USER COLLISION FOR JOINT UTILIZATION OF ELECTROMAGNETIC FREQUENCY BAND: Frequency Allocation, Interference Reduction and Security Threat Mitigation in Radio Propagation and Remote Sensing

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ABSTRACT

The user community of electromagnetic frequency bands within the ULF to FUV bands is rapidly increasing; and the electromagnetic spectrum is being overtaxed in providing required band allocations, resulting in direct confrontations between the active and the passive user groups. The active user group includes the entire terrestrial-space & mobile tele/video-communications industry, tele-navigation, the military and active remote sensing communities, whose interests among themselves are colliding increasingly, requiring introduction of RFI reduction. An introduction to these highly important aspects of securing our capabilities in terrestrial space-tele/video-communications & navigation as well as in military surveillance and environmental stress change monitoring at ground, from air and space is given.

INTRODUCTION

The user community of the electromagnetic frequency bands within the ULF-band to the FUV-band is rapidly increasing; and the *natural electromagnetic spectrum (NES)* – **one of the most fundamental Resources** - is being overtaxed in providing the required frequency band allocations. This has lead to direct confrontations between the active and the passive user groups. The active user group includes the entire terrestrial-space & mobile tele/video-communications industry, tele-navigation including the US GPS (Global Positioning System), the RF GLONASS (GLObal NAvigation Satellite System), and the EU GNSS (Global Navigation Satellite System), the defense and other active remote sensing communities, whose interests among themselves are colliding with increasing frequency because the available spectral bands are not sufficient for satisfying all needs. The passive user group consisting of aeronomy, radio-astronomy and of passive near-field sounding & far-field remote sensing are also colliding because radio-astronomy and in great parts aeronomy are directed outward toward the planetary and galactic space, whereas airborne and shuttle/satellite multi-modal passive and active remote sensing is looking down close-to-nadir on the terrestrial covers, which tends to add to the interference by the active user groups. Furthermore, the rapid increase of expanding narrow-band to ultra-wide-band mobile communication is creating havoc and an unavoidable impasse. Therefore, the entire issue of frequency allocation and radio spectral-band sharing coupled with modern advanced digital techniques, such as digital antenna bean forming, digital coding and correlation plus digital radio frequency interference reduction must be re-addressed totally. Although hitherto remote sensing utilization of the electromagnetic spectrum was absolutely not an economically viable and may remain less profitable venture; we request that an entirely new approach be adopted. This could mean to levy a surcharge for the use of NES from the commercial users for maintaining and operating the passive and active remote sensing and monitoring bands, which must be considered a justified measure in order to be able to monitor on a permanent un-interrupted time-scale the health of planet Earth; and even the *"Modern Telecommunications Complex"* cannot deny that it relies on it. We, the passive & active remote sensing community, we must consider ourselves to be therefore given the astute Professional Status with the innate responsibility of functioning as the *"Pathologists and Radiologists of the Terrestrial and also Planetary Environments",* and be entrusted to keep a watchful eye on the misuse of the "**Natural Electromagnetic Spectrum (*NES*)"**, which is indeed to be sanctified as one of the most "**sacred treasures and resources of Planet Earth**". However, propagation space pollution of ***"NES"*** is not irreversible; and still today measures can be taken to reverse the trend by implementing more efficient spectrum utilization based on advances in digital communications and novel RF interference reduction techniques.

SPECTRAL BACKGROUND NOISE OF MAJOR FREQUENCY BANDS OF THE NATURAL ELECTROMAGNETIC ENVIRONMENT, AND ITS MAN-MADE NOISE AND INTERFERENCE SOURCES

