Feedback systems with FM receivers and transmitters as musical instruments

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Abstract. This paper investigates how FM receivers connected to FM transmitter in a feedback loop can be applied as musical instruments, but with an inherent instability that at the same time breaks with traditional instrumentality. The paper begins with delineating the specific historical situation in Norway with the closing of FM band for national broadcasters, and how this could be seen as a call for action. The paper proceeds with a short review of the application of radios in music and sound art and practitioners working with feedback techniques, before presenting relevant theories of nonlinear dynamic processes and feedback systems. The paper then briefly delineates a simple setup of equipment, and goes on to address issues related to playability and sonic output. The paper shows how certain sonic categories are recurrent, but how different models have different sonic signatures, how some features are unstable and difficult to consistently reproduce. The paper concludes by discussing the findings in the light of the research literature in the field, and potential musical applications of the radio as instrument in different setups and contexts.

Keywords. FM radio, feedback, unstable interfaces

Introduction

This project was spurred by the shutting-down of FM-broadcasting for the national radio stations in Norway in 2017. Digital broadcasting (DAB+), its technological successor, required other receivers, an this resulted in that between 15 and 20 million FM-radios were suddenly useless, according to Dagbladet (Grønneberg 2016). In many regions in Norway at the time of writing the FM-band is almost completely empty of radio stations. E.g. in the Trondheim region (Norway's fourth largest city), there are broadcasts only on two frequencies, one around 87 MHz and the other around 104Mhz. The frequency band in between was therefore like a blank canvas, filled only with static. This project emerged as 1) a reaction to a political decision which effectively created tons of E-waste, 2) an attempt of countering this decision by finding some use for technology, which after many years had developed a certain level of sophistication, 3) the emerging availability of the FM-band as an open space, awaiting transmissions, and 4) an interest in exploring the artistic and sonic potential of FM-technology, inspired by the numerous instances of repurposing and hacking in music technology history (Holmes 2016; Collins 2009; Katz 2010).

The research question so far in this project has been: how can a simple setup with one FM radio coupled with one transmitter in a feedback loop be used as a musical interface? I have explored this research question from the perspective of sonic output, playing actions (input), and how the two are related. One additional aspect of this has been to explore different equipment and setups in search for the most interesting configurations regarding both sonic output and playing actions.

After presenting a historical reference and related work, I will briefly present some relevant theoretical concepts from the literature. I will then briefly present the equipment and the applied setup. Subsequently, I will present the main categories of sonic output before turning to how the setup can be played. The following discussion will draw on concepts from the literature and lead to the conclusion of the paper, with an outlook to future developments.

Background and related work

The artistic explorations of radios and radio technology go back over a century. Only a decade after the vacuum tube was invented by Lee De Forest, the inventor himself saw the potential to use radio technology to make a musical instrument (Holmes 2016, 18). *The Audion Piano* (1915) was based on *the heterodyning principle* using vacuum tubes, the same technology that was to be the core component in broadcasting radio. A few years later, Leon Theremin launched his now famous *Theremin*, based on the same technology, but with a radical way of playing it: without touching the instrument and only using the proximity of the hands (and body) to control pitch and amplitude (Holmes 2016, 18-25). A number of other instruments using the same technology followed.

After radio was developed as a mass medium, its artistic potential was noticed from early on. The two Italian futurists, Pino Masnata and Filippo Marinetti, wrote the artistic manifest *La Radia* in 1933, where they called for the "utilization of interference between stations and of the birth and evanescence of the sounds" as well as the "utilization of noises sounds chords harmonies musical or noise simultaneities of silence all with their graduations of appaggiatura crescendo and decrescendo" (Marinetti & Masnata, 1933). As far as I know, there are no records of Masnata or Marinetti realizing their ideas into an artistic practice.

