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Advances in Frequency-Coincidence

Algorithms for EMC Testing

Constantine Christopoulos

A Thesis

in

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of

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Abstract

Advances in Frequency-Coincidence Algorithms for EMC Testing

Constantine Christopoulos

Whenever a new system is installed aboard an aircraft, Electromagnetic Compatibility/Interference (EMC/EMI) analysis must be performed to determine if the new system causes or suffers unacceptable performance degradation. However, in modern weapon systems the number of possible EMI interactions may number in the thousands. Therefore, a strategy is required to isolate those source/victim interactions that are most likely to result in system incompatibility.

In order to predict potential EMI problems in communication systems, it is necessary to identify all potentially interfering signals by determining the mode by which these signals may couple from the source to a potentially susceptible system and describe the susceptibility threshold and performance degradation for the victim. The compilation and analysis of all the relevant source/victim data, however, is a very lengthy process without the aid of a com, :er.

This thesis describes the modifications and extensions to the Computer Aided EMC Test Plan System (CAETS) program which was developed to assist the Department of National Defence and its contractors in the preparation of EMC test procedures. The CAETS program predicts source/victim frequency combinations used for EMC testing.

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Chapter 1.0

INTRODUCTION

1.1 Overview

Electromagnetic Compatibility (EMC) is the condition which prevails when telecommunications (communications-electronic) equipment is collectively performing its individual designed functions in a common electromagnetic environment without causing or suffering unacceptable degradation due to electromagnetic interference to, or from other equipment/systems in the same environment [1].

Electromagnetic Interference (EMI) often results when transmitters and receivers operate in close geographical proximity, and is becoming more prevalent with the increased number of antennas located on vehicles, ships and aircraft. A receiver antenna, which receives the desired transmitter radiations, may also intercept undesired spurious transmissions from other intentional emitters such as from communications, navigation and radar equipment. Spurious transmissions include intermediate frequencies, and signal channels which can be detected by conversion to the IF band by the local oscillator fundamental and its harmonics [2].

To appreciate the horrendous task EMC engineers today are faced with, consider the following. UHF radar transmitters have increased their radiation from 10W average power in 1940 to levels exceeding 1MW average power today. For a single transmitter, spurious energy 50dB below the fundamental signal, at 1MW, results in 10W of average power of spurious energy, or about the same amount of spurious energy today as energy at the fundamental frequency in 1940 [3].

For many years, the standard approach to achieving EMC was to wait until problems appeared and then attempt to fix or suppress incompatible emissions or responses in order to eliminate or reduce system performance degradation. However, the reduction of existing spectral contamination or EMI after the completion of a system design and its installation becomes much more expensive and often is less effective due to the economics or logistics of a retrofit.

One approach being used to achieve EMC is to impose rigid military standards and specifications on equipment during their planning and design stages. These standards and specifications have been written by agencies in the US Department of Defense to establish EMC performance characteristics against which equipment performance can be measured through EMC testing.

EMC testing is generally performed at three levels: component, subsystem and system. Component testing, includes the testing of such pieces/parts as switches and relays. A subsystem, is any electronic or electrical entity that performs a specific function within the overall system, and is usually characterized as having power and signal leads. The system, by contrast, is the overall complex of equipment assembled to perform together in order to satisfy contractual requirements. The system level test is a performance (functional) test and often includes tests for inter-system compatibility in the expected operational environment.

If a system is being developed for military or certain other government applications, MIL-E-6051D will most likely be imposed as a contractual requirement, and an EMC test plan and control plan will be required [4]. MIL-E-6051D is a document applicable to all agencies of the US Department of Defense and of the Canadian Department of National Defence (DND), and contains system level EMC requirements. If the system is being developed for commercial or other government applications that do not require compliance to MIL-E-6051D, an EMC test plan and control plan should still be prepared and implemented. In either situation, the purpose and content of the EMC control plan and test plan would be the same.

The EMC test plan indicates the means by which EMC shall be verified, and is based upon the EMC control plan, which establishes the methods and procedures which shall be applied throughout the development cycle of the system in order to achieve EMC after integration and to satisfy contractual EMI requirements.

Whenever a new communications system is installed aboard an aircraft, EMC analysis and tests must be performed to determine if the new system causes or suffers unacceptable performance degradation to, or from other systems. Hence, an EMC test plan for communications equipment, requires details concerning frequency ranges, channels, and combinations to be specifically tested such as image frequencies, intermediate frequencies, local oscillator, and transmitter fundamental and harmonically related frequencies [5]. That is, intentional radiators are tested in all modes of operation. Multichannel transmitters and receivers are sampled in all modes of operation at a representative number of frequencies, usually not less than 20 [6]. These sampled test frequencies are used to formulate a test matrix of source and victim channels.

In modern weapon systems, be they aircraft, space, missile, or ground systems, the number of possible EMI interactions may number in the thousands, and therefore, a strategy is required to reduce the matrix to a manageable size. A major objective of this strategy is to isolate those elements of the matrix that are most likely to result in system incompatibility [7]. In order to predict system incompatibility in communication systems, it is necessary to identify all potentially interfering signals by determining the mode by which these signals couple from the source system to a potentially susceptible victim system and describe the susceptibility threshold and performance degradation for the victim. The compilation and analysis of all the relevant source/victim data, however, is a very lengthy process without the aid of a computer.

1.2 Computer Aided EMC Codes

Computer programs are useful in the prediction of EMC and in EMI investigations as they reduce the probability of arithmetic error and speed up the computations. The use of a computer program to assist in the analysis and preparation of an EMC test plan is a time saving tool and may be the only practical method to deal with the multiplicity of potential EMI situations in dense electromagnetic platforms.

The Antenna-to-Antenna Propagation with Graphics (AAPG) program and the Computer Aided EMC Test Plan System (CAETS) program are essentially the only two computer aided EMI/EMC analysis tools available in Canada today. The AAPG code, which was developed at the EMC Laboratory of Concordia University under the auspices of DND, accounts for the amount of energy coupled between a culprit and a victim and, therefore, can be used for granting a waiver to an equipment's MIL-STD-461 EMC limits. However, the AAPG code, in addition to testing only for harmonic interference between a transmitter and a receiver, employs approximate frequency coincidence algorithms in generating source/victim combinations [8].

The CAETS program, Version 4.2, was developed by Bell Northern Research (BNR) under contract to the Department of National Defence to assist DND and its subcontractors in the preparation of EMC test procedures [9][10]. The code tests for four modes of interference between a receiver and a transmitter and between two receivers. Specifically, for every receiver/transmitter system pair, the code tests for harmonic, image and intermediate frequency interference, and for every receiver/receiver system pair, the code tests for local oscillator interference. The code provides a set of discrete source and victim tunable frequencies for the output. That is, the source/victim combinations that are produced correspond to precise system channels of the equipment under test so that the test engineer can tune to the indicated channels and record the levels of interference. The information is tabulated in the form of victim/source tables and have two additional empty columns allocated for ground and air test results to be entered during EMC testing. These victim/source tables are more commonly referred to as *test cards*.

Although some computational techniques for generating source/victim assignments have been reported in this area, they are either geared towards methods which do not employ the aid of a computer and, therefore, are approximate [11], or do not yield accurate source/victim coincidences that correspond to channels of the equipment under test [12][13].

The CAETS program assumes that the interacting systems are co-located. That is, the code does not account for the amount of energy coupled between two systems. A future objective, however, is to link the CAETS code with the AAPG code in order to produce an even more powerful EMC analysis tool.

1.3 Scope of Thesis

The CAETS program, Version 4.2, was plagued with severe algorithmic deficiencies which caused a proportionally large number of invalid test combinations to be produced. That is, the code produced a large number of unusable data that had to be analyzed by hand calculations before proceeding with the test plan. This is supported by the fact that approximately 60% of the frequency combinations produced by Version 4.2 were in error. This deficiency coupled with poor user-interface, inadequate documentation, and lack of graphics, severely crippled the utility of the code [14][15][16].

This thesis describes the revised algorithms of the four modes of interference of the CAETS program. The extent of the algorithmic deficiencies of Version 4.2 were such that the entire set of algorithms has been re-written. Although the original input variables which comprise the EMC database have not been altered, the manner in which the code manipulates most of the input variables has also been modified. In addition, the thesis describes two practical extensions that have been implemented to the code. The entire set of improvements and extensions to the CAETS program, Version 4.2, which have been carried out during the thesis project, shall be introduced to DND and industry, and shall be released in a total of three revisions as follows.

Version 5.0 includes major modifications to the algorithms and program structure as well as improvements in the presentation of the output and the user interface since the previous revision, Version 4.2, did not allow the specification of key variables which are vital to the execution of the code such as the sample size and image order.

Because of the scarcity of shielded hangars and anechoic chambers, Version 5.2 was developed to allow the specification of distinct source frequencies which correspond to authorized frequencies for a given EMC test site. In Version 4.2, the user was unable to specify distinct source frequencies since the code generated its own source/victim frequency combinations.

Finally, Version 6.0 includes graphics. For harmonic and image interference the code provides the visualization of the relationship of the computed test frequencies to the victim and source operating frequency ranges, and for local oscillator and intermediate frequency interference, the code provides the visualization of the system characteristics of the equipment under test. This revision is intended to simplify the selection of optimum test frequencies and to aid the user in the analysis and prediction of spurious EMI.

For simplicity, the modifications and extensions to the CAETS program are presented in this thesis according to the revision for which they have been realized.

1.4 Survey of Thesis

The contents of this thesis have been organized in seven chapters as follows. The first three chapters constitute the introductory phase, in which the heterodyne transceiver, as well as the various modes of EMI in communication systems are examined, and the CAETS program is introduced.

In Chapter 4, the revised algorithm that performs source/victim assignments is examined, and whenever possible, is compared to that of Version 4.2. The major deficiencies of Version 4.2 are identified and the output is compared to that of Version 5.0.

In Chapter 5 and Chapter 6, two extensions to the CAETS program are presented, which address practical issues that arise during EMC testing and analysis.

In Chapter 7, the main contributions of the thesis are reviewed and key ideas for extending this work are presented.

Finally, a modular flowchart along with a brief description of the changes implemented to the code are included in the Appendix.

Chapter 2.0

EMI IN COMMUNICATION SYSTEMS

2.1 Introduction

As discussed in Chapter 1, MIL-E-6051D dictates that communication systems must be tested in all modes of operation in order to determine if a new system is compatible in its intended operational environment. Therefore, it is important that the EMC test engineer understand the fundamental principles of transceiver operation in order to predict and analyze potential EMI situations in communication systems. Even when computer-aided EMC analysis tools are employed, an accurate description of the equipment under test requires knowledge of these principles since the degree of accuracy at which the equipment has been specified reflects the validity of the results obtained. That is, proper equipment modelling is an essential requirement if meaningful results are to be achieved. As such, this chapter examines the heterodyne receiver and transmitter as well as the various modes of interference between communication systems.

In general, equipment modelling requires the break-down of each system into its receiver and transmitter characteristics. The operating characteristics of the equipment can be extracted from the block diagrams or the electrical schematics available in manufacturers' technical specifications manuals. Information on each CF aircraft can be obtained in the Canadian Forces Technical Orders (CFTO) [17].

2.2 The Heterodyne System

Almost all receivers in use today employ the heterodyne concept. A block diagram of the heterodyne receiver is shown in Figure 2.1. Heterodyning means shifting or translating in the frequency domain. Thus, a heterodyne system receives the incoming modulated signal via the antenna, amplifies the signal and then translates the signal to a fixed new frequency, independent of the centre frequency of the received signal. This new frequency is known as the intermediate frequency (IF). The received frequency, now translated to the IF and occupying and equal bandwidth, can easily be amplified, filtered and demodulated.

The translation of the incoming frequency to the IF is performed at the mixing stage by the local oscillator (LO) frequency, which is either above or below the incoming signal by the amount of the IF. If the IF is below the incoming signal but above the final output signal frequency, the receiver is of superheterodyne type. Furthermore, when the IF is added to the LO to determine a system channel, the sign of the receiver is positive, otherwise, when the IF is subtracted

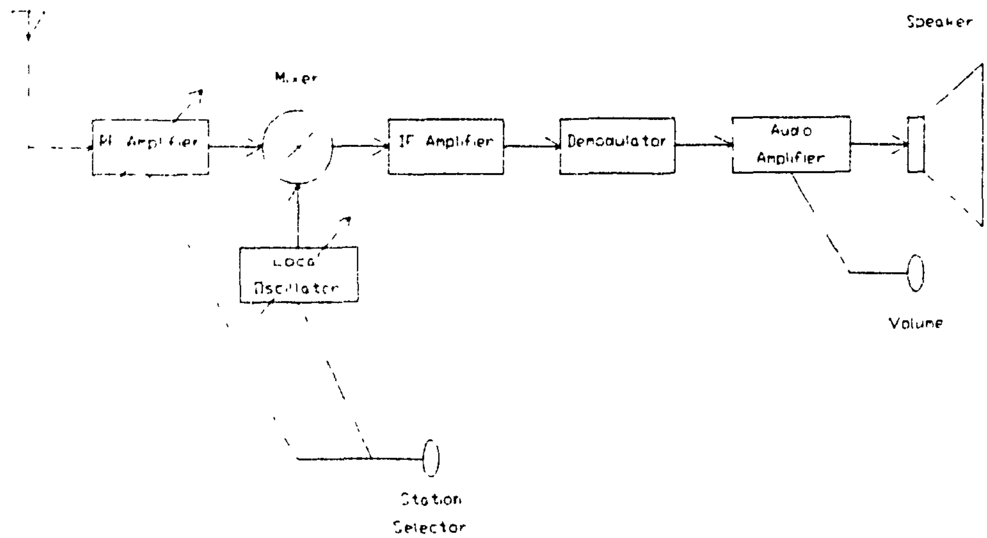

Figure 2.1 The Superheterodyne Receiver [18]

from the LO, the sign is negative. The system channels are, therefore, determined as follows:

$$f_o = abs(f_{LO} + (-1)^{SIGN} f_{IF}) \quad \textbf{(2.1)}$$

where f_o *is the incoming frequency*

f_{LO} *is the local oscillator frequency*

f_{IF} *is the intermediate frequency*

SIGN *is the sign of the receiver*
(negative for SIGN=1 and positive for SIGN=2).

