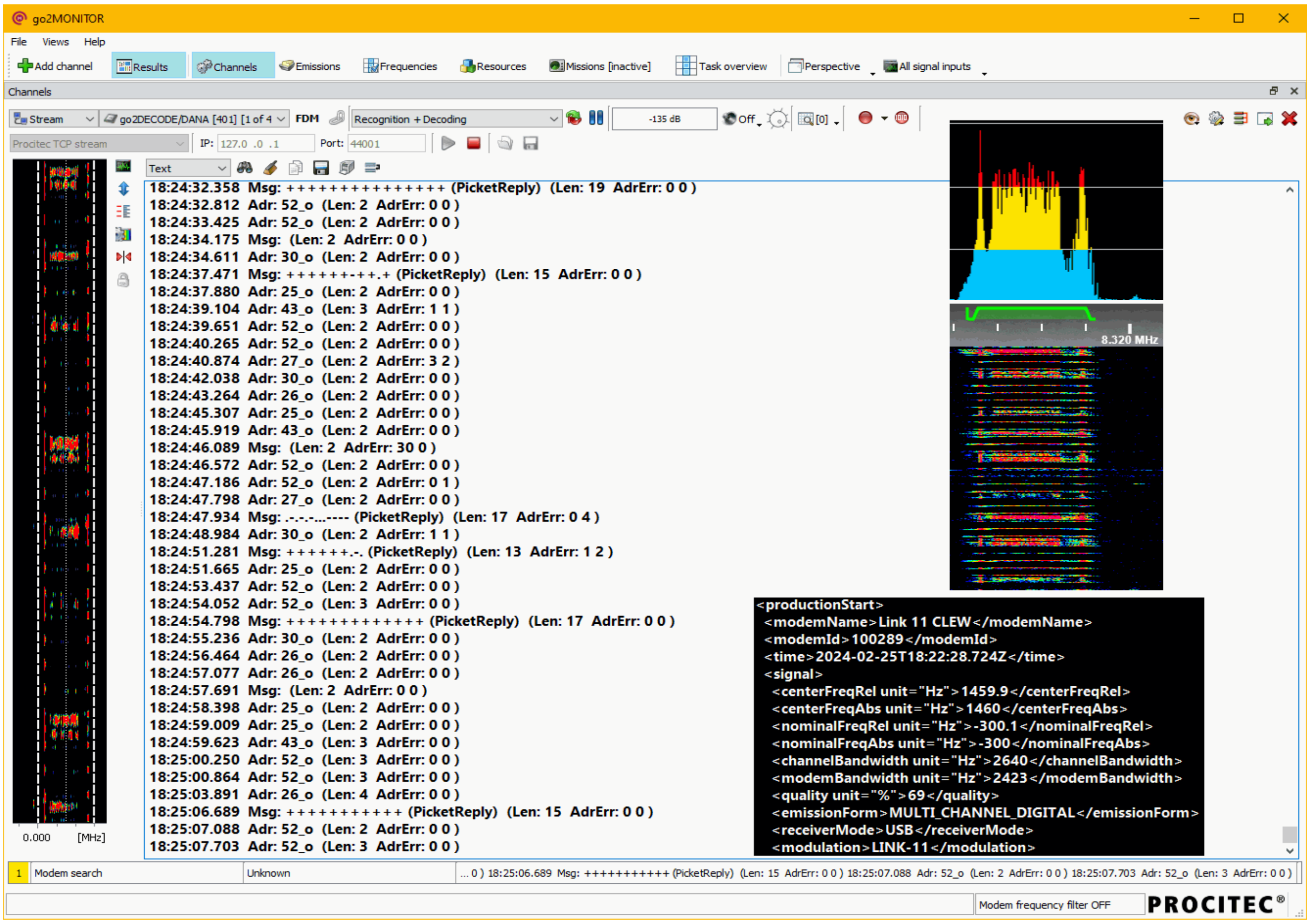
The tremendous benefit of HF is the long-range communication capability when (read: if!) aided by favorable ionospheric conditions. The critical point is the "lack of dependability" of the ionosphere, i.e. whether the HF link can be established or not, and how long the link will remain active after being established. This instability drastically limited the use of HF especially for the military, because there is no assurance that communication in critical situations can be established on demand.