It was first and foremost with John Cage, with pieces like *Imaginary Landscapes No.4* (1951) and *Radio Music* (1956), that radio definitely found its way into Avant-Garde music. For Cage, using radios as a musical instrument was one way of opening music to all kinds of sound, but it also fit well with his aesthetic of intdeterminacy, since the sonic content only to a limited degree would be determined by the performer and composer (Kostelanetz, 1986; Gurevich 2015). Later, also Karlheinz Stockhausen took up the use of radios in his music, especially with *Kurzwellen* (1968), *Spiral* (1968), *Pole* (1970) and *Expo (1969-70).* In these pieces, the performers used short wave radio receivers with sonic materials consisting of a combination of noises and whatever is broadcast at the time of performance. More recently, other performers and sound artists have used FM-radios together with transmitters, sometimes connected into feedback loops and sometimes not, among them Tetsuo Kogawa, Gert-Jan Prins, Anna Friz and Matthew Burtner (Friz 2009; Collins 2009, 15; Burtner 2003). Kogawa's political take on radio-art certainly resonates with the backdrop of the current project, although the context for his practices has been different (Kogawa 2008).

Unstable and nonlinear interfaces

In the history of electronic and experimental music, people like Robert Ashley, Steve Reich, Alvin Lucier and Gordan Mumma are presented pioneers of using audio feedback as an intended part of their performance practice (Holmes 2016; Chadabe 1997). The pieces and practices these and later artists working with feedback created, were often playing with the feedback in amplified sound systems and its interaction with the acoustics of the room they are localized in. Even simple microphone-loudspeaker feedback, also sometimes referred to as Larsen effect, can demonstrate many interesting nonlinear and chaotic effects and behaviors (Mudd et al. 2014). Several such effects or features are discussed in the research literature on feedback systems and nonlinear dynamic processes in music. Here, I will briefly introduce some effects and properties that can be relevant for the current setup.

- **Critical thresholds**. In a paper focusing on nonlinear dynamical processes in digital musical instruments, Mudd and colleagues are particularly interested in what they call "edge-like interactions", which happen around critical thresholds where there is a jump or abrupt transition from one state to another (Mudd et al. 2019).
- **Nonlinearity**. Although this term in itself is not very precise, it is often being used to describe situations where the relationship between input and output is discontinuous, warped or disproportionate in any way. Thus, it will in principle also include abrupt transitions as mentioned above. In addition, it can embrace situations like e.g a) the input is fixed while the output is changing (Mudd et al. 2014), b) the input changes, but there are no observable changes in output, c) there are small changes in input that create big changes in sonic output (see example in Sanfilippo and Valle 2012).
- **Hysteresis**. The state of the system depends on its history, so that e.g. a certain setting of input parameters might not give the same results when the history is different (Mudd et al. 2014).
- **Unpredictability**. Many nonlinear and chaotic systems will despite their deterministic nature in

practice appear unpredictable, especially around critical thresholds, as mention above (Mudd et al. 2019).

Method and Equipment

In the project reported in this paper I have chosen a highly exploratory and practice-based method. I have started out with an initial exploration to get a sense of the possibilities of different equipment and setups. Subsequently, I have had a number of sessions playing with the most interesting configurations of equipment and settings (see the subsection below), and these have been recorded on video. I have also made notes after sessions about experiences and lessons learned. The video recordings and the notes have then been reviewed with the intention of answering the research question.

Equipment and Setup

Although I have experimented with more complex setups, the focus of this paper is on very simple setups with feedback loops between one single radio and one transmitter, as in the setup Burtner (2003) reported (see Figure 1). Using this setup, I have experimented with a number of different radios and three different transmitters, and my conclusion from this experimentation thus far is that the choice of both radio and transmitter will affect the sonic outcome.[1] The setup is dependent on some form of audio output connection, usually in the form of a mini-jack output, which is then connected to the line input of the FM-transmitter. By tuning in to the same frequency of the transmitter one effectively will create a feedback loop. However, since the mini-jack output is usually intended for headphones, the radios will most of the time go silent when a plug is connected. In those cases, an additional radio for monitoring is needed. For some radios, one can also insert the mini-jack only half way, so that the radio will transmit the signal without silencing the audio output. This solution is somewhat unstable, since the connection might easily be broken, or alternatively, be fully connected, so that the radio will be silenced.

