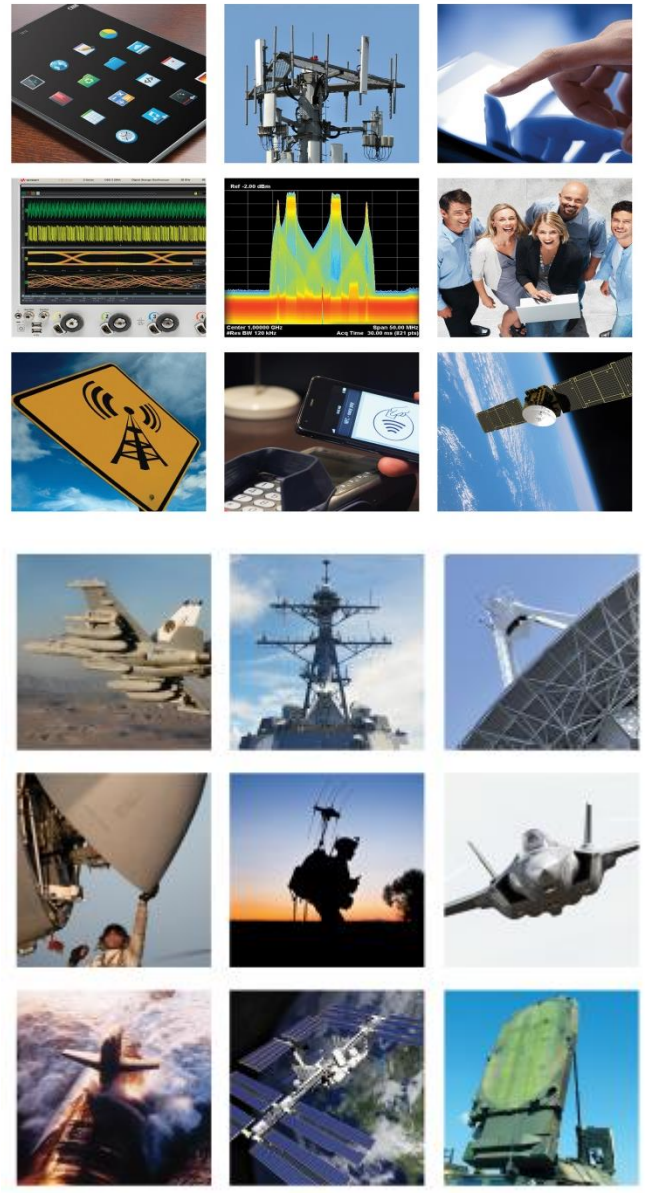
低空空域中存在的无线通信系统

- 无线通信网络 (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



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低空空域的频谱环境

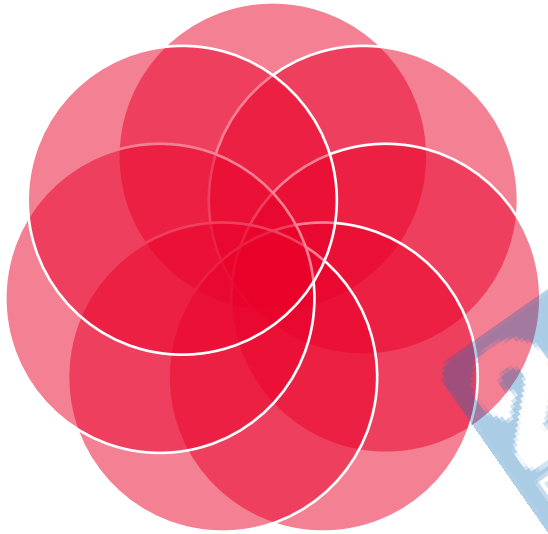
充满相互干扰！

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



信号管理软件，管理协调多个站点

路测，监测某个航段是否有强干扰信号

信号的记录与回放

实时频谱分析，查找瞬态信号

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Fieldfox手持表

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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

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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: 10/40120MHz

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

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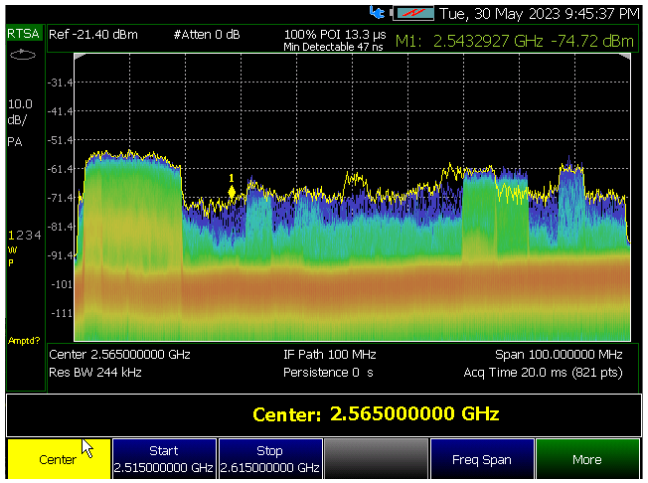
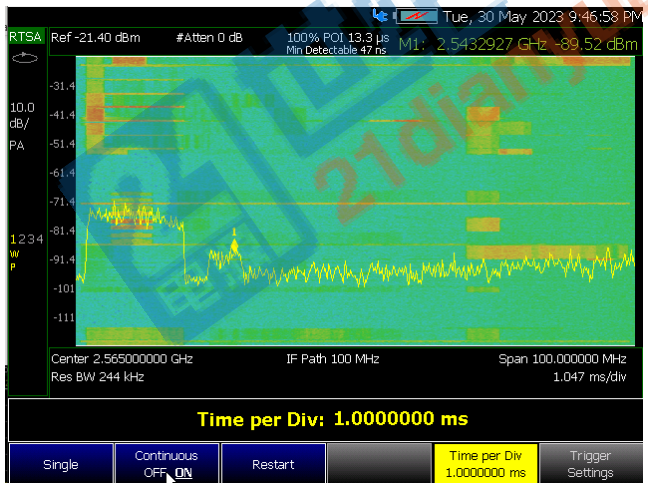
瞬态信号、突发信号的查找与捕获

