Government
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REPORT ON IMMUNITY TESTS - TV RECEIVERS, EMC EVALUATIONS

M. NIHAT YAZAR
AL R. LAVIS

REVISED EDITION - DECEMBER 1977

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SUMMARY

Background - The Department of Communications' inspection workload has increased considerably in the last few years due to complaints of TV set owners that their reception was disrupted by the emissions of radio transmitters in the vicinity. Investigations have shown that some of these complaints were due to inadequate ability of the TV receivers to reject out-of-band radiation but little quantitative data was available on the out-of-band susceptibility of typical modern TV receivers.

Objective - To acquire, within existing personnel and capital resource limits, factual information regarding the susceptibility of TV receivers to out-of-band radiation, viz:

- for a limited sample of TV receivers typical of those currently in use
- for two values of desired input signal
- for the frequency range 0.5 - 500 MHz
- for interference entering by the antenna terminals
- for interference coupling through the power leads (restricted scope)
- to measure the level of unwanted signal required to create at least one subjectively defined grade of picture degradation.

Conclusion

1) TV receivers are susceptible to out-of-band emissions coupled through their antenna ports.

2) TV receivers are susceptible to out-of-band emissions coupled through their power leads.

3) The degree of susceptibility varies widely from set to set.

4) The susceptible frequency range varies widely between sets.

5) No set tested was immune to levels of out-of-band input signal such as are likely to be encountered in their normal environment due to the emissions of licensed transmitters (see Appendix A).

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1. INTRODUCTION AND OBJECTIVE

a) The explosive growth of radio services and the related increase of electromagnetic radiation ambient levels brings modern society to the point where the relatively severe regulations introduced to control interference at the source are no longer adequate. It has become apparent that the burden of permitting the simultaneous operation of radio/television receivers and transmitters does not fall solely on the transmitter manufacturer but also on the receiver manufacturer. The receiver manufacturer must provide sufficient immunity to signals outside the desired pass-band.

b) In comparison with the interference on the tuned frequency band of TV receivers, which is relatively well covered by the literature, there is little information available concerning the behaviour of a receiver in a strong electromagnetic field outside its pass-band. As part of a program for dealing with the lack of immunity to electromagnetic radiation of consumer electronic equipment, receiver susceptibility evaluation tests were performed at the DOC Telecommunications Engineering Laboratory. The objective of the tests was to gather preliminary susceptibility data on actual TV receivers outside their operating pass-band in order to evaluate the immunity inherent in the current design of TV receivers within the time and resource limitations of the laboratory.

c) The evaluation, tests, observations, and results are presented in some detail due to the originality of the subject.

2. BACKGROUND

A preventive program for improving immunity of consumer electronic equipment has been undertaken by the Department of Communications (DOC) and consists of:

1) Improved public awareness through the dissemination of radio field information and interference complaint statistics,

2) Consultation and cooperation with the home entertainment electronics industry to develop, as a first step, a voluntary standard for equipment immunity,

3) Promotion of international recognition of the problem and international action to resolve it.

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A major problem with the development of voluntary standards for equipment immunity is the lack of electromagnetic compatibility (EMC) methodology for testing the equipment to immunity standards. A total of about 17 possible main EMC modes (characteristics and tests) are needed to fully characterize the EMC behavior of electrical/electronic equipment (13) and these are described in Table I (5 emissions, 10 susceptibility, 1 internal compatibility and 1 stability). Twelve of these modes would be applicable to TV sets.

There is no established complete methodology, as far as TV receivers are concerned, for measuring interference effects. There are about 10 documents (standards, specifications, regulations) available dealing more or less with some limited aspects of EMC tests on TV receivers, References (1) to (10). None of them is complete or directly applicable (i.e. includes all frequency ranges, procedures, set-ups, modes, parameters, etc.).

Due to time and resource limitations, it was decided to perform conducted susceptibility tests, into antenna terminal input (CS04) and power supply line input (CS02) of actual TV receivers outside their operating pass-band. The applied tests were among the least controversial and most straightforward modes as far as the set-ups (but not the limits and evaluations) are concerned. Three documents (2), (7), (9) deal with CS04 method and one document (7) deals with CS02 method limited to signal and IF rejection.

3. SUMMARY OF THE TESTS PERFORMED

The following tests were performed in accordance with the objectives and requirements established in Section 1, the Test Plan prepared by Telecommunications Engineering Services, and Telecommunications Engineering Laboratory, and the subsequent evaluative discussions held between the experimenters during the tests:

3.1 CS04 - Spurious response to interferor (CW, 20-300 MHz) injected into antenna input terminal of 11 receivers, each operating in normal reception mode (channels 2, 5, 7, and 13);

3.2 CS04 - Extension of Test 3.1 with interferor covering .5-20 and 300-500 MHz bands for 4 receivers;

3.3 CS02 - Spurious response to interferor (CW, 20-300 MHz) injected into power supply line of 4 receivers, each operating in normal reception mode (channels 2, 5, 7, and 13);

.../6

3.4 Evaluation of the susceptibility of the test results to changes in parameters such as: desired signal type (cable input, colour bar simulator), signal level, the effect of AM and FM modulation of interfering signal, picture quality and degradation assessment, sound degradation, the use of directional coupler instead of splitter, single channel feed, etc.

The tests were performed by A. Lavis and N. Yazar with the close cooperation of Laboratory and HQ staff, and were completed within the projected time duration of about 10 working days.

4. TEST PROCEDURE

4.1 Procedure Applied

The following steps were applied for the tests:

SET-UP para (4.2)	(1) Set-up as per Figure 1 (for antenna terminal interference), or Figure 2 (for powerline interference).
INPUT SIGNAL para (4.5)	(2) Adjust the tunings and settings of the TV receiver to obtain the best colour bar display for antenna terminal signal input level of 0 ± 5 dBmV.
INTERFERING SIGNAL para (4.6)	(3) Set the CW interference signal injection level to 60 ± 2 dBmV calibrated at injection point (to Antenna input cable, or Power Line Networks) at 20 MHz on 50 or 75 ohm load, delivered through 10 dB step attenuator and low-pass filter (items #3 & 2 of Table II and Fig. 1 & 2)
PROCEDURE DISCUSSION para (4.7)	(4) Start scanning the frequency of the interference signal (fast manual scanning of about 1 MHz/sec in low range, 10 MHz/sec in high range) until a disturbance (*) on the TV display is noticed.
	(5) Make sure that the disturbance is not caused by the harmonics of interference signal generator by switching the low pass filter to the proper range.

(*) SEE NOTE NEXT PAGE

DEGRADATION CRITERION para (4.3)

TEST PHILOSOPHY para (4.4)

(6) Decrease the frequency until the disturbance disappears, then increase slowly until the disturbance becomes clearly visible. Switch OFF and ON the interference signal generator output in order to ascertain that the effect is caused by the injected signal (*). Record this frequency (MHz with one decimal point) as the lower edge of the perceptibility bandwidth.

(7) Increase the frequency until the disturbance becomes unnoticeable, then decrease slowly until it becomes clearly visible. Ascertain as in step (6) that the effect is due to the injected signal. Record this frequency (MHz with one decimal point) as the higher end of the perceptibility bandwidth.

(8) If interference occurs in a narrow frequency range (less than 0.5 MHz), just record that frequency ±0.2 MHz.

(9) Measure all interference-causing frequency bands repeating steps (4) to (8) throughout the projected evaluation frequency range under consideration.

(10) Repeat steps (4) to (9) for interference levels of 50, 40, 30, 20, 10, and 0 dBmV, each time introducing the required attenuation by switching the 10 dB step attenuator.

4.2 Test Set-up, Measuring Equipment and Site

Test set-up block diagrams are as shown in Fig. 1 (antenna terminal input interference) and Fig. 2 (powerline interference).

The test equipment used during the tests is listed in Table II.

(*) - The disturbance to be observed is similar to Moiré patterns in optics. It has the shape of parallel bars and/or hyperbolic or parabolic configuration (changing) dependent on sig. gen. and TV oscillator stability.

- Disregard white noise interference, which may be caused by the interference sig. gen. white noise on the pass-band of TV channel, which appears as snow or confetti noise all over the CRT face.

Although it would be desirable to perform the test in a low noise environment, the size and the type (racks) of the input signal simulator (items #9 to 17, Table II)precluded the use of a shielded enclosure. The use of such facility with some of the equipment installed outside the shielded room requires more elaborate set-up and therefore more time.

The test set-up location was near the colour bar generator racks in the Lab. usually reserved for TV evaluations.

The positioning of the equipment (ground planes, equipment height, etc.) was not a parameter having appreciable effect on the results of the tests under consideration.

4.3 Degradation Criterion

There is no established quantitative method for measuring interference effects in video and audio signals and investigations concerned with the development of such a standard were considered beyond the scope of the project.

Three EMC documents containing TV degradation criteria prescribe:

- "Just visible pattern" (2) (7)

- "Just perceptible level" (9)

- "Disturbance of the brightness or synchronization" (7)

The minimum perceptible change in a video or audio signal subjected to interference appears to be relatively consistent among persons with normal vision, hearing, and with similar tolerance. A "Clearly Perceptible" change was accepted in our case as the least subjective degradation criterion possible considering the circumstances (see para 4.4).

There are no recent studies which develop a reliable relationship between the subjective acceptability of a TV image when interfered with by a discrete frequency in the presence of noise (12).

4.4 Test Philosophy

a) There are two possible testing philosophy directions (based on ideal or real life conditions) which may be adopted:

(1) High quality requirement, worst-case approach:

The determination of minimum level of interference causing minimal amount of defect as evaluated by a very sensitive and intolerant (discriminating) viewer, assuming that a very good TV picture transmission is available.

(2) Average-case approach:

The determination of a clearly perceptible level of interference for an average tolerant viewer, assuming that average commercial TV picture quality is generally poor due to several real life conditions.

b) The philosophy to be accepted depends on the purpose of the test, the nature of the display, the nature and value of the parameter to be measured (subjective-objective), the required accuracy and time & resources available.

The adopted direction was the average-case approach for the following reasons:

(1) The tests were conceived in order to obtain preliminary information on the general behaviour of a group of available TV sets in a very limited time period.
Accurate TV evaluation tests require much more time and resources than is generally realized, see Ref(11) as an example.

(2) The picture quality during the tests was generally poor due to uncontrollable interferors and the condition and the quality of TV sets, therefore precluding an accurate (better than ±5 dB) determination of perceptibility level.

4.5 Input Signal, desired

The desired input signal was provided by the colour bar generator (items #9 to 17, Table II, Fig. 1 & 2) available in the Lab. This source yielded a steady and reliable display (i.e. constant reference) throughout the measurements for all TV sets.

There was no appreciable difference in test results when CATV or direct reception were used as input signals, compared to colour bar display, provided that enough time was spent waiting for a relatively steady picture. Therefore, colour bar source was preferred.

The input signal level (picture carrier) for all channels were set at about 0 dBmV. The degradation did not depend on signal input level from about -10 dBmV to +10 dBmV. This behaviour is characteristic of high power wide band interference in contrast with frequency dependent spurious responses which are a function of the desired signal level applied.

4.6 Interfering Signal

The interference signal up to 1 Volt level (0.5 to 500 MHz) was simulated by a signal generator (item #1, Table II). Controllable AM and FM modulations were available. The tests were performed using CW interference injection for simplicity and for the reason explained below.

The observed interference pattern on the screen had the shape of rotating parallel bars (alternate dark and bright lines and mixed colours) for interference below about 20 MHz and was optically equivalent to the superposition of two moving mesh screens in VHF range. CW interference causes gross, (thicker line) patterns. The modulation of interference yields finer patterns (staggering and subdivision of interference bars).

The level of accepted degradation criterion (para 4.3) is about the same for modulated and unmodulated signals provided that the peak powers of CW and of the strongest spectral component of modulated signal are the same.

Injected interference level maximum was 60 dBmV due to the signal generator output limitation and also to avoid probable damage to rented TV sets. Available documents prescribe different maximum levels such as: -10 dBm (2), as high as possible (7), and a minimum of 2 Volt in (9).

4.7 Procedure, Discussion

This matter will be presented here in some detail due to the interest shown and comments made by more than one contributor.

.../11

a) There are two possible detailed measurement procedures which can be followed for plotting a response curve consisting of a level y (ordinate - horizontal level) vs. frequency x (abscissa - vertical value) depending on which parameter is taken as variable, the other one being kept as constant.

In our case the perceptibility point (degradation criterion para 4.3) vs. frequency can be determined either by injecting a constant level of interference and varying the frequency (horizontal cross section of response curve) or by keeping the frequency constant and changing the level until the perceptibility threshold is reached (vertical cross section).

The procedure to be followed depends mainly on the purpose, slope of the curve, required accuracy (frequency & level), the nature of the display, measuring instrument capability, and above all on the convenience of measurement and time available (if there are hundreds of measurements to be performed).

b) The adopted procedure consisted of taking horizontal cross sections (perceptibility bandwidth measurement very similar to e.g. 3 dB or 20 dB bandwidth measurements) in order to reduce search-and-measure time to a manageable 5 days total (about 2000 points, one minute each).

Perceptibility level resolution (for the available picture quality) was about ± 5 dB therefore there were about seven differentiable levels from 0 to 60 dBmV interference. Vertical cross section method would require more than 10 days testing time only, for 5-10 MHz spacings 1.5 minutes each (frequency setting $\pm\Delta F$ search, several level adjustments with step attenuator and vernier, analog dial reading), and additional plotting and curve averaging time.

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4.8 Powerline Test (Conducted interference susceptibility)

There is only one TV-EMC document available (IEC-107) dealing with CS02 methodology and only for the signal frequency and for the intermediate frequency (Mains interference suppression ratio, para. 4.6). There is no available manufactured standard connection network but the circuit arrangement is shown in Figure 18 of this document (7).

The injection of the RF interference into the power line may be provided by using the networks specified for CE03 tests (conducted emission, power line). There are five such documents (1) (3) (5) (6) (10). The prescribed Power Line impedance networks basically consist of coupling capacitors for RF injection and A.C. isolation and inductances for the isolation of the mains side. One of the functions is to define and stabilize the impedance. One such device (usually called an IRE network) was available in the Lab and and was used during our CS02 test (item #18, Table II & Fig. 2).

A preliminary evaluation of the connection method (injection to one line at a time or to both lines in parallel) revealed that some of the TV sets were more susceptible to interference on one line than the other. It was decided, for the sake of reproducibility and simplicity of measurement, to inject RF to both lines in parallel. Ref (7) also prescribes that approach.

The real level of the injected voltage depends on the TV design, cable connections, and the impedances involved. So the calibration procedure applied consisted of the measurement and adjustment of the injection point level at 60 dBmV (50 ohm match) with the spectrum analyzer (item #4, Table II) and then the application of that available power to the RF connection terminals of the network.

5. ITEMS TESTED

The tests were performed using randomly available TV receivers in the rental market. Ten colour TV sets (mostly 19", different makes) were rented from rental companies. A total of 11 sets were tested with the addition of one set available in the Laboratory. The sets were numbered

from 1 to 11 for the purpose of de-identification in order to avoid non-qualified value judgements.

The sampling (limited in number) represents fairly well a cross-section of TV sets under normal usage conditions.

A subjective picture quality assessment was carried out in order to have a relative record of the condition of the receivers (see para. 7.2.1).

6. ACCURACY OF MEASUREMENTS

No test will be complete without the discussion of the accuracies and tolerances involved. The accuracy control in EMC is a very elusive subject which regularly escapes the grasp of analysts.

First, a discussion of accuracy range in EMC measurements will be presented. Secondly, some of the parameters related to our measurements will be reviewed in order to have an idea about the range of variables involved. Finally, the concept of an EMC standard as applied during the tests will be explained.

6.1 EMC accuracy range, discussion

a) There is no use in arguing about the decimal points of the gain of a VHF antenna. There is even no point in discussing whether the antenna has 2 or 4 dB gain when other variables introduce a higher range of statistical dispersion, say ±12 dB (i.e. a factor of x 100 over 4 dB).

In EMC an acceptable ratio of desired to undesired signal is very difficult to arrive at because of the additional subjective nature of the problem.

However, when the analyst-engineer is compelled to do so he is able to solve the problem (or rather he approximates a solution) with:

i) many assumptions in order to confine the problem to some manageable parameters,

ii) a reasonable amount of experiment to get the feeling that one is dealing with real entities.

A good example is given by W.L. Hand (12) in the case of CB-TV interaction. Despite the many assumptions the range of the variables are confinable to about ±30 dB on transmitter, and ±25 dB on receiver parameters.

b) Now one of the important points we have to retain is that accuracy costs money. There is no use in discussing accuracy without considering the corresponding resources required to obtain it. Secondly, we shouldn't look for accuracy levels we may never need.

As a general measure ±5 dB and even ±10 dB accuracies are pretty good in individual EMC laboratory tests, but similar accuracies in combined real life tests (e.g. TX + RX) are out of the reach of the EMC experimenter.

6.2 Parameters involved

The variables in our tests and their estimated accuracy ranges are as follows.

6 2.1 Degradation Criterion

The threshold of perceptibility (para 4.3) depends on what the product beat frequency is with respect to the line rate. Several studies (14) indicate that the perceptibility range may vary from ±4 dB up to ±9 dB.

In our case this variation was kept to a minimum by the fine tuning of interference in order to produce maximum visible effect.

On the other hand an unavoidable inaccuracy was introduced, due to the external interference and the picture quality difference of the TV sets (inherent quality due to design + maintenance condition).

Perceptibility thresholds (clearly visible effect) as recorded correspond to higher interference inputs, than if the tests were performed in lower noise environment (in shielded rooms). If a just perceptible effect was taken as criterion, the sets (all of them) would appear more susceptible than the recorded results. This corresponds to a parallel shift for all sets (i.e. a constant error of about 10 dB).

It was recognized that other errors relating to the subjectivity of estimating degradation exist but due to limited data on subjective assessment as related to these tests, no rigourous evaluation of these components was possible.

6.2.2 Signal input type and level

There are two variations related to signal input type (direct reception, CATV, or colour bar simulator) and the interference type (broad or narrow):

a) The desired input signal used during the tests was provided by the colour bar generator (para 4.5). If CATV is used the perceptibility thresholds would be higher (i.e. the sets will appear less susceptible) by about 10 dB for moving pictures and by about 5 dB for still pictures if not enough observation time is allowed.

b) The degradation effect is not particularly sensitive to variations of the desired signal input level for wide-band responses but it is a function of the level for narrow-band spurious responses (e.g. image) especially in the low signal level range. To give an idea about the magnitude: below 0 dBmV signal and 40 dBmV interference the threshold would be lower (i.e. the sets will appear more susceptible) by about 10 dB for each signal step of -10 dB for narrow band responses (11).

6.2.3 Interfering Signal

There are two slight variations related to interference signal type and level:

a) The level of interference depends slightly on connection lengths, and interference signal level variations of ±2 dBmV occurred during frequency tuning. That variation does not have an appreciable effect on the results.

b) The interference thresholds would be slightly higher (i.e. the sets will appear less susceptible) for a modulated interfering signal due to the more tolerable finer pattern produced by AM & FM signal (para. 4.6).

6.3 EMC Standard Concept

a) A standard in EMC (e.g. radiation, field, set-up, antenna, or device) is an arbitrary simulation set to have some comparison reference.

For example 1 or 3 m. distance cabinet radiation evaluation in chambers has no relation with the real life situation, first because there is no unique real life condition, secondly because the exact nature of the field at these distances is not known.

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The relationship between successfully meeting a particular interference criterion and achieving system EMC has never been clear, if indeed such a relationship exists.

b) As an example this concept was applied during the measurements of Power Line Conducted Susceptibility (para 4.8).

The real injected interference level depends on many parameters (design, impedances, etc.). What we did was to apply an available power at the injection point. We do not need to know the levels for all the frequencies, a difficult and lengthy task. Even if we measure them accurately that wouldn't provide much information because the rest of the link (from P.S. to susceptible circuit) is not known. All we were concerned with was the reproducibility of the test and comparability of different sets.

7. TEST RESULTS

7.1 Susceptibility evaluation tests

The results are shown in attached diagrams (pp 28-65). The overall page sequence is arranged as per the TV receiver number order. Page 28 incorporates information regarding the interpretation of all the diagrams. The data cover the following tests:

a) TV receivers #1, 4, 5, and 9.

- Antenna input responses 20-300 MHz
- Antenna input responses 0.5-20 & 300-500 MHz
- Power line input responses 20-300 MHz

b) TV receivers #2, 3, 6, 7, 8, 10, 11.

- Antenna input responses 20-300 MHz

Four pages of comparative data which were prepared during the tests are also annexed (pp 66-69). The data covers antenna input responses for 20-300 MHz and interference levels of 30 to 60 dBmV.

7.2 Other evaluation tests

7.2.1 Picture quality assessment

All the TV sets and channel settings yielded pictures of different qualities. Therefore a record of relative picture qualities was made on all sets and channels, for colour bar

and CATV display for future reference purposes. Also the corresponding signal levels were measured and recorded.

The adopted total number of grades were initially five as follows:

1 - Very Good (VG), 2 - Good (G), 3 - Fair (F), 4 - Poor (P), 5 - Very Poor (VP).

Then it was decided to extend the number of grades to about 10 to satisfy the need expressed by the evaluators (a total of 4 experimenters).

1 - Very Good (VG), 2 - Very Good to Good (VG-G),
3 - Good (G), 4 - Good to Fair (G-F),
5 - Fair (F), 6 - Fair to Poor (F-P), 7 - Poor (P),
8 - Poor to Very Poor (P-VP), 9 - Very Poor (VP),
10 - Very Very Poor (VVP).

7.2.2 Sound degradation assessment

The picture deteriorated with much lower interference levels and long before any sound degradation except on specific narrow spots. Therefore the degradation was based on picture degradation (para 4.1). A limited preliminary evaluation of sound degradation revealed that:

a) Perceptible degradation on the IF sound carrier occurs with about 15 dB less interference level than the picture degradation at the same frequency (CS04 mode).

b) Interference levels required to produce perceptible degradations on picture and sound are about the same at channel #2 sound carrier frequency (CS04 mode).

On all other frequencies sound degradation requires much higher interference levels.

7.2.3 Higher level degradation assessment

A relatively subjective and limited test was performed on one TV set (#9) to assess the difference of interference level (increase in dB required) to yield an "annoying level" of degradation compared to "clearly perceptible" level.

7.2.3.1 a) The average increase in the interfering signal to degrade the picture from "clearly perceptible" to "annoying" was:

- about 6.8 dB for evaluator #1 (+3, -3 dB)
- about 6.0 dB for evaluator #2 (+4, -2 dB);

where the same "clearly perceptible" level was used as a starting point. Individual maximum evaluation difference was 3dB between evaluators. The slight difference may be attributed to display stability variations with time as well as to value judgements.

b) The average increase required was consistent within the same range 6-7 dB as above for another evaluator #3, provided that he was allowed to set himself the initial "clearly perceptible" level.

7.2.3.2 The limited conclusions drawn from the test are that:

a) The difference in interfering signal levels required to produce "clearly perceptible" and "annoying" grades of picture degradation is likely to be consistent for any observer, although individual observers might have different opinions as to what constitutes a degradation corresponding to the term "clearly perceptible", and hence also to "annoying". In other words, the baseline level may vary between viewers, but the incremental difference between that baseline and the next degree of degradation remains relatively constant for all viewers.

b) The difference in interfering signal level between that required to produce "clearly perceptible" degradation and that necessary to produce "annoying" degradation corresponds approximately to the S/N differences (8dB) in the TASO grading system to change from a "passable" to an "inferior" picture grade (15).

c) Since, based upon these limited tests, there appeared to be a constant offset between levels of the interfering signal required to degenerate from one degree of picture degradation to the next, the remainder of the tests evaluated only the interfering signal necessary to produce a "clearly perceptible" degree of degradation.

7.2.4 UHF assessment

One TV set (#5) was evaluated at channel #24 direct reception setting, while the interference frequency was injected into it's VHF antenna input. The recorded data shows that the TV is susceptible to signals at IF down to a level of -20 dBmV (100 µV).

8. THE EVALUATION OF TEST RESULTS

How susceptible are the TV Receivers?

Any receptor is susceptible (i.e. fails to perform its function due to interfering fields or voltages) at any frequency. The unknown parameter is at what interference level a specific product degrades or ceases to function.

a) The attached curves show that set #2 which has a poor immunity level responds at channel 7 for a total injected interference frequency band of 280 MHz = 300-20 MHz as follows:

antenna input interference level	Total freq. width susceptible	Percent range susceptible
40 dBmV	78 MHz	28%
50 dBmV	108 MHz	39%
60 dBmV	217 MHz	77%

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b) a rather good set, #9, at channel #2 responds as follows:

antenna input interference level	Total freq. width susceptible	Percent range susceptible
40 dBmV	47.9 MHz	17%
50 dBmV	62.9 MHz	22.5%
60 dBmV	83.7 MHz	30%

c) the response of that same set #9 at 300-500 MHz

antenna input interference level	Total freq. width susceptible	Percent range susceptible
40 dBmV	23 MHz	11.5%
50 dBmV	86 MHz	43%
60 dBmV	114 MHz	57%

d) The trend shows that most of the TV receivers would be susceptible over the entire frequency spectrum at the next level of interference of about 70 dBmV. The results confirm and consolidate the fact that the actual TV's can barely stand conducted interferences in the order of 100 mV or less and will be completely useless at 70 dBmV interference. Similar results were obtained in 420-450 MHz and 3.1-3.5 GHz ranges on 50 samples (11).

9. SUMMARY AND CONCLUSION

The salient points of the evaluation, test, observation, and results are as follows:

9.1 Civilian/Industrial equipments, especially TV receivers are normally not designed nor manufactured in accordance with any particular EMC standards or specifications.

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9.2 The tested TV sets are susceptible to interference at any frequency. The range of injected voltages to cause interference outside the operating frequency channel (pass-band) is:

a) 30 to 100 mV at some frequencies,

b) 1 to 3 volts at all frequencies.

These injected voltage levels correspond to voltages which would appear at the antenna terminals of a TV receiver in the urban environment, as described in Appendix A, revealing that the receivers tested demonstrated very poor ability to operate satisfactorily in the electromagnetic fields which exist in urban areas.

9.3 The literature survey carried out for the documentation of the tests (methodology, procedure, etc.) shows that:

a) There is no substantial information available on the TV-EM Compatibility subject

b) The effect of radiated interference coupled via the case/chassis is expected to be more than the conducted interference effects (11).

c) There are no usable TV EMC standards or specifications (13).

10. DATA AND INFORMATION

For detailed data and more information please contact the EMC Analysis Division (Ottawa (613), 995-7862) of Telecommunication Engineering Services, Department of Communications.

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(14) Gene Walding,
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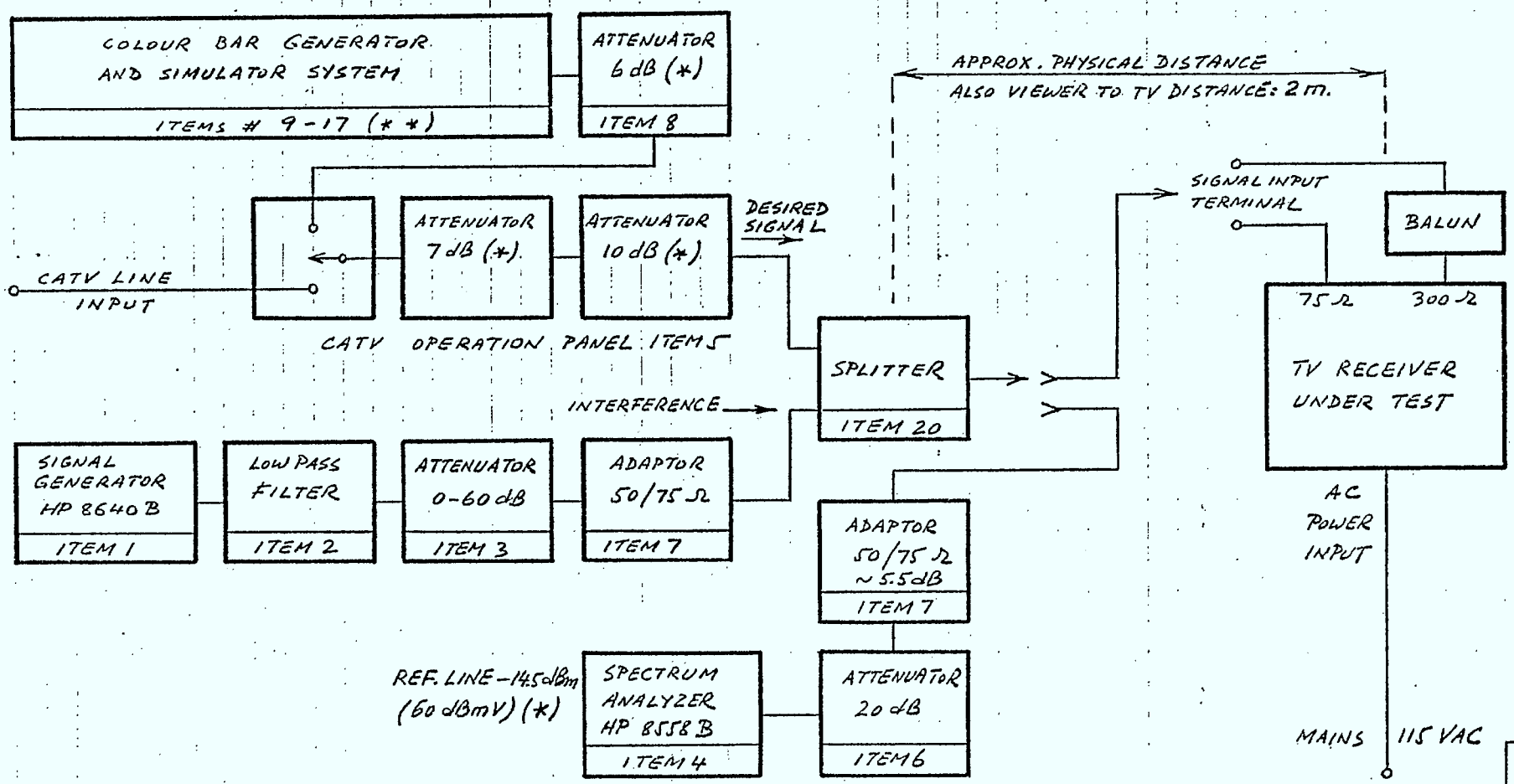
to Interference Ratios and their Application to
Description of TV Service.
IRE TR. on Broadcasting, Jan., 1961.



(*) VALUES RECORDED FOR REF. PURPOSES
(**) SEE TABLE II FOR ITEMS DESCRIPTION

FIGURE 1 : SET-UP, TV IMMUNITY TEST (CS04)
CONDUCTED SUSCEPTIBILITY (2 SIG. GEN. METHOD)
REJECTION OF UNDESIRED SIGNALS AT INPUT TERMINALS

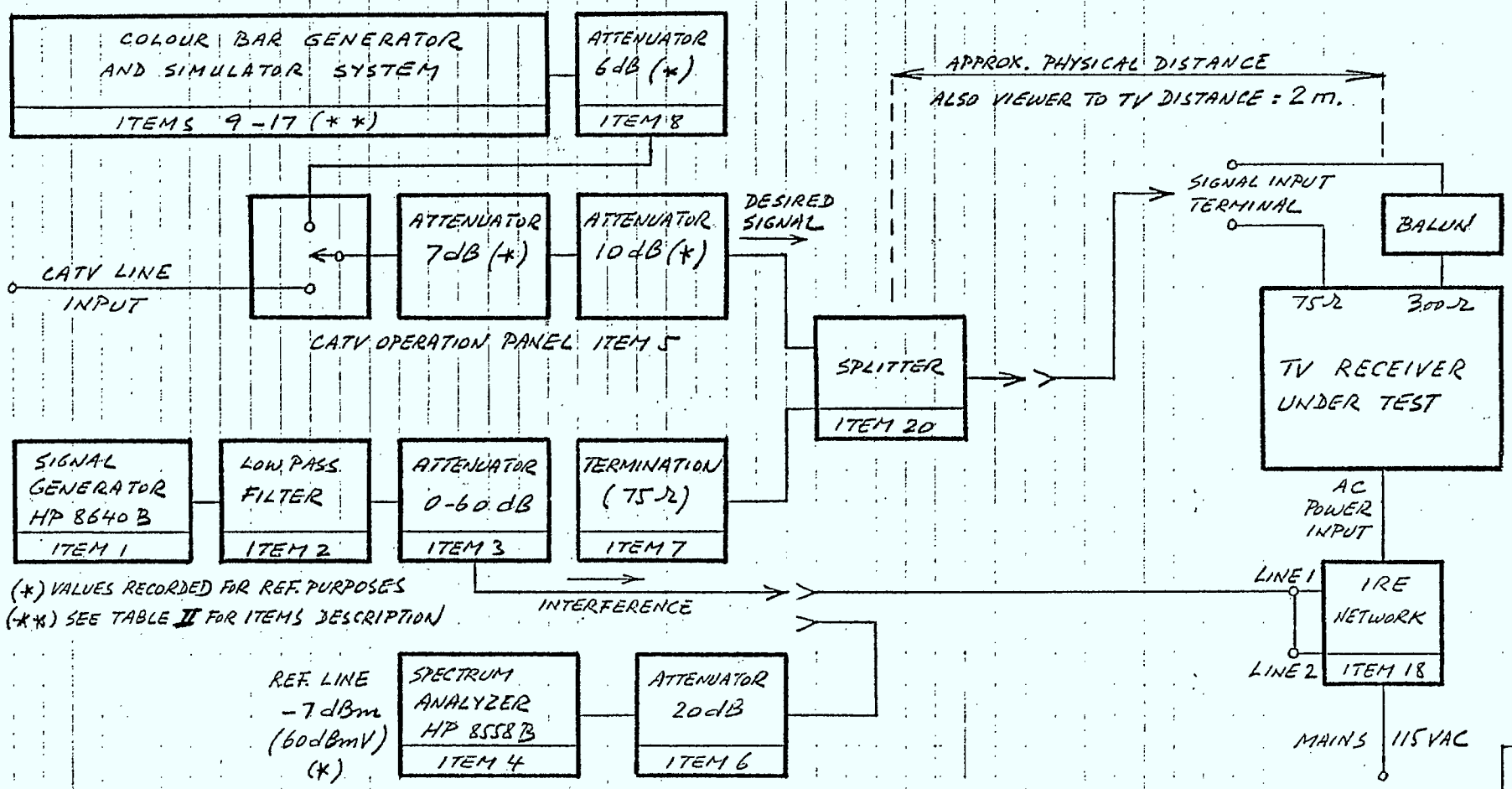


FIGURE 2 : SET-UP, TV IMMUNITY TEST (C502)
CONDUCTED SUSCEPTIBILITY
REJECTION OF UNDESIRED SIGNALS AT POWER SUPPLY INPUT

RECEIVER EMC CHARACTERISTICS TABLE I

EMC ITEM #	C: CONDUCTED R: RADIATED / MIL-STD CODE	E: EMISSION S: SUSCEPTIBILITY / TEST DESCRIPTION	METHOD DEVICE	FR. RANGE(*) AF/VIDEO	LOW ADJACENT	OPERATING	BAND PASS	HIGH ADJ.
1	CE01, 03	CE POWER LEADS	LINE NETWORK OR PROBE	X	X	X	X	X
2	CE02, 04	CE CONTROL&SIGN.LEADS	PROBE	X	X	X	X	X
3	CE06	CE ANTENNA TERMINAL	LOADING NETWORK	X	X	X	X	X
4	CS01, 02, 06	CS POWER LEADS	PARAL.OR SERIES INJECT.	X	X	X	X	X
5	CS03	CS I/P INTERMOD	2-3 INTERFERENCE 3-4 SIGNAL GEN.	X	X	X	X	X
6	CS04	CS I/P DESENSITIZATION SELECTIVITY, SPURIOUS	1 INTERFERENCE 2 SIGNAL GEN.	X	X	X	X	X
7	CS05	CS I/P XMOD	2 SIGNAL GEN.			X	X	
8	CS07	CS ALL CONTROL CIRCUITS	SQUELCH, AGC, AFC REMOTE/CONTROL			X	X	
9	CS08	CS I/P SPURIOUS RESP.	1 SIG GEN.	X	X	X	X	X
10	RE02, 03	RE ELECTRIC FIELD	ANT. PICK-UP		X	X	X	X
11	RE04	RE MAGNETIC FIELD	FIELD SENSOR	X				
12	RS01	RS MAGNETIC FIELD	RADIATION LOOP	X				
13	RS02	RS INDUCTION FIELD	P.S.&PULSE,WIRE WOUND	X				
14	RS03	RS ELECTRIC FIELD	SINGLE & MULTIPLE FIELDS	X	X	X	X	X
15	RS04	RS RADIATED FIELD	SPECIAL METHODS	X	X	X	X	
16	-	INTERNAL COMPATIBILITY	CS TO CE RS TO RE	X			X	
17	-	EMC STABILITY	ACCELERATED ENVIRONMENT	RELEVANT EMC MODES				

(*) AF, VLF, LF, MF, HF, VHF, UHF, M/W (L,S,C,X, etc.)
There will be interaction effects depending on E&S levels and designs throughout the spectrum; however, it will suffice to consider only four frequency ranges of dominant value for a sufficient characterization in most practical cases. The operating frequency range has two areas of different behaviour: the tuned frequency area (band pass and vicinity, including IF) and the remaining tunable range.

