Humboldt Universität zu Berlin
Seminar für Medienwissenschaft

EM-Sniffing

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> Electromagnetism is woven in tightly with current physical models of reality [1]. In these models, Electromagnetic fields help explaining how a wide variety of phenomena in the universe on all scales fit together. Only recently, in larger historical context, has Electromagnetism become a focal point in scientific interest and has been elaborated to serve as part of the fundaments of technology. We want to elucidate this aspect of the world from the point of view of electronic media technology and practice with an emphasis on the relation to sound.

This document was written as a homework assignment in the course "Sound Arguments - Sonification, Audification, Auditory Display" held by Axel Volmar during summer term 2007 at the Seminar for Media Studies, Humboldt University of Berlin.
For the audio links later on to work from within the pdf, its best to put the audio files on the same level as the pdf. Alternatively you can load up the entire audio file directory in your player and navigate the list manually in sync with the text. Audacity [39] is a great tool for viewing spectrograms and has been used throughout development of this text for that purpose.

1 Introduction

Electric and magnetic forces have come to be interpreted as Electromagnetism a relatively long way into the orthodox history of science. The culmination of attempts of electromagnetically retro-coding and modelling reality can be tied with sufficient congruence to the 19th century. Basic aspects of both electricity and magnetism have been considered on and off during the centuries preceding this range of time, especially the behaviour of light has received great attention in scientific study but their unification into a common theory notably occured with James Clerk Maxwell's work, (particularly a set of papers published in the 1860s), which built on the work and observations of a long line of other researchers.
The electrically attractive force of amber has been known in ancient times. This went alongside ontologies of mutual pervasion of things being, defining materiality and interactions of objects as phenomena of "essential" radiation, resonance and reflection as Zielinski lays out by bestirring Empedokles and Demokrit [49]. Already there we find the idea of emptiness (vacuum) as a medium for some kind of interactions of the elementary constituents of life. Other displays of electrical and magnetic forces, identifiable a posteriori, have been observed and documented but remained largely unexplained and unmanipulable.
After some period of epistemogenic blankness, treatments of magnetic and electric knowledge resurface in scholarly publications at a certain point, incisevely so William Gilberts "De magnete magneticisque corporibus", purportedly published in 1600 and advancing science for 250 years according to this source [37]. From there on it gained momentum until

> In the mid-1800s electricity began developing into the Fascinosum of natural sciences [49], pg.189.

Around this time, interest in and evidence of electricity and its manipulability has long started peaking. In the 1780s Galvani took his early stance on bioelectricity, which was going to be picked up by the mid-1800s physiologists, Müller and Bois-Reymond, while he himself was moved into the Off shortly after because of his insistence on the exclusive biological origin of electricity. In 1800 Volta constructs his voltaic piles while Ritter, among other things, produces an early accumulator, Ørsted in 1820 demonstrates magnetic deflection close to current carrying conductors, Ampère starts working on theoretical backings of these recent demonstrations, thereby giving birth to electrodynamics. At the same time Michael Faraday already is at work, eventually arriving at the field concept, followed and amplified by the work of Henry, Weber, Gauss and many others. Work which J.C. Maxwell thankfully lifts up to well known results, further polished by Heaviside. Consequently, these theories laid ground for the emerging *Art of Wireless*, arguably still one of the most topical areas of natural and technological research.
So much for a highspeed version of the history of electrodynamics. This epistemic trajectory sounds only consequent from todays vantage point but had to be and was accompanied by broad re-conceptions of reality among

[1] Some authors are even more enthusiastic about the importance of Electromagnetism in the "civilized" world in the 21st century, see for example van der Vorst et al..

the protagonists. Concepts of oscillation and vibration lying at the heart of the phenomenal world had to be postulated and elaborated on the behaviour of readily accessible media like fluids. This recurs prominently in [37] and condenses to the assertion that

> . . . , the media of electromagnetism are 'afloat' in an anti-laplacian or anti-newtonian discourse.

This discourse in turn is inseparably connected to a discourse of waves: electricity, sound, light, heat, etc. A voice from the distance sings about music being the most relevant of arts, closest to reality because of its foundation in the waves principle. The choir of Ampère and Ritter: all that is, vibrates.
At this point, the ensuing implementation of ideas by electromagnetic means calls many more players on the scene. Hertz confirms Maxwell's theory empirically in 1887, followed by the realization of wireless telegraphy starting in 1895. At this point we might be led to observe with Dieter Daniels that

> The discovery of wireless signal transmission is the last great legacy of the 19th to the 20th century [6].

Physical implementation of transmitting conditions is arcane at these times but gaining huge momentum and practicability by the invention of the electron-tube in 1906 by de Forest (and von Lieben). The electronic amplifier and oscillator made possible by the (feedbacked) vacuum-tube and the thusly enabled disposal of the "defect" of early radio technology, commented on by one prominent engineer of that era, namely its undirectedness in both geo- and frequency-space marks the beginning of a fragmentation of the electromagnetic frequency continuum. While passing through the techno-logical and -cultural explosions (literally) in the 20th century, the continuum's discoursive perception devolves into its current skewed form.

We will try to pin this down to exemplary maneuvers to that end in the course of the text. When On/Off-Keying was replaced by more sophisticated keying schemes in the infancy of wireless telegraphy, suddenly, it wasn't the channel anymore, that was *heard*, but only some of the channels characteristics or properties. The tuned oscillator made extremly narrow slices of the spectrum addressable as channels. Reginald Fessendens broadcast from 1906, first legislations from before WWI and the commencement of regular public broadcasts, "all these dates mark the end of radio as a producer of media knowledge" [11]. Entertainment and measurement seem to diverge.
Listening to radio is not listening to radio but listening to radio programme [28], and yet: not all is lost. Atmospheric conditions can be extracted from the behaviour of radio waves, regardless of modulation, among other things. We will pick this up later when looking at the DCF77 based geometric approach. This is our equally highspeed heterology of applied electromagnetism.

Producing some insight into or perceptual deregulation of this ongoing process of the unwiring of techno-culture provides a good part of the motivation for this investigation, exercising navigation between the islands of Natural Radio and Technical Radio and the encompassing ocean.

> "Natural Radio" describes naturally-occurring electromagnetic (radio) signals emanating from lightning storms, aurora (The Northern and Southern Lights), and most importantly, the Earth's magnetic-field (the Magnetosphere) [29].

Astronomical radio might be included into this definition depending on the agent's preference. Civilization radio in turn describes all man-made electromagnetic emission. Obtaining any such insight clearly requires enhanced perceptual abilities, allowably mediated by electronic devices. Radio as such is in no way "about broadcasting but about space and communication" [12], time and oscillation one might want to add.
Technocultural discourse on radio is impeded it seems, by misfocussing on narrow spots within the spectrum available and their programming, while the development of radio technology is not hindered in this way. It is owed mostly to amateur radio practices again that some relevant line in this discourse has not died out. Sniffing as a gesture certainly grows out of "amateur" curiosity and aims at choice and at experiencing the spectrum's vastness and ubiquity.
Nonetheless media-archaeological investigations seem adequate in accompanying the increasing spread of concerted media deployment as in internet streaming, podcasts, WLAN, mobile telephony, geolocation and the

introduction of RFID technology. All of which are radio-related and interweave in wide-area, local-area and body-area networks. UWB (ultra-wideband) communications with its low power levels and large spectral spread posing an exceptional challenge in this regard.
Finally, we want to contribute towards a heightening of the auditory in the ranking of our senses, following Gerold Baier's proposal. Since Aristotle vision took firm residence at the top of the hierarchy of sensory perception, another indication of a distorted view of the electromagnetic spectrum.
"Sniffing" then shall mean a specific mode of reception, a mode that enables us to listen to the medium at work and as such is much broader than what is regularly understood by listening to radio. This mode allows for the extraction of raw signals, for the most part ignoring the protocol stacks, aquiring only SIGINT in [37]'s terminology. This mode may be applied to study the two strands of radio emanations introduced above:

- natural radio phenomena
- the technological radio landscape: information transmissions, detection and identification apparatus, operational noises, etc.

How the apparitions enumerated are related to sound is now missing to be explicated in more detail. Obviously, they are related by the oscillatory dispositive. Abstractly, all radio phenomena can be discussed in terms of oscillations of different frequencies. What exactly oscillates, becomes and vanishes, is, within certain discoursive limits, of no importance. These oscillations can be unfolded from certain carriers onto others by technological means. The figure, in turn, is also the bridge to one of 20th century's contributions in deepening of the knowledge on energy and matter, by way of Louis de Broglie. What has to be considered then besides power levels, amplification and filtering effects are nonlinearities in the transduction chain, sensor and post-processing modules.
This assertion lives in accordance with the observation of a tendency in communication, the separation of the message from the body of the messenger. Zielinski iterates the example of the slave messenger and evokes a header / body dichotomy. Interestingly enough, the function of header and body has been swapped in technical communication protocols, because a packet's header is as necessary for moving the content around as the slave's body, and the body has become a tight fit for the message and nothing else. That's not the end of the story however, since an ensemble of headers may provide enough information to subject an unknown message to fruitful extrapolation as shown in [48].