The requirement of pre-planned frequency allocations for the establishment of a communication link - even if the system supports multi-band modes - is another problem. State-of-the-art radio systems make use of the revolutionary SDR technique for dependability, sustainability, and predictability: they <u>automatically</u>

- find the frequency band that is reliable for communication with its counterpart located thousands of kilometers away across the entire 3 - 30 MHz HF frequency range;
- switch to the new frequency band without disrupting the ongoing communication;
- adjust its communication protocol to sustain the communication while maximizing the link capacity through its adaptive/cognitive engine under widely varying channel conditions;
- tune its advanced antenna matching circuit to the selected HF band.

For military users, up-to-date technology provides already today the whole range of data, e-mail, fax, video, and voice communications via secure = encrypted HF radio circuits. Tactical backbone systems easily integrate with external Internet-Protocol (IP) networks. Basically, there are two approaches to increase traditional HF data transmission rates:



8317.3 kHz Digital data station using the NATO Standard Link-11 (CLEW) system

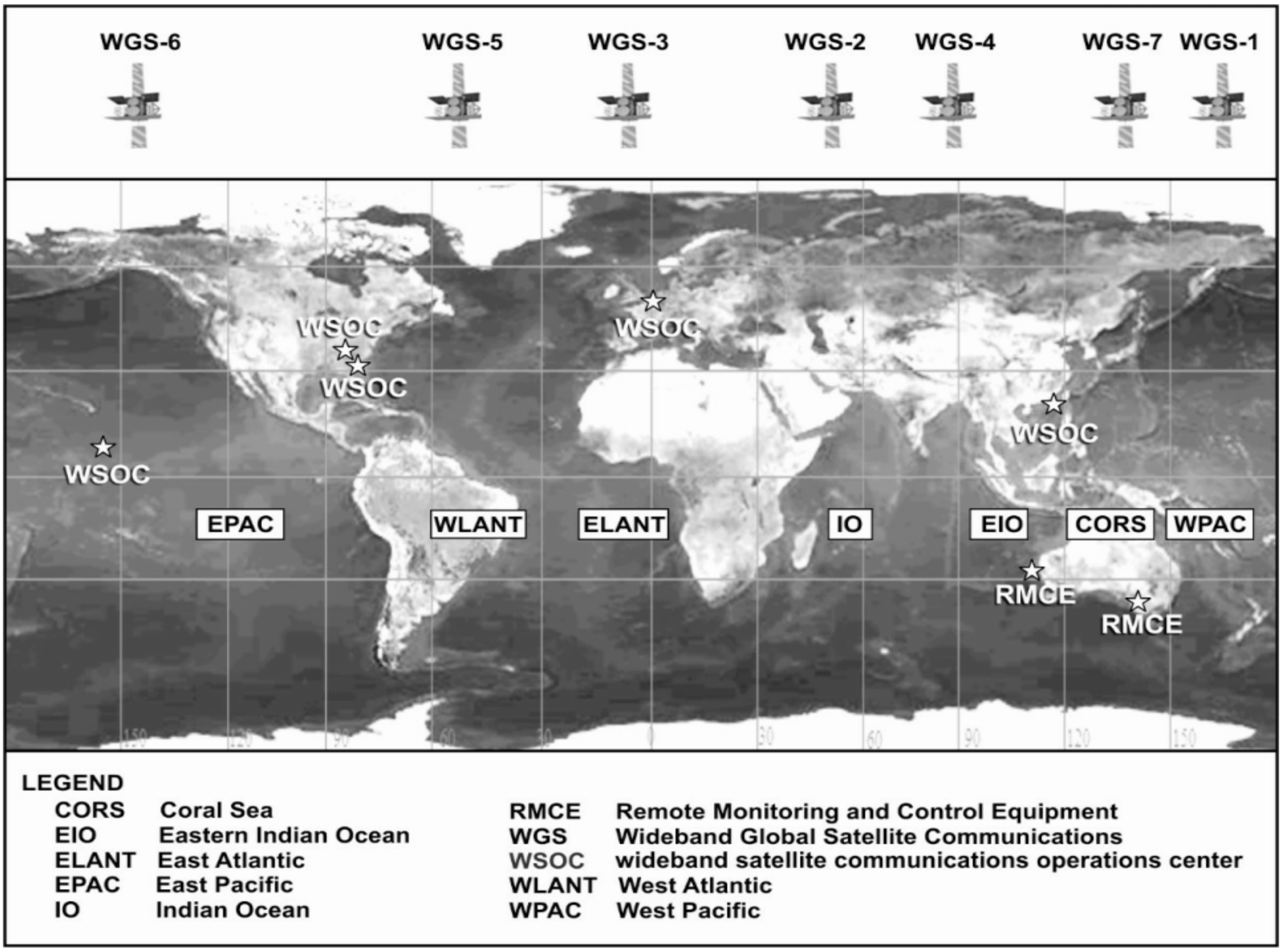
- NATO member states, and the United States of America - read: ROCKWELL COLLINS - and its allies in particular, have increased the bandwidth of the relevant radio channels by a factor of eight, creating radio "superhighways" able to absorb the growth in traffic. However, these drastically expanded PSK aggregate signals to not concede with traditional ITU frequency channel / country allocations regulated by international agreements. Anyway, "Wide-Band HF" operating costs are a fraction of those associated with a SATCOM system. By consequence, these signals can now be found all over the HF spectrum, perfectly disregarding any current HF frequency plans that, to say it quite clearly, are simply outdated in today's technological environment.
- Countries such as France - read: THALES - have adopted a different approach, which involves using eight standard channels in parallel - though not necessarily adjacent channels! - to increase voice and data capacity. If necessary, this adaptive multi-band system can be increased to 16 channels. It automatically selects the most suitable radio channels in real time, based on the actual propagation conditions encountered. Initial tests in December 2016 between Paris and Toulon, covering a distance of 730 km, were pretty successful. "HFXL", as they named their baby, has been proposed as a NATO standard as well.