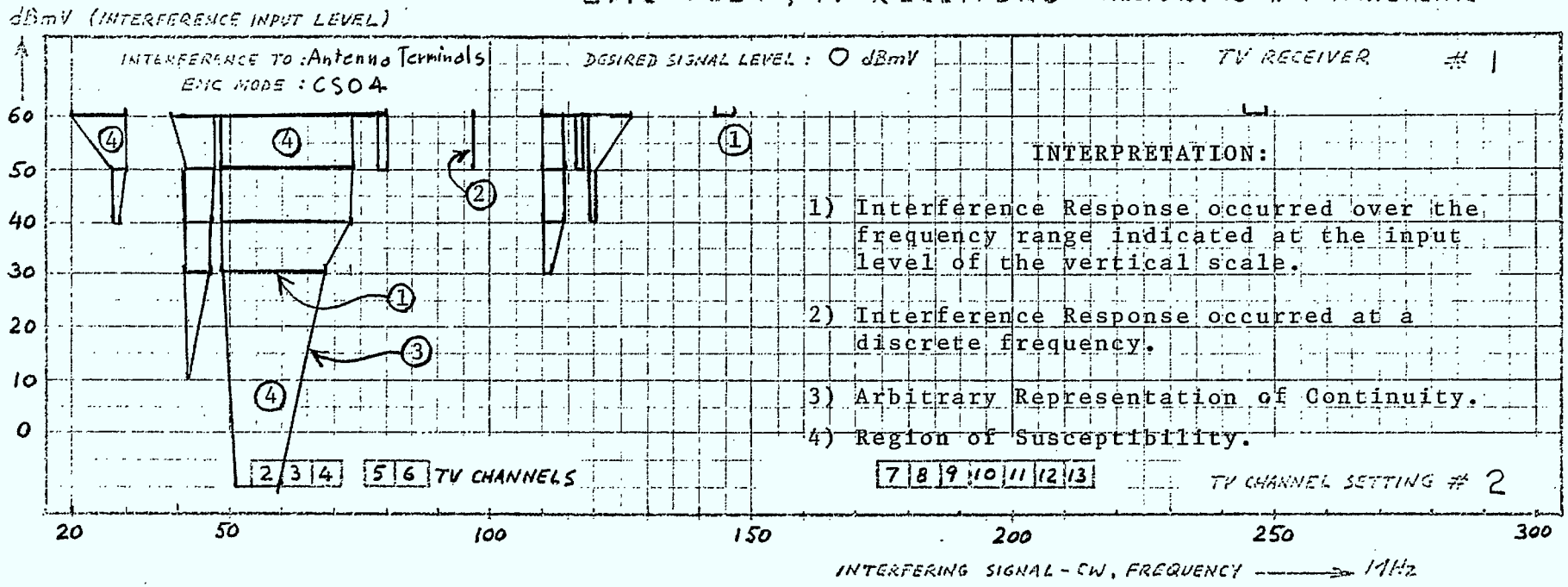
TEST EQUIPMENT TABLE II

ITEM NO.	NAME	MAKER & MODEL	LAB. EQUT. NO.	GENERAL CHARACTERISTICS
1	Signal Generator	HP 8640B	G252	0.5-1024 MHz, - 140 to +20 dBm(50Ω)
2	Low Pass Filter	Rohde & Schwarz PTU-BN 49131	F326	Switchable: 30,45,70,110,170, 250,350,500,750,1000,1350, ∞MHz(50Ω)
3	Attenuator, Switchable	Telonic TAD-50A	A360	0-1 GHz, 50Ω 1 w Max 1-110 dB (1 dB steps)
4	Spectrum Analyzer	HP 8558B	A407	0.1-1500 MHz, -100 to 30 dBm (50Ω)
5	CATV Operation Panel			Coax Switch & Attenuators 0-50(10dB), 0-10(1dB), 75Ω
6	Attenuator Fixed	Weinshel 2-20	A384	DC-18 GHz, N-TYPE, 20 dB
7	Adaptor 50/75Ω	Texscan ZM-57	P616B	∿5.5dB, BNC-TYPE (QTY:2)
8	Attenuator Switchable	Texscan 577	A357	0-70(10dB), 0-10(1dB)
9	TV Signal Simulator	Benavac MK II	C607 -608	
10	Waveform Monitor	Tektronix 1480R	M710	
11	Vector Scope	Tektronix 520-NTSC	0118	or item #16
12	Colour Bar Generator	Richmond Hill Labs MF5	G500	
13	Video Selection Panel		S350C & D	Switch

TEST EQUIPMENT - TABLE II(Page 2)

ITEM NO.	NAME	MAKER & MODEL	LAB. EQUT. NO.	GENERAL CHARACTERISTICS
14	Video Test Signal Generators	Richmond Hill Labs	G502	
15	Synchronizing Pulse Generator	Richmond Hill Labs	G501	
16	Test Signal Generator	Tektronix 149A-NTSC	G508	Or Item #11
17	Vision-Sound Modulator	Rohde & Schwarz BN 4161005	G203	With IEC, F-34 Function Generator for 1 KHz Tone
18	IRE Network REF (10)	Lab	N106	With 2 x 50Ω terminations Tektronix 011-049, 50Ω, 1W
19	Splitter	Delta Electr. CH S2-4	Catalog #1069	75Ω, 4 way, 6 dB.
20	Splitter	Delta Electr. CH S2-2	Catalog #1057	75Ω, 2 way, 3 dB.

EMC TEST, TV RECEIVERS - RESPONSE TO RF INTERFERENCE



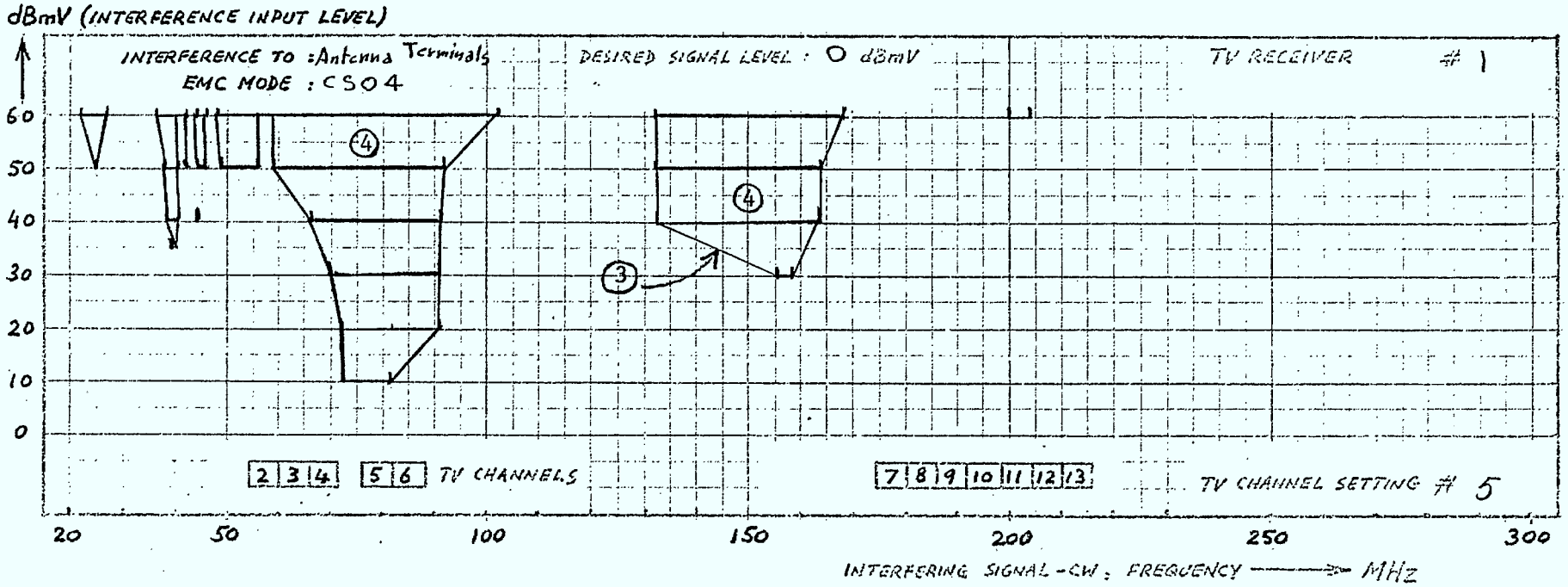
INTERPRETATION:

1) Interference Response occurred over the frequency range indicated at the input level of the vertical scale.

2) Interference Response occurred at a discrete frequency.

3) Arbitrary Representation of Continuity.

4) Region of Susceptibility.



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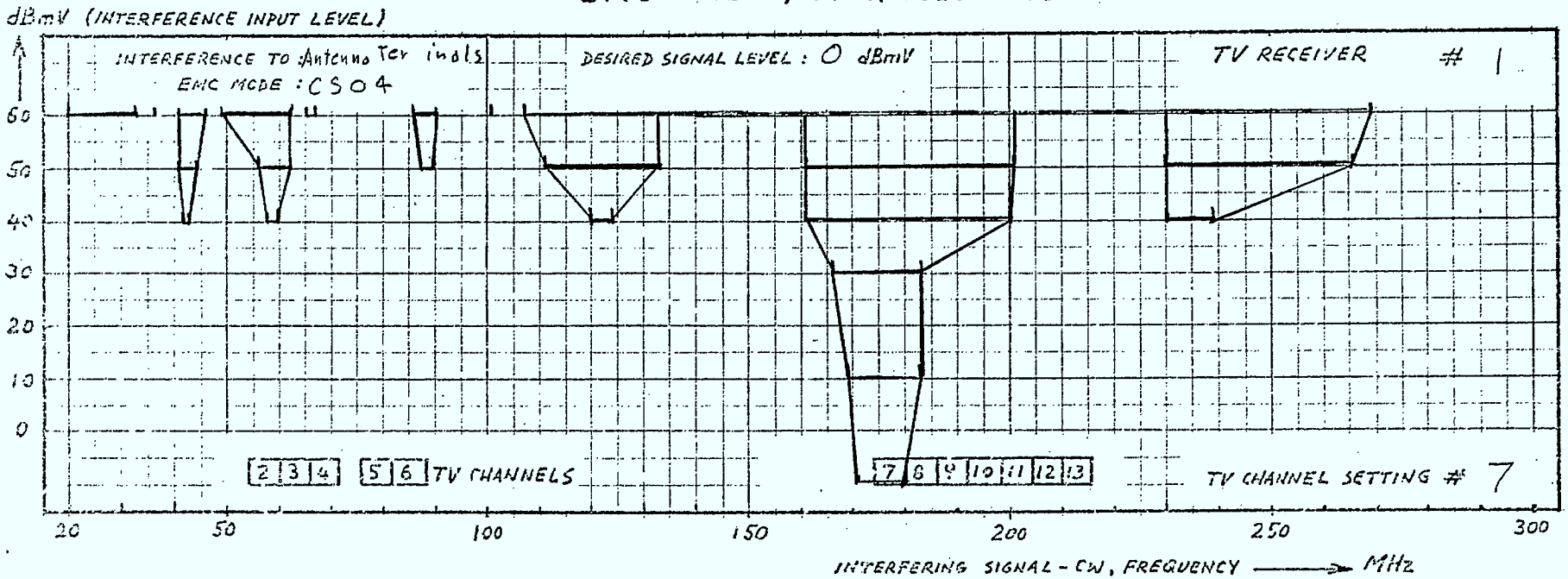

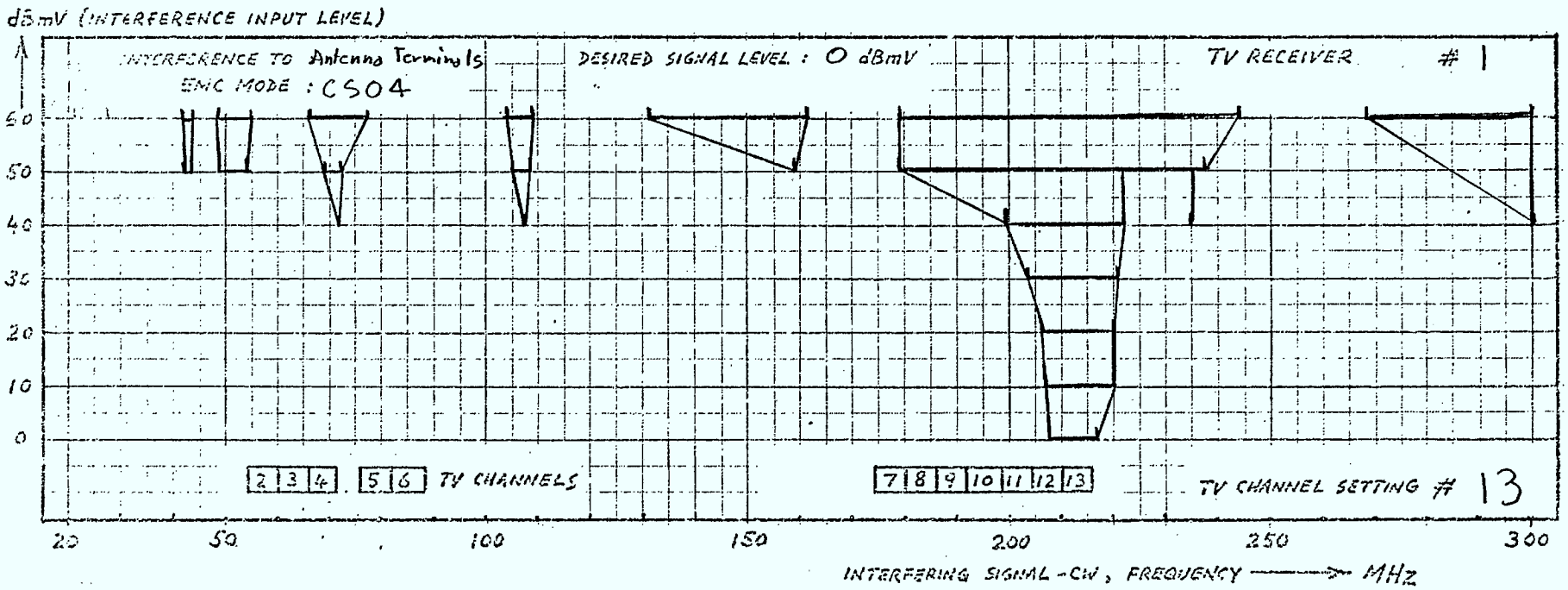

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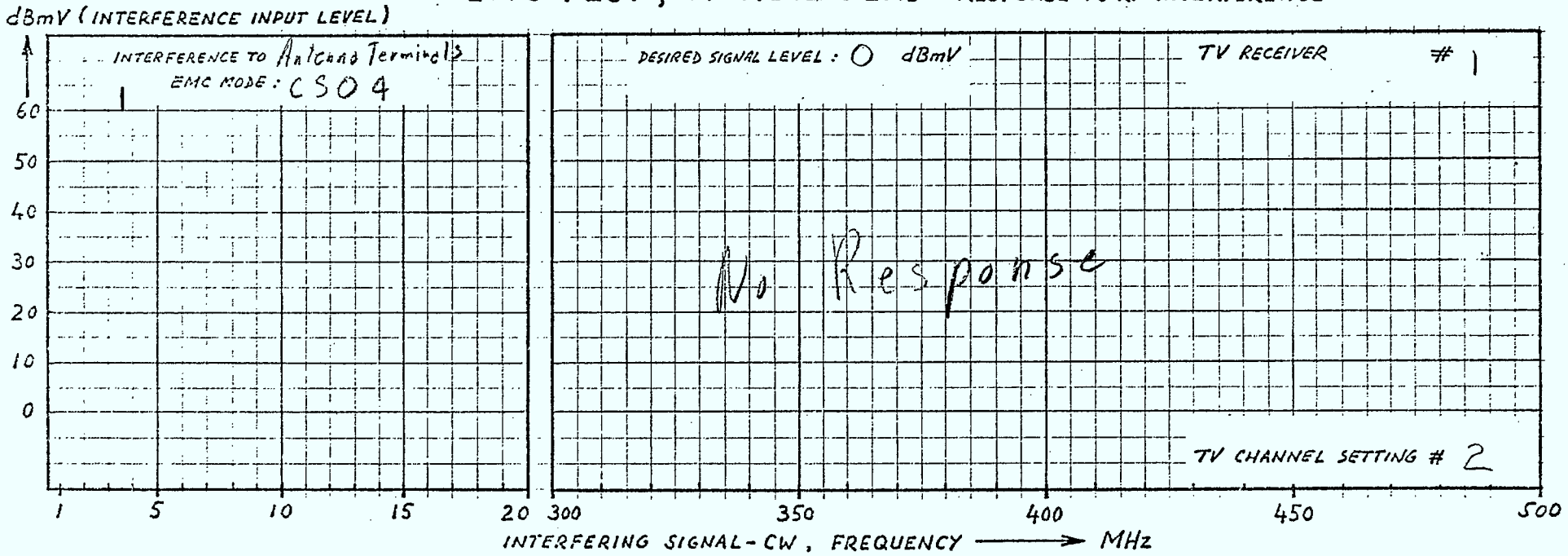

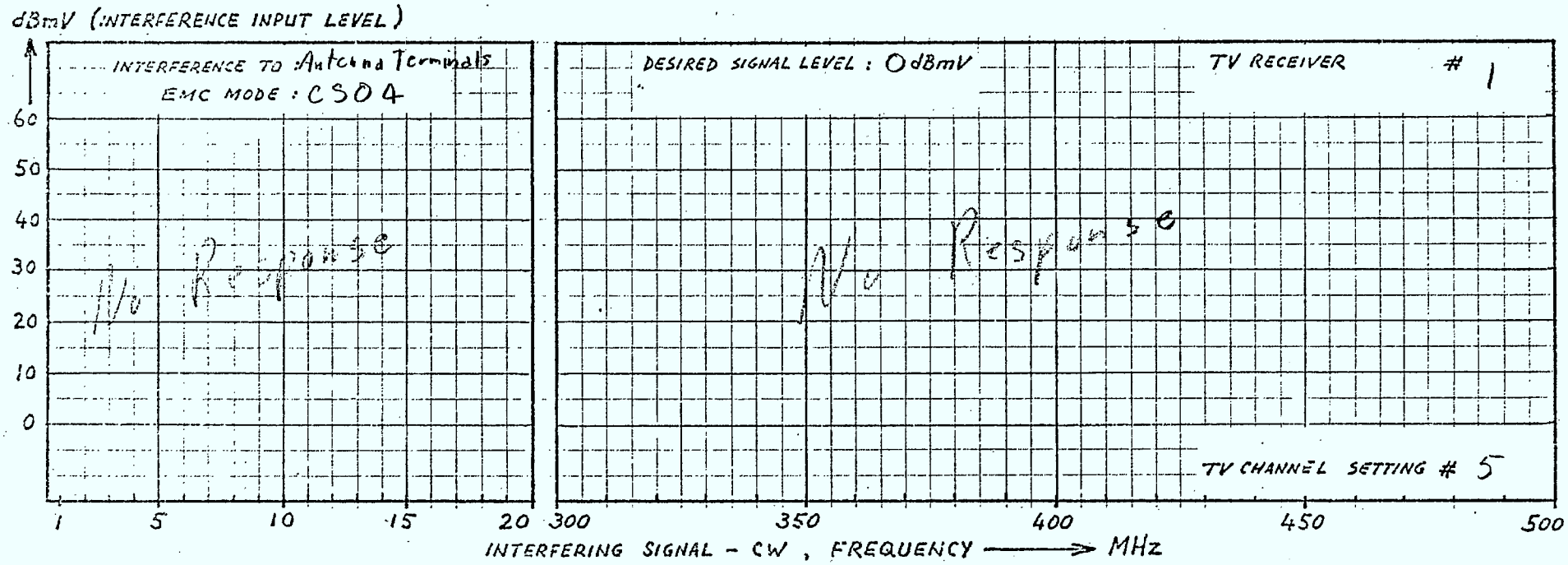

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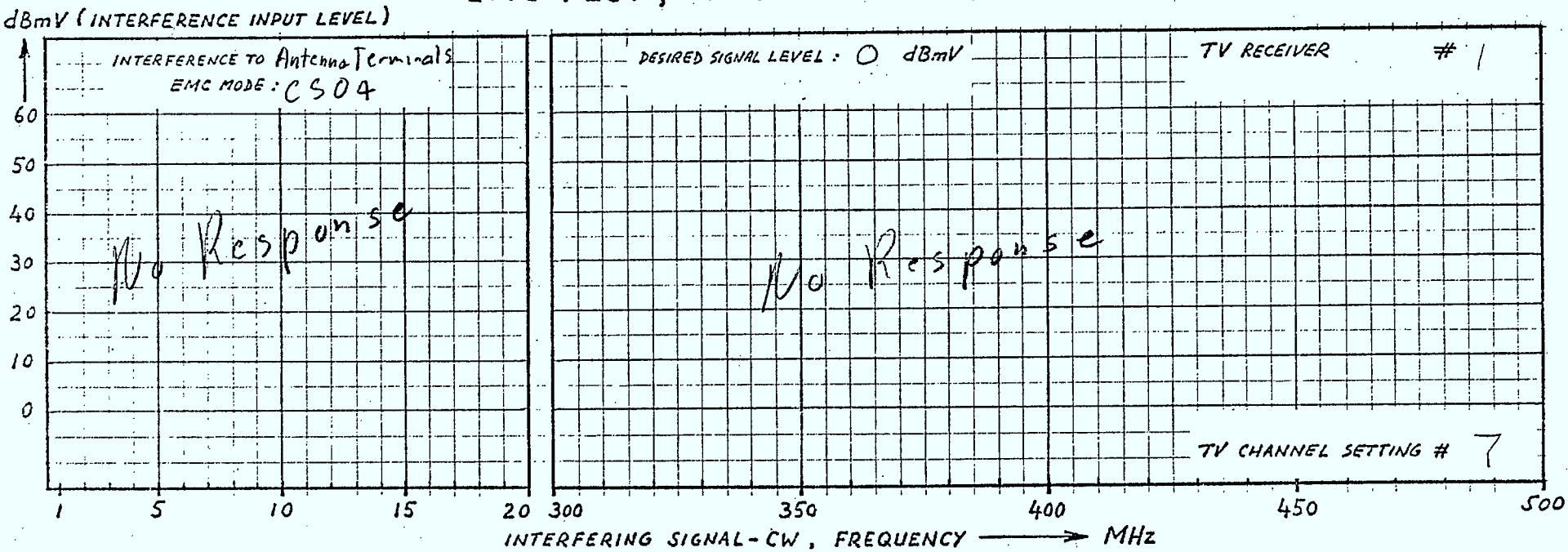

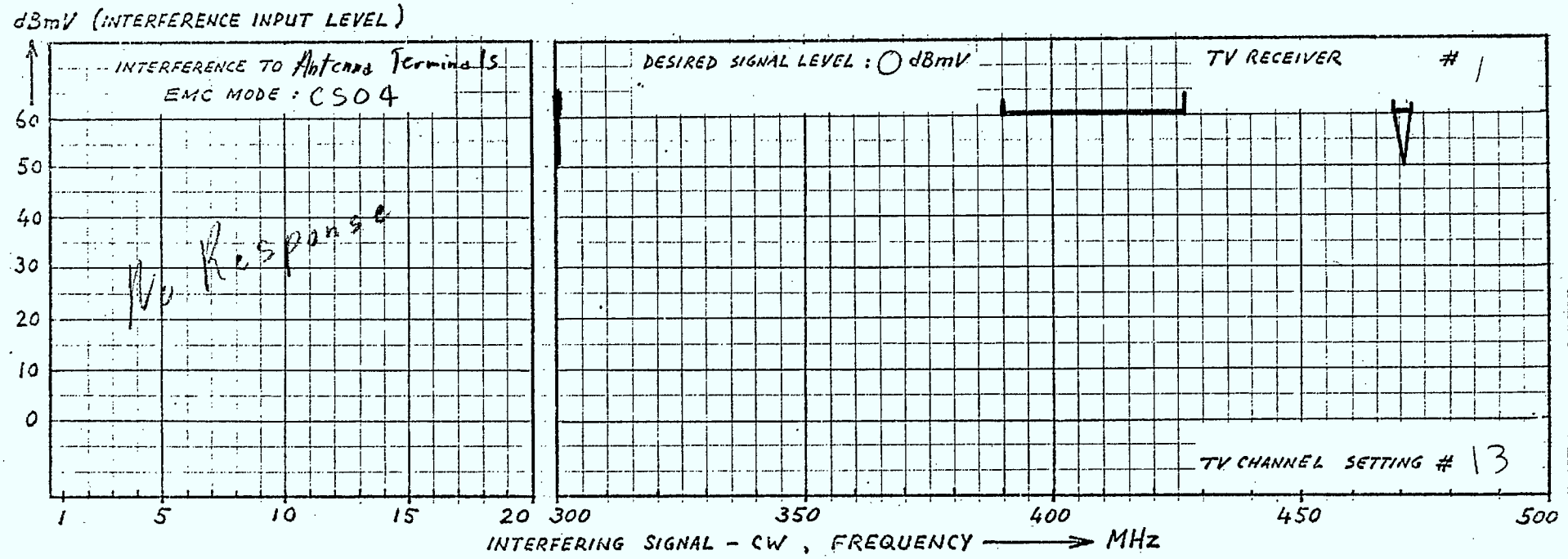

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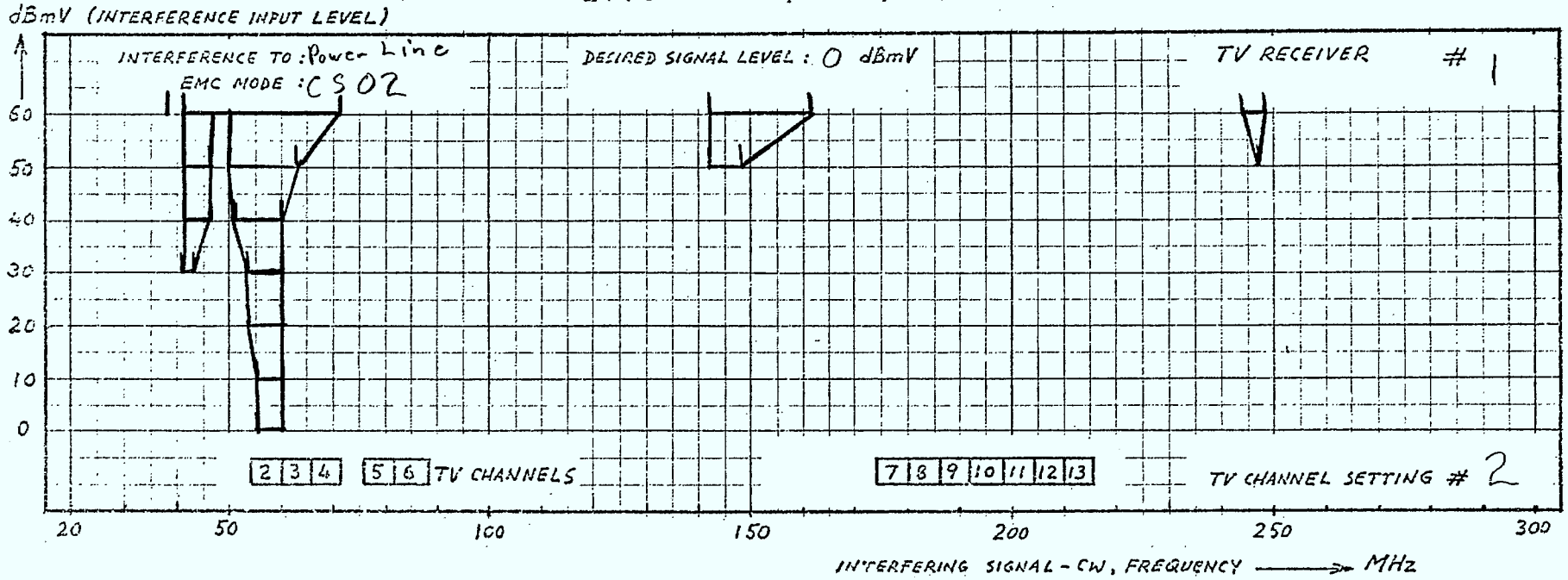

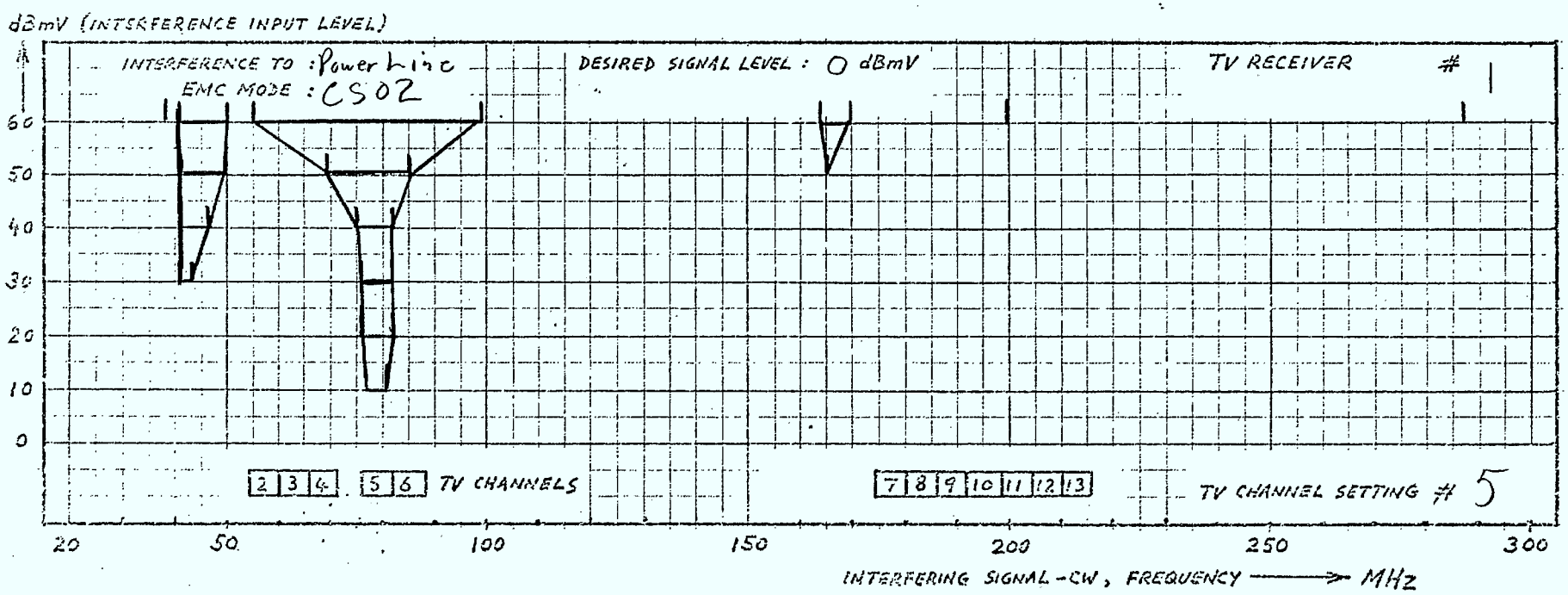

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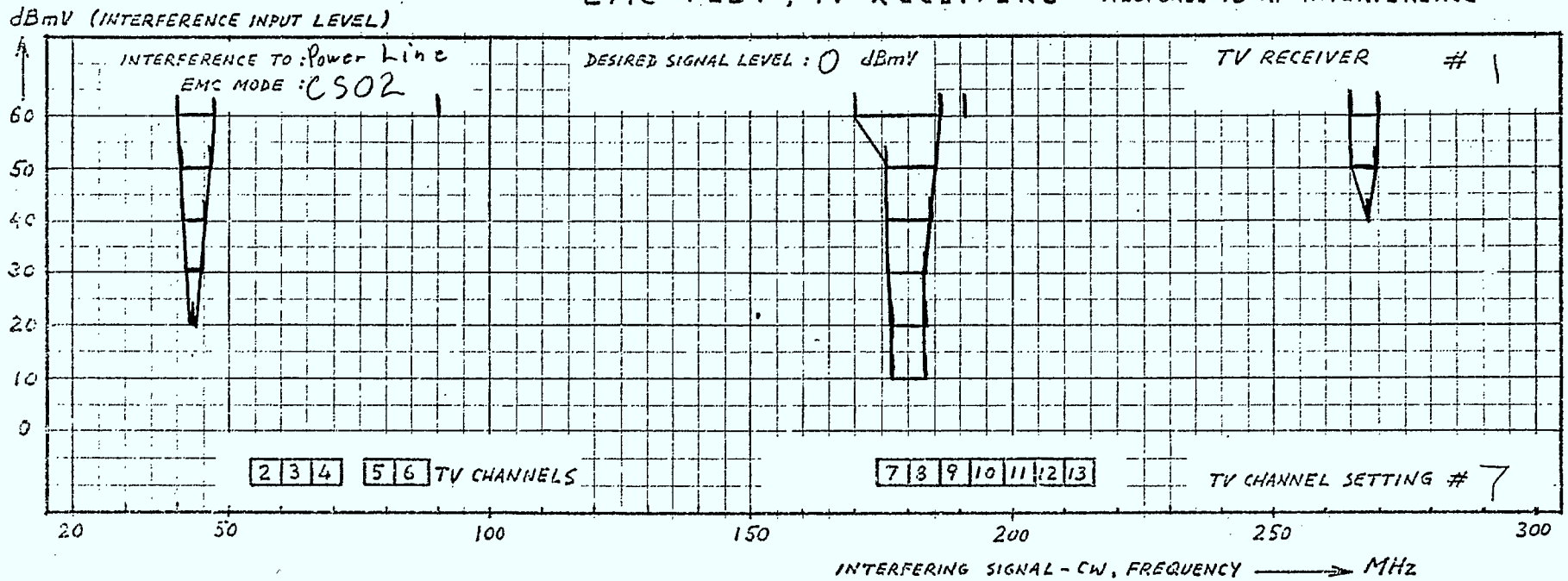