It is certainly appropriate now to have a brief look at the theory of electromagnetism to narrow our definition of the media under discussion.

2 EM Theory

> It (Maxwells work, OB) made it possible to realise that the entire Universe is the site of an incredible variety of modes for the propagation of oscillating electromagnetic waves – waves that can be read in a vast spectrum of frequencies ranging from zero (continuous or unidirectional current) to 10^{20} hertz [34].

What are these waves? Waves are *propagating* organized disturbances in the field. As indicated above, it is possible to apply the view of Electrodynamics to a very wide range of natural phenomena but we shall limit ourselves to the range of radio- and micro-waves, corresponding to field-intensity fluctuation frequencies on the order of approximately 0 Hz to 2.5 Ghz (Microwaves actually going up to somewhere at 2 Thz), leaving aside anything above like light (of all colours) and ionizing radiation. So we probe further and ask,

> What is a field? No one really knows. [9].
>
> ...
>
> According to Richard Feynman, a field is a mathematical function we use to avoid the idea of action at a distance [9].

A charged particle (electron or its positively charged counterpart) causes an electric field surrounding it. It extends over empty space and exerts a force on other charged particles present in the field. Coulomb's Law states that the field strength is proportional to the charges involved and inversely proportional to the square of the distance between the charges.

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} \quad \text{(Coulomb's Law)}$$

If a charged particle is in motion (as is the case with electric current) relative to a resting reference frame, it causes a magnetic field which exerts a force on other moving charged particles.
The development of the field concept is ascribed to Faraday but people like Romagnosi, Ørsted, Ampère, Maxwell, Heaviside and Hertz all had their share in the forming and differentiation of that concept in the 19th century, as we have seen above. It serves as a very low-level concept in Electromagnetism. A field can be characterized by force-lines. In an electric field, the force-lines terminate at charges and are perpendicular to the charge if it is at rest. Magnetic force-lines on the other hand form closed loops. The force also has a direction, so it is a vector and points from positive charge to negative charge in the case of an electric field and from magnetic north-pole to magnetic south-pole in the case of the magnetic field. Pictures are readily available in physics textbooks, such as [1].

2.1 Field Basics

A field can thus be thought of as a "special state of space", lending structure to it and which manifests itself by letting forces act on other charges through empty space. In the case of a singular charged particle, the field extends to infinity from the source. This is interesting in relation to ideas of aether, since viewed as such, empty space is not empty but pervaded by fields of a multitude of sources, naively speaking.

2.1.1 Electric Field

The electric field strength is $E = \frac{F}{Q}$ (force per charge) in a homogenous field, such as between the plates of a capacitor, its unit is given as Newton/Coulomb or Volt/meter and decreases roughly with the square of the distance from the charge, see Coulomb's Law above [43]. The elementary charge of the electron $e = 1.60210^{-19}As$. Charges at rest cause an electrostatic field. F and therefore E have a direction, hence are vectors which are tangent to the field lines, which point from positive to negative charges. The denser the lines the stronger the field, although they are not an absolute measure and are real only as discoursive tools. In inhomogenous fields the notion of potential (to a selected reference point) is used together with equipotential areas, which is the path integral over $\vec{E}$,

$$U = \int_1^2 \vec{E} d\vec{s},$$

with 1 and 2 the reference points. Another important field quantity are flux and flux density where flux equals charge and flux density is charge per area or $D = \frac{Q}{A}$, its unit given as As/m^2. A dielectricum is a non-conducting material which is pervaded by an electric field. As flux density is proportional to field strength, $D \sim E$ in almost all materials, this dependency can be replaced by $D = \varepsilon_0\varepsilon_r E$ with $\varepsilon_0\varepsilon_r$ denoting permittivity. Permittivity of free space $\varepsilon_0 = 8,85410^{-12}As/Vm$ and ε_r being relative permittivity of the material in question. There are materials whose permittivity depends on field strength, like barium titanate [20].

2.1.2 Magnetic Field

The use of compasses especially in marine activities seems to have been established around 1300 with William Gilbert [46] supplying some theory to this practical knowledge around 1600.
Ørsted discovered in 1820 (and Romagnosi a bit earlier) that a compass needle is deflected in the proximity of a wire under current. Every moving charged particle (current) generates a magnetic field. Magnetic lines of force are closed loops in contrast to electric field lines, which terminate at the charges. By using coils of wire, a stronger magnetic field can be produced with the same amount of electrical energy and by inserting cores with higher permeability the effect can be further amplified.

Magnetic field quantities, analogously to the electric field quantities we have seen earlier are

- magnetic field strength: $H = \frac{IN}{l}$ with H field strength, I current, N number of coil windings and l coil length. The direction of the force is along the coil axis [17], [47],
- magnetic flux density: $B = \frac{F}{Il}, [B] =$ Tesla
- permeability: flux density can be written as $B = \mu H$ with $\mu = \mu_0 \mu_r$, $\mu_0 = 4\pi 10^{-7} \frac{Vs}{Am}$ and μ_r the permeability number of the material pervaded by the field. Ferromagnetic materials have a permeability number significantly larger than 1 [20].

2.2 Combined Field

As it turns out, what is thought of as "light" is actually a propagating oscillatory disturbance in the electromagnetic field, i.e., an electromagnetic wave. Different frequencies of oscillation give rise to the different forms of electromagnetic radiation, from radio waves at the lowest frequencies, to visible light at intermediate frequencies, to gamma rays at the highest frequencies [43].

A changing magnetic field produces an electric field, a changing electric field produces a magnetic field (charged particles in motion are equal to electric current). Siegert goes into great detail about this special relation as a manifest on-off principle [37]. Because of this strong interdependence both fields can be considered as a single coherent entity (or rather, the other way round): the electromagnetic field [43].
A charged particle in motion produces a magnetic field, because its electric field becomes dynamic through the movement in relation to a stationary frame of reference.

$$\vec{B} = \frac{1}{c^2} \vec{v} \times \vec{E}$$

The particle movement $\vec{v}$ is perpendicular to $\vec{E}$ and $\vec{B}$ [9]. The discovery of a time-varying magnetic field producing an electric field is due to Faraday and Henry, ca. 1830 [36]. The E-field (electric) and the H-field (magnetic) are simultaneously present and linked by the Maxwell-Equations. If one component is known, the other can be calculated.
Maxwells Equations then are (in differential form):

$$\begin{aligned} \bigtriangledown \cdot \vec{E} &= \frac{\rho}{\varepsilon_0} \\ \bigtriangledown \cdot \vec{B} &= 0 \\ \bigtriangledown \times \vec{E} &= -\frac{\partial \vec{B}}{\partial t} \\ \bigtriangledown \times \vec{B} &= \mu_0 \vec{J} + \mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t} \end{aligned}$$

These together with the Lorentz force law are the laws of classical electromagnetism [44] and basically apply to both static and dynamic cases. See [30] for a gentle breakdown on the equations.
The electromagnetic force exerted on a charged particle in the field is one of the four basic forces in physical theory (besides weak and strong nucleic forces and gravitational force).
The speed of light is constant and depends on permittivity and permeability of free space. This realization was one of Maxwell's major achievements [41], pg. 24. It provides a steppingstone to more elaborate versions of electromagnetic theorization. Within special relativity it is shown that electric and magnetic fields that are moving, transform into the other symmetrically. Consideration of electrodynamics from relativistic and quantum theoretical angles is attractive but clearly out of proportion here.

2.3 Antenna, Loudspeaker, AD Conversion

Radiation is a phenomenon characterizing the RF/microwave range. It is well known that structures radiate poorly when they are small with respect to the wavelength. For example, the wavelengths

> at the power distribution frequencies of 50 and 60 Hz are 6.000 and 5.000 km, respectively, which are enormous with respect to the objects we use in our day-to-day life. In fact, to radiate efficiently, a structure has to be large enough with respect to the wavelength λ. The concepts of radiation, antennas, far field, and near field have to be investigated [41] pg.8.

We will try and fulfill this last advise. Radiation is the transfer of energy from electric current in a wire to field fluctuations in free space. This point in the chain is crucial in consideration from a media perspective, because it constitutes an interface between different modes of propagation of information. Information is transformed when crossing this boundary in either direction depending on the constitution of the terminals, antenna and surrounding space. There are many details about the way this happens, some of which we try to consider.

> Antennas are metallic structures designed for radiating and receiving electromagnetic energy. An antenna acts as a transitional structure between the guiding device (e.g. waveguide, transmission line) and the free space. The official IEEE definition of an antenna as given by Stutzman and Thiele follows the concept: "That part of a transmitting or receiving system that is designed to radiate or receive electromagnetic waves" [31].