Note that in Eq. (2.1), a single LO setting may translate either a single incoming frequency to the centre of the IF band, or several incoming frequencies to the IF band. That is, the IF band may be *fixed* or *variable*. In the latter case, an additional mixing stage is required to differentiate between the incoming signals that have been shifted to the IF band. Therefore, the translation to an IF may be repeated several times. Receivers that employ more than one conversion stage are called multiple-conversion receivers.

Consider, for example, the AN/ARC-552A transceiver which operates on any one of the 1750 channels spaced at 0.1MHz in the frequency band of 225.0 to 399.9MHz. The LO range of the first conversion stage of the AN/ARC-552A extends from 200 to 370MHz in steps of 10MHz, and the corresponding IF band extends from 20.0 to 29.9MHz. The first LO setting, f_{LO}=200MHz, converts the first 50 channels in the frequency band of 225.0 to 229.9MHz to the IF band. Therefore, an additional conversion stage is required to differentiate between these signals. In the AN/ARC-552A receiver, this is achieved by means of a second LO range extending from 21.85 to 31.75MHz in steps of 0.1MHz, which further translates the first-IF signals to the second IF, fixed at 1.85MHz. Note that the amplification and filtering is performed at a fixed frequency regardless of the input signal. This is the primary advantage of a heterodyne system.

The fundamental operation of a transmitter is identical to that of a receiver, however, the signal flow is reversed. That is, the baseband signal is modulated, filtered, then amplified at the IF band, and finally transmitted via the antenna.

2.3 Modes of Interference

All systems possess some degree of non-linearities which distort the ideal mode of operation of a system. The presence of these non-linearities are essentially the cause of most EMI situations. Consider the typical susceptibility characteristics of a receiver shown in Figure 2.2. The absolute minimum, centred around $f_0=f_{LO}-f_{IF}$, corresponds to a fundamental frequency of operation. Note that the sign of the receiver in Figure 2.2 is negative since the IF is subtracted from the LO in order to determine the fundamental frequency, f_0. Furthermore, there is a series of local minima that appear to the left and to the right of the fundamental frequency, f_0. These frequencies, which are known as the *spurious frequencies* of the receiver, are due to the non-linearities of the mixer and the LO, and are significantly above the fundamental susceptibility level.

The most prevalent of these spurious frequencies is the one appearing immediately to the right of the fundamental, and is better known as the *image frequency*. The other spurious frequencies involve higher order terms (harmonics of the LO and the received frequency) and are less significant. These spurious frequencies are shifted along with the fundamental

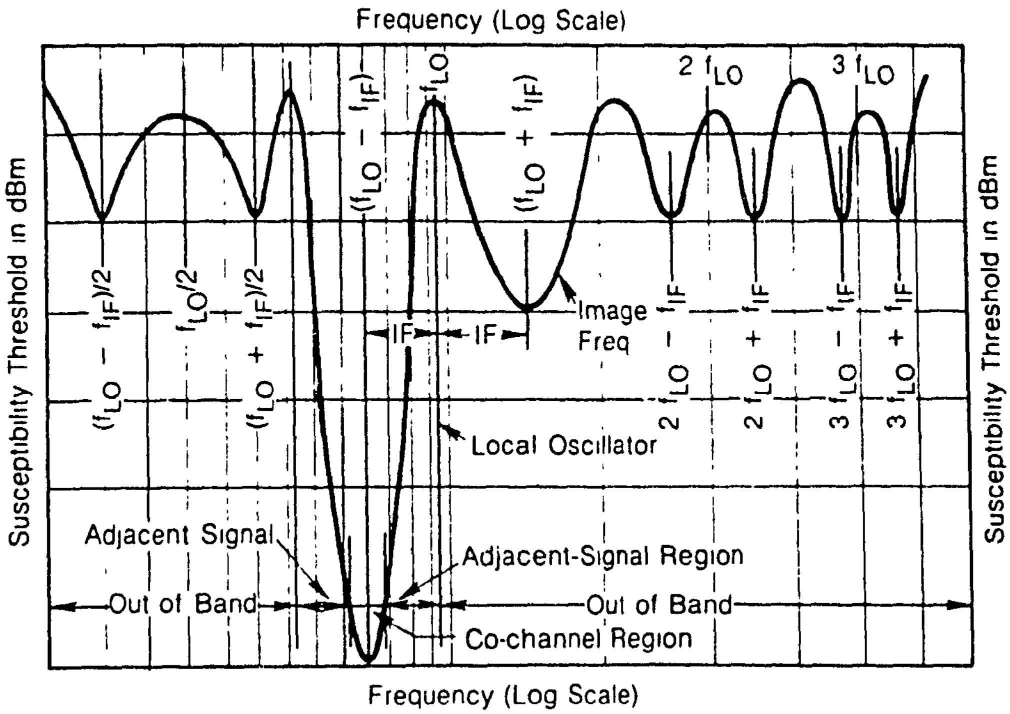

Figure 2.2 Receiver Susceptibility Characteristics [19]

frequency to the IF, where further discrimination between these signals is impossible. If transmitter fundamentals or their harmonics appear within these regions, they will be translated to the IF as well, and will interfere with the victim frequency, f_o. Due to the relative levels of attenuation and strength of the signals involved, some of the source frequencies may appear below the noise floor and, hence, do not pose a serious EMI threat.

In contrast to the receiver's susceptibility characteristics, the frequency spectrum at the output stage of a transmitter consists of an absolute maximum or lobe, centred around the transmitter fundamental frequency, and several local maxima to the right of the fundamental. The amplitude or strength of the local maxima decreases with increasing frequency and are centred around the harmonics of the fundamental.

All modes of EMI can be classified into three basic categories -- co-channel, adjacent channel, and out-of-band. Figure 2.2 illustrates the three regions in terms of the receiver's susceptibility characteristics.

A co-channel interfering signal is one whose frequency coincides with the fundamental frequency of the receiver or exists within the narrowest passband of the receiver. In the intentional mode of operation the incoming signal must fall within this region.

An adjacent-channel interfering signal is one whose frequency exists near the fundamental frequency of the receiver. Incoming signals that fall within this region and that have sufficient bandwidth, will overlap the fundamental frequency, f_o, and will result in EMI. The adjacent-channel region is usually related to the fundamental frequency in the following manner:

$$0.75<\frac{f}{f_o}<1.25 \tag{2.2}$$

where f *is the frequency of the adjacent-channel signal*

f_o *is the fundamental frequency.*

An out-of-band interfering signal is one whose frequency is significantly outside the receiver passband and is most prevalent when transmitter harmonics interfere with receiver fundamentals or when transmitter fundamentals interfere with a receiver's spurious response.

The basic modes of EMI between a receiver and a transmitter are graphically summarized in Figure 2.3 and are presented in order of descending importance. The interaction between a transmitter's harmonic with a receiver's spurious region is, of course, the least significant form of EMI and, therefore, does not warrant extensive investigation. There are, however, other forms of EMI that can occur between communication systems. Suppose for example, a transmitter operates at the IF of a victim receiver. If the receiver's IF is not properly shielded, the culprit signal may penetrate the IF shield and pose a serious EMI threat to the entire operating frequency range of the victim receiver. In addition, EMI can occur between two receivers. A receiver's LO can act as a transmitter if provided with a suitable radiator, conduction or leakage path. Therefore, LO radiation can be troublesome within a receiver itself or to other co-located receivers. A more detailed description of the four dominant modes of EMI follows.

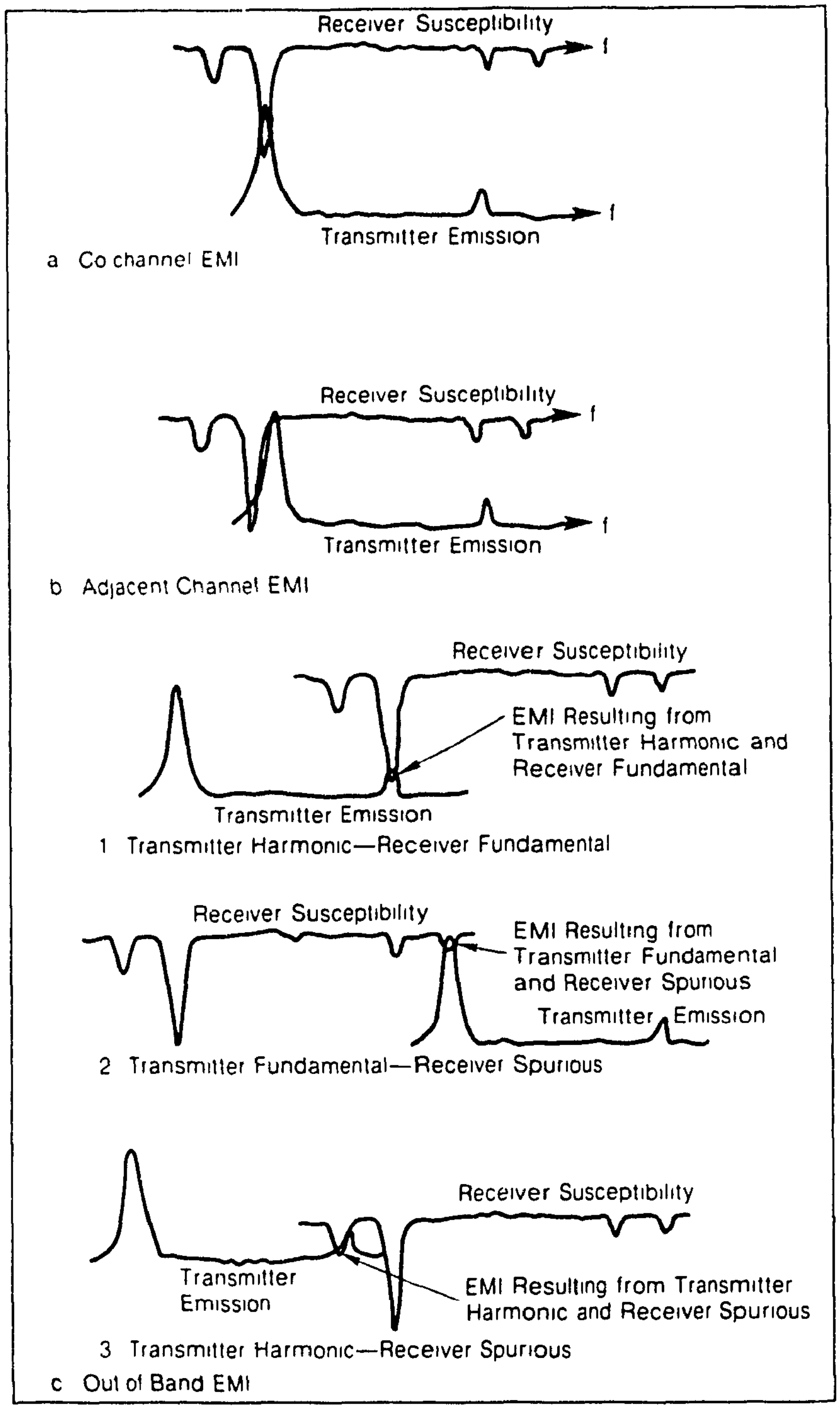

Figure 2.3 Receiver/Transmitter EMI Modes [20]

2.3.1 Spurious Interference

Spurious interference is the most complex form of EMI between a receiver and a transmitter and is best illustrated by means of an example. Suppose the reception of 1030MHz is desired. If the LO is working at 1090MHz, the input signal will be translated to the IF band centred around 60MHz (1090MHz - 1030MHz = 60MHz). If a transmitter is operating at 1150MHz, then this signal will be received equally well (1150MHz - 1090MHz = 60MHz). That is, signals above and below the LO by the amount of the intermediate frequency, will be converted to the IF where no further discrimination between the signals is possible. The channel operating at 1150MHz is referred to as the image frequency of the incoming signal. When mixer non-linearities and LO impurities are present, the image problem becomes more complex.

The most general analytical approach to spurious signal interference, in the first stage of multiple-conversion receivers, is the one involving the 'P-Q' equation given by:

$$f_S = abs\left(\frac{P * f_{LO} \pm f_{IF}}{Q}\right) \tag{2.3}$$

where Q is the harmonic order of the input signal, f_S

P is the harmonic order of the local Oscillator, f_{LO}

f_{IF} *is the intermediate frequency.*

The input signal, f_S, is the source frequency, while the product $Q*f_S$ is referred to as a spurious frequency. Note that the harmonic multiplier, Q, is due to the non-linearities of the receiver and not of the transmitter. As discussed previously, EMI can occur between transmitter harmonics and receiver spurious but is unlikely because of the levels of attenuation and the relative strength of the signals involved. As such, the following discussion examines only transmitter fundamentals interacting with receiver spurious. The numerator of Eq. (2.3), therefore, represents the spurious frequencies, which are symmetrically displaced above and below the harmonics of the local oscillator, $P*f_{LO}$, by the amount of the intermediate frequency, f_{IF}. For simplicity, the words *spurious* and *image* are used interchangeably.

For variable-IF receivers, f_{IF} in Eq. (2.3) can assume any value within the IF band of the receiver, in contrast to fixed-IF receivers, where f_{IF} is fixed. Finally, the victim frequency can be easily determined by applying Eq. (2.1) where f_{LO} and f_{IF} are the same as in Eq. (2.3).

The sum 'P+Q' defines the image order of a receiver. When the image order is greater than or equal to three, there are two images as implied by Eq. (2.3). When the image order is equal to two, there is only one image since the other frequency corresponds to a fundamental channel of the receiver.

When a receiver design employs more than one conversion stage, the image problem becomes even more complex. A dual-conversion system will have primary and secondary images. A triple-conversion receiver will have primary, secondary and tertiary images, and so on. As such, for multiple-conversion systems, f_{IF} and f_{LO} in Eq. (2.3) represent the first IF stage and the first LO stage of a receiver, respectively.

The assumptions which allow the derivation of the 'P-Q' equation are given below [21].

1. The current output, I, from the RF section and the voltage input, E, to the RF section are harmonically related in frequency. That is, the current-voltage relationship of the RF section is an n^{th} order polynomial described mathematically as follows:

$$I=a_0+a_1E+a_2E^2+a_3E^3+...+a_nE^n \quad \textbf{(2.4)}$$

2. The output from the mixer stage contains all possible sum and difference frequencies of the input signal, f_S, and the local oscillator, f_{LO}, and the harmonics of these signals, i.e.,

$$abs(Q*f_S \pm P*f_{LO}) \quad \textbf{(2.5)}$$

3. Mix products between several RF signals are assumed to be negligible.

Therefore, non-linearities present at the RF section of radio sets introduce harmonics of the received signals thus resulting in spectral contamination. To alleviate such problems, preselectors are added at the input stage of receivers.

