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# Problems Recording the Hum

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People concerned with the phenomenon known as the “Worldwide Hum”, (or just “The Hum”), [1-13] would understandably expect postings/discussions on the Internet to include, if not to prominently feature, clickable playback opportunities for recordings of the said Hum. Indeed, wouldn’t that seem to be to the point. With so many recording devices in the world (in so many pockets!) today, any information source is expected to provide recordings. No such authenticated recordings of the Hum are found.

We begin by pointing out that sound recording is non-trivial. It just seems like it should be easy. You can be at a relatively small meeting and hear everyone just fine, just as you sit. If you take out a cell phone or voice recorder, just switch it on and surely (so it would seem) you will record everything in a satisfactory manner; the audio is “out there” and you just grab it. If you have tried this, you know it generally has failings. There must be a reason the “talking heads” on TV are so carefully miked. Audio engineers are paid professionals for a reason.

So recording requires considerable care even under the most favorable conditions. Attempted recordings of the Hum can be much harder or even impossible (not unlikely, there may not be any existing physical acoustic signal at all to record). If the signal does exist physically, it is certainly already of a very low volume level, a very low pitch level, and there is no reliable notion of a source location (nothing to point the mike at). Ordinary recording devices (cell phones or other home recorders) just are not even intended to meet the task.

So let’s consider the case where you hear a hum, but others are doubtful. To prove your point, you turn on your recorder, naively assuming it just grabs whatever you are hearing. In addition to a hum, you hear a bird call, a car going by, and a child laughing. Of course, following the recording attempt, you almost certainly test the playback. Did you get it? You hear the bird, the car, the child, perhaps an airplane going over just now as you play back, AND the hum. Now the complications come in.

First assume that you are experiencing a hum sound of a hum-pretender as a real acoustic phenomenon - as a constant happening. That is, YOUR hum is something really buzzing along, the exact source of which you might well have stumbled upon – but haven't yet. It is perhaps a pump or a truck up the block or some curious sound of perhaps bizarre origins in a wide environment. Further, assume your equipment is capable of, and does capture it. And in playing it back, you are at the same recording location, so the hum is still generally there. In that case, during playback you don't hear just the recorded material but also a live, overlaid, new version of the hum, just as the purposed airplane was new during playback. But there should have been some interaction (like "beating") if the recording/playback was valid. And others should hear it (both) as well. Potentially this is useful to your cause.

If on the other hand, it is "The Hum", and is internal to the individual hearer, then no acoustical hum-sound was actually recorded. Nonetheless, the hearer will believe that the Hum must have been recorded, along with the bird, child, and car in the background. But the recorder has recorded only the background events. There was NO Hum as an acoustics phenomenon. During the playback, the Hum hearer will experience an (internally generated) replacement version of the Hum, but it also would be experienced before and after actual playback. During the playback itself, there is no interference between the assumed recorded Hum and the new Hum "track" being created courtesy of the internal mechanism. Overall, it probably sounds to the hearer basically right. The witness to the recording playback will hears only bird/child/car, and disclaims any recorded hum, just as the live hum was not originally experienced. Add to this (frustrating) lack of "corroboration" on the part of the witness any impending notions that something is confounded with regard to the observations now in evidence. That is – you are losing the case.

Numerous other cases involving different internal/external source possibilities, perceptual thresholds, different locations, and equipment use/misuse are easy to dream up. Each is likely problematic.

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Our initial purpose in attempting to record the Hum was likely as "proof" (for ourselves as well as others) that it really existed. Perhaps we wanted to take it to a public meeting or to a meeting with a utility or factory official. If we thought about the possibility that a replayed recording could be "heard" while a personal visit to the live scene failed, we might have had second thoughts. If it does not even exist acoustically, it of course does not record. If it is a real acoustic event, but is very low level and very low pitch (that is – the ear is already giving up), it is expected that the attempted recording may well fail. If the equipment is new to us, and not given test runs, perhaps a button was just not pressed correctly. Only for something that is already very evident would we expect to make convincing presentation by way of a recording.

While we generally think first of recording as capturing audio for audio playback, it is also often possible to use a recorder as a "data acquisition device" that produces a file for engineering analysis. Such capabilities may be shown as features (time-displays and/or spectral-displays) built into the recording equipment, or as a capability to export a file to a computer (USB cable). Once digitized (properly sampled), the prospects of wide-ranging and useful analysis tools are promising.