Any current going through a conductor sets up a field. The relation of frequency in question to the length (and shape) of the conductor determines the amount of energy which is radiated. The more harmonic the relation the larger a portion of the elctrical energy will be radiated from the conductor. Reversely, this is valid for the induction of electric current by a fluctuating electromagnetic field in the conductor [32]. Technically, the antenna becomes resonant when its impedance Z becomes purely ohmic, a relatively simple matter for a dipole antenna. It is not necessarily a single frequency for which this is the case in a given antenna though, and in some applications multiband characteristics of an antenna are desired. One simple approach is to use a very short wire in the LF band and so operating in a flat portion of the antenna's frequency response. Another approach is to build electrically voluminous structures as in conic or cylindrical antennas.
A second important aspect of antennas is their directivity, that is their radiating behaviour with respect to space. The two poles in this case are the ideal isotropic radiator (omnidirectivity) and the narrow beam. Now there is possible a wide variety of combinations of an antenna's frequency-related and spatial radiation properties.
In receiving mode, which solely occupies our attention, the signal can be postprocessed by analog circuitry or digital signal processing routines after the field fluctuations have been converted to electrical current. The lift to digital representation is in itself another locus of mediatic jump. What we have to deal with are variations in a physical magnitude over a potentially broad range of frequencies which sum up to specific waveforms in the time domain. In classical radio communication, a narrow filter (resonant circuit) will be employed to select the desired band but for our purposes we are more concerned with broadband reception and analyses of the resulting signals. These analyses will be conducted in the digital domain leaving almost exclusively amplification to the analog part. Amplication is no small deal. A WWI eavesdropping specialist is quoted as

> "You hear flies crossing the table, as if horses pattering over plaster, you hear the faintest breeze like the rumbling of thunder; you hear the earths movements brought about by the growth of grass; you hear earthworms crawling. Microphones underneath the wallpapers in prisoner camps enable us to eavesdrop on whispered conversations. The slightest sounds of mining in the ground can be assessed" in [37], pg.394.

Clearly, if signals fall below the least significant bit of the ADC's level range, we have lost everything.
Once the signal is adequately embodied in electric currents, it is immediatly possible to make them heard, to audify them. As researchers in different fields repeatedly have shown (telephone earpiece and action potentials, geiger counter, detector clicks in physics laboratories, early computer debugging), in practice, audification can result in large epistemic gain, since, electricity is generally not directly perceptible for humans while sound is. A signal has to be either visualized or audified for analysis. Indirect mathematical approaches on the raw numbers can more easily be leveraged after certain base parameters have been determined.
Above's immediacy has one big problem though, that of bandwidth. Ultimately the bandwidth of our auditory system. We are able to gather signals in the range from 0 Hz up to many GHz with little effort. All of this

can't possibly be listened to at once, both technically and semantically. Luckily we can employ the technique of mixing (heterodyning) combined with filtering or directly apply spectral tools to manipulate and shift around and compress suitable portions of the spectrum at hand.
To sum up, the media-terminals we are dealing with are antennas, AD/DA converters and loudspeakers. In open space, electromagnetic waves propagate in a trivial manner, any kind of material structure however such as walls, buildings, plants and landscape as well as energetic structures such as other fields will have an effect on the propagation, like shielding (absorption), reflection and refraction. Electric fields will be absorbed by many materials in our surroundings, not quite so magnetic fields [5]. This brings up sizes again.

> There is an interesting feature to note about microwaves: They cover, indeed, the frequency range where the wavelength is of the order of the size of objects of common use, that is, meter, decimeter, centimeter, and millimeter, depending of course on the material in which it is measured [41].

Matter resident in a field is being polarized [41] pg.11. There may be frequency-dependent permittivity und permeability. In the near field, only the B-field is present, the E-field reappearing at a distance of $2D^2/\lambda$ from the source, D being the antenna's largest dimension, which marks the transistion from near field to the far field. See [9] for details on what is happening physically in the transition from near to far field, why the E component is cancelled close to the antenna and reemerges at a certain distance from it. For the low-frequency range, the static case approximates the situation with sufficient accuracy. EM-waves come as transversal waves, the E-part perpendicular to the B part and both perpendicular to the direction of propagation. In a bounded medium the waves are reflected, such a bound may also be realized by differing wave-impedances brought about by immaterial objects.

2.4 Modulation

We should briefly touch modulation, since it has already been brought into play above. Modulation, or keying in digital radio, is the way information is encoded in a signal's parameters, that is, a particular mechanism and mathematical model by which the transfer of information onto the carrying entity is achieved. Keying schemes are multitude and can be laid out as in [45]. There, analog, digital and spread spectrum techniques are distinguished. The basic signal parameters are amplitude, frequency and phase, all of which can be used to impress information onto a simple waveform carrier. Spread spectrum may even be regarded as a particular form of frequency modulation, that is the carrier is smeared over a wider band but in discrete steps. Importance falls to the sequence. Various multiplexing methods may additionally interfere with the signals shape, particularly Time-Division Multiplexing in digital wireless transmissions, e.g. mobile telephony. A special case of amplitude modulation is given with On/Off-Keying, relying solely on the presence or absence of the carrier signal.

2.5 Interaction with Biological tissue

As a last move in this theoretic part we want to look at electricity and biological matters. Starting, at the very latest, with the research and approaches of Galvani and Ritter, electricity is intimately tied to biological substance. For example,

> only in the 1840s the experimenter's body has been replaced by the Galvanometer [37], pg 346.

Consequently,

> knowledge of the frog, and thusly of man is subordinate to the apriori of frequency since 1838 [37], pg 347.

This view has been modulated by additional findings since and comes full circle with the accumulating presences of electromagnetic emissions in the environment. Consideration of the interaction of fields with other fields or with matter becomes most relevant in at least two areas. One being electro-magnetic compatibility of electric circuits, the other being "biological compatibility", that between em-fields and living cells and cell compounds. The latter shall be quickly examined here - even if we cannot delve fully into this most interesting subject at this time - because the production of biological effects gives awareness on the potential intricacy of electromagnetic effects in general and its interwovenness with the behaviour of matter and organisms in particular, hence reemphasizing its relevance to fundamental questions of physics and life. Electrical engineering may only regard those domains a system has been designed to effect but we are interested in any kind of action that may be brought about, especially in an environment where technical apparatus is methodically crippled due to manufacturing cost considerations [24]. Additionally, the sheer quantity of man-made electromagnetic presence seems overwhelming. Robert Becker has given an estimation of this quantity:

> Since then (WWII, OB), the density of electromagnetic radiation has doubled every four years, and electromagnetic pollution has been multiplied a hundredfold over the past thirty years [8].

The existence of thermal effects is unquestioned in the scientific community, of which the microwave oven by way of RADAR is emblematic, and precipitating itself in the choice of exposure limits in legislation concerning electromagnetic emissions. That's not all however.

> Differential effects have indeed been observed after exposure to pulsed-wave with respect to continuous-wave (CW) microwaves. In practice, biological effects have been observed under a variety of exposure types: CW, sinusoidal amplitude-modulated wave (AMW), pulsed wave (PW), and pulsed modulated wave (PMW) [13] [41], pg.33.

And more generally,

> We should not consider power, however, as the only parameter able to induce effects. For instance, differential effects have also been observed after exposure to plane- versus circular-polarized waves [41], pg. 33.

This leads to questioning the sufficiency of definitions like the SAR (Specific Absorption Rate) used in the assessment of microwave equipment. Of additional interest is the relation between natural and man-made radiation sources that organisms might be exposed to. Here we find that

> Cosmic noise extends from about 20 MHz to about 4 GHz. Man-made noise is an unwelcome by-product of electrical machinery and equipment operation and exists from frequencies of about 1 MHz to about 1 GHz. The peak field intensity in industrial areas exceeds the value of cosmic noise by several orders of magnitude, which draws attention to the need for judicious ground station site selection [41], pg.34.

Frequency and spatial behaviour are connected tightly as we already know. When material is exposed to a field, the field strength decays inside the material. This can be formalized into a parameter called skin depth, which is frequency dependent.

> As an example, the skin depth is three times smaller at 900 MHz, a mobile telephony frequency, than at 100 MHz, an FM radio frequency, which means that the fields are three times more concentrated near the surface of the body at 900 MHz than at 100 MHz. It also means that internal organs of the body are submitted to higher fields at lower than at higher frequency.
>
> . . .
>
> We are less and less transparent to nonionizing EM radiation when the frequency increases. In the optical range, skin depth is extremely small: We are not transparent anymore [41] pg.42.

The body's transparency and the eye's peak sensitivity obviously engage in an interesting relation of measureabilty. In other bands the human body is indeed partially or totally transparent.

