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TARANG: A Low-Cost, Man-Portable Software-Defined Radio System for Automated Wideband Passive RF Spectrum Monitoring, Signal Detection, and Direction Finding

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Abstract- The electromagnetic spectrum has become a decisive dimension of modern tactical operations, yet the receivers traditionally fielded for spectrum surveillance still scan one narrow channel at a time and can miss short, intermittent, or frequency-hopping transmissions. This paper presents TARANG, a man-portable passive radio-frequency (RF) monitoring system built around low-cost software-defined radio (SDR) hardware and open tooling. TARANG uses a HackRF-class SDR driven by a wideband sweep engine to observe an entire frequency band near-simultaneously, and a purpose-built digital signal-processing (DSP) chain to turn each sweep into a clean list of detected emitters with an accurate carrier frequency, received power, and signal-to-noise ratio. A parabolic peak-refinement step recovers the carrier location between fast-Fourier-transform (FFT) bins, while multi-sweep averaging, an adaptive noise-floor gate, adjacent-bin grouping, and channel bucketing together suppress spurious detections and stabilise the reported frequency of a fixed transmitter to a single channel. A baseline-driven module flags jamming and interference against a learned per-band reference, and an optional KrakenSDR five-channel coherent array provides relative bearing (direction finding) to a chosen target frequency. The complete system runs on a small tablet-class computer, is powered from a field battery, and logs every detection for later analysis. Field testing against a handheld land-mobile radio confirmed that the refined pipeline resolves a transmitter to its exact operating channel with stable, repeatable readings, in contrast to the several-hundred-kilohertz wander produced by a naive peak reading. TARANG demonstrates that a capable, deployable spectrum-monitoring and direction-finding capability can be assembled at a small fraction of the cost of conventional surveillance receivers.

Keywords— Software-defined radio, spectrum monitoring, electronic warfare, signal detection, direction finding, HackRF, KrakenSDR, FFT peak estimation, passive surveillance.

I. INTRODUCTION

Control of the electromagnetic spectrum underpins almost every contemporary military and security activity, from voice and data communications to navigation, remote sensing, and the command of unmanned systems. The ability to observe which frequencies are active, when, and how strongly is therefore a foundational capability for electronic support and situational awareness. Historically this task has been performed with dedicated surveillance receivers: sensitive, well-engineered instruments that nonetheless embody an older architecture in which the receiver is tuned to one channel, dwells there briefly, and then steps to the next. On a spectrum that is increasingly crowded with brief bursts, digital protocols, and agile, frequency-hopping emitters, this sequential approach carries an inherent risk: a transmission of interest may occur precisely while the receiver is listening somewhere else.

Software-defined radio changes the economics and the physics of this problem. By digitising a wide slice of spectrum and performing the channelisation and detection in software, an SDR can observe a broad band effectively at once, record it for later study, and apply modern detection and classification algorithms that a fixed-function receiver cannot. Crucially, capable SDR hardware is now inexpensive and compact enough to be carried by a single operator.

This paper describes TARANG, a man-portable RF monitoring system that was designed and built to exploit exactly this shift. TARANG combines a HackRF-class SDR for wideband scanning, an optional KrakenSDR coherent array for direction finding, and a custom software application that performs sweep capture, signal detection, frequency estimation, logging, interference detection, and analysis. The remainder of the paper motivates the design against the limitations of a representative traditional scanner, reviews the SDR hardware options and the rationale for those chosen, details the system architecture and the signal-processing methodology, presents the implementation and field results — including a measured improvement in frequency accuracy — and discusses operational relevance, limitations, and future work.

II. MOTIVATION: WHY WIDEBAND SDR IMPROVES ON A TRADITIONAL SCANNING RECEIVER

To make the motivation concrete, it is useful to compare TARANG against a well-known class of traditional wideband communications receiver, exemplified here by the AOR AR5000. The AR5000 is a capable superheterodyne receiver covering a very wide tuning range and has long been used for general-coverage monitoring. Its architecture, however, is fundamentally a tuned-receiver architecture: it listens to a single channel at any instant and searches a band by stepping through channels in sequence. This design has five practical consequences that limit its effectiveness against modern signals, each of which TARANG is specifically intended to overcome. Fig. 1 summarises the comparison.

