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EMC CONDUCTIVE EMISSION PERFORMANCE OF PROFESSIONAL POWER AMPLIFIERS - A PRELIMINARY STUDY

K Dibble (1) & A Mornington-West (2)

(1) Ken Dibble Acoustics, Rugby.
(2) Quad Electroacoustics, Huntingdon

1. INTRODUCTION

This paper arises from an amplifier review project commissioned by Lighting & Sound International magazine in which eight professional power amplifiers having rated output powers ranging from 2 x 450W to 2 x 3.3kW were subjected to an engineering appraisal, test bench evaluation of the principal specifications and auditioning.

Since over 50% of the review samples submitted employed switchmode or other advanced circuit topology the authors became concerned over the possible contamination of the public AC mains supply and risk of conducted interference to other apparatus which often arises from such technology. With the impending UK implementation of the EU EMC Directive little more than a year away it was decided to extend the scope of the project to include EMC Conductive Emission testing. As it turned out, this was to be the first ever published review of professional audio equipment to include any aspect of EMC evaluation and as such attracted a great deal of attention from an industry apparently ill prepared for the new regulations.

An introductory article setting out the scope of the project, along with the first 3 amplifier reviews, was published in the 1994 September edition of L&SI, with 3 further reviews in the October issue and 2 more, along with some concluding observations, scheduled for publication in November. The subject matter of this paper is limited to the EMC aspects of the project, the testing procedures adopted, the results, and the early conclusions drawn.

2. EMC STANDARDS

The European Union (EU) has issued a Directive (89/336/EC) and related later amendments [1] which require that from 31 December 1995 all electronic apparatus offered to the market or taken into service within the EU shall be capable of demonstrating compliance with appropriate Electromagnetic Compatibility (EMC) standards. This has been enacted in the UK as Statutory Instrument 1992/2372 [2].

The preferred route to demonstrating compliance is through the use of product-specific, or product family-specific standards. Self certification can only be achieved by this route. Further clarification from the European electrical standards body

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CENELEC states that where product family-specific standards exist they shall have precedence over the generic standards. The generic standards EN50 081/1/2 (emissions)) and EN50 082/1/1 (immunity) - both of which are currently under revision - are thus only available to those who are manufacturing or importing apparatus which will need to show compliance with the Directive by the production of a Technical Construction File (TCF). The production of a TCF is not a trivial matter and perhaps the only apparatus throughout the whole of the audio and video product spectrum to which this may apply is the bulk eraser. We apologise for using so many two and three letter acronyms (TLA) but they do form part of the European Acronym Mountain (EAM).

Those not resident in the EU, or not aware of the effect of the enacted legislation, should note that a criminal offence may be committed by the person who places on the market or takes into service any apparatus which ix not able to demonstrate compliance with the appropriate EMC standards. This is because such a product can not have the CE Mark legally affixed. The principal method by which it is expected that manufacturers will declare compliance is through the act of self-certification. The declaration of conformity (DOC)) is a legal document which must be signed by a responsible EU national on behalf of the manufacturer or importer, and should be provided with each instance of the product. Essentially a manufacturer or an importer is required to evaluate the design and assembly and carry out such tests, for both emissions and immunity, as will provide sufficient confidence. As a matter of technical and commercial prudence the manufacturer, or importer, will retain copies of the evaluation and test data in a technical file (this is not the same as a TCF) since this file may be requested by a trading standards or customs official should the need arise to settle any enquiry. Manufacturers who will be producing large numbers of the same item in the production process will undoubtedly wish to subject the apparatus to the full range of emission and immunity tests This is a specialised and complex procedure which will normally require the services of a nationally accredited EMC text house.

A group of concerned engineers from the professional audio, video and lighting control industries (PAVI) came together to represent the wide swathe of industry which is encompassed by that umbrella and now work as a BSI panel. They recognised that the generic standards would require excessive interpretation by EMC test houses in relation to the apparatus under test and that, in conjunction with the view that some of the tests required were either inappropriate, irrelevant, or even dangerous, started to work on a proposal for a PAVI oriented standard. In accordance with EU procedures this activity was announced to CENELEC under the Vilamoura Procedure and since 1993 the focus of the work has been European. At the time of writing the standards are close to being published as drafts for public comment (DPC) and are likely to be titled prEN55 103/1 (emissions) and prEN55 103/2 (immunity). The generic documents have, however, been used to provide guidance as to the essential requirements. Apparatus intended to radiate - radio microphones and mobile TV cameras arc examples - are subject to additional regulations which have been published by the European Telecommunications Standards Institute (ETSI) {3}.