> The human body has also become (has always been, OB) an antenna: the waves spreading through the atmosphere are captured by radio and television antennas, but also by the nervous system. A radio antenna continually captures all the broadcasting stations whose radio waves cover its geographic location. The adjustable electric circuits within the device filter out all the frequencies but one ...
>
> ...
>
> There exists no definite border between the electromagnetic fields maintained by the bodys metabolism and those that exist in the environment. Cells are electrical systems sensitive to their electromagnetic milieus, cell membranes are capacitors. Cell tissues are traversed by alternating and direct currents... In short, in the world constituted by electromagnetic cosmology (and industry), understanding the electromagnetic field is the only way to understand ourselves and our surroundings [8].

2.6 Summary

To sum up this episode and to close the switch on the theoretical current source and the sink of practice, we will reiterate the epistemic objects encountered so far. Abstractly speaking we have dealt with waves, that is propagating organized fluctuations of intensities of certain magnitudes. These may be enformed in electromagnetic fields, in currents and voltages or in density of matter (pressure). These enforments may be transformed into each other by transducers, examples of which are antennas, loudspeakers and microphones. The method of audification flows forth from this arrangement as a special case of such a transformation, because:

- Electric signals are close to the Auditive through the loudspeaker (telephone) dispositive.
- The 0 - 20000 Hz frequency-range is close to the Auditive by identity in frequency space.

> Within the electric and a fortiori electro-magnetic media the techno-mathematical dispositive of oscillation finds only itself in its entire ontological limitlessness [37], pg.308.

3 EM Practice

First off we want to derive the idea of sniffing more explicitly. In hacking culture it has a sharp definition [35].

```
sniff: v.,n.
   1. To watch packets traversing a network. Most often in the phrase
      packet sniffer, a program for doing same.
   2. Synonym for poll.
```

In addition to that area of validity, sniffing has acquired meaning in the electronics and amateur radio scene. These trajectories merge with digital radio applications (WiFi, Bluetooth, RFID, ...) and their respective debugging tools, which leads to a seemingly legitimate extension of the jargon definition. While in one case information quanta (packets) are delivered by a software only probe, in the other the target signal has to be extracted physically from the carrier medium (conductor, air, free space, ...). Both situations imply minimal interaction with the observed signal.

As EM Practice we will consider the use of sniffing devices, mainly broadband or allband receivers but with an eye on measurement in general, in the practice of the electromagnetical experimenter. A first historic example is Luigi Galvani, as indicated by [2] pg. 42, who, while occupying himself with the study of animal electricity was in parallel "looking for atmospheric fluctuations in electricity" with antenna wires. This was in the late 1700s. This spirit gained more contour throughout the development of the wireless art up to the present day, a spirit embodied by radio amateurs, physical researchers, hackers and artists. In this sense, Natural radio not only has been transmitted throughout earth's history, but also was first in being received during the development of a wired communication technology, the telephone:

> Watson would sit at the telephone for hours at night and listen to electromagnetic activity (ca. 1880) [50] pg.158.

Contact with the raw spectrum came as a techno-logical consequence for many early radio amateurs. Before and during the first World War and well into the 1920s, they often had to build their equipment down to every single electric component from scratch. In this atmosphere of experimentation, the media-archaeological phase of radio,

> Human and technical communication signals mixed in with the hissing and crackling of cosmic radiation [7] pg.35.

They still do, even. When utilization of the aether became more strictly regulated after ca. 1910 and prefabricated receivers started to become available later on, engagement with the residual of successful electric operations (transmissions) and ensuing knowledge generation [11] had to become more purposeful. The residual approach resonates strongly with "Ansichten von der Nachtseite der Naturwissenschaft", that which commonly falls short of examination by analytic reason. Reality and possibility produce each other like light and shadow while it is left open, which is which.
A proposal for a map of activities that may be encompassed by our usage of the term follows.

> the hacker's sniffer along WiFi, Bluetooth, RFID and other digital radio detection and manipulation methods.
>
> Measurement in physics and in engineering.
>
> Various partitions in the amateur radio scene, such as Radio Direction Finding (Foxhunting), Dxing and bandwatch (Bandwacht).
>
> Extended amateur radiation research: dedicated E/B-field sniffers like the Aatis HF-Sniffer, Burkhard Kainka's LF-amplifier as well as research conducted by Natural radio enthusiasts such as Stephen P. McGreevy or Wolfgang Friese in Germany working on lightning detection, thunderstorm prediction, sferics detection etc.
>
> Radio astronomy.
>
> Radio Detection and Ranging or radio measurement.
>
> Mini-spy detectors
>
> Intelligence operations: EM-leakage or Compromising Emanations (CE) as demonstrated openly by Wim van Eck, recently refreshed in connection with electronic voting machines [10] in Germany.
>
> Subtle and hypothetic wave phenomena such as N. Kozyrev's time-waves, S. Shnoll's gravitational waves and the search for correlation in random number generators as demonstrated in the GCP and related projects.
>
> The recycling of these approaches into artistic and musical experimentation.

We will focus on the last item in what ensues. We will not dissect intricate protocols, but stick to the direct approach. The chain we have identified in the preceding chapter presents itself as vibrating electromagnetic field - alternating current - vibrating paper-cone. Only when we start operating in a separate thread with a mathematical toolset on the signals will we get back into protocols, symbols and content. This step clearly represents the shed between audification and any kind of more elaborate sonification in Kramers terminology.
To <<gather that which is>> [27], pg. 460, brings us much closer to the medium itself, firstly, by the direct coupling of vibrations in different domains and secondly, by capturing the secondary effects of electrical activity, not to be confused with secondary fields as resulting from vortex currents in LF fields. The information captured is not what is being dealt with at the intended level of access to a device (e.g. voice communication) but information

about the operation of the devices themselves. Acquisition of these methods seems indispensable in the wireless age.
In a military context, this approach co-existed with dedicated radio communciation right from the beginning. During the first World War, the Germans equipped radio listening posts to gather intelligence (and entertainment) content from the opponent, which, as a matter of course, was turned back on them, Radio games has been invented, a subgenre of electronic warfare.
Since then, they are repetitiously found in radio history. Deflection, manipulation and jamming became common weapons in violent conflicts in the 20th and 21st century, even before World War I, in the Turkish-Bulgarian war in 1912.

> The turks cannot relay this realization, because their telegraph wires have been cut and bulgarian jammers interrupt radio communication with high command in Constantinople. In the air above Adrianople an information war takes place in which the new electronic weaponry of jamming transmitters take out conventional reconnaissance via balloons and so commence bulgarian victory [6] pg.124.

These games become more elaborated. In the second World War, the British could confuse the German's radio navigation system by intelligent jamming [37], pg. 400–401.

3.1 Examples in experimental and artistic practice

Radio navigation directs our gaze again at the spatial and geometric connotations of Electromagnetism. We live in an invisble landscape, shaded in colours our eyes cannot transduce. This landscape changes not only with spatial movement but also with frequency (colour) selection. Things that reflect a 400 THz signal may not behave in the same way at 2.4 GHz. Antennas (eyes) are limited in frequency and spatial coverage, which calls for the use of multiband arrays. From here we can connect to Lucius Burckhardt's strollology and electronic freestyle GPS experimentation. A recent invitation by the HMKV Dortmund (a media art organisation) for a workshop on strolling read:

> Within the frame of the symposium, strolling is going to be examined as an autonomous format. At the center of attention is space pervaded by immaterial streams of information [40].

Knowledge is not static, obviously, but is itself generated by movement of either observer or observed, relativistically equal. In this regard we find that

> The true locus of reflexion is not the working desk and not the academic chair but transit in time. Who is moving in this way, can hardly comment on the state of affairs in research and has to develop a precarious relation to knowledge as possession [49], quoting Dietmar Kamper on pg.29.

This certainly has been facilitated by the fledging of the tools of knowledge production. Owing a great deal to transistor technology, radio measurement gear can be carried around with little effort. Projects like Howse's "scrying", nanotube transceivers and intermediate miniaturization stages strongly hint at organized large scale distributed measurement or even movement replaced by spatially dense populations of such devices.
The complex event "GPS" happens in protocol space, but plotting of the invisible landscape can clearly be an aim in sniffing [22, 4, 18]. Particularly interesting is a project by Wolfgang Friese for examining buried underground structures, based on different propagation conditions of LF waves in areas of different material and hence, conductive quality with applications to non-invasive archaeology. Interestingly enough, he uses the DCF77 frequency normal and time signal, emanating from Germany's Mainflingen transmitter site [18]. This approach recycles the signal's purpose in a parasitic twist. While radio signals are used to map material objects in this case, "Ethermapping", an artistic endeavour by New Zealand artist Zita Joyce uses bureaunomic data to map radio-activity in the area around Auckland [50], pg.174. The companion piece "Tales of the Ether" emphasizes the radioshpere's *cairotic* moment, time-varying propagation conditions (soil salinity, atmospheric conditions) and temporally confined source activity.