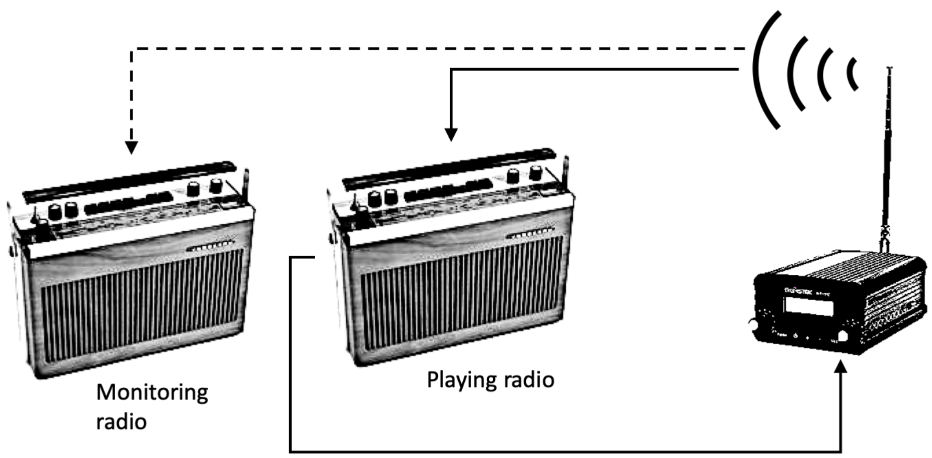

Figure 1: Equipment setup

[1]Although I have been experimenting with more complex setups, e.g. using 4-5 transmitters and just as many radios connected in multiple feedback loops, this will not be discussed in this paper.

Transmitters

So far, I have tested three different transmitters with this project, all belonging to the consumer segment of electronic products: 1) Belkin Tune Cast II[2], 2)CZE-T200[3], and 3)CZE-05B.[4] Of these transmitters, I have definitely found the T200 most useful, since it has a good range, is not subjected to grounds hum and can work without external power supply. Unless otherwise noted, I will refer to playing situations and sonic output using the T200.

Receivers

I have tested around 10 receivers in this project ranging from the 1960s to the 2000s, and from the cheapest consumer radios, to high-end models. Although one can achieve a certain variety of sounds with most of these, some of the radios have a larger palette interesting sonic properties than the others.[5] Among the most interesting, and the ones I will focus on in this paper, are *Radionette Kurér 1001* shown in Figure 2a), *Philips* (no type mark on the radio), shown in Figure 2b, *Tandberg TP41*, shown in Figure 2c, and *Blaupunkt derby de luxe*, shown in Figure 2d.

These radios have in common that they are high-quality table radios from the late 1960s or early 1970s. As mentioned, a mini-jack headphone or record out connection is an essential to achieve the described setup, and all of the radios possess this feature. All of them also have the following knobs and buttons, which are the primary control knobs of the radios when playing them: 1) tuning (receiving frequency), 2) volume, and 3) tone controls. I will expand on how turning these controls are used in playing below in addition to other modes of playing. In addition, all radios except the Kurér have a button for automatic frequency control (AFC). Although it will in some conditions change the sonic output, I have not focused a lot on using this.

Sonic output

Through my practical explorations I have found that the different combinations of equipment and configurations can produce a wide range of sounds. With a background in electroacoustic music studies I have found it useful to apply terminology from that domain to describe the sonic output. Especially, I will lean on post-schaefferian terminology from Lasse Thoresen (2007) and Denis Smalley (1997).