2.3.2 Harmonic Interference

Harmonic interference, as opposed to spurious or image interference, results from the non-linearities present at the RF section of the transmitter. In addition to the fundamental frequency, f_s, harmonics of the fundamental frequency are also present at the output stage of a transmitter. Although these signals are weak, they are often above the susceptibility threshold of the fundamental frequency of a receiver. Harmonic interference is described mathematically by equating the harmonic frequency of the transmitter to the fundamental operating frequency of the receiver as shown below:

$$L*f_s=f_{LO}+(-1)^{SIGN}f_{IF} \quad \textbf{(2.6)}$$

where L is the harmonic order of the source frequency, f_s.

2.3.3 Intermediate Frequency Interference

It was previously noted that a culprit signal may penetrate the IF shield by means of radiation or conduction, thus resulting in EMI. To alleviate such problems, the intermediate frequency and its sub-harmonics must be at the preselector's ultimate attenuation zone in order to prevent unwanted signals from operating at the IF band of the receiver. Intermediate frequency interference is described mathematically by equating the fundamental source frequency to the IF as follows:

$$f_S = f_{IF} \tag{2.7}$$

Note, however, that several fundamental frequencies of a receiver are victimized when a source frequency is operating at the IF of a receiver. In fact, there are as many victim channels as there are LO settings. This becomes immediately apparent by examining Eq. (2.1) where f_{LO} is now a free variable that can assume any value that corresponds to an LO setting. This is true, regardless of whether the receiver employs a single-conversion stage or multiple-conversion stages.

2.3.4 Local Oscillator Interference

Finally, EMI can occur between two receivers since a local oscillator can act as a transmitter if provided with a suitable radiator, conduction or leakage path. Therefore, preselectors must also reduce radiation from the receiver's LO out of the receiving antenna. Because the harmonics of the LO are, in general, weak signals, only the fundamental LO settings pose an EMI threat. Local oscillator interference is described mathematically by equating the LO setting of the culprit system to the victim fundamental channel as follows:

$$f_{LOs}=f_{LO}+(-1)^{SIGN}f_{IF} \qquad \textbf{(2.8)}$$

where f_{LOs} *is the LO setting of the offending receiver.*

If the offending receiver has a fixed IF, the corresponding source channel can be determined by employing Eq. (2.1) where f_{LO} is replaced by f_{LOs}, and f_{IF} and SIGN correspond to the fixed IF value and the sign of the offending receiver, respectively. For variable IF receivers, however, there is a range of fundamental channels of the offending receiver that can be considered as a source channel since f_{IF} in Eq. (2.1) is now a free variable that can assume any value within the IF band. The above analysis, of course, is valid only for a single-conversion receiver or for the first stage of a multiple-conversion receiver. Local oscillator radiation from the second or third conversion-stage of a receiver is more complex and beyond the scope of this thesis.

Although the modes of EMI previously examined follow simple mathematical equations, there are numerous subtleties involved in generating precise source/victim combinations for EMC testing. These subtleties will become apparent in Chapter 4 where the revised algorithm of the CAETS EMC analysis code is thoroughly examined. Finally, the importance of generating precise frequency combinations is best explained by examining Figure 2.2 where it is readily apparent that if a culprit signal does not fall exactly on, or at least very near, a local minimum, the culprit signal may not get translated to the IF and, therefore, EMI will not be detected.

Chapter 3.0

THE CAETS PROGRAM

3.1 Introduction

The Computer Aided EMC Test Plan System (CAETS) program was developed to assist DND and its contractors in the preparation of aircraft EMC test plans. The code, in addition to predicting EMI between narrowband systems, generates tables for the broadband equipment, with empty cells allocated for test results (flight and ground) to be entered. The word *narrowband* should not delude the reader into thinking that the frequencies involved are narrowband in nature. Narrowband and broadband classification of signals is entirely dependent on the bandwidth of the receiving system. Herein, *narrowband equipment* implies equipment intentionally designed to operate on discrete or pre-set frequencies, i.e., digital radio sets. Furthermore, *broadband equipment* includes equipment such as intercom, meters, lights, indicators, heaters, et cetera.

Before the program can output any results, an accurate EMC database is required which describes the equipment installed aboard the aircraft and its avionic systems. A total of five input files are required -- the aircraft data file (AIRCF.DAT), the receiver data file (RXER.DAT), the transmitter data file (TXER.DAT), the broadband data file

(BB.DAT) and the power data file (PCODE.DAT). The first three files describe the narrowband equipment while the last two files describe the broadband equipment aboard the aircraft. Figure 3.1 depicts the CAETS (Version 6.0) functional relationship of the EMC database to the various options available to the user. In essence, the CAETS structure is divided into three major functions: 'Edit' EMC database, 'Print' EMC database and 'Test' aircraft.

The 'Edit' option allows the user to modify the EMC database, while the 'Print' option generates a printout of the EMC database in order to verify and document the aircraft description. The following EMC analysis outputs can be generated by selecting the 'Test' option from the CAETS main menu -- 'Narrowband', 'Spectrum Chart', 'Narrowband Graphics', 'Test Specific Frequencies', 'Broadband', 'Power', and 'Intercom'. The first four test options pertain to narrowband equipment and are referred to as *narrowband options*, while the last three test options pertain to broadband equipment and are referred to as *broadband options*. The broadband options are beyond the scope of this thesis and, therefore, shall not be discussed further.

All output may be directed either to a file for editing (default file is PRINTER.LST) or to a printer. However, before the code can generate any output, the user must input the aircraft name to be tested, the sample size and the maximum image order. The sample size controls the number of

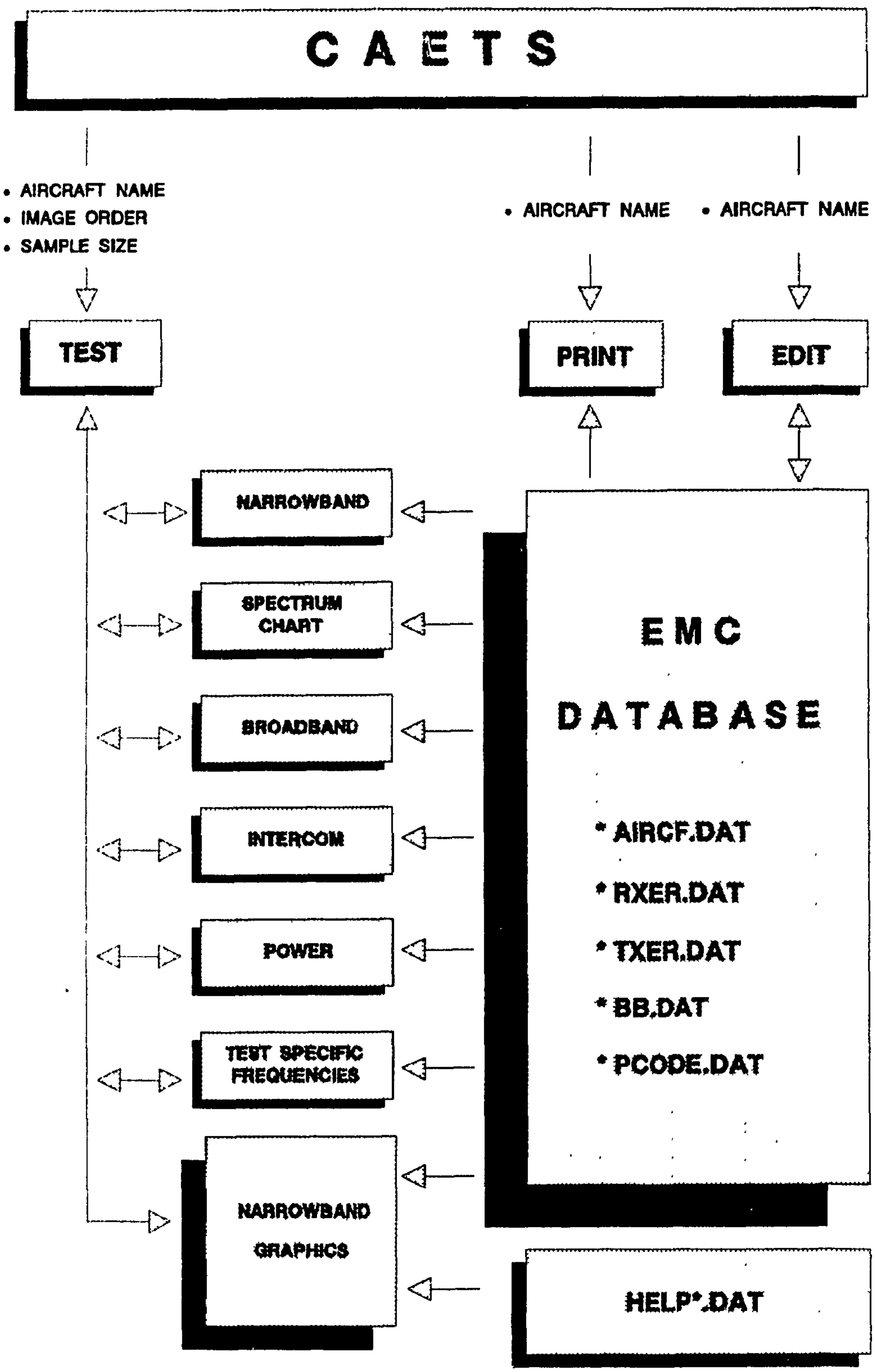

Figure 3.1 CAETS Functional Flowchart, Version 6.0

frequency combinations that the code will generate for every interacting system pair it encounters. The maximum image order is defined as the sum of two integers which represent harmonic multipliers of the received frequency and local oscillator (see receiver structure in Chapter 2).

3.2 The Narrowband Database

This section describes the parameters stored in the narrowband data files in hope that the reader will gain a better understanding of the subtleties involved in defining a receiver, transmitter and transceiver system. Proper equipment modelling is an essential requirement if meaningful results are to be obtained. Furthermore, the same EMC database described in this section is used to illustrate the examples presented in the following chapters.

3.2.1 The Aircraft Data File

The aircraft data file indicates to the program which receivers and transmitters should be read from the receiver data file and the transmitter data file, respectively. Figure 3.2 depicts the aircraft data file for the CH124 Sea King helicopter as produced by the CAETS 'Print' option. The file contains the aircraft name, the narrowband system name, and the number of receivers and transmitters that belong to that system. In addition, a two-letter code is used to describe the system type -- 'TT' (transmitter), 'RR' (receiver), and 'TR' (transceiver).

The code allows the user to specify more than one receiver and/or transmitter per system in order to simplify equipment modelling. However, when testing for interference between two narrowband systems, the code does not test a radio set against itself. That is, the code will not test narrowband receivers and transmitters that belong to the same system.

3.2.2 The Receiver Data File

Figure 3.3 depicts the receiver data file for the CH124 Sea King helicopter as produced by the CAETS 'Print' option. The file contains the receiver name, the operating range, the LO range, the LO stepping, the channel spacing, the IF band which also codes the sign of the receiver, the parameters V and W, and the dial setting of the receiver. Since the CAETS program makes the assumption that interference can occur only at the first stage of a heterodyne receiver, the LO range and its stepping as well as the IF band describe the first stage of a multiple-stage receiver.

AIRCRAFT DATA FOR CH124 (AIRCF)

AIRCRAFT	SYSTEM NAME	TYPE	#REC	#TRANS
CH124	AN/ARC-552A	TR	1	1
CH124	AN/ARC-505A	TR	2	1
CH124	AN/APX-77A	TR	1	1
CH124	AN/APS-503	TR	1	1
CH124	AN/R-1047A/A	RR	1	0
CH124	POWER SYS 400Hz	TT	0	1
CH124	AN/ARN-59(V)	RR	1	0
CH124	AN/APN-117	TR	1	1
CH124	AN/ARN-504-(V)	TR	4	1

Figure 3.2 Aircraft Data File for CH124 ('Print' Option)

While the channel spacing represents the separation between two adjacent system channels in the frequency domain, the dial setting of a receiver is used for displaying the frequency combinations to their correct decimal places. That is, the frequency combinations provided will correspond to channels of the receiver, displayed to their correct decimal places as dictated by the dial setting of the receiver (i.e., MHz, KHz).

RECEIVER DATA FOR CH124 (RXER)

SYSTEM	FREQUENCY RANGE MHZ	1ST L.O. FREQUENCY MHZ	FREQ.STEP MHZ	CHANNEL SPACING MHZ	1ST I.F. FREQUENCY MHZ	W MHZ	V MHZ	RECEIVER SETTING MHZ
AN/ARC-552A	225.0 - 399.9	200.000- 370.000	10.000	0.100	20.000- 29.900	10.000	20.000	0.100
AN/ARC-505A	2.000 - 6.999	12.500- 8.500	-1.000	0.001	-14.500- -15.499	1.000	14.500	0.001
AN/ARC-505A	7.000 - 29.999	10.000- 32.000	1.000	0.001	-2.001- -3.000	1.000	-3.000	0.001
AN/APX-77A	1030 - 1030	1090.000- 1090.000	0.000	0.000	-60.000- -60.000	1 Hz	60.000	1.000
AN/APS-503	9375 - 9375	9315.000- 9315.000	0.000	0.000	58.000- 62.000	1 Hz	60.000	1.000
AN/R-1047A/A	162.250 - 173.500	222.250- 233.500	0.375	0.375	-60.000- -60.000	1 Hz	60.000	0.001
AN/ARN-59(V)	0.190 - 1.750	0.3325- 1.8925	0.003	0.003	-0.1411- -0.1439	1 Hz	0.1425	0.001
AN/APN-117	4300 - 4300	4300.000- 4300.000	0.000	0.000	0.000- -0.006	1 Hz	0.000	1.000
AN/ARN-504-(V)	962 - 1024	1025.000- 1087.000	1.000	1.000	-60.500- -65.500	1 Hz	63.000	1.000
AN/ARN-504-(V)	1151 - 1213	1088.000- 1150.000	1.000	1.000	60.500- 65.500	1 Hz	63.000	1.000
AN/ARN-504-(V)	1025 - 1087	1088.000- 1150.000	1.000	1.000	-60.500- -65.500	1 Hz	63.000	1.000
AN/ARN-504-(V)	1088 - 1150	1025.000- 1087.000	1.000	1.000	60.500- 65.500	1 Hz	63.000	1.000

Figure 3.3 Receiver Data File for CH124 ('Print' Option)

In Figure 3.3, the lowest tunable frequency corresponds to the first system channel and subsequent channels are determined by incrementing the first channel by the channel spacing. If the channel spacing is set to zero, the receiver operates on a fixed channel. The channels of the receiver are computed by employing Eq. (2.1) in Chapter 2. Furthermore, since the code only considers digital receivers, a non-zero value is expected for the first local oscillator stepping of multichannel systems.

