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Interference & Distortion Reducing Capabilities of Woven *PowerKords*™ *

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** AC cables employing weave manufactured by Kimber Kable Inc.since 1979*

00 - Contents Guide

Sections **0** & **1** introduce the subject, and furnish background.
Sections **2** & **3** cover the design of tests to show woven cables' effects, then the analysis of the results.
Section **4** looks at how RF ingress causes distortion in Hi-Fi equipment, with a measured example.
Section **5** examines RFI on the AC supply, and audibility mechanisms.
Section **6** unravels the EM basis of woven cable. *Glissando effect* is christened, and a model derived.
Section **7** concludes.

Appendix **1** relates to section 4 & 5.
Appendix **2** relates to sections 0, 1 & 6.
Appendix **3** relates to sections 2, 3 & 4.
Bibliography & further reading. Text citations have integer numbers in square brackets thus [1].

0 - Introduction

Abstract: The scope of this paper is to demonstrate the mechanisms of distortion and noise being reduced, hence greater fidelity, when using woven cables to connect AC power to hi-fi equipment. In so doing, a unique feature of woven cables is identified and christened, as The Glissando *effect.*

Most Hi-Fi equipment [section 1.1] operates from an AC supply [1.2], and most AC supplies suffer from diverse sorts of Electro-Magnetic Interference (EMI) [1.3] also known as Radio Frequency (RF) noise, RF interference (RFI), or electronic pollution. It has been observed by music listeners, that reducing or removing EMI or RF interference improves the sound quality. This is usually by inference: that taking steps known (or configured so as) to remove or diminish EMI or RF, reduces the levels of noise and/or distortion in the audio signal path, and this affects acuity of listening and human ability to hear the legitimate, wanted signal - which is music (or similar, eg. movie sound track, or poetry on BBC Radio 4).

Specially-made, *woven* cable [1.4] (as designed and sold worldwide by *Kimber Kable Inc.*) may be obtained as plug-in accessory upgrades, widely employed by three generations of Hi-Fi listeners, and employed as the final (or first - depending on the perspective) few feet (1 to 3m) of the AC supply's conductor path. The weave acts by filtering RF to a far greater and wider degree than a conventional AC flex (designated as '3183Y') can, hence diminishing the amount of RF entering equipment, to introduce noise or exceed detection thresholds, which otherwise can lead to distortion (as well as noise). Both effects will be shown later by measurement.

The changes may be subtle compared to other areas of electronic signal handling, but they are objectively measurable, and the result is 'improved sound', ie. capacity to better hear and focus on the wanted signal, usually music - but also emotionally-charged human speech (as found in films, plays, poetry).

It should be borne in mind that in some instances, small reductions in RF levels can disproportionately reduce or even clear up, the adverse effects of the RF noise or signals, on audio equipment and music reproduction. This *non-linear* manner of behaviour (due to a threshold being exceeded or not) has long been documented by Amateur ('Ham') Radio hobbyists & operators, who have dealt with RF affecting domestic audio equipment since the 1920s.

Although woven cables have been in worldwide use by thousands of music listeners for some 30 years, measured information or even theoretical data demonstrating their practical effect or effectiveness, or a delineation of their operation, is scarce or non-existent. Much the same can be said of twisted and braided constructions - see Appendix 2. The situation arises in part (first) because electromagnetic (EM) modelling - that should aid theoretical comprehension - of such visually taxing 3-dimensional (3D) structures, is in turn even more highly complex. And because the few 3D-EM computational and mathematical tools that exist are limited or fettered in their capacities, since trivial and regular transmission line situations are 'grist enough', mathematically speaking.

Second, outside of EM modelling, information about woven cable has been hitherto absent because the measurement of its effects has required 'out of the box' investigation far outside of conventional and standards-led audio, RF or EMC test regimes. Working on a premise of open-ended research, the author determined that *well* over 1 million measurement permutations were required to search out some of the effects of weave, if done systematically - with different modes, different excitations, and different instruments surveying in diverse ways.

To find suitable test equipment and as a measure of the size of the project, over 50 electronic test maker's catalogues were checked, going back to the 1960s and 70s, some with over 500 pages, to check for every sort of test instrument produced. The search then moved on to instruments stocked by test equipment suppliers, with well over 2000 instruments of all types, considered and scrutinised as to applicability. A number of the instruments that were eventually put to use, and that were short-listed and on hand, are listed in Appendix 3.

When an equation set is too complex, the behaviour of - in this case weave - can be inferred from its development and first principles. In other words, a plausibility argument can be constructed. A major first principle is that when a pair of conductors passing a signal are crossed, they are able to reject external induction, and their own radiation is also suppressed, by reciprocity. Another first principle is that that the amount of reduction is generally in proportion to the number of crossings per unit distance. This was reported by the maker as having been observed at the developmental stage of the woven cable as a product. If such were not the case, there would be no impetus to create the highly specialised (and by inference, very expensive) machine tools required to create woven cables.

The weave, when exposed (when used as an AC cable, it has to be *over-sheathed* for obvious safety reasons) very visibly contains a large number of crossings. Further characteristics can be deduced by careful observation, and '2.5D' § modelling.

§ The 'half' dimension refers to mapping a 3D configuration, into a circuit simulator, which works with meshes, that are 'more' two dimensional, and drawings on paper that are largely 2D except where crossings etc, have to be orchestrated using 'a spot of ' the 3rd dimension. Exactly as with crossing 'hoops' in circuit schematics. Section 6 has more on this.

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1 - Definitions & Background

1.1 - **Hi-Fi equipment**: high quality audio reproduction equipment made for prolonged and repeated listening to, and scrutiny of, recorded music, usually in a domestic setting. May be stereo or even mono reproduction from high quality sources as available, generally from discs - vinyl, CD to Red Book standard, and latter-day formats, viz. SA-CD, HD-CD, DVD-A, *et al*.

1.2 - **The AC system** powering most hi-fi equipment is usually a public utility supply. There is generally negligible monitoring as to use, and so the supply is open to abuse, often by innocent users of poorly designed electronic equipment. Despite EMI reduction initiatives (such as joint-national EMC regulations and maker/importer certification requirements), a vast amount of equipment both in use and being manufactured, pollutes or degrades the AC mains supply in diverse ways. In some cases each apparatus contributes 'below threshold' pollution, that is escalated to a significant problem by dense mass usage which particularly occurs in urban and suburban areas. Even where local in-house AC power generation is employed, the AC supply is usually treated as 'public', with varied types and degrees of load, able to be randomly placed on and off the line, with of course, no thought as to possible consequences to other users. At the same time the energy source has finite capacity and thus a finite source impedance. This combination of uncontrolled use, connection of loads that pollute, and a network (AC supply wiring system) of finite impedance shared by many, creates the conditions for AC pollution to be arbitrarily propagated amongst many users.

1.3 - **EMI** is broadly any unwanted EM (ElectroMagnetic: electrical, electronic) signal or activity, that occurs both naturally and as a result of imperfections in man-made equipment and systems across a wide swathe of the EM spectrum, from audio and AC power frequencies (low Hz), up to microwave realms (above 1GHz, 1 million times higher than 1kHz). Different sorts of sources, different modes of arrival, and different modulation or coding patterns are all able to cause raised noise within audio equipment by a number of inter-related mechanisms. In particular, amplitude modulated signals (which need not be intentionally created) can additionally cause, or contribute to raised levels of, distortion in analogue audio circuitry.

1.4 - **Woven cable** is made like a polypropylene rope. The techniques involved to make a cable woven from even just 4 conductor pairs (8 strands), are difficult for most people to visualise, yet versions with 32 pairs are in regular manufacture and use. With more and more pairs, a test or definition of a woven cable is that it tends towards a three-dimensional tube, as each wire must be threaded not just laid into position (as in a plait). An individual conductor, one half of a pair, rotates under and over just the opposing pole conductors. It crosses these at angles that are finite (where a parallel position with an angle of 0° would be considered an infinite angle), and approaching the ideal 90° angle in the limit,

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according to the weave's dimensional expansion. It is worth repeating that as a woven cable's *strandage* increases, it becomes more obviously a tube and defaults into that condition, as increasing numbers of conductor pairs intensify the pattern.

When woven cable is used for AC power (or for a balanced signal), a conventional earthing or grounding or drain conductor is required, and is fortunately able to be run up the centre of the weave. This meets system earth-ground (safety) bonding requirements, while having little influence on the active power conductors, as their woven structure, albeit highly adjacent, cancels induction to a high degree, and even capacitance, thus any earth (earth-ground) conductor a.k.a. 'cpc' (circuit protective conductor) currents, will be 'self-shielded'. While not tested here, such is clearly beneficial when the earth conductors acts as an RF noise drain, as in the case of equipment containing an AC line EMI filter module employing 'Y' capacitors - which unfortunately pass 50/60Hz current from the live side, to earth.

Note: Using an outer woven sheath over an inert core is technically known as *kernmantle* (from German).

As they may be superficially confused, it is important to realise that a weave is *not* 'Litz', nor a multi-twisted wire (as in 'rope-' or 'hawser lay'), nor even a plait. In **Appendix 2,** weave is compared to these, and in section **6**, to the more regular and near universal geometries of cables and lines to illustrate and clarify the essential differences.

2.0 Scope of Tests

We seek to demonstrate how woven cables, as manufactured in the USA by *Kimber Kable Inc.*, do have special properties. These are evaluated in a broadly equipped Electromagnetic Investigations (EMI) laboratory, using high quality test equipment, along with specially designed holding jigs.

The woven cables were tested in conformity, so far as is practicable, with how they are used. For example, with the same connectors, typical lengths, and initial tests were planned feeding a typical Hi-Fi equipment's power supply.

2.1 - Products Evaluated

The tested products were Russ Andrews *Classic PowerKord™*, *Reference PowerKord™*, and *Signature PowerKord™*,. These are present-day versions of the longest used (since 1980s) and most widely sold, woven, AC cable sets. They comprise respectively 8, 16 and 32 woven conductors, in pairs, with a single central earth (earth-ground) wire or cpc, and with an IEC 'Euro' plug at one end (usually 6/10A IEC 320, also known as C13). A national/regional plug is attached at the other end, in this case the British standard type, commonly known as 'rectangular pin' or '13 Amp', to BS1363. The plugs at each end are the highest quality models available in their type.

The three woven cables were compared with two standard 'IEC' cables [2.2/1]. These comprised 3183Y flex cable [2.2/2], with ends terminated with the same types of connectors as the above PowerKords™. One cable was mass-produced, with connectors moulded-on, and with a cable length - defined as the length between the plugs - slightly under 1m (as the maker's cable 'length' specification included the plugs); the other was assembled in the lab, using quality, re-wireable connectors as used on the PowerKords™, and to the exact same length as the PowerKords™.

Two or three samples of all five of the above cables, were each tested in sets of 1m length.

The three models of PowerKord™ are available in 2m & 3m lengths also. For these lengths, all five types of cables were measured as single samples.

[2.1/1] 3183Y is a designation for a regular 3 core (3 conductor) flex (cord), in this case with overall twisted conductors of 0.75mm^2 c.s.a, comprised typically of 24 strands of 0.2mm diameter of annealed copper, untinned. This cable is the sort most often fitted to universal mains flexes with a 'national/regional' plug at one end, and an IEC plug (commonly known as a 'kettle plug' or 'Europlug' in UK), at the equipment end.

[2.1/2] Strictly, the latter connector is actually a type C13 'female line plug' or a cable or in-line socket, to IEC 320 or even more unmemorably, IEC-60320.

2.2 - Test Design & Staging development

A matrix of tests was devised to cover the many potential aspects of the woven cables' effect/s and transmission properties. It may be salutary to see how readily test permutations in excess of 1 million, are reached. In the following list of tests and conditions, a 'least number' of variations for each stage and menu - while aiming to cover all the possibilities evenly - is given at the end of each line in brackets (n). Each test facet is factored with the next on the basis that free combination is valid in most instances, although not all.