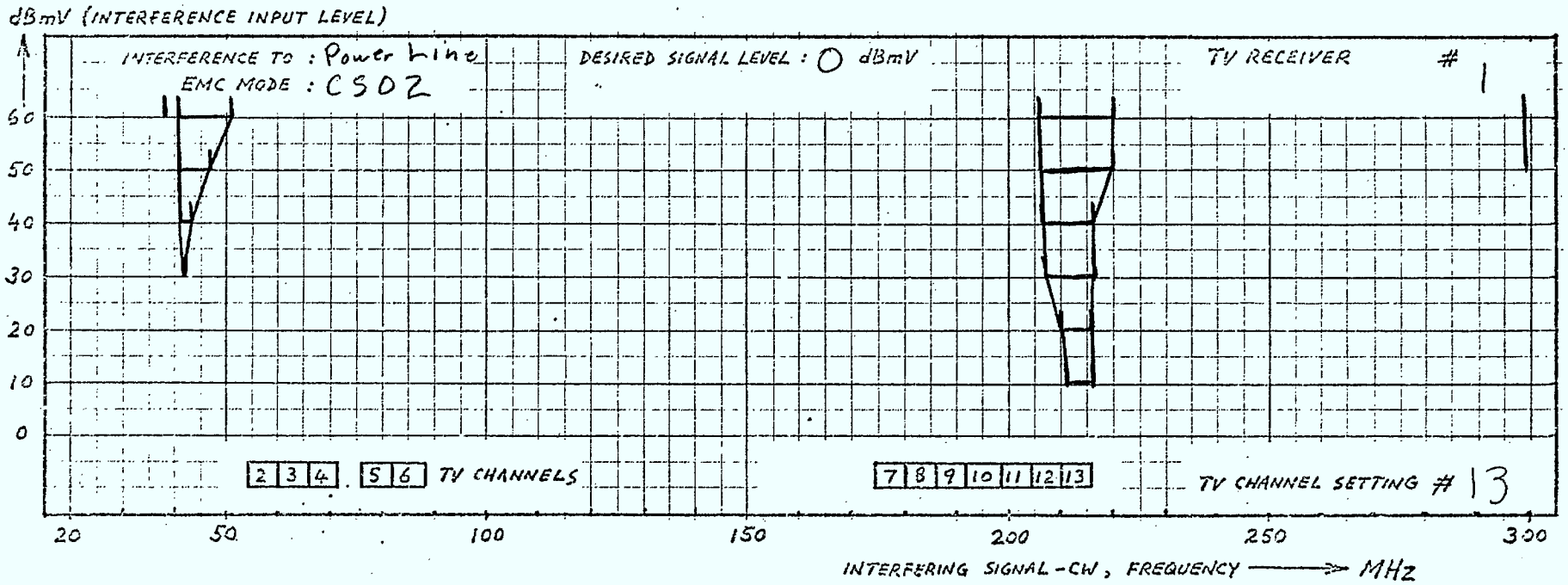

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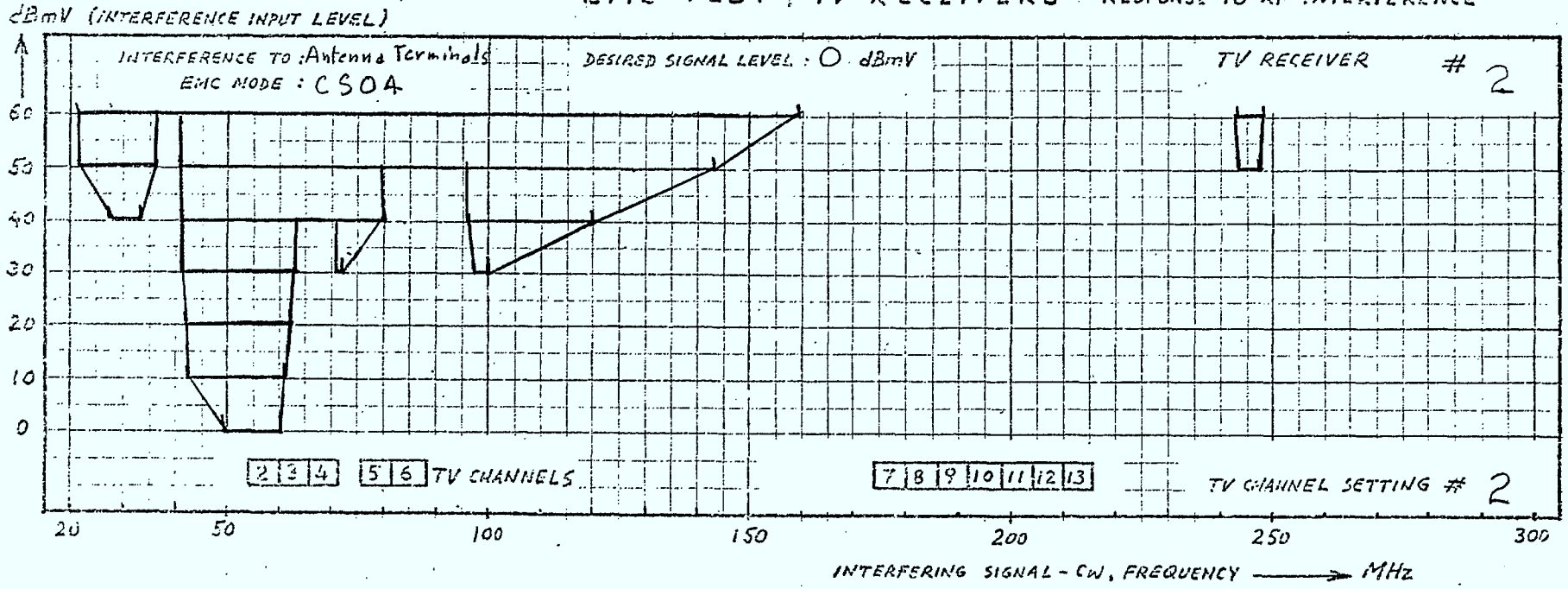

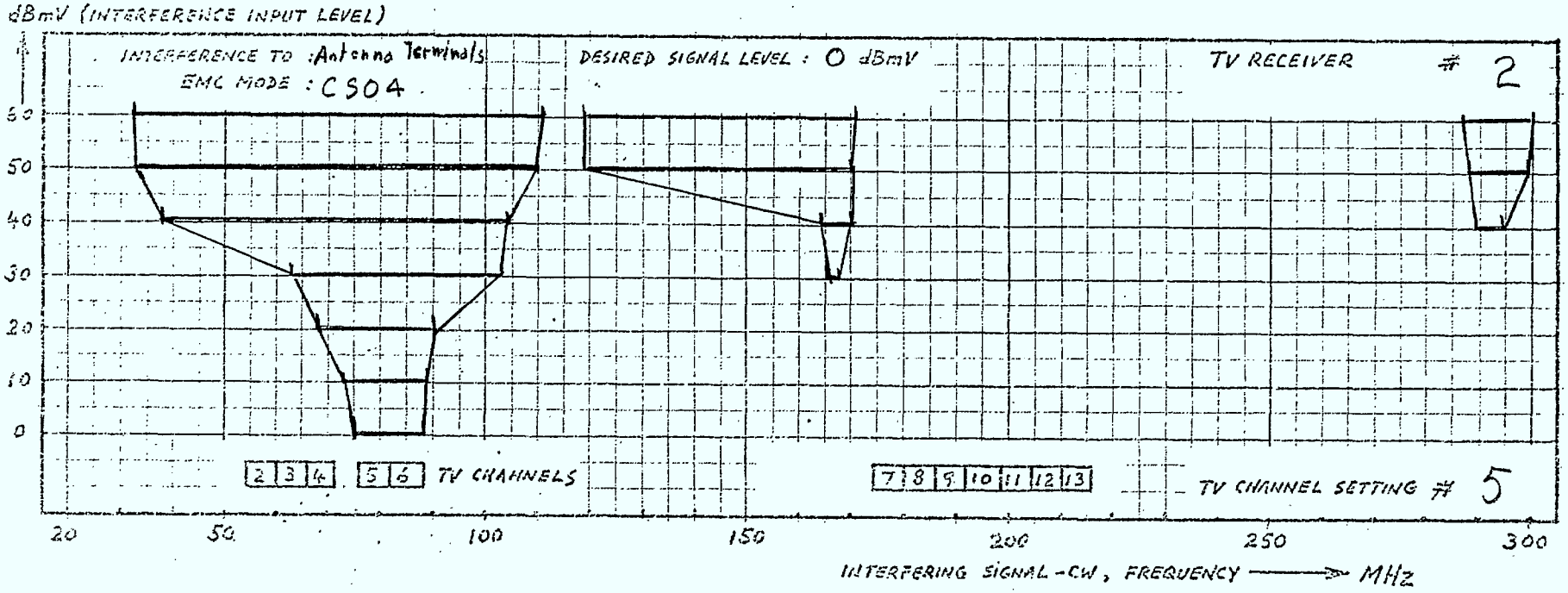

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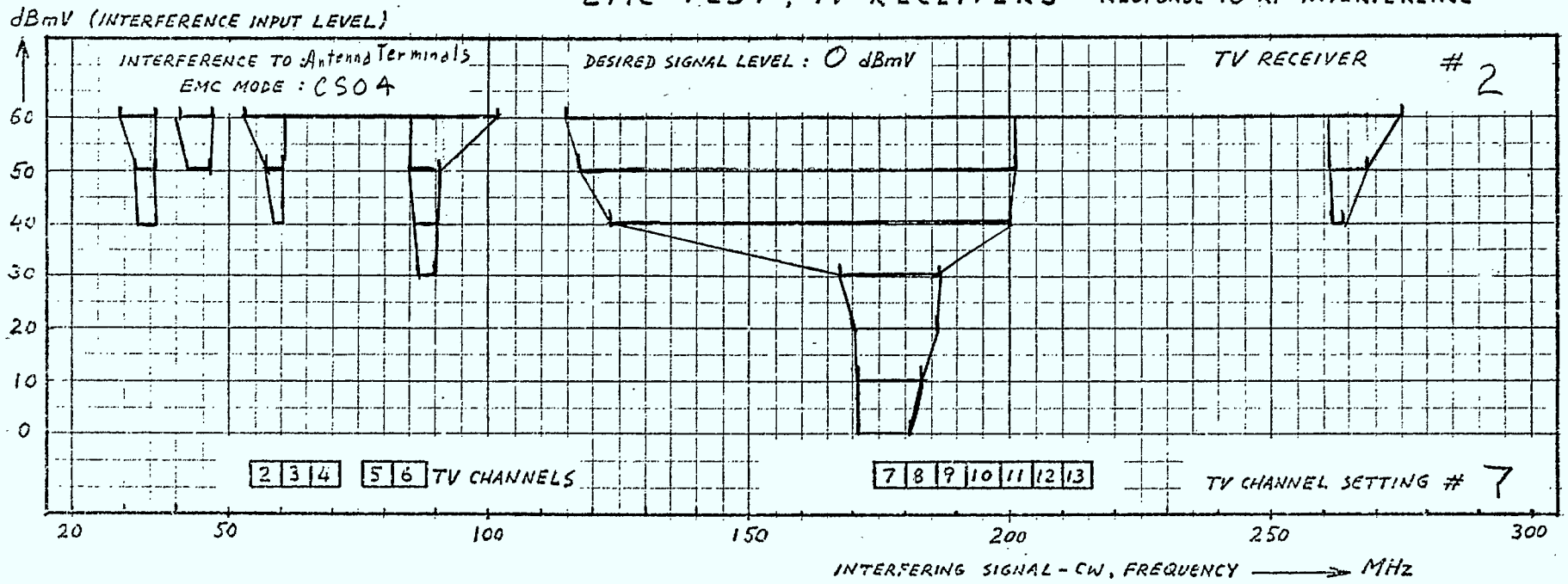

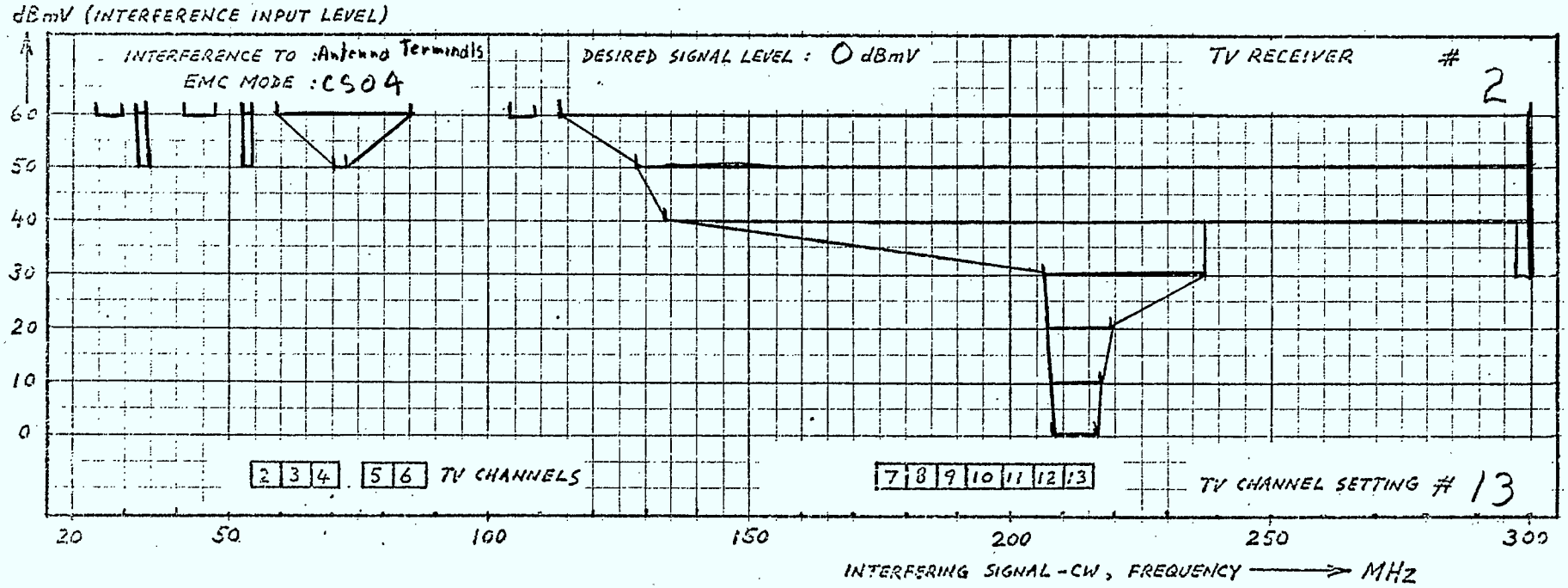

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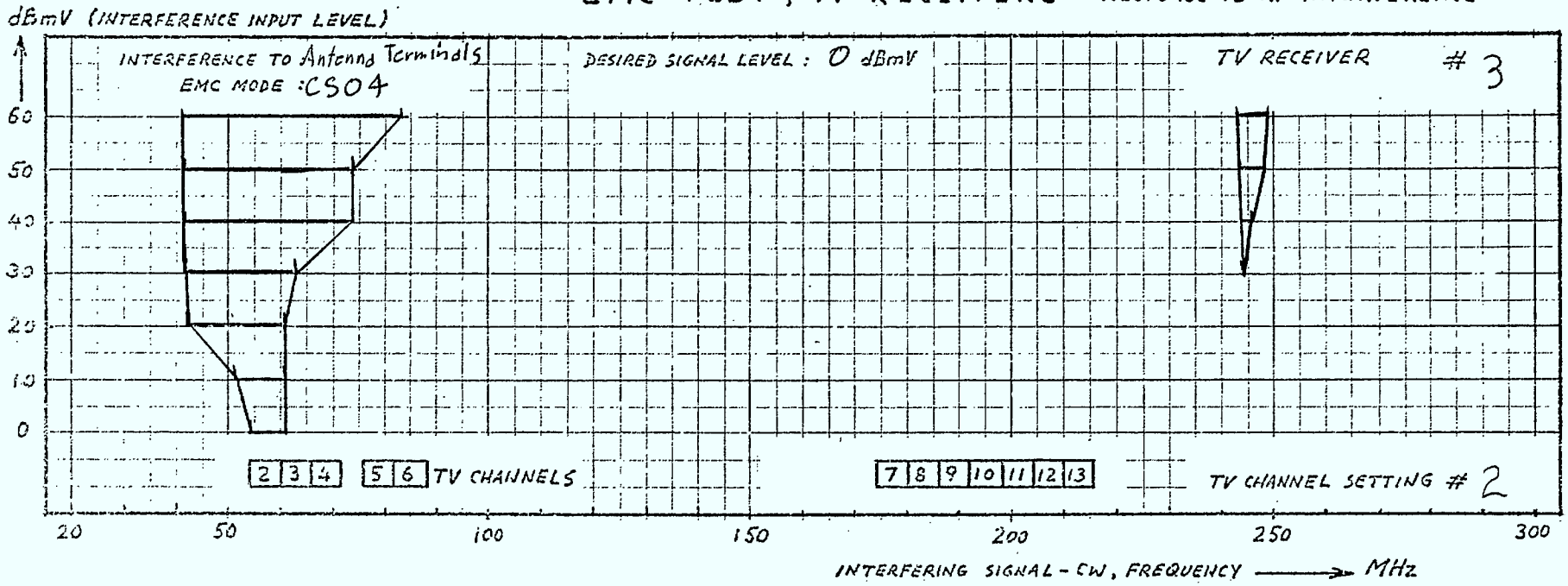

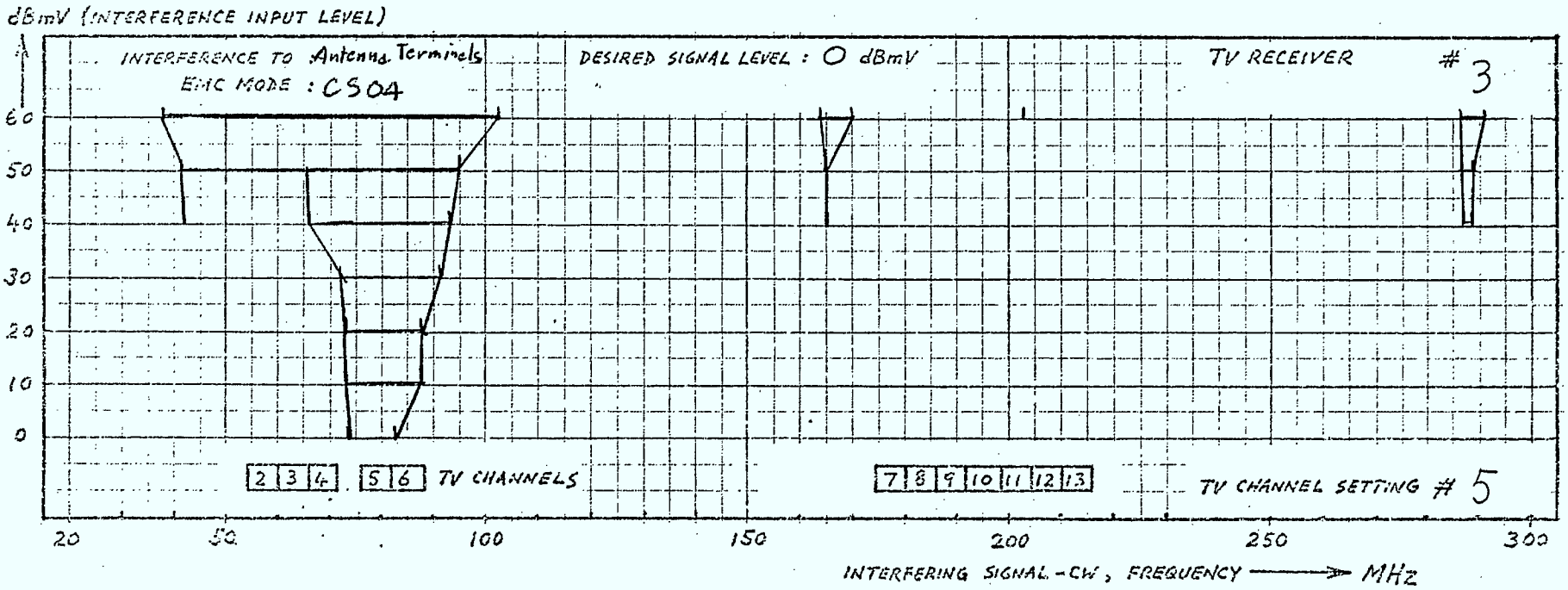

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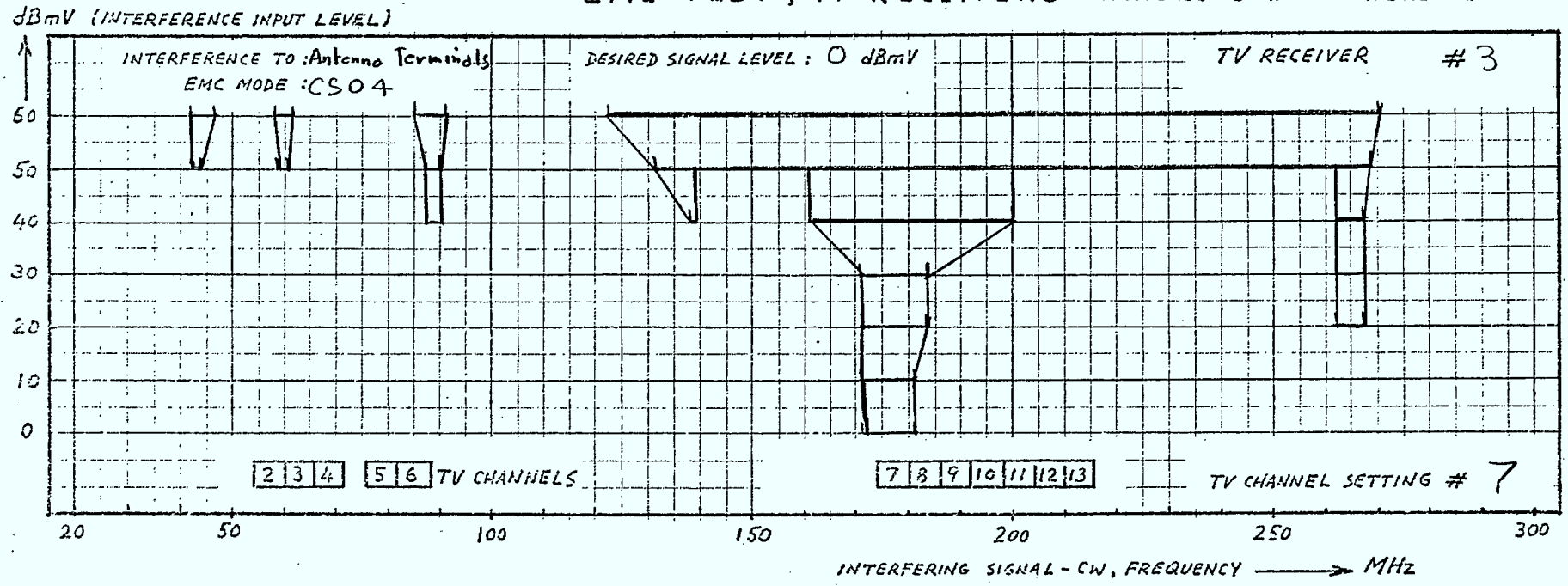

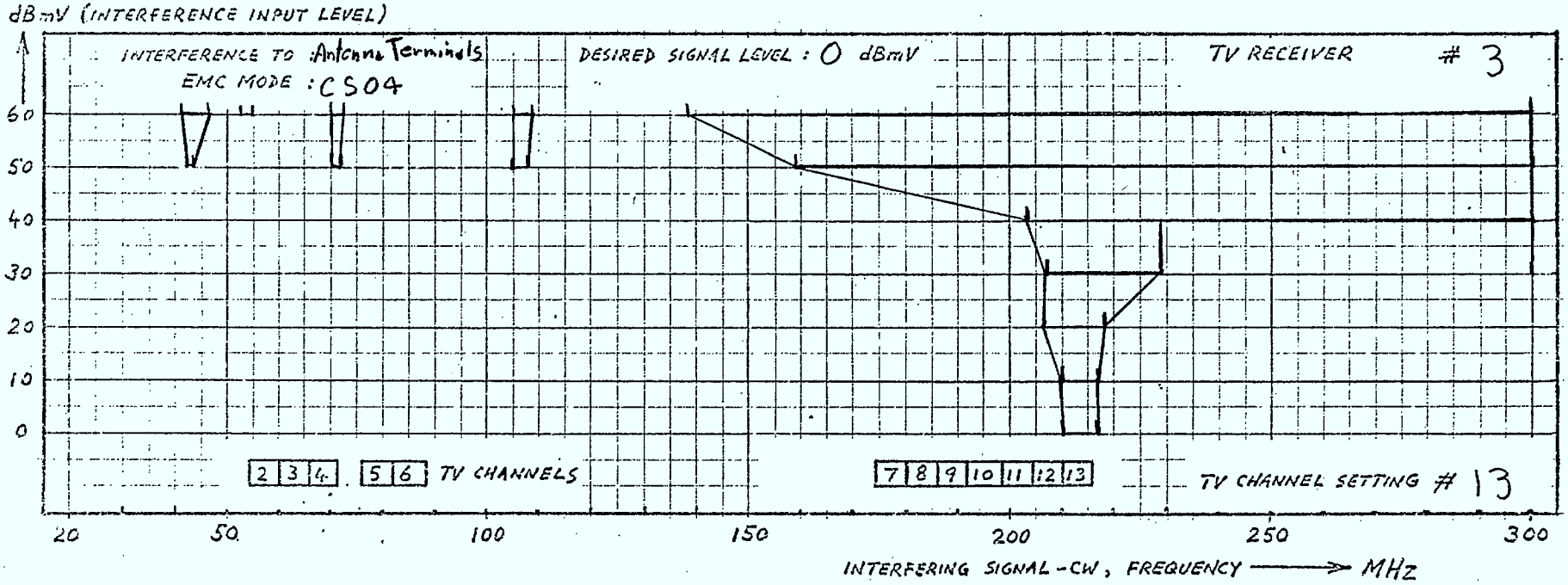

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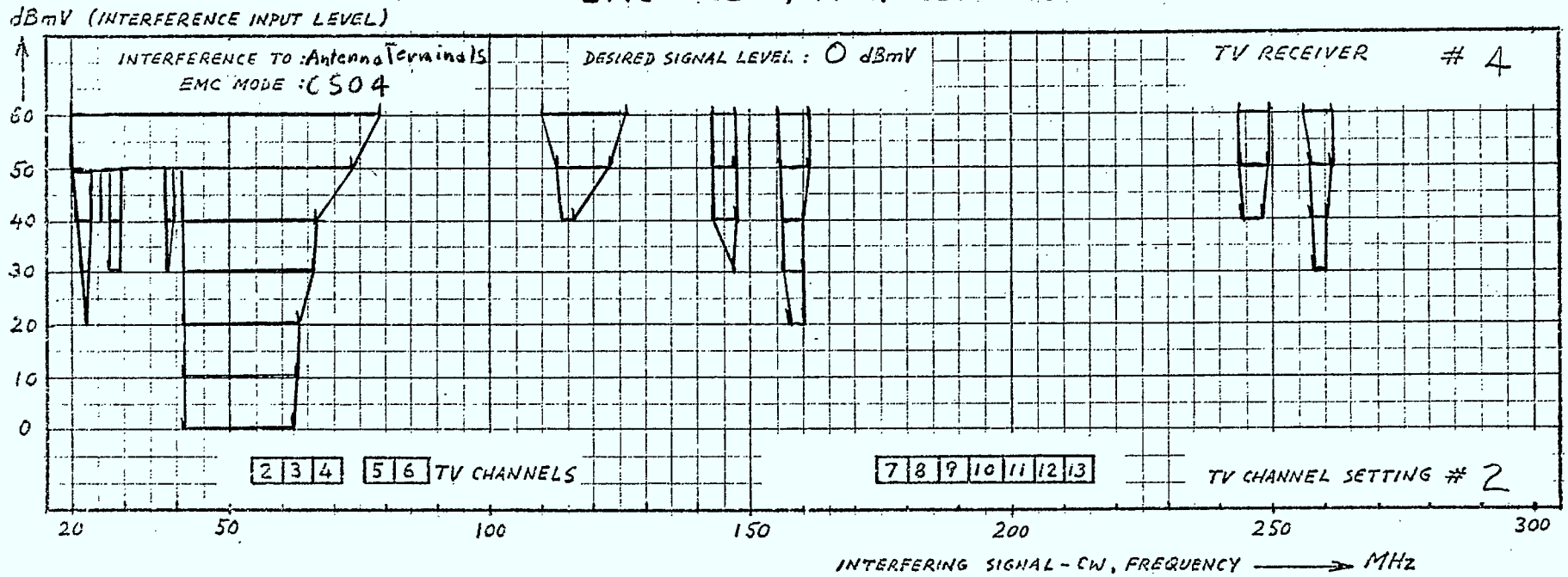

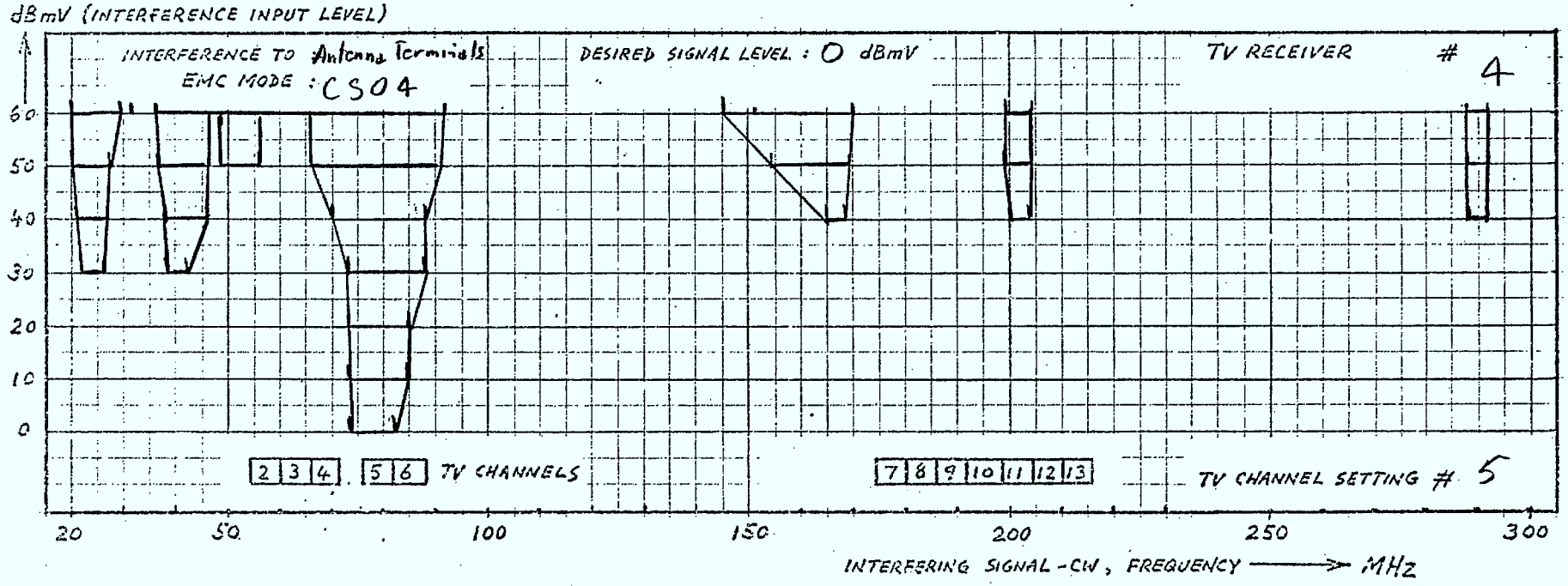

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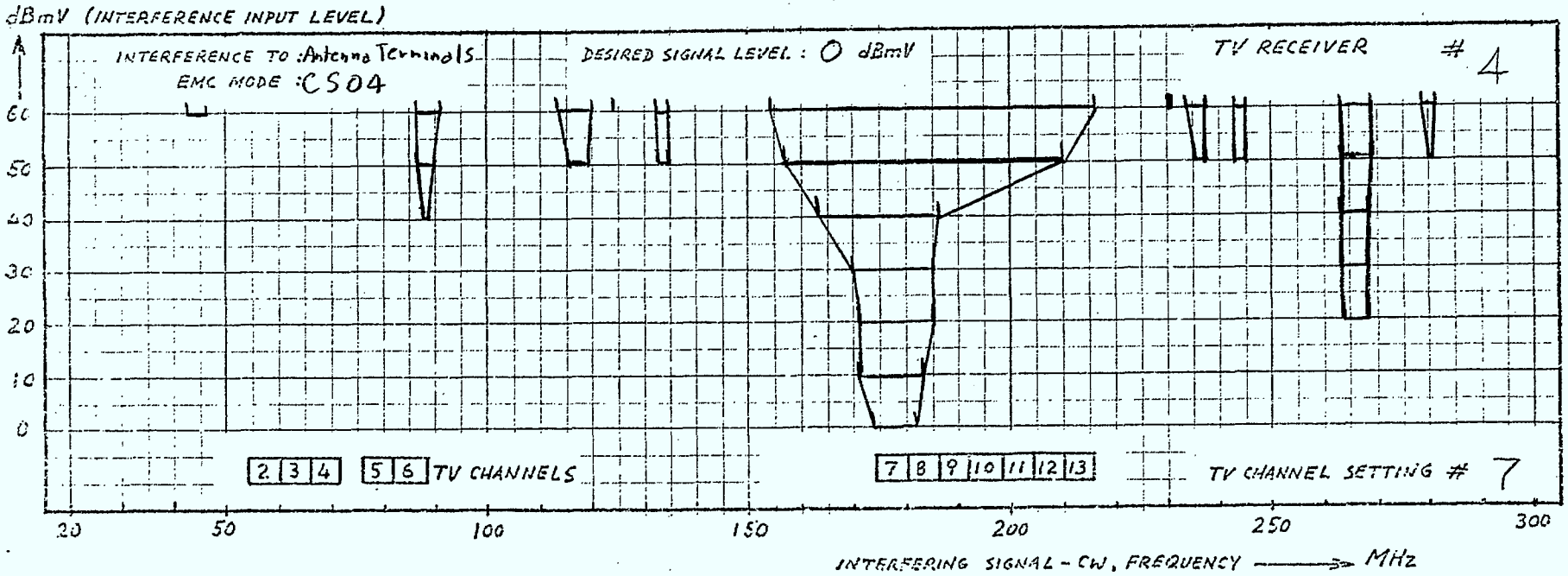