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

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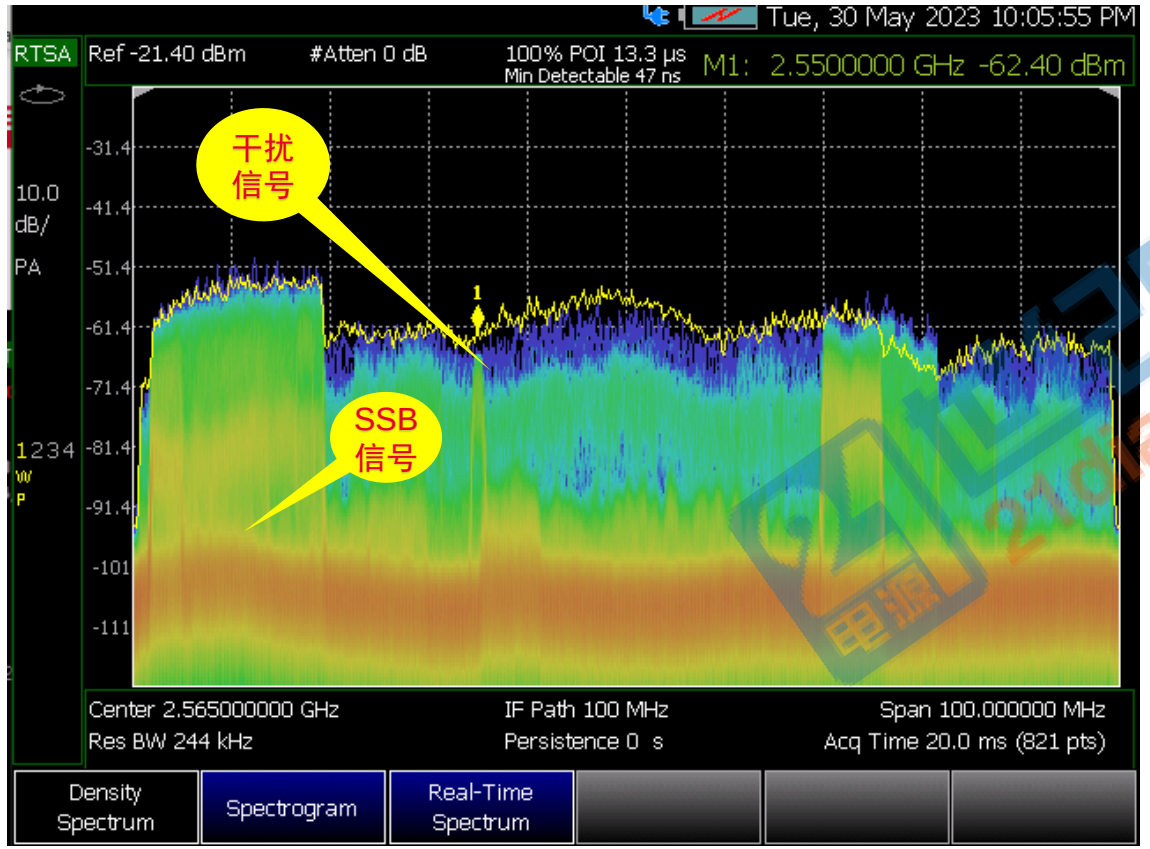
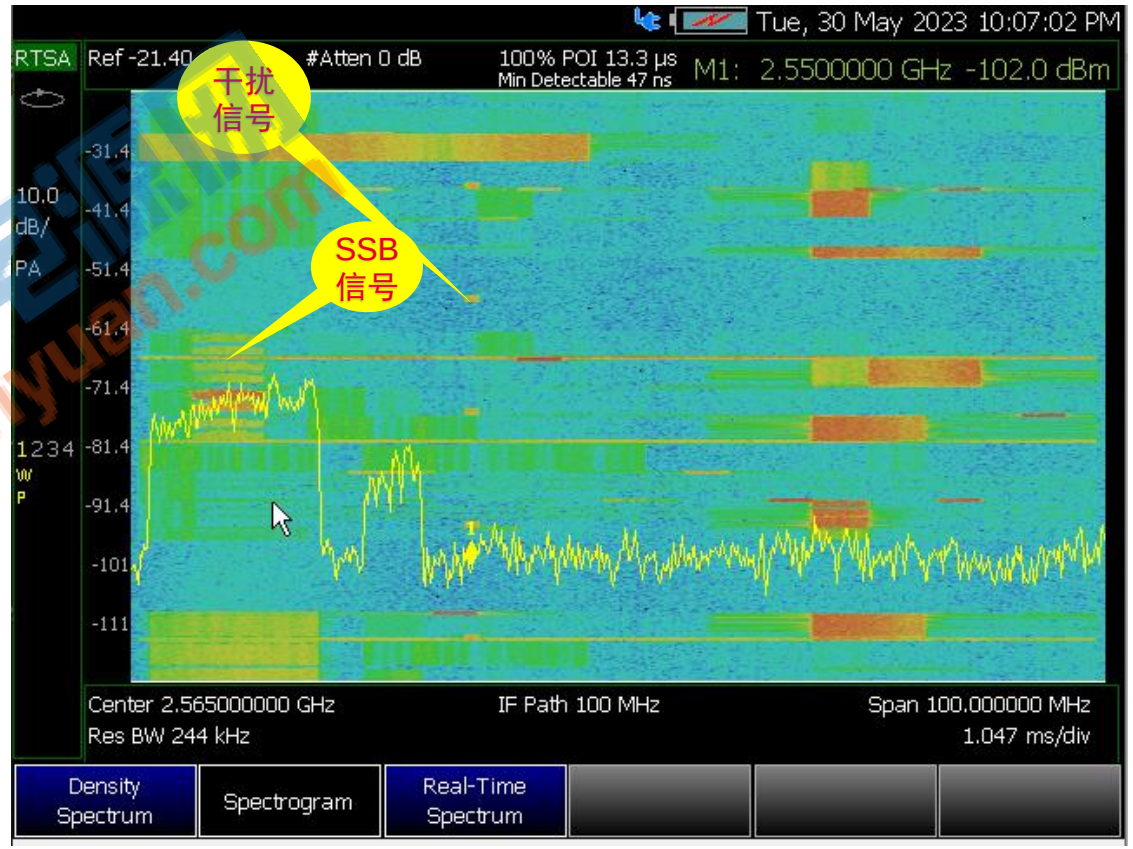
实时频谱查看掩藏在5G NR信号下的突发信号





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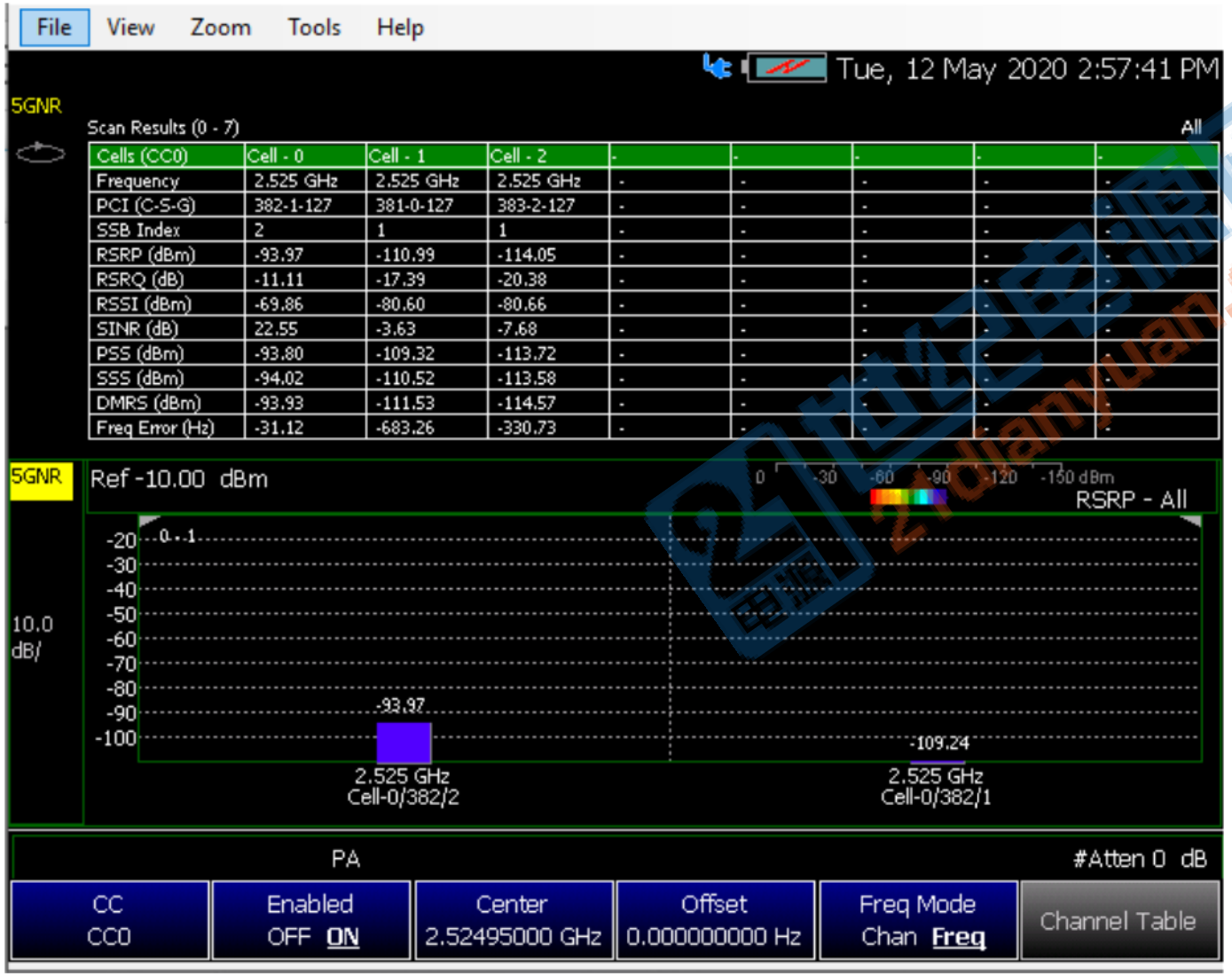
OTA 空口测量获取更多信号信息