Slow sequential scanning. Because a tuned receiver hears only one channel at a time, brief or bursty transmissions occurring elsewhere in the band are simply missed during the dwell on other channels. TARANG instead observes the whole selected band in each sweep, greatly increasing the probability that a short transmission is captured.

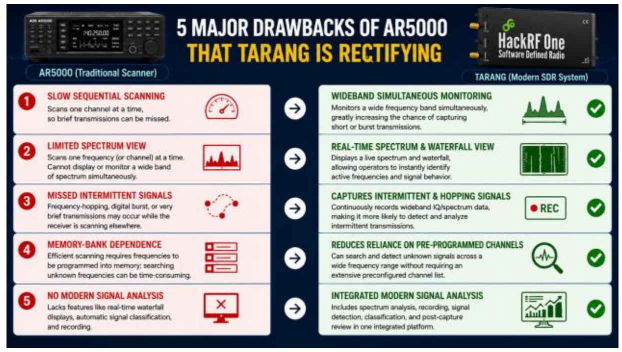

Fig. 1. Five limitations of a traditional sequential scanning receiver (represented by the AOR AR5000) and how the TARANG wideband SDR approach addresses each of them.

Limited spectrum view. A scanner cannot present a wide band of spectrum simultaneously. TARANG produces a live spectrum and a rolling waterfall, so an operator sees the activity across the entire band at a glance and can immediately recognise which frequencies are busy and how their occupancy changes over time.

Missed intermittent and hopping signals. Frequency-hopping, digital-burst, and very short transmissions may fall between the receiver's visits to a channel. Because TARANG continuously records wideband spectrum data, such intermittent emitters are far more likely to be detected and can be reviewed after the fact.

Dependence on pre-programmed channels. Efficient scanning on a traditional receiver relies on frequencies being programmed into memory banks in advance; searching for unknown emitters is slow and manual. TARANG searches an operator-defined range without a preconfigured channel list, so previously unknown activity can be discovered.

No integrated modern analysis. Legacy receivers lack real-time waterfall display, automatic signal detection, logging, and post-capture analysis. TARANG integrates detection, priority triage, time-stamped logging, an analysis dashboard, and — optionally — direction finding, in a single application.

The intent is not to claim that an inexpensive SDR outperforms a professional receiver on every metric of sensitivity or dynamic range; a purpose-built receiver retains advantages in front-end quality. The argument is architectural: for the specific task of finding and characterising activity across a band under time pressure, wideband simultaneous observation with software detection is better matched to the modern signal environment than narrowband sequential scanning, and it can be delivered in a package that a soldier can carry.

III. SOFTWARE-DEFINED RADIO: TYPES, ROLES, AND SELECTION

A software-defined radio moves the boundary between hardware and software as close to the antenna as practical. Rather than implementing filtering, mixing, and demodulation in fixed analogue circuits, an SDR digitises the incoming signal at radio or intermediate frequency and performs the remaining processing in software. This yields two properties that TARANG depends on: the same hardware can address a very wide range of frequencies and tasks, and the detection logic can be improved purely in software without changing the receiver.

Several SDR platforms are available, and they trade off frequency coverage, instantaneous bandwidth, number of coherent channels, transmit capability, and cost. Table I lists the platforms most relevant to a man-portable monitoring role. TARANG is designed around two of them working in complementary roles: a HackRF-class device for wideband scanning, and a KrakenSDR for coherent direction finding.

Table 1. Representative SDR platforms for man-portable spectrum monitoring and direction finding.

Platform	Coverage	Instant. BW	Role	Notes
HackRF One / Pro	1 MHz – 6 GHz	up to ~20 MHz	Wideband scan	Half-duplex, 8-bit; ideal for fast sweeps across a large range.
KrakenSDR	24 – 1766 MHz	~2.4 MHz	Direction finding	Five phase-coherent channels for angle-of-arrival estimation.
RTL-SDR	24 – 1766 MHz	~2.4 MHz	Low-cost receive	Single channel; the building block of the KrakenSDR.
USRP / BladeRF	wide (model-dep.)	tens of MHz	High-end R&D	Higher performance and price; less suited to a carried kit.
LimeSDR / Airspy	wide (model-dep.)	several–tens MHz	Receive / Tx-Rx	Capable mid-range alternatives to HackRF for scanning.