Traditional SW digital data transmissions use data rates of up to 2,400 bps with multi-channel voice-frequency telegraphy (MCVFT) and frequency-division multiplex (FDM) phase-shift keying (PSK). A typical system generates a composite audio signal consisting of a set of 18 tones within the standard SSB bandwidth of 300 to 3,000 Hz. 16 of these tones are spaced 110 Hz in the band 935 - 2,585 Hz being modulated in differentially encoded quaternary PSK (DE-QPSK) mode at 75 bps; this gives a total transmission speed of $16 \times 2 \times 75 = 2{,}400$ bps. A 605 Hz tone is used for the correction of end-to-end frequency errors including any Doppler effect, and an 825 Hz (or 2,915 Hz) tone is chosen for system synchronization to avoid excessive loss at the lower (or upper) band edge. Lower data rates such as 1,200 or 600 Baud enable dual ($2 \times 1{,}200$) or quadruple (4×600) diversity. Advanced systems using 8PSK and a packet radio protocol achieve data rates of 5,400 bps. Latest protocols such as PACTOR-4 claim to run at 10,500 bps for text only.

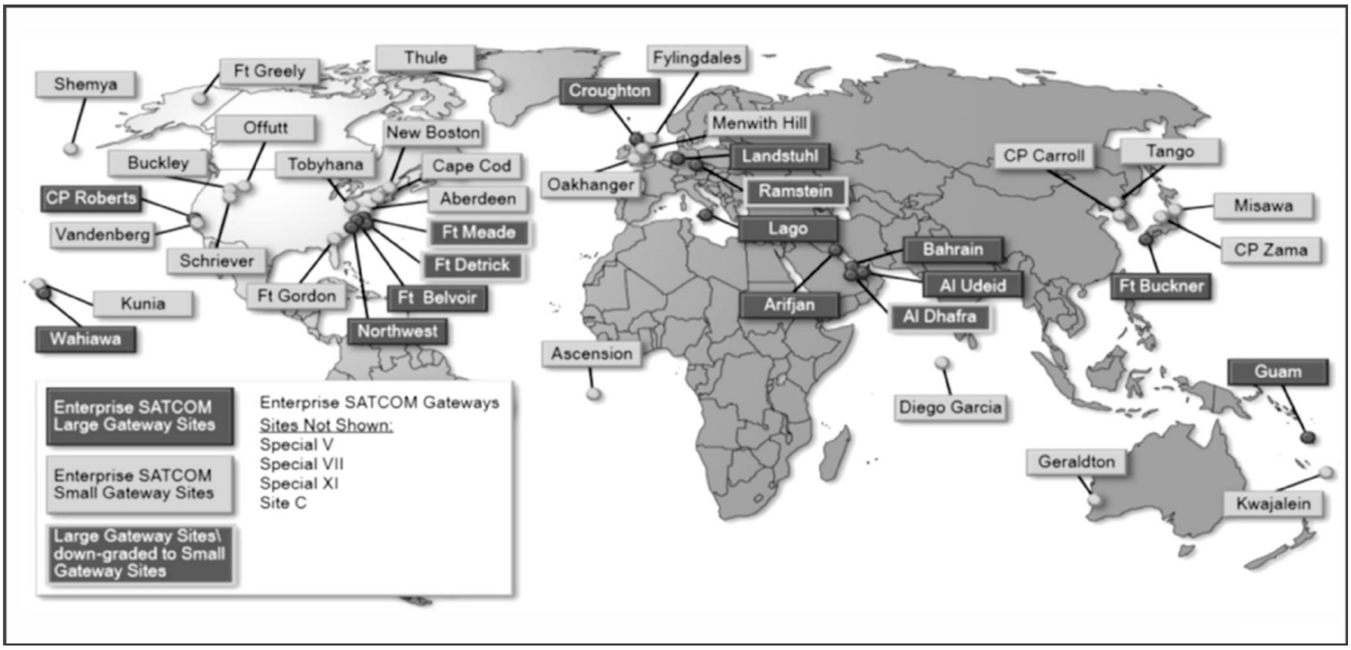
SW digital radiotelephone systems using speech signal encoders (so-called vocoders) with occasional scrambling have been monitored. These operate at 600 or 1,200 bits per second (bps) with error-correction coding for long-range communications using skywaves. 9,600 bps are used for short-range links using ground waves. The modems applied in these systems are basically the same as those for data transmissions (see below).

Today's era for long-range HF communications is the result of recent advances in radio and Digital Signal Processing (DSP) technology. HF radio is no longer limited to those slow traditional 9,600 bps data rates mentioned above. Modernized PSK systems can deliver rates up to 240,000 bps on a 48 kHz wide channel, allowing the same levels of data