As the electromagnetic noise levels of civilization are increasing worldwide at an alarming pace, it is essential to recover the frequency-dependent characteristics of the natural electromagnetic noise environment – *unperturbed by civilization* - across its entire spectrum and as accurate as it still can be done. The entire electromagnetic spectrum inclusive its natural background noise and resonance (eigen-frequencies) behavior must be treasured as an irreplaceable ***"fundamental natural resource"*** that must be protected from erroneous anthropogenic noise and other blatant misuse. It is safe to state that there does not exist a single spectral-band within which one or the other natural geophysical phenomena within the terrestrial covers do not possess explicitly associated electromagnetic resonances as weak as those might be but essential they are for monitoring the health of planet Earth. In order to assess the deteriorating noise and RF interference on the effects on the natural unperturbed propagation space and remote sensing, it is essential to establish the average and peak natural spectral characteristics across the entire finite e-m spectrum; because every possible frequency band will soon be utilized for satisfying man's ever expanding communication needs.Therefore, first an identification of the major spectral regions of the electromagnetic spectrum is provided together with the currently established average natural background noise characteristics from the ULF/ELF to the IR/OPT/UV frequency bands utilized by modern technology for remote sensing the natural environment, for information transfer and navigation, and for defense and civil surveillance. The pertinent e-m and acoustic spectral bands are identified in Fig.1. Its characteristic properties are analyzed separately providing currently approved averaged background noise tables and graphs; and major sources of man-made noise and interference are identified in order to be able to assess the performance criteria for the truly necessary and beneficial uses of the electromagnetic environment. In the near future, we need to scrutinize those users that should be excluded from free propagation-space operations, and that can be relegated to the exclusive utilization of the continental and trans-continental non-interfering optic-fiber network, which possesses excessive bandwidth, is still highly under-utilized, and eliminates unwarranted pollution of the open propagation environment.

$[10^x$ Hz$]$ x:	-6	-3	0	3	6	9	12	15	18	21	24
$[10^y$ m$]$ y:	14	11	8	5	2	-1	-4	-7	-11	-14	-17
GLF	SLF	ULF	ELF	LF-HF	UHF-EHF		IR	UV	X-γ	Cosmic	

|← micro-mm → |←optical→|

← infra-sonic →| sonic |← supra-sonic →

Fig. 1: The Extra-Wide-Band Electromagnetic Spectrum with Associated Acoustic Bands

a) Electromagnetic Background Spectra within GLF/ULF/ELF Bands: 10^{-5} to 10^{+5} Hz

The frequency-dependence of the averaged spectral characteristics over a wide frequency band of natural electromagnetic emissions within the Earth's covers and its surface are not well known – especially not toward the lower end of the spectrum. Its determination becomes ever more hopeless with an increasing civilization unless isolated **"electromagnetic quiet zones (sites)"** are being identified and are being sanctioned as such to becoming permanent ***'World Natural Heritage Electromagnetic Ground-truthing Quiet Sites'*** by the United Nations. Aeronomists have sought for and identified a few isolated *"electromagnetically quiet sites*" for establishing the **'Average Amplitude/Power-Spectra'**, especially for the ULF/ELF/VLF spectral bands. Similarly, one of radio astronomy's prime goals is to determine the '*virgin radio signatures'* before modern civilization was perturbing it. For technological applications it is essential to know as precisely as ever possible the average characteristics together with reproducible lower and upper (peak-power) bounds within which man-made systems must operate.

b) Natural Electromagnetic Characteristics within the ULF to LF/MF/HF Spectral Region

Solar-Terrestrial Sources: The major natural electromagnetic background noise emissions are generated by solar-induced currents in the ground as well as in the ionosphere, which differ widely from point to point, and are strongly dependent on sun-spot activity. There exist now several ground-based as well as satellite systems providing reliable hourly and daily sunspot images as well as prediction data. Various ground-based and a multitude of highly useful satellite instruments for predicting the solar-terrestrial interaction are maintained by NOAA, and information is available via the NOAA Solar-Terrestrial Physics Information Center at Boulder

Deep-Sounding and GPR: The Earth's crust, and its geologic layers possess very distinct resonance behavior in these spectral regions, and so does dense tropical vegetation at the upper HF-Band. **Ground Penetrating Radar (GPR)** systems are used by scientists and practitioners to explore the shallow subsurface of the earth and probe into man-made structures. GPR has the highest resolution of any geophysical tool for non-invasive subsurface investigation. In addition, it is one of the very few geophysical methods capable of detecting non-metallic objects and dielectric contrasts, such as organic chemical contamination, plastic land mines, plastic gas pipes and fibre optic cables. To penetrate the ground effectively, GPR operates within a frequency range from tens of megahertz to several gigahertz. However, high resolution requires a broad bandwidth, which is easier to achieve at higher frequencies. In addressing this compromise, GPR systems are designed to operate across many different frequency bands centered from 10 MHz to 3 GHz, with each band having a fractional bandwidth exceeding 100%. This characteristic puts GPR into the most extreme class of ultra-wideband radars. Like most other ultra-wideband technologies, GPR devices currently fall outside of any formal regulatory framework, and concerns have been raised about their potential interference with licensed radio frequency receivers.