So, to be clear, if we have The Hum as an internally generated sensation that does not exist as a physical audio pressure wave in the environment, but presumably in some form in the ear, nothing other than incidental background will be in a recording or be available for data analysis. Likewise, if there is a real audio signal, but it is below loudness and/or pitch thresholds of the equipment. The only possible point of information would be that at least the humming sound is not at all strong.

If on the other hand, a significant audio signal is obtained/recorded/analyzed, much might be learned – potentially a full explanation and possible remedy. In such a case, we should probably have seen failures in the checklist [12] for the traditional Hum. For example, a house full of friends might all agree that a transformer up a pole across the street seems to be buzzing. Playback, a time display, and particularly a spectral analysis might be the "smoking gun" that a deteriorating transformer (for example) is at fault

## THE VIEW FROM THE FREQUENCY DOMAIN

What would we look for in a spectral display? Of course - - - Whatever we can get!

However, since we use the term "hum", there is a general view that the phenomenon is a periodic signal, or a good approximation to one. As such, we think in terms of a "Fourier Series" (FS) representation (the simplest of the Fourier transform objects [14]) and the "pitch" of a periodic presentation [15]. Since I have never even achieved a display of the Hum (nor have I seen any published), I can only speculate, based on extensive experience with audio, that my Hum signal has a fundamental of about 64 Hz and at least a moderate $2^{nd}$ harmonic at 128 Hz as a FS.

There are numerous way in which a sum of sinusoidal waveforms could arise – the first of which is quite simply to arrange a parallel set of oscillators and add them. While simple in concept – "additive synthesis" - (and more general than for just a FS), this is tedious and unlikely as a hum mechanism.

Two other mechanism seem more interesting to consider. Of these two additions, the first is to begin with a harmonically rich waveshape (perhaps a sawtooth or narrow pulse) and filter it to pass only the intended sinusoidal components – "subtractive synthesis". This means that some sort or excitation "drives" a system (a filter or resonator) that is coupled to it. Perhaps a woodpecker drumming on a hollow tree trunk is an example. Only exact harmonics are expected in this case.

The remaining method considered here is to have an already periodic signal pass through a non-linear system. This we will look at in some detail since it may well be involved in the generation of a hum-like sound emanating from electrical power distribution equipment, and would likely appear as a real acoustical phenomenon. It is common for an audio system, even with the volume control turned all the way down, to have a low-level "AC-hum" that comes from the speakers. This we understand in terms of flawed grounding or of deteriorated power supply filtering capacitors – fairly well understood electrical issues. Often this is related to normal consequences of common "full-wave rectified" (FWR) AC to DC conversion (see below). Here we are talking about a hum or buzz (vibration) that is heard as a sound from an electrical device; not supposed to produce audio (no loudspeakers).