transmission speeds, quality and security of a narrow-band SATCOM system - particularly useful for more robust communications in hostile environments. These WBHF waveforms - a "very wide" PSK aggregate indeed, preceded by a pilot tone - can be easily identified on a wide-band sonagram: see page 25. Typical bandwidths are 12, 24 and 48 kHz. Most of these communication systems are military. The Australian Defence Force recently transmitted high-quality still images and video via internet protocol (IP) over a state-of-the art wideband PSK HF radio link between the RAAF base at Townsville and the RAAF base at Wagga! See *https://news.defence.gov.au/news-events/releases* for details.

With the rise of Communist China, and the Russian Federation trying to resume superpower status in the 21st century, we're now witnessing the Second Global Cold War. SATCOM is increasingly vulnerable from jamming, and from potential total failure as a result of attacks on spacecraft or through the use of anti-satellite surface-to-air missiles.



NATO wideband global military SATCOM coverage areas



United States of America - Department of Defence worldwide SATCOM gateways

While uplink jamming (UJ) - i.e. corrupting the signal transmitted from a ground station to the satellite - is able to degrade the satellite's signal for all of its users, downlink jamming (DJ) has a localized effect since it blocks transmissions from the satellite to certain terrestrial receivers only. Logically, UJ requires a much more powerful signal in order to reach the satellite's transponders. The point is that today, powerful SATCOM jamming tools are increasingly inexpensive ... A pretty interesting summary of Chinese and Russian activities in this field, entitled "Challenges to Security in Space", can be found at *http://swfound.org/media/207162/swf_global_counterspace_capabilities_2021.pdf* .