The parameters V and W are used to describe the variability of the receiver's IF band. Note that in Figure 3.3, when the sign of a receiver is negative, the IF band limits are displayed as negative. This is for mathematical purposes indicating that the IF should be subtracted from the LO to determine the system channels. The user can employ the 'V-W' equation to calculate the intermediate frequency of receiver channels in order to verify the results by hand. The 'V-W' equation is given as:

$$\mathrm{IF}(f_o) = abs(W * fract(\frac{f_o}{W}) + V) \tag{3.1}$$

where f_o *is a fundamental channel of the receiver.*

If the first local oscillator stepping is equal to the channel spacing of the receiver, the IF is fixed, otherwise, the IF is variable. For fixed IF receivers, W is set to 1Hz and V is set to the exact IF frequency of the receiver (usually the centre frequency of the IF band, IFfixed). For variable IF receivers, the parameters V and W depend on the sign of the receiver and whether the local oscillator range is above or below the IF range. Table 3.1 summarizes the modelling of the parameters V and W. In Table 3.1, variable FLOSP represents the first local oscillator stepping, and variables FIFMIN and FIFMAX represent the minimum and maximum frequency limits of the IF band, respectively.

Table 3.1 Parameters V and W

SIGN OF RECEIVER	CONDITION	IF	V	W
+	----	Fixed	abs(IFfixed)	1Hz
		Variable	abs(FIFMIN)	abs(FLOSP)
-	IF > LO	Fixed	abs(IFfixed)	1Hz
		Variable	abs(FIFMIN)	abs(FLOSP)
	IF < LO	Fixed	abs(IFfixed)	1Hz
		Variable	-abs(FIFMAX)	abs(FLOSP)

Each line in the receiver data file is 137 characters long and describes a single receiver. Presently, the user can specify the input variables to within five digits of accuracy. This limitation should be lifted to accommodate for a more precise specification of the input variables. Furthermore, the input lines should be increased to two per system to accommodate for the additional variables required for future linkage of the CAETS program to the AAPG program.

3.2.3 The Transmitter Data File

Figure 3.4 depicts the transmitter data file for the CH124 Sea King helicopter as produced by the CAETS 'Print' option. The file contains the transmitter name, the operating range, the maximum harmonic order to be considered when testing for harmonic interference, the transmitter channel spacing and the transmitter dial setting. These parameters are similar to their counterparts discussed in the receiver data file.

TRANSMITTER DATA FOR CH124 (TXER)

SYSTEM	FREQUENCY RANGE MHZ	HARMONIC NUMBER	CHANNEL SPACING MHZ	TRANSMITTER SETTING MHZ
AN/ARC-552A	225.0 - 399.9	6	0.100	0.100
AN/ARC-505A	2.000 - 29.990	20	0.001	0.001
AN/APX-77A	1090 - 1090	6	0.000	1.000
AN/APS-503	9375 - 9375	6	0.000	1.000
POWER SYS 400Hz	380 Hz - 420 Hz	6	1 Hz	1 Hz
AN/APN-117	4300 - 4300	6	0.000	1.000
AN/ARN-504-(V)	1025 - 1150	6	1.000	1.000

Figure 3.4 Transmitter Data File for CH124 ('Print' Option)

3.3 Narrowband Options

Once the EMC database has been compiled, the user can proceed to test an aircraft. The CAETS narrowband options (except 'Spectrum Chart') test for image, harmonic, intermediate frequency and local oscillator interference between the narrowband systems. If the code establishes that two narrowband systems interfere, it assigns a source and a victim frequency to that system pair. These frequency combinations correspond to channels of the equipment under test so that the test engineer can tune to the indicated channels and record the level of interference.

The 'Narrowband' output is displayed on victim/source tables. Figure 3.5 depicts a sample narrowband printout for the CH124 Sea King helicopter. The table contains (from left to right) the victim name, the victim channel, the victim response, the source name, the source channel, the source emission, and two empty columns for the ground and air results to be entered during EMC testing. In Figure 3.5, each line corresponds to a source/victim frequency combination. In the first line, for example, the user tunes the AN/ARC-552A to 226.4MHz and the AN/ARC-505A to 28.300MHz and records the EMI results in the last two columns. Note that the 8^{th} harmonic of 28.300MHz, coded as '8 RF' in the source emission column, interferes with 226.4MHz which is a fundamental channel of the AN/ARC-552A, coded as 'RF' in the victim response column.

NARROWBAND TEST COMBINATIONS FOR CH124 PAGE 1

VICTIM	FREQUENCY (MHZ)	VICTIM RESPONSE	SOURCE	FREQUENCY (MHZ)	SOURCE EMISSION	RESULT GROUND	RESULT AIR
AN/ARC-552A			AN/ARC-505A				
	226.4	RF		28.300	8 RF		
	238.4	RF		29.800	8 RF		
	229.1	RF		25.456	9 RF		
	265.0	RF		29.444	9 RF		
	231.6	RF		23.160	10 RF		
	291.4	RF		29.140	10 RF		
	233.8	RF		21.255	11 RF		
	317.5	RF		28.864	11 RF		
	235.8	RF		19.650	12 RF		
	343.4	RF		28.617	12 RF		
	237.7	RF		18.285	13 RF		
	369.0	RF		28.385	13 RF		
	238.3	RF		17.021	14 RF		
	377.6	RF		26.971	14 RF		
	238.3	RF		15.887	15 RF		
	377.6	RF		25.173	15 RF		
	238.3	RF		14.894	16 RF		
	377.6	RF		23.600	16 RF		
	238.3	RF		14.018	17 RF		
	377.6	RF		22.212	17 RF		
	238.3	RF		13.239	18 RF		
	377.6	RF		20.978	18 RF		
	238.3	RF		12.542	19 RF		
	377.5	RF		19.868	19 RF		
	238.3	RF		11.915	20 RF		
	377.6	RF		18.880	20 RF		
	230.8	IF		20.800	1 RF		
	228.7	IF		28.700	1 RF		
			AN/APX-77A				
	390.0	-IM 3, 1		1090	1 RF		
			AN/ARN-504-(V)				
	370.0	-IM 3, 1		1030	1 RF		
	397.0	-IM 3, 1		1083	1 RF		
	360.0	+IM 3, 1		1040	1 RF		
	390.0	+IM 3, 1		1130	1 RF		
	299.0	-IM 4, 1		1051	1 RF		
	313.0	-IM 4, 1		1137	1 RF		
	279.0	+IM 4, 1		1029	1 RF		
	300.0	+IM 4, 1		1140	1 RF		

Figure 3.5 Sample Narrowband Output for CH124

Therefore, the victim response and the source emission represent the mode by which interference may couple from the source to the victim, and are coded according to Table 3.2.

Table 3.2 Narrowband Output Codes

INTERFERENCE TYPE	VICTIM RESPONSE	SOURCE EMISSION
Image	$(-1)^S$ IM P,Q	1 RF
Harmonic	RF	n RF
Intermediate Frequency	IF	1 RF
Local Oscillator	RF	1 LO

In Table 3.2, variables P,Q and n represent harmonic multipliers of the local oscillator, the received frequency, and the transmitted frequency, respectively, while S represents the sign of the victim image region. The first code in Table 3.2, indicates to the user that a fundamental channel of the source, denoted as '1 RF', interacts with a spurious frequency of the victim, denoted as '$(-)^S$ IM P,Q' which essentially codes Eq. (2.3) in Chapter 2. The second code indicates harmonic interference, and is self-explanatory, while the third code indicates intermediate frequency interference and informs the user that a fundamental source channel, denoted as '1 RF', interferes with the IF band of the victim receiver, denoted as 'IF'. Finally, the last code indicates local oscillator interference between two receivers and occurs when a fundamental LO setting of one receiver, denoted as '1 LO', interferes with a fundamental channel of another receiver, denoted as 'RF'.

Note in Figure 3.5 that there are two frequency combinations outputted for every interaction type. That is, there are two 8^{th} harmonic combinations, two 9^{th} harmonic combinations, et cetera. This is governed by the sample size. The user can specify up to ten samples for every interaction type. However, the code will not output repetitive frequency combinations if it has exhausted all the possible frequency interactions between any two systems. In Figure 3.5, for example, the AN/APX-77A operates only at 1090MHz and, therefore, only one '-IM3,1' interaction exists with the AN/ARC-552A.

The user can also request a spectrum chart display which allows rapid scanning of the avionics systems to obtain a rough order of coincidence between the equipment under test. Figure 3.6 depicts a sample printout of the spectrum chart for the CH124 Sea King helicopter. The chart displays the tuned frequency range, the local oscillator range and the intermediate frequency band of every receiver, and the tuned frequency range and its harmonics, up to a set limit as specified in the transmitter data file, of every transmitter. These regions are displayed on a logarithmic scale.

NARROWBAND FREQUENCY SPECTRUM CHART FOR CH124

AN/ARC-552A		
TUNED FREQUENCY (REC)	225.000 -	399.900 MHZ
TUNED FREQUENCY (TX)	225.000 -	399.900 MHZ
HARMONIC 2	450.000 -	799.800 MHZ
HARMONIC 3	675.000 -	1199.700 MHZ
HARMONIC 4	900.000 -	1599.600 MHZ
HARMONIC 5	1125.000 -	1999.500 MHZ
HARMONIC 6	1350.000 -	2399.400 MHZ
INTERMED FREQUENCY	20.000 -	29.900 MHZ
LOCAL OSCILLATOR	200.000 -	370.000 MHZ
AN/ARC-505A		
TUNED FREQUENCY (REC)	2.000 -	29.999 MHZ
TUNED FREQUENCY (TX)	2.000 -	29.990 MHZ
HARMONIC 2	4.000 -	59.980 MHZ
HARMONIC 3	6.000 -	89.970 MHZ
HARMONIC 4	8.000 -	119.960 MHZ
HARMONIC 5	10.000 -	149.950 MHZ
HARMONIC 6	12.000 -	179.940 MHZ
HARMONIC 7	14.000 -	209.930 MHZ
HARMONIC 8	16.000 -	239.920 MHZ
HARMONIC 9	18.000 -	269.910 MHZ
HARMONIC 10	20.000 -	299.900 MHZ
HARMONIC 11	22.000 -	329.890 MHZ
HARMONIC 12	24.000 -	359.880 MHZ
HARMONIC 13	26.000 -	389.870 MHZ
HARMONIC 14	28.000 -	419.860 MHZ
HARMONIC 15	30.000 -	449.850 MHZ
HARMONIC 16	32.000 -	479.840 MHZ
HARMONIC 17	34.000 -	509.830 MHZ
HARMONIC 18	36.000 -	539.820 MHZ
HARMONIC 19	38.000 -	569.810 MHZ
HARMONIC 20	40.000 -	599.800 MHZ
INTERMED FREQUENCY	14.500 -	15.499 MHZ
	2.001 -	3.000 MHZ
LOCAL OSCILLATOR	12.500 -	8.500 MHZ
	10.000 -	32.000 MHZ

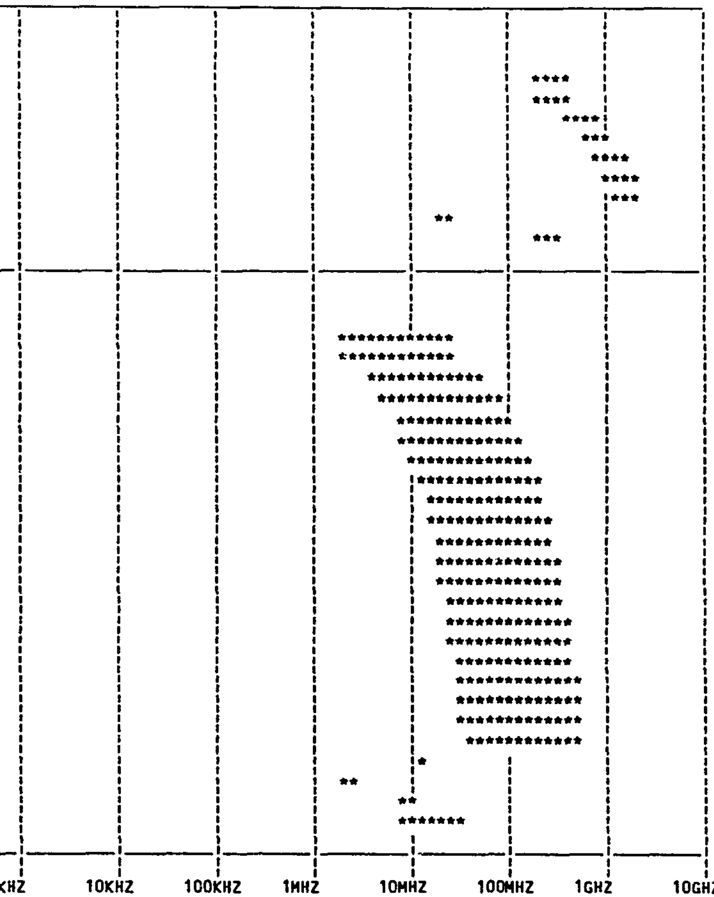

Figure 3.6 Sample Spectrum Chart for CH124

To illustrate the utility of the spectrum chart, note that the tuned frequency range of the AN/ARC-505A transmitter overlaps the intermediate frequency band of the AN/ARC-552A receiver and, therefore, potential EMI exists in the overlap region which extends from 20.0 to 29.9MHz. In fact, this interaction is detected in Figure 3.5 and corresponds to the last two frequency combinations between the AN/ARC-552A and the AN/ARC-505A systems.