Sound spectrum

Regarding the sound spectrum part of Thoresen's typology[6], I have noticed considerable variation in the sounds I have been able to produce, but most sounds can be classified as either pitched or complex.[7]

Overall, and perhaps not very surprising, the most frequently found sounds fall into the complex category, close to what one could characterize as highly saturated or white noise. For example, whenever one deviates enough from the TF, one will eventually hear typical "radio static", i.e. a sustained complex sound with saturated spectrum, in Thoresen's terminology, close to what one would hear as white noise. This is a kind of "default" sound of the radio, perhaps comparable to e.g. playing open strings on a guitar (Sound example 1a, complex sound). However, by using both tuner and tone control, one can produce a variety of complex sounds (Sound example 1b, variations of complex sounds). Occasionally, I have also

[2]The *Belkin Tune Cast II* is definitely the least flexible, since the only adjustment one can do is to change the tuning frequency (digitally). Moreover, it doesn't allow for an external connection other than its 15 cm long included mini-jack cable. In other words, the transmitter has to stay very close to the radio. The low effect of the device (the documentation says nothing about the exact effect in Watts) requires that the receiver is placed on a distance up to 2-3 meters, at least for a clean signal (the documentation claims 30 feet). This feature can although be interesting in a performance perspective, since it enables you to use the distance to the receiver as a parameter to affect the degree of noise in the signal.

[3]The *CZE-T200* is the most flexible and versatile of the transmitters, since it is battery operated, has a mini-jack line and microphone inputs, and can modify both the input volume, transmission frequency (TF) (digitally) and RF power setting (0.01mW, 10mW, 100mW, 200mW) steps.

[4]The *CZE-05B* is the strongest one of the three transmitters, but less flexible than the T200 since it needs a power adapter. As the T200 it has analogue input volume controls, but only two power settings (100 mW and 500mW), and these can only be set when turning the device on. It also has a telescope antenna which secures a strong transmission. If localized close to the receiver, it may produce some grounds hum, which can be interesting in some contexts, but undesired in others.

[5]It would require profound research into the electronics of the radios to explain these differences. Although this is interesting, it is not a priority for the project at the moment.

[6]As all of Thoresen's framework, this is strictly an experiential category

[7]Without any perceivable fundamental, often towards what one would refer to as noise.

(a) Radionette Kurér 1001

(b) Philips (no type)

(c) Tandberg TP41

(d) Blaupunkt derby de luxe

Figure 2: The four radios discussed in this paper

sometimes found sounds close to a subcategory of complex sounds in Thoresen's system called *nodal* sounds, i.e. complex sounds with a spectral emphasis that produces a pitch-like experience, like bandpass filtered noise with a narrow band width.

All of the radios I have tested can produce sounds in the *pitched* category. These sounds can vary a lot in pitch and timbre, from relatively pure to heavily saturated with noise and overtones in the harmonic series, and from the very low, sometimes crossing into the realm of rhythmic pulses, to the very high. Perhaps the most typical pitched sound, that all of the radios can produce, is a sustained sound with a single relatively stable pitch in the low-mid range (Sound example 2a, pitched sound). Most of the time, the pitch has some irregularities, but not rarely these sounds can also have a more or less static pitch.

The *Blaupunkt* has proven to reliably produce sustained sounds with what perhaps could be characterized as having dual pitch, although the frequencies are so high that they are at the edge of perceivable pitch. Interestingly, the two pitched components do not respond similarly to playing parameters, so that the pitch distance also will vary when playing (Sound example 2b, dual pitch).

Energy articulation

As a general observation, the *energy articulation* of the sonic output, i.e. how the energy or intensity of the sound is shaped in time, most often falls in the *sustained* or *iterative*[8] categories of Thoresen's main typology (Thoresen 2007, 133). Only rarely or with specific intentions and rehearsal, one can achieve sounds belonging to the *impulse*[9] category. This corresponds to an emphasis towards the texture part of Smalley's (1997) concept pair gesture-texture.[10] I will get back to how playing technique, certain states of the system and specific faults of one of the receivers, all can produce sonic output more towards Smalley's gesture category.