An early example of an electronic instrument and simple spatial mapping device is Lev Theremin's famous machine. It not only employs a field-based interface but uses this field within a radio-oscillator circuit. The theremin in its original form was only possible due to application of the heterodyning principle, in order to relate material qualities, the orders of magnitude of the elements involved and a particular part of the frequency spectrum, ultimately, the LF band. The theremin is one of the most ingenious oscillatory apparatuses, radio without compromise.
Practically, the frequency relations mean this: anything in the VLF frequency range really only needs to be amplified and put onto a loudpspeaker for the data to reach our ears. In turn, anything above 20kHz, more practically above 12–15 kHz (for most ears) needs additional treatment. One easy way to achieve the transfer of these higher frequency ranges is the use of mixing and consequent filtering of the sidebands. A demonstration of this technique will be given in the examples section below.
All the radio based methods for navigation, detection and ranging are inseparably tied to time, the transit time of wave-fronts. Waves, and bearing them, oscillations in turn can be argued into identity with time. Analogically, this holds for rotation, macroscopic and microscopic, again a spatial operation. This is the nexus of a discourse evoked by Aristotle, Ritter, Ampère, N. Kozyrev and Rössler among others as well as that of time-critical media processes so prominent in SO22. It is a pointer towards manipulability of time itself. This medium, more than any antecedent, sharpened, and continues to do so, our senses of space and time.

In 2006 an exhibition was staged in Riga, Latvia, by the Centre for new media culture RIXC titled 'Waves - Electromagnetic waves as material and medium for arts' which aimed at re-initializing a discourse about art & technology,

> . . . , considerung the materiality on which the work was based. In our analysis we came to two fundamental layers, as we called it, waves and code [50].

This conclusion is in accordance with the view of several authors, stating, for example, that

> Alternating current is the 'essence' of technical media - or rather: it would be the 'essence', if alternating current as a purely differential principle would not a priori detract itself from any constitutional metaphysics [37], pg. 308,

and pointing at the heritage of the epistemology of alternating currents as Wolfgang Hagen does in "Alternating currents and Ether". He strengthens Tesla and his eminent contribution to alternating current knowledge by extrapolating back from Fessenden via his engineer Alexanderson and theoretician Charles Steinmetz [19].
Every sensor is a sniffer by enabling the transition from one phenomenological domain into another, by converting non-electrical magnitudes to electrical ones. But if we looked very close at how this conversion takes place, we would reexperience how deeply the electromagnetic force is at work in the fabric of reality. Or more accurately, in our model of all that.
This alternating current is the element we use in tying together electromagnetic and mechanic vibrations. Armin Medosch gives a crisp introduction to experimental radio culture in the catalogue of this exhibition. Starting by demanding this new discourse, he invokes a series of historic characters to illustrate the indeed amazing change in phantasizing the world which the discovery of electromagnetism brought about, among them the dream of instantaneous worldwide communication and concludes with the

> concept of WAVES: . . . some artists simply shifting away from radio waves as carriers of apparently meaningful "signals" and turning their attention to the medium, the signals, the waves themselves [50], pg.18.

He states, that "radio is an experience of displacement". As much an experience of displacement as an experience of distant times. Only that our natural temporal sense does not become aware of that easily or unless considering astronomical distances. In that sense, all EM-signals are archaeological signals and sniffing is a form of enacted archaeology, again most obvious in radio astronomy.
Let us now plunge into a list of works either featured in the exhibition or related to its curational vector.

There is Franz Xavers RT03 project, consisting of a stationary 3 m dish antenna, the receiver tuned to the resonant frequency of hydrogen, about 1400 MHz. The systems output is played back straightforwardly in realtime as an internet audio stream. Xaver points out an additional aspect about antennas.

> The antenna has the properties of an old-fashioned object or sculpture but also serves as a device, which allows us to access Hertzian space. [50], pg.19.

The antenna accomplishes its interfacial duties by fractally unfolding into $\mathbb{R}^3$. This forces us to think about generic objects as antennas, which Xaver does along with Waves-contributor Joyce Hinterding and it diverts our pointer back towards biological interactions.

> For Hinterding, antennas in themselves have important sculptural implications because they demonstrate via electromagnetic induction —"the most extraordinary concept"—that "everything is active; all materials are active". She had earlier become interested in incorporating sound into her work because resonance and sympathetic vibrations in sound exemplified "what exists between things rather than things" [25].

Acknowledgement of this pervasive activity in the environment, exemplified by telegraph wires and fences, already covering space in the pre-radio era, utilized by Thomas A. Watson, allow for a redefinition of the approach so far promoted. This ubiquitous activity can be regarded as objects doing sniffing, without a listener or other spectator, enabling "gather that which is" become a "do that which is done". "It tempers the conceit that humans are the authors of radio, and it opens the technology to the environment" [25].
Another intruiging piece is the WIFI CAMERA OBSCURA. This work uses a low-cost cantenna type directional antenna on a motor-controlled tripod to record an image of its field of vision in the 2.4 GHz ISM band, which brings the optical analog mode of perception very close again.
An exceptionally acute contribution, subtitled "Using radio to make sense of our universe", comes from researcher and artist Honor Harger.

> Radio has, in effect, created an electromagnetic 'portrait' of our world. We can not only look at this portrayal, but by employing the very technology which Marconi and Tesla brought into being, we can also listen [50], pg. 160.

Harger is involved with the programmatic experimentation collective radioqualia, who, among many other forays into alternate modes of radio enactment, have focussed on radio astronomy and its relation to sound. One of their recent projects, aridly named "radio astronomy" [33], is akin to Franz Xaver's "RT03" in principle but the data is pulled from separately operated receiver stations. The movement clearly exposes "radio" as a vast and rather uncharted territory, a radio programme even, but programmed only marginally by humans and shows how the pieces fit together.

> The work of McGreevy, Stammes, and other radio hobbyists who work with natural radio resonates with an eminent branch of physics, which also utilizes radio to monitor natural phenomena. Radio astronomy, the study of celestial phenomena at radio wavelengths, was invented after the accidental discovery of cosmic radiation by radio engineer Karl Jansky in 1933 [21], pg.466.

And beyond more articulate sources, the cosmic noise-floor is teeming with promises while COBE is up and listening.
Martin Howse's "scrying" is another remarkable approach to heightened spectral awareness, while transcending a purely passive defintion of sniffing. Connecting to alchemist and magic practices it is nothing less than a comprehensive micro-controller based sniffing suite, modular and low-cost, covering anything from spectral waste and byproducts to radio astronomy but essentially being an open spatial computing platform. The system is conceived mainly as an infrastructure for artistic production and consists of several modules, small circuit boards carrying out different measurement, communication, storage and processing functions [23].

If not obvious, it has to be added that this is by no means a complete survey on artistic works employing electromagnetique techniques and considerations. A whole branch of experimental music has been left out for example. For a more thourough approach to covering the field, [50] may be used a starting point.

3.2 Hands on examples

To illustrate our case further, we want to finally delve into a few hands-on experiments. In a very simple case, no dedicated hardware is required. Rather, its a technique of using a standard radio receiver, maximally detuning it in one of the AM bands and considering spatial movement or specific high energy phenomena (lightning). The unintentional part of radio phenomena is already embodied in such a device. SuperCollider code for heterodyning (filtering and ring-modulation) is essentially:

```
( // single-channel version until smarter solution
SynthDef("DiskinMono", {|bufnum = 0, freq = 1000,
rq = 0.25, mfreq = 0, fftbuf = 0, ffreq = 0.5, amp = 1.0|
var in, chain, outsig, shft;
var str = DiskIn.ar(1, bufnum, 0);
chain = FFT(fftbuf, str);
chain = PV_Cutoff(chain, ffreq); // High Pass filtering
outsig = IFFT(chain);
shft = outsig * SinOsc.ar(mfreq, pi/2); // Amplitude modulation
Out.ar(0, shft * amp);
}).writeDefFile;
)
```

and is provided in usable context together with this text either locally[2] or here [3].

3.2.1 Experiment 1

The radio receiver is a Supertech WR-004 receiver. It is tuned to short-wave at ca. 5.8 MHz, where under unspecific conditions no audio is detectable. This works, because many emissions are spectrally broad and turn up throughout many bands. An alternative run tuned to 800kHz already gives slightly different results but is omitted from presentation here. The receiver is connected to a Zoom H2 digital audio recorder, recording at 96kHz sampling rate. We use this high rate for looking more comprehensively at our detecting system's output. We first notice that the output levels of the radio receiver indeed seem lowered in the band above 20 kHz. Since we realistically only hear signals up to something like 12 kHz, this is of course no direct drawback when regarding the unmediated audito frequency range. Visting a couple of electric devices in our immediate surroundings we already get a feel of the possibilities of such an approach. What becomes immediately evident is how unsurprisingly well metallic systems embedded in the building like heating and electricity wires amplify fields adjacent to the structure, that is, where no audio-channel could be heard standing in the middle of the room, suddenly music and a lot of other noises appear when approaching the heater.