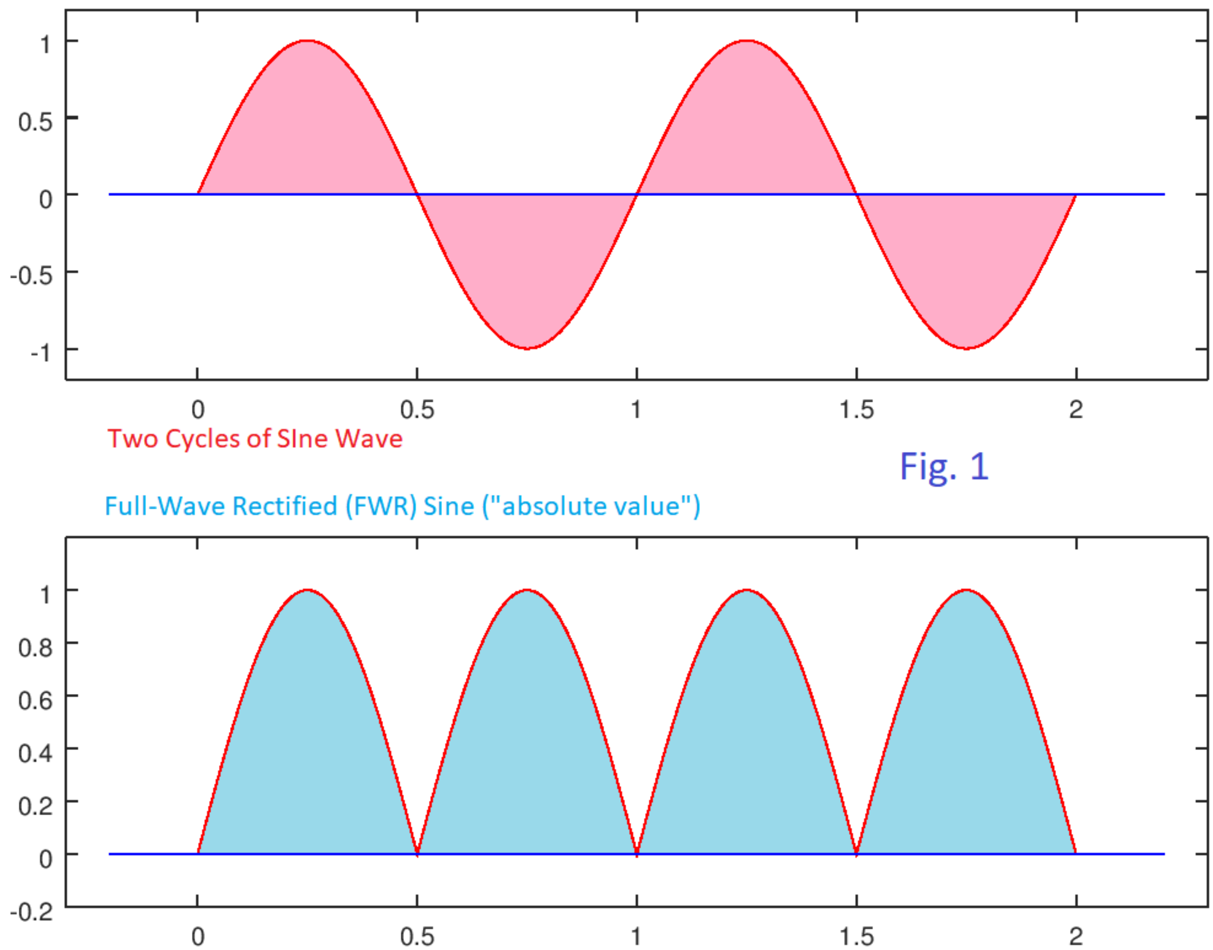


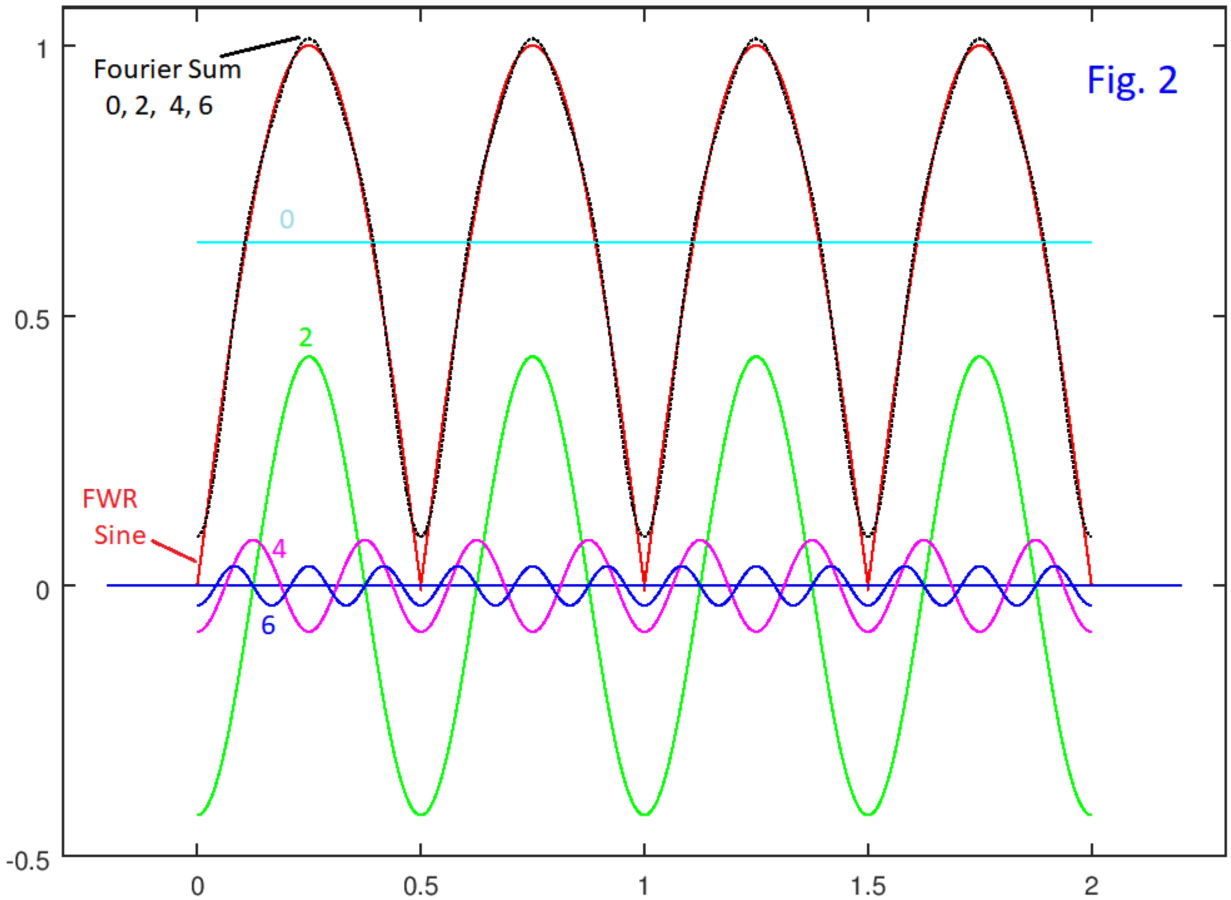

Fig. 1

An interesting feature of a FWR supply is illustrated by Fig. 1. The top panel shows two full cycles of a sinewave. Note that it swings from +1 to -1 and so on. The FWR method inverts that negative going lobes. Mathematically it is called “absolute value”. Superficially the result, which now swings between 0 and +1 looks a bit like a sinewave of twice the frequency. In fact, it is periodic with period 0.5 instead of 1.0, and has no remnant of the original frequency. The average value is 2/π = 0.6366 which makes it useful (once filtered) for use in a DC power supply.

The actual FS of a FWR sinewave is tabulated [16] or is easily derived by considering the FWR sine to be the original sine multiplied by a square wave (representing the sign of the sinewave). This multiplication in the time domain is a convolution of the FS coefficients. Thus the FS coefficients of the FWR sine are those of a square wave shifted up by one added to the square wave coefficients shifted down by one. The coefficients for the case shown (Fig. 1, and in detail, Fig. 2) are:

$$A_k = \frac{-\frac{4}{\pi}}{(k-1)(k+1)} \qquad \text{k= 2, 4, 6, …..}$$

Fig. 2 shows the FWR sine (red) and the sum of the first four terms of the FS (black). The individual components for DC and k= 2, 4, and 6 are also shown. Note that the k=2