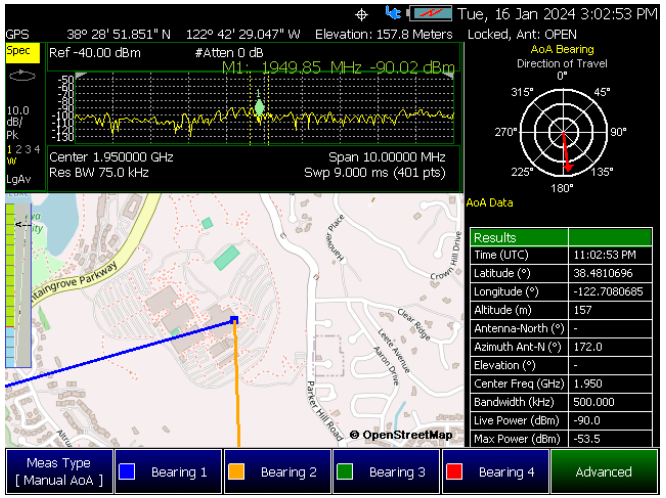
5G NR OTA为例



- 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

New



- 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

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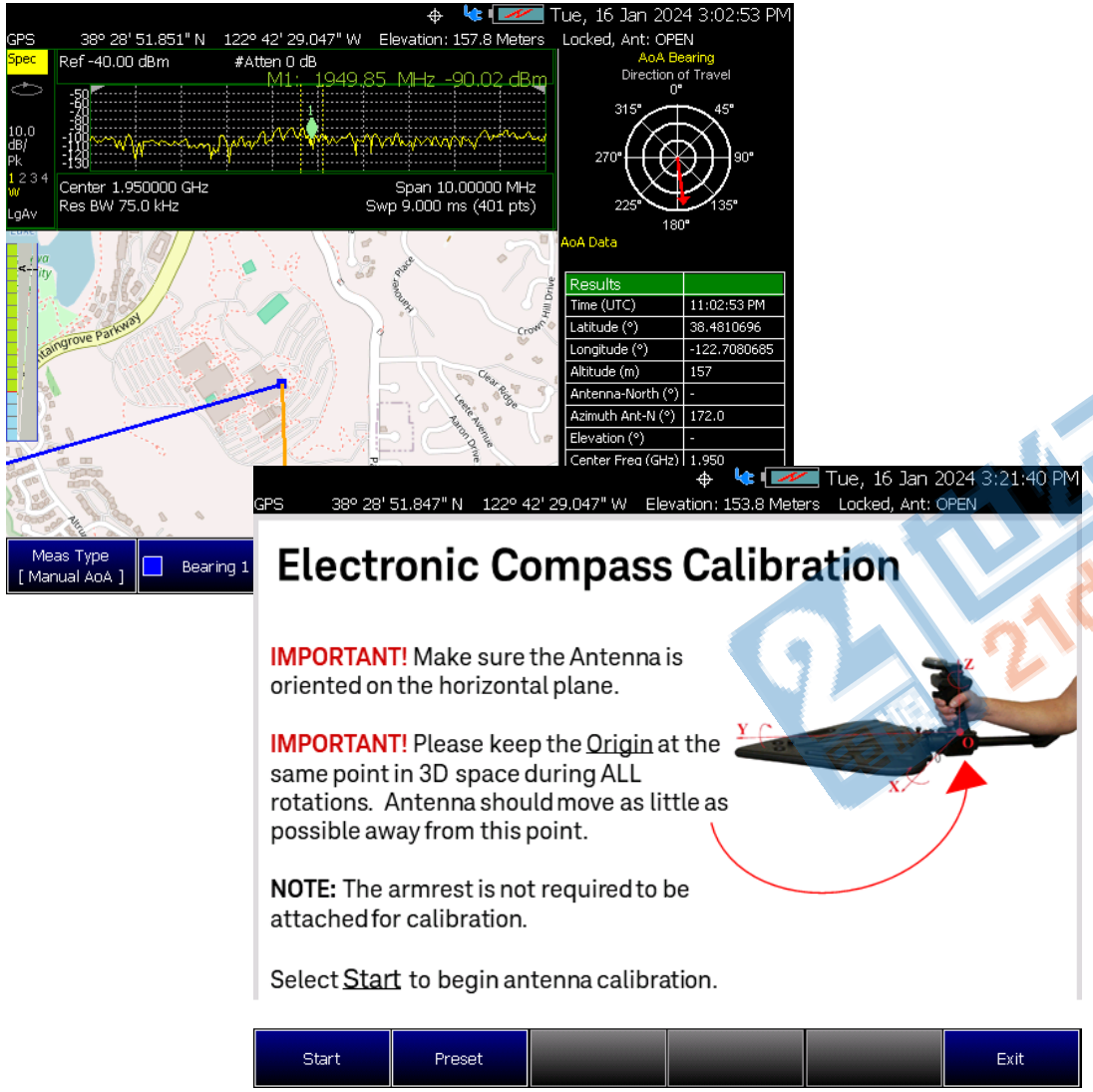
手持DF天线 带数字罗盘



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

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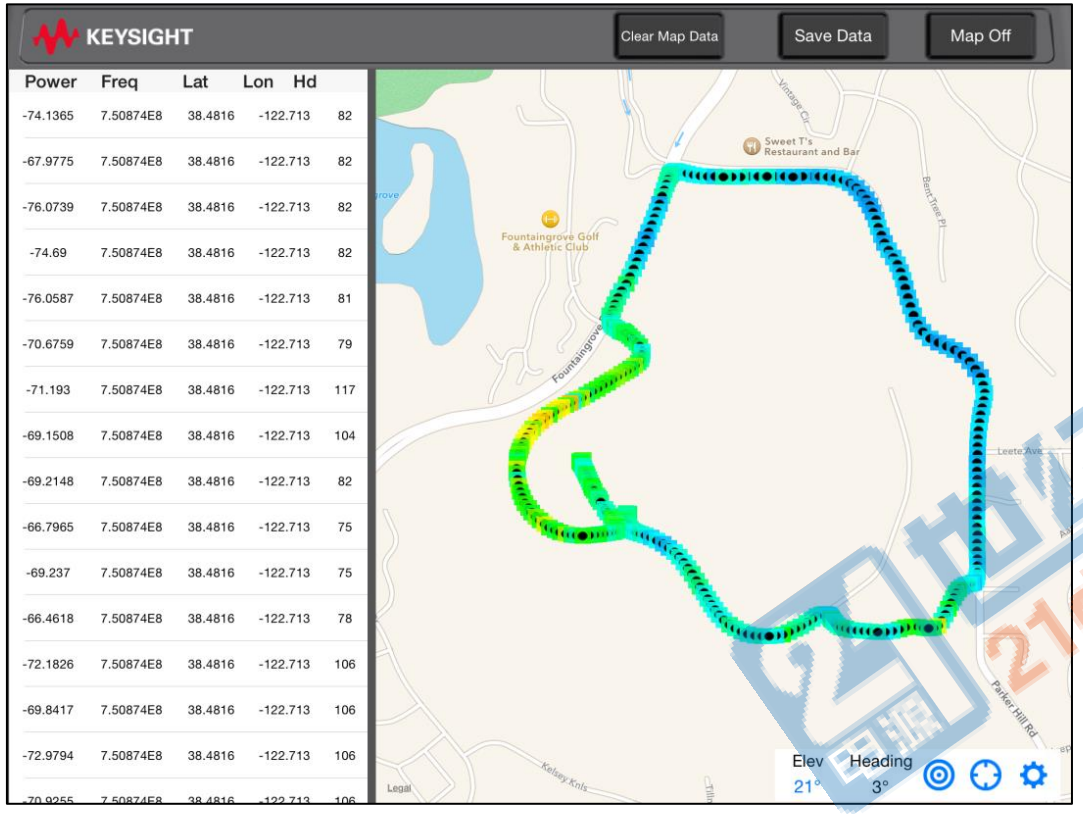
信道扫描 (Channel Scanner)

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



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

Google Earth

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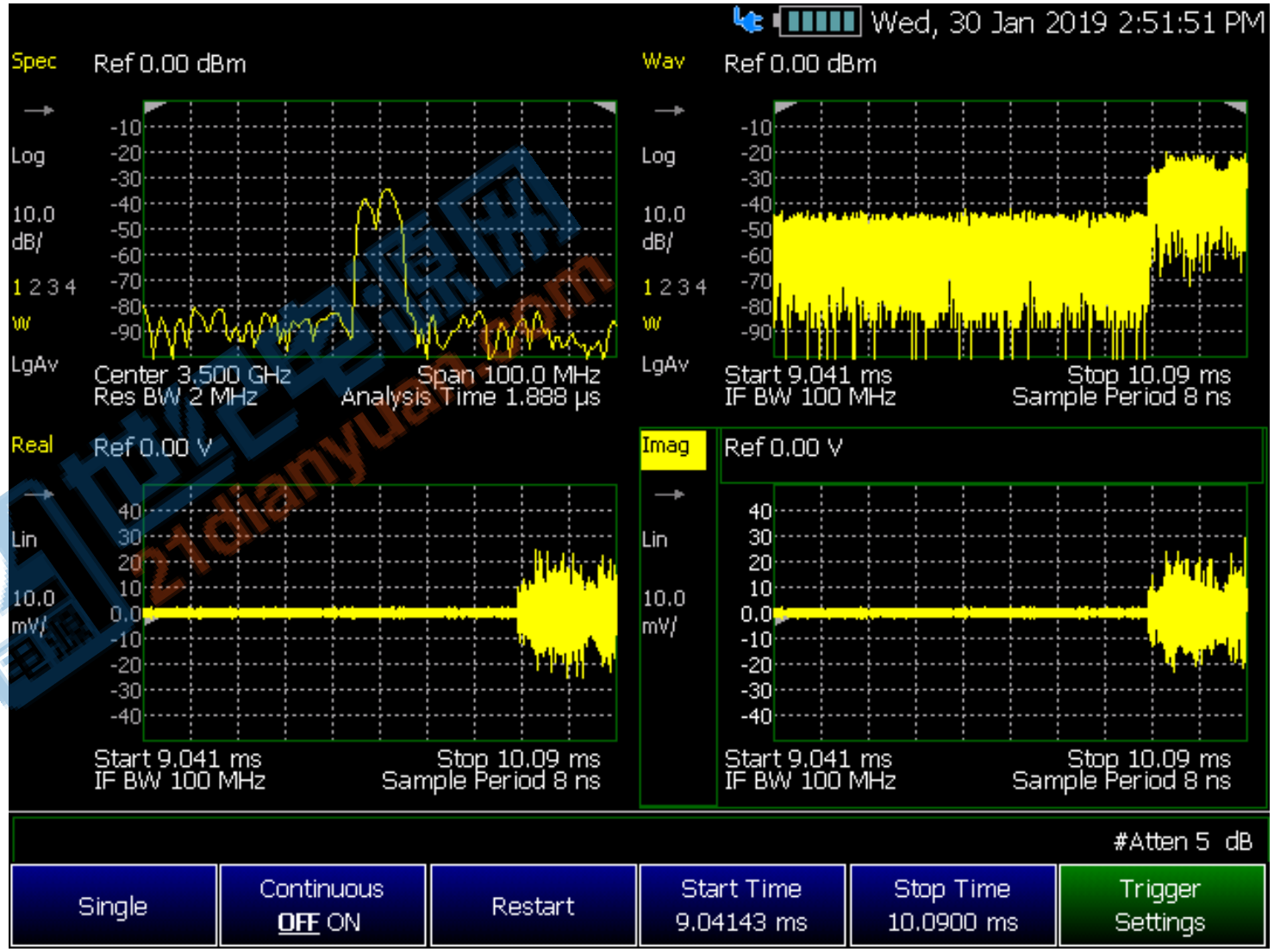
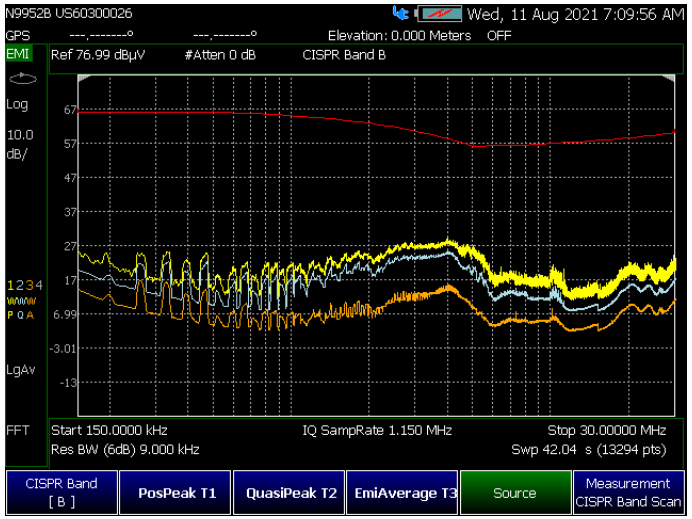
记录数据 把外场搬回办公室