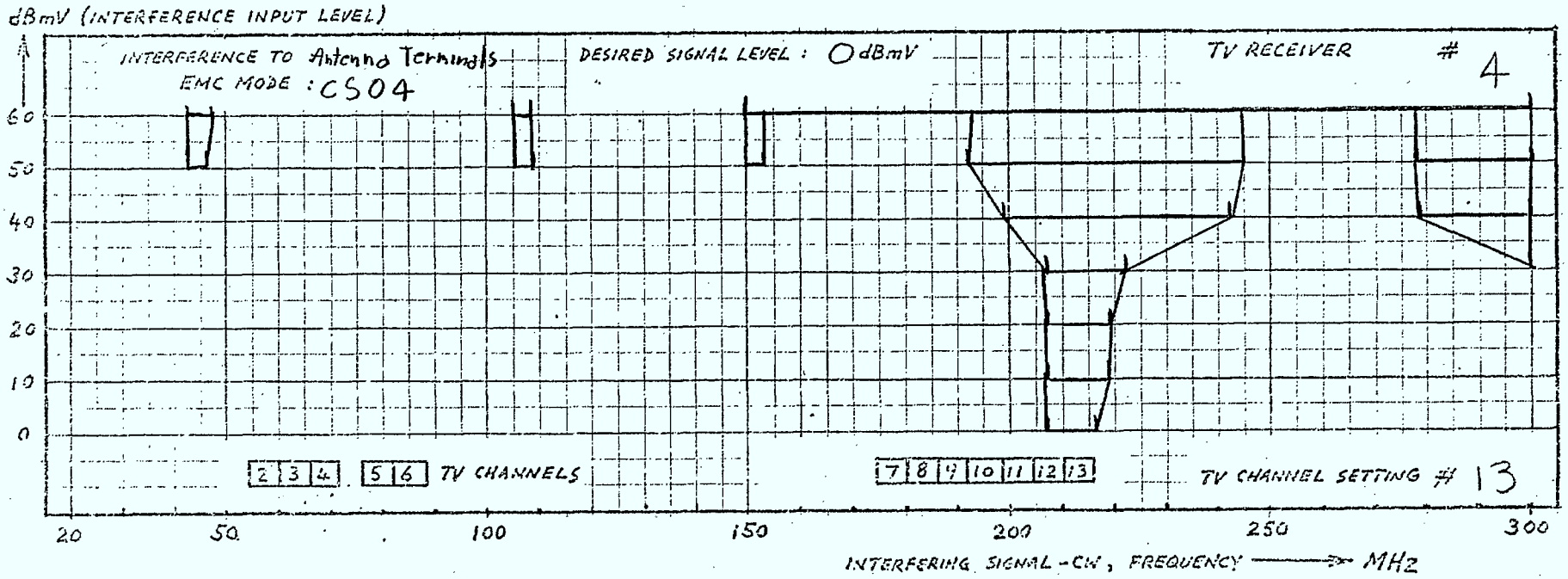

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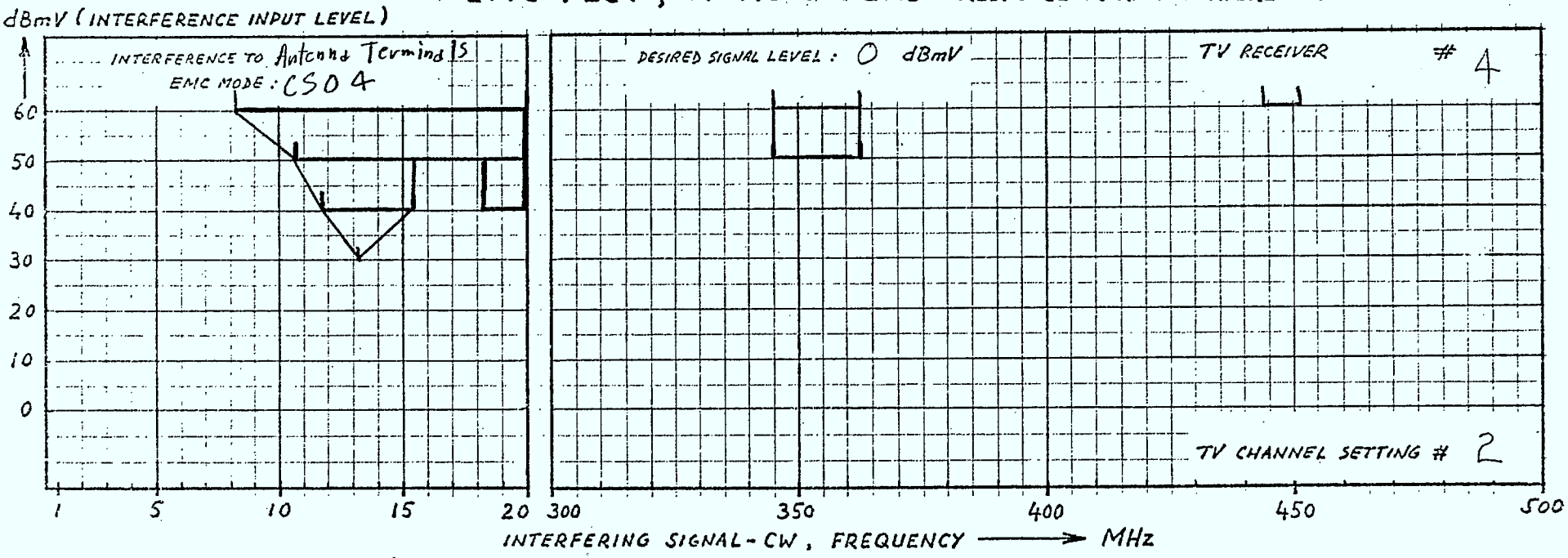

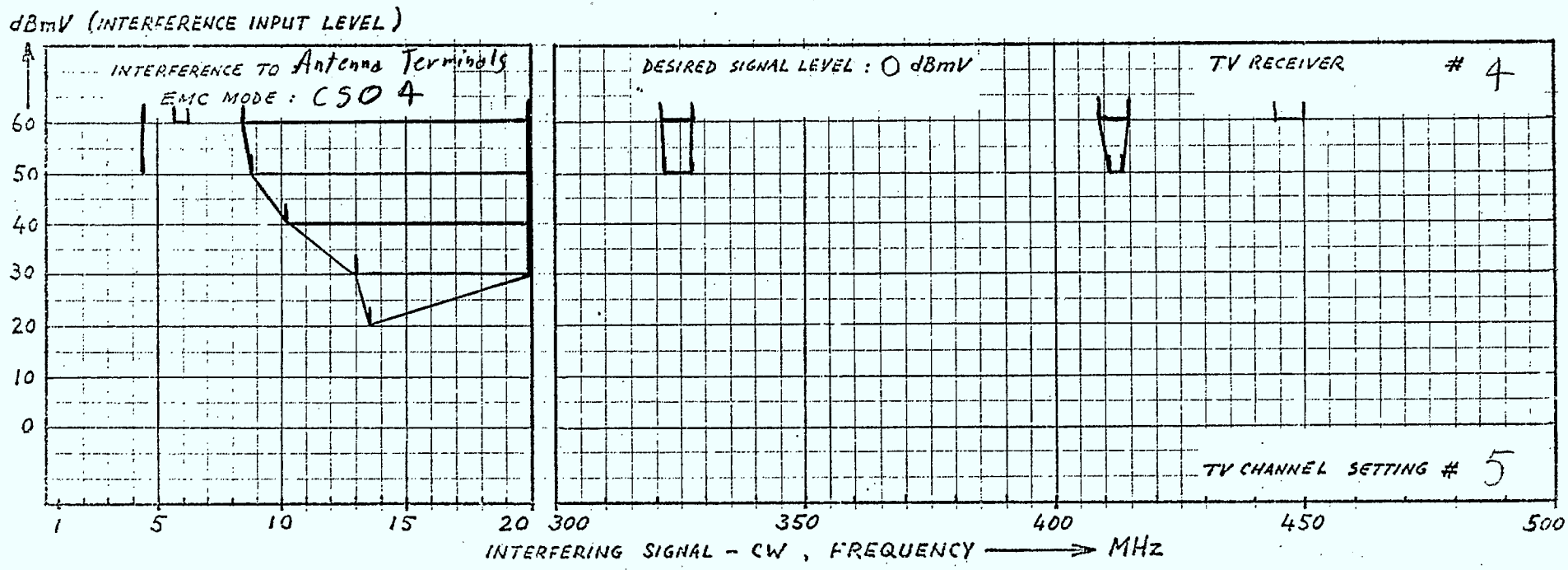

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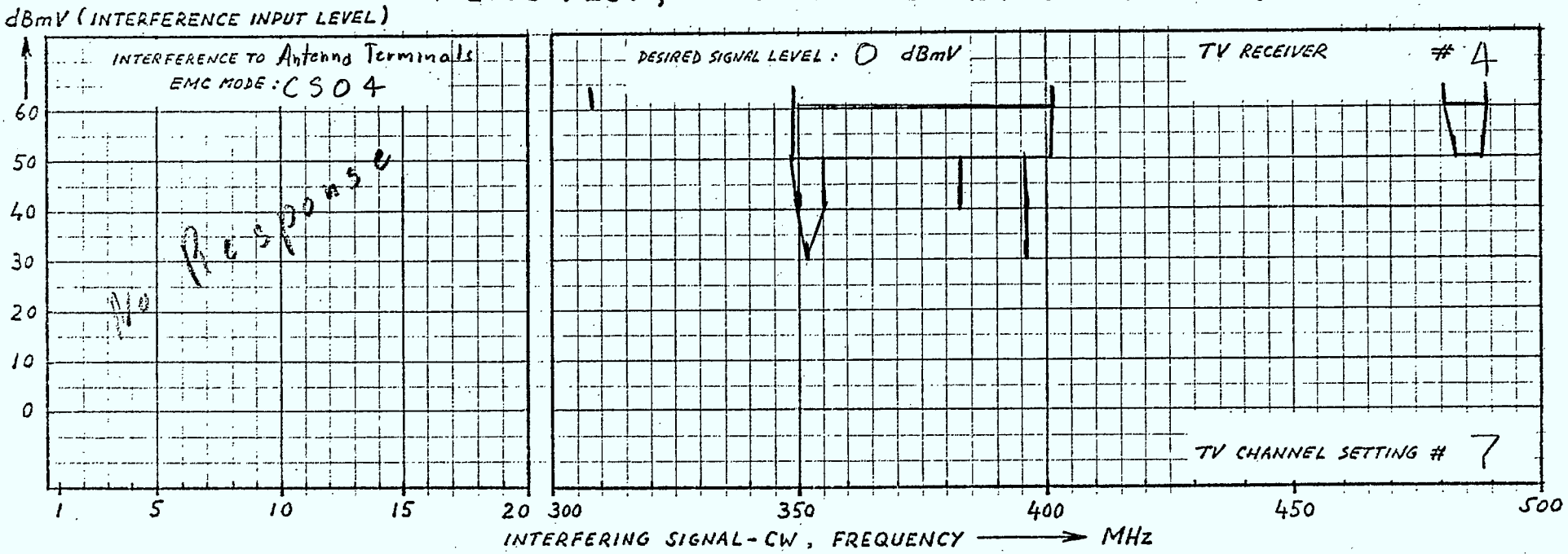

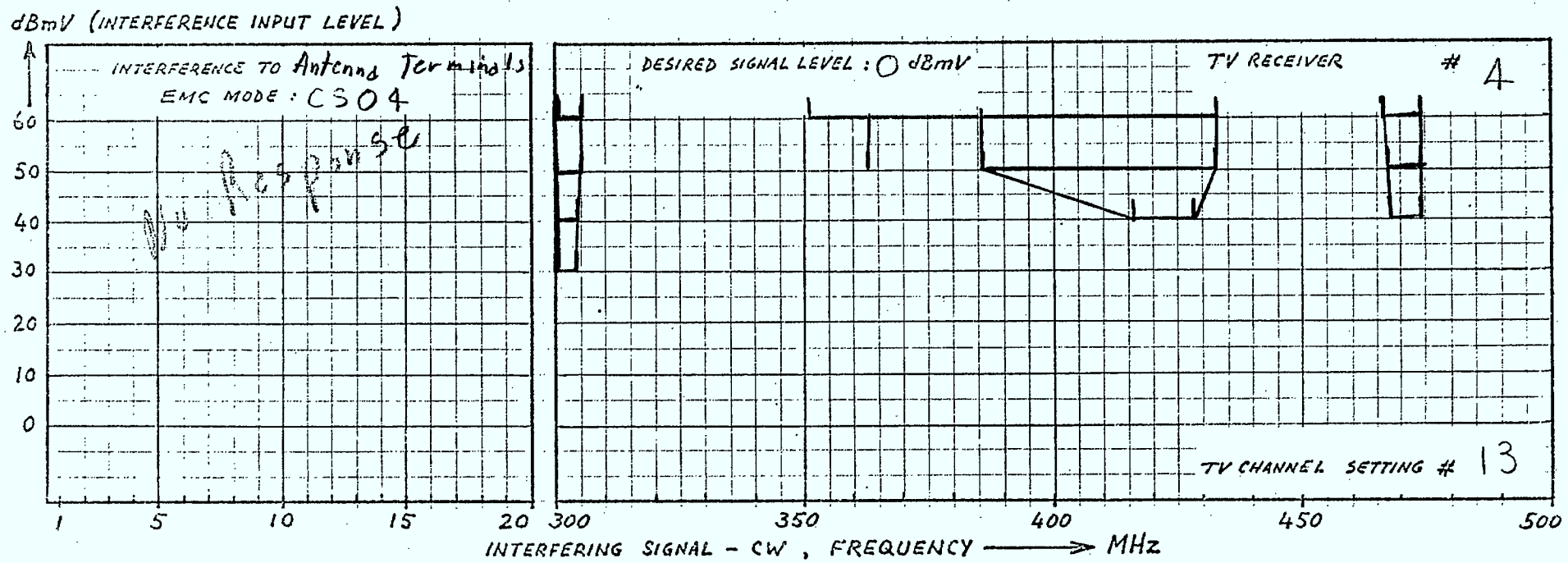

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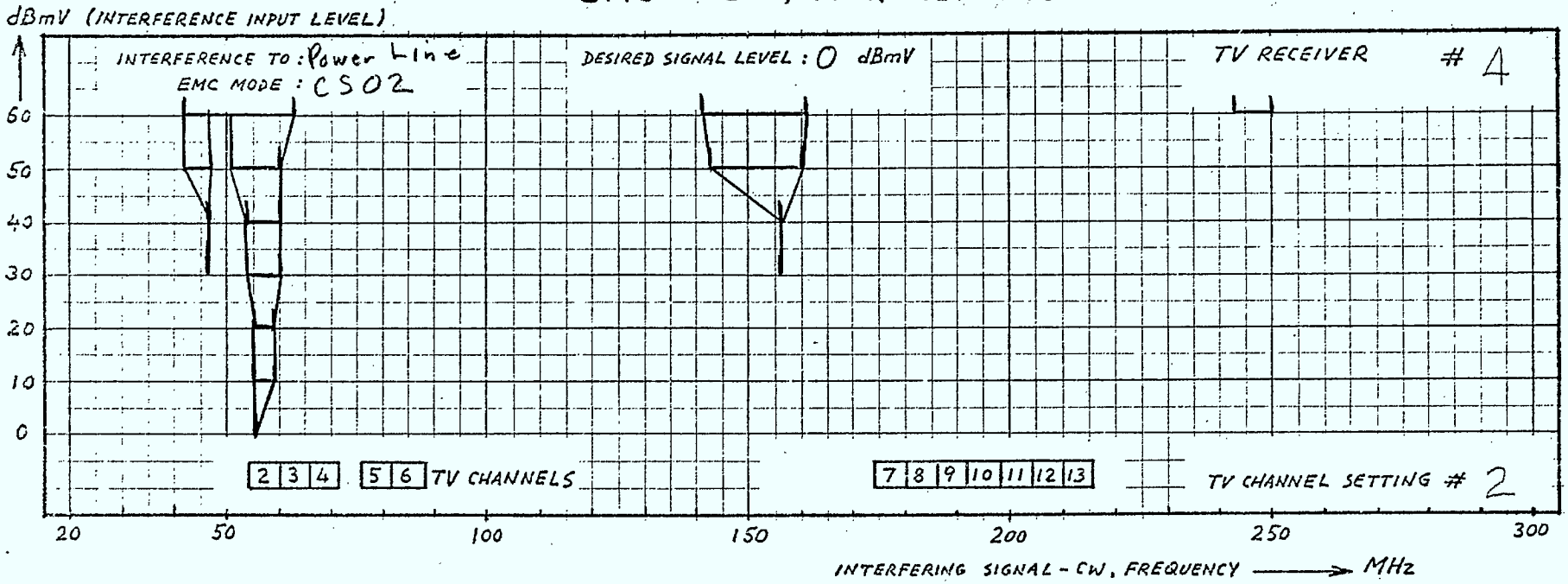

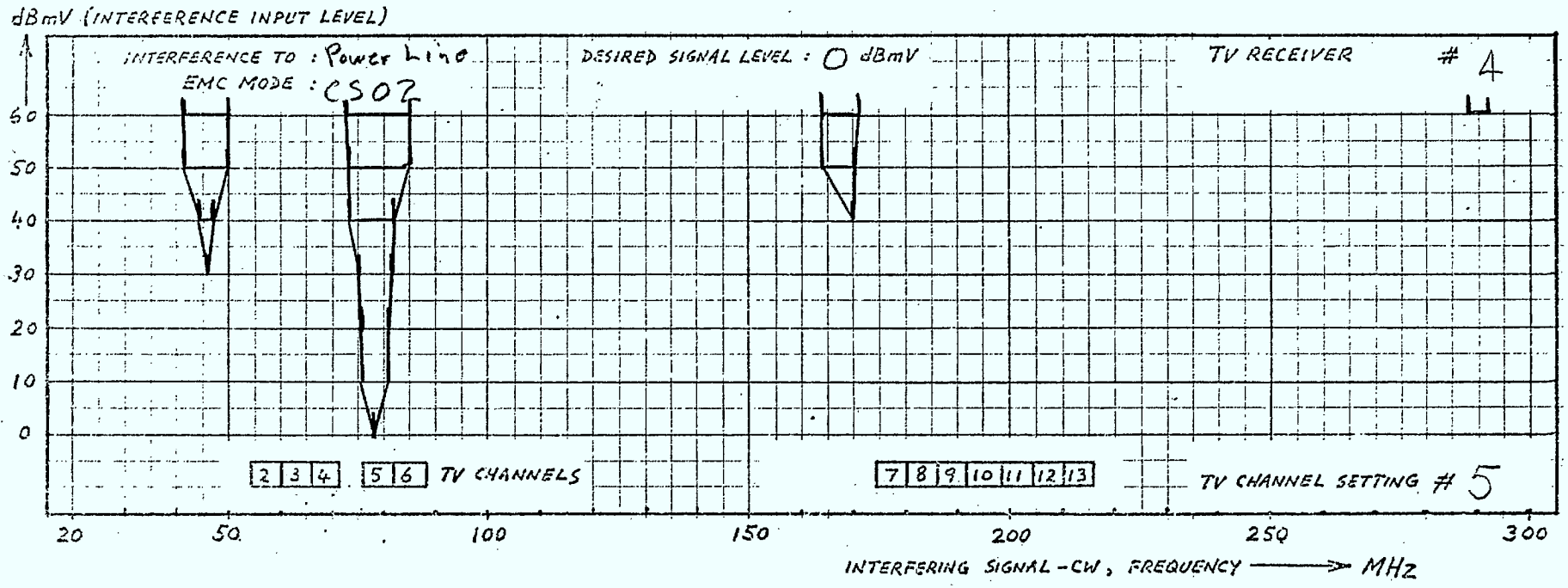

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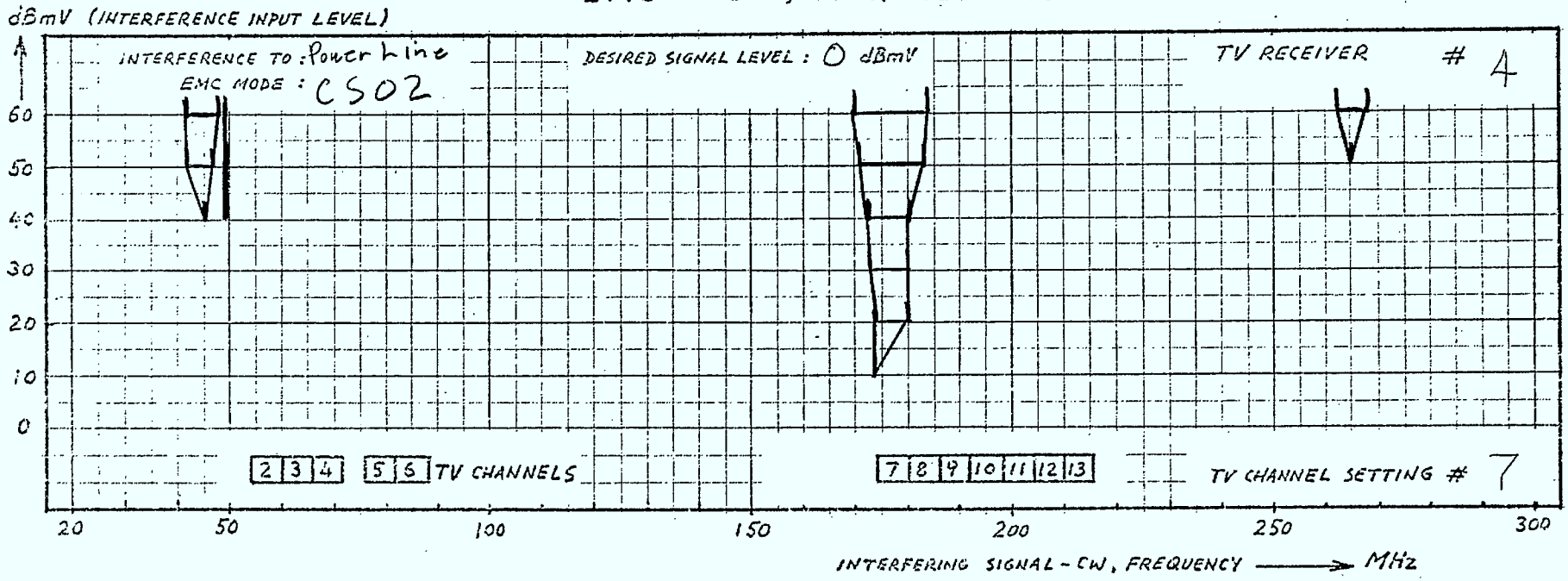

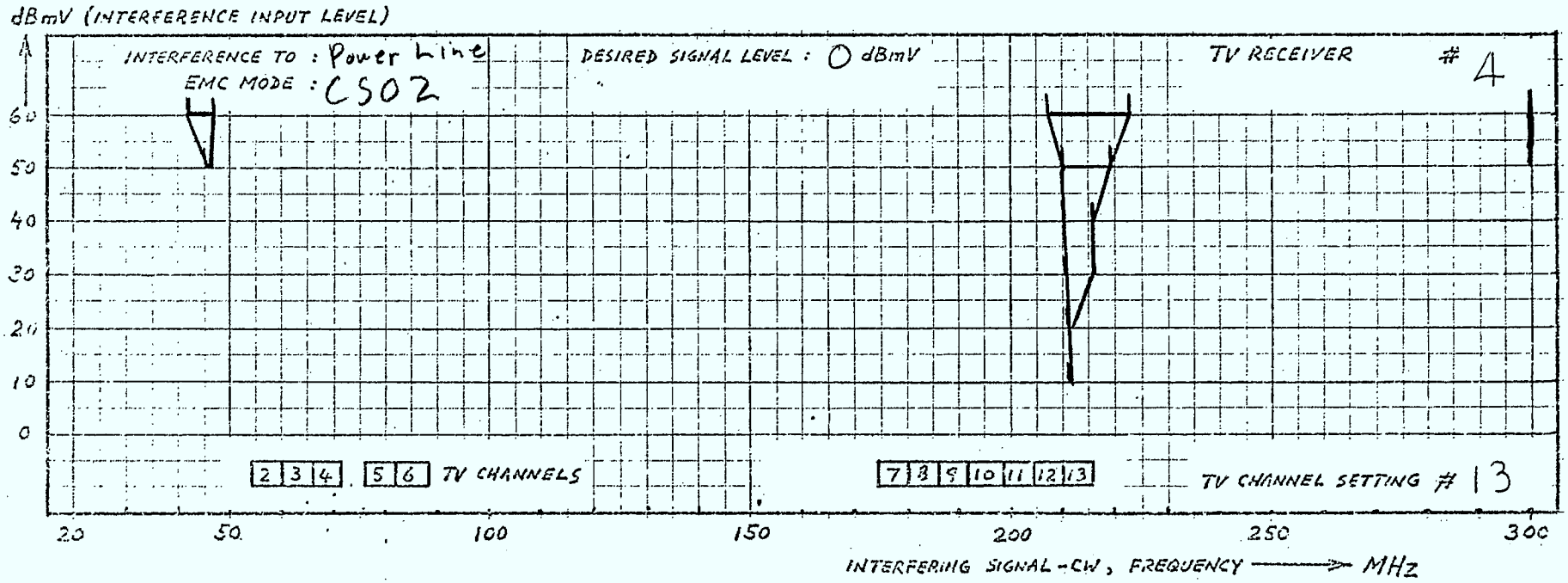

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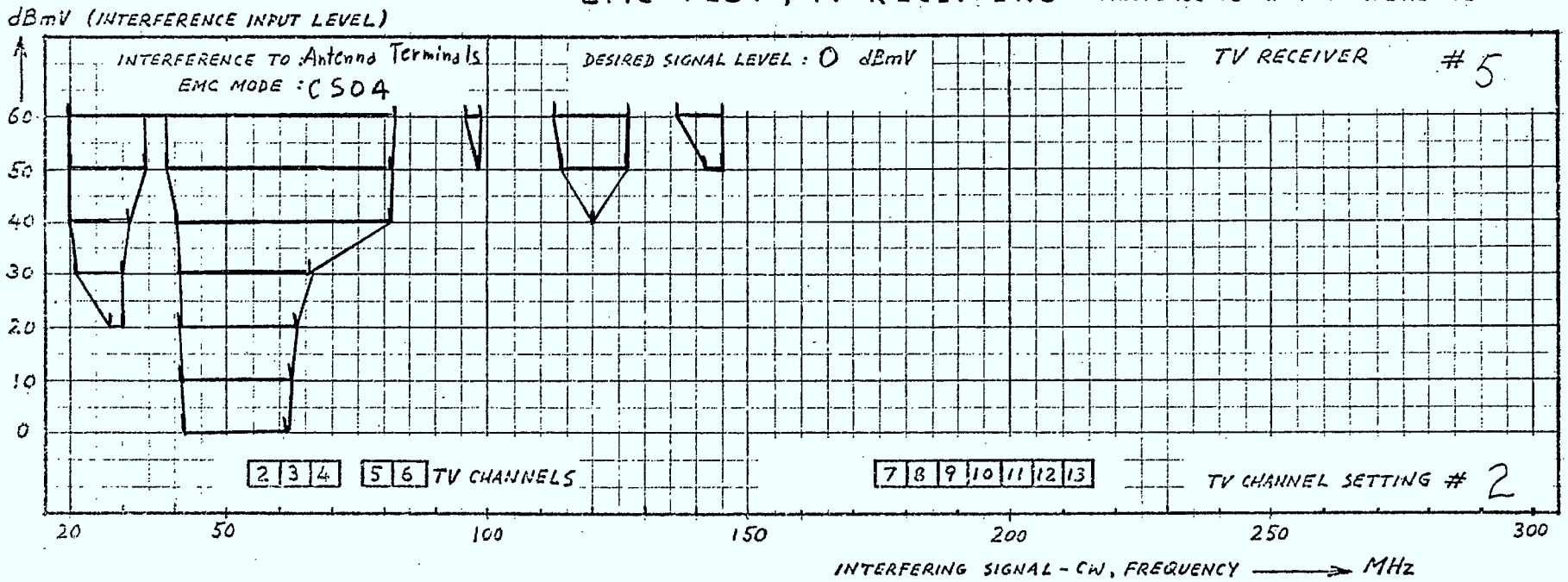