component (green) is basically responsible for the audible pitch (twice the original frequency). Nothing is remarkable here except for the fact that the "fundamental" is now 2, and not 1. Viewed (erroneously!) as period 1 instead of period 0.5, it may look like a fundamental of 1 with only even harmonics. There can be no such thing, and the ear will not hear the pitch corresponding to a frequency of 1. Rather a pitch of 2 with all harmonics is heard. In terms of power mains of frequencies: 60 Hz (N. America) would be heard as 120 Hz, plus all harmonics, and 50 Hz (rest of world) would be heard as 100 Hz, plus all its harmonics. Note that a harmonic-free sinewave at 50 Hz or 60 Hz is hard to hear [17], while the significantly higher pitches of 100 Hz or 120 Hz, as supported by harmonics, are relatively easy to hear and seem much stronger.

Above the FS results have probably been first thought of as electrical signals, or just math. So when we thought of them as audio we probably thought of any one of numerous electrical FWR circuits as pre-processing a sinewave prior to feeding it to a loudspeaker. Is there any way for a FWR sinewave to arise as a natural vibration? None come to mind.

Yet, consider the possibilities when a AC-carrying electromagnet coil has a time-varying magnetic field that interacts with either a non-magnet (yet a ferro-magnetic substance - say iron), or with an actual (permanent) magnet, as in the four cases of Fig. 3. In this figure, objects in green are iron, but not magnets, while objects half blue and half pink (different poles) are permanent magnets (PM). The coils are assumed to be carrying AC signals that are sinewaves.