1. HackRF for Wideband Scanning

The HackRF family (HackRF One and the newer HackRF Pro from Great Scott Gadgets) is a half-duplex SDR covering roughly 1 MHz to 6 GHz with an instantaneous bandwidth of up to about 20 MHz and an 8-bit quadrature converter. For TARANG's scanning role, coverage and sweep speed matter more than raw dynamic range, and here the HackRF is an excellent fit. Its companion utility, hackrf_sweep, retunes the front end across a requested range in wide steps and reports the FFT power of every bin it observes, effectively building a picture of the whole band. Fig. 2 contrasts this wideband sweep with the sequential channel-stepping of a traditional scanner: where the tuned receiver hears only one channel while it dwells, the swept SDR measures every FFT bin across the band on each pass, so intermittent and hopping emitters are far more likely to be seen.

The physical device used in the field build is a HackRF Pro connected to a wideband antenna. Because the HackRF is a receive-and-transmit device, it is important to stress that TARANG uses it strictly passively — for reception and monitoring only.

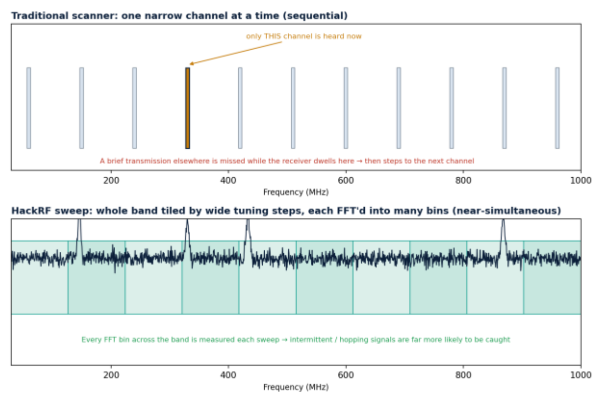

Fig. 2. Wideband sweep (bottom) versus traditional narrowband sequential scanning (top). The HackRF tiles the band with wide tuning steps and computes many FFT bins per step, observing the whole range near-simultaneously.

2. KrakenSDR for Coherent Direction Finding

Detecting that a frequency is active answers the question "what is transmitting?" but not "from where?" Direction finding requires a receiver that can compare the same signal across several antennas whose relative phase carries the geometry of the incoming wavefront. The KrakenSDR provides exactly this: five phase-coherent receiver channels (built on the RTL-SDR architecture and therefore covering roughly 24–1766 MHz) that sample a single frequency simultaneously. When the five antennas are arranged as a uniform circular array, the small differences in path length from an emitter to each element appear as measurable phase differences; a direction-of-arrival algorithm such as MUSIC resolves those phases into an angle of arrival. Fig. 3 illustrates the principle.

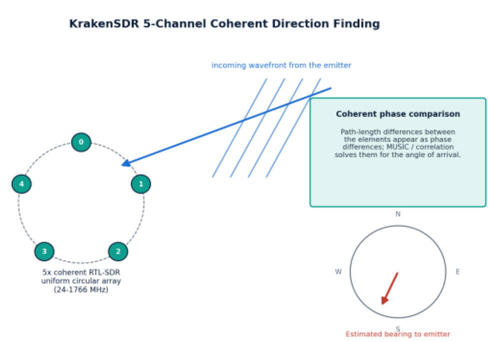

Fig. 3. KrakenSDR coherent direction finding. A five-element uniform circular array samples one frequency on five phase-coherent channels; path-length differences between the elements become phase differences, which a DoA algorithm resolves into a relative bearing to the emitter.

In TARANG the two radios divide the work naturally. The HackRF scans broadly and surfaces active frequencies of interest; the operator then hands a chosen frequency to the KrakenSDR, which tunes all five channels to it and reports a relative bearing. The bearing is relative to the physical orientation of the array, so it provides a line of interest rather than an absolute geographic fix; combining bearings from more than one location, or from a moving platform, allows the emitter to be localised.