The 'Test Specific Frequencies' option (Version 5.2) allows the specification of distinct source frequencies which correspond to authorized frequencies for a given EMC test site. In Version 5.0 the user can not specify distinct test (source) frequencies since the code generates its own source/victim frequency combinations according to a sampling equation described later in Chapter 4.

In this option, the user merely inputs the system name under test and a maximum of ten source frequencies to be tested. The code tests only for interactions between these source frequencies (and their harmonics up to a set limit specified in the transmitter data file) and the receivers. That is, the code will not test for local oscillator interference since this mode of interference requires that both systems be receivers. The output is displayed in victim/source tables similar to the table depicted in Figure 3.5.

The CAETS program provides an effective tool to analyze and predict EMI in communication systems and significantly reduces the time required to prepare an aircraft EMC test plan. However, for a typical EMC database, the code produces more data than can be tested. Hence, Version 6.0 was developed to include graphics which provides visualization of the relationship of the computed test frequencies to the victim and source operating frequency ranges, and visualization of the system characteristics of the equipment under test. This option simplifies the selection of the optimum test frequencies and aids the user in the analysis and prediction of spurious EMI. Sample outputs available from this option are shown in Figure 3.7 and Figure 3.8.

Figure 3.7 illustrates a sample template for harmonic interference. However, the same template is used for image interference. It consists of the source axis (Y-axis) and the victim axis (X-axis) which extend from the minimum to the maximum tuning ranges of the equipment under test. The frequency divisions on the axes correspond to system channels and are displayed according to the dial setting of their corresponding system. The entire set of lines displays the complete response for a given mode of interference between the two systems. Each line displays a specific interaction in the mode of interference under test, and is clipped against the four boundaries defined by the minimum and maximum tuning ranges of the equipment under test.

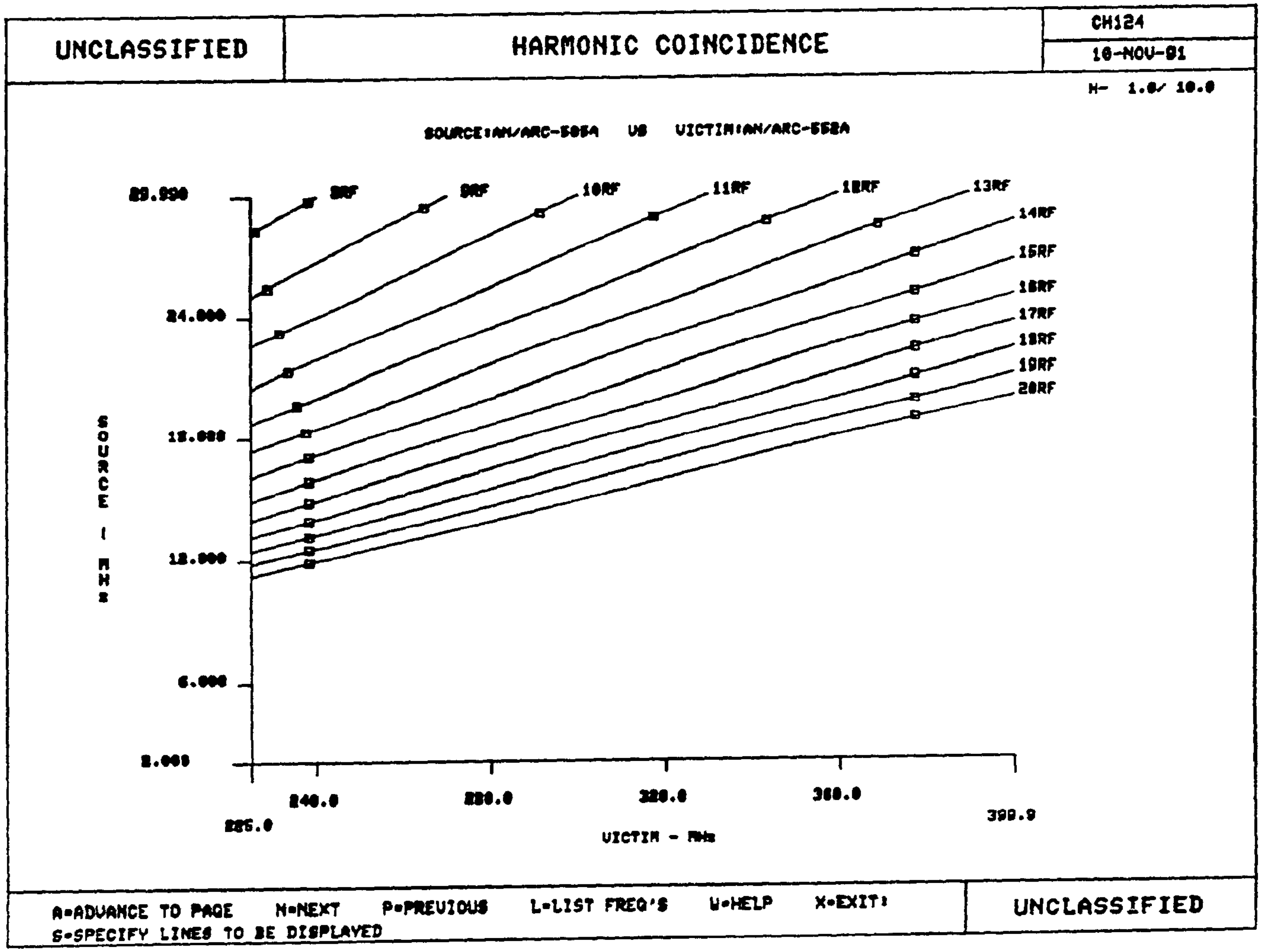

Figure 3.7 Sample Template for Harmonic and Image Coincidence

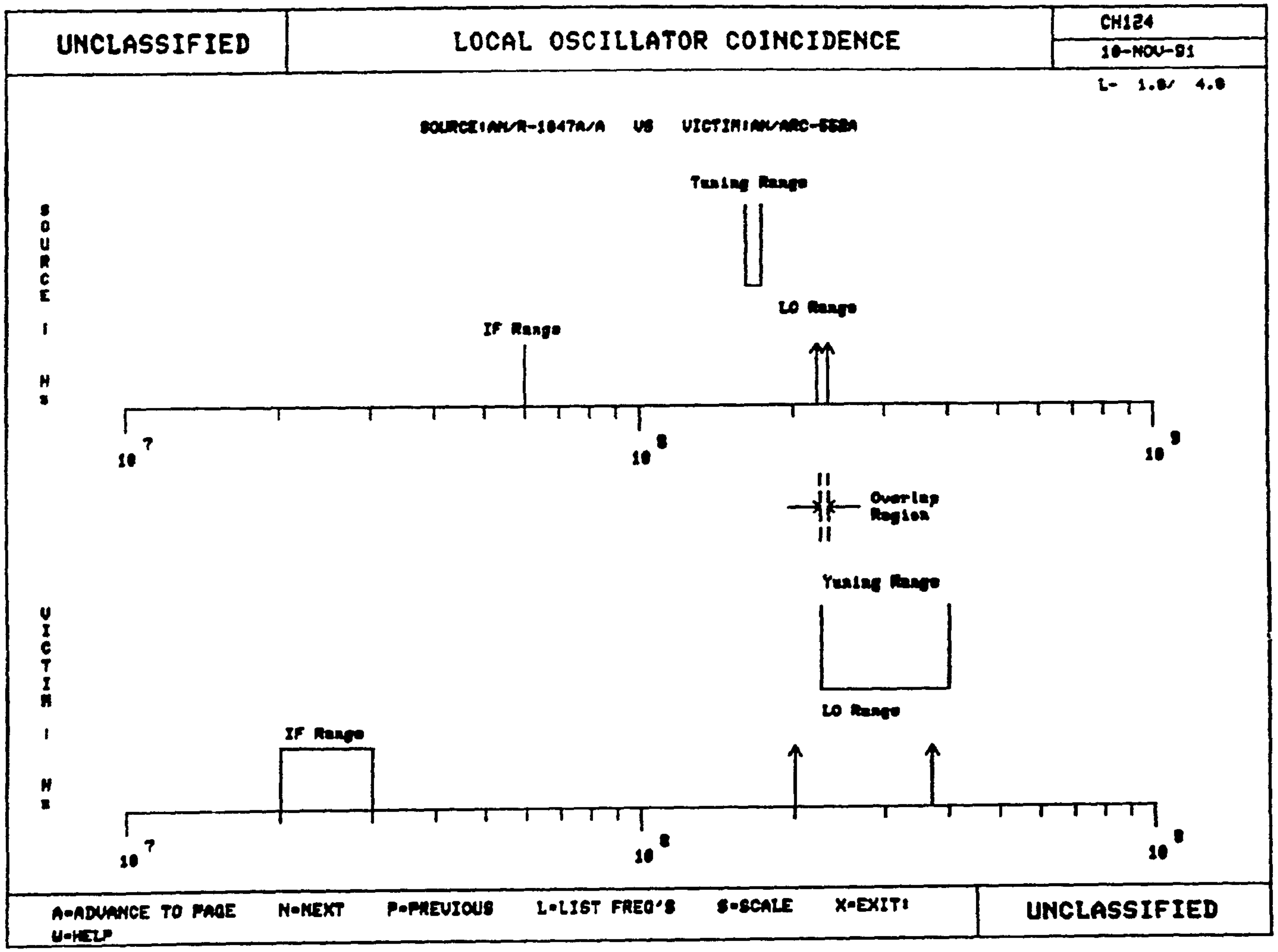

Figure 3.8 Sample Template for LO and IF Coincidence

Note that the square placemarks on the lines correspond to the first 26 sampled source/victim frequency combinations identified in the narrowband table shown in Figure 3.5. These sampled test frequencies appear near the ends of each line and correspond to approximately the 10% and 90% frequency marks of each line.

The three fields located on the top right-hand corner of Figure 3.7 display the aircraft name under test, the date of the printout, and a code which displays the current page number along with the total number of pages for that same mode of interference. For example, Figure 3.7 depicts the first page of a total of ten pages of harmonic interference. The other pages, of course, also display harmonic interactions but for different interacting system pairs. Finally, the options located at the bottom of the graph essentially allow the user to scan through the pages either sequentially or randomly, provide a listing of the sampled test frequencies, and allow the user to de-clutter a cluttered display by specifying a set of lines to be displayed. A help command which explains these options is also available to the user.

Figure 3.8 illustrates a sample template for local oscillator interference. However, a similar template is used for intermediate frequency interference. The top half of the graph displays the system characteristics of the offending receiver while the bottom half displays those of the victim receiver. Essentially, the code displays the tuning range, the local oscillator range and the intermediate frequency band of the equipment under test. The code also displays the overlap region which is defined as the intersection of the LO range of the offending receiver with the tuning range of the victim receiver. Although the interaction in Figure 3.8 is depicted on a logarithmic scale, a linear scale is also available.

For intermediate frequency interference the code displays only the tuning range of the offending system since the source system is a transmitter. Furthermore, the overlap region is defined as the intersection of the tuning range of the offending transmitter with the IF band of the victim receiver.

The various fields and options available to the user in this template are similar to those discussed earlier for the harmonic and image template.

3.4 Hardware/Software Requirements

CAETS Version 6.0 requires a Tektronix 4015 terminal (or compatible) to run the graphics option, and a printer that supports 132 characters per line. A PC-386 work-station with MicroWay NDP-Fortran-386, Version 2.1.0, and a Phar-Lap DOS Extender was used for the work covered in this thesis. The program has also been successfully run on a VAX (using VMS) and on a UNIX work-station. Most Fortran compilers available for PCs limit the program size to 640 Kbytes. This is only marginally acceptable for the CAETS program. To handle large amounts of data requires the use of a compiler that does not have this restriction. Microsoft Fortran 5.1 overcomes this limitation when used with Microsoft Window 3.0.

Finally, by examining the various narrowband test options it is evident that the CAETS program is, indeed, a powerful EMC analysis tool that can be used to analyze and predict EMI in communication systems and is intended to automate EMC test procedures. That is, the code generates the results in the form of *test cards* which can be easily integrated into an EMC test report. The manner in which the CAETS program manipulates the variables which comprise the EMC database, in order to perform source/victim assignments, is discussed in the following chapter.

Chapter 4.0

NARROWBAND ALGORITHM AND OUTPUT COMPARISONS

4.1 Introduction

This chapter describes the revised algorithm of the CAETS program that performs source/victim assignments. Version 4.2 of the CAETS program, which was the latest revision prior to the work covered in this thesis, was plagued with severe algorithmic deficiencies that limited the utility of the code. The extent of the modifications to Version 4.2 are such that the entire set of modules that performs narrowband calculations has been re-written. Whenever possible, the underlying equations of Version 4.2, which erroneously perform source/victim calculations, are presented and compared to those of Version 5.0. Finally, in order to appreciate the extent of the contribution of these modifications, the narrowband results of Version 4.2 and Version 5.0 are examined.

As a final note, the equations described in this chapter are presented in a quasi-FORTRAN notation to make it easy to relate the code to the underlying equations and for consistency with previously released deficiency [14] and EMI reports [15][16].

4.2 Narrowband Algorithm

The CAETS narrowband algorithm tests every receiver/ transmitter (Rx/Tx) system pair for image, harmonic and intermediate frequency interference, and every receiver/ receiver (Rx/Rx) system pair for local oscillator interference. This is carried out in the following sequence.

In order to establish a correlation between two narrowband systems, the code loops through the entire narrowband database and assigns a victim and/or a source region to every narrowband system. If a source region of one system overlaps the victim region of another, then potential interference exists between the two systems.

The code then samples the overlap region and assigns victim and source frequencies to every interacting system pair according to the sample size set by the user. The sampled frequencies correspond to channels of the equipment under test so that the test engineer can tune to the indicated channels to measure the level of interference.

Before terminating the calculations for a particular interaction the code tests adjacent source channels to ensure that every victim/source combination provides the most severe response. That is, the code tests if the assigned source channel is the most suitable candidate for its corresponding victim channel, since there can be many source channels that will interfere with that same victim channel, and vice versa.

4.2.1 Assigning the Overlap Region

The CAETS program assigns the tuning range (and its harmonics) of transmitters and the local oscillator range of receivers as sources of EMI, and the operating range, the image regions and the intermediate frequency band of receivers as victims of EMI. The intersection between a victim region and a source region defines the overlap region. In fact, each harmonic line displayed in Figure 3.7 in Chapter 3 essentially corresponds to an overlap region for harmonic interference, and is usually expressed in terms of the tunable range of the victim system. Variables FMIN and FMAX store the lower and upper frequency limits of the overlap region, respectively, and correspond to the Y-coordinates of the endpoints of the lines shown in Figure 3.7.