3. THE CE MARK

The CE symbol - a specifically designed logostyle based on the letters CE - is required to be affixed to a product to which an appropriate EU Directive applies in order to Indicate that the product can demonstrate compliance. Incidentally the term "product" comprises the physical object itself, the packaging and the marketing mix by which it is presented. This is important as products intended for different markets attract different EMC family-specific standards. The PAVI standards refer to professional products. only and the packaging and marketing convey the distinction between those products which are otherwise intended for strictly household use [4].

However the CE mark also indicates compliance with other Directives which may be in force at the time of placement on the market of a particular product. In this regard it should be noted that as of 1995 January 01 the CE Mark may also indicate that an electronic or electrical product also satisfies the EU Low Voltage Directive (LVD) [5]. There is a 'phasing in' period up to 1997 December 31 after which time compliance will become mandatory. For PAVI apparatus this will mean compliance with EN60 065. This is similar to IEC 65 and BS415:1994.

4. TESTING

One of the key processes in setting these standards has been the need to check that the limits and tests are appropriate to the apparatus in use and capable of being met. Accordingly some of those taking part In the UK BSI panel have been able to share the results of such EMC. tests as have been available. Several problems exist in this regard. The PAVI panel comprises represents of several UK trade and industry bodies including the Audio Engineering Society British Section (AES), the Association of Professional Recording Services (APRS), the Association of British Theatre Technicians (ABTT), the Institute of Sound and Communication Engineers (ISCE), the International Association of Broad&ast Manufacturers (IABM), the Professional Light and Sound Association (PLASA), the Sound and Communication Industries Federation (SCIF), and representatives from competent bodies (nationally accredited EMC test houses). Quite understandably many of the individuals involved work for companies who are also applying themselves diligently to the issues of achieving compliance. Naturally it has been difficult to receive any but anecdotal evidence as to their progress in achieving compliance and it has been sufficient to rely on the absence of any complaint that the standards can not be achieved in order to be assured that the limits proposed in the standards are realistic.

Hiring an accredited test house is an expensive process. Depending on the type of work and the need to provide written reports, the figure ranges from £500 to £1000 per day though "loyalty deals" are usually available. In the context of the amplifier review project we were fortunate in being offered one day at RFI in Dunlop, Ayrshire, at no charge, to carry out a set of measurements of just one of the several EMC phenomena which are required under the standard. Since we were primarily interested in the power supply topology of these amplifiers we chose to look at the AC power port conducted emission phenomena over the range 15OkHz to 30MHz. - which appears as test 6 in the current draft standard.

5. EQUIPMENT SETUP

Each amplifier in turn was installed in an RF shielded room and its mains input cable connected to a Rohde and Schwarz type ESH2-Z5 Line Impedance Stabilising Network (LISN). This device provides filtered AC mains power to the apparatus under test (AUT) from a uniform impedance source and makes the interference component available at a test socket. The measurement equipment comprised a Rohde and Schwarz ESB1-RF measuring receiver with a type ESAI-D display unit located in an adjoining instrument room.The LISN was positioned on a wooden table 4OOmm from one of the galvanised steel walls. The AUT was mounted with its front panel 400mm from this wall and with the chassis side 400mm from the LISN, as per the requirements of EN 61 000. This orientation was chosen to provide convenient access to the rear panel connectors and mode switches for ease of connecting up.The amplifiers were exercised and set up with the aid of support equipment which was mounted on the same bench further away. This comprised a fan cooled 6kW dual-channel non-inductive dummy load, a 20Hz - 20kHz band limited pink noise source with a 6dB crest factor, a calibrated true RMS DVM and a dual beam oscilloscope.