3. Other Platforms

Single-channel RTL-SDR dongles are the least expensive receivers and are useful for fixed-frequency reception, but their limited bandwidth and single channel make them unsuitable for fast wideband search or for direction finding on their own. Higher-end platforms such as the USRP and BladeRF families offer greater instantaneous bandwidth and better converters, at substantially higher cost and size; they are better suited to laboratory development than to a carried kit. LimeSDR and Airspy occupy a useful middle ground and can serve as scanning front ends in place of a HackRF. The HackRF-plus-KrakenSDR pairing was chosen for TARANG because together they cover the two required roles — broad, fast search and coherent direction finding — at low cost and in a portable form factor.

IV. System Architecture

TARANG is organised as a pipeline from antenna to operator display, with an optional direction-finding branch. Fig. 4 shows the overall structure. Radio energy from a wideband antenna enters the HackRF, which the sweep engine drives across the selected band; the resulting per-bin power data is parsed and handed to a DSP and detection engine. That engine produces a list of detected emitters, each with a refined frequency, power, and signal-to-noise ratio. Detections flow in parallel to the operator interface, to a time-stamped log and analysis dashboard, and to a baseline-driven threat engine that compares current activity against a learned reference to flag jamming and interference. When required, a detected frequency is passed to the KrakenSDR branch for a bearing.

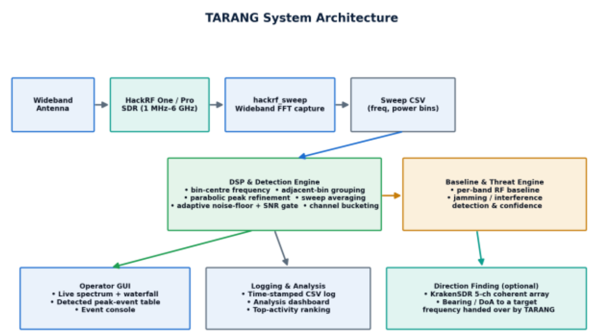

Fig. 4. TARANG system architecture. A HackRF-class SDR feeds a wideband sweep engine; a DSP and detection engine produces refined detections that drive the operator interface, logging and analysis, a baseline-driven interference/jamming engine, and an optional KrakenSDR direction-finding branch.

The entire system is deliberately lightweight. In the field build it runs on a small tablet-class computer powered from a portable battery, with the HackRF connected over USB, as shown in Fig. 5. The kit fits in a small pouch, sets up in minutes, and requires no external infrastructure, which is what makes the capability genuinely man-portable.

Fig. 5. Field configuration of TARANG: a tablet-class computer running the application, a portable battery, and a HackRF Pro SDR. The complete kit is carried and operated by a single person.

V. SIGNAL-PROCESSING METHODOLOGY

The value of TARANG lies less in the hardware, which is off-the-shelf, than in the processing that turns noisy sweep data into a trustworthy list of emitters with accurate frequencies. This section describes that pipeline, summarised in Fig. 6. The design goal throughout is twofold: report every genuinely strong signal, and report each one at its true frequency as a single, stable value rather than a reading that jitters from one update to the next.

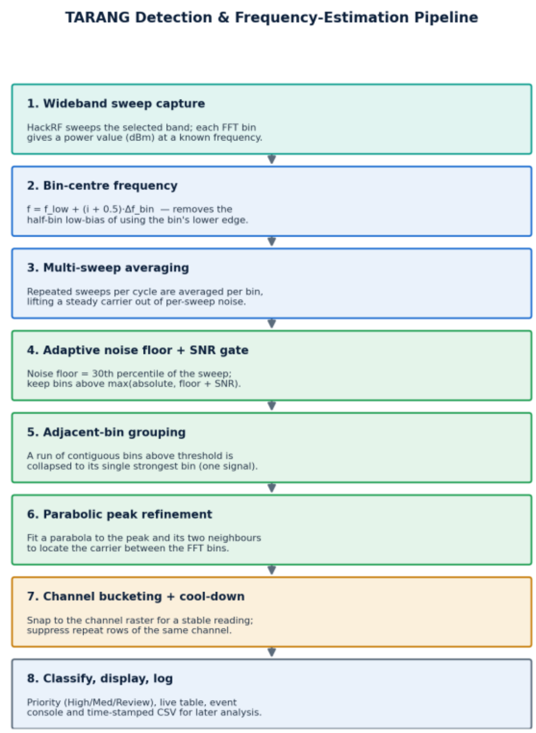

Fig. 6. The TARANG detection and frequency-estimation pipeline, from wideband sweep capture through to classification, display, and logging.