4.2.1.1 Image Interference

Figure 4.1 depict the flowchart for image interference. The first block in Figure 4.1 defines the image region. Given P, Q and S, the image region of a receiver (coded as $(-1)^{s}$ IM P,Q in the CAETS output) is defined by the frequency limits F1 and F2 given as follows:

$$F1=\min(abs(FA),abs(FB),abs(FC),abs(FD)) \qquad \textbf{(4.1)}$$

and

$$F2=\max(abs(FA), abs(FB), abs(FC), abs(FD)) \quad \textbf{(4.2)}$$

where $FA = (P*FLOMIN + (-1)^{S} *FIFMIN)/Q$

$FB = (P*FLOMIN + (-1)^{S} *FIFMAX)/Q$

$FC = (P*FLOMAX + (-1)^{S} *FIFMIN)/Q$

$FD = (P*FLOMAX + (-1)^{S} *FIFMAX)/Q$

and

FIFMIN and FIFMAX are the first IF limits

FLOMIN and FLOMAX are the first LO limits

S is the sign of the image region
(S=1 for negative and S=2 for positive)

P and Q define the image order

If either of the products FA*FB, FC*FD or FA*FC is negative, the lower frequency limit of the image region will be negative while the upper frequency limit of the image region will be positive. This will result in the *reflection* of the negative portion of the image region, about the origin and onto the positive frequency axis, since the limits defining the image region must be positive. Hence, the lower frequency limit is set to zero. A graphical interpretation of image reflection is presented in Chapter 6 where the narrowband graphics output is examined. Furthermore, the limits F1 and F2 define the *worst case* which implies that the exact image region of the victim receiver is a subset of the image region defined by F1 and F2.

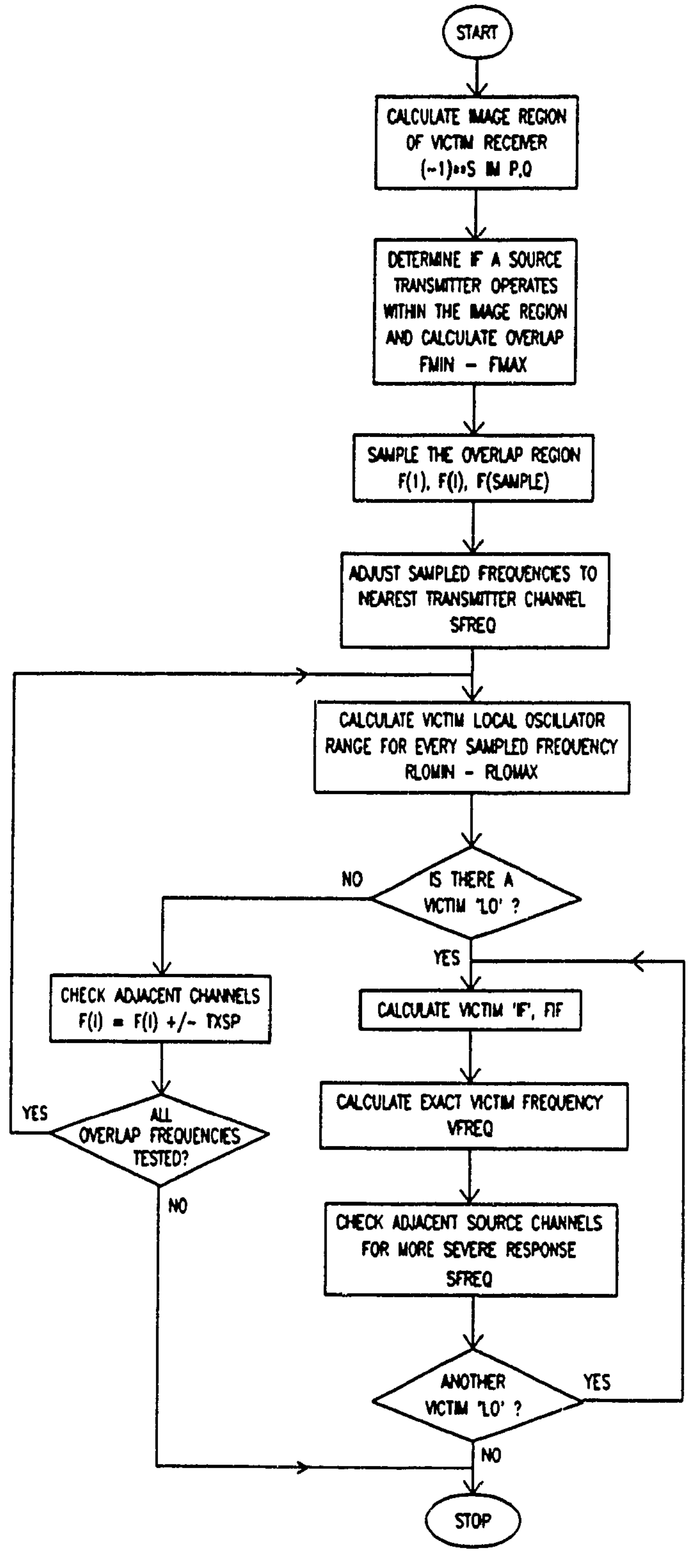

Figure 4.1 Flowchart for Image Interference

Version 4.2, in addition to neglecting image reflection, erroneously defines the endpoints of an image region by F1' and F2' given as follows:

$$F1' = abs\left(\frac{P*FLOMIN+(-1)^{S}*IF(FRMIN)}{Q}\right) \quad (4.3)$$

and

$$F2' = abs\left(\frac{P*FLOMAX+(-1)^{S}*IF(FRMAX)}{Q}\right) \quad (4.4)$$

where FRMIN and FRMAX are the minimum and maximum tuning frequencies of the victim receiver, respectively

IF(FR) is defined according to Eq. (3.1) in Chapter 3.

F1' and F2' define the image region of a receiver as a subset of the exact image region when the sign of the image region under test is opposite to that of the victim receiver. The following example illustrates the argument.

<u>Example 4.1:</u>

The AN/ARC-552A transceiver operates on any one of the 1750 channels spaced at 0.1MHz in the frequency band of 225.0 to 399.9MHz. The first local oscillator range extends from 200 to 370MHz in steps of 10MHz, and the corresponding IF range extends from 20.0 to 29.9MHz. It is apparent that the sign of the AN/ARC-552A is positive since the IF is added to the LO to determine a system channel. When P=3, Q=1 and S=2, the entire image region, +IM3,1, defined by F1 and F2, is given as follows:

F1 = 620.0MHz and F2 = 1139.9MHz

However, the precise image region is given by F1'' and F2'' as follows:

F1''= 625.0MHz and F2''= 1139.9MHz,

since the radio set is restricted from operating in the frequency band of 220.0 to 224.9MHz, which corresponds to the image region extending from 620.0 to 624.9MHz. The code employs the *worst case* image region, defined by F1 and F2, and later determines whether the sampled image frequencies correspond to operating channels of the equipment under test in order to simplify the assignment of the image regions. Furthermore, Eqs. (4-3) and (4-4) yield:

F1'= (3*200 + 25.0)/1 = 625.0MHz

and F2'= (3*370 + 29.9)/1 = 1139.9MHz

which is identical to the exact image region since the sign of the image region under test is the same as the sign of the receiver under test, i.e, positive.

However, for P=3, Q=1 and S=1, or -IM3,1, Eqs. (4-1) and (4-2) yield:

F1 = abs(FB) = (3*200 - 29.9)/1 = 570.1MHz

and F2 = abs(FC) = (3*370 - 20.0)/1 = 1090MHz,

which corresponds to the exact image limits, whereas Eqs. (4-3) and (4-4) yield:

$$F1' = (3*200 - 25.0)/1 = 580MHz$$

and $F2' = (3*370 - 29.9)/1 = 1080.1MHz$,

which, of course, is a subset of the exact image region. Consider, for example, the -IM3,1 image frequency of the first channel of the victim receiver. When the AN/ARC-552A is operating at 225.0MHz, its LO is working at 200MHz and, therefore, 225.0MHz will be translated to the IF band at 25.0MHz. As such, the -IM3,1 image of 225.0MHz is easily determined by applying Eq. (2.3) in Chapter 2:

$$(3*200 - 25.0)/1 = 575.0MHz,$$

which obviously does not fall within the image region defined by Eqs. (4-3) and (4-4).

Therefore, when testing for image interference, the victim region corresponds to the image region, defined by the frequency limits, F1 and F2, while the source region corresponds to the operating band of the transmitter. The intersection of these two regions defines the overlap region and corresponds to the second block in Figure 4.1. Subsequent blocks in Figure 4.1, describe the steps for sampling the overlap region and assigning source/victim combinations and are examined in the following sections.

4.2.1.2 Harmonic Interference

Figure 4.2 depicts the flowchart for harmonic interference. In harmonic interference, the victim region corresponds to the tunable band of the receiver, while the source region corresponds to the operating band of the transmitter along with its harmonics. This is described in the first two blocks in Figure 4.2 and is illustrated in the following example.

Example 4.2:

Consider the AN/ARC-552A victim receiver and the AN/ARC-505A source transmitter. The AN/ARC-505A radio set can transmit in the frequency band of 2.000 to 29.999MHz with its channels spaced 1KHz apart. The 17^{th} harmonics of the offending system extend from 34.000 to 509.983MHz. Therefore, potential interference exists in the overlap region which covers the entire tuning range of the victim system (FMIN=225.0MHz and FMAX=399.9MHz).

4.2.1.3 Intermediate Frequency Interference

Figure 4.3 depicts the flowchart for intermediate frequency interference. Intermediate frequency interference occurs when a transmitter operates at the IF band of a victim receiver. Because the harmonics of the transmitter are, in