Following the recommendations in EN61 000-3-2 and EN60 065 section 4.6.2b the amplifiers were set up to produce 1/8th of their rated output power into a 4 ohm load using the pink noise as the excitation signal. When the gain is adjusted such that a properly calibrated amplifier clipping indicator is just triggering on pink noise signal peaks, the RMS power output will be found to be very close to 1/8th power. The operating conditions were monitored using the DVM and the oscilloscope.

6. EXPERIMENTAL PROCEDURE

Firstly, as with all good laboratory practices, a no-load plot was recorded to show the residual RF noise of the room and the measurement apparatus with only the support equipment operating. This is shown at Fig. 1 which will also serve to illustrate the format of the results presentation. The two limit lines show the Class B average and quasi-peak limits taken from the draft PAVI standard.

The full test procedure requires that each amplifier is measured for conducted emissions on both live and neutral lines using both quasi-peak and average detectors. This is a time consuming business which would have halved the number of amplifiers we could assess in our allotted day. In the light of this limitation we elected to plot both live and neutral lines - there Is sometimes a significant difference - but using a peak detector as this is considerably faster. Justification for this is that we expected most of the amplifiers would perform well above the limit and that post measurement processing could be used to determine the precise average and quasi-peak values of any marginal activity peaks. Indeed, of one of the results, the supervising engineer commented that a broadcast licence should really have been applied for! There was, however, one amplifier in particular whose performance using the peak detector was so close to the limit that a brief investigation at some spot frequencies was justified.

Also because of the time restriction we were unable to carry out any significant investigative analysis of the results at the time and neither was it possible to attempt any remedial work with the units. In this sense the AUTs were being assessed in much the same way as any unaccompanied apparatus might be assessed.

7. AUT TOPOLOGIES VS PLOTTED RESULTS

For reasons of anonymity the plots reproduced here are identified by their test reference numbers followed by the total rated output power at 1kHz into 4 Ohms. For economy of space only the live line plot is shown.

CS/01/01 (1kW) This is an extremely compact PWM switching design which shows strong evidence of its 66kHz internal power switching frequency and a significant clustering of energy around the 7MHz region.

CS/01/02 (1kW) uses an entirely conventional power supply but with a high conductivity esoteric steel transformer core to minimise winding density. This shows programme related excursions up to 30dB beyond the limits between 150kHz & IMHz.
CS/01/03 (3.6kW) This very powerful amplifier has two separate power supplies based on conventional transformers, bridges and smoothing capacitors. Each psu provides two separate DC supplies which are automatically switched in parallel to drive low load impedances or in series to provide double the voltage swing when driving higher load impedances or handling high headroom programme. It has a grounded bridge amplifier topology. It can be seen that there is again considerable emissions activity below 1MHz which we believe to be signal related.

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CS/01/04 (900W) This is a conventional minimum signal path (MSP) Class AB design fed from a switch-mode power supply running at 100kHz, apparently without the provision of any significant mains filtering. The EMC conductive emissions plot clearly shows the odd order harmonics of the switching frequency out to the 29th harmonic with peak levels a clear 30dB above the Class B limit lines.

CS/01/05 (2kW) This amplifier shows significant evidence of an EMC-conscious design approach. It uses an advanced form of self regulating switch-mode supply running at 27kHz, with a load and drive level dependent output stage voltage regulator which incorporates an oscillator circuit running at 820kHz. Neither of these frequencies are reflected in the EMC plot, which was considered sufficiently close to the limit lines to warrant a spot check on the quasi-peak and average values:-

F (MHz)	qpk level	avg level	qpk limit	avg limit	qpk margin	avg margin	pass/fail
0.1618 MHz	65.9dBuV	59.7dBuV	65.4dBuV	55.4dBuV	-0.5dB	-4.3dB	fail
0.2136 MHz	56.1dBuV	51.4dBuV	63.1dBuV	53.1dBuV	7.0dB	1.7dB	pass
3.2760 MHz	49.6dBuV	49.5dBuV	56.0dBuV	46.0dBuV	6.4dB	-3.5dB	fail

CS/01/06 (1400W) This amplifier employs a patented charge/store power supply concept which is entirely load dependent, does not employ a high frequency oscillator, and drives a commutated rail Class H amplifier topology. Therefore we would expect to find excitation related, rather than harmonically related, emissions. Although considerably quieter than AUTs with conventional supplies, and not-withstanding the substantial RFI filter network discovered in the AC mains input circuit, the EMC peaks were sufficiently beyond the limits to preclude further checks.