EMI test source - conducted (direct injection) or received (radiated at). (2)

x

Discrete Frequencies or Frequency ranges - LF, through low RF, to high RF. 1Hz to 1GHz is 9 decades. At 1 frequency per decade, at least 10 discrete test frequencies - if not hundreds. If swept, 9 decades can be covered in 9 or 10 sweeps but wider & narrower sweeps also useful. At least (15).

x

Signal Types - fixed and swept sinewaves; sinewave bursts; sinewaves modulated with AM, SSB, FM, digital FSK, etc; Impulses, pulses with various p.r.f.s, and stochastic, ie. noise, music. Readily (10).

x

Connection Paths & Reception *Modes* -
Common Mode (CM), Differential Mode (DM), also CM to DM. Subsidiary kinds of DM & CM conditions or testable points are commonly encountered, and ad-hoc designated (eg.) CM2, DM3. Readily (3).

x

Interference Destinations - locations evaluated. Signal path test points. Readily (5).

x

Instrumentation and Data-Capture domains -

* **Data logs of voltages & currents** as rms, peak holds. Per test-point. Readily (4).
* **Post processing of data** logs for subtle data content, eg. further averaging, convolution. Readily (2).
* **Analogue storage oscilloscopy**, with various display options, eg. 4 storage settings, 3 timebase settings, 3 trigger settings. Readily (10).
* **Wave & Spectral analysis** - manual, swept real -time and FFT, with averaging options. At least (3).
* **Network/Frequency Response** analysis, with amplitude (dB), phase and dual, polar displays. With all three, and three settings for each. Readily (9).
* **Distortion Analysis** - *if linearity is a consideration*# - Total harmonic %THD+N, and for IMD, SMPTE, CCIF and other intermodulation test schemes, against frequency. More, if harmonic crest factor is examined, or with post processing, plotting 3D Volterra space, or if Bateman's dynamic sub-ppm harmonic analyser, etc, are included. Readily (4).

this paper does not discuss conductor linearit, but this is incidentally germane, since the woven cables under test, which comprise the majority of those in use, are of demonstrably greatly purer copper than 3183Y, when in actual use. While cable non-linearity appears as a separate matter from the perspective of demonstrating beneficial effects of woven cable, AM RF is detected by non-linear, impure copper conductors, albeit at a low-level, and it does not appear to be an ideal practice for any audio-related AC cabling, let alone an RF line filter, to contain any appreciable harmonic generation capacities. As a point of comparison, 'smoother' metals are employed in conventional L & C filter components. For inductors, the conductor as winding wire has generally better annealing, has suffered less flexure strain, and there is less potential for surface oxidation, than for AC cable conductors. While for capacitors, the conductive surfaces are not drawn and strained like wires often are, as metallised capacitor plates are vapour deposited, and foils are rolled. The extra pure copper in the woven cable can thus be see, not as over-specification, but as simply regaining a condition generally enjoyed by lumped L&C components.

The number of test permutations soon expands rapidly. When the product is then multiplied by the minimum of 2 tested cables - 3183Y and woven (let alone the 9 permutations actually tested

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for this paper), the above list comprises well over 1 million, and it readily expands to over 10 or even 100 million permutations, by thinking of "anything else missed" (the above list is not claimed to be comprehensive) and/or by expanding *just a few* of the possibilities listed above. This is along with *also* the monitoring of ancillary matters at the time, eg. AC line voltage and wideband spectrum scanning, during the central measurements.

In order to obtain results in a reasonable time frame, without trudging through every permutation, the 'test master' has to orchestrate the 'vectoring' of tests, beginning with an initial focusing on any tests felt likely to be fruitful, and then prioritising other tests accordingly. At this point, instinct plays a valuable part in an otherwise objective process.

Further, having drawn up an holistic investigation campaign, it is important to understand that none, or only one of the tests might be fruitful, or conversely that just one type of test might prove successful in adequately demonstrating beneficial differences between woven and plain cables.

Before any tests could take place, and in anticipation of testing at medium and higher radio frequencies where it is known by experienced RF practitioners that small positioning or tensioning differences might affect some readings greatly, a jigging system had to be devised so that the physically less-well defined positioning of the woven cables' weave (particularly when bent) could be repeatably compared with the less deformable standard 3183Y AC cable. Still, at and above mid-to-high VHF (say 100MHz), even the 3138Y cable's dress and deformability became significant.

The jigging systems needs to be seen in perspective. Shortly we will see that both woven and 3183Y type cables have bumpy responses. When plotted with fine detail, the RF responses of real components are not the smooth ideal sort seen in many textbooks but are ragged, with many minor resonances or reflection-caused peaks and dips. Whenever *any* flexible cables (cords) are bent and manipulated, internal parts are squashed, squeezed and bent, and so the underlying mechanical causes of some of these resonant and reflection-borne points will shift about, and some of the dips and peaks may further vary in height. This may have no great effect on the overall response - it is just detail, but it creates extra uncertainties when a late-discovered need for repeat test or differently scaled plots has involved replacing a cable at a later time. This physical instability - shared by most AC flexible cables at RF - also means that data cannot be overly analysed. It is possibly fuzzy at the edges, since in the real world the cable may just have been moved after domestic cleaning. Still, adding further uncertainty where such is able to be readily minimised, is best avoided.

In any test system it is normal for the stimulus and output/reception cabling to be mutually adjacent. On the other hand, it is normal for cables (working as signal A-to-B transmission lines) to 'go somewhere'. Topologically, the simplest way to have 'both ends at one end', is to bend the cable into a 'U' shape. This, rather than coiling, or folding-up the 'excess length' of the cable under test, was felt to stand more chance of leading to a repeatable disposition by not having the conductors both part taut and part loose along much of the cable's length - wherever there is curvature.

A suitable jig was made from a baseplate of plywood sheet, with a U-shaped plywood block, termed 'U-form', located on top and able to be moved and tightened down wherever set (Plate 1). With the connection points fixed, the jig enabled each tested cable to be tautly set (almost stretched) against the 'U-form' regardless of its length. Brass and nylon fasteners furnish a non-magnetic construction. In use the jig was placed either in free air, or was laid on a wooden bench, with no metal immediately adjacent.

At an early stage it was decided that tests should, if possible, be free from AC mains voltage. This was to avoid potentially major damage to delicate and costly test equipment arising from injecting into, and particularly receiving, RF signals from live AC circuits; let alone to avoid unnecessary risk of personal hazard. The dangers of LISNs (Line Impedance Stabilisation Network, used for filtering and standardising the impedance for AC power testing) are rarely cited - see [1] by British EMC practitioners. Like- wise for lab-grade EMI filters for AC power - see Appendix 3, [2]. It would be a major challenge alone to create the necessary large signal attenuation and protection/filtration network for wideband RF equipment, with high certainty that it would not compromise or mask legitimate tiny signals or subtle results; which may go to explain why such protection is not fitted on the high-end equipment concerned, in the first place.

An initially solid basis for 'test appropriateness', without AC being simultaneously present, is that a typical AC supply is modelled with a linear network. The CENELEC generic model for a public AC supply is simply a resistor and inductor in series. There will be non-linearities but, by and large, a linear network suffices as a general model – at least while the fairly linear loads continue to dominate. There are limits as to degrees of non-linearity on the AC network, in part because of the base load of such linear loads (heaters, remaining incandescent lamps, steady running motors). But also because tightly dimensioned transformers in AC power systems cannot stand high levels of even harmonic content, such that the sum of *a*symmetric distortion, as even harmonics, has to be kept down. Ideally to well below 1%.

The upshot, in any event, is that the connection (or absence) of AC mains needn't affect the test conditions in a way that will greatly alter or obscure the filtrative or transmissive qualities in the woven cable that the investigation is initially focused on. For example, a generic AC mains source impedance, whether modelled or actual, creates an 'overlay', that can be subtracted from a measured response. At 800µH, the generic model's inductive impedance is, in any event, one that presents a high impedance (relative to 50Ω) above 100kHz, let alone at the far higher swept frequencies employed for tests. In the meantime, actual conducted EMI and invasive RF signals are unlikely to have 'tidy' source impedances, let alone frequency independent resistive loadings, of 50.0Ω or 75 ohms.

Preliminary tests focused on EM susceptibility, which demonstrated that the difficulties would be in making '*Apples for Apples*' comparisons between the two types of cable, particularly at frequencies above 300MHz, where even very small variations in the positioning and lay of the different tested cables, in relation to a near-field radiation source, would alter results, making repeatability poor.

The author then took the step of reasoning that whereas the woven cable is claimed to be its own filter for any EMI or RF it has received, it is likely needing to be far more effective at dealing with conducted EMI or RF induced into all the preceding wiring in the locale. The preceeding wiring is longer, more diverse, and has little, if any, twisting, shielding or other anti-reception remedies. In addition, it has many EMI & RF generators connected directly to it. On this basis it seemed valid to inject RF directly. In effect, 'conduction fits all'. The matter of sweeping and tracking, with spectral analysis, was resolved into taking the relatively radical step of treating the woven mains cable as a discrete RF component, then using an RF network analyser.

This requires inter-laboratory co-operation. Jigs were built to convert the IEC and 13Amp plug ends to the respective receptacles, and thence to BNC terminations#, with a short and rigid connection. The woven mains cable was mounted in the wooden 'U' jig, and was then attached to a workhorse RF network analyser at one of the lab's RF test stations (Plate 1).

In larger organisations, the author suggests, 'The RF group' would not like AC cables/cords to be made connectable to their equipment!

From an audio engineer's perspective, an RF network analyser is in essence like a subset of an *Audio Precision* test set 'for RF '; capable plotting just gain and phase against frequency, more commonly known to audio engineers as plain 'frequency response' (strictly amplitude *vs.* frequency), and phase response. Although phase response is not considered further in this paper, it can be useful to know that this would be input *vs.* output, voltage-to-voltage phase shifts through or across a device, *not* the current/voltage phase relations of reactive power loads on a source, eg. loudspeakers or AC power circuits.

A special feature of an RF network analyser is that the drive level is monitored at a wideband resistive splitter (so called 'power splitter'), and is automatically *levelled*, so that despite any impedance variations in the driven device (such as sudden increases in the current demanded at a spot frequency), the driving voltage is kept very nearly constant across a sweep of test frequencies, with variations only beginning to rise above the negligible, say 0.5dB, towards the range's high frequency end. The necessity for levelling becomes apparent when it is recalled that 'for matching purposes' (more directly put as: 'To prevent reflections messing up the readings'.), the source impedance of the generator will be nominally 50Ω. So compared to an AC supply or a power amplifier, the effective output level is far more liable to dropping off, by more than 0.5dB say, with quite modest loading. Also, at high RF frequencies the variations can be complex, and dense, so are not so easily subtractable.

With the woven cable connected it was quickly shown that it exhibited both more and deeper rejection nulls than the regular 3183Y cable, and that these nulls were in the region of tens of dB, when initially sweeping from around 5MHz up to around 1GHz. With the HP 8754A network analyser used, the reference cable response (with in/out connected via the power splitter via short coaxial cables), had imperfections which were far smaller, although they grew above 300MHz. In order to show the absolute values of the responses, an accessory component was required: a Storage Normaliser - to perform data subtraction, hence normalisation. But this and the dedicated cable *and* a necessary adaptor card weren't simultaneously available. Fortunately, a later and more powerful HP analyser set (HP4396A) was obtained, with automatic reference subtraction, and also data output, for post-processing.

2.3 - Description of the adopted Test Set-up

Out of the many possible test permutations, the one described above was adopted, appearing sufficient to descriminate easily between woven and non-woven cables. After dismissing many other tests and their permutations, this chosen test alone soon developed plenty of permutations of its own. To develop the initial investigation as discussed above, we employed an HP 4396A *dual*-mode spectrum/network analyser, operated here as a Network Analyser.

In this mode, it covers 100kHz to 1.8GHz. Our published results are limited at the top end to around 810~820MHz. As this includes virtually the entire broadcast bands, the majority of communication transmissions, and particularly, many local transmission bands - see Appendix 1. The frequency range is limited at the top end because although one can measure higher, (and this was done informally), the connective system employed, with BNCs and RG58 flexible coaxial cable, requires enhancement above 800MHz to control reflections, ideally using special semi-rigid cables, also terminated in 'N' plugs. This then removes the adaptor reflections, which become noticeable from above around 800MHz. Also, the Power Splitter employed is rated to a maximum of 1GHz.

Equally, the dress of the tested cables becomes more sensitive, such that it becomes advisable to cast or entomb the cables under test, eg. in a resin which must also possess a low dielectric constant to well above 1 GHz. Without this, even slight movement, handling or a tension change caused by relaxation durations (since the last movement) or the room temperature, would likely upset the baseline required for a fair and repeatable comparison.

Such arrangements are delicate and cumbersome, explaining why they are not employed until they become essential, by frequency extension. Without these changes, the sum of worst case uncertainties (that may be pessimistic, but which also need to be kept track of) might grow to ±6dB or more.

Fig.1 shows the setup adopted. The tracking generator source was arranged to inject a levelled, swept-frequency test signal, simulating conducted RF noise, into the cable-under-test's source end. The HP 4396A's (tracking) input then receives the signal emerging from the output end of the cable under test, and the data is displayed as a Level *vs.* Frequency response.

To verify the system, including the power splitter, external cabling and adaptors, the cable under test was able to be readily substituted (without changing or moving anything else), by a nominally 1m 'U' -formed section of coaxial cable, of a high grade type designed for use as a wideband transmission line up to at least 1GHz, ie. RG58c. The remainder of the cabling comprises this same, standard instrumentation type of coax, all fitted with 50 ohm BNC plugs. *DeoxIT*® contact cleaner was employed to clean all contacts at the outset. As the power splitter and network analyser are expected to operate to higher frequencies they have N-connections. A series of N-to-BNC adaptors were therefore required. While of high quality, and individually contributing only small reflections, the effects add up.