NATO is significantly dependent on SATCOM for the planning and execution of operations. Members and partner forces are suffering from a disruption of SATCOM, particularly along the alliance's eastern flank where Russian armed forces continue to conduct electronic warfare. By consequence, there is a widespread comeback of HF in local and global communications. Says C4ISRNET on 22 September 2020, in a paper titled "The military renaissance in high frequency communications" at *www.c4isrnet.com/battlefield-tech/it-networks/2020/09/22/the-military-renaissance-in-high-frequency-communications*: "In an online presentation to the Association of Old Crows on 6 August 2020, Paul Denisowski, product management engineer at Rohde & Schwarz North America, described how communications satellites are vulnerable to antisatellite systems as well as ground-, air- and space-based 'kill vehicles'. China, Russia and the USA have all carried out anti-satellite (ASAT) tests, and many other countries are developing ASAT capabilities."

The Economist of 3 February 2024: "America, China and India have all tested Earth-based ASAT missiles like Russia's *Nudol*. Other threats include ground-based 'directed energy' weapons: lasers, high-power microwaves and radio-frequency jammers."

It seems that the recent Russian attack and invasion of the Ukraine has, again, changed all that. *The Economist* of 7 January 2023 in "The satellites that saved Ukraine": "Russia's armed forces have lots of electronic-warfare equipment that can locate, jam or spoof radio emissions. But the Starlink signals are strong compared with those from higher flying satellites, which makes jamming them harder ... Starlink's use in Ukraine marks 'the beginning of the end' for the value of anti-satellite missiles."

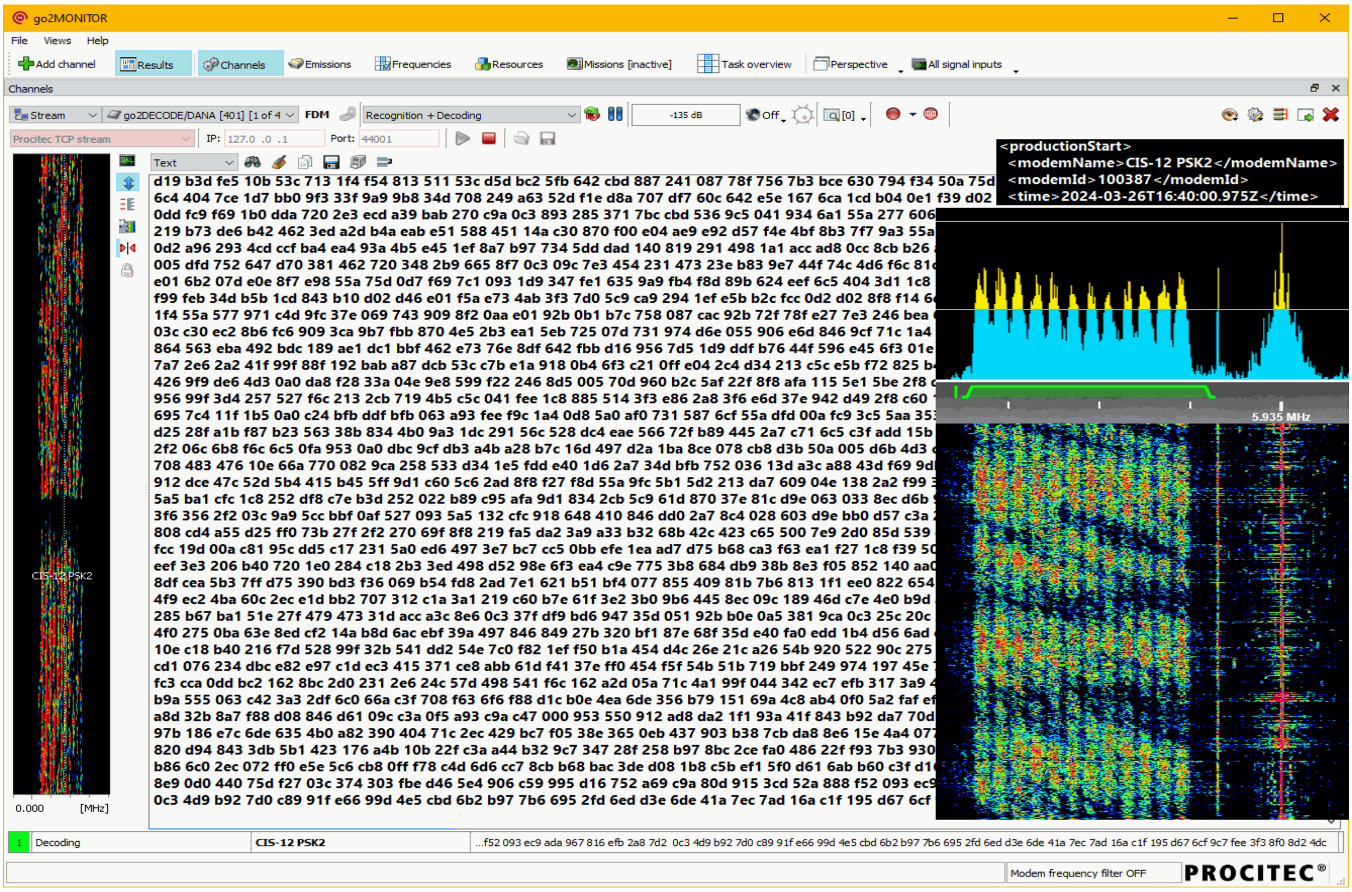
On 6 November 2020, the United States Military Academy has published an interesting paper entitled "Resiliency by Retrograded Communication - The Revival of Shortwave as a Military Communication Channel" at *www.ieeexplore.ieee.org* : "In the last three decades, the great powers have become increasingly dependent on SATCOM, VHF, and UHF, providing high bandwidth line-of-sight communications. These military communication channels lack resilience because an electronic war campaign can affect both VHF and SATCOM simultaneously. The 1940's preferred spectrum, HF, with its different propagation pattern, offers an opportunity for military communication resiliency in the 21st century."