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

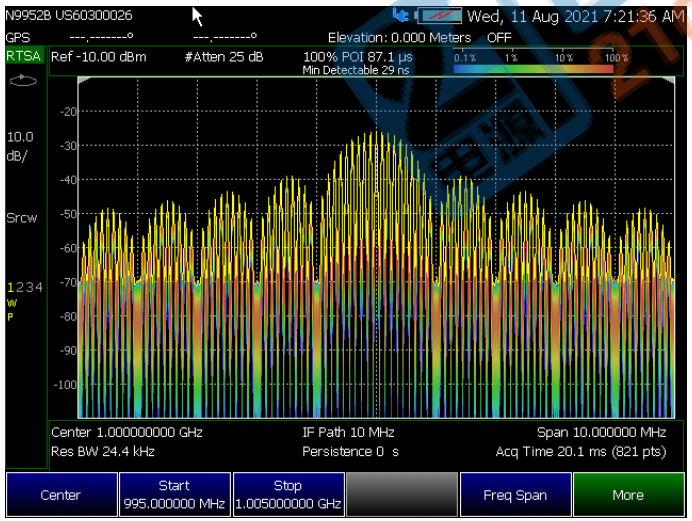
APD (Amplitude Probability Distribution)

- CCDF
- Histrogram
- CISPR and MIL 461 6dB bandwidth

实时频谱分析

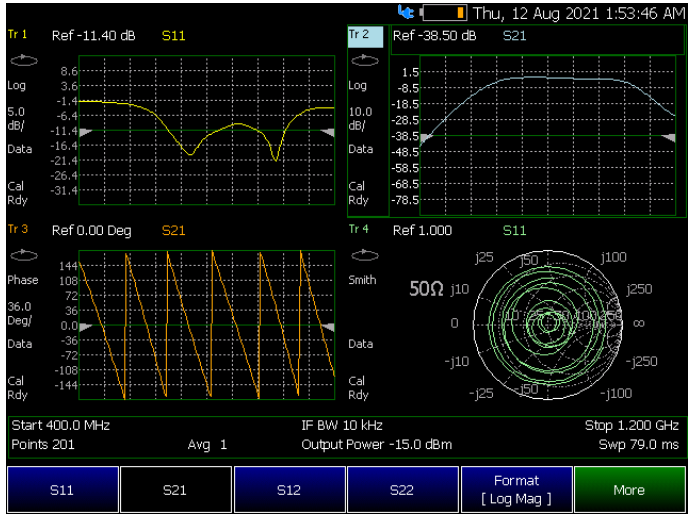
120MHz real time bandwidth

- 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



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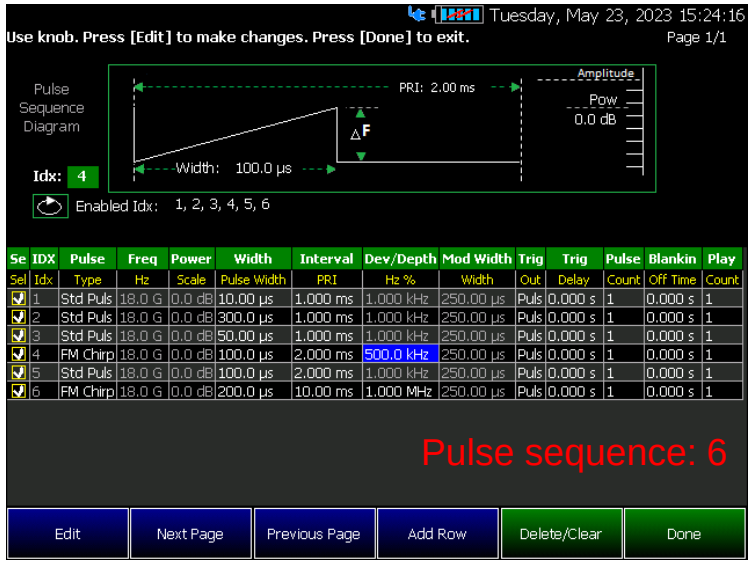
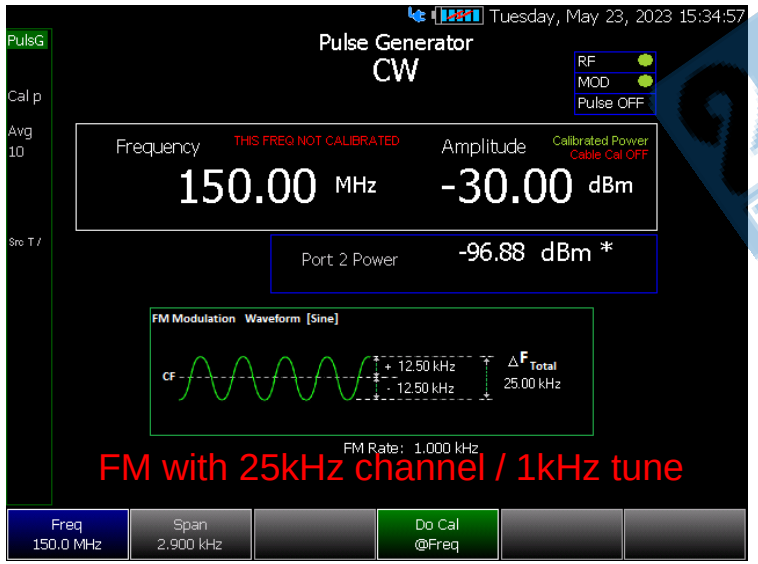
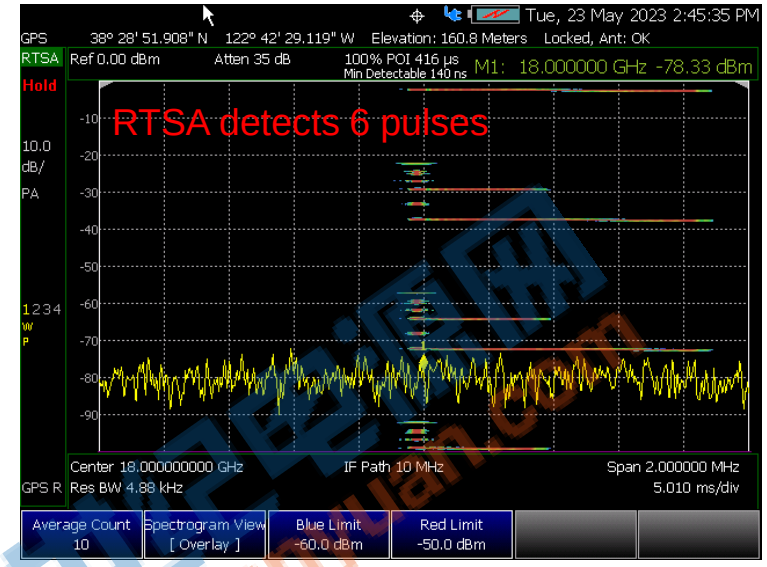
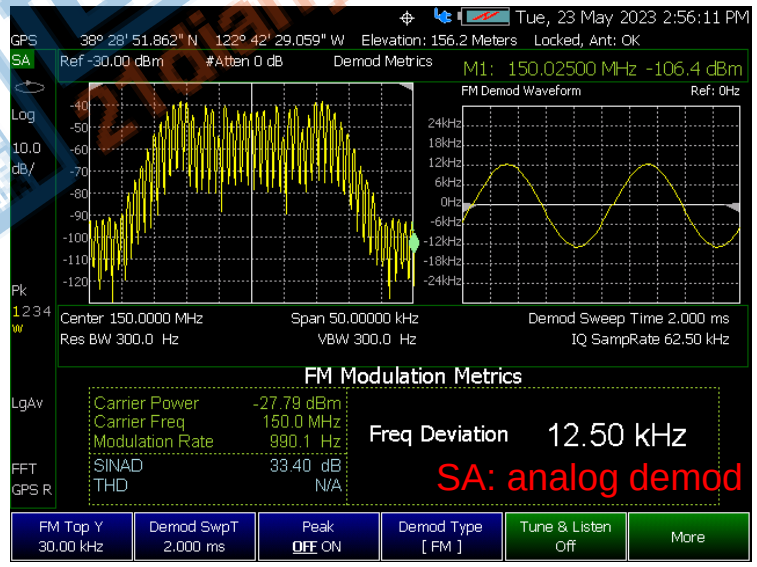
脉冲发生器