The swept RF test level was set at 0dBm, the maximum. The actual test level on the tested cables is lower by some 6dB, due to the power splitter's insertion loss, this due to 2-way signal division with the correct 50Ω loading of each port. This loss is frequency-invariant, at least to 1GHz, the limit being down to gradual error build-up, due to the power splitter's own reflections ie. non-ideal VSWR, becoming greater with frequency.

As we are not presently concerned with any differences that might be caused by non-linearities (a quite separate matter to weave, but to be borne in mind nonetheless), the amplitude of the test signal matters mainly in regard to the S/N ratio (SNR) of the measurement. The cables under test are not shielded. So, they can be expected to pick up a small amount of ambient RF or EMI.

The amount is first limited by (i) avoiding nearby emissions so far as possible, eg. unused equipment and mobile phones are switched off. (ii) the cable U-form arrangement was also chosen to cancel reception, at least at MF & HF. Cancellation occurs in the same way that a 'U-formed' 'non-inductive' resistance element is self-shielding, but less effectively with cables or cords, because of the spacing required to avoid strain from too much bending. Then (iii), for the weave, its own RF rejection; and for the 3183Y cable, the proximity of its conductor pair (despite the third one 'in the way'). In the latter instance the loop area is very small, while in the former, highly cancelled, so the cables make poor aerials until high VHF or UHF at least. Beyond the cables under test, the coaxial cabling and associated RF 'plumbing' used, would not be expected to 'let in' any appreciable RF, say above –90dBm, for the ambient levels observed.

The RF level was then measured in the cables under test, with the driven end remaining terminated with 50 ohms (with the power splitter disconnected), and the HP 4396A operating in Spectrum Analysis mode, with the input connections unchanged. This showed that the ambient RF in typical 3183Y and in typical woven cable, was at least 20dB below the greatest levels of RF rejection in the graphs that we will shortly see in Section 3.1 A possibly germane detail is that the earth wire (cpc) was left unterminated at each end for the present tests. As this wire interacts with the two types of cables (woven and 3183Y) in diametrically opposite ways, and with there being various different ways to connect it 'fairly', depending on viewpoint, it adds substantial extra test variables that would require a separate investigation - a subject for another paper.

The effects of any RF are further reduced by averaging the plots. On the basis that the RF has a discontinuous amplitude or spectrae (ie. not just a fixed tone at a fixed frequency), then averaging reduces the influence of any intermittent or no-coherent pick-up, random noise included.

To map the RF environment, an omnidirectional (discone type) VHF & UHF scanning aerial was connected to the analyser's input operating in Spectrum Analysis mode. Over 4000 received signals were logged, and all were many (tens of) dB below the levels shown in any of the results about to be displayed. This furnished added confidence that there was no significant RF in the tested cables' environs, having sufficient field strength to affect the results, at the lowest levels recorded in the graphs to follow.

A shielded space was not used, expressly as AC power cables for hi-fi cables are not normally ever employed in such conditions, and regular metal shielded spaces can further cause as many problems as they solve, by their 'brute force-ness' causing hard-to-eliminate reflections.

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3. Results

When analysing the information in the following graphs, readers will need to take into account a possible (worst case) variance of up ±3dB in RF levels (possibly slightly more in the worst case) per plot, being the worst case agglomeration of various factors. Therefore, general patterns count more than specific or isolated events.

3.1 Individual Results - graph descriptions

All readings are from left to right.

Fig. 2 (G1) shows the response of the network analyser, and the fixtures alone, over the common span of 100kHz to 820MHz, with a linear scale, and a nominally ideal, wideband transmission-line cabling in place of any of the cables being tested.

In other words, the 1m cable under test (CUT), is replaced by a 1m long, RG58 50Ω coaxial cable, crimp terminated in 50Ω BNC connectors. Two different cables were tested (Z1, Z2), showing the range of variation *by just changing this section* - and with nominally identically-specified cabling. The average of these has also been plotted (Z1, Z2). The peaks and dips are the result of resonances at lower frequencies, while at high UHF, towards the right hand side of the graph, they are the result of reflections (hence imperfect VSWR) caused by slight imperfections in the connectors, adaptors, or the conductor dress. For example, consider the ramifications if merely one short section of the coax has been slightly squashed or is 'off centre'. Overall, the averaged variation from the expected flat response amounts to no more than ± 1.5dB across the near 1GHz span. With the section 2.4 caveat in mind, it can be reported that informal extended testing shows that variations up to 1.8GHz did not exceed ±2.2dB.

Fig. 3 (G2) shows the response of a typical 3183Y cable (flex, cord), obtained from the local hardware shop, and fitted with plugs, to the exact same length as the 1m woven cables (G4). Note the 6-fold 'wider' dB level scale. Three nominally identical samples were made-up (D1-3), and their individual plots can be seen alongside the average result. The curves are all very similar. Attenuation is greater, increasing monotonically at about 0.25dB per 10MHz on a smoothed average, reaching about –20dB by 820MHz. Overall, there is a mild low-pass filtering effect, known to RF coax installers as an attenuation or loss, of so many dB per 100m @ X MHz, due to the PVC insulation. And then undulations, albeit larger, are similar in pattern to those of G1, with resonances and VSWR imperfections and reflections, being the main cause.

Fig. 4 (G3) shows the response of another, typical type of 3183Y cable, having moulded-on connectors of the required type, at each end. The two samples were equally slightly under 1m, when measured in the same way as the other tested cables. The Far Eastern maker evidently felt that the plug bodies in their entirety could be justified as part of the advertised 1m length, as recorded earlier. This is one aspect that was able to be controlled in the made-up cables (in G2). There are some small differences in the depths of the peaks and dips around 400 to 650MHz, possibly caused by slight variations in the thickness of the PVC insulation, or the conductors' lay. The responses are both self-consistent, and also neatly similar to the lab-built cables (G2).

Fig. 5 (G4) is a cumulative graph set which repeats responses seen in the previous three figures, along with averages for the three types of woven cables, all lengths being 1m. The uppermost plot (consistently near 0dB), is that of the reference 1m BNC-BNC cabling in Fig.2 (G1) again, but re-scaled. It provides a reality perspective, reminding us that even high-grade coaxial cable and top quality RF 'plumbing' all adds an inevitable small, undulating zero (baseline) error of its own.

Below, the respective two *averages* (D1-3, E1-2) of the two types of 3183Y 'Std' (standard) cables can be discerned, with their scale unchanged. There then follows the three woven cables' *average* results, for three samples of each of the models. Averaged results are naturally shown to avoid excess clutter which would hinder discernment of the trends.

The plots show very clearly that all the woven *PowerKord*™ cables reject RF - in comparison to standard mains cables - by a substantial extra degree, typically ranging 10 to 20dB (a reduction of between three and ten times in terms of voltage or current, or about 1/10th to 1/100th in terms of power), and in instances by an even greater amount, this continuing across a broad frequency range of some 30 to 820MHz or 10½ decades. While the maximum rejection varies with frequency, there is a smaller (and still fully useful) reduction *at most high radio frequencies*.

The measurements *also* demonstrate that, very much as claimed by the maker, the progressively 'higher-weave' *PowerKord*™ cables show progressively deeper, and more frequent nulls or areas of rejection. 'Higher weave' involves a denser weave with more conductors: *Classic* PowerKord™ comprises 4 woven pairs, *Reference* PowerKord™ has 8, and *Signature* PowerKord™ 16. In contrast, quite apart from geometric differences (see Appendix 2), 3183Y cable (as well as RG 58 coax) comprise just 1 pair (or 'pole pair', to be emphatic).

An added feature is that for the most part, the woven cables do not create counteracting peaks that lie above the response of the 3183Y cable. If ordinary, 'brute-force' (LC) EMI line filters were compared here, greater attenuation may be seen in lab conditions, with 'neat' wideband resistive terminations. But in real conditions, where AC line impedances have random individual local qualities, this comes at the risk of a resonance being undamped, and creating peaks and spikes which might make EMI levels at *some* frequencies *many* dB higher than they were before, or are, at necessarily singular standard test conditions. This is described by many hi-fi listeners who have tried to use lumped component filters, in terms of "The cure being worse than the disease". At the same time, in the present graph of the 3 woven cables, none of the dips are needle sharp, and most are broad sided *(the graphs' very wide frequency span should be borne in mind when judging this)*, &/or are part of broader dips. This amply demonstrates that the resonances are multiple or 'spread spectrum' and are generally well damped.

Note: In the following three graphs, for multiple lengths, a zero offset of –6dB is clearly identifiable, probably caused by software keying error. ¶ *However, this only affects the following 1m to 3m comparisons (G8-G9),and may be viewed as a useful separation of the fresh data, from that already viewed.*

Fig.6 (G5) moves to showing *one* type of *PowerKord™*, the *Reference*, in 3 of the commonly used lengths, viz. 1m, 2m, 3m. Clearly, the greater lengths tend to have greater rejection, although there are variations. Note that the scale has had to be changed and expanded to accommodate the deep null, at some 250MHz, and of –42dB ¶, for the 2m length. At this frequency, RF is being reduced by some 40dB or 100 times in voltage or current, equal to 10,000 times in power, below the level in a 3183Y cable.

Fig.7 (G6) then shows the variations in the *Signature*, the *PowerKord™* model with the 'highest weave', in 1, 2 and 3m lengths. In comparison to the preceding figure - and the next, the general picture is clear: there are more nulls (in a given frequency range) for all lengths, and attenuation is generally greater, typically by 6 to 10dB.

Fig.8 (G7) completes the series, with the 'lowest weave' *Classic PowerKord™* in the 3 commonly used lengths. Of course, the generally uppermost (1m) curve for this and the preceding has already been seen to be 'superiorly attenuative' in comparison with the 3183Y 'Std' cable. Clearly indicated here is that the greater lengths offer more attenuation, albeit with some specific exceptions. For example, a 2m *Classic PowerKord™* is particularly effective (even over the higher weaves) if a user has problems around 740 and/or 770MHz. To maintain a sense of perspective, the same specificity can be true of LC networks (within RFI/EMI filters) when 1, 2 and 3 seriesed-section versions are compared.

Readers used to ruler flat curves at audio frequencies need to be aware that across 10+ decades (In perspective: audio is very wide itself, covering 3 decades of frequency, and considering that all human colour vision is within one decade) including UHF and SHF, even specialised and highly-honed RF components exhibit imperfectly level responses. The potential for wild dips and peaks and other performance variations, increases in all parts with increasing frequency, as their dimensions approach a wavelength at the high frequency concerned. Many parts will loose operability with degradation of major characteristics which continues once the critical large fraction of a wavelength is reached. Very many electronic components are not specified or graphed above 100MHz, for this reason.

Fig.9 (G8) moves to the 3183Y ('Std') cable, now showing the type with moulded plug ends in 1, 2 & 3m. The greater lengths retain the same down slope, while the reflections or resonances become smaller and more frequent. It not recommended to extrapolate this result to the fixed AC wiring, as the cable topology is quite different, in UK, at least, with side-by-side conductors and earth (the cpc) separating the neutral. Assessing such, in realistic usage conditions - including possibly 30 years of oxidation, is a separate project.

Fig.10 (G9) then shows all the 2m (cable length) data at once, all starting at –6dB. This loss is clearly the effect of the power splitter, which the user can subtract or not, and the keying error for the preceding graphs is therefore simply a technical inconsistency. The present graph shows at a glance the generally successively lower RF across the band, in the *Classic* over 3183Y, and then in the two high grades of *PowerKords™* over the *Classic*. Overall, woven cable is shown to continue to attenuate more RF than 3183Y when the length of both is doubled, and also, the higher weaves are shown to attenuate more, albeit with some specific

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exceptions, clearly visible in the graph. Such as the *Classic* being best in the 700-800MHz area and *Reference* around 250MHz. Local signal strengths at these frequencies might determine which 'sounded best' or had the most effect - see Section 4 & Appendix 1.

Fig. 11 (G10) finishes off the comparison matrix, with the 3m data for all. Here, the 3183Y does in one place alone, far better than the woven cable, this in the 740 to 820MHz area. This shows that 'something like 3183Y' before and even after the Woven cable ('after' being *inside* the equipment), even a few inches, might do 'one useful thing - if nothing else'. The informal testing above and to 1.8GHz (just over 1 octave) shows this situation soon reverses, with the Woven cables then showing the (far) deeper attenuation. Although the data tolerance is wider here, the difference was also large enough to be substantive.

In this present graph, the salient information is that with 3m lengths, the higher weaves' extra benefits are clear up to 500MHz, when the highest weave alone dominates, then above 700MHz, all the woven cables regroup to a similar attenuation (at some –20dB), and loose their deep nulls. However, as stated in the previous graph text, the “tables are turned” in the 1 1/3 octaves above 820MHz, rather akin to an 'up-mapping of the 200 to 400MHz area results, for example.