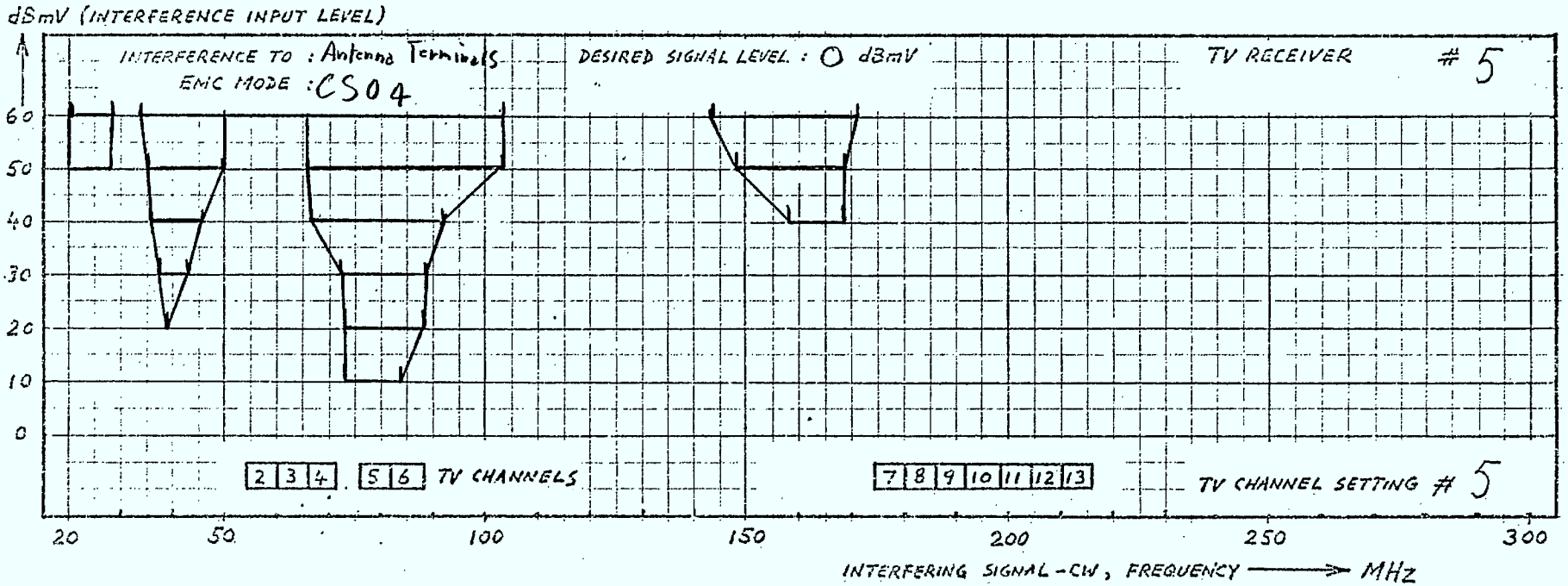

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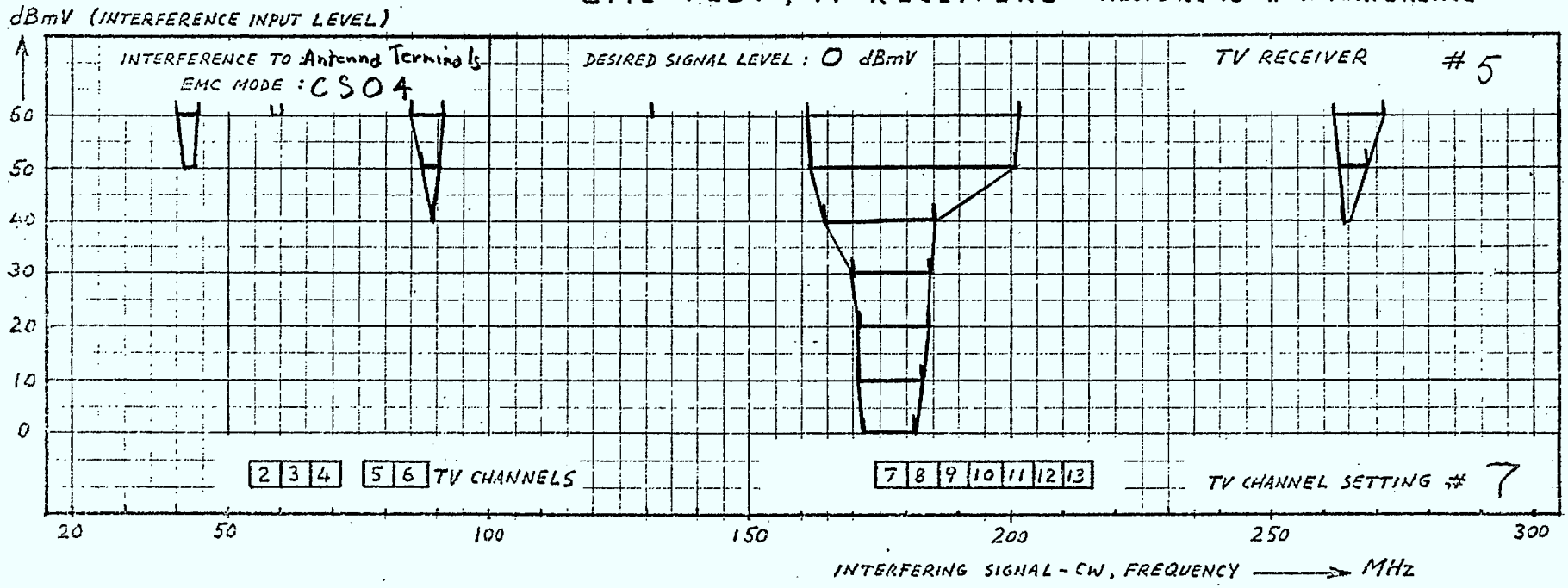
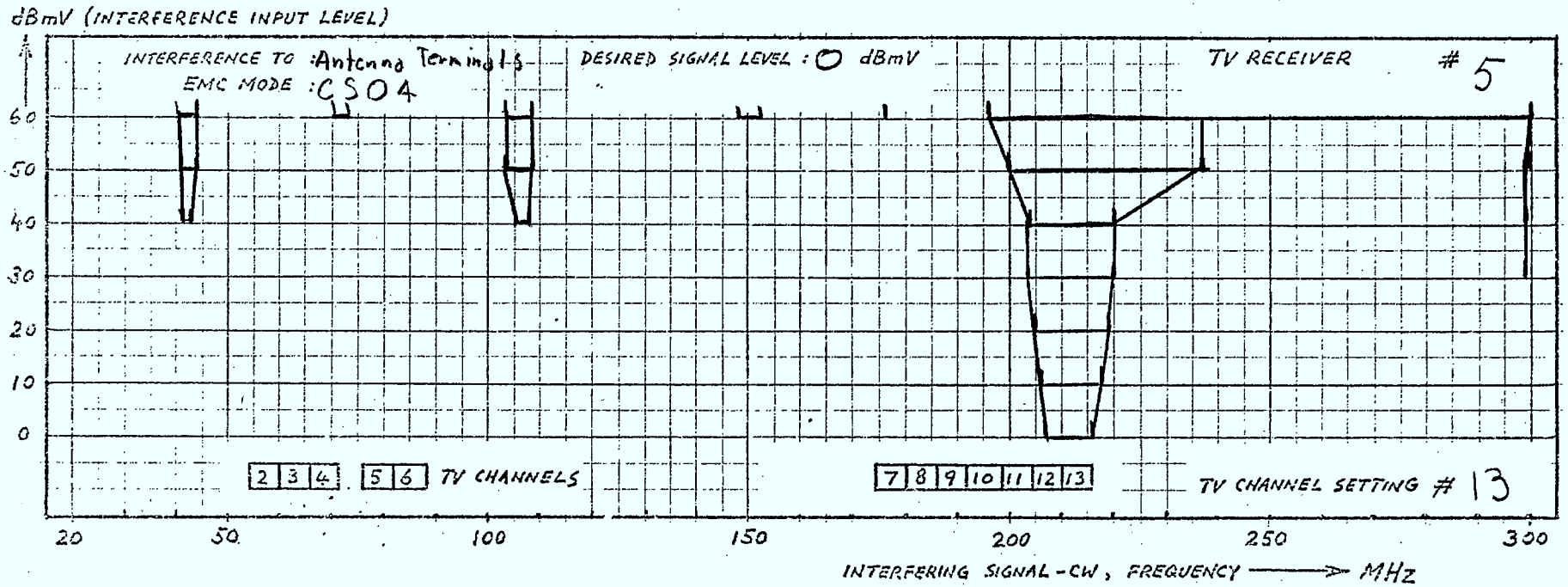
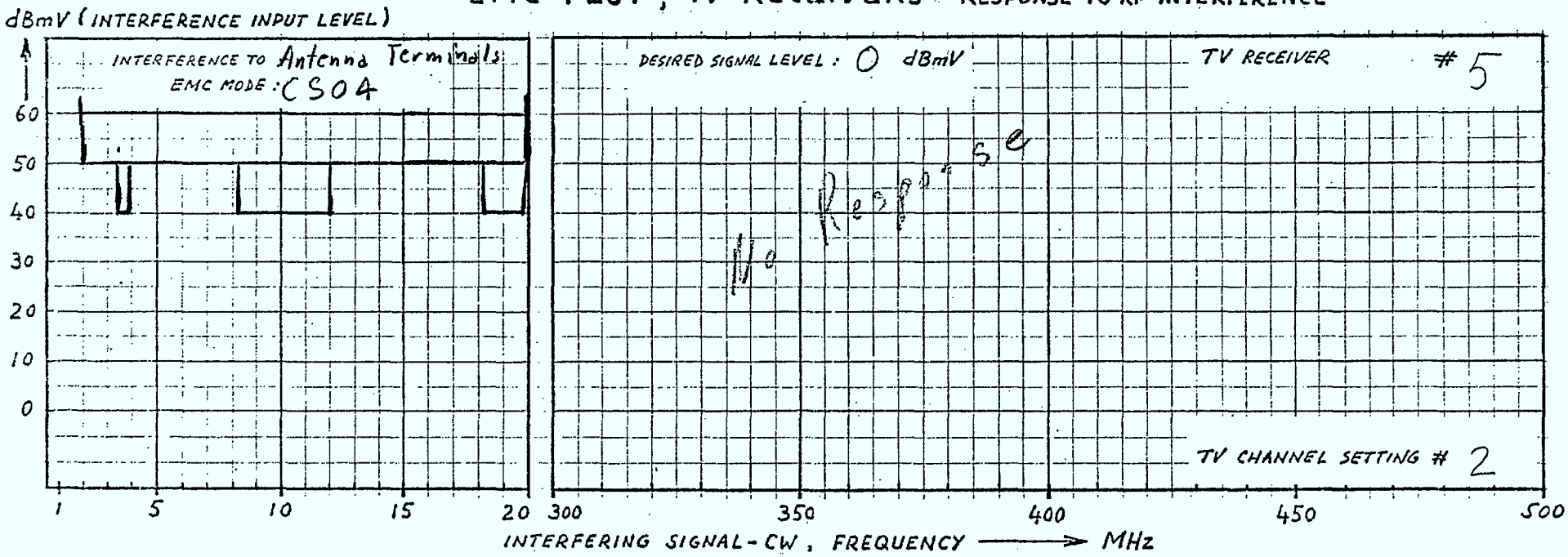
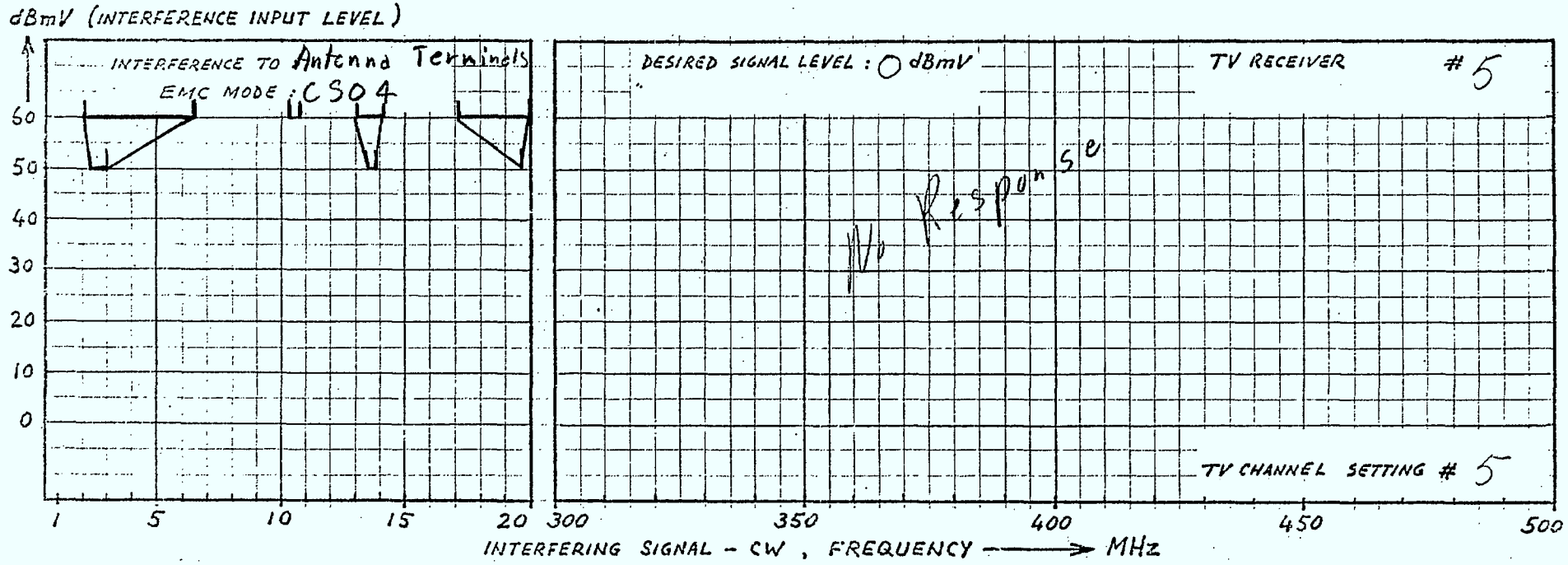


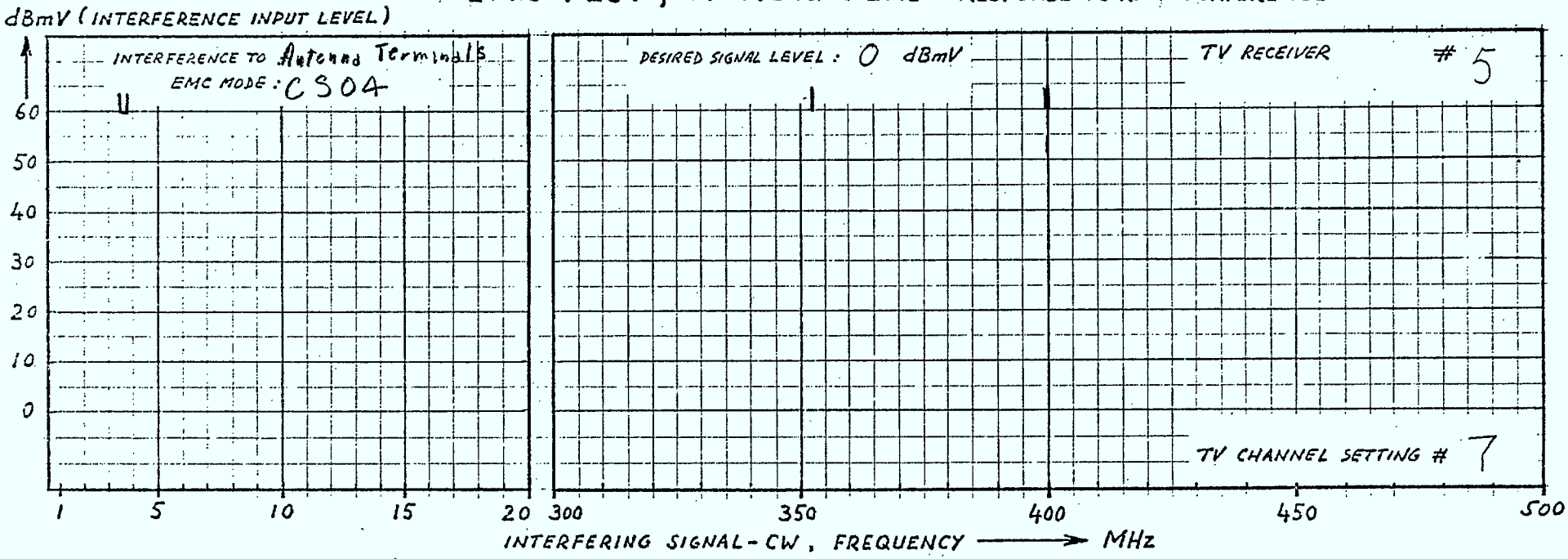


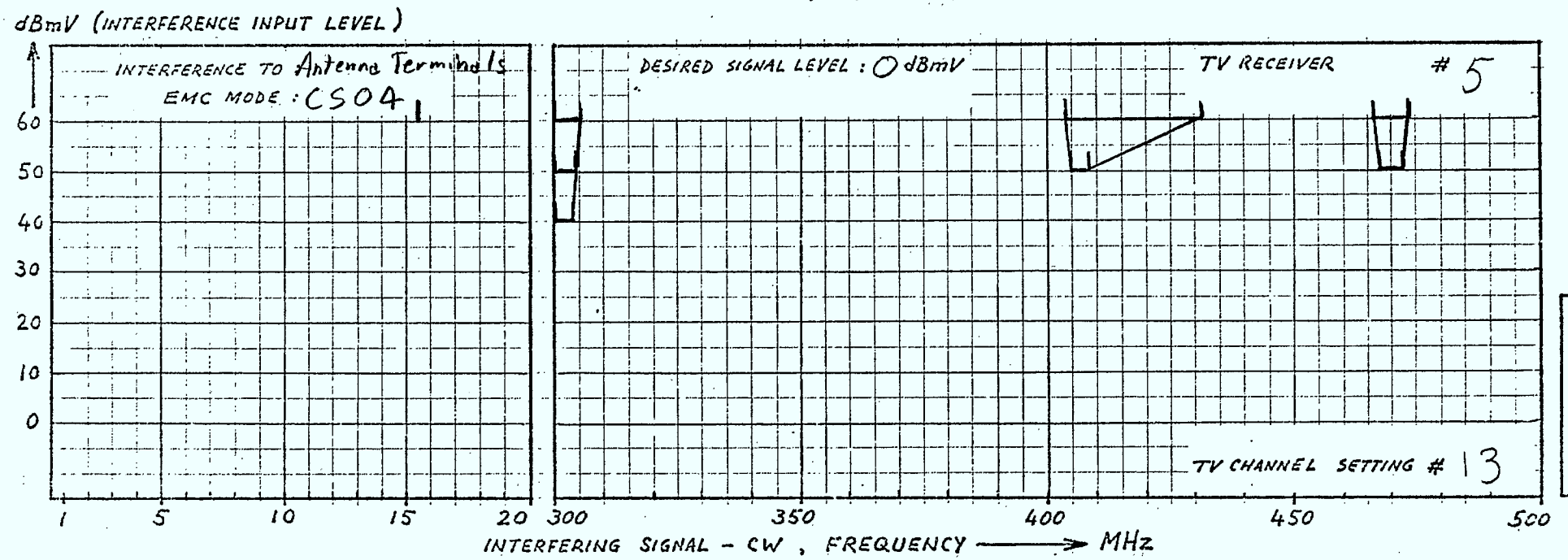
EMC TEST, TV RECEIVERS – RESPONSE TO RF INTERFERENCE





EMC TEST, TV RECEIVERS - RESPONSE TO RF INTERFERENCE





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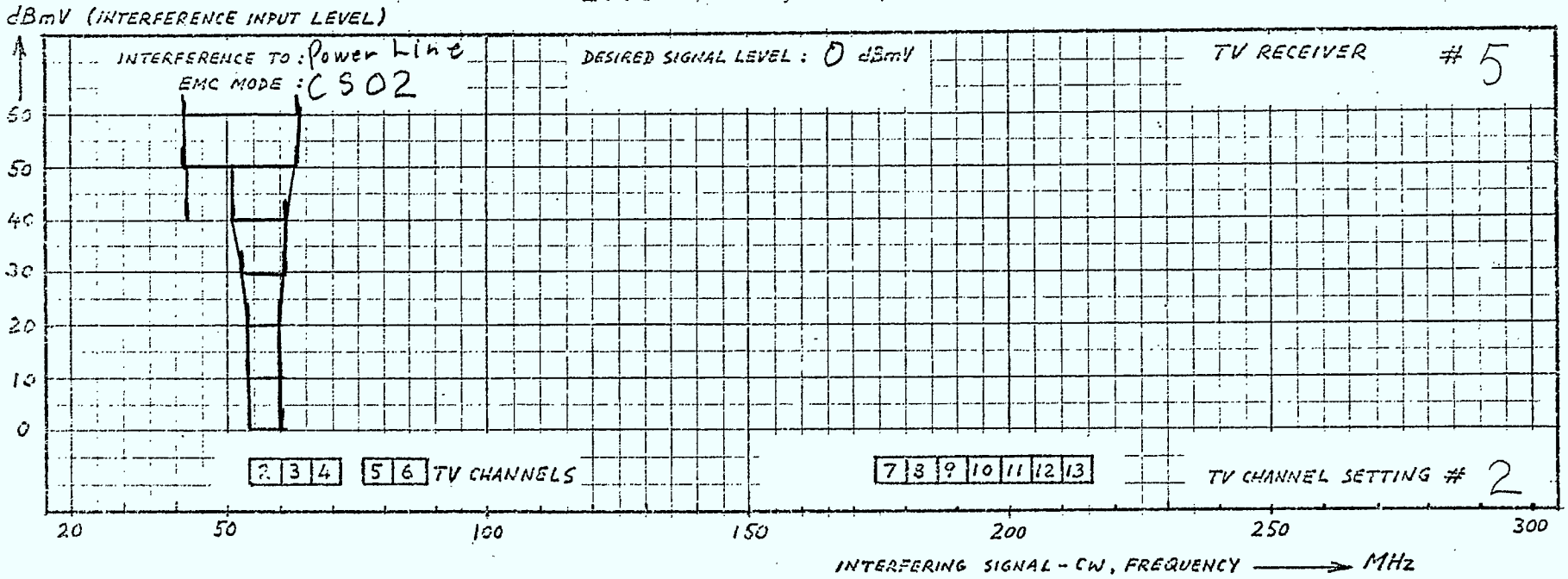

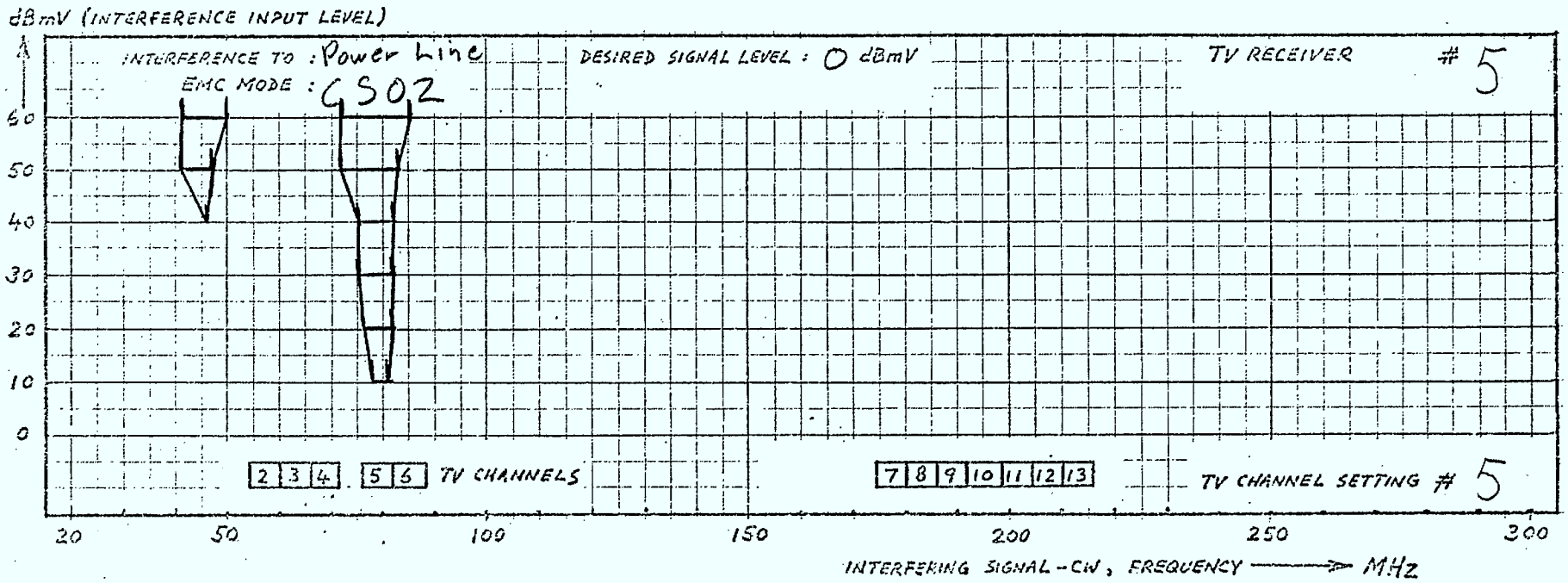

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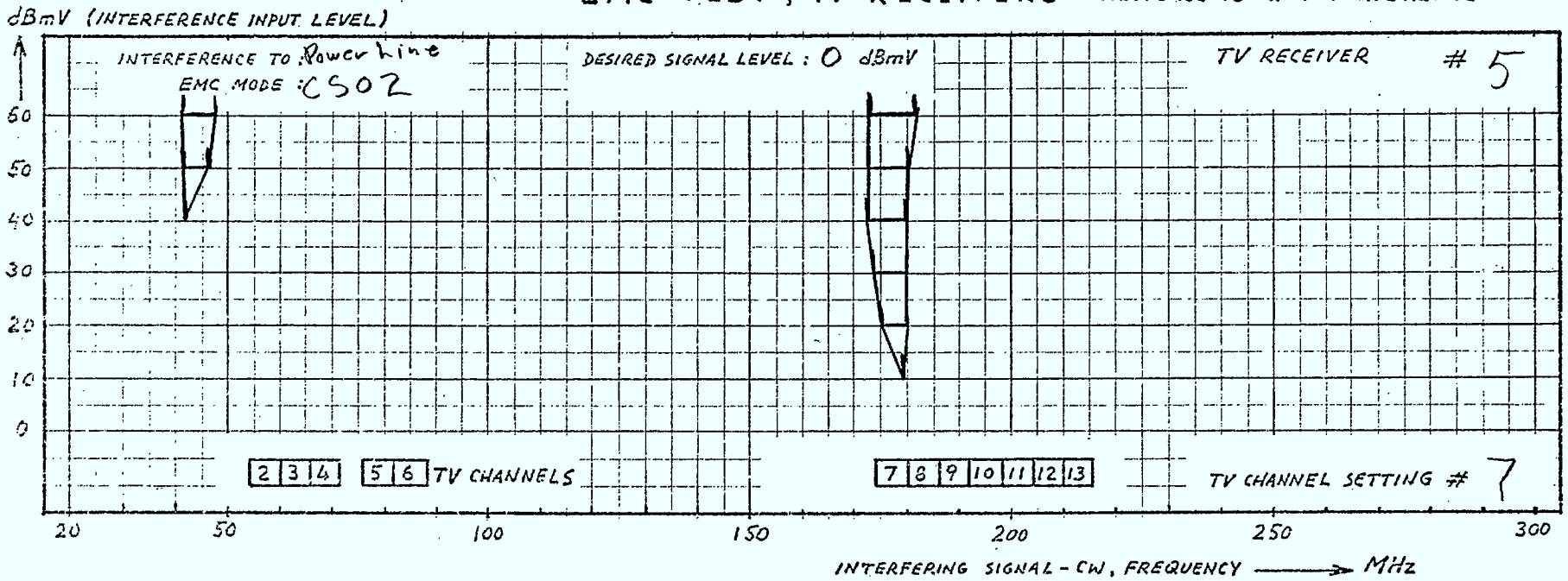

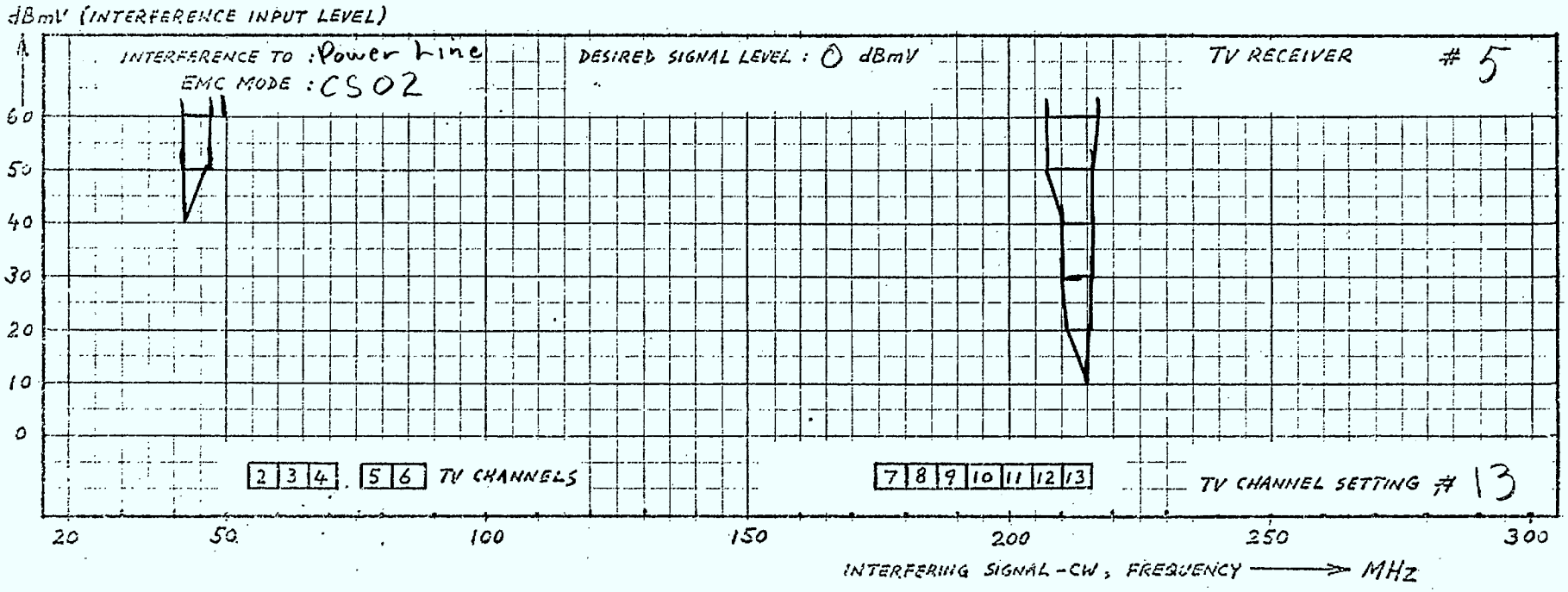

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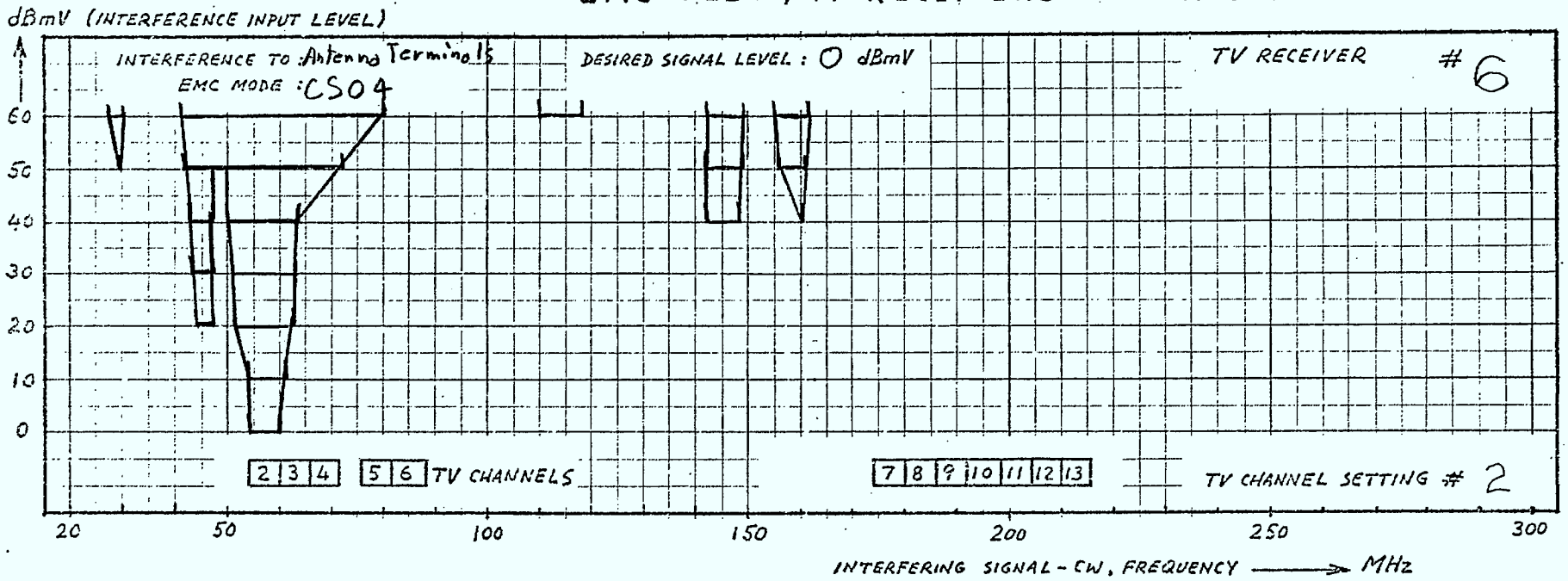
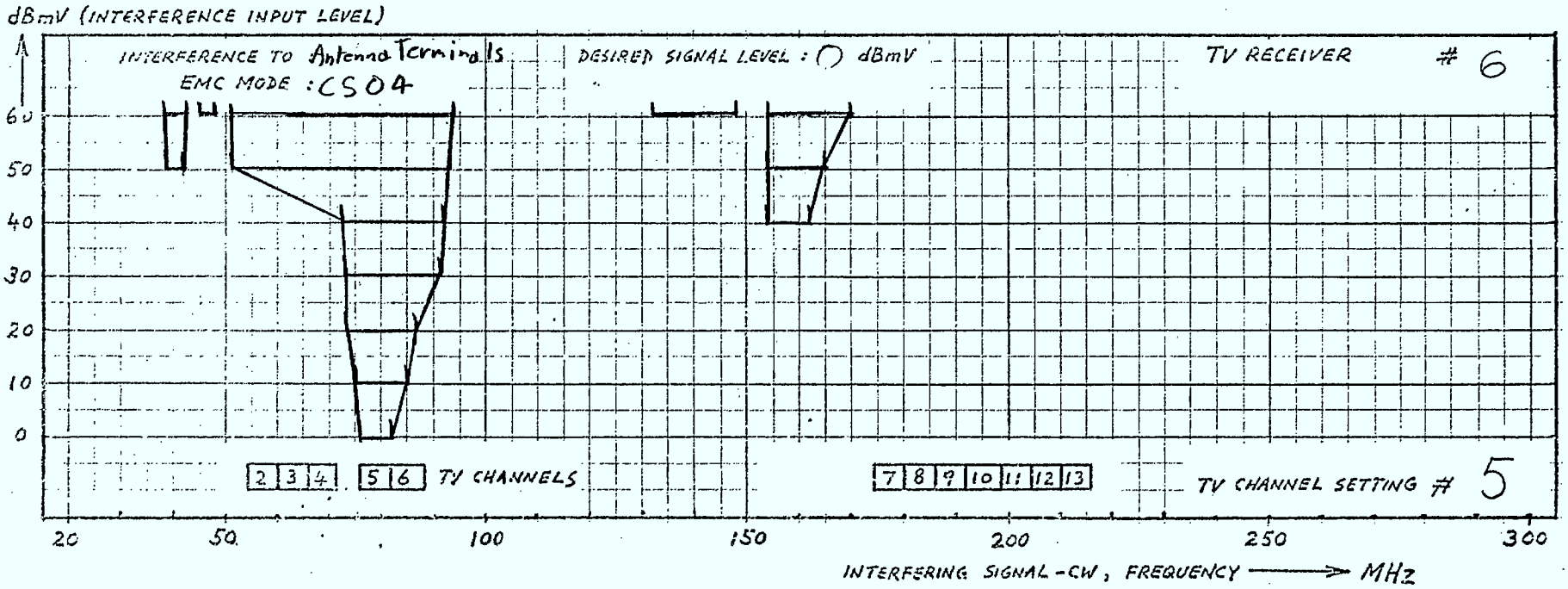
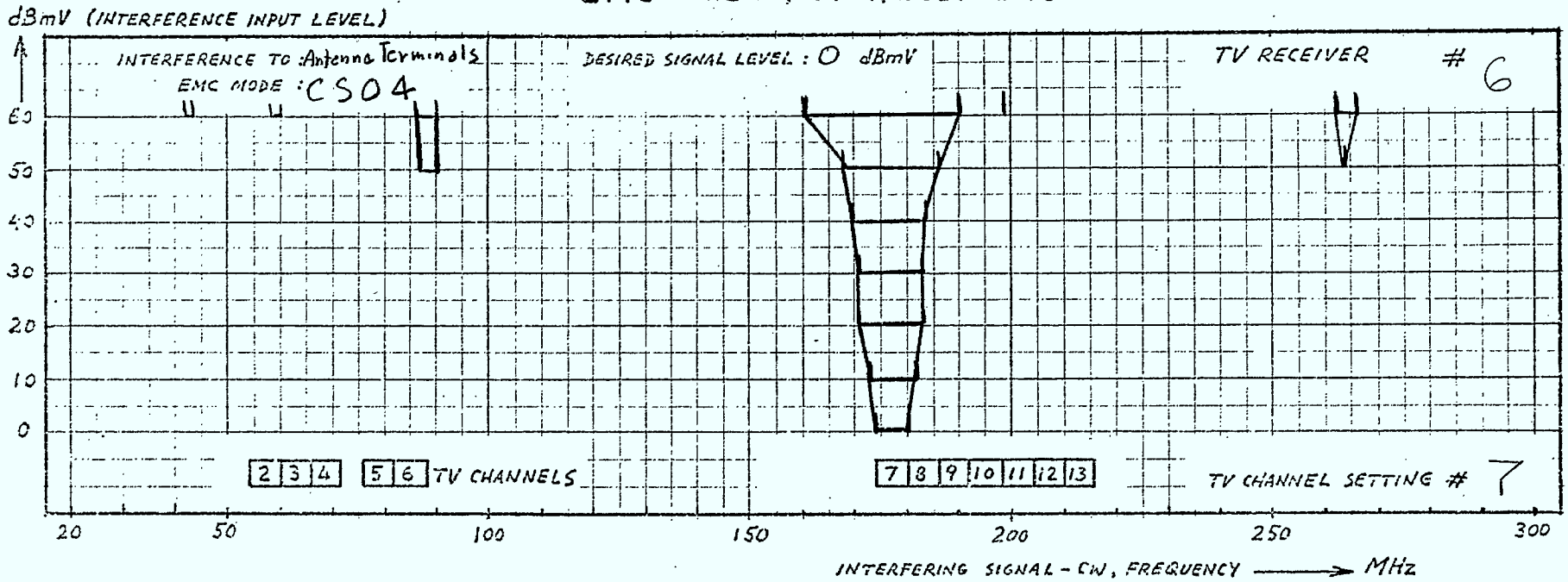
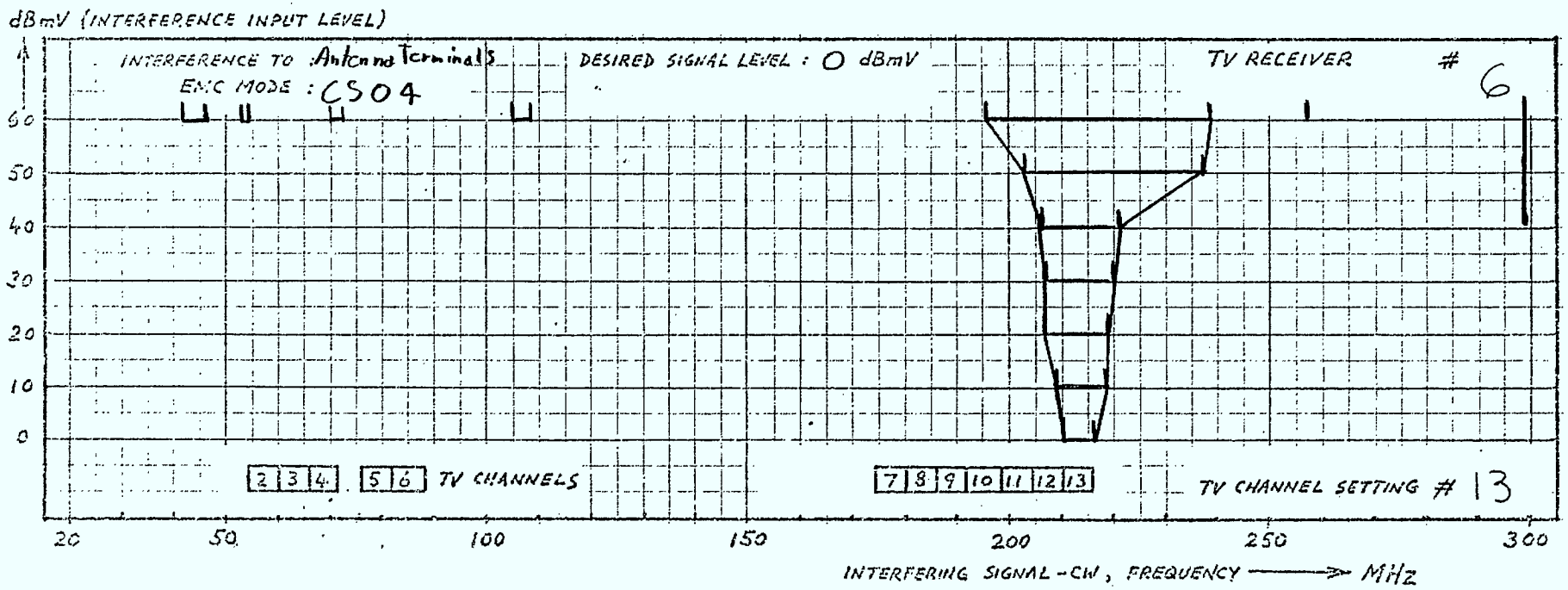