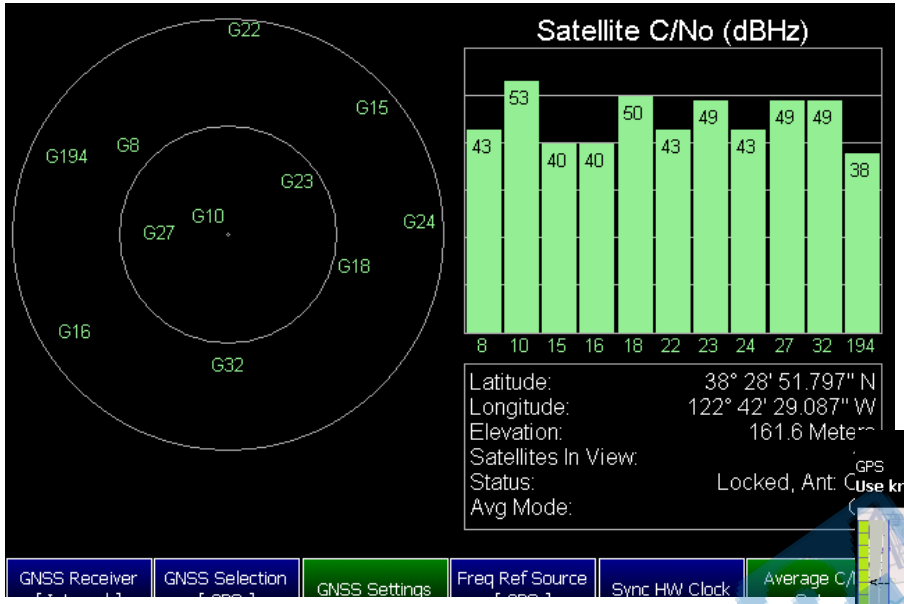




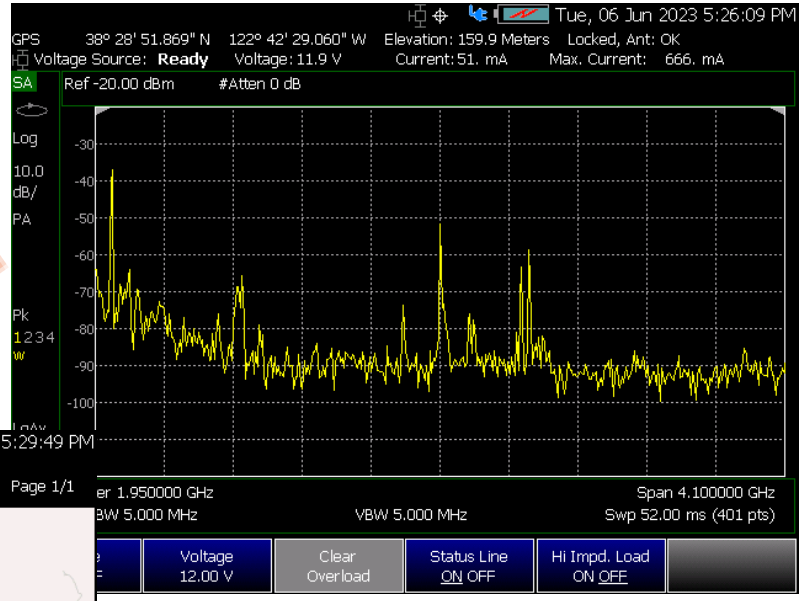


	Features
Frequency	100kHz to 50GHz
Output power	Calibrated with SA
Pulse width	> = 1us
Modulation	Pulse, chirp, triangle, FM and AM
Pulse sequence	On box and can be saved for future recall
FieldFox models	N995xA and N996xA