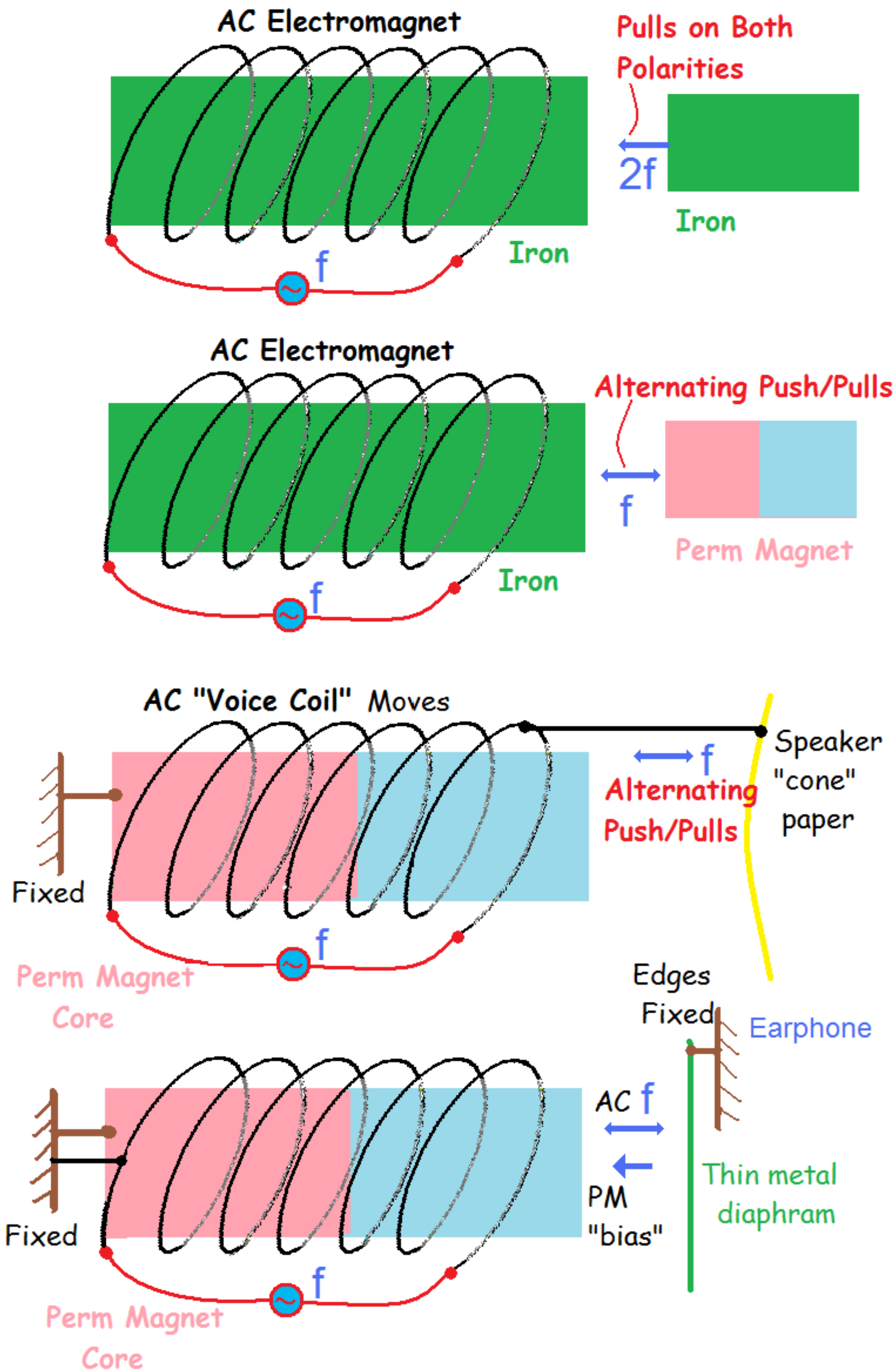

AC Electromagnet
Pulls on Both
Polarities
2f
Iron
Iron
f
AC Electromagnet
Alternating Push/Pulls
f
Perm Magnet
Iron
f
AC "Voice Coil" Moves
f
Alternating
Push/Pulls
Speaker
"cone"
paper
Fixed
f
Perm Magnet
Core
Edges
Fixed
Earphone
AC f
PM
"bias"
Thin metal
diaphram
Fixed
f
Perm Magnet
Core

Fig. 3

In the top of Fig. 3 we have a standard electromagnet of the type most of us built as kids: wire wound around a bolt or nail and connected to either a battery (DC) or perhaps a transformer (AC) and was used to snare paperclips and like bits of iron/steel largely for amusement. The polarity (or AC or DC) did not mater – the metal was always attracted. Let's assume the current is an AC sinewave and that the smaller green block can move slightly but is constrained by a spring, while the electromagnet is fixed in position. Every time the AC cycles, either as a positive lobe or a negative lobe, the block is attracted, but released as the magnitude returns to smaller absolute values. It matters not at all to the block whether the electromagnet is pulling as a North pole or as a South pole – it is just pulled and released. Thus it is pulled in an identical manner TWICE each AC cycle. The AC frequency of f is transformed to a vibration rate (audible pitch) of 2f. It is in effect, an electro-mechanical form of FWR. Apparently, frequencies are doubled.