Overall, all these graphs (G1-G10) demonstrate that with standard jigging and impedance conditions (50Ω R_s and 50Ω load), (i) the woven cables reject more RF and over a wider band range, than 3183Y. (ii) The higher the weave, the more the RF rejected - with niche exceptions at one or two specific and very high radio frequencies. (iii) 3183Y makes a far poorer quality cable for transmitting RF than RG58c coax; but is vastly better for this purpose than woven cables. (iv) Longer cables (woven or not) generally reject or filter more RF. But this may only be useful in so far as they are self-immune to reception, ie. likely to only be useful if woven.

Immunity of flexible AC cables to broadband EM/RF reception forms a major subject for research, necessarily for another paper.

4.0 - Demonstrating RF energy as a cause of Distortion in Audio Signal paths

Although the results above show very clearly that RF low-pass filtration and damping/absorption is taking place over an unusually wide bandwidth (in comparison to many RF devices), some observers might fairly question how any of this RF is audible, or how it affects audio gear, in order to become audible.

4.1 - Introduction

It has been long known, and is widely established, that Radio Frequency (RF) energy (more broadly described as electromagnetic (EM) energy) is able to interfere with the operation of signal processing and amplification equipment, and hence to alter, disrupt or distort, or otherwise corrupt signals passing through such paths. This is commonly known by its outcome, either as EM *Interference* (EMI) or RFI (Radio Frequency *Interference*).

As an anarchic act, the effects of EMI or RFI can be highly variable. At the same time it is worthwhile considering that *while* effects and events caused by RF noises/EMI can at times be difficult be pin down *if* the RF injected into equipment by AC power (let alone by signal in, out and auxiliary cables) were some trivial or 'non'-issue, then the rationale for a large part of the vast worldwide Electro-Magnetic Compatibility (EMC test) industry - of laboratories, highly specialised test gear, and detailed test standards, would also be called into question. There (perhaps ironically) remains plenty of EMI noise around and in 'the air', in domestic environments, despite the fact that Electromagnetic Compatibility (EMC) is a requirement in law in many countries, backed-up by an infrastructure of highly equipped certification laboratories to evaluate products prior to product launch; and that meeting EMC requirements implies a low level of EM emissions

Some readers will be aware that well-resourced broadcast and recording studio operations, as well as many serious recorded music listeners, employ specific AC power distribution and grounding arrangements, to prevent or avert the degrading effects of mains supply interference on sound quality.

It may be helpful to point out that EMC standards aren't directly applicable here. While interesting, generally informative, and the result of a great deal of very good engineering work, they are boilerplate and overly-specific and rigid standards that furthermore consider relatively gross effects as compared with the significantly more stringent ideal EM purity requirements of high quality audio reproduction equipment.

4.2 - Test Method for RF-generated distortion

The tested hi-fi equipment was subjected to RF by direct injection into the IEC (AC) inlet, in differential mode (L,N). This was through a BNC socket mounted onto the rear of an IEC female line plug. Although the AC power switch was closed to allow the injected RF into the equipment, it is worth noting that for some measurements, when checks were made, the position of the switch didn't affect results, due to the RF bypassing effect of the nominally 10nF arcing suppression capacitors, connected across the switch contacts.

The equipment was powered, without employing AC mains (at least at the hi-fi equipment's intake), through a diode-OR'd connection from a DC lab supply (Thurlby PL 320), which having linear regulation, 100% free of switching, furnishes DC with very low noise, particularly above 1kHz.

In this context, diode OR'ing, means that the necessary DC supply voltage is injected by diodes (akin to those forming the existing bridge rectifier array/s), with their 'output sides' (cathodes) each arranged in parallel with the '+' and '–' outputs of the usual AC rectifier bridge. As the source is DC, the diodes need do no rectifying. This arrangement prevents the external supply from 'seeing' or energising the transformer secondary, and without need to perform *any* alteration or disconnection of any parts, wiring, etc, and thus with only negligible disturbance to the usual 'signal path', that RF noise on the incoming AC, would ordinarily meet.

A common-mode inductance and resistive damper, in the form of a ferrite ring-core, was added in series with the supply feed lines, as they reached the amplifier innards (but before the OR-ing diodes), to help offer a rejection of any RF present in VHF and UHF regions, in the 20" long or so supply wires, which were twisted flexes, with only the final 2"/50mm or so split out, at each end.

The rationale for powering the unit externally is as follows (*continuing from the discussion in section 2.3*):

To recap and expand, audio & RF Spectrum and Network Analysers and Sweep Generators are costly instruments, having delicate input and output ports. Some are quite easy enough to destroy, with one HP unit being damageable by any DC voltage (even *milli*volts) *or* an unspecified one-shot LF pulse appearing at its input (via a supposed series protection capacitor). Another problem is that with even not particularly old instruments, the highly specialised and vulnerable front-end parts are no longer available. A prize instrument could instantly be reduced to scrap. A need therefore existed, to avert absolutely risk to the instruments, let alone the researchers/operators, by connecting them to the AC supply even through *any* sort of simple isolation or protective network. In addition, any robust and failsafe protective network creates a test condition artificiality, and for example, will likely not pass RF signals absolutely uniformly across the wide RF range evidently involved, up to 1GHz.

Next, powering from the public AC supply introduces multiple extra variables. A LISN or a notionally 'powerful' RF line filter and galvanic isolation can overcome some of these, but then other complexities *and also* considerable variations from every-day use, are then introduced. The diode-OR'd fed DC supply closely approaches the usual powering conditions, with a low level of uncontrolled variables.

It always needs to be borne in mind that the AC power is only active, ie. delivering power, to the DC supplies in nearly all audio equipment, for two brief periods *within* each AC cycle (latter's full duration being nominally 20.0 ms and 16.7 ms, for 50 & 60Hz AC respectively). The onset of these brief periods of activity in successive AC half cycles, is sometimes described as the 'conduction angle', based on a cycle being divided into 360 degrees. If the angle or point of onset of conduction is 'late' (a higher number), the available conduction period is shortened, and available power is usually reduced. The conduction period is more 'accessibly' described in simple % terms. Roughly speaking, for each cycle or half cycle or any integer half-cycle period, the conduction period is between 5% and 10% of the total.

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This percentage depends on where the line is drawn as to useful power delivery, and anyway varies cycle-by-cycle, according to the instantaneous and also immediately preceding, voltage and current conditions. For example, the angle will change when a high current draw is reducing, as a loud musical section is fading down, and the capacitors have just started to finish recharging. Or, the angle will change if the AC supply voltage rises abruptly by 5 volts rms, because someone nearby, has just switched off a heavy load.

The *rest* of the time, when rectifier conduction is not occurring, RF passes readily through the substantial capacitances of the typically two or more parallel rectifier diodes in every bridge or bi-wave rectificatory arrangement. Just as it unexpectedly 'passed through' a power switch that was set 'Off'. Meanwhile, the AC supply continues to still present itself, so far as is the source impedance of any of the RF noise it is conveying. The keynote here, is that there is nothing unusual about RF noise continuing to be injected, in those substantial periods (90 to 95% of each AC cycle) while useful, power-delivering 50/60Hz AC current *flow* is largely or completely absent. One difference that can be taken into account, is simply that were intermodulation products tested for, by spectral analysis, then AC-frequency related products would be absent, or at least reduced in magnitude.

The DC voltage applied from the Thurlby PL 320 supply (successor design now made by TTi Ltd) was not quite as high as the nominal power supply rail for 'the equipment'. This was because the power stages generally employ somewhat higher voltages than those available from widely used, low current, low noise class of lab bench top supply, in this case limited to 32v DC. Still, this voltage was established by the author as sufficent to operate all the circuits normally. It is helpful to know that the DC rail voltage that an audio power stage (of all the common sorts of transistor amplifier) operates at, is not over critical to performance. Only power delivery is affected, in voltage-swing terms. In fact, wearing the hats of an experienced power amplifier designer and of a reviewing lab tester, it is found that most analogue power amplifiers will operate at even only half their usual voltage, when relays and fans are not needing to be involved. Which is the case in this instance. This is possible because most audio power amplifiers employ *un*regulated DC supply rails, the voltage of which varies with the AC supply's own peak voltage fluctuations, as well when any real power is delivered, with voltage drop due to transformer source resistance and smoothing capacitor voltage sag.

The presence of RF was then nominally checked for within the tested audio equipment. A Tek 7834 oscilloscope mainframe was used, along with 7B92 timebase, calibrated down to 500pS, with 7A24 350MHz and 7A26 200MHz Y-plug-ins as necessary, to permit visual RF wave monitoring to above 400MHz. For the 7A24 with its vulnerable 50 ohm input, any over-dissipation risk was avoided by monitoring through a sensing coil.

The scope was used to check that the RF wave corresponding to the injected signal was present on all three terminals of (any) one of the bipolar output transistors, of the equipment. The fact that the signal is "about the same all over" demonstrates a quality of RF that was most aptly described in a letter in *Hi-Fi News* magazine by Chris Bryant (British Hi-Fi technical writer) in one nail-head-hitting adjectival word: *Systemic*. The positive supply rail was then employed as the monitoring point for the substantial RF signal presence, that the AC port injection furnished. This was done on the basis of it being the point least likely to be disturbed by connection to a 'scope. A problem with monitoring RF over 100MHz is a lack of differential connections. Fortunately, with the AP's galvanically isolated connections, and the particular test conditions, any 50Hz loops caused were not an issue. Of course, it was noticed that the size of the RF wave varied as the frequency was swept upwards, with varying spans of frequency showing 20dB or greater variations in signal level. "Of course" is the sentiment, since Hi-Fi equipment is just as much a random, 'wholly undesigned' conduit for RF, as the AC supply.

The BDR Audio Precision *System One* 'Gen 1' generator output was then connected to the tested audio equipment's CD input. The volume control was set - and locked with gaffer tape - at maximum, and the generator's level adjusted, to be a few dB below clip, as defined stably by the regulated DC supply voltage used. The maximum setting meant that the knob setting would not be lost or uncertain[§].

[§] Footnote: In 25 years of test work, and studying component weaknesses, arbitrary potentiometer settings 'ring alarms bells', in regard to a high risk of such making the precise test conditions un-repeatable.

The Audio Precision (AP *System One*) Gen-1 drive was unbalanced, but transformer (galvanically) - isolated. This is essential for making reliable repeatable measurements, without ground loops and associated problems [3].

The tested audio equipment's output, taken from the side (stereo channel) corresponding to the driven input, was connected to the AP's balanced and transformer (galvanically) isolated receiver input. The AP receiver's load impedance is normally 100kΩ, which presents a negligible loading for a power amplifier.

The tester then has to be aware that the this AP-S1 input is being presented with an RF, swept over a few MHz up to 1GHz. If this were to affect the instrument, there would be a risk of false readings. And while the AP-S1 is professional, top grade instrumentation specifically designed for the highest sensitivity audio measurements, and so quite RF-immune by design, the RF immunity is not defined. In fact, despite EMC regulations, the author has never seen *any* audio/LF equipment's immunity to RF published or noted, anywhere. What is known from audio switching-amplifier designers, is that the AP can be upset by quite large squarewave signals in the ultrasonic range, with harmonics possibly ranging into many MHz , and that AP's later instruments have ameliorative modifications. In order to offer confidence that the AP S1's own circuitry is not being affected by the RF injected into the audio equipment, BDR's specially designed RF input filter[*], that rejects DM and CM signals to different degrees, and with separate switches, can be introduced. For example if the three stages of DM filtering, and 1 stage of strong CM filtering do not alter the measured %THD+N, then one has reasonably shown that the AP instrument is not the cause of any change.

[*] a plug-in, in-line XLR/XLR diecast metal cased RF-grade accessory, as notified to AP's chief designer & co-founder, Bruce Hofer.

In the results shown in Fig.12, the lower **AP-S1** plot (green) shows the amplifier's output level, which relates to the rhs scale (approx +26dBu is around 14v rms). The blue plot above then shows the harmonic distortion level (%THD+N). The low level of some 0.0034% or so (see the lhs for % distortion) shows that the signal path is healthy. Both quantities are plotted against frequency, and are largely invariant over the audio range chosen (1kHz to 15kHz).

Using a Marconi 2019, a high-grade lab signal generator, an RF test signal was then injected between or across the IEC inlet's Live and Neutral terminals, and swept in suitably graded steps, from 1MHz, all the way up to 1000MHz. The signal was amplitude modulated at 60%, a typical mean level for AM signals.

The amplifier's distortion rose by a factor of x2 or more at a number of frequencies spread randomly, across this wide RF range, and it rose far more, up to *ten times*, at some frequencies. Level was important and the level for an effect varied. A threshold effect *was* distinctly in evidence, ie. below a given level, the distortion increase due to RF would vanish altogether, rather than fading away in proportion to a reducing RF level, much as noted by Radio Hams and Hi-Fi enthusiasts over many years. The uppermost test plot (red) shows the effect of RF at just one of the many frequencies that this particular sample unit proved susceptible to. Different production versions of this Cyrus model, let alone different hi-fi equipment will likely give quite different, yet also generically similar results.