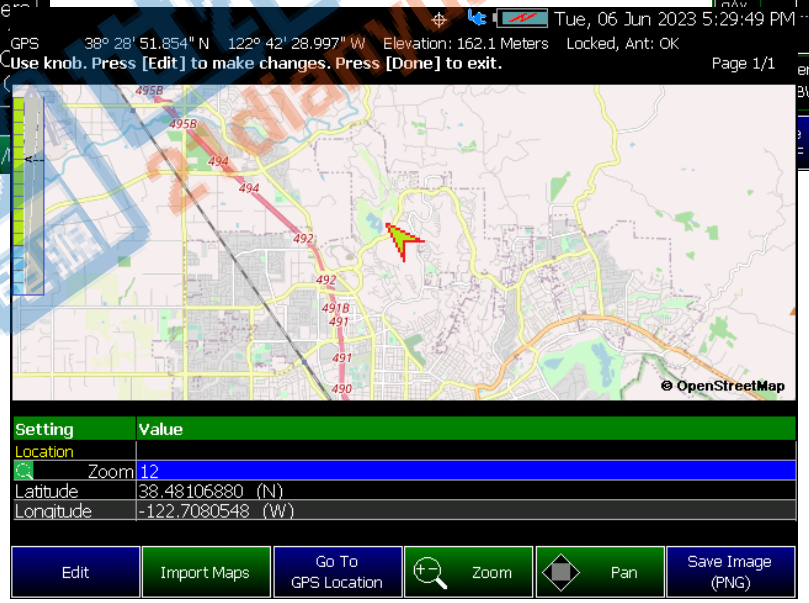
功能



GNSS /GPS



DC Voltage Source



Map

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KSMS 频谱管理、信号监测软件

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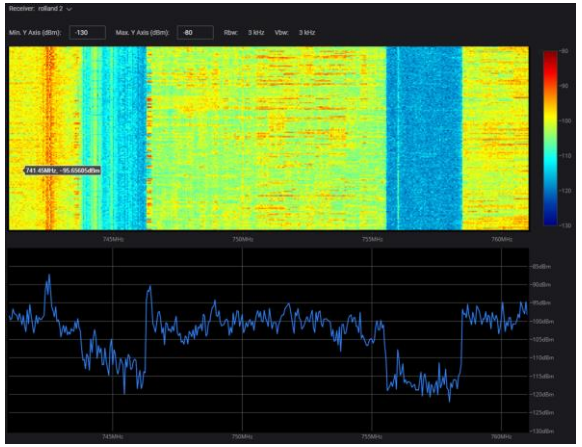
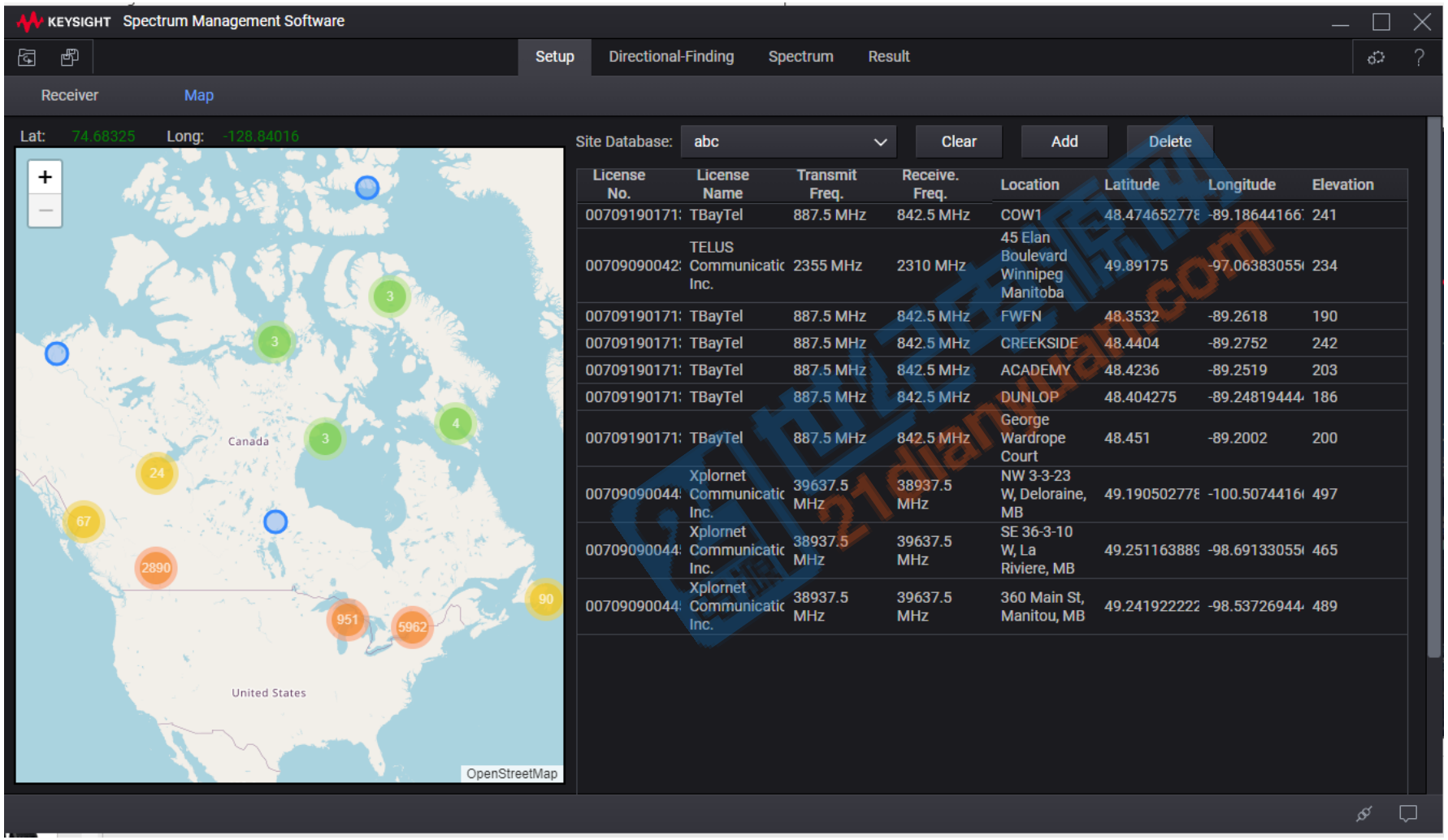
移动频谱管理KSMS 使用FieldFox手持表



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

支持站点数据库导入



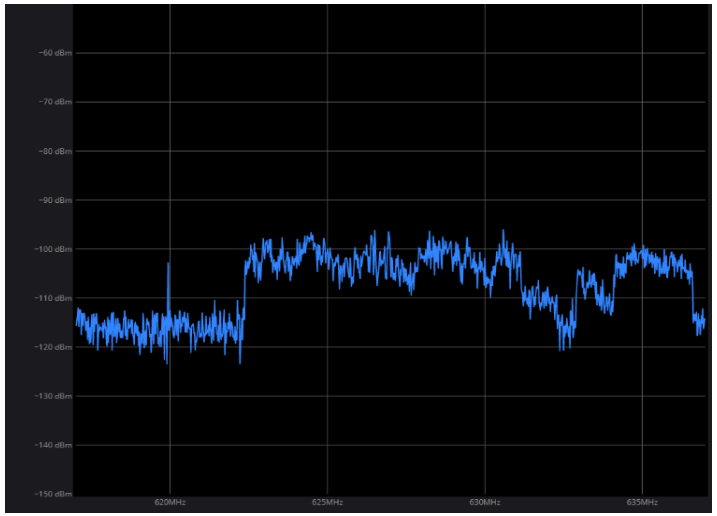
- CSV file
- Import any site data base with database header mapping template, a text file to map database keywords to KSMS import