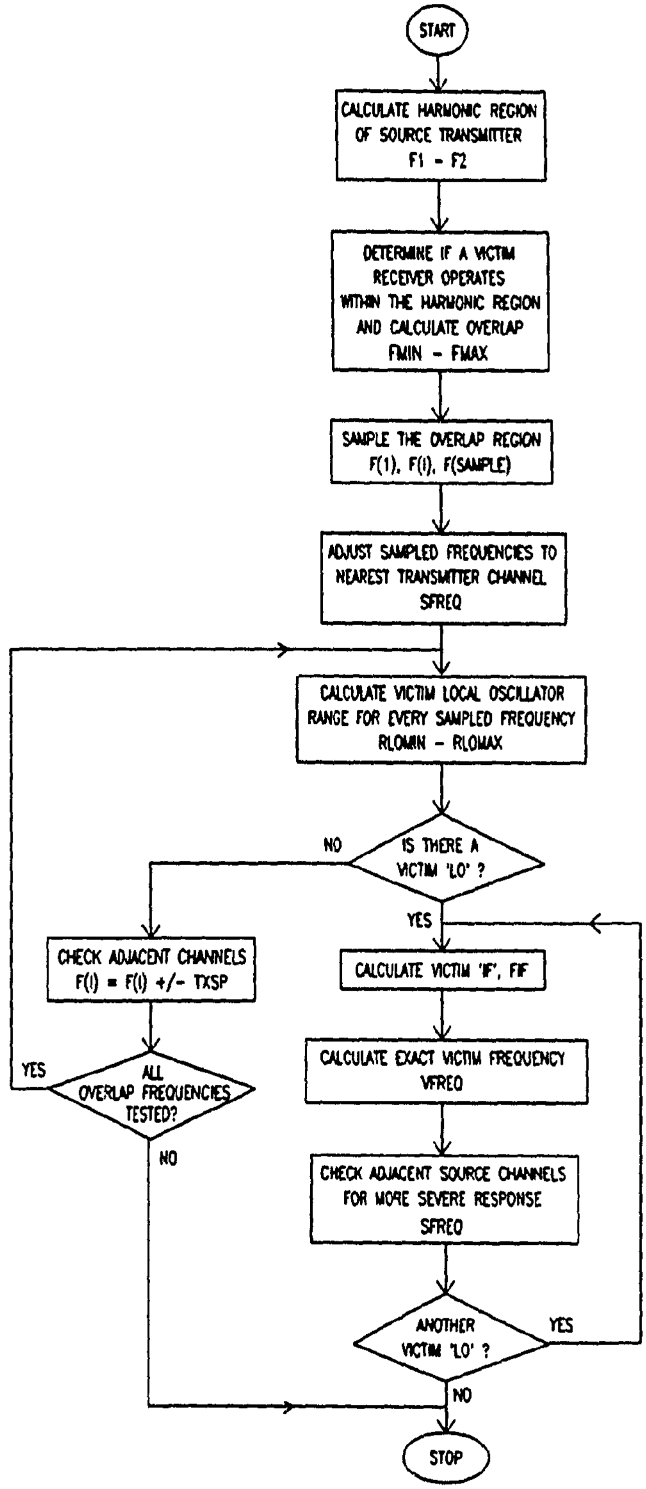

Figure 4.2 Flowchart for Harmonic Interference

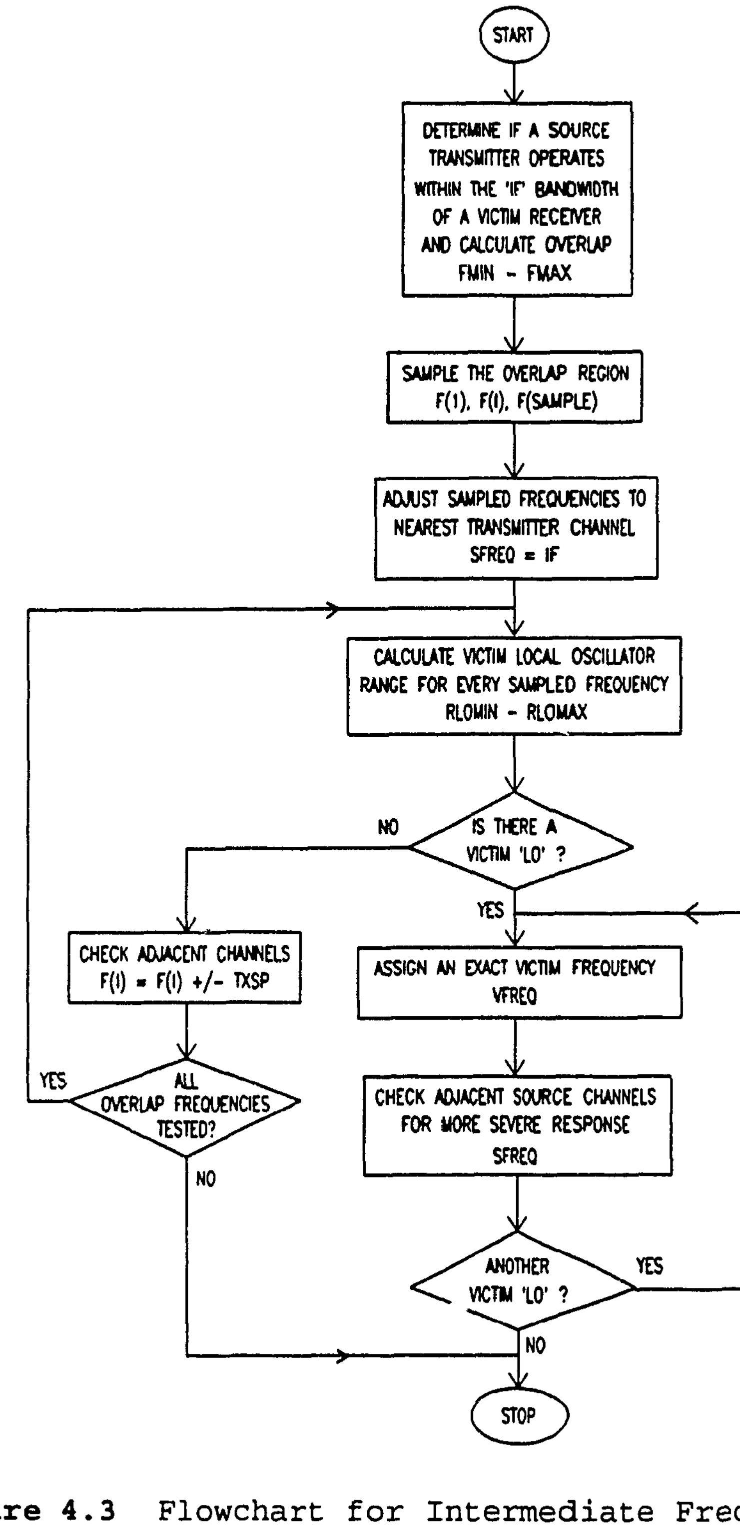

Figure 4.3 Flowchart for Intermediate Frequency Interference

general, weak signals, only the fundamental channels are tested for interference. Hence, the overlap region is defined as the intersection between the tuning range of the source transmitter with the IF band of the victim receiver. This is described in the first block in Figure 4.4 and is illustrated in the following example.

Example 4.3:

The AN/ARC-505A source transmitter operates from 2.000 to 29.999MHz which interferes with the IF band of the AN/ARC-552A receiver (20.0 to 29.9MHz). Hence, the overlap region extends from FMIN=20.0MHz to FMAX=29.9MHz.

Version 4.2 assigns the overlap region as the intersection of the tuning range of the source transmitter with the average IF value of the victim receiver. This approach is obviously incorrect for both variable-IF and fixed-IF receivers.

4.2.1.4 Local Oscillator Interference

The narrowband algorithm also tests interference between two receivers. Rx/Rx interference occurs when the first LO band of a source receiver overlaps the tuning range of another receiver. Only fundamental harmonics of the first LO stage are tested. Figure 4.4 depicts the flowchart for local oscillator interference. The first block in Figure 4.4 essentially defines the overlap region and is illustrated in the following example.

Example 4.4:

The first LO settings of the AN/R-1047A/A source receiver are spaced 0.375MHz apart in the frequency band of 222.25 to 233.50MHz. Since the tuning range of the AN/ARC-552A victim receiver extends from 225.0 to 399.9MHz, the overlap region (FMIN=222.25MHz and FMAX=233.5MHz) covers the entire first LO range of the source.

4.2.2 Sampling the Overlap Region

When the overlap region has been defined, the code samples it according to the sample size. In essence, the sample size dictates how many frequency samples, F(I), will be considered in the overlap region for every interaction. The user sets the sample size (SAMPLE) before entering the 'Test' option.

When the sample size is set to one, the overlap region defined by FMIN and FMAX is sampled as follows:

$$F(1)=10^{\left(\left(\frac{(\log_{10}FMAX-\log_{10}FMIN)}{2}\right)+\log_{10}FMIN\right)} \quad \textbf{(4.5)}$$

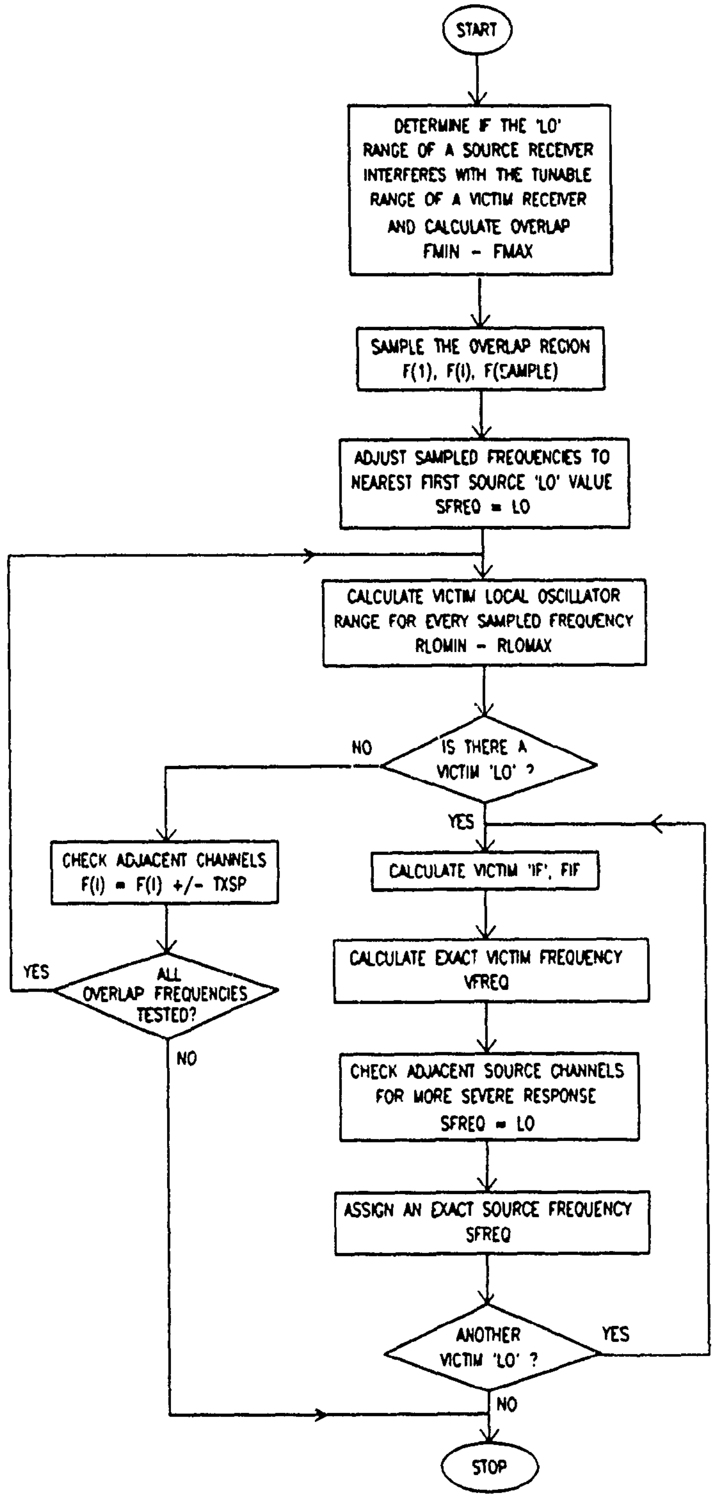

Figure 4.4 Flowchart for Local Oscillator Interference

When the sample size is set to two, the overlap region defined by FMIN and FMAX is sampled as follows:

$$F(1) = 10^{(((\log_{10}FMAX - \log_{10}FMIN) * 0.1) + \log_{10}FMIN)} \quad (4.6)$$

and

$$F(2) = 10^{(((\log_{10}FMAX - \log_{10}FMIN) * 0.9) + \log_{10}FMIN)} \quad (4.7)$$

Finally, when the sample size is set to three or greater, the overlap region defined by FMIN and FMAX is sampled as follows:

$$F(1) = 10^{(((\log_{10}FMAX - \log_{10}FMIN) * 0.1) + \log_{10}FMIN)} \quad (4.8)$$

$$F(SAMPLE) = 10^{(((\log_{10}FMAX - \log_{10}FMIN) * 0.9) + \log_{10}FMIN)} \quad (4.9)$$

and

$$F(I) = 10^{(((\log_{10}F(SAMPLE) - \log_{10}F(1)) * \frac{(I-1)}{(SAMPLE-1)}) + \log_{10}F(1))} \quad (4.10)$$

where $2 \leq I \leq SAMPLE-1$.

Note that sampling is performed on a logarithmic scale in order to generate test frequencies that span the entire frequency range of the overlap region. A linear sampling scale, on the other hand, would favour higher frequencies. The sampling equations have not been modified in Version 5.0 and correspond to the third block in Figures 4.1 and 4.2, and to the second block in Figures 4.3 and 4.4.

4.2.3 Assigning Victim/Source Channels

At this stage, the objective is to assign a source and a corresponding victim channel to every frequency sample, F(I). The code determines the source channels, SFREQ, by adjusting each frequency sample to the nearest channel of the offending system. The assignment of a corresponding victim channel, VFREQ, involves the selection of a suitable victim LO setting which will translate the source channel to the IF band of the victim system, and then adding or subtracting the IF from the LO (depending on the sign of the receiver) to determine the victim channel of the receiver.

It appears that the process of selecting a suitable victim channel can be simplified by adjusting the frequency sample to the nearest receiver channel, and therefore, the corresponding victim LO setting and IF value, which define a channel, would be redundant. If a source channel correlates exactly to a victim channel, this would be true. However, if a source channel does not correlate exactly to its corresponding victim channel, it is necessary to search for a victim LO setting which will convert the source frequency to the IF band of the victim receiver. That is, the IF band and the LO settings provide the means for testing whether two systems interact, to within a certain tolerance. The following example illustrates the argument.

Example 4.5

Consider the AN/ARC-552A victim receiver and the AN/ARC-505A source transmitter from Example 4.2. The 17^{th} harmonics of the source extend from 34.000 to 509.983MHz. Therefore, potential interference exists in the overlap region which covers the entire operating band of the victim (FMIN=225.0MHz and FMAX=399.9MHz).

If the code randomly selects the source channel as SFREQ=17.649MHz, the most suitable victim frequency would be VFREQ=300.033MHz (= 17 * 17.649MHz) or VFREQ=300.0MHz, rounded to the nearest channel of the victim system. In fact, all six channels in the frequency band of 17.645 to 17.650MHz can be considered candidates for harmonic interference, since they all have their 17^{th} harmonics rounding to VFREQ=300.0MHz. Therefore, the code must test every candidate to determine which one will provide the most severe response.

At first it appears that SFREQ=17.647MHz would provide the most severe response because this has the closest 17^{th} harmonic to 300.0MHz (299.999MHz). However, only SFREQ=17.648MHz maximizes interference for the selected victim frequency. This is because when VFREQ=300.0MHz the LO is working at 280MHz. As such, 299.999MHz, after interacting with the LO operating at 280MHz, will be converted just outside the victim IF band. However, SFREQ=17.648MHz, which is the next closest candidate, will be converted to the IF band.

4.2.3.1 The Source Channel

The code determines the source channel, SFREQ, for Rx/Tx interference by employing:

$$SFREQ=FTMIN+integer\left(\frac{(F(I)-L*FTMIN)}{(L*TXSP)}+0.5\right)*TXSP \quad \textbf{(4.11)}$$

where F(I) is the sampled frequency

TXSP is the channel spacing of the offending transmitter

FTMIN is the minimum operating channel of the offending transmitter

L is the harmonic order of the offending channel (L=1 for image and IF interference).

In essence, Eq. (4.11) adjusts the frequency sample to the nearest operating channel of the offending system. The lowest operating frequency corresponds to the first channel of the system under test, and subsequent channels are determined by incrementing the first channel, FTMIN, by the channel spacing, TXSP.

If the channel spacing of the offending system is zero, the code rounds the frequency sample according to the dial setting, TXDIAL, of the transmitter as follows:

$$SFREQ=TXDIAL*integer\left(\frac{F(I)}{L*TXDIAL}+0.5\right) \tag{4.12}$$

However, Version 4.2 does not round the sampled frequencies to actual system channels. Instead, it employs Eq. (4.12) regardless of the channel spacing, TXSP. This approach does not necessarily yield frequencies that correspond to actual channels of the equipment under test.

When testing for LO interference between two receivers, the frequency samples, F(I), correspond to first LO settings of the source receiver. As such, the frequency samples are rounded to an actual LO setting of the offending receiver. That is, instead of using Eqs. (4.11) and (4.12), the code employs:

$$LOs=FLOMIN+integer\left(\frac{F(I)-FLOMIN}{FLOSP}+0.5\right)*FLOSP \tag{4.13}$$

where LOs is the source LO setting of the offending receiver

FLOSP is the LO spacing of the offending receiver

FLOMIN is the minimum LO setting of the offending receiver.

Although the code uses LOs as the source frequency in performing the remainder of the calculations, before terminating the calculations for a particular interaction, the code will assign a source frequency to LOs which corresponds to a tunable channel of the offending receiver.

For fixed-IF receivers, there is a one-to-one correspondence between the LO settings and the tunable channels. That is, every LO setting corresponds to a specific tunable channel of the system under test, and vice versa. The same does not hold true, however, for variable-IF receivers. That is, several channels can have the same LO setting. As such, there is a dilemma regarding which channel should be selected as the source. In order to alleviate the problem, the code selects the source channel that corresponds to the centre frequency of the IF bandwidth. Hence, when testing for LO interference, the source frequencies are determined by:

$$SFREQ = LOs + (-1)^{SIGNs} * FIFs \qquad \textbf{(4.14)}$$

where SIGNs is the sign of the offending receiver

FIFs is the IF of the offending channel
(If W=1Hz then FIFs=V, else FIFs=abs[0.5[V+W]]).*

The source frequencies are then rounded to a channel of the offending system according to Eq. (4.25), if the channel spacing of the source receiver is other than zero, or Eq. (4.26), if the channel spacing is equal to zero (with *VFREQ* and *victim* being replaced by *SFREQ* and *source*, respectively).