Turning finally to the top plot, in red, the RF test signal is at 871MHz[*] and at a level of 224mV rms. The distortion is at 0.012%, so over 3 times (in voltage) higher, than the plot before RF (Blue). The effects, with real world conditions, and so with multiple RF sources acting (albeit many at lower levels), can be imagined. The often disproportionately beneficial effect of a small reduction in RF, has also been clearly seen & measured, but will take more work to graph.

[*] Our informal tests above 820MHz suggest that the PowerKords™ are effective at suppressing this frequency area, over the 3183Y.

5. RF/EMI on the AC Supply

A question that might be raised, more by non-technical readers, is *how* high frequency or RF noise (EMI, RFI) comes to be conducted down, or 'in', the AC power wiring ?

First, we should observe that from an EMI or general interference perspective, 'noise' or 'interference' is any *un*wanted signal.

In the context of AC power, it is *any* signal *other* than 50 or 60Hz ±1% and the necessary odd-order including the sometimes *naturally* occurring *triplen* harmonics (as listed in Section 5.1). In a Hi-Fi context, the desired signal usually represents musical information that one wishes to listen to. Music is a higher form of sound, but other music, or speech or even birdsong, can be as interfering as more obvious sorts of noise (road drills, jet planes) when they are extras randomly intruding on the wanted, usually musical, signal.

So, sources of noise broaden from clearly ugly and aggressive 'noise' sounds, into escaping communications, leaky broadcasts and even other people's music. Likewise, distortion products. When RF 'down modulates' into the audio band, and this is coherent with the music signal, the sonic effect is particularly offensive. The resulting 'fuzzy'-sounding melange, can be from two clean signal sources. A ring modulator, as found in a musician's analogue synthesisers, with its X & Y inputs fed with quite different sorts of acceptable music, will provide a simple example of the 'sonic mess' that arbitrarily received and 'mixed' (non-linearly processed, multiplied, modulated) signals, can spawn. A feature here, is that in being first 'ugly' (or hard on the ear), and second, with so many more frequencies being created and involved in the resultant signal (due to non-linearities causing intermodulation, which 'breeds' signals at new frequencies), such noise is likely more perceivable than other small signals, or put another way, less likely to be masked. See further reading [3].

Next, we must consider what we mean by *noise* in the varying contexts of electronics. Normally, by this, electronics and audio engineers strictly refer to stochastic (or 'statistical') noise, heard as hiss, or rougher versions of the same. But the word has another meaning, particularly for hi-fi: Signals that are primarily not the wanted signal. These are commonly 'ugly'. Moreover, 'signal' can *include* noise in the context of unwanted signals or noises. This is reasonable since both random and more orderly signals behave in much the same way, in the context of electrical networks and electronic circuitry.

In this paper 'noise' principally refers (as a matter of priority) to larger and more explicit sorts of random and unwanted signals (noise signals), and not generally the often smoother and generally far lower sorts of 'natural' noise self-generated by components. But there is no hard and fast line. If the AC supply and our planet were ever bereft of larger EM noises, then the smaller and generally smoother stochastic sorts of noises, might start to be of concern. Equally, some natural noise signals, such as static discharge, corona from high-voltage lines, and the like, are large and also 'ugly' enough (*cf.* smooth thermal 'white' noise), to be included within the explicit noise signals. The noises we are interested in may be clarified as 'noise signals', but might equally be described (based on audio amplifier circuit analysis terminology) as *large-signal*, and as '*principally non-stochastic* but also stochastic *noise*'.

5.1 - RF into AC line - access mechanisms

Most of the ways that RF 'gets into' the AC line are widely covered in previous papers, writings, and most are long established, see references [4]. As already mentioned, a large segment of the world industry of EMI 'management', and EMC testing and certification, would be in question or at jeopardy, if the AC supply didn't in reality carry or support, any amount of 'signals' other than the generated sine wave (50 or 60Hz), or even just it, and its principal harmonics (principally odd ones - 3rd, 5th , 6th , 7th , 9th, at 150, 250, 300, 350, 450Hz; and for 60Hz: 180, 300, 360, 420 & 540Hz, all ±1%).

Although in no sense designed to do so (in most cases), the AC power system, from the broader network down to domestic ring/branch and equipment flex wiring, can intercept, carry or support, signals up to 1GHz and above. Between this, and say 540Hz (see above), lies a vast swathe of RF 'real estate' - containing the large majority of everyday radio communications. The total span is expressible as a frequency difference of over one million times, or over six decades.

The common mechanisms for RF & EMI being present in AC wiring, are:

i) **Direct Conduction**. Intercoms, music distribution, signalling or monitoring; also RF modulated digital 'applications' (eg. Bluetooth), using the AC system, wiring, etc for distribution. *In*direct conduction is what can occur after (ii), next.

ii) **Interception/Reception** - AC wiring acts as an aerial. Books on aerial design show that almost any length or shape of wire or metal will favour the reception of signals at some or other frequency or plane of polarisation. Connecting a sensitive hi-fi system's power supply to a random set of aerials (with RF and noise sources galore, all around) is plainly not the best idea. It might not be permitted today, were it only recently thought of.

Every part of the mains wiring offers a separate aerial 'opportunity'. Even if the impedance matching is imperfect, signals collect (on the 'aerial' conductors), and flow in the wiring, hence indirect conduction. Even around homes with an underground AC supply feeder, the aerial system that is formed by the distribution wiring and attached appliance cables, offers reasonably effective reception of radio signals from low hundreds of kHz (LW), and potentially excellent at HF/SW (above a few MHz) and on up to high UHF, and even above. The signal strength may be low, but in equipment as sensitive as Hi-Fi gear coupled to human ear + brain, is enough to give rise to audible extra noise, or distortion.

Note also that interference is able to be 'varyingly variant' as to timing, some being sporadic, as sources turn on and off (eg. taxi radios, local industrial processes), others continuous - like a fluorescent light left on all the time in an adjacent public building; and some rhythmic, for its own reason. And, just because one part of the wiring has not received signals, does not mean it will not do so at some another time, when signals at the frequencies the accidental aerial is most sensitive to, choose to come along.

Reception [§] can also be by capacitative or inductive coupling, the latter more particularly at lower frequencies, say 5MHz and below, or wherever impedance conditions favour it.

[§] 'Susceptibility' in 'EMC-speak'.

Of course, reception and conduction are *the* sole core mechanisms for noise signal entry to an electrical network. Some less commonly documented variations on these are:

iii) **Nuances of the above** include re-radiation, reflection, resonance ('peaking'), etc. Where some or any part of the AC mains wiring indirectly contributes to an interception of a noise signal. For example, one part of the wiring may intensify a signal, while another part receives it. 'Another part' might include the current-sensing coil of a partly faulty RCD unit, even possibly unused, but still connected to neutral, and acting as a MW aerial receiver and differential signal injector [5].

Resonances can magnify signals at particular frequencies – in a way that seems strikingly disproportionate to the casual onlooker – while electrical and electronic parts designed for 50 or 60Hz use can have possibly quite unexpected effects when operated well outside their design envelope. With RF, other than wires becoming aerials *or* reflectors, oxidised connections and contacts that are arc-damaged act as unwitting AM detectors. AC supply wiring having a ring main topology (as used in UK since 1943) can provide fine MF or HF (LW, MW or SW) loop aerials, particularly if one end of the ring wiring is loose or open circuit, a common finding. Meanwhile, with RF, capacitors act 'more as' inductors above their resonant frequency, and inductors act like capacitors above their resonant frequency. And, solid-looking link connections that are known as 'rock solid' short-circuits at 50Hz, can look like high impedances or even an open circuit, at specific frequencies in the UHF band.

With the amount of RF energy and the frequency span of it today, a complete interpretation of the competence of components used for AC mains is needed for every decade of radio frequency span. There are at least 6 decades involved. Over these decades, even expensively designed RF parts made to span wide bandwidths, will exhibit a number of sharp dips and peaks at and around a number of inevitable resonant frequencies. So some seemingly random and abrupt changes in the levels of RF at diverse frequencies are to be expected all the more with parts never considered for, nor measured for, hence not remotely optimised for high frequency transmission, let

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alone rejection. The action of the two capacitors across the 2 pole AC power switch in the latter part of section 4.2, is an example of an unexpected low impedance where audio and low frequency experts may feel they *know* there can only be an open circuit, with the switch set 'off'. They did after all 'prove it', using an ohm meter.

iv) **Faulty equipment - 'Technology in the community'**

Homes can contain all manner of non- or part-functioning devices, part-disconnected circuits, 'get out of a fix' electrical & appliance 'bodges', and the like. Electrical contractors report that homes with no earth connection (wires cut by a lawn strimmer) are surprisingly common.

Thence, all sorts of regular assumptions (such as the AC supply having any sort of earth continuity) may be unsound, completely altering knowledge based on stable and highly structured, and often exceedingly artificial, EMI test conditions in a laboratory; or simplistic analyses of AC mains behaviour.

An example of such an *ad hoc* situation is distorted music being heard over a hi-fi system. The cause was traced to an adjacent room, and the 'conduit' was found to be the AC supply. This was at a trade show, but it could equally have been the hi-fi or audio setup of a family member, or a neighbour. The cause was uncertain, but as this was not a familiar mechanism, it seems likely that something familiar and ordinary, somewhere in the locality, was 'one step' adrift or otherwise unusual.

A colourful but illustrative example, might be that with a valve (tube) hi-fi amplifier, where a spare output winding (available if 4 ohms required, but else out of use) might have been accidentally wired between AC earth and neutral. This can occur in first instance as the chassis (which must be connected to AC earth/ground for safety) is often also tied directly to 0v in valve/tube amplifiers. This slack practice may be excused as a case of romantically emulating 1930-1960s standards, when the AC was rather cleaner of EMI and RF.

The condition that may have occurred only requires *one* wire to be misplaced in a typical valve/tube equipment's under-chassis wiring maze. The mistake could be likely put down to an output termination tag having a mains neutral tag almost next to it, after accountants saved on a tag spacing. And *both* with white wire, where different colour systems have accidentally coincided. Now we have completely unexpected, almost lab-grade, conducted noise injection, which is outside of any textbook or 'boiler-plate' EMC standards, and probably requires the system's earth-to-neutral (PME) link connection at the supply intake, to be broken (not unknown), for the music injection to be both noticed and occur as a problem. This, and maybe having no RCD on the intake. Experienced electricians know that such combinations of dysfunctional or dated electrical system practice, are by no means exceptional.

Another possible explanation in the preceding instance, of music from one hi-fi system leaking onto another via the AC supply, is that the amplifier was self-oscillating, at RF. This is potentially widespread and even common with Hi-Fi equipment, particularly when cables and real-world load and source impedances are in place, rather than the design/check situation, often on rather clinical lab benches. The RF may *only* be present when equipment is *first* turned on and the room is a bit cold; when a particular source is selected; at, above or below a particular volume setting; or when a train or truck/lorry goes by and shakes a dry jointed capacitor intended to suppress RF oscillation. Or 101 other 'fluke' conditions able to give rise to RF pollution that won't be discovered by EMC or factory line tests. In real use, remarkably few people monitor[¶] what is 'on' their speaker cables. Users would need to be looking out for generally sine-like or coherently patterned waves, upwards of 100kHz, and as high as the monitoring oscilloscope can go, to at least 50MHz, if not to over 200MHz. It may be salutary to learn that regular small signal, silicon epitaxial bipolar junction transistors have been able to oscillate at and above 100MHz since the mid-1960s, viz. Mullard BC109 introduced *ca.* 1964, was metal-cased to TO-18, and notorious for parasitic VHF oscillation that was hard to detect by hobbyists, in the days when 'scopes with bandwidths above 5, 10 or 20MHz were unaffordable objects of fantasy.

[¶] Using a suitably wide-bandwidth 'scope which should also be 'floated' or more safely, have differential input connections, to avoid *creating* ground-loop hum or buzz and related EMI

RF oscillation that is accessible by 'scoping at the output of hi-fi equipment may be stronger at earlier less-accessible internal stages, and may travel and arrive just as effectively at the AC power intake (where a 'scope had best not go). The keynote is that 'events outside the box' - that an audio amplifier or preamp is actually working unbeknown to all, as an AM radio transmitter - can, and very likely will, result is a quite unexpected injection mechanism, a combination of conduction *and* carrier waves, needing only bad contact or bridge rectifier along the way to recreate - by demodulation - an audible signal.

5.2 - Audibility Mechanisms and Modulation Considerations

In order for some of the unwanted signals that arise on AC Mains cabling to become audible, there are two long established mechanisms for different components of the noise signal. Non-linearities in the path cause intermodulation whereby audible noises are formed (as are some of the many products) by the direct beating or 'clashing' of any two or more waves, not ever remotely audible in themselves. The BFO feature on a communications receiver provides a monotone example. A carrier inaudible in itself springs into audibility, like developing invisible ink.