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

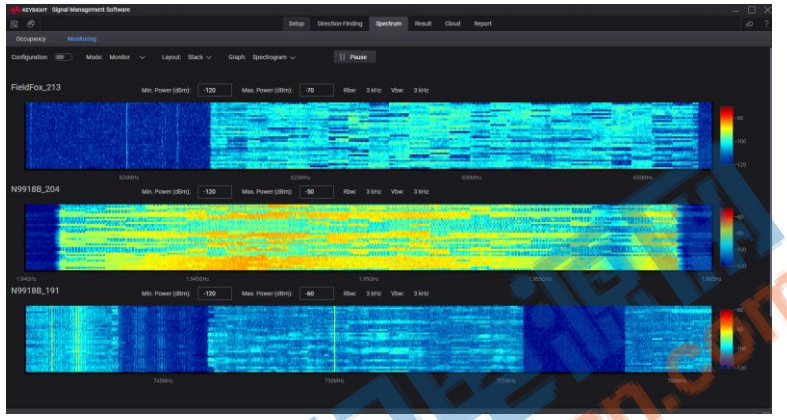
Spectrum overlay



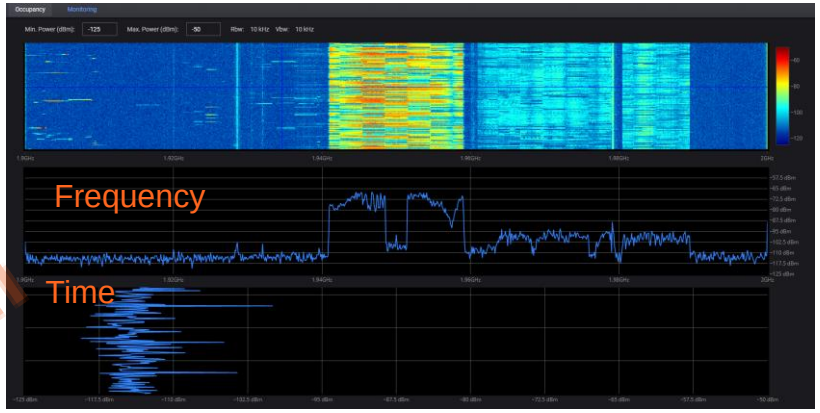
Single receiver spectrum

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

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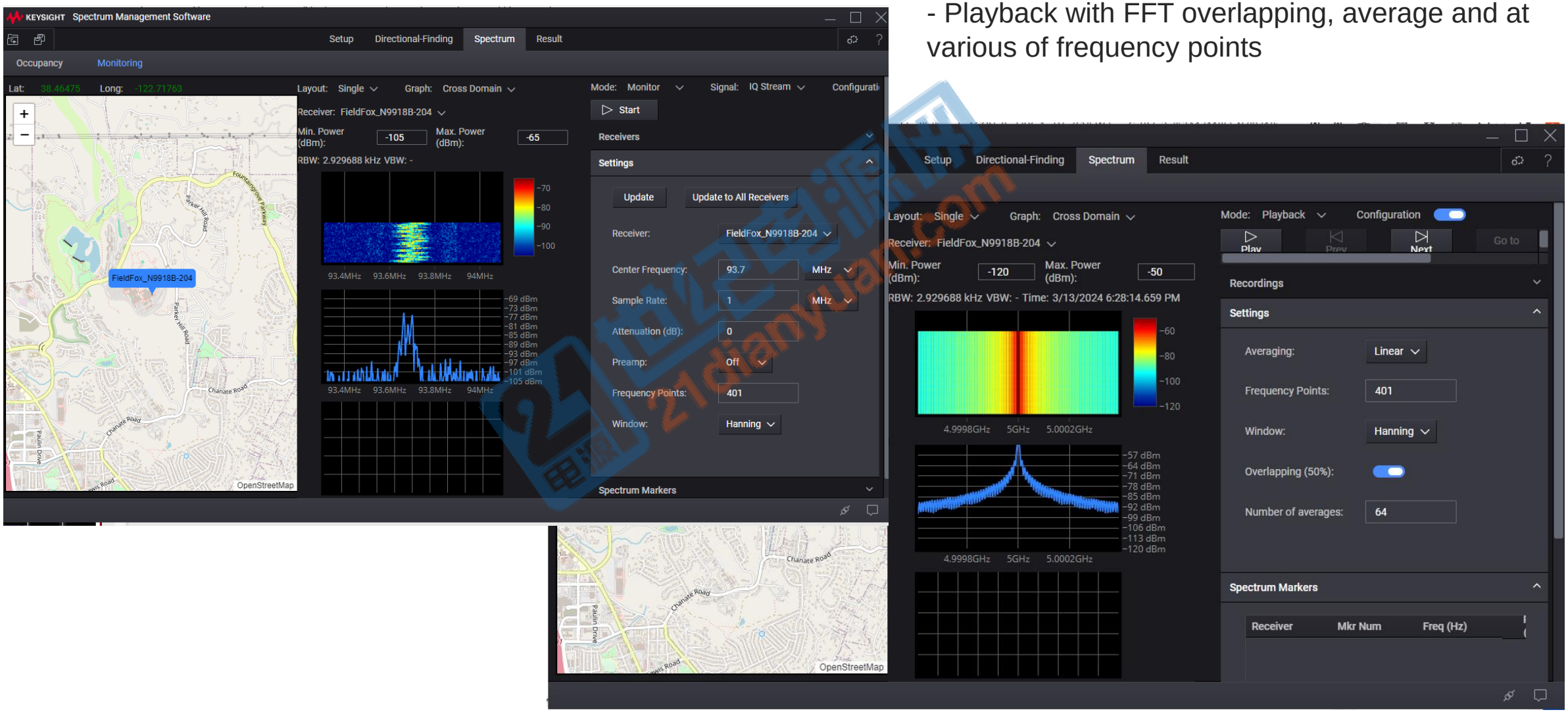
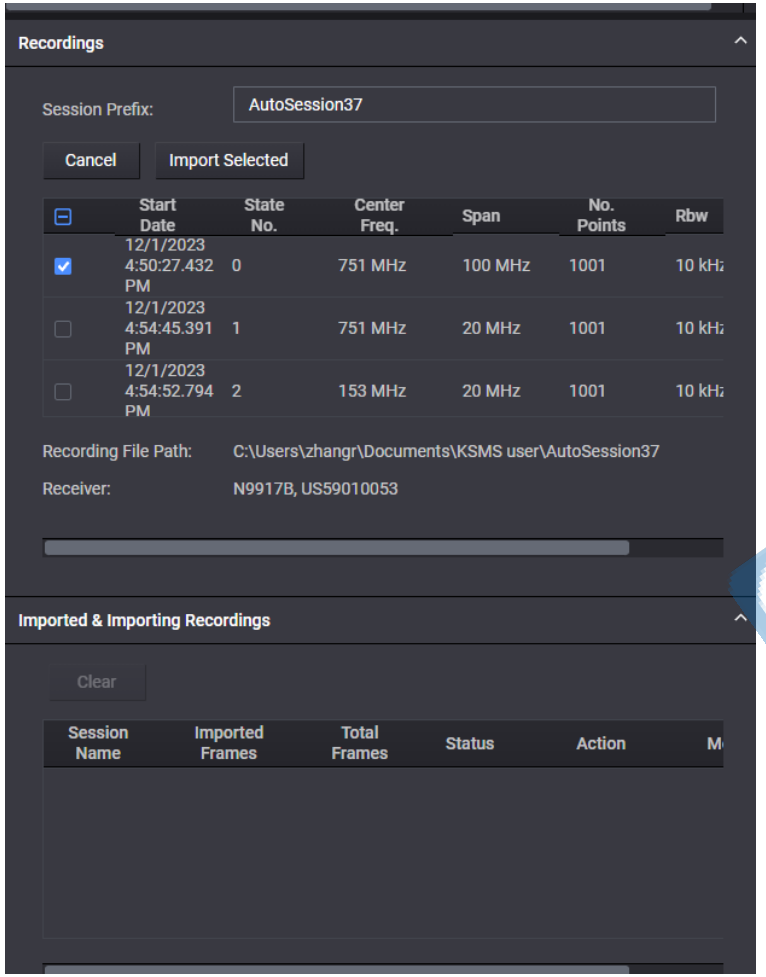
IQ 数据流盘，记录和回放