1. Sweep Capture and Bin-Centre Frequency

Each sweep from the SDR yields, for a series of frequency bins, the low edge of a bin, the bin width, and a power value. A naïve implementation labels each power sample with the low edge of its bin, which biases every reported frequency downward by half a bin width. TARANG instead assigns each sample the centre frequency of its bin:

$$f_i = f\_low + (i + 0.5) \cdot \Delta f\_bin$$

where Δf_bin is the FFT bin width. This single correction removes a systematic offset that, at a coarse bin width, can be a large fraction of a megahertz.

2. Multi-Sweep Averaging

When more than one sweep is captured per cycle, the same frequency bin is measured several times. TARANG averages those repeated measurements bin by bin:

$$\bar{P}(f) = (1/N) \cdot \Sigma_n P_n(f)$$

Averaging raises a steady carrier clear of the per-sweep noise. This matters directly for accuracy: with a single noisy sweep, the strongest bin of a signal can hop to a neighbouring bin from one update to the next, which is the dominant cause of a wandering frequency reading. Averaging suppresses that hopping so that the strongest bin — and therefore the estimated frequency — stays put.

3. Adaptive Noise Floor and SNR Gating

A fixed detection threshold is a poor fit for a spectrum whose noise floor varies across the band. TARANG estimates the noise floor robustly from each sweep as a low percentile of the observed powers, and admits a bin as a candidate detection only if it clears both an absolute floor and a margin above the estimated noise:

$$\eta = percentile_{30}(P(f)) \qquad T = max(A, \eta + S) \qquad SNR = P\_peak - \eta$$

where η is the noise-floor estimate, A is an operator-set absolute threshold, and S is the required signal-to-noise margin. Reporting relative to the measured floor keeps a busy band from flooding the display with noise while still allowing a genuinely strong but isolated signal to be surfaced. Raising A and S is the direct lever an operator uses to show only strong emitters.

4. Adjacent-Bin Grouping

A real transmission usually occupies several adjacent FFT bins, all above threshold. Reporting each such bin as a separate detection would produce a cluster of near-duplicate rows for one emitter and quickly overwhelm both the display and the log. TARANG collapses each run of contiguous above-threshold bins to its single strongest bin, so that one signal yields one detection.

5. Parabolic Peak Refinement

Even with the bin-centre correction, the strongest bin can only ever place a carrier at the centre of a bin; the true carrier generally lies somewhere between bins, and it leaks into the neighbouring bins in proportion to that offset. TARANG recovers the sub-bin position by fitting a parabola through the peak bin and its two neighbours. If P_{-1}, P_0, and P_{+1} are the powers of the left, peak, and right bins, the fractional offset of the true peak from the centre bin is

$$\delta = 0.5 \cdot (P_{-1} - P_{+1}) / (P_{-1} - 2P_0 + P_{+1}) \qquad \hat{f} = f_0 + \delta \cdot \Delta f\_bin$$

The estimator is used only where the three points genuinely describe a maximum and lie within the same sweep segment; otherwise the bin centre is retained. This step is what allows TARANG to place a strong carrier far more precisely than the raw bin spacing would suggest.

6. Channel Bucketing and Cool-Down

Many services of interest — land-mobile radio in particular — operate on a fixed channel raster (for example, 25 kHz or 12.5 kHz spacing). For such an emitter the most meaningful, and most stable, report is the channel it occupies. TARANG snaps the refined frequency to the nearest channel on an operator-selected raster:

$$f\_channel = round(\hat{f} / c) \cdot c$$

where c is the channel spacing. Combined with the accuracy improvements above, this yields a single, repeatable frequency for a fixed transmitter. A per-channel cool-down then suppresses repeated rows for a signal that persists on the same channel, keeping the event list readable.

7. Baseline-Driven Interference and Jamming Detection

Beyond cataloguing individual emitters, TARANG can judge whether the character of a band has changed in a way consistent with jamming or strong interference. It learns a per-band reference — a baseline of normal occupancy and noise — and compares live sweeps against it. A broad, sustained lift of the noise floor across a span of spectrum, rather than a discrete carrier, is the signature the engine looks for; it reports a jamming or interference indication with an associated confidence and the affected span. Because the judgement is made against a learned baseline rather than a fixed rule, it adapts to the local environment in which the system is deployed.