For parts of the noise signal that comprise audible frequencies (when transduced by a speaker of course), these may arrive directly. But in order for audible (LF, audio) noise that has 'hitched a lift' on an RF wave, to be able to be 'turned back' into audible frequencies, Amplitude Modulation (AM) is the required format. The demodulation part is trivial, as there are natural rectificatory contacts galore in electrical circuits. How many people polish their plugs, fuses and switch contacts regularly, if ever? Then there are bridge rectifier diodes, often 4, 8 or 12 or more, per item of equipment. And electrolytic capacitors, used in 1920s as AM demodulators. And yet more contacts. There is nothing new in this. In the valve equipment era, radio receivers and hi-fi amplifiers alike were upset by *modulation hum*, caused by RF on the AC supply [3]. Overall, AM detection is amply well provided for, in the AC supply wiring and power supplies, that are connected in turn to hi-fi equipment.

If not in the AC circuit or the power supply, then it is well established knowledge that semiconductor and also imperfect connector junctions within *considered to be the linear* parts of the signal path of hi-fi equipment may (and can) cause spurious, often highly level-dependent rectification: hence the detection of amplitude modulated RF, and so upset the biasing and operation of ordinary bipolar transistors - and also ICs (such as op-amps) having BJT front-ends (such as the widely used NE5532 and its klones).

AM is not only the original and simplest scheme for 'launching' audible signals with RF. In a cruder form, it is also a 'default scheme' or natural occurrence for any modulation that happens of its own accord, viz. man-made, but quite accidental, interference signals. Intentional RF, eg. broadcast transmissions, may be modulated more efficiently or effectively, with CW or SSB, which may be seen as special forms of AM; or with FM - along with the related phase (angle) modulation; or frequency shift (eg. FSK) - and various related 'digital' schemes.

A little known fact, uncovered by the author in the papers research division of this broad project, is that many signals contain AM components, ie. are radiated partly in AM, although their official and designated modulation scheme (by regional &/or inter-governmental agreement) is described quite differently. See **Appendix 1**.

Some might reasonably ask that this be demonstrated. In order to do so, a former (and quite rare) Racal Communications Ltd type RA 1795, a sophisticated VHF/UHF communications receiver (ex-UK Military), was obtained and used to examine the characteristics of typical VHF and UHF FM transmissions. This was done without listening to any transmissions which we were not authorised (or waivered by the British Secretary of State), to receive. Fortunately, the audio monitoring speaker could be largely switched off, as the information sought was obtainable from the Racal's (2^{nd}) IF output.

The availability of a buffered, external IF output furnishing an 'in-range' RF signal is fortuitous, since all commercially available modulation meters require RF levels in the tens of millivolts. The IF signal was duly connected to two different automatic modulation meters, made in UK by Wayne-Kerr (AMM-255) and the former Farnell

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Instruments (model AMM). Both gave similar readings, and showed that UK commercial radio and also analog(ue) TV sound signals, had peak levels of AM in the 10% to 18% area. Likewise with an FM CB radio transmission. Possibly the effects of the commonplace using of a 'linear' power amplifier as booster or 'burner', may be involved here.

Some other signals also had well over 1% AM, but their nature and frequency may not be disclosable. What matters here, is that just 1% of AM alone, or less, is sufficient to put a *demodulate-able* noise signal, into place, and in line, with parts that will supply the demodulation.

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6. Woven Cable Modelling

Further work was undertaken to explain transmission lines employing a weave. This was felt necessary, because it is not apparent from the limited and simplistic, rather fettered 'school-level' information given in all the many books investigated by the author about transmission lines, to understand how a woven cable can act as a low-pass filter and also 'absorb' or damp, high frequencies.

6.1 - The E-M basis of Woven Cable

When examined with an 'electromagnetician's eye', woven cable is found to furnish a number of special, even remarkable properties. It may be helpful at this stage to be reminded that woven cable is a development of the twisted pair (as used for eg. instrumentation, data & phone wiring), and transposed spaced pair, as originated for open-wire phone lines, and still employed with lengthier multicore telecoms cabling. This lineage can be plainly seen in retrospect.

One of the first observations on woven cable, after some methodical analytic scrutiny[ϕ] (Fig 14) is to notice that any given pair of conductors of opposing polarity (we will call them *pole pair* wires), follow separate paths, while they cross repeatedly. Between crossings, the spacing between them at first increases, and then decreases. The change of spacing is fairly linear (depending on the 3D to 2D mapping scheme used) and also symmetrical (in terms of axial distance travelled). The rate or slope of divergence depends on the pitch, the number of conductor pairs, and also whether the woven cable is in a flattened or tubular state. As in moving between the two, the weave angle naturally changes. Returning to the varying spacing between any pole pairs, it might be said that this distance is in a constant state of change or flux, never settling but undergoing continuous divergence then convergence.

[ϕ] Easier said than done with actual woven cable which has PTFE-type insulation, hence is slippery, and also resists marking, and that has 4*n* conductors without markings, so which all look the same, then again for the other pole colour. And with both sides rotating contra-wise, and uniformly interwoven, so no particular place differs from any other. The design has been hard to create, yet even harder to analyse, the latter evading all attempts (by diverse parties) until 2008.

To reiterate, this is quite different to nearly any of the regular transmission lines and cable geometries, with their mutually parallel conductors, that text books and all previous papers seen have been confined to. To be fair, probably some 99.99% of signal transmission lines in use, at any frequency, involve either standard coaxial or sheathed 2 core twisted cables that have obvious 'shortest distance between two points' geometries, based on conductors being and staying parallel at all points down the line and at higher frequencies (above a few GHz) are essentially parallel-sided wave-guides. Twisted pairs of conductors – and twisted waveguides – are included. For with round wires (although with conductor-pairs, individual path is not straight, and the parts in parallel contact are shifting at each point), electrically speaking each side wall part of the conductor is as good as any other part, therefore twisted together conductors nevertheless retain a constant mutual spacing and hence constant mutual parallelness.

A special feature of an alternation of divergent, then convergent conductors, is that the two pole pair wires end up at the same place, yet *are not in parallel* for any distance. The conductors could only be considered as being *tangentially* parallel over thin slices, at many discrete distances. It is clear with hindsight that (without 'sloping-plate' capacitor models) this is one way that the effect is able to be modelled. With this approach, we could state that the pairs *are* parallel (that would for example, explain how they end up at the same place), yet their spacing is also varying at every stage. In turn, 'parallel in many discrete steps' provides an explanation for each pole-pair's apparent circle-squaring quality. Of course, these details are simplified 2D mappings - for example the many steps are spiralling in a tubular space. But such simplifications are necessary to get a foothold.

The author has christened the alternating divergence and convergence as *The Glissando effect*, recalling speaker designer, sound engineer colleague and musician, John Newsham, playing glissando notes by moving a 'gliss bow' up and down his acoustic guitar, on a world-event experimental music stage¶. The analogy appears apt since gliss is best played with a long repeat echo so the strokes of the bow overlay each other in time creating a layered 'woven' type of sound.

¶ Footnote: Glastonbury Festival, Experimental Sound Field, England, June 1992. Gliss earlier performed in pioneer ambient music by former colleague S.Hillage, eg. *Rainbow Dome Musick* performed London Olympia 1979, and still earlier by D.Allen/Gong.

The Glissando effect becomes a *Glissando capacitance* (another new term, first used here) when the effect of *non* parallel 'plates' is considered. In every text book, and paper on capacitor technology that the author has met, capacitance is considered between conducting surfaces that are, if nothing else, parallel. In the absence (probably beneficial) of any reductive mathematical treatment, we can simply observe that the effect is like having many capacitors across the line, representing the *per-slice* capacitance with divergent (increasing) or convergent (decreasing) values, with a nett value equal to the measured capacitance for a given section or length. For example, if there is 200pF per metre between pole pairs (which would be seen in 3183Y type cable), if 'sliced-up', as 200 x 1pF capacitors every 1/200th of the metre distance, then instead (with a hypothetical single 'pole pair') we have (where Y is a coefficient to be determined) YpF, at the closest distance (at the crossing point) then say ½ YpF, ¼ YpF, $^{1}/_{8}{}^{th}$ YpF and so forth, per unit distance either side, until the sum reaches 100pF (being half of the total capacitance) at the half way point, then the reverse, ie. a mirror image of the steps as above, evenly distributed in the same 'half distance'.

The binary series is used as a necessarily crude approximation of the (multiple-ly non-linear) change in capacitance per step, the step itself having a non-linear size, due to 3D to 2D mapping of divergent spirals, whereas capacitance reduces exponentially with linear distance. But round conductors, with but sparse area, will behave differently to wide or infinite plates. There are fringe effects, highly complex to analyse. Then likewise, any interactions with other pole conductors and pole pairs needs factoring-in. In turn, modelling the curve of capacitance's rate-of-change is not trivial, but it's also non-essential, and so also outside the scope of this paper.

The effect of a *Glissando Capacitance* is this: if we assume for now, for simplicity, that both the other two constants (R & L) were to remain 'normal and regular', hence almost constant per unit length (as in *eg*. 3183Y type cable), then the transmission line is changed into a series of R-L-C steps which do not repeat *ad infinitum* to create an eventual convergence leading to a resistive, wideband effect [6], but offer a sequence of ascending, then descending –3dB rolloff points. Moreover, we have a parallel set of these lines (the other 3 or 7, etc, of the pole-pairs, for 4 and 8 pair weaves respectively) all *slightly different*, so there are many extra, discrete resonances, some compiling into deeper or wider nulls. As seen in the response plots.

All this is understandable from basic E-M principles, and some visualisation. It can help to understand how transmission lines are modelled as lumped circuits when they are short enough to be so treated, and how above this (a relatively vague) point, they become increasingly best seen as lines having a *characteristic impedance*. For the approximately 1m (or 1.5m) lengths of woven cable normally used, this should be broadly the case up to low/mid VHF (up to around say 75MHz). This is by conventional reckoning, where a line length that approaches a fair fraction - say ¼ ~ ⅓ of the wavelength ($\lambda \cong$ 3m at 100MHz; so 1m is a ¼ wavelength, at 75MHz; and 100MHz is ⅓rd wavelength, for a 1m cable; and about 67MHz for a 1.5m cable).

But then the highly unsettled 'impedance' (if it could be called that) of the woven line, changing at every point, forestalls the development of the convergent series (described adequately in so very few textbooks - *cf.* the clear description offered in a British book [6], that creates the curious effect of 'characteristic impedance' (curious to those working at low frequencies, with short wires), such that the appropriateness of lumped parameters extends up to higher frequencies than is the norm. So, maybe 800MHz (or above), rather than around 80MHz. This has been able to be evaluated, within the existing tests. As follows.

Once a transmission line (signal carrying pair) exhibits characteristic impedance (either by having enough length for a given frequency; or signals at a high enough frequency for given length), then its impedance ideally reduces to (by and large) just resistance. Like a 50 or 75 ohm load resistor. This would suggest it should not be able to act as a comb filter, granted a modicum of 'impedance' matching (by choosing the right line-loading resistance, and using a wideband RF resistance element), above the frequency range where individual L, C and R quantities 'morph' into characteristic 'impedance' (latter being cited in inverted commas, being rather oxymoronic, with it ironically being a (pure) resistance: "The one time"). The weave may inject a circular argument here, that explains one of its special properties, since if a transmission line has no *one* stable 'per-unit' L, C & R values 'set', then either there is arguably no characteristic impedance, or else there are multiple characteristic impedances.

In support of the weave not settling to a characteristic impedance, our initial tests *above* 820MHz, up to 1.8GHz, show the woven cables *continuing* to provide their comb filtrative effect, to at least 1.8GHz, and likely beyond. These exploratory results are outside the scope of the present paper, since the weave's effect is already adequately demonstrated , and (as already explained in section 2.4), more SHF-suitable RF 'connective' equipment is required to offer information at these microwave frequencies, to the same level of certainty, as at the lower radio frequencies.

Meanwhile, in analysing the weave, the mutual inductance (L_m) between close pole pairs (that normally serves to largely cancel the series loop inductance (L_s) in a 3183Y type cable), are also *Glissando'ing*, for the same reason as the capacitance. For, as the pole-pair conductors diverge, the *mutual* inductance degrades or reduces. Therefore the cancellation of the series inductance (L_s) of a solo conductor *in*creases in effect, hence the *series* inductance rises, then falls - as the pole-pair's spacing increases, then reduces again (towards the next crossing). The lowest value of L_s will be that of a conventional, highly mutualled pair, the norm. This grants low inductance, but also strong proximity effect, with high currents. The latter is clearly minimised when the conductors are crossed at angles, and are otherwise disparate, compared to the strongly mutualled norm, for AC and also loudspeaker cables. We can also see the weave as comprising a series of loops, hence literally loop area increases, which raise L_s . This value then, varies in the opposite sense to the capacitance value.