Many of the complex sounds mentioned above belong to the sustained category of energy articulation, and usually have a predictable envelope. While iterative sounds can also be highly predictable, I have found that they often have irregularities in timing and spectral content, which often make them highly interesting in my perspective. In the following sound examples, (Sound example 3a-e, iterative sounds with irregularities), one can hear a) an iterative sound, mainly with irregularities in onset timings (Blaupunkt), b) an iterative sound with irregularities in onset and duration timings (Blaupunkt), c) and d) iterative sounds with timing and spectral irregularities, modest (c) and d) large respectively (both TP41), and e) an iterative sound with relatively regular timing, but with spectral irregularities (Kurér).

Even if the categories I have presented thus far comprise most of the sonic output produced with the system, there are also moments which transcend these, with rarely occurring "gems" of sound, often close to critcal thresholds, where there are a number of irregular variations and sound categories involved. For example, during an improvisation with the Kurér, I hit a state of the system with an irregular vacillation between bursts of sounds with different typologies and values, as well as irregular onset timing an duration: a) saturated complex sound (noise), b) a pitched sound in the mid-range, varies slowly, c) a pitched sound in the low range, about an octave below b, and d) a complex impulse with an attack with relatively low spectral brightness (Sound example 4, composite). In Thoresen's system this may be characterized as a sustained composite sound with complex and pitched components with irregular timing.

Playing Radio Receivers

Adjustments on the transmitters can indeed have an effect on the sonic output, for example input gain setting (it is only the CZE-05B that has a button which allow for analogue changing of the value), placement relative to the receiver, and degree of extension of the antenna (for the CZE-05B). However, the receivers as objects have a broad cultural, historical and technological signification that the transmitters lack, and conceptually it is the receivers which constitute the links to the ideas of the project. Moreover, being around half a century old technological artifacts, they also have flaws and idiosyncrasies due to wear and tear that often make them more interesting. The *Kurér*, for example, reacts with a burst of noise that gradually fades out when one touches the volume button, probably a result of a worn potentiometer. All in all, I have therefore chosen to focus on using only to play the receivers in this project.

Playing with Knobs

The knobs on the receivers typically function as in normal radio listening when the system is set to operate below the critical threshold. At the critical threshold the signal level, usually controlled by the volume knob, but also affected by the tone buttons and tuning, has to reach a certain point at the same time as the receiver is tuned to, or close to, the TF. At this point the knobs functionality change almost completely. Here are some observations I have made during several sessions playing with the knobs close to or above the critical threshold of feedback:

- The function of each knob is much less predictable than below the critical threshold.
- The volume and tuning knobs generally make more drastic changes, whereas the tone controls will generally will make smaller changes in the sound.

[8]Overall sustained, but with sub-elements which has quick repetitions

[9]With a short thrust of energy

[10]Smalley (1997) suggests that gesture and texture are two central forming principles in electroacoustic music, where gestures are related to human physicality, have shorter time span, and are forward driven while textures stretches out on a more environmental time scale, don't have much forward impetus and tends to create a focus towards inner detail.

- The pitched sounds often appear close to the critical threshold, whereas the iterative sounds with irregular properties often appear far from it
- Close to the critical threshold turning the knobs slightly usually makes a large sonic change, often changing the overall sonic category (cf. Sonic Output section).
- Further away from the critical threshold turning the knobs will generally produce less sonic changes.
- All knobs might in some cases affect the same sonic parameter, like for example pitch or spectral brightness.
- The physical shape and resistance of the knobs as well as the "resolution" with which they can affect their parameter will affect the interaction a lot. The Blaupunkt has e.g. a very fine resolution and high resistance allowing for minute changes in tuning frequency and thereby very subtle control, whereas the Kurér is has a resistance and resolution that often will produce a change in the values with small jumps.
- The receivers are different when it comes to the critical threshold. While for the TP41 it might be highly variable how high the volume needs to be turned up to achieve feedback or how low it needs to be turned down to stop the feedback, the Kurér seems to have a quite consistent critical threshold.
- If the radio is in a certain state that allows for some adjustment of knobs without changing the sonic category, but instead modifying a sonic quality or parameter, it is possible to approximate a form of stepwise playing. Thus, it is possible to play simple quasi-melodic sequences, or sequences with distinct timbres.