In the second configuration, the green iron block is replaced by a permanent magnet (PM). Now, each AC cycle has two lobes that are different with respect to the magnetic target item. One lobe attracts while the other repels. The frequency f in the coil remains f in the PM. Unlike the top, we now have the potential of forming an audio transducer (a loudspeaker or earphone) since frequencies are not changed.

The configuration second from bottom in Fig. 3 represents a loudspeaker. Here there is a magnet (PM)* that is fixed. Unlike the kid's toy, the wire (field coil) is not would tightly around the magnet, but is suspended closely around it, supported by the paper cone, but can move along it driving the cone in consequence. Here the PM needs to be large and heavy, so it is best to move the coil and cone.

The most curious object is perhaps the bottom configuration representing a headphone or earphone. Indeed, it is the oldest familiar form of transducer – a major element of our kid-adventure "crystal set" radios. The phones (one for each ear if you were rich enough) were muffin sized, always black, and happily, the covers screwed off like jar lids. What was inside? A thin metal diaphragm about 2 inches in diameter. These could be lifted away, but something tried to hold them in place – the diaphragm was pulled down by magnets. Were they PMs or electromagnets? They were both, coils of very fine wire about the PMs, both firmly fixed to the case as solid units. The coils were driven by the leads going to the radio. Books explained that the magnetic fields of the <u>electromagnets</u> vibrated the diaphragms producing the faint sounds. Good enough for a 12 year-old. So – why the PMs? This question I have finally asked 60 years later!

Without a PM, one would have rectified the audio. [ It does seems unlikely that the thin diaphragm could have been made into an actual PM, as in drastically flattening the block horizontally in the second from the top. ]

The concept of a DC bias, <u>in a circuit</u> with a single-polarity power supply, was common, say 80 to 40 years ago. Bipolar AC signals (i.e., audio) were represented by a unipolar voltage with a DC offset. Audio was coupled/decoupled on/off to this bias level using capacitors. The simple requirement was that the sum of the bias and the audio should not reach outside the supply limits or else something non-linear was assured (for example, the FWR of the audio) resulting in harmonic distortion.

The biasing PM in the earphone slightly warps (overwhelms) the maximum expected changes due to the coil currents, so that the diaphragm is always bent inward. The bent-in zero current equilibrium position is then slightly increased or decreased by the AC current, allowing the diaphragm to flex in a near linear (small signal) manner, always pulling. The displacement about equilibrium is proportional to the magnitude of the AC current, and is inward or outward depending on the AC current polarity.

If one attempts to find an account of how the need for a magnetic (PM) bias in the standard earphone came about, very little is discovered immediately. One can find peripheral bits, but nothing complete. Nothing specific about the fundamental need for the bias, or why there were two magnets inside or their polarities (they were wired in series, but which way). A bit about harmonic distortion being an issue. I'm still looking.

## SUMMARY

In summary, proposals to detect/record/display/analyze an apparent hum are problematic. In cases where you seem to be involved with the "traditional" hum" [12], be aware that others have tried very hard without any success – there may well be no acoustical event to even record. And, in any case, unless there is a very strong audio signal more-or-less evident to everyone around you (non-traditional), equipment that is already unfamiliar (new to you) may be being used outside ranges familiar even to professionals. Is a negative result perhaps just the experimenter's failings?

That all being true, in cases where a real acoustic signal does yield to an engineering analysis, important clues may emerge. For example, the discovery of a sharp set of even harmonics of the local power frequency strongly suggests something vibrating in response to a magnetic field of a transformer, or similar.

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* In the early days of loudspeaker (amplified) radio sets, strong PMs were impractical, and the core was an electromagnet. This magnet was in fact used double duty (as were many features of the clever designers of the day) as it also served as an inductor ("choke") in the smoothing of the AC to DC power supply, later replaced by large electrolytic capacitors for the function. This necessarily meant that hum components of the power ripple found their way to the voice coil. The solution was to add a "hum bucking" coil to be used along with the voice coil. A level of ingenuity that is unhappily rarely seen today!