1. 20081017-we-heizung-01.wav[3], approaching the heater.
2. 20081017-we-LCD-clock.wav[4], receiver with a few centimeters of the microwave's LCD clock display.
3. 20081017-we-LCD-sps.wav[5], receiver close to LCD computer display and a switching mode power supply.
4. 20081017-we-DECT-dsl.wav[6], operational LF noises from the DECT base-station.

This setup also works as a close-range lightning detector which announce themselves as short impulses, stretching over a good part of the spectrum, testable when a lightning storm is occuring right overhead.
As an intermediate step we will consider a special setup of sorts, consisting of a simple field-meter. This is an ammeter, with one pole of a dipole connected to each meter terminal, connected by a GE-diode, available

[2] EM-Sniffer-NRT.sc
[3] 20081017-we-heizung-01.wav
[4] 20081017-we-LCD-clock.wav
[5] 20081017-we-LCD-sps.wav
[6] 20081017-we-DECT-dsl.wav

for example as a microwave radiation warning device Voltcraft MT-128. When this device is placed directly on the antenna bit of the DECT base station, it gives sufficient movement of the pointer, which, as a side-effect, is transduced to sound by the mechanic activity, recorded via a piezo-pickup and microphone amplifier. Arrangement shown in Figure 1 and listenable via **20081020-piezo-feldstaerke-dect-station-mono.wav**[7].

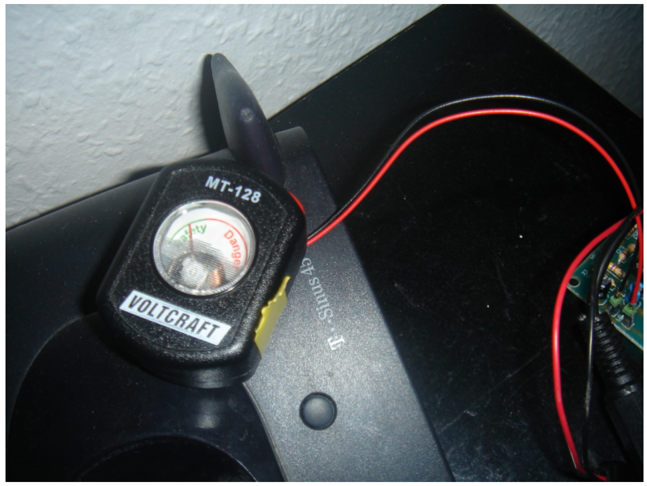

Figure 1: Arrangement for piezoelectrical pickup of field strength meter noises. The piezo is attached to the back of the meter.

3.2.2 Experiment 2

Having shown whats possible with such a simple setup, we switch over to something technically even more simple although requiring some soldering in practical application. Amplifiers. One device used in these experiments is the 3-stage amplifier by Burkhard Kainka, presented in [26]. In the recording sessions, two of these devices have been used. One equipped with a monopole antenna, the other with a small coil antenna. Straight wires tend to be more receptive to the electrical field component whereas coils react to the magnetic part, see above.
A second device used is the so called "HF-Sniffer" which AATiS e.V. provides as a kit via their website [15]. This circuit is based on the MAX4000 logarithmic amplifier chip series and is sensitive over the range from 100 MHz to 2,5 GHz. There is a big difference in in how these two devices operate in relation to our hearing range. The LF part of the spectrum goes through a direct oscillatory coupling, the HF part only relates to us the LF components of the HF signals, that is, amplitude variations, especially from pulsed transmissions. Demodulation takes place in part on the electronics side as well as in the auditory system itself, if the speaker would reproduce frequencies above our hearing range. The HF-Sniffer has been equipped with dipole antennas tailored to 900 MHz and 2.4 GHz wavelengths.
First, the indoor route already travelled by the AM receiver is repeated. Afterwards an urban outdoor EM-scape will be examined.
In many of the samples taken in the LF-range, the magnetic part, that is, the right channel, seems more interesing. Listening on headphones gives increased detail.
20081020-lf-em-computer-hd-LCD-sps.wav[8]: Here the antennas are moved over the desktop area. They are being passed over a laptop computer, an external USB hard-drive, its power supply and finally over the laptop's switching power supply. Articulations of specific fields can be clearly made out.
20081020-lf-em-DECT.wav[9]: A short sample where antennas are brought close to a DECT phone base-station.

[7] 20081020-piezo-feldstaerke-dect-station-mono.wav
[8] 20081020-lf-em-computer-hd-LCD-sps.wav
[9] 20081020-lf-em-DECT.wav

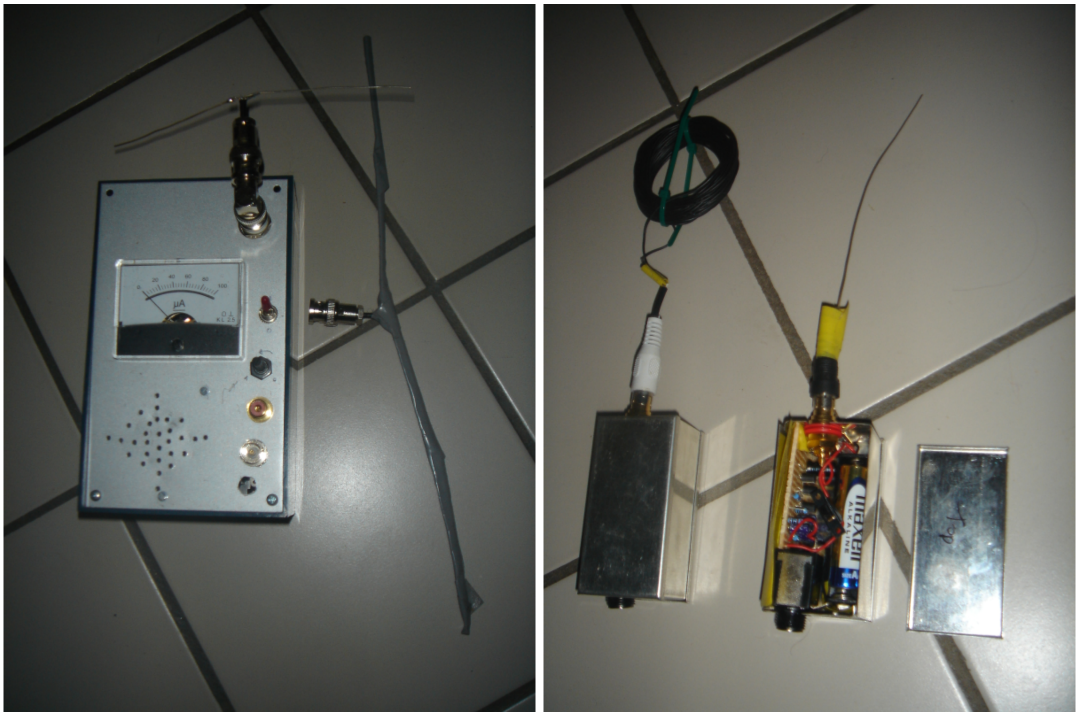

Figure 2: On the right, the HF-Sniffer in casing with the two dipole antennas used in the measurements, on the left two LF-amplifiers with coil and straight wire antennas.

20081020-lf-em-DSL-modem-various-angles.wav[10]: A longer example of the sniffer moved around within a distance of ca. 50cm from a Lucent Cellpipe DSL modem. If we look at the spectrum of the recording in Figure 3, we notice some interesting looking figures in the upper half of the spectrum.
Now we will make use of the mixing technique mentioned above. First, the lower half of the spectrum is silenced with an FFT based highpass filter. Then the remaining signal will be multiplied samplewise with a pure sinewave of 24kHz. This will give us two sidebands, one at the sum and one at the difference of the participating frequencies. Since after filtering the lowest frequency left over from the original resides at 24kHz, the lower sideband will be moved into the lower half of the spectrum. Looking at the result, we also notice how the upper sideband resides top-down in the upper half of the spectrum because of aliasing (**20081020-lf-em-DSL-modem-various-angles.wav-trans-1.aiff**[11]).
20081020-lf-em-approach-microwave-and-on.wav[12]: Here we listen to what comes out of an active microwave oven at low frequencies.
In the following the list of different recordings is continued with some annotation on what can be heard.
Domestic HF scapes give: **20081020-hf-bluetooth-unid-pulse-DECT.wav**[13] features transmission of a camera picture file to the PC over bluetooth, overlayed on some DECT noises and and unidentified constant pulsed signal. **20081020-hf-bluetooth-unid-pulse-DECT.wav-trans-1.aiff**[14] is the same with upper half-spectrum transposed down by mixing. **20081020-hf-DECT-unid-pulse.wav**[15] are the last two sounds alone again. **20081020-hf-unid-pulse-unid-pulses-unreg.wav**[16]: the same constant pulse again, with more irregular unidentified pulsed