CS/01/07 (3.8kW) This substantial amplifier employs two separate, entirely conventional, transformer/bridge/capacitor power supply systems (even down to providing separate captive mains leads) and conventional Class AB output stages in which the high power output is derived from vertically and laterally cascaded output devices fed from a simple op-amp driver stage in common source configuration. Unfortunately only one of the supplies would fire up at the test site and so we proceeded on a single channel basis. Thus we would expect the net performance of both channels working to show the effect of twice the disturbance power and, given that both channels would be excited using the same pink noise signal, we might expect up to 6dB increase in interference. This would take this unit almost 30dB beyond the limit in places.

CS/01/08 (7kW) As might be expected from its power rating, this was a substantial amplifier in both physical size and weight terms. It employed a very large and exceedingly heavy 50Hz toroidal transformer with its attendant bridges, capacitors and regulators to generate three separate supply rails at +/- 16V, +/- 65V and +/-

165V. Amplification is accomplished in three stages according to the signal demand. Small signal conditions are handled in "audiophile" Class A, moderate signals in Class AB with peak or transient signals handled in Class H deploying the 165V rails. The EMC performance shows programme related modulation in excess of 30dB beyond the limit up to 400kHz with significant activity continuing up to 2MHz. Clearly, the introduction of an RFI filter to a 10kVA rated appliance would not present a practicable solution in terms of physical size or cost.

8. A FURTHER TESTING OPPORTUNITY

Courtesy of Rohde & Schwarz UK and ISCE, we were able to run a demonstration of EMC testing at Lighting & Sound '94 exhibition at Earls Court 2, with test specimen CS/01/07 as the AUT. Recognising that the Earls Court environment cannot reflect the controlled conditions obtaining at the RFI test site, we took the precaution of carrying out an RF background noise test. Although this was higher than in the RFI screened room (Fig.1), it was nevertheless not out of order, being typically around 15 - 20dBuV. Further confidence was gained when the 1/8th power pink noise plot for this amplifier measured during the demonstration bore striking resemblance to that measured at RFI, so it seemed that we were measuring more or less the same things despite the lack of a controlled RF environment.

The common factor amongst the review amplifiers with conventional power supplies is the emission activity between 150kHz and 1MHz, usually with a rising amplitude characteristic towards the lower end of the frequency scale, and which we have loosely attributed to the fluctuations in the pink noise test signal appearing as current modulation in the mains transformer primary windings. To verify this we retested CS01/07 under no signal conditions and found a very different EMC result.

Unfortunately we did not have a plotter on the stand and so can only report the findings from notes and sketch plots taken down at the time. Fig.2 shows a hand drawn reconstruction of the background noise and the CS/01/07 no-signal results, superimposed on the Rohde & Schwarz grid for illustration purposes. The broadband activity below 1MHz has been replaced by a peak centered on approximately 750kHz. Similar tests carried out on two further professional power amplifiers, both with conventional power supplies, showed essentially similar characteristics.

In an attempt to further investigate the emerging EMC characterisics, we tested two power supply units from a video doorphone system which was stated by its manufacturers to have a 6MHz video carrier frequency. One psu employed a conventional toroidal transformer and regulator, the other, switch-mode topology. On load, the conventional transformer/regulator psu produced the same 750kHz peak characteristic but at a lower level - typically 75dBuV - plus a series of notable peaks at

6, 12 and 18MHz, which were attributed to the video carrier frequency. Off load these disappeared, leaving just the 750kHz peak above the limit lines. The switch-mode supply appeared to conform to the limit lines on and off load. Like the switch-mode amplifiers tested, it did not produce that 750kHz peak, but it did appear to reflect the video carrier harmonics. Fig.3 shows a hand sketched reconstruction of these results.

9. CONCLUSIONS

The effect of using a random excitation signal is that detail within the envelope of the conducted emission disturbances vary. Were it possible to carry out duplicate sweeps at fixed frequency sinewave tones then consistent structure might be revealed and this would be useful in any remedial work. Some of the plots however show considerable structure which reflect the chopping rate of the high power, high frequency switching within either the amplifier or the power supply system. In others it is possible that radiation from internal microprocessors or other switching activity has been poorly handled. Internally some units showed evidence of attempts to control RF emissions whilst in others this was at best vestigial if not entirely absent.