8. Relative Range Indication

For situational context TARANG can compute an indicative free-space distance from received power using a standard path-loss relationship:

$$d = 10^{[\,(P_t - P_r - 20 \cdot \log_{10} f + 27.55)\,/\,20\,]}$$

with f in MHz and powers in dBm. This value must be read with strong caution: it assumes a known transmit power and free-space propagation, neither of which holds for an uncooperative emitter in real terrain. It is therefore presented only as a coarse relative indicator, never as a calibrated range, and localisation proper is left to the direction-finding branch.

VI. IMPLEMENTATION

TARANG is implemented in Python, with a graphical interface built on customtkinter and live plotting through matplotlib. The SDR is driven by the hackrf_sweep utility, invoked with an operator-selected start and stop frequency, FFT resolution, number of sweeps per cycle, and gain settings. The application is structured so that the radio capture runs on a background worker thread while the user interface remains responsive: the worker performs the sweep, parses and processes the data, and passes finished detections to the interface through a thread-safe queue, so that the graphical toolkit is only ever touched from its own thread. This separation is what keeps the display fluid even while a sweep is in progress and allows a scan to be stopped promptly.

Fig. 7 shows the main monitoring window. On the left, the live spectrum is plotted with the current controls above it — start and stop frequency, FFT resolution, channel spacing, and the absolute and SNR thresholds — together with a status line reporting the sweep time and estimated noise floor. On the right, detected peak events are listed with their time, frequency, power, SNR, and a priority triage of High, Medium, or Review derived from power and SNR. An event console mirrors the detections as a scrolling text log. Controls allow the operator to start and stop scanning, export the log, and open the analysis window.

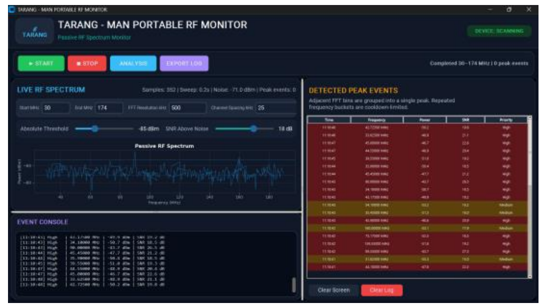

Fig. 7. The TARANG main monitoring window: live spectrum and sweep controls (left), and the detected-peak-event table with priority triage (right).

Every detection is written to a time-stamped CSV log that records the refined frequency, the snapped channel, power, noise floor, SNR, priority, the scan settings in force, and any interference indication. The log is the basis of the analysis dashboard shown in Fig. 8, which reads back the recorded events and summarises the most active frequencies — ranking channels by how often they appear and reporting their average and peak power, average SNR, and the time each was last seen. This turns a raw stream of detections into an at-a-glance picture of which frequencies dominate a location over a period of observation.

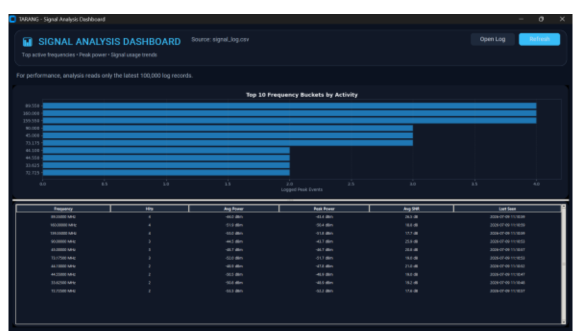

Fig. 8. The TARANG signal-analysis dashboard: the most active frequency channels ranked by

occurrence, with average and peak power, average SNR, and last-seen time.

VII. DIRECTION-FINDING INTEGRATION

The direction-finding branch is integrated so that it can be driven from the monitoring workflow rather than as a separate task. A frequency observed in the monitoring window can be sent to the direction-finding function, which tunes the KrakenSDR's five coherent channels to it, waits for the receiver to settle and for a stable angle-of-arrival solution, and then displays a relative bearing on a compass together with a confidence figure. The controller is written to locate the KrakenSDR service whether it runs on the same computer or on a companion single-board computer on the local network, and it validates that the requested frequency lies within the array's supported range and matches the physical antenna configuration in use. Because the result is a bearing relative to the array, obtaining a location fix requires bearings from more than one position; the system provides the per-position bearing that is the necessary input to that process.