[10] 20081020-lf-em-DSL-modem-various-angles.wav
[11] 20081020-lf-em-DSL-modem-various-angles.wav-trans-1.aiff
[12] 20081020-lf-em-approach-microwave-and-on.wav
[13] 20081020-hf-bluetooth-unid-pulse-DECT.wav
[14] 20081020-hf-bluetooth-unid-pulse-DECT.wav-trans-1.aiff
[15] 20081020-hf-DECT-unid-pulse.wav
[16] 20081020-hf-unid-pulse-unid-pulses-unreg.wav

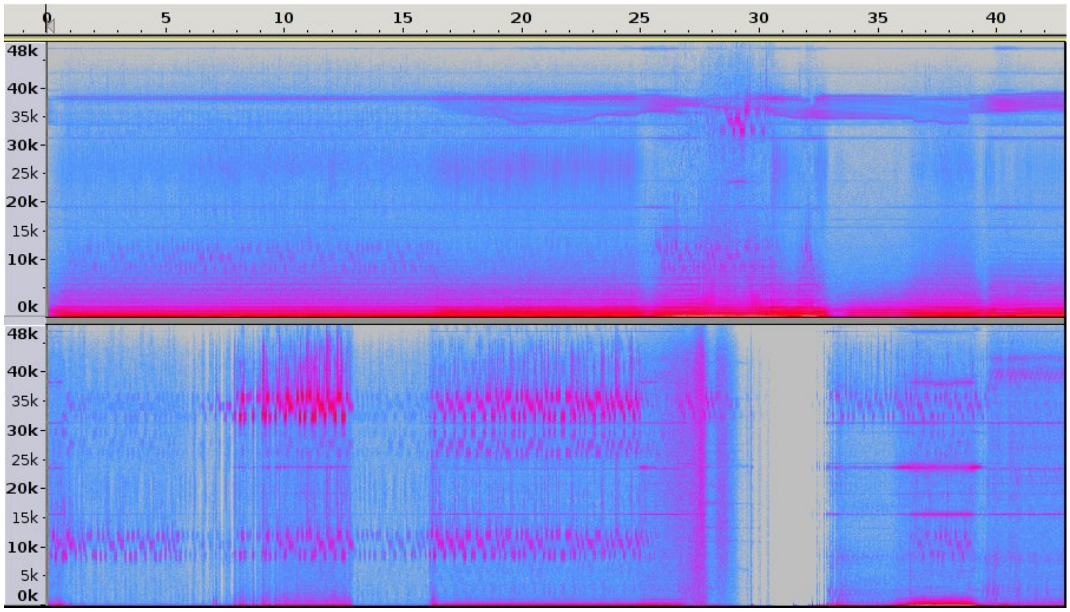

Figure 3: Spectrum of movement in DSL modem near field, x-Axis: time (s), y-Axis: frequency (kHz)

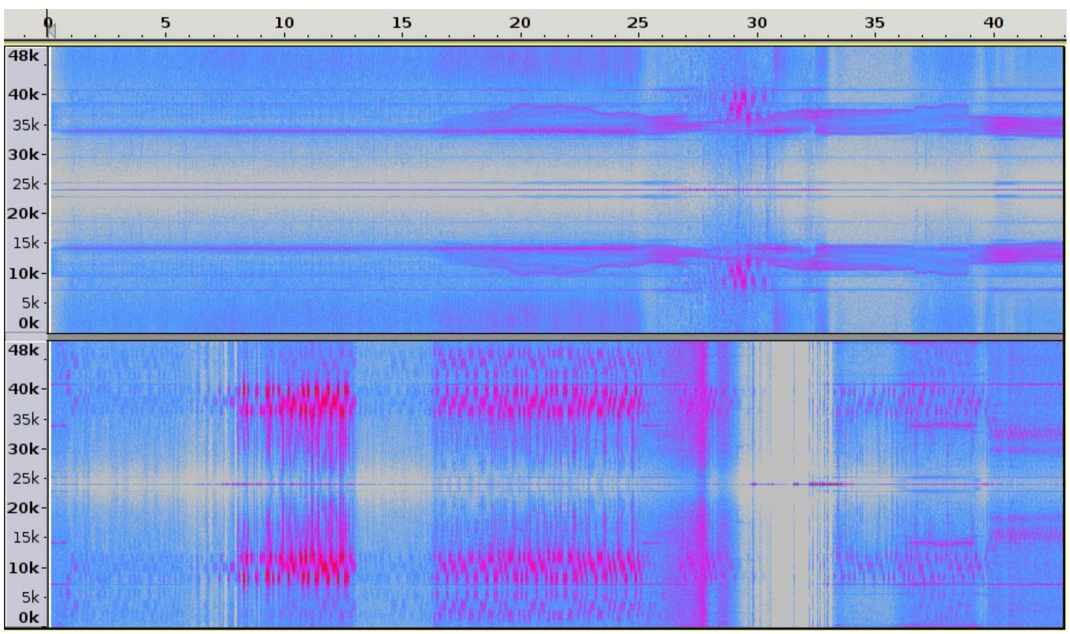

Figure 4: Spectrum after down-mixing, Axes as above

noises (possibly TV transmissions). **20081020-hf-unid-wlan.wav**[17] brings the sound of wireless LAN. **20081021-hf-lf-anschalten-and-WLAN-frag.wav**[18] is a longer capture with both HF and LF receivers on the table while

[17] 20081020-hf-unid-wlan.wav
[18] 20081021-hf-lf-anschalten-and-WLAN-frag.wav

switching on computers.
Taking everything outdoors we are able to snarf the following. **20081021-lf-strasse-01.wav**[19] is an idle street scene, soon arrives a tramway car lending these sounds: **20081021-lf-strasse-02-strassenbahn.wav**[20], **20081021-lf-strasse-03-strassenbahn-passing.wav**[21]. Later on we notice structures in the upper band in **20081021-lf-strasse-04-upper-band-unid.wav**[22] and **20081021-lf-strasse-05-upper-band-unid.wav**[23]. Again we transpose the signal in **20081021-lf-strasse-04-upper-band-unid.wav-trans-1.aiff**[24] and **20081021-lf-strasse-05-upper-band-unid.wav-trans-1.aiff**[25].
The same route again as heard through a different spectral window of sensitivity. In **20081021-hf-GSM-BS.wav**[26] we hear the unrelenting whistle of a GSM base-station. Such a base-station emits mainly two kinds of constant signals, one resulting from the length of the TDMA frame of 4.615 ms thus giving 216.7 Hz, the other resulting from the inter-timeslot delay giving rise to a frequency of 1.734 kHz. Here we hear the same ubiquitous tones moved slightly in the background in **20081023-hf-04-background-GSM.wav**[27]. When moving in the street, shadows from houses and other structures in the propagation area of the base-station can be clearly made out. This is the case in the hf-GSM-BS recording. In **20081023-hf-05-unid-blip-sequence-short.wav**[28] we can hear 4 short blips of unidentified provenience with seemingly constant inter-blip delay of about 10.18 seconds. This signal could only be picked up in specific areas of town. In **20081023-hf-06-GSM-BS-1734-30-45.wav**[29] the two tones reappear as also shown by the spectrogram in Figure 5.

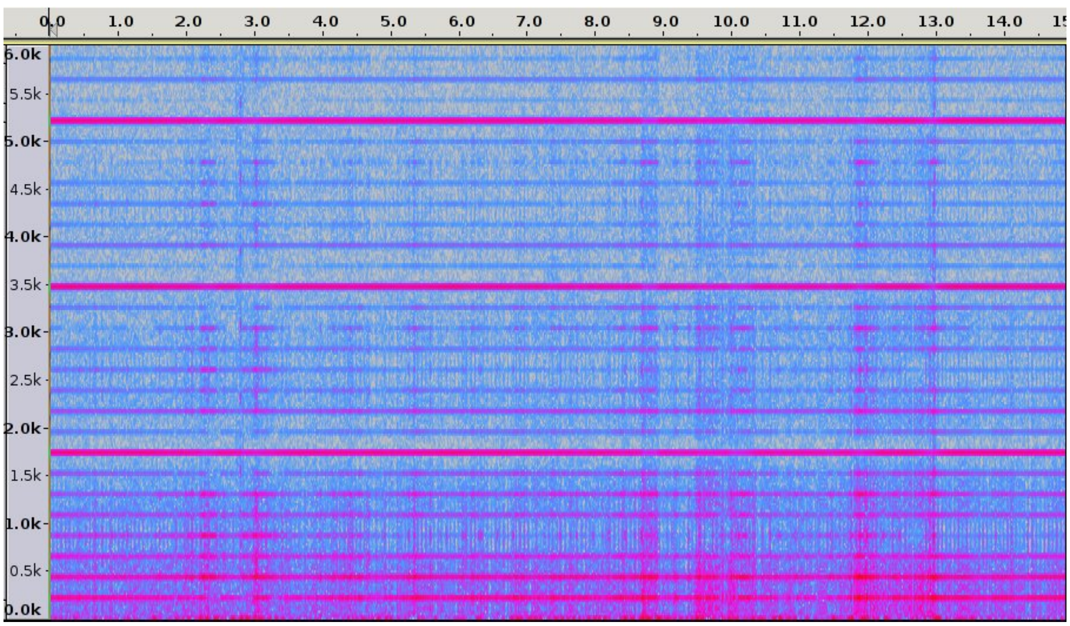

Figure 5: Spectrogram of a fragment of "static" GSM base-station signal. Clearly visible are base frequencies at 216 and 1734 Hz.