Any conclusion has to be tentative, partly because it was not possible to investigate the emission performance in any detail nor the circuit topology in any depth. All of the AUTs are currently marketed as professional audio power amplifiers. It may be fair to comment that those units which employed conventionally based approaches to power supply design - ie mains transformer, heavy duty diode bridge and large storage capacitors with no filtering - seem to present the worst plots. It is likely that these units might prove more difficult to tame - although test specimen CS/01/04 embodies a switch-mode supply yet is well outside the draft PAVI limits and thus appears to break the rule. The most promising unit, CS/01/05, provided evidence that it is possible to produce high powers - 1kW into 4 ohms per channel continuously - whilst approaching the required limits for conducted emissions. This unit was closely followed by CS/01/06 which was a little worse but, in the experience of the test house, might be retrievable with a little further work.

A note of caution should however be sounded because there are other phenomena which are listed In the current draft of the PAVI standard. The current full list shown here reflects recent changes which were proposed after the tests herein reported were carried out:-

Enclosure radiation 80MHz to 1000MHz
Enclosure magnetic field from 50Hz to 10kHz measured at 100mm
Enclosure magnetic field 50Hz to 10kHz, measured at 1m
AC power port conducted emissions, mains current harmonics 0Hz - 2kHz;

AC power port conducted emissions, voltage fluctuations imposed on the supply
AC power port conducted emissions 150kHz to 30MHz
AC power port conducted emissions, clicks and discontinuous disturbances
AC power port conducted emissions, inrush current
Antenna aerials of receivers conducted emission 30MHz to 1000MHz
Signal and control ports, DC power ports conducted emissions 150kHz to 30MHz

It Is likely that the problems experienced by large power amplifier manufacturers are not those which are shared by manufacturers of other audio and video products. This may be partly because the power demand of such units is more constant and that for some time, designers In this field have had to cope with the need to eradicate the audible evidence of processor noise from signal input and output ports. However there is, at present, little evidence to show that any serious evaluation of the EMC performance of any of these units has been carried out. What is becoming clearer is that electronic design cannot be sensibly accomplished with the limited resources of first year university or college electronics courses and the overabundance of zeal of a proselytising disc jockey on speed! It is clear that future designs must incorporate a proper evaluation of the EMC aspects of the design from the outset. This factor alone should force mature companies to recognise the worth of fully qualified design and production engineers on their staffs as it is no longer satisfactory to rely on amateur attitudes and its consequent half science.

10. ACKNOWLEDGEMENTS

We were grateful to RFI for making their test house facility available to us and for conducting the tests for no charge. We are also grateful to the providers of theAUTs. We hope that the Industry will appreciate that the problems associated with EMC will not go away but that the technologies do exist by which the EMC Directive can be met.

References:-

[1] The initial Directive was 89/336/EC, as amended by 92/31/EC. Official statements concerning Directives and their adjustments are made in the Official Journal of the EC (OJEC) and is published in several languages.
[2] The EMC Regulations, Statutory Instrument 1992/2372, HMSO, London.
[3] Draft Standard ETS RES 080301, 1993 March "EMC Standard for Wireless Microphones & Similar RF Audio Link Equipment".
[4] The generic standards for residential, commercial & light industrial environments are EN50 081/1 for emissions and EN50 082/1 for immunity.
[5] "CE Marking and the Low Voltage Directive ", DTI, 1992 September.
[6] EU Directive 93/C28/02 "Harmonised Use of the CE Mark", OJEC, 1993.