EMC TEST, TV RECEIVERS – RESPONSE TO RF INTERFERENCE





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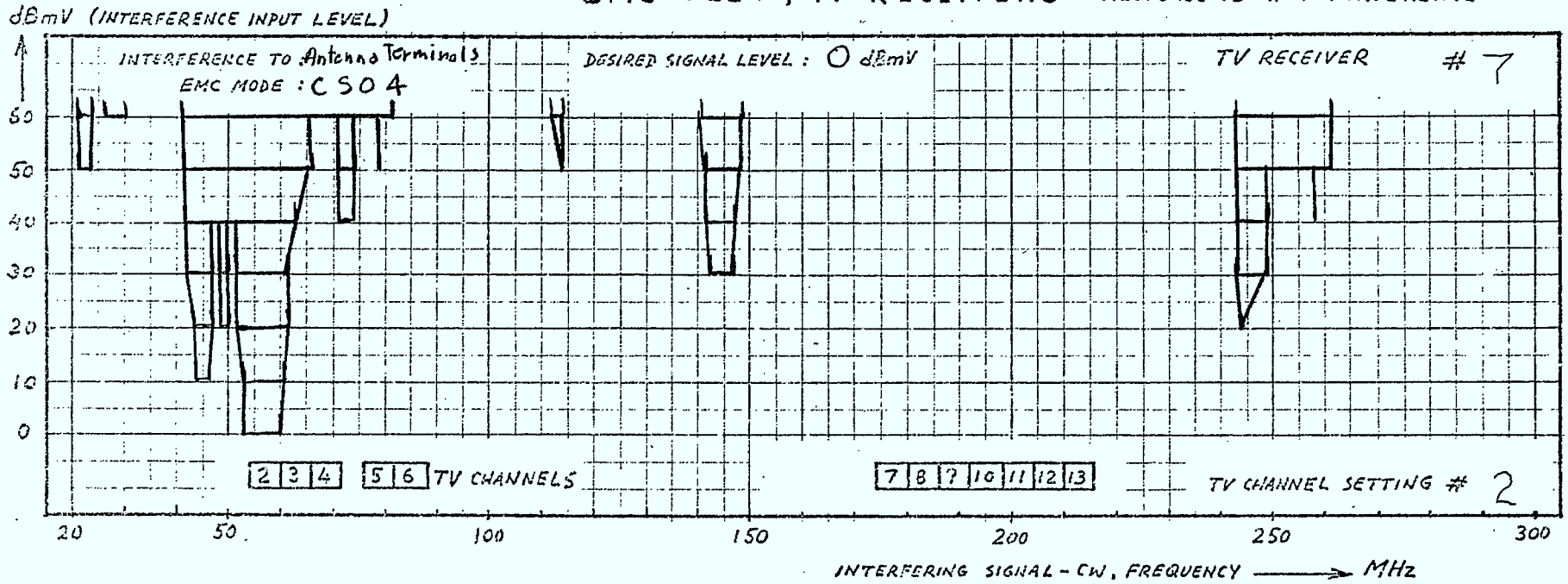

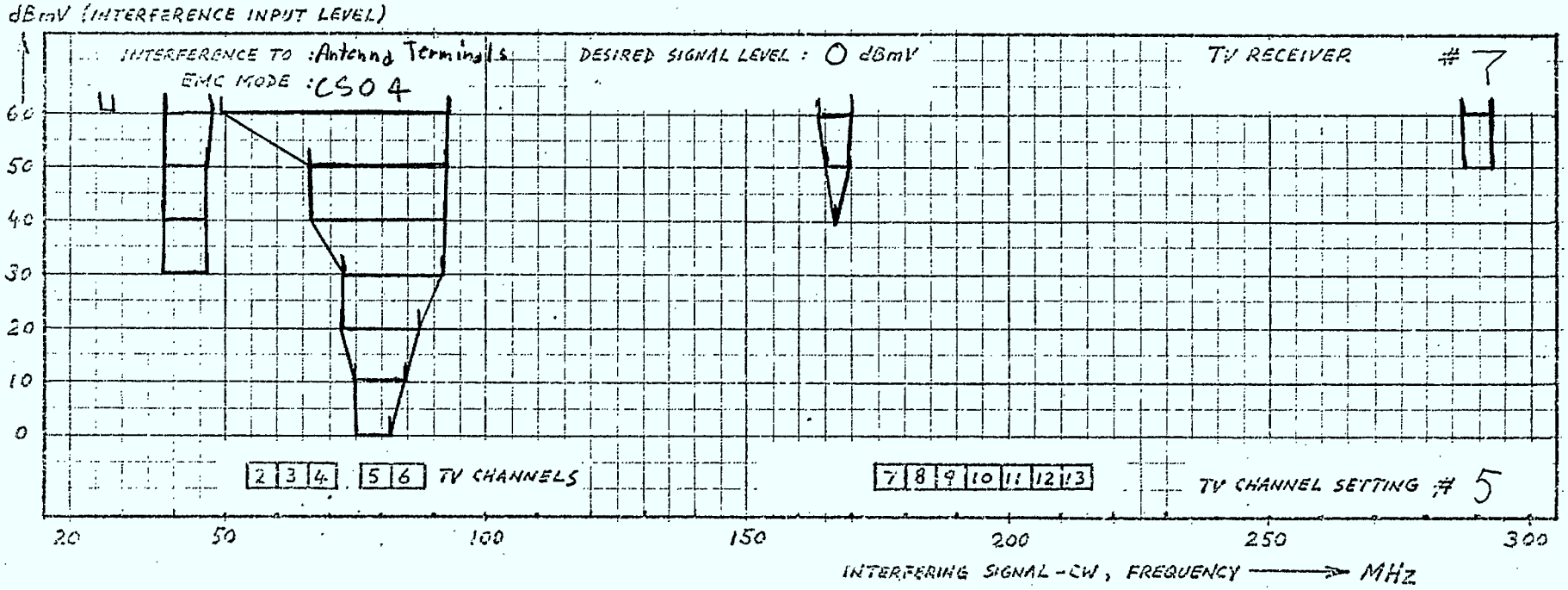

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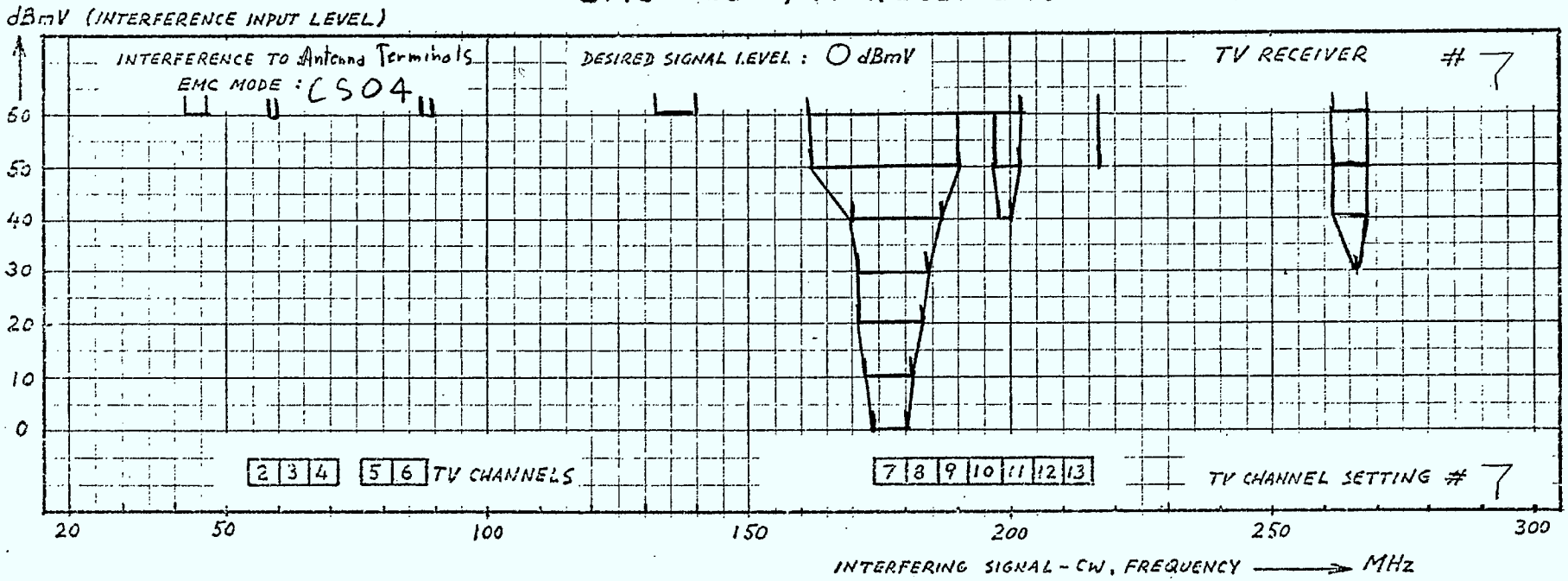

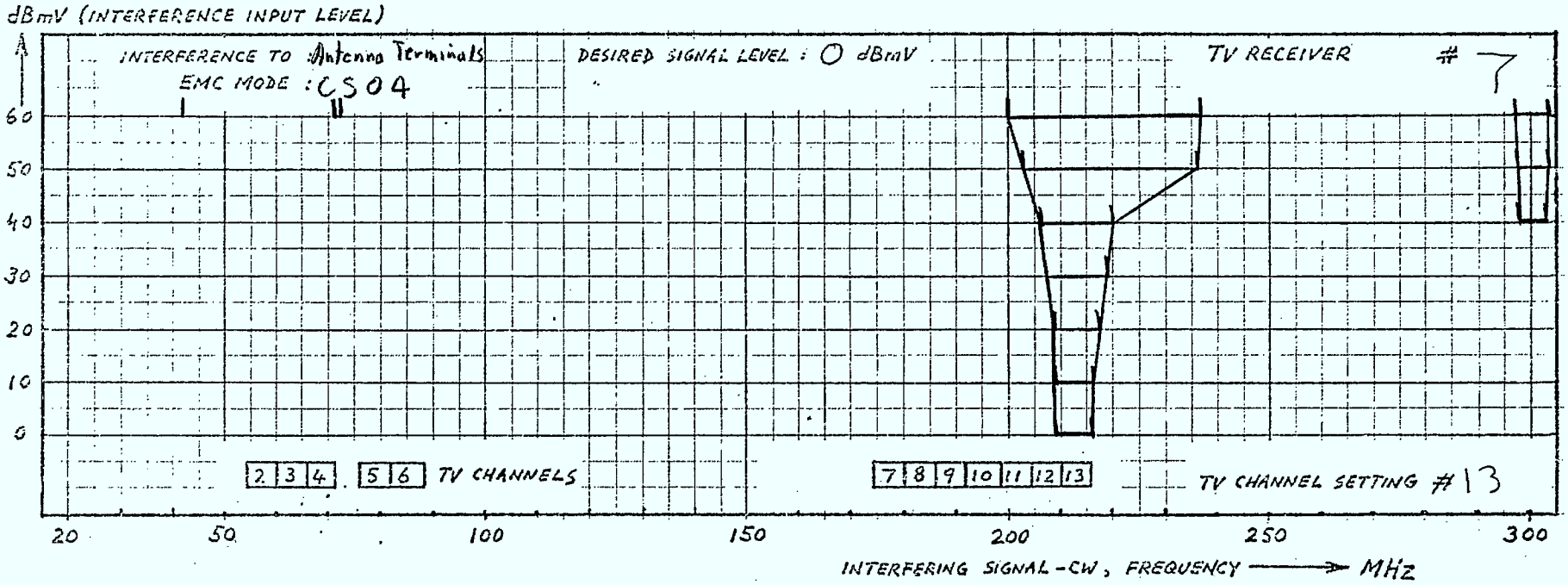

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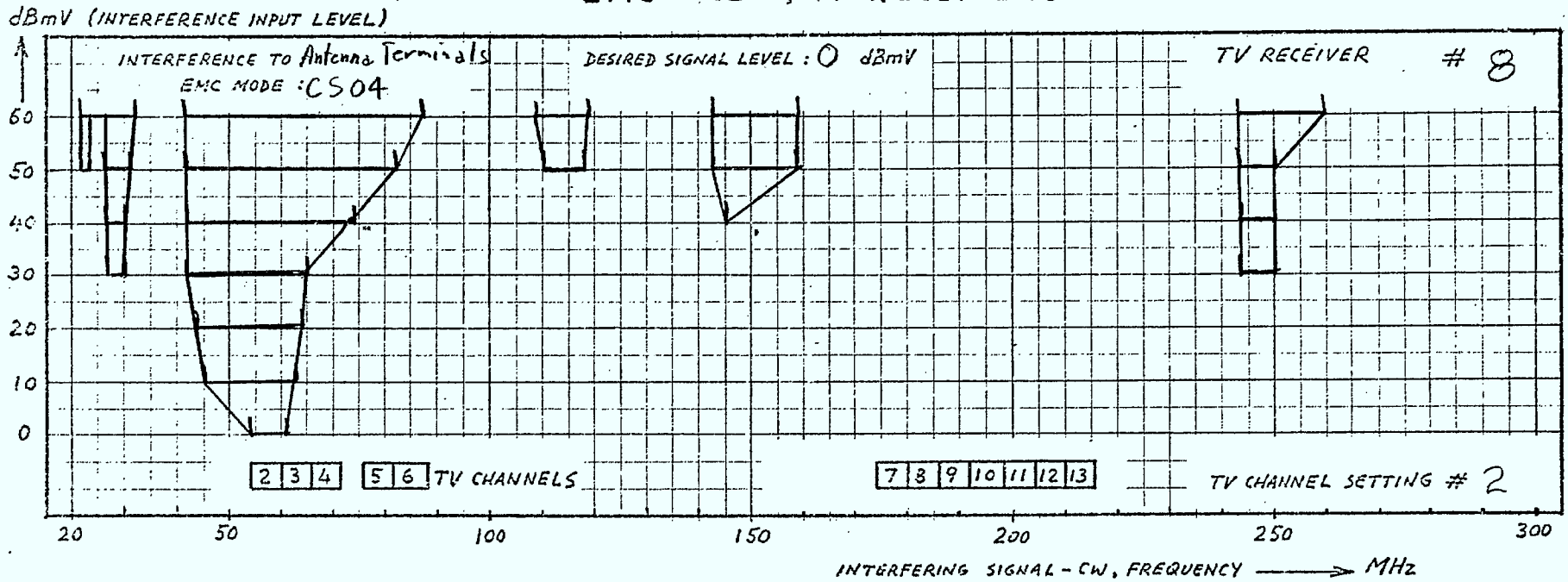

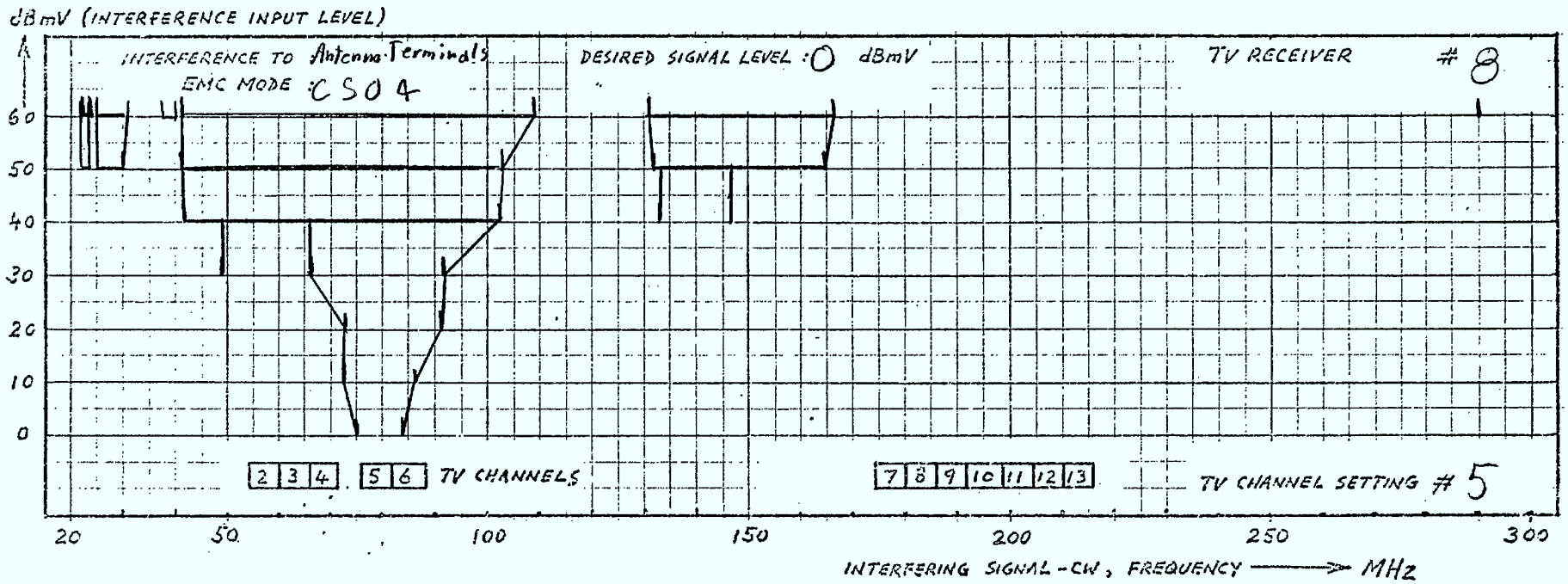

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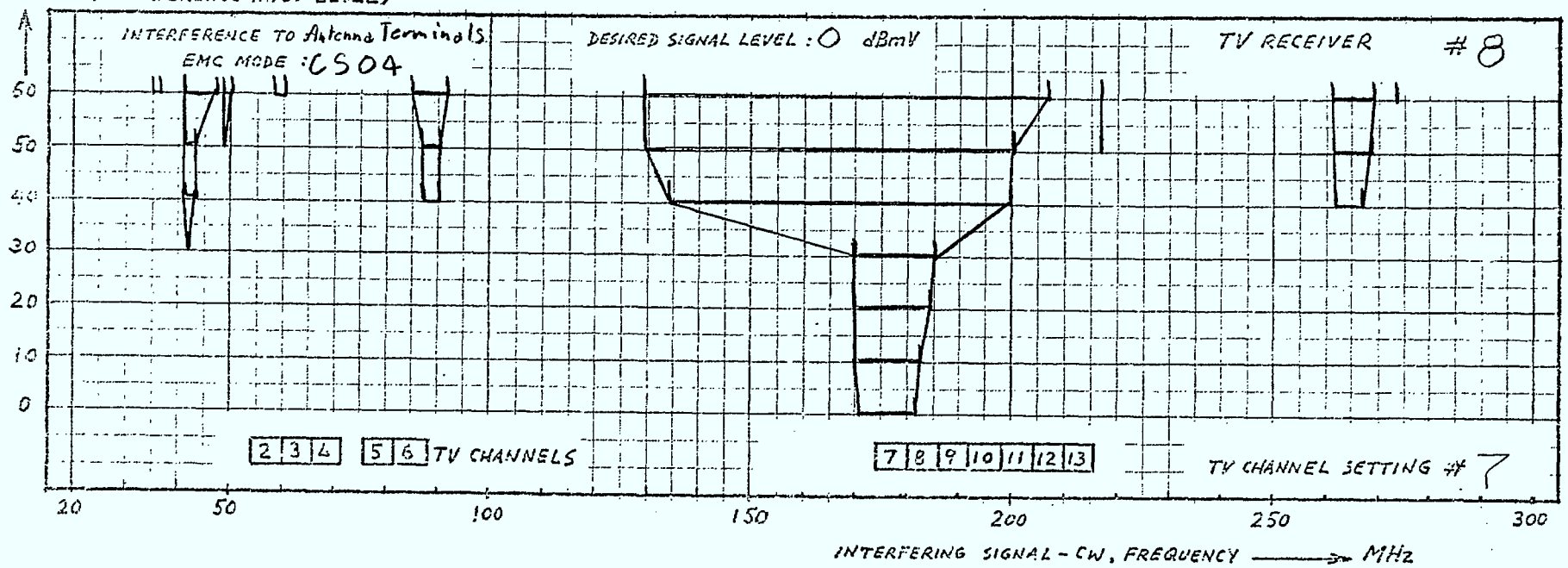
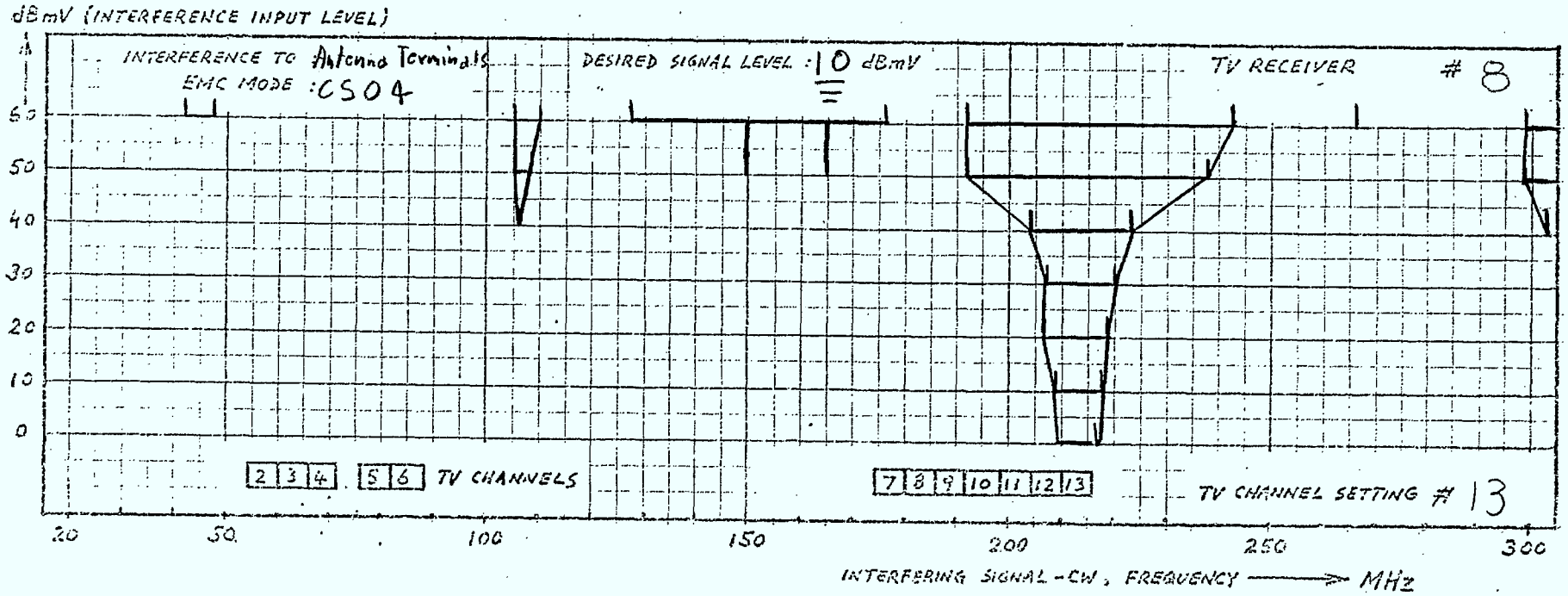
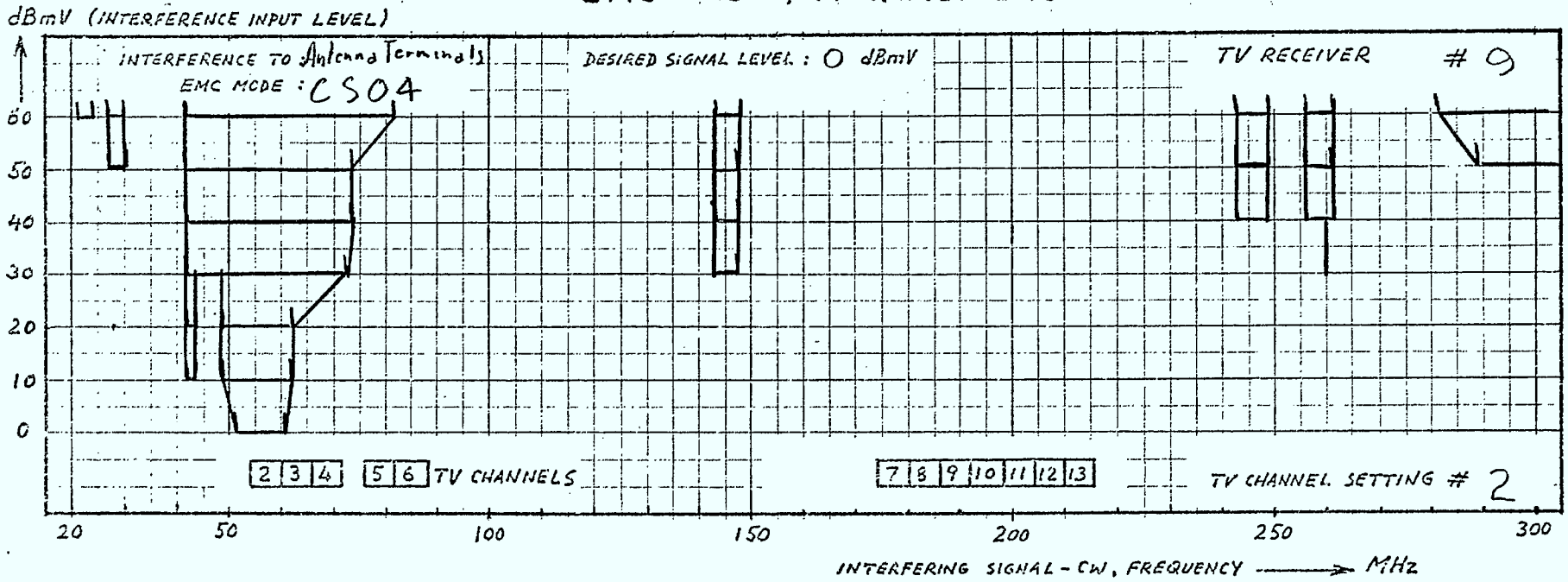
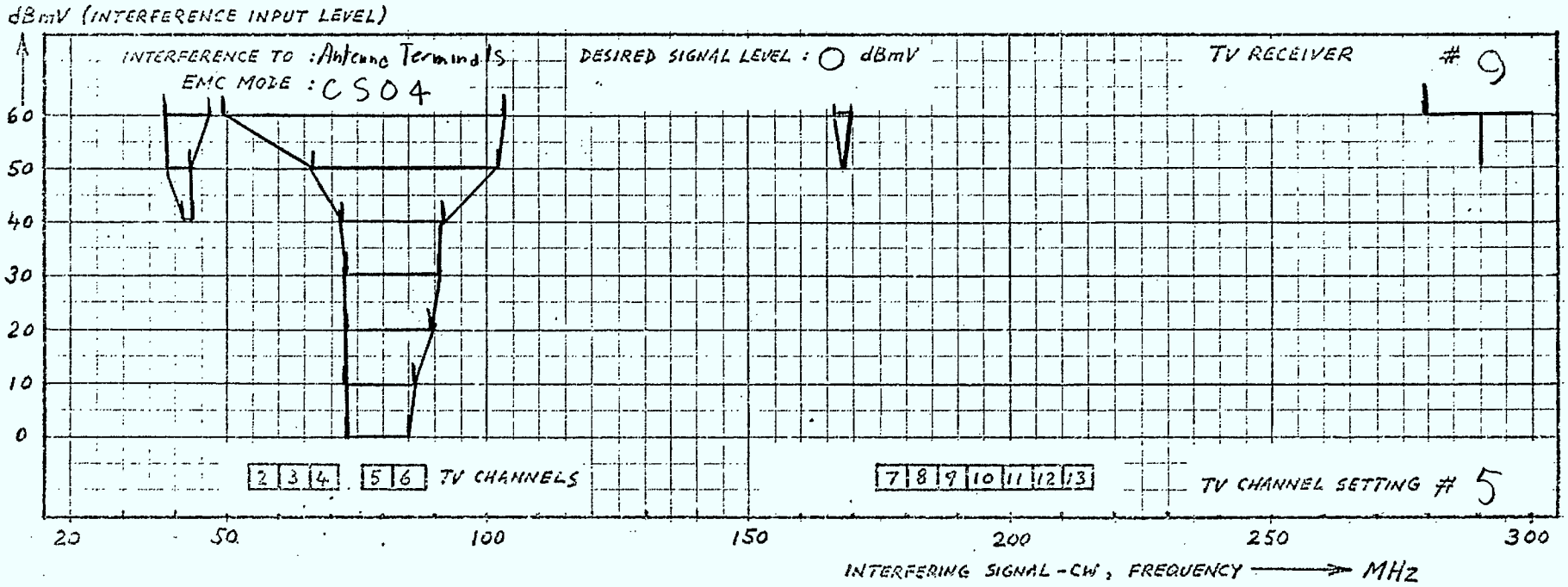




EMC TEST, TV RECEIVERS – RESPONSE TO RF INTERFERENCE





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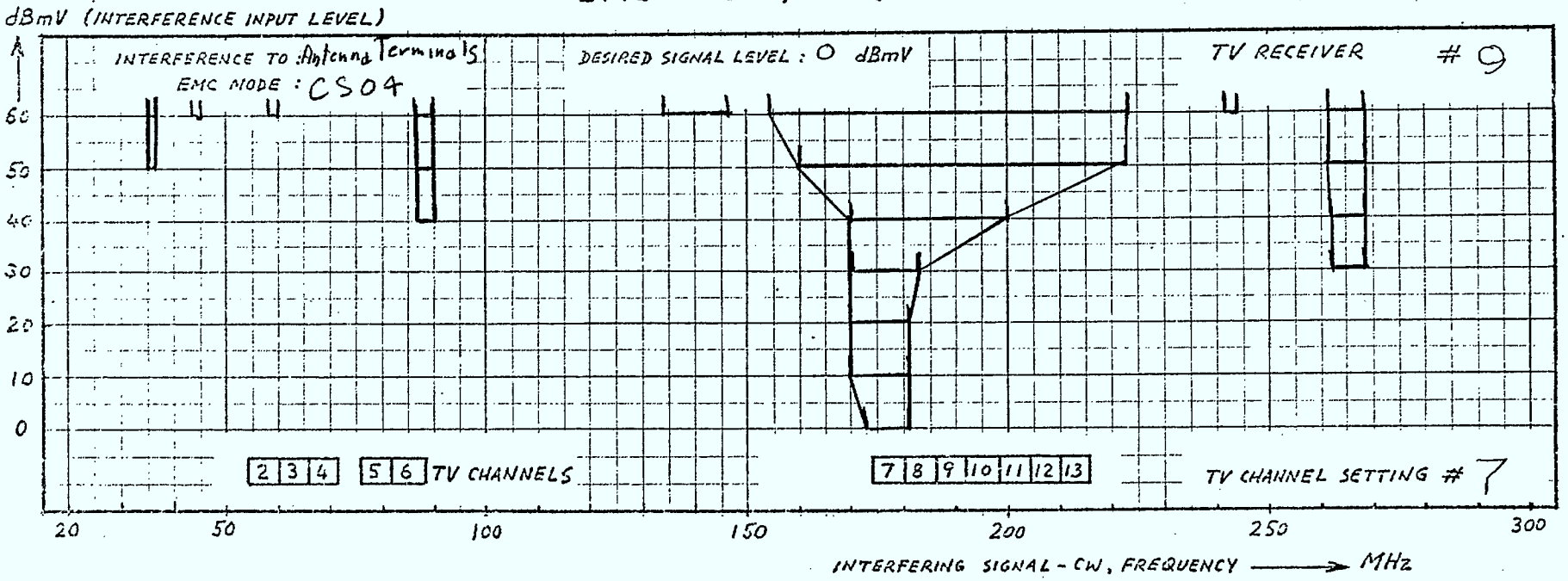
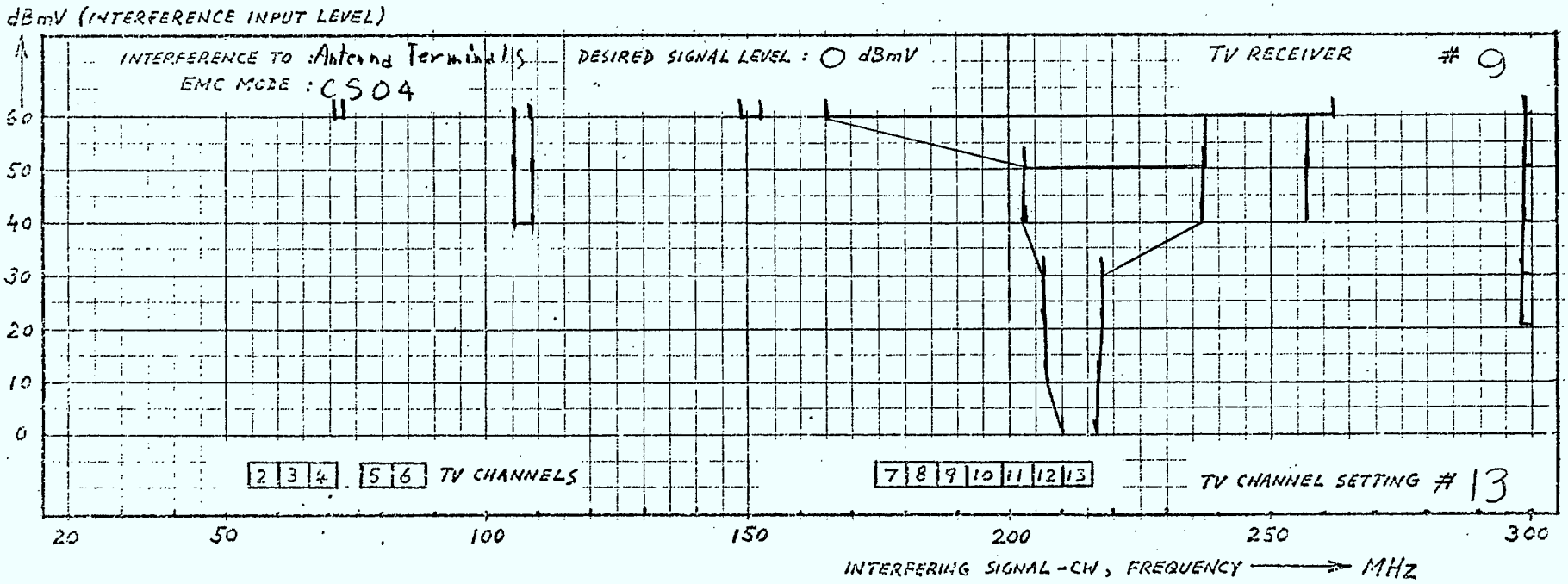
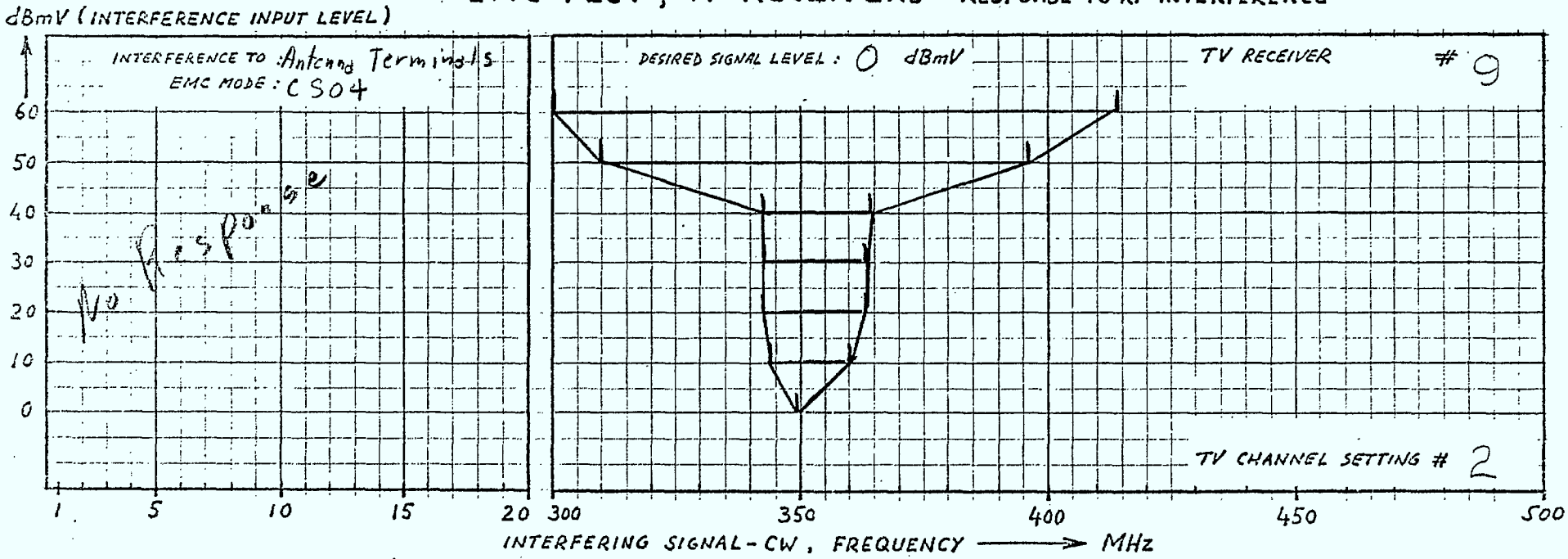
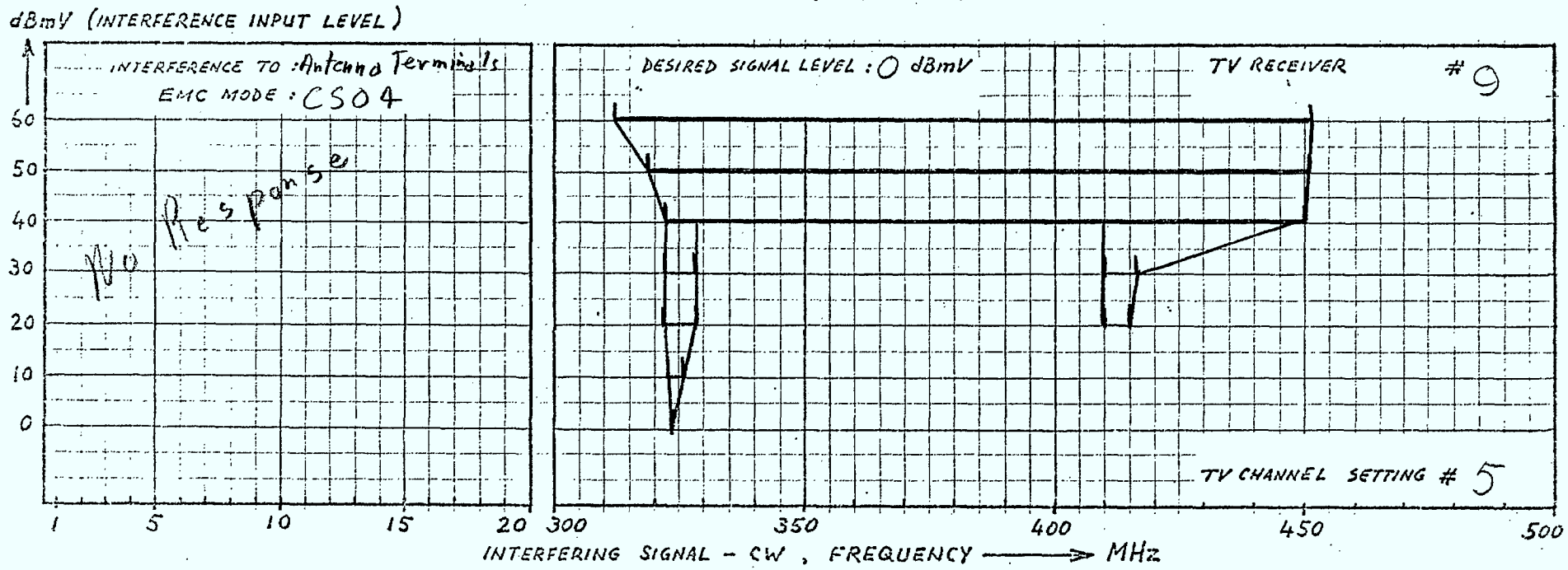