[19] 20081021-lf-strasse-01.wav
[20] 20081021-lf-strasse-02-strassenbahn.wav
[21] 20081021-lf-strasse-03-strassenbahn-passing.wav
[22] 20081021-lf-strasse-04-upper-band-unid.wav
[23] 20081021-lf-strasse-05-upper-band-unid.wav
[24] 20081021-lf-strasse-04-upper-band-unid.wav-trans-1.aiff
[25] 20081021-lf-strasse-05-upper-band-unid.wav-trans-1.aiff
[26] 20081021-hf-GSM-BS.wav
[27] 20081023-hf-04-background-GSM.wav
[28] 20081023-hf-05-unid-blip-sequence-short.wav
[29] 20081023-hf-06-GSM-BS-1734-30-45.wav

Finally some samples from rural areas. There, background signals change significantly and rarely anything marked will appear. Noise and faint hums predominate. One example is **20081018-lf-monopole-gr-buckowsee-frag1-1.wav**[30], recorded in the woods surrounding the Grossen Buckowsee north of Berlin. An autobahn ran along the area in about 1–2 km distance.

3.2.3 Experiment 3

For a low-cost desktop based sniffing method we borrow from the procedure described in [16]. Using a suchly modified bt878-based tuner-card and a simple coil antenna as given in [42] we capture an unspecific signal of 448kHz bandwidth and listen to an ascending sequence of segments through that band of measuring ca. 20 kHz in breadth.

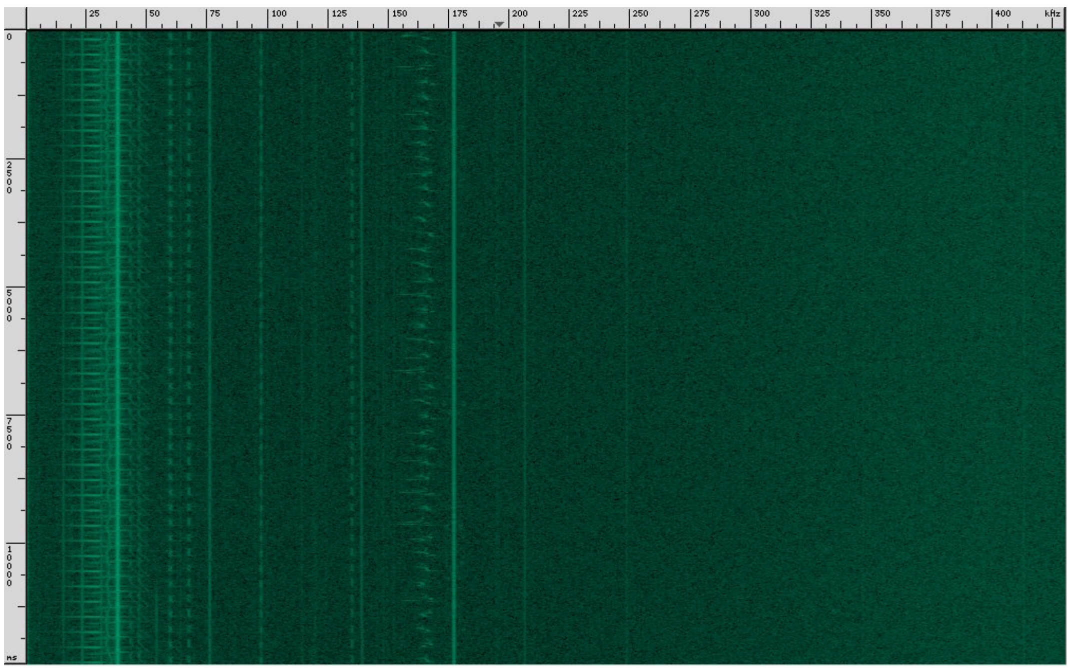

Figure 6: Spectrogram of the 448kHz band captured with a bt878 based tuner card.

The combined ELF, SLF, VF (Voice Frequency) bands would deserve extra attention as there is much information embedded in a quite narrow band, including the power grid's SLF emanations but also products of many natural (terrestrial and astronomical) phenomena. For reasons of space we will nonetheless only carry out our rigid investigative bandsweep. A few particularly eventful clippings are the undisplaced audio frequency bit from the original **20081024-SDR-bt878-01.wav**[31], and segments starting at 44800 (**20081024-SDR-bt878-01.wav-trans-02-96.wav**[32]), 156800 (**20081024-SDR-bt878-01.wav-trans-07-96.wav**[33]) and 179200 (**20081024-SDR-bt878-01.wav-trans-08-96.wav**[34]) Hz respectively. The last one rudimentarily uncovers Deutschlandradio Kultur on 177 kHz.

There are hints of wide-scale, especially computer-based, reception practices of signals in all of the LF spectrum (ELF, SLF, ULF and VLF) as it is readily available with any computer featuring a sound input device. Anything above requires extra hardware simply speaking. There are varying defintions of all these bands, but LF here shall

[30] 20081018-lf-monopole-gr-buckowsee-frag1-1.wav
[31] 20081024-SDR-bt878-01.wav
[32] 20081024-SDR-bt878-01.wav-trans-02-96.wav
[33] 20081024-SDR-bt878-01.wav-trans-07-96.wav
[34] 20081024-SDR-bt878-01.wav-trans-08-96.wav

mean generally frequencies in the range from 0 to a few hundred kilohertz. These hints line up nicely of course with the general idea of radio sniffing.

4 Concluding remarks

From the promising quick results above a couple of different steps propose themselves immediately.

- Refinement of the recording chain,
- and related to that, refinement of antennas. For example, using directional ones like log-periodic arrays and other types will certainly increase accuracy of mapping.
- Use of an external mixer in computer setups.
- A host of alternative amplifier and receiver designs is waiting to be employed and tested.
- The use of stationary, spatially distributed systems along with temporally extended or continous observations suggests itself, complementing mobile sniffers and high-end measurement efforts.

We have seen that the electro- and magneto-sphere changes significantly from urban to rural areas and even within the urban, that is, techno-energetical densely populated domains, there exists a highly differentiated and dynamic environment mostly excluded from everyday experience. Examples of electromagnetic signal-generators or electromagnetically active structures are simply myriads, going from subatomic and atomic entities, to all sorts of microwave-resonant objects both natural and technical (here and throughout the text already adopting a distinction for rethorical purposes), to global and planetary processes out into space and siderial em-activity. Iterating techno-cultural objects alone appears to be an infinite endeavour already, but they may be categorically subsumed under electronic wireless communication and probing systems such as mobile telephony, security and access control systems (EAS, Airport security), radar, broadcasting, WiFi, carlocks, IR-remotes, RFID, Bluetooth, Zigbee and so forth. All of these for sure have strong mid-term political or social implications and if they can't be miniaturized away it is still tried to hide them from public perception. So, besides its relevance for natural research in the astro-, geo- and biophysical directions, there is mounting motivation to come to terms with electromagnetism in more direct ways, since it is such a major player in contactless object identification, tracking, classification and control technologies.

It could be hoped for, that increasing availability of open handheld computer platforms might give radio-awareness a push. Looking at projects like `http://www.rjdj.me`, these kinds of input are going to be part of Tomorrow's ipod- and mobile-based music dissemination culture. More field sensors in *NG* mobiles, more interactive music, convergence with more general purpose mobile handheld computers.

In entertainment media terms, sniffing is a way of making a medium where none is, in technical and epistemological terms, the medium is vast and sensitivity and selectivity are key to running successful perceptual processes on certain aspects of reality.

Nonetheless, the view on the entirety of the oscillatory spectrum and the sites of transitions from one oscillating domain into another should be pulled to the center recurrently. The classic antenna as one such transitory spot, the radio-nanotube which "directly" turns electromagnetic into mechanical vibration another, maybe novel one.

A lot is left open, barely touched and otherwise treated inexhaustively as a matter of volume in all regards: historical, technical, auditory and experimentally. Hopefully brief contact with a different kind of radio discourse and low-cost experimentation could be established, as well as the close relationship technique and discourse entertain with sound could be pointed out.

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