Vegetation Penetration and Biomass Estimation in Dense Tropical Jungle Forests: Very dense and highly conductive vegetation which resides within dense tropical jungles require active remote sensing at frequencies as low as the upper HF and the lower VHF spectral domains, and there does exist the realistic demand for making available pertinent frequency bands on a time-sharing basis for this purpose. Under certain precipitation and vegetation conditions, dense tropical jingle forests behave close to conducting soils, and for SAR remote sensing, we need to develop – at least – airborne POL-SAR Imaging and Sounding systems, similar to CARABAS, operating within (800 KHz) 1 Mhz to 100 MHz (200 MHz); and we refer here, for example, to the well-done web site prepared for the CARABAS system.

c) Natural Electromagnetic Terrestrial Surface & Vegetative Characteristics within the VHV/UHF Bands

The major contributors to the natural electromagnetic background noise are ionospheric sources and especially propagation through the ionosphere becomes polarization-dependent resulting in the Faraday polarization state rotation and spectral band widening effects, which can impair both passive and active remote sensing severely depending on the magnetic latitude and longitude plus altitude. Within the VHF/UHF Bands the terrestrial surface with its soil/rock layers, vegetation and water/snow/ice covers possess some of its most distinct characteristic resonances for biomass determination and vegetation cover plus soil-parameter description. Whereas at polar and sub-polar boreal and austral regions the higher K/X/(C)-Band spectral bands may be ideally suited for ice/snow/vegetation cover determination using air/space-borne SAR, the closer one is monitoring toward the equatorial densely vegetated tropical belt, the lower the critical frequency bands become. For example, at the temperate mid-latitude belts the C/S/L-Bands maybe optimal; and in the equatorial belt the L/P/VHF/HF-Bands are ideally required. However, for space-borne SAR sensors and imagers, great care must be taken in correcting for Faraday-Rotation & Spectrum-Spreading effects at the L-Band and below; and very decisive progress was made in this respect. The major sources of interference for both the passive radiometric as well as active SAR sensors and imaging systems are definitely the Communications, Transport/Navigation (GPS), the Defense & Security bands. The spectrum of about 100 KHz to 10 GHz is cramped full, and the "***Active plus Passive Remote Sensing Community"*** may have no other choice but putting up a stiff, very forceful fight for regaining at least some narrow but also some wide bands within this spectral region. The underlying physical laws of nature dictate and fully support this quest, and irrespective of various methods of available and near-future RFI reduction techniques, we – *the passive & active remote sensing community* - need to acquire our own permanently assigned and licensed bands.

d) Natural Electromagnetic Microwave & Millimeter-wave Characteristics

The vegetative layers display their most distinct resonance behavior in these spectral regions; and water vapor resonances begin to appear, which become more pronounced as one approaches the infra-red spectral domain. Within these spectral bands the major natural electromagnetic background signatures are defined by the Faraday-Rotation effects towards the lower end, and atmospheric gaseous resonances and attenuation windows toward the upper end. As is to be expected, this spectral region of the electromagnetic spectrum is also ram-packed, yet it is so very essential for a multitude of environmental remote sensing tasks that requests for opening up various narrow and also some ultra-wide band windows be made and realized subject possibly to well arranged and licensed time-sharing procedures.

e) Natural Absorption and Resonance Signatures of the Atmospheric to Mesospheric Covers

Within these spectral bands atmospheric to mesospheric gases including water vapor display their characteristic resonance behavior, and establish the **"Natural Electromagnetic Background Signatures**", which must definitely be treasured and protected from the blatant misuse of the telecommunications complex as designated and licensed bands at least for communication within the atmospheric to ionospheric covers.

f) Ionospheric & Magnetospheric Natural Signatures and the Faraday-Rotation Effect