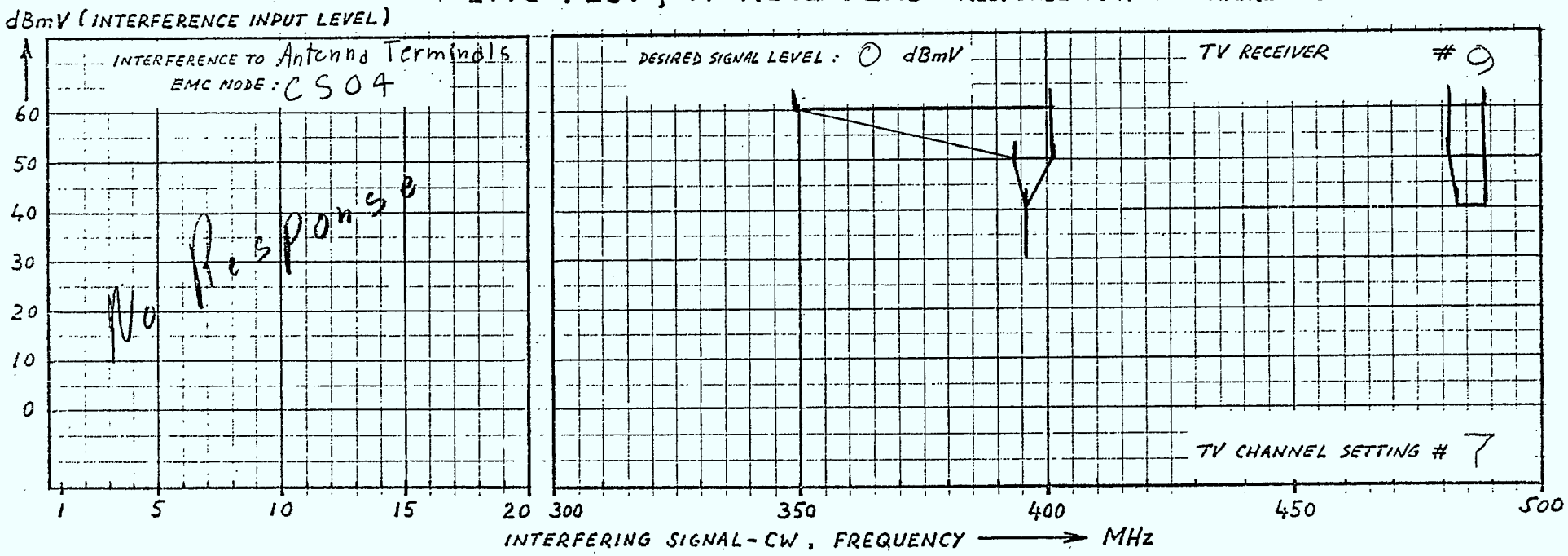


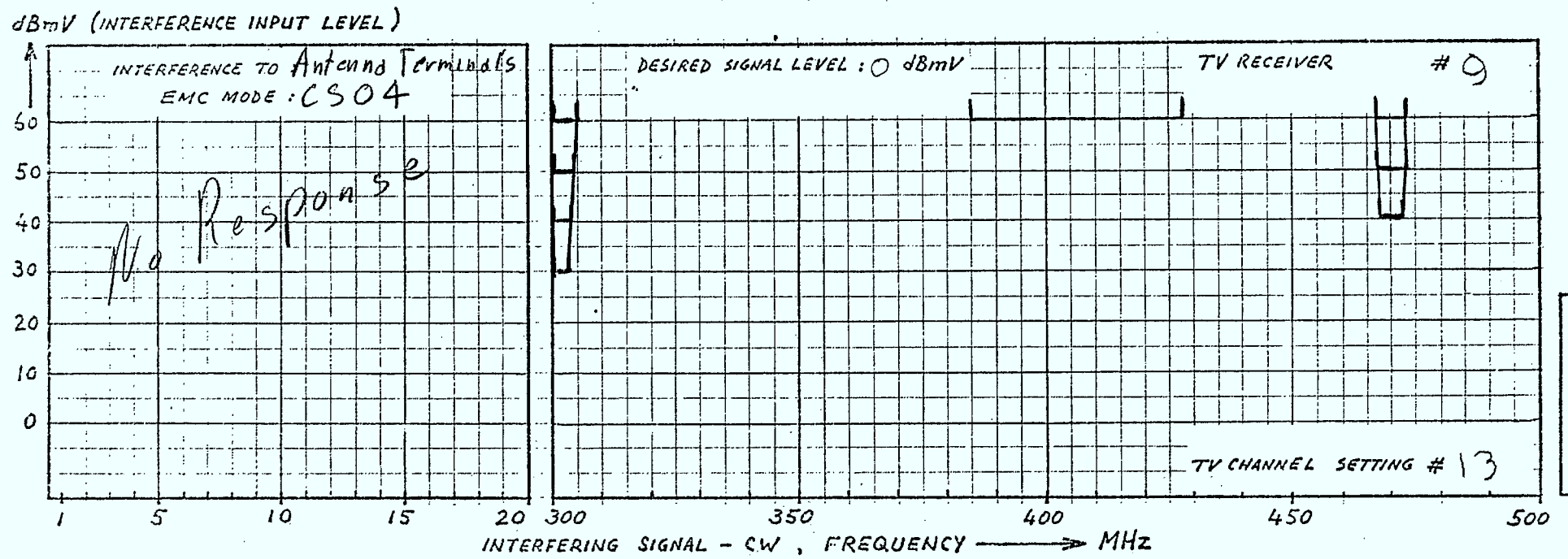
EMC TEST, TV RECEIVERS – RESPONSE TO RF INTERFERENCE



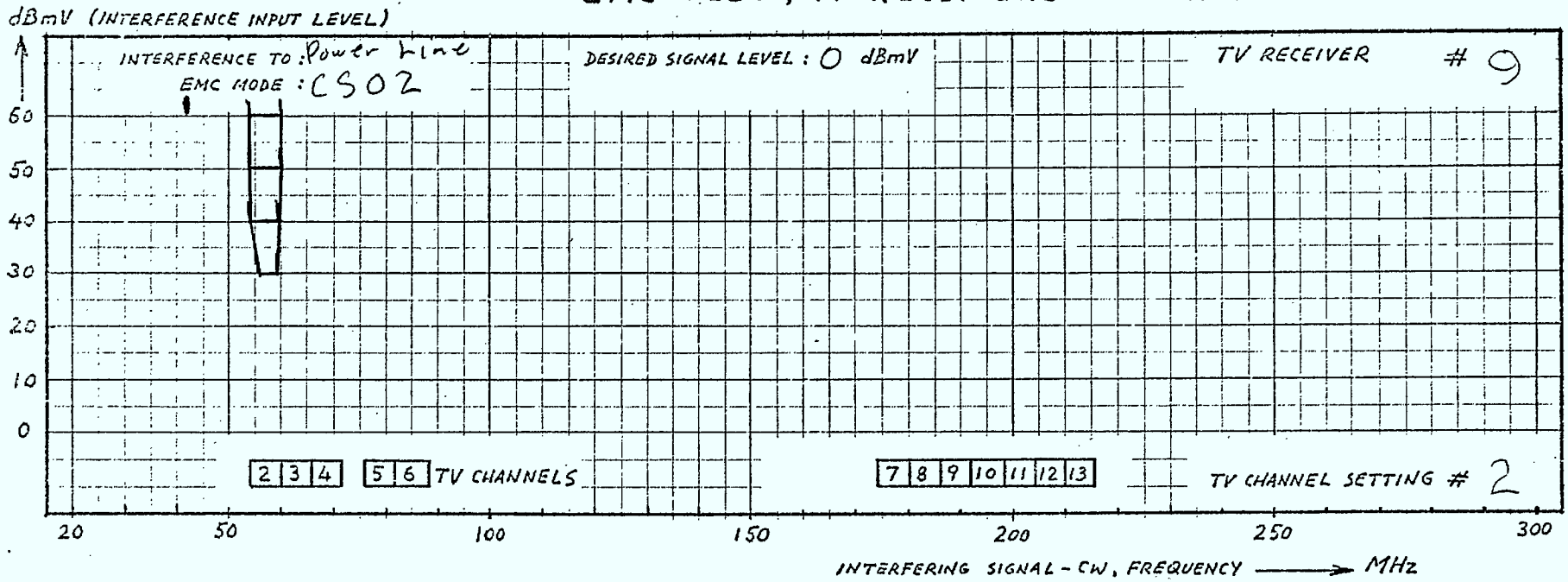


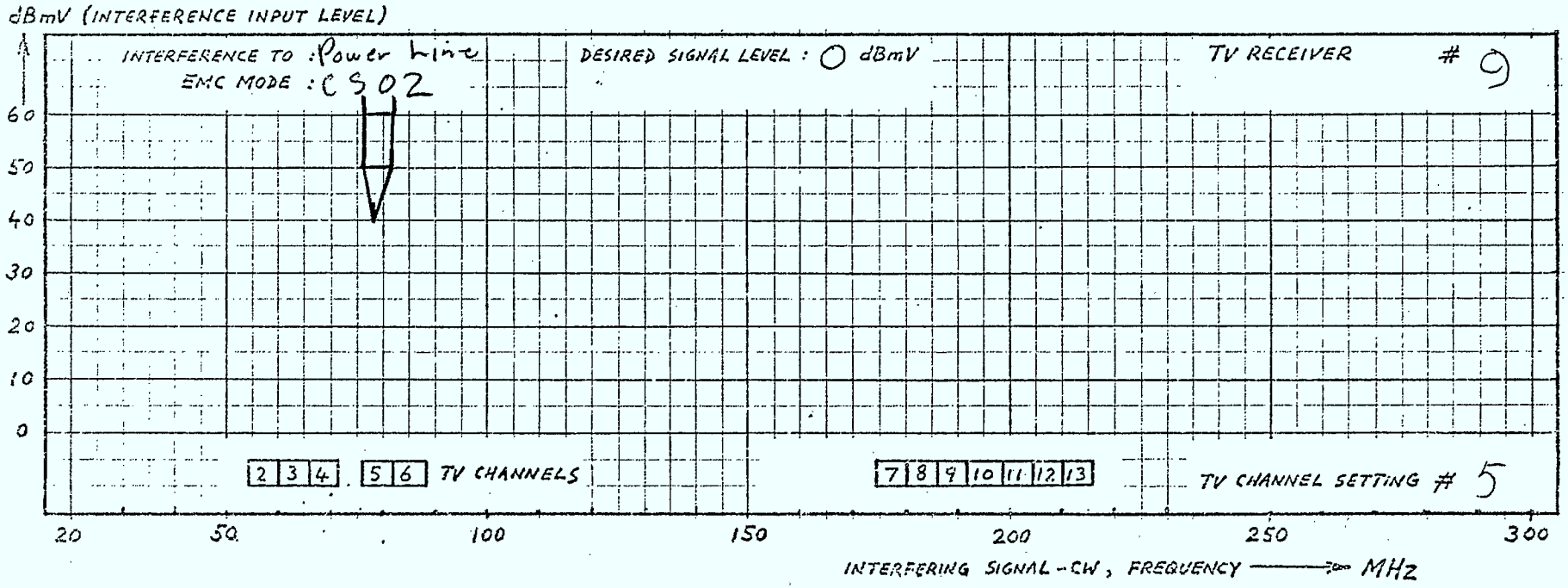
EMC TEST, TV RECEIVERS - RESPONSE TO RF INTERFERENCE



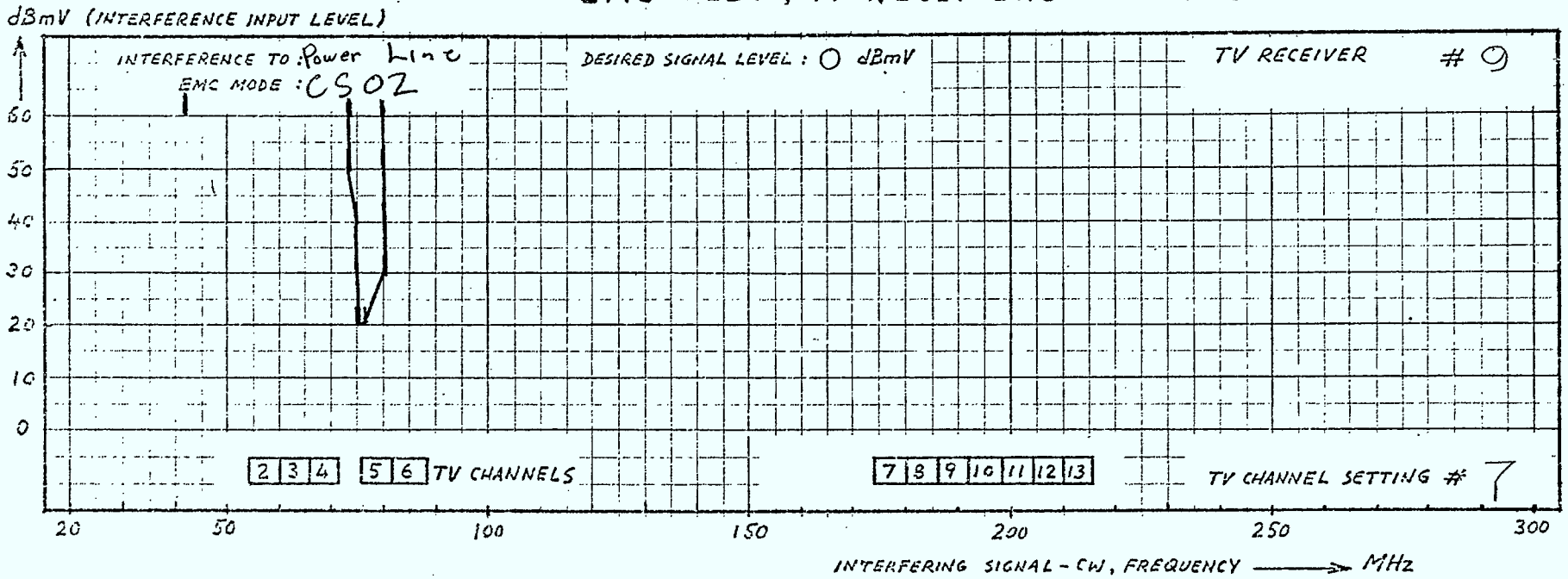


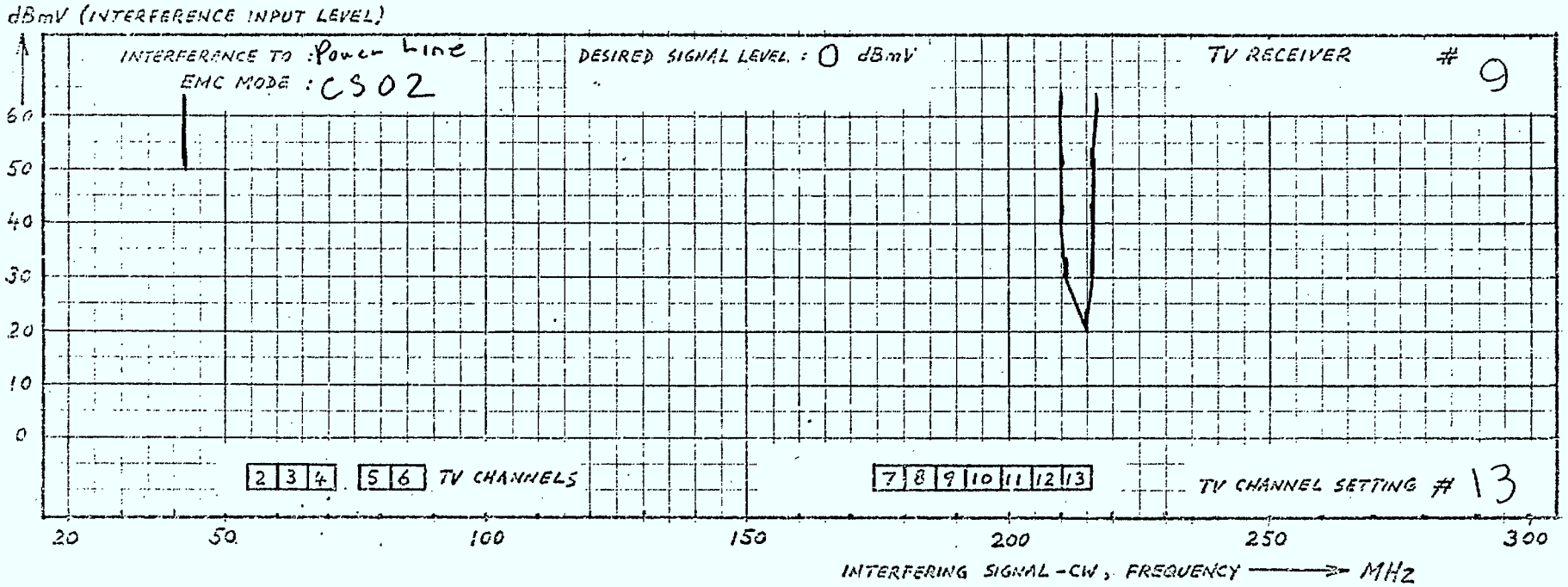
EMC TEST, TV RECEIVERS – RESPONSE TO RF INTERFERENCE





EMC TEST, TV RECEIVERS – RESPONSE TO RF INTERFERENCE





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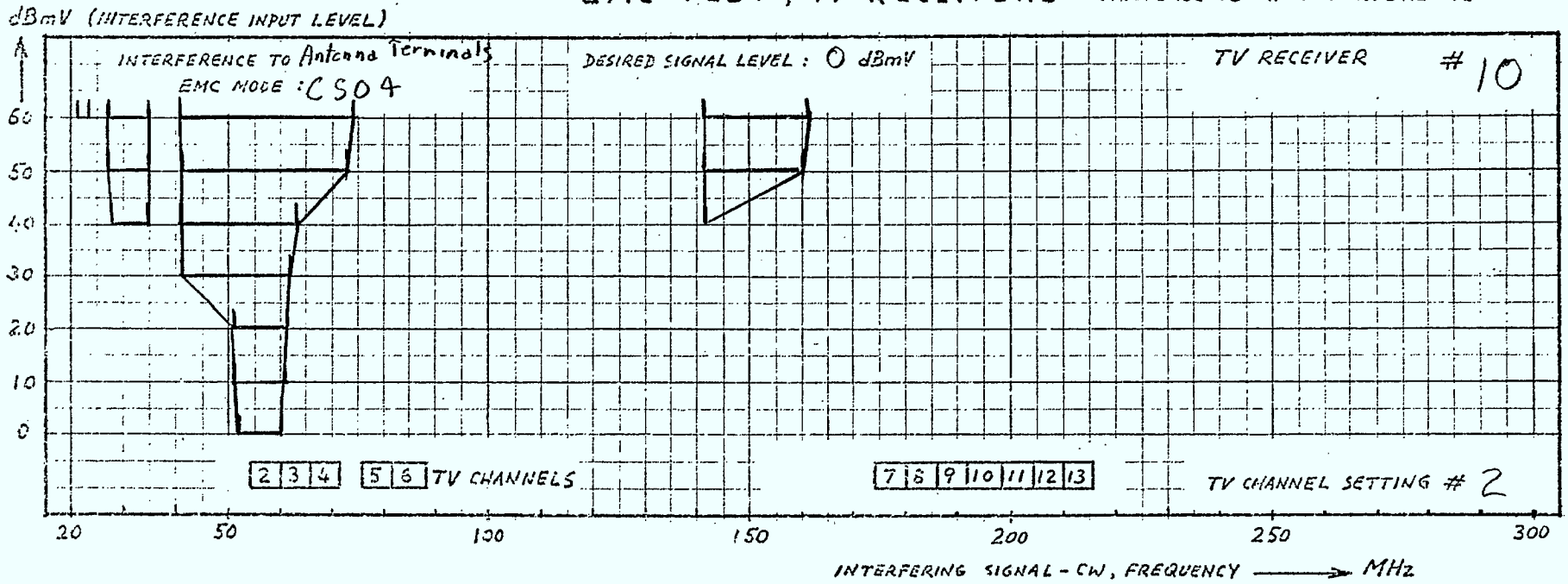
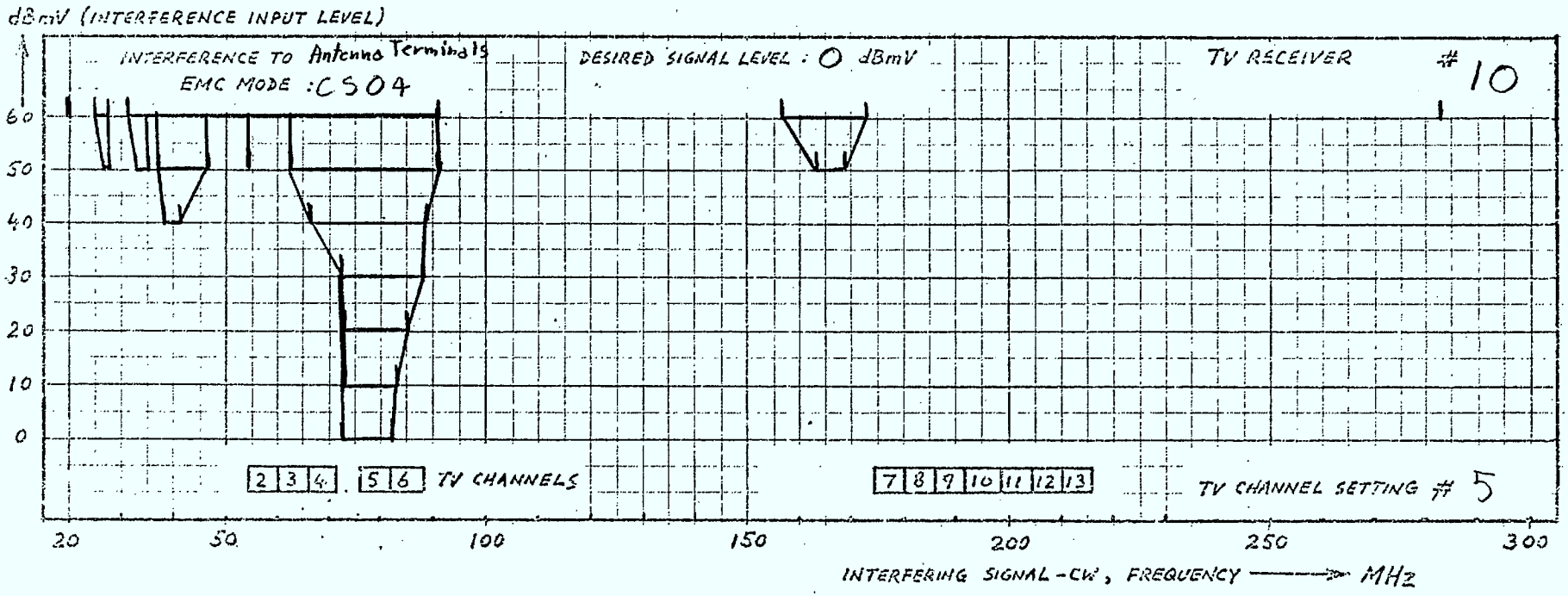
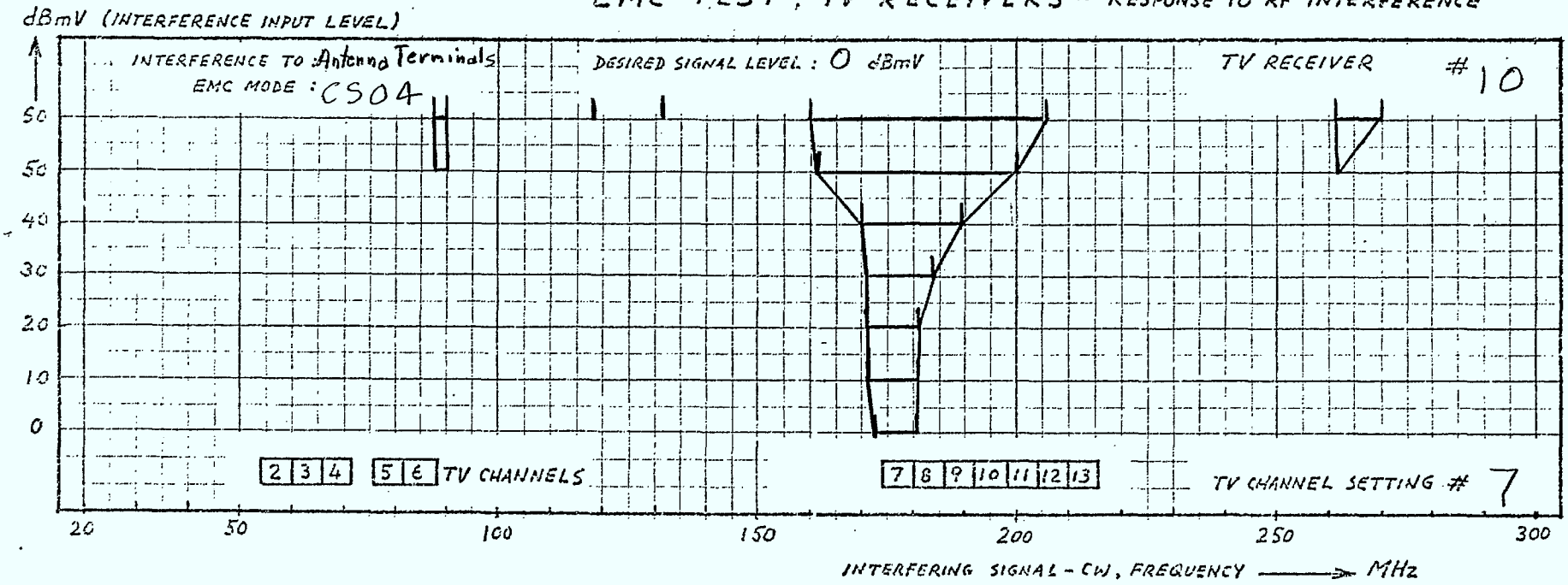
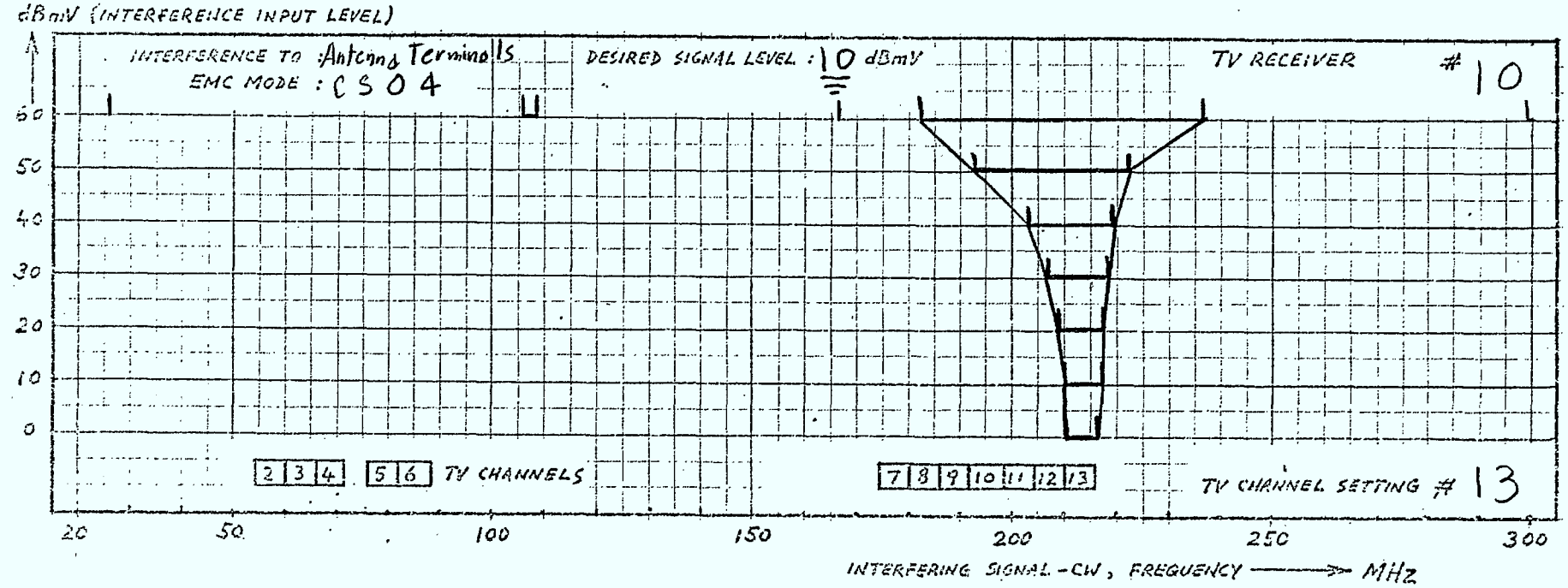