Says Armada International from Bangkok, Thailand - one of the world's leading and most respected defence publications! -, on 9 January 2024 at *www.armadainternational.com* : "Available SATCOM bandwidth is under commercial pressure and at risk from jamming and cyberattack, as the Ukraine war has shown. - HF has established itself as a reliable long-range communications protocol with significant military utility. - HF provides intercontinental ranges, but its waveforms can be comparatively difficult to jam. Moreover, HF frequencies are free to use and do not suffer the congestion of some SATCOM bandwidths. - As we plan redundancy in communication in military organisations, HF is often a contingency method to command and control troops on the ground. This enables warfighters to receive their orders in emergency situations, especially when Internet, cellular or SATCOM are not an option."

However ... one never knows. Says Jeff Haverlah from Texas: "HF remains a viable post attack communications means because ground and orbiting hardware can be destroyed but Earth abides. It's been understood since the late 1950's that the ionosphere is rapidly self-healing after disruption due to a nuclear event." And Ronald Edberg from London comments in October 2023: "The sun is not acting normally. There are too many flares, coronal mass ejections, and plasma ejections. In my opinion, the world is going to lose some of its strategic satellites. The Internet and grid are under extreme stress from a variety of sources, leaving HF the main source of communication in the future. However, there is also a high level of atmospheric noise, making it difficult at times to hear low power stations ..."

Says Daniel Ayers ZL1DFA on 26 October 2023: "Take a look at this US Government document *www.cisa.gov/sites/default/files/publications/19_0307_CISA_EMP-Protection-Resilience-Guidelines.pdf* on protecting against nuclear Electro Magnetic Pulse (EMP) damage and maintaining communications after a nuclear blast ... It advocates using HF as the most reliable means of communication that needs no electronic infrastructure, and mentions the High Frequency Emergency and Evacuation Network (EEN) ..." See page 302 for some United States Embassy EEN frequencies!

Regarding the current rise of Communist China that we already mentioned above, *The Economist* published detailed articles on the fascinating subject of Open-Source Intelligence (OSINT) in its editions of 7 August 2021 and 19 February 2022. Using easily-sourced data such as satellite images, aircraft and ship tracking websites, social-media information and so on, another interesting field is professional radio monitoring. China illegally claims dozens of islands and reefs in the South China Sea and has built extensive military installations such as aircraft runways, missile launchers, and ... large HF antenna arrays. Johns Hopkins University's Applied Physics Laboratory recently published detailed reports with revealing and shocking pictures at *www.jhuapl.edu/Content/documents/High-FrequencyCommunications.pdf* and *www.jhuapl.edu/Content/documents/Inter-IslandCommunications.pdf* . Enjoy!



5932.8 kHz · Russian military station in the broadcast band - on the right is Xizang People's Broadcasting Station from Baiding, Tibet, China, on 5935 kHz