- 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

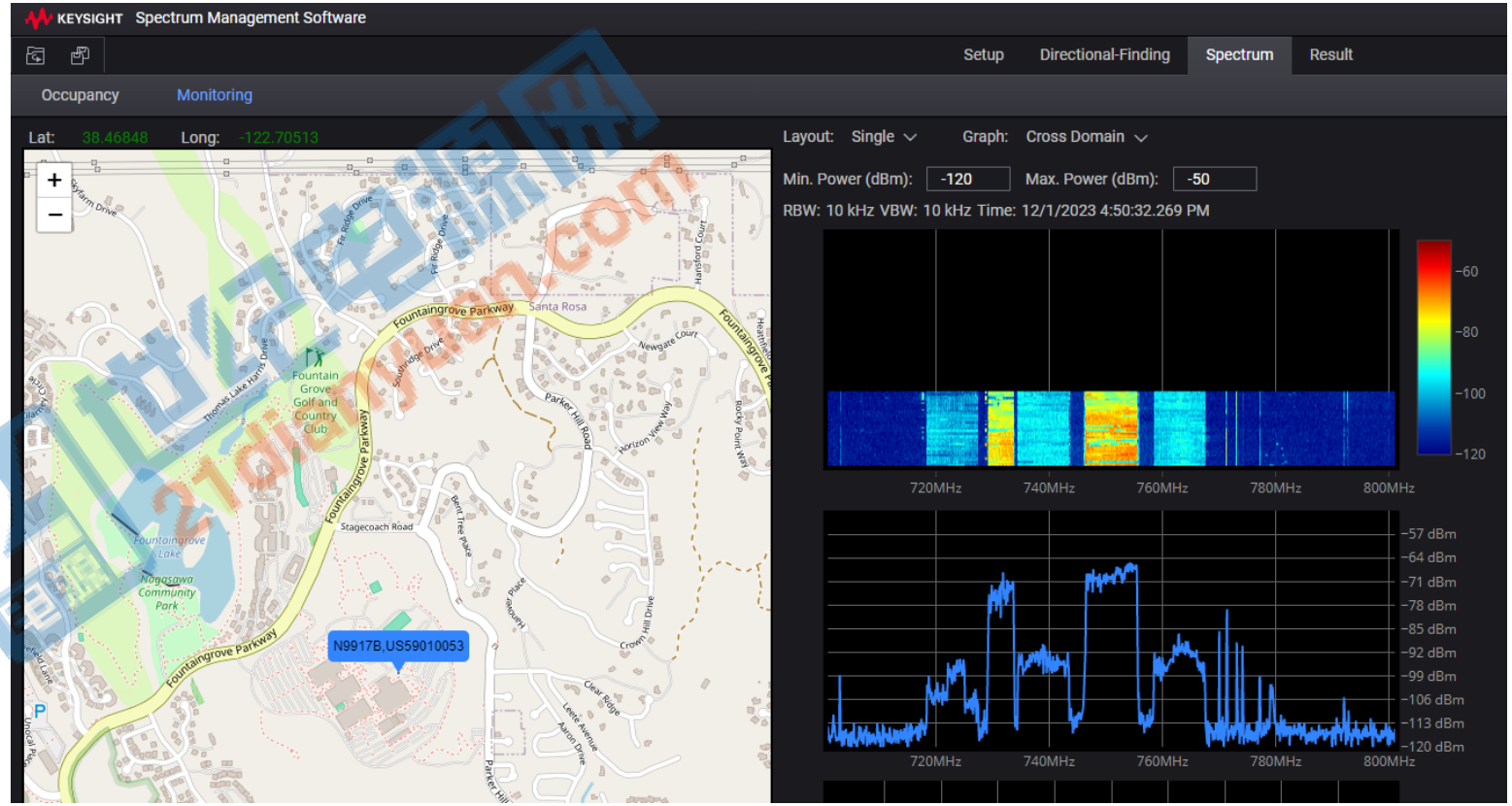


频谱轨迹数据记录和回放 Fieldfox记录频谱数据导入

Record spectrum with limit line trigger

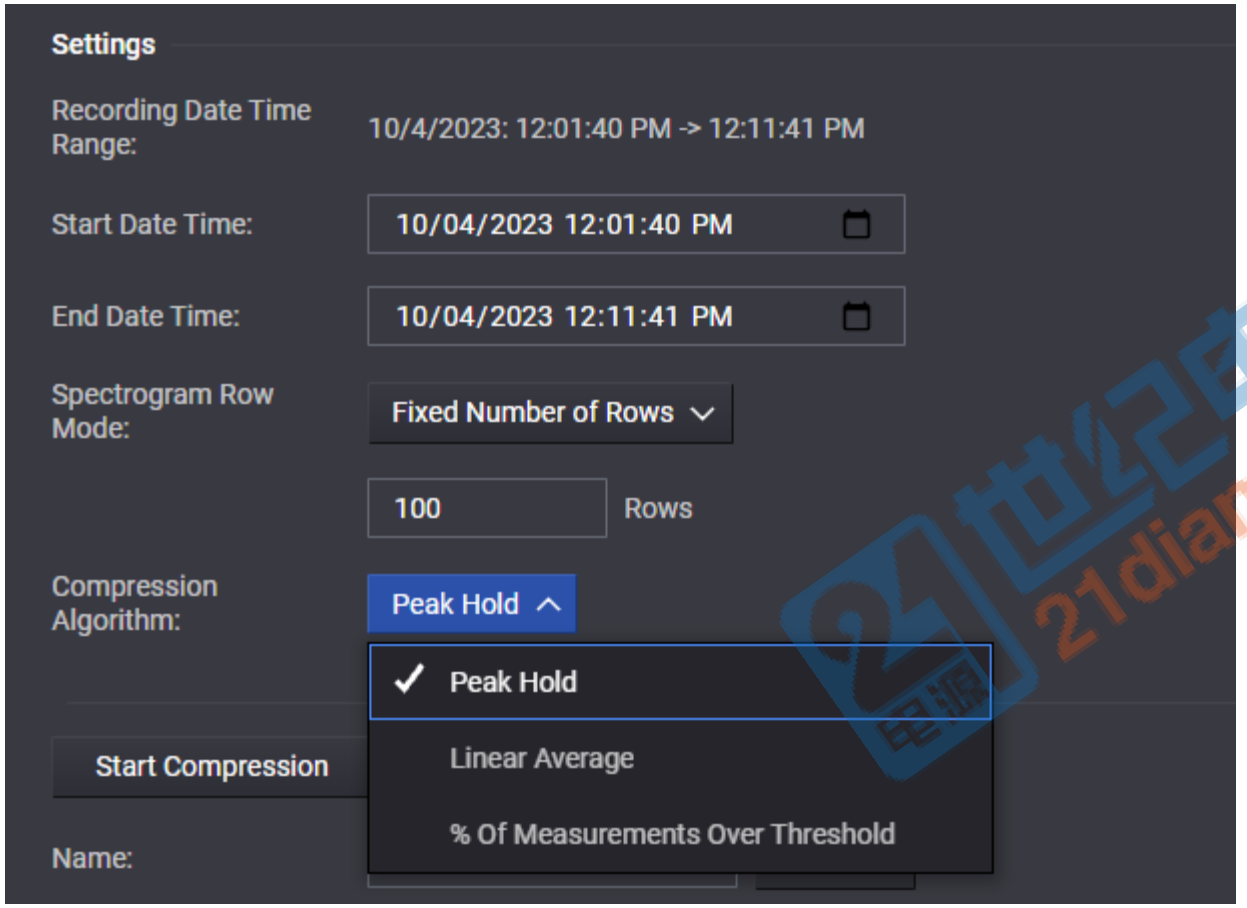


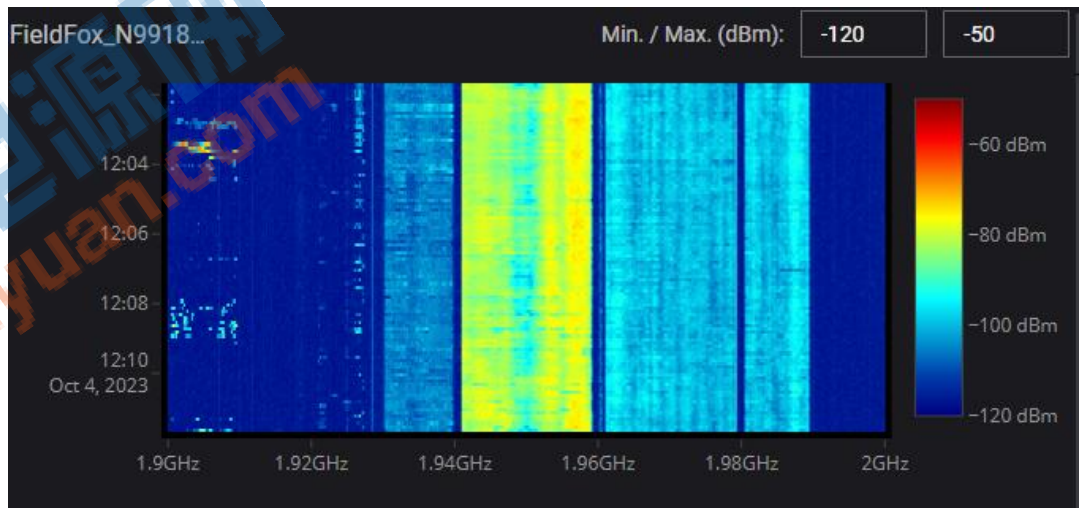
Import recorded file



Playback with location and run data analysis

压缩的瀑布图展示 用于能量检测





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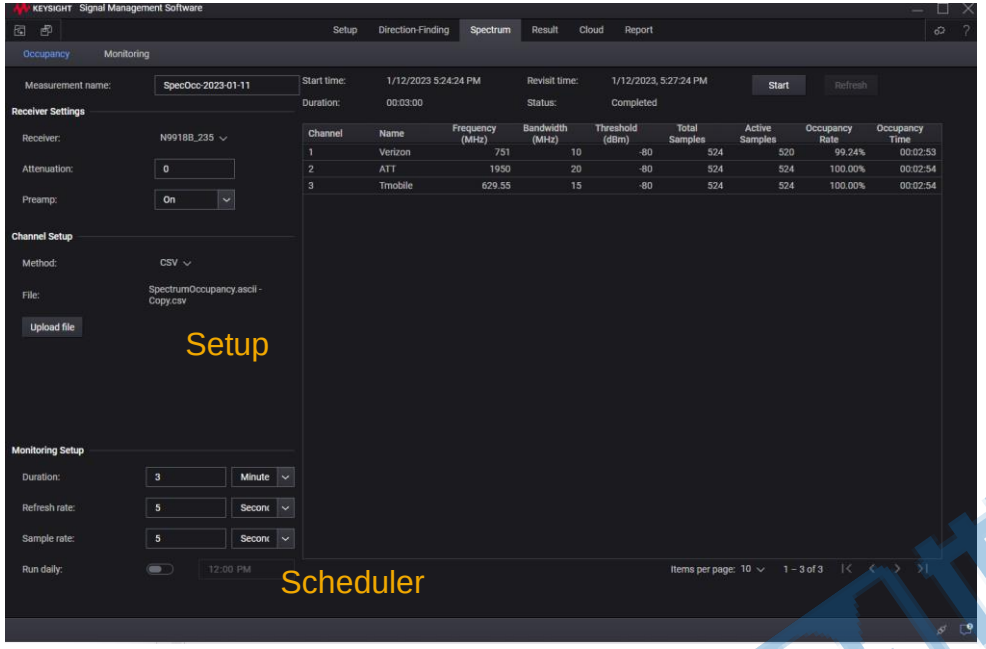
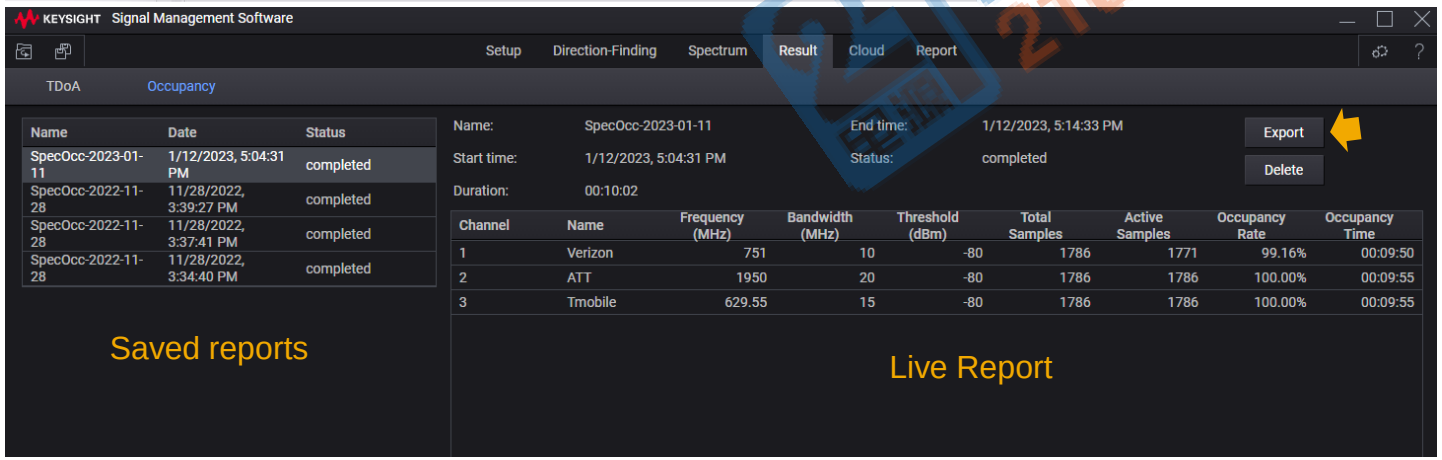
频谱占用度测试





- 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

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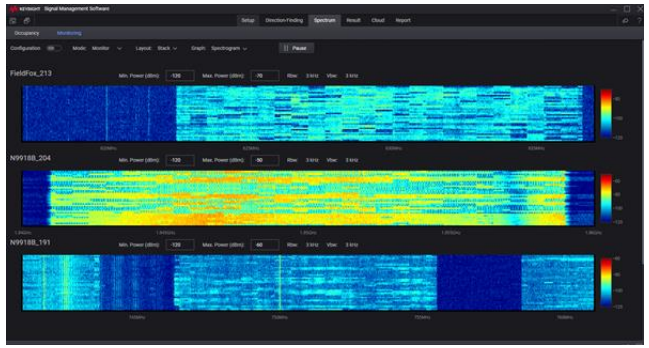
总结

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



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KEYSIGHT

Thank you

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