VIII. FIELD EVALUATION AND RESULTS

The system was exercised in the field with the configuration of Fig. 5, scanning the land-mobile band and observing a handheld radio as a controlled reference emitter. Two aspects were evaluated: the number and relevance of detections, and the accuracy and stability of the reported frequency.

Detection relevance. With the detection thresholds set conservatively, the event list filled with many weak bins only marginally above the noise, obscuring the signals of interest. Raising the absolute threshold and the required SNR margin restored a clean list dominated by genuinely strong emitters, confirming that the adaptive-threshold controls give the operator direct and effective control over sensitivity.

Frequency accuracy and stability. With a coarse FFT resolution and a single sweep per cycle, the reported frequency of the fixed reference radio wandered by up to a couple of hundred kilohertz between updates — the strongest bin was hopping between neighbours under noise. Applying the full pipeline of this paper — finer FFT resolution, multi-sweep averaging, parabolic refinement, and channel snapping — collapsed this wander to a single, repeatable channel reading. In controlled reproduction of the effect on representative sweep data, the snapped channel was identical across every capture cycle for an on-raster carrier, while the raw peak continued to vary; the reported frequency became stable and correct rather than drifting.

Figs. 7 and 8 show representative output from the running system: a populated live spectrum, a table of detected peak events across the scanned band with power and SNR, and an analysis summary ranking the most active channels. Together they demonstrate the end-to-end capability — from raw wideband capture to a triaged, logged, and analysable list of emiters — achieved with entirely low-cost hardware.

IX. OPERATIONAL RELEVANCE AND DISCUSSION

The practical significance of TARANG is that it lowers the barrier to a spectrum-awareness capability at the tactical edge. A single operator can carry the kit, define a band of interest, and within minutes obtain a live picture of activity, a logged record for later analysis, and — when needed — a bearing to a specific emitter. The wideband, software-defined approach is well matched to an environment of brief and agile transmissions that defeat sequential scanning, and the baseline-driven interference detection provides an early indication of deliberate jamming. Because the detection logic lives in software, the capability can be refined and extended in the field without new hardware, as demonstrated by the frequency-accuracy improvement described above.

It is equally important to be clear about what the system is not. It does not replace a calibrated measurement receiver for precise power or spectral measurements, and its 8-bit wideband front end has less dynamic range than a dedicated instrument. Its strength is search, detection, triage, and cueing —

the tasks that most directly support electronic support and situational awareness — rather than fine measurement.

Limitations, Safety, and Legal Considerations

- The wideband SDR front end trades dynamic range and sensitivity for coverage and cost; very weak signals near strong ones may be masked.
- The free-space distance estimate is indicative only and must not be treated as a calibrated range.
- Direction finding yields a relative bearing that depends on the physical array geometry and orientation; an absolute fix requires multiple bearings, and accuracy degrades with multipath.
- Reception coverage and direction-finding range are bounded by the chosen hardware (for example, the KrakenSDR's coverage extends to roughly 1766 MHz).
- The system is strictly a passive receiver in the monitoring role. Spectrum monitoring and any related activity must be conducted only under proper authorisation and in accordance with the applicable legal and regulatory framework.

X. CONCLUSION AND FUTURE WORK

This paper presented TARANG, a low-cost, man-portable software-defined-radio system for automated wideband passive spectrum monitoring, signal detection, and direction finding. By pairing a HackRF-class SDR for broad, fast search with a KrakenSDR for coherent direction finding, and by investing in a carefully engineered detection and frequency-estimation pipeline, the system delivers a capability — simultaneous wideband observation, accurate and stable frequency reporting, interference detection, logging, analysis, and bearing estimation — that traditional sequential scanning receivers cannot, at a small fraction of their cost and in a form a single operator can carry. Field evaluation confirmed both relevant detection under operator-controlled thresholds and a marked improvement in frequency accuracy and stability from the refined pipeline.

Future work includes automatic modulation recognition and signal classification, tighter and more automated fusion of monitoring with direction finding, multi-node operation for emitter localisation from several positions, and improvements to sensitivity and dynamic range through better antennas and front-end conditioning. The software-defined foundation means that each of these can be pursued as an incremental enhancement of the existing platform.

Acknowledgment

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