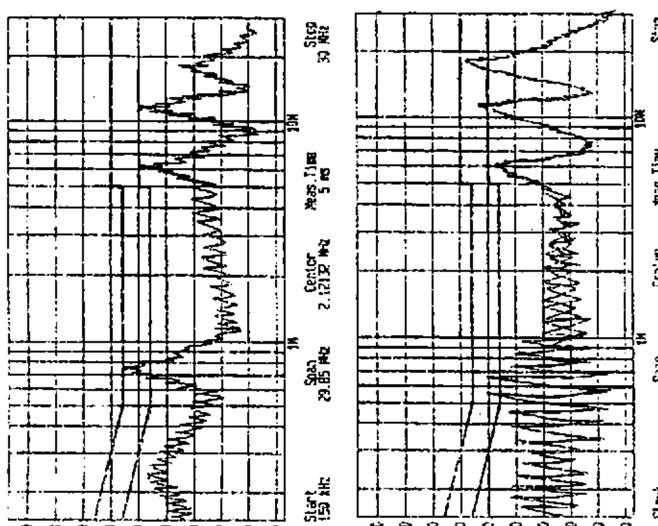

Fig 3 POWER SUPPLY CHARACTERISTICS

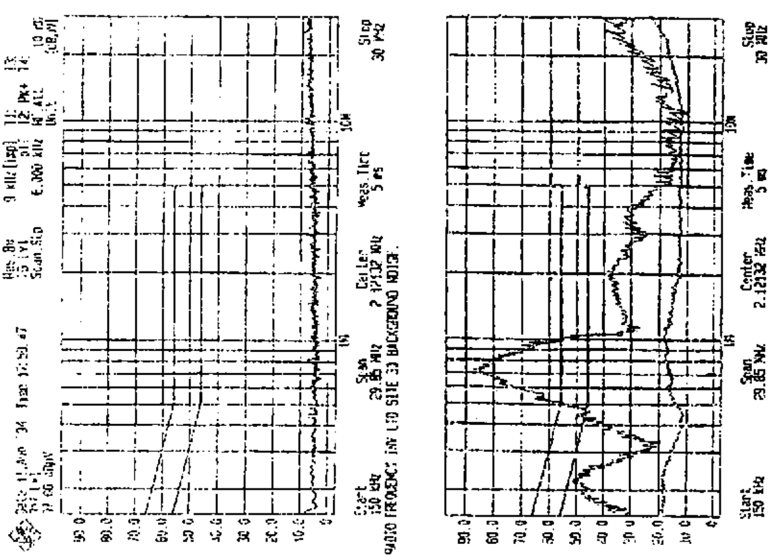

Fig.2 C30/1/87 NO SIGNAL + B/GND NOISE

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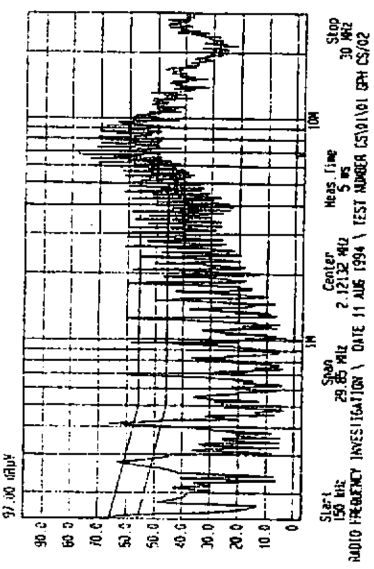