These complementary L & C variations (which might be thought to offer a constant resonant frequency*) are not perfectly value- reciprocal, due to differing effective laws of reduction with distance, not forgetting literal side (fringe) effects of the other pole-pairs, alongside. Each of the many series L and shunt C value-pairs provide the conditions instead for resonance at multiple adjacent or quite similar, discrete centre frequencies. Inevitable variations in spacing and exact dress turn out to be a useful feature of woven cable, likewise helping to create a random variance in the resonant frequencies. Hence the nulls are widened, rather than over deepened. For absorbing RF, this can be far more effective. Deep, narrow nulls betray a high Q, a condition which cycles energy, rather than absorbs it.

* If they were able to vary perfectly in-step, reciprocation law-wise, then they would maintain a constant resonant frequency (or set of resonant frequencies)

In effect, we have a series of many differently resonant or tuned circuits, and the sum of each (per pole conductor's length) are damped by the parallel pole conductors, *where their L-C conditions differ,* even if only slightly.

Variations in a third fundamental quality, resistance (R) are, by contrast, small and purely down to manufacturing tolerances (and possible small

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changes to dynamic or AC resistance) down to dress altering the impedance caused by proximity effect, and there only for AC powering or low impedance speaker connecting applications, ie. with high peak currents. For a first-order analysis, R may be taken to be consistent per unit length, with stipulations as to tautness of lay (as per the U-jig, see earlier), just as in a 3183Y type cable.

Based on the tested cables, the woven cables' overall R, L & C values are such, that with the short lengths employed (1 to 3m, as tested here), the comb-filtrative effects do not begin to take effect until the low MHz area, therefore acting as a low pass filter, well suited for passing audio and AC power signals, and handling these with no hint of its high frequency rejective behaviour.

In *lieu* of finding suitable 3D EM modelling capacities, a model of one pole-pair's *Glissando* capacitance and inductance was assembled with *MicroCAP 9* circuit simulation software. In comparison this required the 3 spacial dimensions to be translated down to 2+bit dimensions of electrical mesh analysis - as already footnoted in the introductory section 0. The model is *lumped*, ie. uses regular discrete components, and covers just 8 pole -pair crossings. The 'SPICE' (an oxymoron name as there is no “IC emphasis” at all) 'transmission line', a standard suite which has many subtleties and some inevitable hidden limitations, was 'contra-indicated' at an exploratory stage, in part as it is no more ideal over the frequency span involved, and with the distance of just a few inches/tens of mm for the simulated length, than the lumped model that has been used in preference. With discrete parts, the model creator also stays in fuller control, and when required, the UHF & SHF behaviour of capacitors may be modelled by tables.

The present model's single pole-pair and few crossings still involves many series R+L and shunt C sections, in T-format (shunt capacitance between half the nett per section L_s + R), with the just described diverging C & L values, per constant unit R value. As is usual for simple cable modelling, the constants for one side are collapsed into the other side, so the return side is just drawn in simulation as a wire called ground. This creates a 'half-section' model. So, we have a half section model using iterative T-sections of lumped R+L/C/L+R sections, with a few binary C & L steps (see next), then reversing. This then repeated seven more times.

The divergence & re-convergence of the C & L values has been initially modelled with just a few (four) binary steps, ie. of halvings and then doublings, between crossings, giving a raw exponential change. Effectively the curves of the diverging or converging C & L values have been 'chopped' or sliced, at 4 points, and the average value across taken each quarter. So the change pattern is built minimally with just 4 slices, giving rise to the name 'raw slice'. Akin to a 5 step signal. Then to simulate the imperfect dress of the a real woven cable, the precise L & C values were manually randomised ("made a bit different") around the target value.

The ends of simulated woven cable, just one pole pair remember, dubbed '*Raw Slice Lumped Model'*, were then connected to source (75Ω) and load impedances (1kΩ), considered reasonably typical of real-world test conditions. It should be emphasised that due to the size and complexity of the model for just *one* pole-pair and just a few crossings, this already comprising over 50 capacitors, 100 inductors and 100 resistors, the initial low-pass corner frequency and also the frequency range of dominant effects, are both shifted upwards. Such is acceptable for a preliminary investigation. The frequency scale of all the data might be 'down mapped' by a factor of say fourfold, say.

The same circa 4"/100mm length of 3183Y cable was also modelled, using the same 'T-based' lumped component technique.

The response of both models is shown in fig.15, plotted together, as in the earlier results with actual cables. Here, even with such a skeletal and simple, interim modelling of such a complex ElectroMagnetic *structure* [ω] , both curves are encouragingly similar in their general behaviours, to the measured results, both in their relationship and in their individual patterns.

[ω] The visually imaginative reader might imagine 'walking' inside a giant woven cable (using 3D video) and seeing the fluxes of E & H, as computer generated 'glowfields' in two colours.

A full (1m length) and more detailed (25 step say) model might readily require 10,000 parts, and about as many nodes to be debugged. But, this is the subject of another paper.

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7. Conclusion

The results (in Graph sets G1-G9) clearly demonstrate that a woven cable (within the definitions given) acts as a broadband low-pass filter and RF absorber/damper and attenuator, or 'energy repeller' (exactly where the removed energy goes may itself be debatable), and this across a very wide range of Radio Frequencies, starting in the HF (SW) or low VHF band area. In addition, informal testing above 820MHz shows that useful attenuation, well in excess of the slope of 3183Y, continues to at least 1.8GHz.

It has been asserted by some engineers (usually with academic leanings), that cables can only possibly introduce simple, linear 'RLC' effects (and these largely outside of the audio band), with at most, effects culminating in gradual, monotonic changes ie. a slight frequency response slope or rate variation. In other words, cables that are claimed to improve or enhance reproduced sound, are acting 'only' as subtle fixed tone controls, or tonal adjusters. This may be the sole measurable quality in regard to cables of essentially regular construction, similar to 3183Y. Woven cable is demonstrably in another class.

The above 'RLC only' assertion is clearly shown here to be a 'dumbed-down' or 'lower-dimensional' view of the woven geometry. As with %THD+N measurements, which are widely known and long acknowledged (for over 50 years) to belie and actively *hide* the audible nuances arising from the underlying harmonic structure or pattern [7], R-L-C measurements (however expensive or precise the R-L-C analyser used), are *lower* dimensional and have been shown in this paper, to be a crude measure capeable of hiding more complex, intricate and *useful* behaviours. One analogy for this is weighing books to determine their value, another is measuring the orthogonality of a house's walls, to prove its perfection.

Something of a 'lower-dimensional hint' as to a woven cable's hidden, and more complex behaviour, is that they show an unusual combination of *both* low loop inductance *and* low shunt capacitance. This is like squaring the circle - as normally if one is made to be very low, the other is forced high.

Overall, all of the claims of the makers of woven cables, that have been investigated, have been more than substantiated. Woven cables have very interesting, unique, and in today's polluted EM environment, highly apt properties. They are not better known as they are not in textbooks, and cannot be easily copied as their manufacture requires extreme dedication . This dedication would be unlikely to survive 30+ years if they did not have a beneficial function.

In a world increasingly saturated in RF emissions, the benefits of using woven cables adjacent to sensitive equipment are clear for audio equipment's AC power. And, the same benefits do rather clearly also carry over directly, to audio signal cables, including loudspeaker cables.

Appendix 1

Some sources of Strong &/or Local RF emissions - with AM capacities

* Local AM radio transmissions - public broadcasts on LW, MW and SW. In UK, AM stations commonly employ relay transmitters in localities with poor national reception, and additional local AM transmissions may carry regional services, eg. in UK, for Scotland, Wales and Northern Ireland. In the US, there are multiple AM radio (public broadcast) transmissions in almost every locality.

* Overhead aircraft - air comms. Most likely to be strong and continuous near military air bases and civilian airports, and underneath main flight paths. Also, in the vicinity of helicopter pads, and possibly, leisure launch sites for eg. micro-lites and hot-air balloons.

* AM CB radio. Although not legal in the UK at any time, it continues to be used. As un-managed, and as products are left to foreign market-forces, high and commonly 'unclean' RF power amplification may be used. Use, whether legitimate or outlaw, may continue in many other countries.

* AM radio Mics, used by musicians and for shows and events - as AM CB radio, above.

The following are notionally FM or 'other non-AM', at least under laboratory conditions. Although audio circuitry, whether perfectly linear or not, *should* be immune to pure and perfect FM signals, the following public broadcast and other widely encountered sources, *are* reliably stated as being capable of being converted into [8], or possessing [^] components that are, amplitude modulated (AM). Modulation metering [Section 5.2] has further demonstrated that this is the case, in all the available cases so far examined.

* Public FM radio broadcasts. Usually on VHF Band II, nominally 88 to 108MHz. Commercial radio was observed to emit the highest % of AM [Section 5.2].

* Analogue FM TV sound & vision signals. Generally 471 to 863 MHz in UK and similar across Europe. US and other countries may still also broadcast in Band III or adjacent high VHF frequencies, ie. 174 - 216MHz.

* TETRA is a European/EU-wide trunk 'PMR' (Public Mobile Radio) system, also employed in UK. Already controversial for apparently causing clusters of illness in regular users (eg. Police officers) and those living or working next door to transmission aerials. An engineering appraisal indicates that the radiation of AM components is intrinsic to the scheme.

* Other PMR users. Many tens of thousands of Personal Mobile Radios are operating, and many while driving around, others stationery, in the 76-87MHz, 137-173MHz and 440 - 478MHz bands, in the UK and Europe.

* FM Radio microphones, and related performance event radio links, eg. wireless guitar.

* Digital Television - compares to a typically 44+ year old analogue system (as above) this appears to be needing (in UK at least) a significant increases in radiated transmitter power, to regain the coverage and also picture & sound quality and even picture stability against real-world events such as flocks of birds, rain/drizzle and freezing mist, which 1950s technology had proved immune to.

* FM CB. Less common, but possible "anywhere, anytime", and since it is un-managed, radiated powers above the legal 4 watts (in UK & EUro-land) may be used, and a high % AM has been observed [Section 5.2].

* Mobile Phones. Some analogue phone traffic may still operate in the 917 to 949 MHz band. But most UK and European phones employ spread-spectrum techniques, and digital signals, so any demodulated signal will be some kind of noise pattern, and frequencies are either adjacent (890-915MHz or 930-960MHz); or else on a higher band, just above 1.8GHz, which is outside the scope of this paper - although our informal tests showed the Woven cables still giving rejection at 1.8GHz, ahead of standard 3183Y cable.

At the opposite end of the spectrum, non-AM yet noisy signals, can arise in the long-wave (LW, LF) regions. See [9].

* Encrypted military signals traffic may occur, employing FSK modulation - a kind of 'digital' signal.

* Standard, national time signals as broadcast at 60kHz from eg. Rugby UK and Fort Collins, Colorado, US), have to be strong all over some

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countries (such as UK), as electricity meters in cellars have to receive them reliably, to switch tariffs. Forms of digital modulation are employed, eg. MSF.

Other strong LF/LW signals occur near airports for radio navigation (LORAN, ALPHA), and along coasts, marine and submarine transmissions, etc. For example, LORAN is a navigational system, *pre*-GPS but also stabler, which operates at several MF and LF frequencies, eg. LORAN C is at 100kHz, with strong signals present in North America, and also across much of Europe.

These days, the above information may be verified and enhanced and updated for the reader's region, by web searches, with interpolation possible, due to the extensive and generally professionally presented web contributions by radio comms listening & monitoring enthusiasts.

In future, with more spectrum space subject to being rented out, as government-owned real estate, or as a means of funding social good and facilitating new human communication & IT facilities, some of the above may be subject to change, or additional widespread noise signal sources may well arrive. For example, plans to send signals or data-streams of many MHz or GHz, 'down' the AC supply, are in use in limited areas, and have not 'gone away', in terms of being potentially rolled-out. Many, rather than fewer, RF sources will be densely active. Devices capable of wideband RF filtering and absorption will not be lacking in work load.

Concluding on a real world note, the HP 4396A operating in spectrum analyser mode, was connected to a scanning aerial, and the signals received recorded. The levels are uncalibrated, but the relative levels are clear enough from the spectra in Figure 13. Several of the larger signals occurred at broadcast frequencies, and frequencies listed by Ofcom for PMR. Because it is unlawful in the UK to disclose information about signals at frequencies that we are not authorised to receive, the identity of some of the spectral spikes can't technically be disclosed, and the frequency scaling is left relatively unclear for this reason. However, the graph shows (perhaps for the first time in public) the Radio Frequency spectrae in a relatively rural area of the UK. Other than the 18 or so salient-most signals, the airwaves seem comparatively sparse. But beneath these, lie *another* 8000 transmission spectrae, and they are just those above a somewhat arbitrary –114dBm cut-off line. It would be an extreme feat if many of these spectral lines were not coincident with one of the many null frequencies or attenuating frequency regions, of a woven cable.