Lastly, I want to make a comment about playing to achieve sounds with a more gestural quality (cf. Sonic Output section), through having an energy articulation that is relatable to a human gesture. This means normally that it has a relatively clear beginning and ending, and that it does not last more than a few seconds. Through experimentation I have found that the receivers afford different possibilities for creating a more gestural sonic output. On the Kurér, with its highly consistent critical threshold, it is possible to move between silence and sound by a very slight turn on the volume button. To transcend a simple on-off gesture, changing the sound quality, e.g with the bass knob to change the pitch and noisiness of the sound, can give additional shape to the gesture (Sound example 5a, sequence of gestures). With the Blaupunkt, however, this is easiest to achieve when there are areas of the band close to TF that are either close to silent or much lower in intensity than an area of the band close to it. Then, one can by a relatively small movement of the tuner control the onset and ending of the sound. The size of the movement of the tuner can then be used to shape the gesture additionally, e.g. changing the pitch and noisiness (Sound example 5b, sequence of gestures with quasi-melody).

Playing with Proximity and Touch

When the setup is in a certain state, one can change a property of the sound by touching or changing the proximity of hands and/or the body to different parts of the radio: this can be the antenna, but touching the volume and/or tuning knobs will sometimes also have an effect. Here are some observations about playing with proximity and touch:

- The proximity of hands or the whole body might act as a continuous control
- Curving the hands around the antenna can affect the sound. In some cases, changing the height of the curved hands can continuously change the sound.
- Touching the antenna, or letting go of it, often creates an abrupt sonic change. The same can apply for touching knobs.
- It is difficult to reproduce states in which proximity and touch might effect the sonic output.

Discussion

It is quite clear that the setup described in this paper demonstrate many properties described by the literature on nonlinear dynamic processes and feedback systems as presented in the Background section above. The term critical threshold, as introduced by Mudd and colleagues (2019), seems highly adequate for the point when feedback becomes audible in the setup. This is also a really important point of reference when playing. The radios seemed to differ, however, in the degree to which this point could be reliably retrieved, with the TP41 demonstrating a clear hysteresis effect with its changing location of the critical threshold. That the relationship between playing input (turning knobs, touching, or changing proximity) and sonic output is highly variable also attests to the nonlinearity of the system, even if certain states could demonstrate close to linearity for certain parameters. The nonlinearity is also evident from the fact that very often all knobs will affect the sonic output in the same way, at least within a certain range.

The nonlinearity of the setup can have a positive effect if one appreciates a way of playing and interacting with the system driven by exploration (cf. Mudd et al. 2019). The complexity and variability of the sonic output also supports an exploratory approach. While I have demonstrated that it is possible to play the system in with a more instrumental approach, where the control of single parameters is desirable, this is very limited and needs a lot of practice. Thus, the setup described in the paper seems more fitting for a free-improvisation setting, where exploration, surprises and sonic variability can be valued. The fact that in certain states, the system can render highly interesting sounds with both temporal and spectral variability also invites adding more layers, either in the form of other instruments or other similar systems. This is something I will proceed with in the future.

The radio receiver as an interface has one feature that would be well-known for an electronic musician: knobs. Playing by proximity and touch is less common, but e.g. in the ICLI and NIME communities, this would probably also relatively well-known.

Conclusion

I have argued in this paper how radio receivers connected to transmitters in a feedback loop can be used as a musical instrument. This setup might very weakly comply with a traditional sense of instrumentality, but in certain contexts which favor nonlinear mapping between playing gesture and sonic output, sonic richness and variation, free improvisation and exploration, it might be highly adequate. Although the sounds produced by a single system might not always be very interesting, combining several systems might create additional musical interest. This is something I would like to pursue in the time to come. Testing different setups with a group of users to validate the findings in this paper is also planned for the future.

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