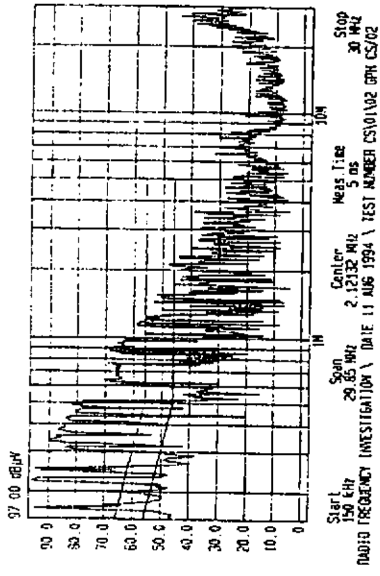

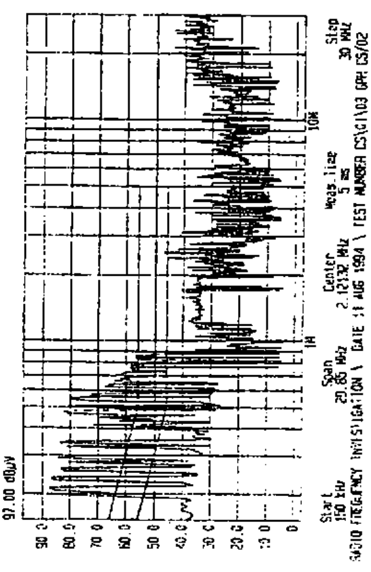

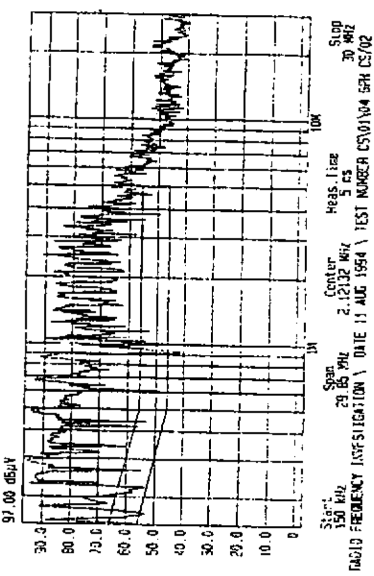

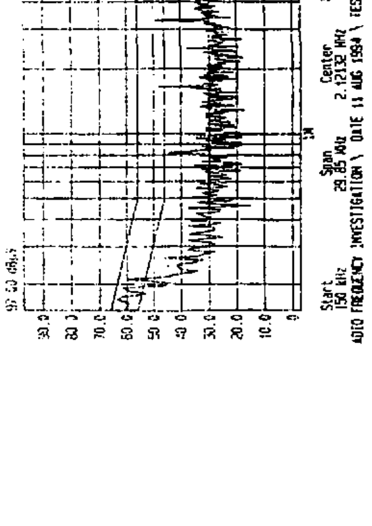
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90.0
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50.0
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1M
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Start 150 kHz
Span 29.85 MHz
Center 2.12132 MHz
Meas.Time 5 ms
Stop 30 MHz
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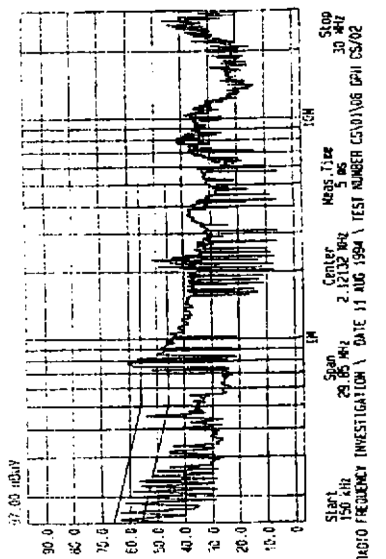
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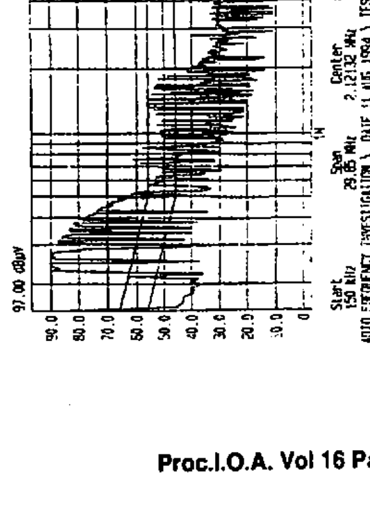
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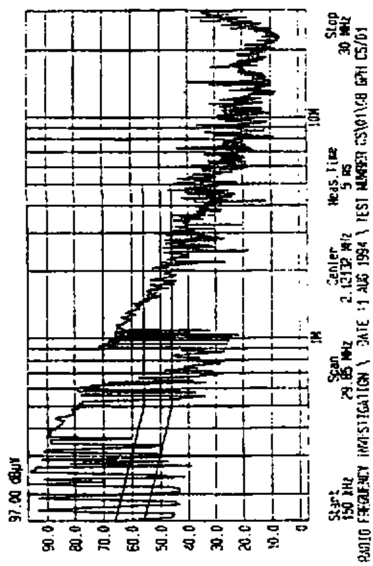
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Start 150 kHz
Span 29.85 MHz
Center 2.12132 MHz
Meas.Time 5 ms
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