Ionospheric and magnetospheric background characteristics are most essential factors in designing various passive and active remote sensing space-borne but also air-borne monitoring systems, especially when operated in polar auroral regions. Of specific interest is the Faraday rotation effect to the operation of communication and remote sensing plus surveillance satellites – passive and active, and considerable studies are currently being conducted on how to reduce the effect on orbiting satellite microwave sensor systems.

g) Basic Spectral Band Allocations & Demands for Passive and Active Remote Sensing of the Terrestrial Covers, Primarily the Biosphere and the Atmosphere

There exist very realistic high-priority demands for hardening the licenses for existing, and for requesting additional narrow as well as ultra-wide band remote sensing windows for (i) the GPR , and (ii) for the space remote sensing community, which need to be protected and licensed for the ***"Earth Exploration Satellite Services (EESS)".*** Licensing may include well arranged time-sharing agreements as was discussed in three companion papers.

TECHNICAL MEANS OF RADIO-FREQUENCY INTERFERENCE SIGNAL REDUCTION

Various spectral-band-dependent algorithms were developed for pertinent RF-Interference reduction, which require now to be optimized to their ultimate performance levels. These techniques make use, in principle, of polarimetric angle of arrival techniques applicable to both Passive versus Active Sensor considerations. Although technological aspects play a very major role and are of paramount importance. Whereas RFI reduction and mitigation techniques for passive remote sensing systems were first developed in radio astronomy and ULF/ELF aeronomy, the VHF/UHF/EHV, microwave & millimeter-wave passive remote sensing community is now catching up very fast. For active remote sensing, great progress was made by the defense radar community, and major RFI Reduction techniques, which reside within the open literature, deserve to be summarized and cited here. RFI reduction and RF Security Threat mitigation techniques are reviewed separately for the major spectral bands.

CONCLUSIONS: QUEST FOR COMPLETE REORGANIZATION OF FREQUENCY BAND ALLOCATION AND DISTRIBUTION FOR REDUCING COLLIDING DEMANDS OF INCREASING NUMBER OF USERS

Every effort must be made to guarantee that mankind is protecting the **"Natural Unperturbed-by-man Electromagnetic Spectrum"** as a ***"Natural Treasure***", which must be safeguarded against the greedy misuse of the International Communication Complex. In order to fulfill this request, a finite set of isolated "***World Heritage Natural Electromagnetic Quiet Sites***" needs to be identified, so designate, licensed by UNESCO and protected by the UNITED NATIONS. ***Passive & Active Remote Sensing must be given MUCH HIGHER PRIORITY***; anything not requiring the open propagation space must be removed; and the Telecommunications Complex must be forced to work hard in reducing their reliance on the increase of designated spectral bands for their commercial use, in fact must be enticed/forced to reduce their electromagnetic spectral real-estate by many factors with the focused implementation of efficient digital techniques of spectral bandwidth reduction. The passive & active Remote Sensing community must adopt the high professional stature of being the pathologists and radiologists of the terrestrial and also the planetary environment, and nothing less. Much improved RFI reduction and mitigation methods must rapidly be advanced because of the increasing needs of an expanding civilization. This implies introduction of standardized signal coding techniques and time-sharing for the use of identical spectral bands. In every respect general public ought to be educated about the serious state of pollution of the natural electromagnetic spectrum, and especially our educational systems K12 to Post-Doctoral levels – all inclusive – about reducing the undesirable propagation litter! The "International Remote Sensing Community" ought to request that the commercial users be levied with a - *say 10% to 15% or even higher surcharge* – solely to be applied to safeguarding the purity – as far as is physically required - of the "Natural Electromagnetic Spectrum" by providing funds for developing the pertinent "Remote Sensing & Monitoring Ground-based, Air/Space-borne Sensor Systems", including the establishment of "World Natural Electromagnetic Quiet Sites". In other words there has to be a fair distribution of the revenues gained from using *"NES",* similar to levying toll-charges and gasoline tax for designing, building and maintaining clean motorways, etc.; there should be charges introduced for utilizing the " National and International Information Highways". In fact, any misuse of the sacred **"Natural Electromagnetic Spectrum *(NES)"*** ought to be punished by stiff fines; and the intentional and/or careless generation of propagation litter along the *"International Information Highway"* ought to be dealt with similar to fining the ruthless production of refuse litter along our National, State and Local Highways in the US and elsewhere.