Regarding the RF signal strengths, it should be noted that the discone aerial employed has nulls of its own, and also varying efficiency across the frequency range it was employed over. Therefore the above dB figures are not absolute or comparable indications of RF signal strength.

Finally it is worth repeating that for the audio victim equipment, and where the audible effects are being created by non-linearities, merely a *small* reduction in the RF level, of just 3, 6 or 10dB, may well be, and has often been, enough to avert demodulation and/or greatly reduce intermodulation products - as if switching the noise signal off.

Appendix 2

Clarifying some Transmission Line Geometries

It is the author's experience that woven cable is in need of being unambiguously identified, in relation to other types, some of which it may be superficially confused with. As even engineers - audio, electronic *and* electrical - who should be well-versed in wire and cable technology, let alone a non-engineer (while still probably technically intelligent) hi-fi user, can fail to identify differences between conductors and *pairs* or transmission lines, that with a little knowledge - about to be dispensed - and patient observation, are quite easy to grasp.

A2.1 First, all electrical signals in wires need to travel in loops. Whether balanced or unbalanced, RF or audio, signals in a wire have to return by another wire, or, in extremis, some other medium taking the place of a return wire. In the great majority of cables, comprising sets of conductors employed to transmit audio signals or AC power (which is no less a 'signal'), conductors associated with a given circuit loop, are laid together, ie. side-by-side, in an 'enduring' or 'ongoing' parallel format. This is to say that the 'parallel-ness' generally stays true at any point inspected, throughout any length. If any one-sided divergence is essential, it is usually minimal in area and close in distance to the main path. Woven cables sit alongside this latter sub-category - as having at its simplest level, a two-sided, cyclic divergence/re-convergence.

A2.2 Second, it is helpful to realise that a twist does not mean that conductors are not parallel. All sections of a drawn conductor's assumed to be cylindrical (circular) surface, are equal for their effect in a given proximity to the other conductor surface (in a first order assessment, at least). This can be less true for oxidised strands, conductor or bundled strands that are not perfectly round. But that is a second order consideration.

Additionally, for many cables employing parallel conductor pairs, the pairs spiral around an imaginary or actual centre. So between themselves, mutually twisted conductors remain 'no less' parallel. The twist only appears in their relationship with external conductors and EM waves. Imagining the pair as a very long loop into which current may be induced , then each twist reverses the loop's orientation, largely cancelling and frustrating the opportunity for induced current flow.

A2.3 Third, it is also important to realise that twisting is not weaving. It is possible to twist-up wire pairs, then twist-up several pairs, to make a knobbly cable that looks like it is woven, to the untutored eye. There are tests to show this is not real, described later. One immediate test is that in a weave, the pole pairs are not adjacent and parallel. Weaving twisted wires also makes limited sense.

A2.4 Forth, the widely discussed but poorly documented '*Litz*' wire is a perennial cause of confusion. 'Litz' strictly refers to a conductor (not a cable) comprising parallel parts, ie. multiple, insulated strands per conductor. It has this much in common with woven cable. It, or something similar, is reported as having been devised by Nikolai Tesla as a winding conductor over a century ago, to ameliorate skin, and possibly proximity, effects, in hf transformers. As probably the first person to work with high-power AC at ultrasonic frequencies, this makes sense. And since the 1960s, in switching-supply and related convertor transformers operating in the high audio to mid-ultrasonic range (15~500kHz), a form of Litz wire made from twisting together 3, or 5 or more strands of magnet wire is employed, particularly where efficiency is crucial, eg. aerospace.

In the 1920s, this technique was adopted in a miniature format, by radio pioneers for making maximally efficient wireless set tuning coils, presumably first patented in Germany, given the German name. More latterly, Litz *wire* is still seen used for 'AM' (meaning: LW & MW band) radio aerial coils, and is often hidden in other RF coils, chokes, IF transformers, etc. It may also be found in esoteric, high-end audio transformers and used for hook-up in DIY or cottage-industry hi-fi equipment. These small signal uses originally, and remain typically, simply both as above, overall twisted (spiralled), or twisted-twist (further above), or at most, braided (see next). There are also loose dictionary and textbook definitions, that describe Litz as being twisted, plaited, braided or even woven! But all these definitions are made without pictures or diagrams, and without any defining of any of the terms.

It is worth emphasising that Litz is intrinsically a wire ie. a conductor. Not a *pair*, or cable. Were some Litz wires to be paired into a cable (transmission line), one or more Litz pairs could be made into either standard parallel type, *or* into woven cables. Or twisted amongst itself or spiralled around a middle. Making a Litz cable (transmission line) is, strictly speaking, outside the box, because 'what to do with the other conductor' is fully *outside of the concept*. A 'Litzed-Litz' assembly might involve twisted pairs of Litz conductor. But while this and the other permutations may *look* superficially like weaving, none are truly a weave if a key element is absent. In a true (original) Litz, the individual conductors were *not* required to be threaded or woven between others. This latter requires a higher apparent dimension of manipulation, even than twisted-twists. As a low dimensional measure of the different geometry, the characteristic ratios between R, L & C for Litz (where latter lies side by side as a cable made of parallel Litz conductors) are quite different to woven cable, the shunt capacitance C, naturally being far higher, in Litz.

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Confusion over Litz is not helped by the fact that in German, the original name, *Litzendraht*, is able to mean or imply *both* 'woven' and 'stranded', or even just 'thread'. It appears that this one German word replaces multiple English words with quite separate meanings. If anyone reading this is sufficiently nuanced in German, and would like to advise, we would be happy to hear from them.

Definitions of Litz also occur in the next section.

A2.5 Fifth, in a woven cable, multiple conductors are always used, as with Litz. The difference is a more complex and subtle 3D geometry. In the weave, an individual conductor, one of *n*, rotates *under and over* just the opposing pole conductors. It crosses these enduringly at *divergent* angles that are finite, and approaching the ideal 90 degrees in the limit, according to the weave's dimensional expansion - discussed in the next section.

As more conductors are added (usually rising in the binary series 4-8-16, for symmetricality, that is naturally essential to a weave's magnetic and capacitative balance, for good H-field cancellation and low capacitance), the weave tends more obviously towards a tube. Implicit in this, is a largely hollow centre; as if it is a very wide conductor, with 'all the conduction' in both directions, 'meshed' smoothly over the surface.

In order to make the point in another way, in comparison, a Litz of any size or strandage *remains* solid-cored, similar to a rope-laid multistrand conductor except the Litz has any number of strands insulated from each other.

This makes sense as follows. Litz is made and used for maximally efficient 'magnetics' component windings, in the tens of kHz and low MHz regions. Also known as LW & MW bands. You will not usually see Litz in any HF (SW band) coils at any period in RF history. Such magnetics windings also usually require high compactness, for low leakage inductance, manufacturing conformity, and maximum induction density.

A2.6 Sixth, plaiting (pronounced 'plaht-ting' **-** as is done to mainly female hair) requires explanation. Plaited wire appears *superficially* to be similar to Litz and to woven cable. All three can exist as (solo) conductors, eg. woven *wire* (single conductor) is made, or may even be made, by simply connecting the two poles in parallel. A vehicle battery's earth strap is an example of uninsulated, but plaited wire. The individual strands are initially uninsulated, but may become oxidised sufficiently to be insulated over time. But it matters not as plaiting is used here to create a flexible joint that stands much flexing. Insulated plaited wire is like the battery earth strap, flat and 'strap looking'. Also known as braid (think of military uniforms for senior officers), it is dominantly two dimensional, as it grows only wider with increasing strands.

Plaited wires, like Litz, are always *solid*-cored (no hollow centre), albeit tending to be 'bar-shaped'. The keynote is that strands can be braided by laying them on a card tool sequentially. Although they are crossed over, there is no threading through, nor a true counter-rotation. Braid may be thought of as the '2 and a bit' dimensional version of Weave, which is itself closer to being '3 and a bit' dimensional. This dimensional disparity (even if both weave and plait are equally both 'really' plain 3 dimensional, like all other objects in our universe) should help explain why these 'string mesh' topologies can be difficult to comprehend, at least at first.

There are 'loose uses' of nouns in English as well as in German. The copper around a good co-axial cable is commonly described being a braid. But according to our definitions above, being a hollow tube (having many strands it tends well towards this) it is strictly a woven conductor. But with *un*insulated strands. Whereas the woven cable we are concerned with, always has insulated strands. It has this much in common with Litz.

So there are certainly inter-relationships, and so there is much need to look carefully, and not leap to conclusions.

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Appendix 3

Some Test Equipment employed & on-hand

Country of Origin - Maker & Model - Purpose/mode/details

UK, Datron, 1041, peak AC V monitoring using BDR peak-capture jig.
UK, Datron, 1061A, trms AC V monitoring.
UK, Gilyard-Beer, *Datroid*, data-logger system, 8 digit, multi-ch V, I, DC, trms, DCR.
UK, BDR, peak capture jig for Datron DMMs, 240v AC rated.
US, Tek 7834, storage scope frame with 7B92 timebase, 7A26 & 7A24 plug-ins.
US, Tek 7704, scope frame with 7A13 differential, 7A18 & 7A24 plug-ins.
US, Audio Precision *System One*, Audio/LF network, 1/3 octave & distortion analyser.
UK, BDR, CM & DM switchable input RF filter set for Audio Precision *System One*.
US, HP 3581A, manual LF wave-analyser. *
US, HP 141 + 8552B + 8554B, realtime spectrum analyser, 100kHz to 1.2GHz.
US, HP 3561A, LF/low-RF, FFT analyser. *
US, HP 11549 & 11850A Power Splitters.
US, HP 8754, Network Vector analyser.
US, HP 4396A, Network & Spectrum analyser. *
UK, Marconi, 2370, x2 RF spectrum analysers *
UK, Racal, RA1792 & RA1795, digital comms receivers, RF broadcast investigations.
UK, Farnell Instrs, AMM, Auto. Modulation Meter.
UK, Wayne-Kerr, AMM 256, Auto. Modulation Meter.
UK, Racal, 9916, LF to UHF frequency counter.
UK, Racal, 1992, LF to SHF frequency counter.
UK, Thandar/TTi, LF to SHF frequency counter.
China, VHF & UHF discone aerials.
UK, Belling Lee, L-1924 100kHz-1GHz, 60 Ampere, –130dB AC filter-set. [2]
US, EMCO, 20 Ampere LISN, LF to low VHF.
UK, BDR, Type 2 Iso-transformer with floating output & RCD protection.
UK, Thurlby/TTi, PL320 QMD Lab bench psu, 0-32v x2 2A
US, HP plotter & GP-IB interface cards. *

* Hired or loaned pool items

Abbreviations & Terms

Aerial	British term for radio wave gathering device or antenna.
AM	Amplitude Modulation - where a signal (whether noise or intelligent) rides directly on an RF wave in envelope form. This type of modulation is readily demodulated by a rather common thing: non-linearity in anything an AM signal passes through. Most 'RF' we 'hear' is likely any noise that is the demodulation's product, a noise signal which 'hitched a lift' on the RF as carrier wave.
AP	Audio Precision Inc's equipment is *de facto* standard for audio equipment perf. testing, company being founded by ex-Tektronix engineers. Units commonly known by all as 'A P', In Jan '86, author with Jerry Mead was 2nd UK user, after BBC, of the original *System One* instrument; a slightly later unit remains in frontline use today.

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cord	American English for cable or colloquially, flex.
cable	British English for cord or flex-cord.
CM	Common Mode - signals common to a signal pair, measured to some other place, usually ground referred.
c.p.c	Circuit Protective Conductor, British electrical installation terminology for the earth (UK) or earth-ground (US) conductor.
DM	Differential Mode - signals arising in 'the wanted place' - across a signal pair.
FM	Frequency Modulation/lated. A signal riding on RF, with its amplitude variation coded as frequency deviation. Harder still to visualise, signal frequencies are coded as *rates* of deviation. Simplistic explanations of FM in text books at all levels, and back to 1950s, imply or leave the reader assuming, that the signal's amplitude is not amplitude modulated in any way. But natural conditions in transmission path/s can do this readily [8].
HF	High Frequency
LISN	A filtrative and impedance-standardising network specified in some standards for AC power testing.
LF	Low Frequency
LW	Long Wave
mains	The public AC supply, the AC line.
MW	Medium Wave
prf, PRF	Pulse Repetition Frequency, the 'outer' pattern (or envelope) when a signal (having a higher frequency) occurs in regular bursts - the frequency of repetition of those bursts, not that of the signal that forms the bursts.
RCD	Residual Current Device. A device fitted to detect earth leakage currents.
SW	Short Wave
VSWR	Standing Wave Ratio, Voltage. At RF, a measure of the amount of impedance mismatch, voltage-wise. Very much what a radio transmitting 'ham' measures with an SWR meter.
Woven *Cable*	Cable here refers to a single transmission (send & return) path, as regards the weave, even though an earth wire down the centre may be involved, and even though the weave comprises multiple strands (which are paralleled).

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ENDs