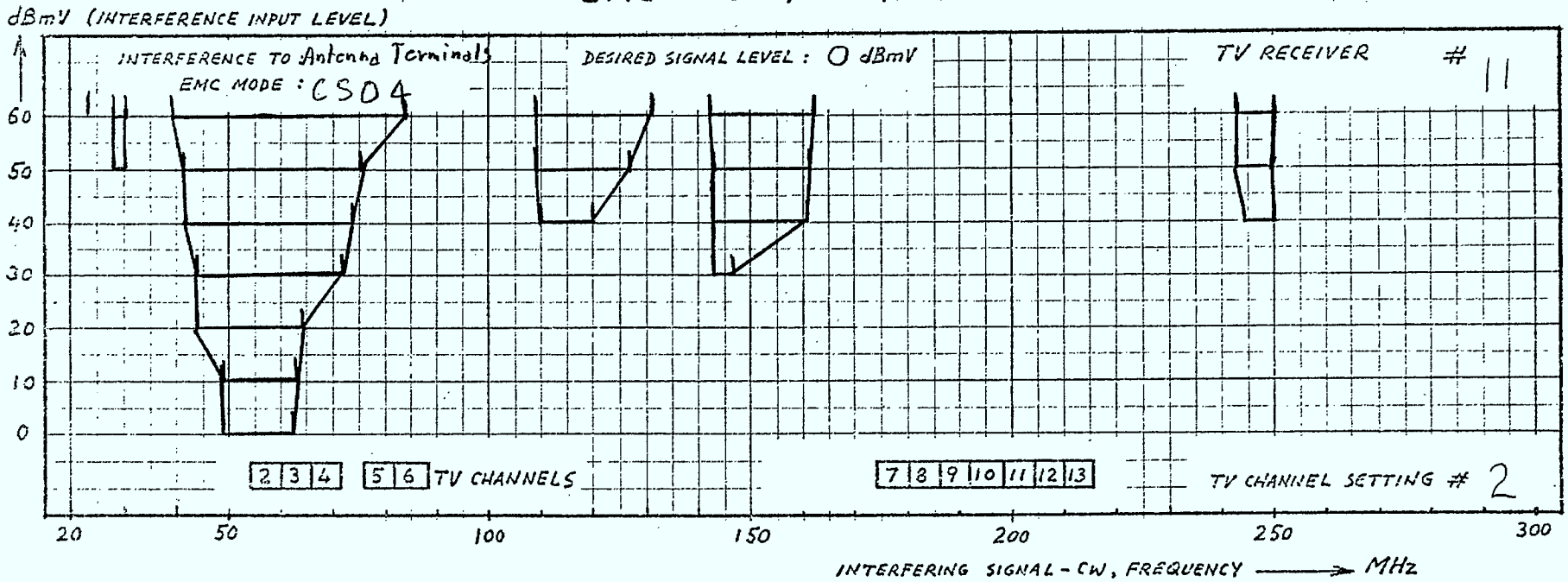


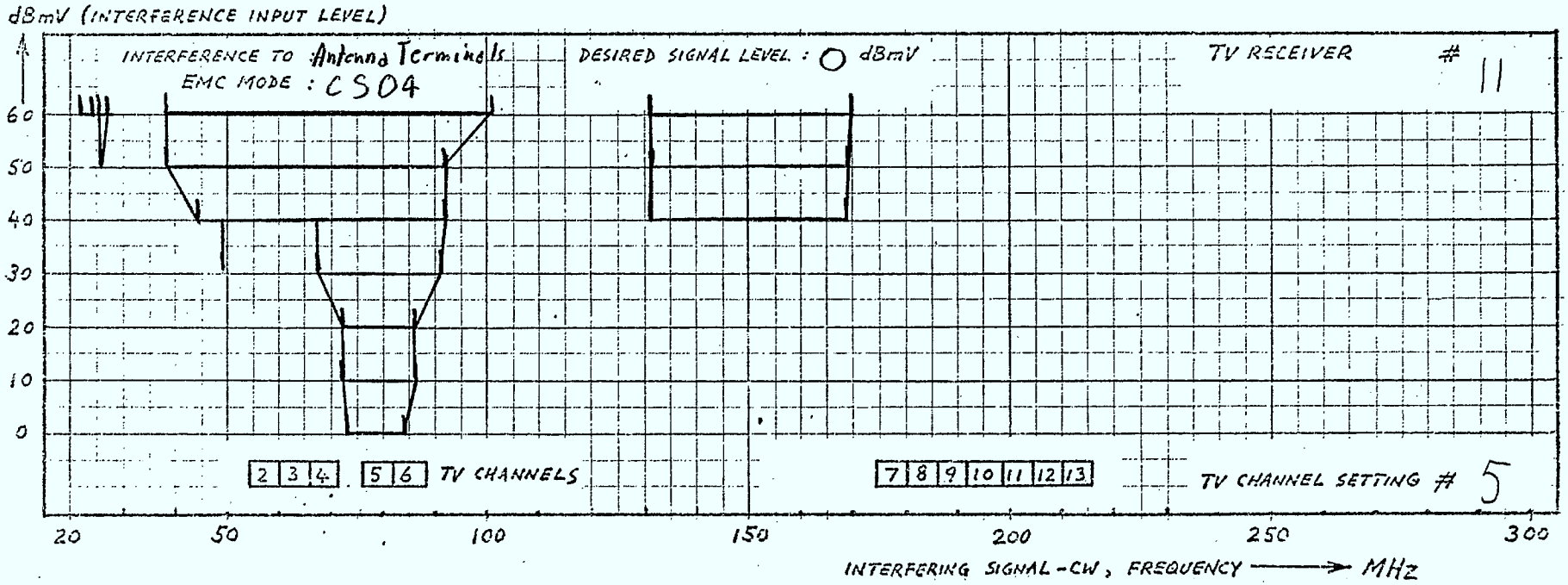
EMC TEST, TV RECEIVERS – RESPONSE TO RF INTERFERENCE



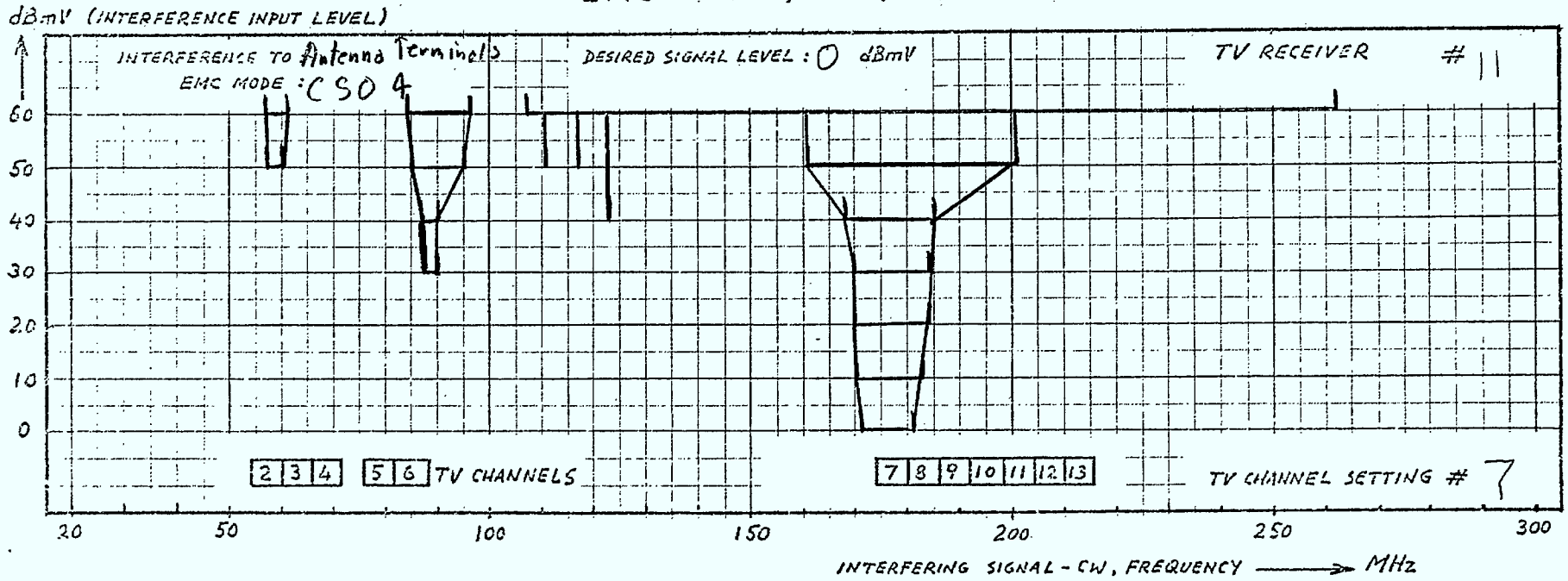


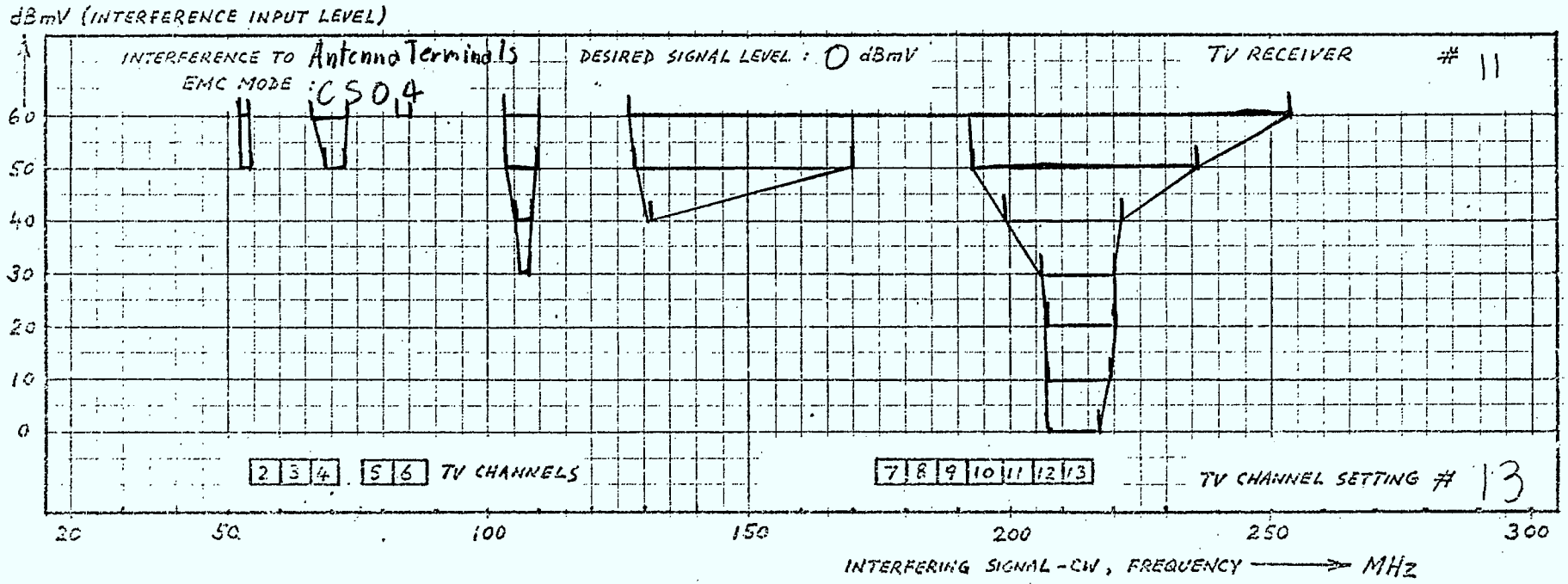
EMC TEST, TV RECEIVERS – RESPONSE TO RF INTERFERENCE





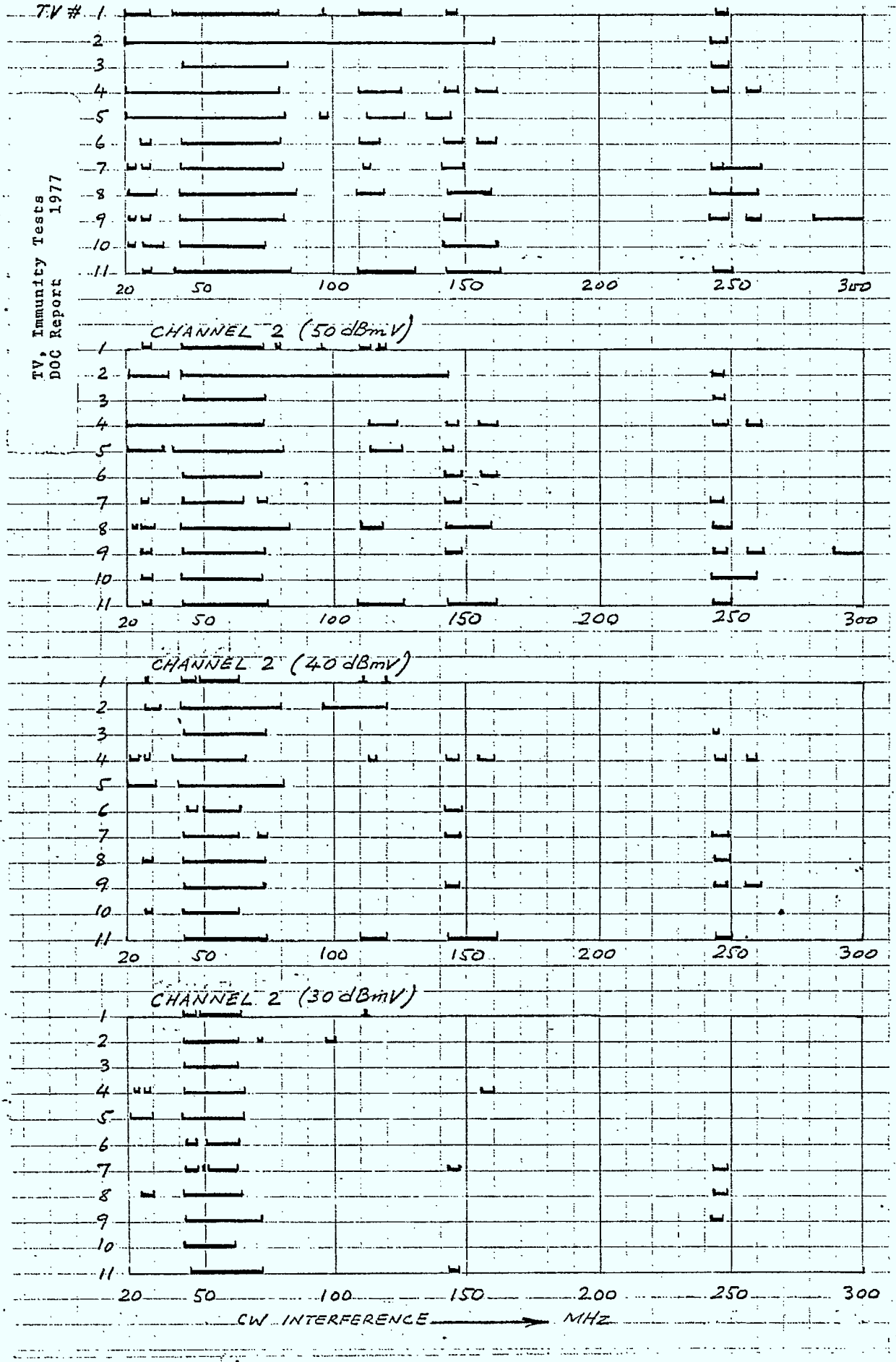
EMC TEST, TV RECEIVERS – RESPONSE TO RF INTERFERENCE



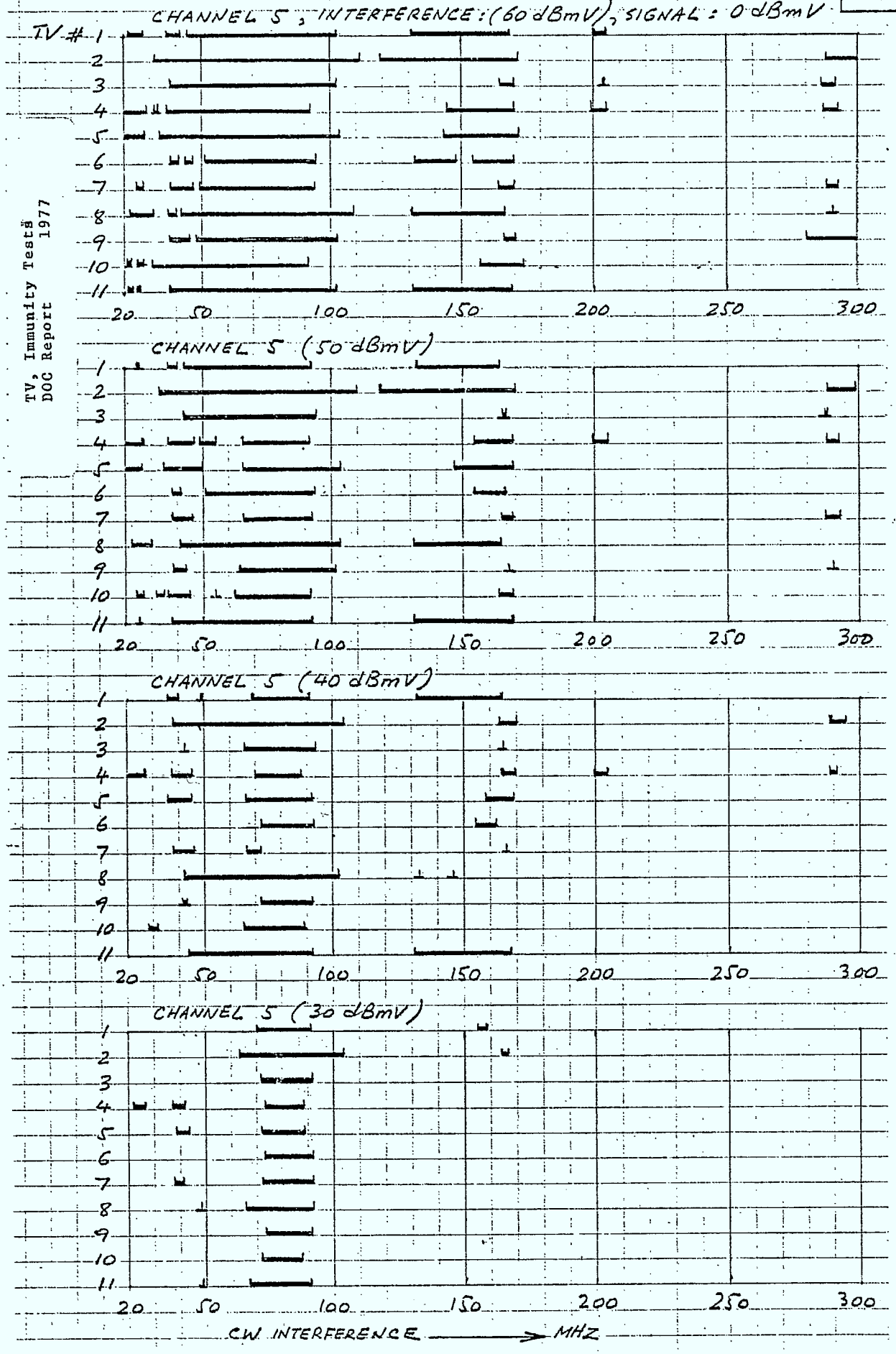


TV RECEIVERS SUSCEPTIBILITY (CS-04 RESPONSE), 20-300 MHz

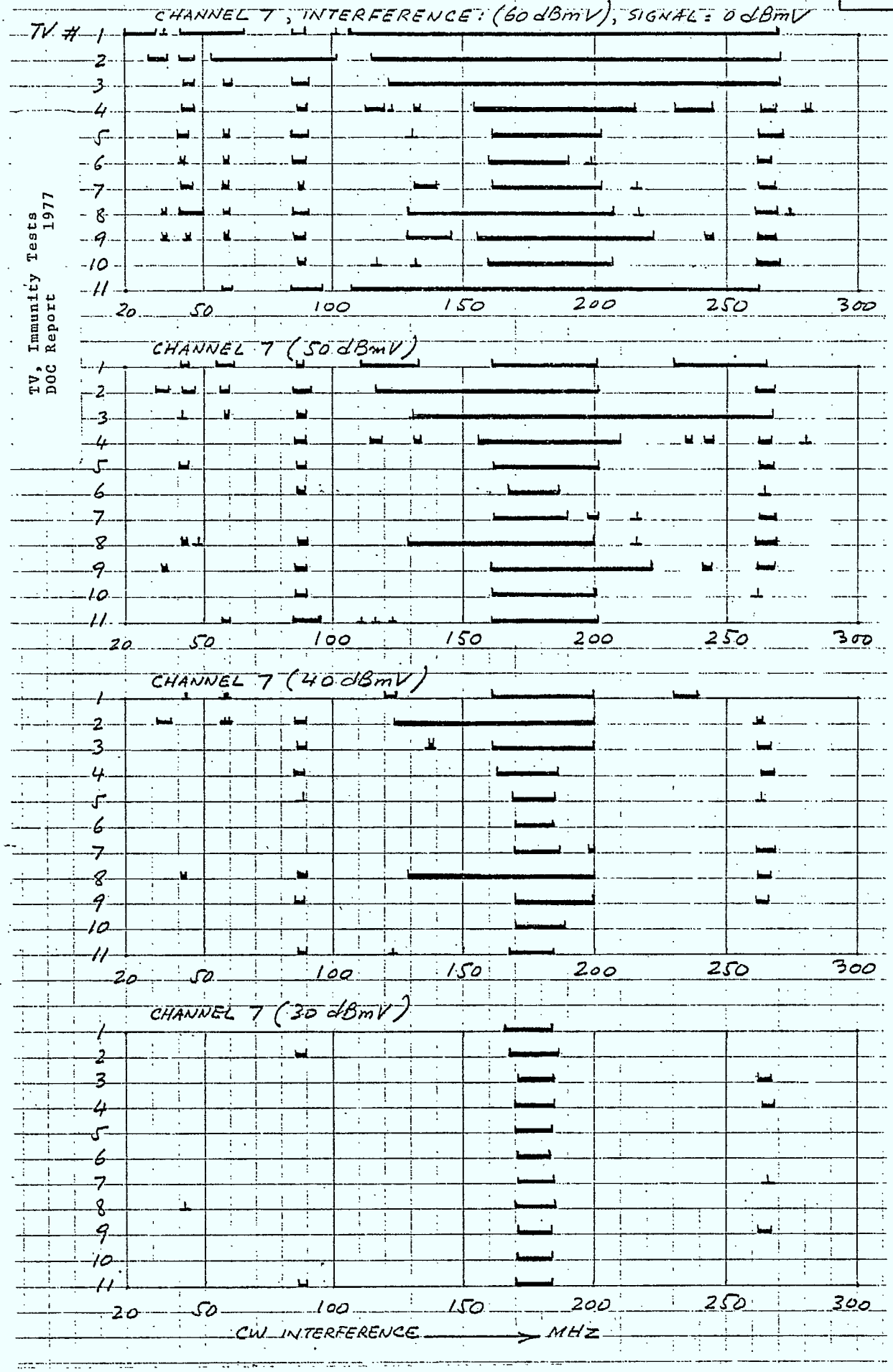
CHANNEL 2, INTERFERENCE: (60 dBmV), SIGNAL: 0 dBmV



TV RECEIVERS SUSCEPTIBILITY (CS-04 RESPONSE), 20-300 MHZ



TV RECEIVERS SUSCEPTIBILITY (CS-04 RESPONSE), 20-300 MHz



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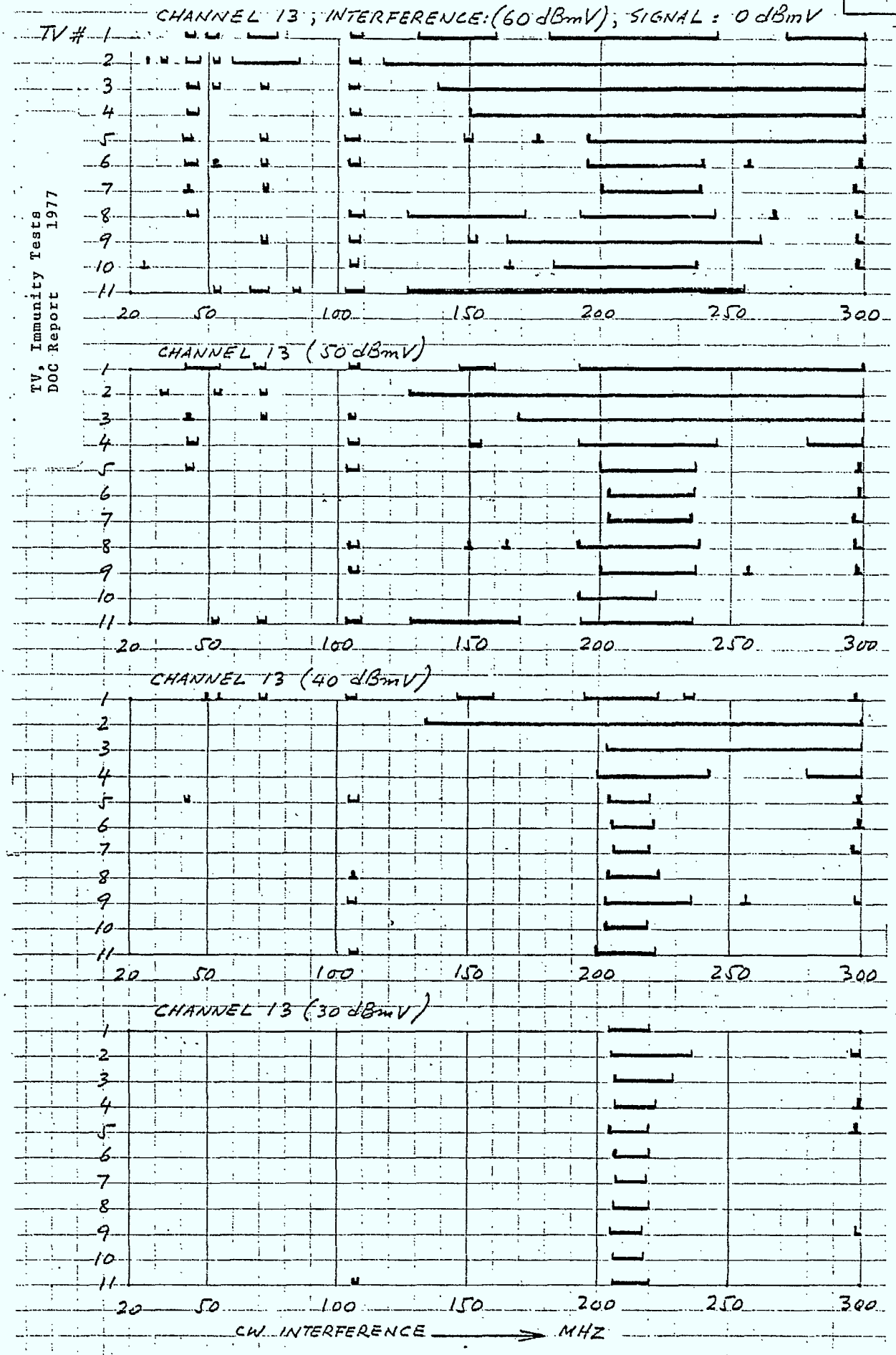

FIELD STRENGTH-TV INPUT VOLTAGE, CORRELATION

A1. INTRODUCTION

The voltage measured at the antenna input terminals of the TV set, although a realistic indicator of the television response to external signals, must be related to the field strength in the environment to be of much value.

Fields such as one is likely to encounter in real life situations are described in a Department of Communications publication EMCAB-1(1). The maximum expected field strengths are between 1 and 90 V/m depending on frequency bands. The ambient field is about 15 V/m at HF, and around 10 V/m at MF & VHF for authorized services. The actual radio environment may be higher than these values due to special circumstances such as the proximity of transmitters, near fields, high rise buildings, mobile stations, etc. Several measurements and studies, e.g. (2)(3), show that the field may go as high as 20 to 60 V/m at HF and VHF frequencies.

In this Appendix the expected TV receiver input levels corresponding to some typical cases will be presented. Radiated susceptibility tests, which are under consideration, will confirm the analyses and the validity of the assumptions.

A2. TV ANTENNA FOR VHF RECEPTION

It is arbitrarily assumed that the antennas feeding the TV receiver are half wave dipoles tuned within the TV band allocations. The simplified equivalent antenna circuit will be as shown in Fig. A1.

---

(1) EMCAB-1, Electromagnetic Compatibility Advisory Bulletin, "Immunity of Electrical/Electronic Equipment Intended to Operate in the Canadian Radio Environment (0.014-10,000 MHz)"

(2) T. Dvorak, "Electromagnetic Field Immunity, A New Parameter in Receiver Design", IEEE TR. on EMC, Aug. 1974

(3) ARRL Studies, e.g. D. Gerue et al., "RF Susceptibility Tests" ARRL Technical Sympo. 1975

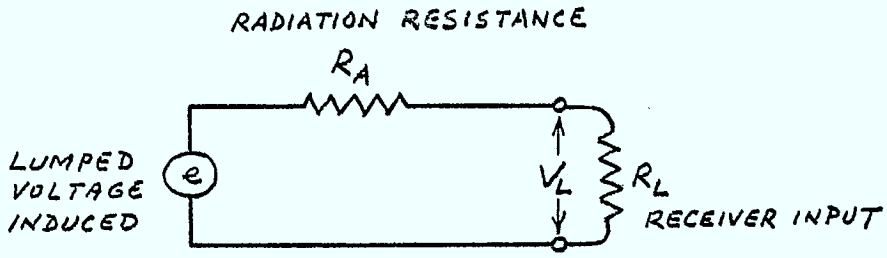

FIG. A1: Equivalent Antenna circuit (resistive)

$$e = E \times h = \frac{\lambda}{\pi} E$$

$$h = \text{effective height} = \frac{\lambda}{\pi} = \frac{2}{\pi} l$$

$$l = \text{actual length} = \lambda/2$$

$$E = \text{field strength}$$

The power P_L delivered to R_L will be maximum for

$$R_A = R_L = R$$

$$P_L = P_D \times A_R = \frac{(Eh)^2}{4R} = \frac{(e)^2}{4R} = \frac{(2\ V_L)^2}{4R}$$

$$P_D = \frac{E^2}{120\pi} \quad \text{Power density}$$

$$A_R = \frac{G\lambda^2}{4\pi} \quad \text{Effective area}$$

G = Antenna gain = 1.64 for tuned dipole

λ = wavelength

The ratio of the receiver input voltage to the field strength as calculated from this data is:

$$\frac{V_L}{E} = \frac{\lambda}{\pi}\sqrt{\frac{RG}{480}} = \text{Antenna Factor (A.F.)}$$

The antenna factors for dipoles (R=73Ω) tuned to channels 2, 6, 7, and 13 are:

Channel	F(MHz)	λ(m)	A.F.	A.F. (dB)
2	55	5.45	0.87	-1
6	83	3.62	0.56	-5
7	175	1.72	0.27	-11
13	211	1.42	0.22	-13

Assuming no impedance mismatch between the antenna and the TV set (nominally 75Ω input) the ratio of terminal input voltage and field strength can vary from -1 to -13 dB within the pass-band of the TV, decreasing for higher frequencies.

The power delivered to R_L for $R_A \neq R_L$ will be:

$$P_L = \frac{e^2}{R_A + R_L} \times \frac{R_L}{R_A + R_L}$$

For example if R_L is 300Ω fed by a half wave dipole the antenna factors will be 1.6 times higher (i.e. the loss will be 4 dB less) as shown in Fig. A2(a) & A2(b).

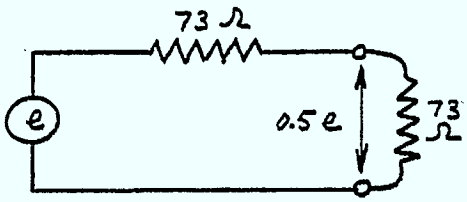

FIG. A2(a) $\frac{0.8e}{0.5e} = 1.6$

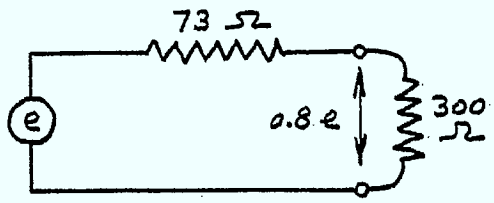

FIG. A2(b)

The actual antenna factor of a TV dipole antenna in the VHF band will depend on actual length settings, orientations, heights, distributed constants, polarization, TV input circuitry, etc. Also the antenna factors for multiband and wideband TV antennas may be higher, as an average, throughout the TV bands. Generally it may be assumed that a VHF interference field will reach the TV receiver input with the same efficiency as TV signals (i.e. about 0 to 15 dB loss). Thus the expected interference (para. A1) in the VHF range may produce much more than 1 volt at the receiver input.

.../A-4

A3. UHF INTERFERENCE

A VHF antenna operates as a long-wire antenna for the UHF band. The directional characteristics and impedance of the dipole vary as the current and voltage distribution change at higher frequencies. The power gain over a dipole may be up to 7 dB for wire lengths of 10λ. But the section of wave front from which the antenna can draw energy extends only about a quarter wavelength from the conductor, so the effective area that the receiving antenna can utilize varies directly with the square of the wavelength ($A_R = \frac{G\lambda^2}{4\pi}$)

As a result the UHF interference coupled through a TV-VHF antenna will be less than the VHF interference for the same field strength.

Unfortunately another coupling mechanism prevails in higher frequency bands. As the frequency increases the interference enters the TV receivers directly through internal connections and units which become comparable in physical size with the wavelengths. This coupling continues to increase throughout the microwave bands. Since this study is confined to antenna terminal input susceptibility no further analysis of this aspect has been made.

A4. HF INTERFERENCE

In the case of HF interference the TV antennas act as short dipoles with very low radiation resistance. In order to estimate the receiver input voltages corresponding to HF field strength it is necessary to review the characteristics of doublets or short dipoles.

(a) The distributed voltages induced in a receiving antenna cause currents to flow, so that if a load impedance is inserted in series with the antenna, energy that has been abstracted from the passing radio wave will be delivered to this load (4). The antenna, insofar as such a load impedance is concerned, can be considered as a generator of voltage e that has an internal impedance Z_A (Fig.A3).

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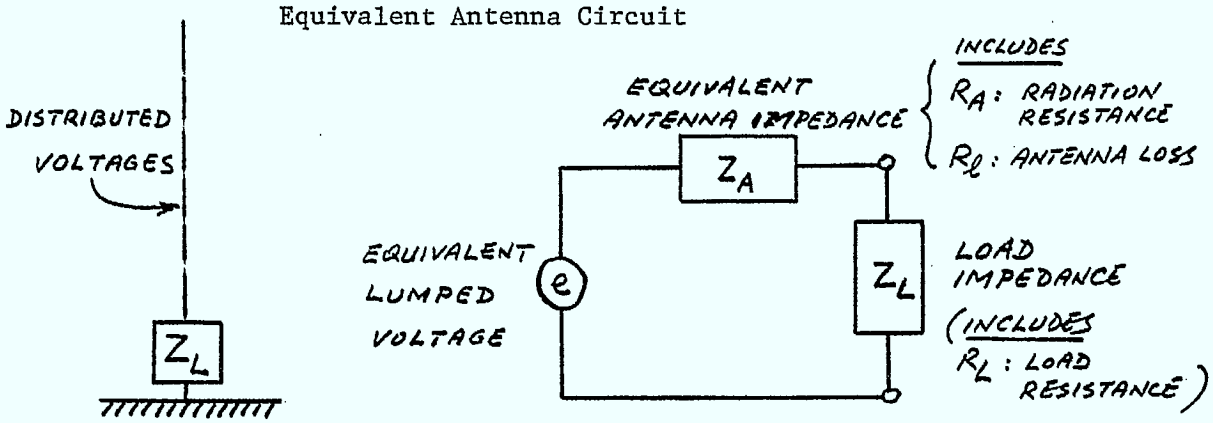
(4) F.E. Terman, Radio Engineer's Handbook, First Edition.

Figure A3

Equivalent Antenna Circuit



e = E x h

h: effective height

E: Component of the field that has a wave front parallel to the antenna and is polarized in the same plane as the antenna.

The maximum amount of energy that is theoretically possible for a given antenna to abstract from a passing wave occurs when the total loss resistance (antenna loss + load resistance) equals the radiation resistance, and the load reactance is equal in magnitude but opposite in sign to the reactance component of Z_A (Fig. A1). The energy corresponding to the current flow through R_A is re-radiated.

(b) In the case of an HF field (1 to 30 MHz) a TV receiver dipole of actual length l=2m appears as a short dipole ($\ell/\lambda \leq .1$). The radiation resistance of a short dipole antenna (doublet) of equivalent length ℓ_e is:

$$R_A = 789 \left(\frac{\ell_e}{\lambda}\right)^2 \text{ ohms} \qquad \ell_e \cong 0.5\ell = 1 \text{ m.}$$

Frequency (MHz)	λ (m)	ℓ/λ	Radiation Resistance (R_A) (Ω)
1	300	0.007	0.009
5	60	0.033	0.2
10	30	0.067	0.9
15	20	0.1	2.0
20	15	0.13	3.6
25	12	0.16	5.5
30	10	0.2	7.9

At frequencies lower than the resonance the reactance of a short dipole will be capacitive. The radiation resistance will be negligible compared to the capacitive reactance of the antenna which is in the order of 0.26K to 8KΩ (for 20 pF). The equivalent circuit is as shown in Fig. A4.

$$e = \frac{E}{2}$$

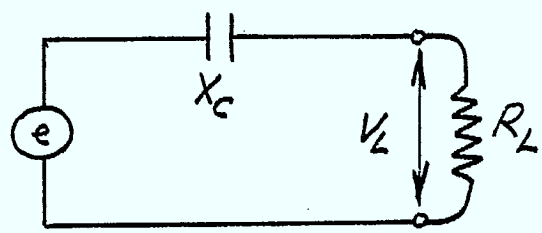


Fig.A4 Short Antenna Equivalent Circuit

The voltage across the receiver input terminals (V_L) will be a fraction of the induced voltage (e). The ratio of the receiver input voltage to the field strength for 73 and 300Ω inputs will be as tabulated below. There is however, a possibility of having higher or lower off-band TV input impedances than the nominal design values and with any inductance in the input connection the A.F. will be higher (i.e. the coupling will be more).

X_c (Ω)	R_L (Ω)	V_L	A.F. $= \frac{V_L}{E}$	A.F. (dB)
260	73	0.27e	0.135	-17.4
8000	73	0.009e	0.0045	-47
260	300	0.76e	0.38	-8.4
8000	300	0.038e	0.019	-34.4

The expected interference (para. 1) in the HF range may produce about 1 volt at lower HF and considerably more than 1 volt at higher HF frequencies.

A 5. INTERFERENCE THROUGH CATV

The measured and estimated induced voltages in Cable TV input coaxial line is about 1 volt at 0.5 to 250 MHz range (see Ref. 3 of this Appendix A.)

A 6. CONCLUSION

It is most probable that 1 volt and more antenna terminal input voltages will be created at MF, HF & VHF bands and other equally disruptive mechanisms will be activated at higher frequencies by interference fields such as one is likely to encounter in real life situations, particularly in proximity to radio transmitters.

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