Version 4.2 handles LO interference separately from the other modes of interference. When testing for LO interference, Version 4.2 does not round the sampled frequencies to actual LO settings. Instead, the code samples the overlap region and assigns each frequency sample as a victim frequency without any adjustments. The code then proceeds to assign the source channel according to Eq. (4.14) where LOs corresponds to the sampled frequency and FIFs is set to the average IF value of the offending receiver. It is obvious that this approach will not yield source/victim frequency combinations that correspond to actual channels of the equipment under test.

4.2.3.2 The Victim LO Range

Once the source channel has been determined, the code searches for a victim LO setting and a corresponding IF value, from which the victim channel can be determined. A local oscillator setting, FLOv, is defined as a victim if it converts the source frequency to the IF band of the victim receiver (harmonics of FLOv are considered only for image interference).

In general, when the IF bandwidth is greater than the LO spacing, there can be more than one victim LO setting. The code tests every victim LO candidate and selects the one which, along with its corresponding victim IF, yields a victim/source frequency pair that will provide the most severe response.

If the code does not determine a victim LO setting within the victim LO range, it considers side channels of the source transmitter and resumes the search for a victim LO setting for the new source channel. If all the side channels that fall within the overlap region have been tested without any success, the code aborts the calculations for that frequency sample and resumes the algorithm with a new frequency sample or, if all the frequency samples have been tested, with a new interaction. However, if the code determines a victim LO setting, it proceeds to calculate its corresponding victim IF.

The challenge is to determine the victim LO range without having to step through the entire first LO range and testing every LO setting individually. For systems with a low channel spacing and a high operating range, an interaction may require millions of iterations if every LO setting is tested. This is essentially the reason for the slow response of Version 4.2. That is, the code starts with the minimum LO setting and steps through the LO range in order to determine a victim LO setting. In version 4.2, a victim LO setting is determined when the source frequency, SFREQ, falls within the region FA and FB, defined as follows:

$$FA = abs\left(\frac{P*FLOv+(-1)^{SIGN}*FIFMIN}{Q*L}\right) \qquad \textbf{(4.15)}$$

and

$$FB=abs\left(\frac{P*FLOv+(-1)^{SIGN}*FIFMAX}{Q*L}\right) \quad \textbf{(4.16)}$$

where FLOv is an LO setting of the receiver

L is the harmonic order of the source (L=1 for image and IF interference)

P and Q define the image order of a receiver (P=Q=1 for harmonic and IF interference).

The region defined above, essentially corresponds to an image region of the receiver when L=1 and P≠1 and/or Q≠1, and to a fundamental channel of the receiver when L=P=Q=1. The code starts with the minimum LO setting, FLOv=FLOMIN, and increments the local oscillator by the LO stepping, FLOSP, until the source frequency falls within the region defined by FA and FB. Note, however, that the sign of the image region in Eqs. (4.15) and (4.16) corresponds to the sign of the receiver, SIGN, regardless of the sign of the image region under test, S. This deficiency in Version 4.2 results in erroneous image combinations when the sign of the image under test is opposite to the sign of the receiver. Therefore, Eq. (4.15) and (4.16) are valid only for harmonic and IF interference.

Version 5.0 takes a different approach in determining the victim LO range. The victim LO range is calculated by the intersection of the entire first LO range of the victim receiver with Region1 and Region2, defined as follows:

$$REGION1: \min(RLOMIN1, RLOMAX1) \rightarrow \max(RLOMIN1, RLOMAX1) \quad (4.17)$$

where $RLOMIN1 = (\ L*Q*SFREQ - (-1)^S*FIFMIN\ )/P$

$RLOMAX1 = (\ L*Q*SFREQ - (-1)^S*FIFMAX\ )/P$

and

$$REGION2: \min(RLOMIN2, RLOMAX2) \rightarrow \max(RLOMIN2, RLOMAX2) \quad (4.18)$$

where $RLOMIN2 = (\ -L*Q*SFREQ - (-1)^S*FIFMIN\ )/P$

$RLOMAX2 = (\ -L*Q*SFREQ - (-1)^S*FIFMAX\ )/P$

and

L is the harmonic order of the source
(L=1 for LO and image interference)

P, Q define the image order of a receiver
(P=Q=1 for LO and harmonic interference)

SFREQ is the source channel.

It should be noted that while both parameters, L and Q, represent harmonic multipliers of the source frequency, their origin varies. The harmonic multiplier L is assumed to originate from the non-linearities at the transmitter's RF stage while the harmonic multiplier Q is assumed to originate from the non-linearities at the receiver's RF stage. Both variables, however, are identical when exercising the response formulas.

In general, only one of the two regions will intersect the first LO region of the victim receiver. However, if the LO range extends from below the first IF band to above the first IF band (albeit, poor design), the victim LO region may not be contiguous.

When testing for IF interference, the overlap frequencies correspond to IF frequencies of the victim system. Hence, the victim LO range comprises the entire first LO range. The code, however, selects the first LO setting as the victim and proceeds with the algorithm.

4.2.3.3 The Victim Intermediate Frequency

There are two victim IF frequencies that are required in the narrowband calculations; the calculated IF, FIFc, at which the source frequency, SFREQ, is converted to by the victim LO setting, FLOv, and the exact IF, FIFe, which corresponds to the IF value of the exact victim channel, VFREQ.

The former IF frequency is required to calculate the victim frequency, from which the exact IF can be determined after the victim frequency has been rounded to the nearest channel. The calculated IF is determined as follows.

For S=2, the code employs:

$$FIFc=Q*L*SFREQ-P*FLOv \tag{4.19}$$

and for S=1:

$$FIFc=P*FLOv-Q*L*SFREQ \tag{4.20}$$

or

$$FIFc=P*FLOv+Q*L*SFREQ \quad (4.21)$$

In essence, the previous expressions represent all the possible solutions to:

$$L*SFREQ=abs\left(\frac{P*FLOv+(-1)^{S}*FIFc}{Q}\right) \quad (4.22)$$

where SFREQ is the source frequency

FLOv is the victim LO setting

P, Q are the parameters in image interference (P=1 for LO and harmonic interference)

L is the harmonic order of the source channel, SFREQ (L=1 for LO and image interference).

When S=1, the code selects the IF value that falls within the IF band of the victim receiver. Furthermore, when the code tests for intermediate frequency interference, because the source frequencies correspond to victim IF values, this step is by-passed.

Version 4.2, however, does not exercise the same equations in determining the victim IF. Instead, the code employs:

$$FIFc=FIFMIN+abs(L*SFREQ-FA) \quad (4.23)$$

where FA is given by Eq. (4.15).

For fixed-IF receivers, Version 4.2 should assign the fixed IF value of the victim receiver as the victim IF instead of using Eq. (4.23). Furthermore, Eq. (4.23) is not always valid, i.e., Q>1.

4.2.3.4 The Victim Channel

Once the code has determined the victim LO setting, FLOv, and its corresponding calculated IF, FIFc, it determines the victim frequency, VFREQ, by employing:

$$VFREQ=abs(FLOv+(-1)^{SIGN}*FIFc) \quad \textbf{(4.24)}$$

where SIGN is the sign of the receiver.

The victim frequency is then assigned to a channel of the receiver under test as follows:

$$VFREQ=FRMIN+integer(\frac{VFREQ-FRMIN}{CHANSP}+0.5)*CHANSP \quad \textbf{(4.25)}$$

where VFREQ is the victim frequency/channel

CHANSP is the channel spacing of the victim receiver

FRMIN is the lowest tunable channel of the victim receiver

SIGN is the sign of the victim receiver.

However, if the channel spacing is set to zero, instead of using Eq. (4.25), the code will round the victim frequency according to the dial setting, RDIAL, as follows:

$$VFREQ = RDIAL * integer\left(\frac{VFREQ}{RDIAL} + 0.5\right) \qquad \textbf{(4.26)}$$

When testing for IF interference, there are, in general, many victim channels that can be assigned to a victim IF value. Specifically, there are as many victim channels as there are first LO settings, i.e.,

$$VFREQ = FLOMIN + N * FLOSP + (-1)^{SIGN} * FIFc \qquad \textbf{(4.27)}$$

where N is any integer that satisfies:

$$FLOMIN \leq FLOMIN + N * FLOSP \leq FLOMAX \qquad \textbf{(4.28)}$$

Hence, when testing for IF interference the code selects the minimum first LO setting, FLOMIN. With N set to zero, Eq. (4.27) yields:

$$VFREQ = FLOMIN + (-1)^{SIGN} * FIFc \qquad \textbf{(4.29)}$$

The victim frequency is then rounded to an actual channel by employing Eq. (4.25) (if CHANSP≠0) or Eq. (4.26) (if CHANSP=0).

However, Version 4.2 does not assign the victim frequency to a system channel. Instead, it employs Eq. (4.26) regardless of the channel spacing of the receiver, CHANSP. This approach does not necessarily yield frequencies that correspond to actual channels of the equipment under test.

4.2.4 Testing for a More Severe Response

Before terminating the calculations for a given interaction, the code tests adjacent source channels for a more severe response. This step ensures that the frequency combinations provided will maximize interference, since there can be many source channels that correspond to a given victim channel, and vice versa (see example 4.5).

The objective is to minimize the deviation between the exact IF, FIFe, which corresponds to the IF value of the victim channel, and the IF value, FIFc, at which the source frequency will be converted to. Therefore, the code minimizes:

$$DEVIATION=abs(FIFe-FIFc) \qquad \textbf{(4.30)}$$

In Eq. (4.30), FIFc is determined by Eq. (4.22) where SFREQ corresponds to an adjacent source channel, while FIFe is determined by the same equation with S=SIGN, L=P=Q=1, and *SFREQ* and *source* are replaced by *VFREQ* and *victim*, respectively.

When testing side channels, the code measures the deviation between the victim and the source at the IF stage of the receiver since only the frequencies which are converted to the IF band will be processed by the victim receiver.

Version 4.2, however, does not perform this step. Therefore, the frequency combinations provided do not necessarily maximize interference.

At this stage, the intricacies involved in performing source/victim assignments are apparent. The improved algorithm performs calculations more efficiently and accurately. This has resulted in at least a ten-fold reduction in the execution time required to generate the narrowband results, despite the fact that all narrowband variables have been declared as double precision. A complete listing of all the narrowband modules that have been modified along with the revised modular flowchart are included in the Appendix.

4.3 Narrowband Output and Comparisons

Version 4.2, does not accommodate for all the subtleties involved in performing source/victim assignments. This becomes immediately apparent by examining the narrowband results.

Figures 4.5a-d depict the narrowband results of Version 4.2 for the CH124 Sea King helicopter. These results

NARROW BAND TEST COMBINATIONS FOR CH124

VICTIM	FREQUENCY (MHZ)	VICTIM RESPONSE	SOURCE	FREQUENCY (MHZ)	SOURCE EMISSION	RESULT GROUND	RESULT AIR	ERROR #
AN/APC-552A			AN/ARC-505A					
	226.400	RF		28.306	8 RF			1
	238.400	RF		29.798	8 RF			1
	229.100	RF		25.459	9 RF			1
	265.000	RF		29.449	9 RF			1
	231.600	RF		23.156	10 RF			1
	291.400	RF		29.140	10 RF			-
	233.800	RF		21.252	11 RF			1
	317.500	RF		28.864	11 RF			-
	235.800	RF		19.652	12 RF			1
	343.400	RF		28.614	12 RF			1
	237.700	RF		18.286	13 RF			1
	369.000	RF		28.386	13 RF			1
	238.300	RF		17.023	14 RF			1
	377.600	RF		26.968	14 RF			1
	238.300	RF		15.888	15 RF			1
	377.600	RF		25.170	15 RF			1
	238.300	RF		14.895	16 RF			1
	377.600	RF		23.597	16 RF			1
	238.300	RF		14.019	17 RF			1
	377.600	RF		22.209	17 RF			1
	238.300	RF		13.240	18 RF			1
	377.600	RF		20.975	18 RF			1
	238.300	RF		12.543	19 RF			1
	377.500	RF		19.871	19 RF			1
	238.300	RF		11.916	20 RF			1
	377.600	RF		18.878	20 RF			1
	225.000	IF		24.950	1 RF			5
			AN/ARN-504-(V)					
	374.000	-IM3,1		1074.000	1 RF			4
	360.000	+IM3,1		1040.000	1 RF			-
	391.000	+IM3,1		1131.000	1 RF			-
	279.000	-IM4,1		1029.000	1 RF			4
	301.000	-IM4,1		1141.000	1 RF			4
	279.000	+IM4,1		1029.000	1 RF			-
	301.000	+IM4,1		1141.000	1 RF			-
AN/ARC-552A			AN/R-1047A/A					
	225.836	RF		165.836	1 LO			6
	232.636	RF		172.636	1 LO			6
AN/APX-77A			AN/ARC-552A					
	1030.000	RF		343.300	3 RF			2

Figure 4.5a Narrowband Output, Version 4.2

NARROW BAND TEST COMBINATIONS FOR CH124

VICTIM	FREQUENCY (MHZ)	VICTIM RESPONSE	SOURCE	FREQUENCY (MHZ)	SOURCE EMISSION	RESULT GROUND	RESULT AIR	ERROR #
AN/APX-77A			AN/ARC-552A					
	1030.000	RF		257.500	4 RF			-
	1030.000	-IM1,3		343.300	1 RF			2
	1030.000	+IM1,3		383.300	1 RF			2
	1030.000	-IM1,4		257.500	1 RF			-
	1030.000	+IM1,4		287.500	1 RF			-
			AN/APN-117					
	1030.000	-IM4,1		4300.000	1 RF			-
			AN/ARN-504-(V)					
	1030.000	RF		1030.000	1 RF			-
	1030.000	+IM1,1		1150.000	1 RF			-
	1030.000	-IM2,2		1060.000	1 RF			-
	1030.000	+IM2,2		1120.000	1 RF			-
AN/APX-77A			AN/ARN-504-(V)					
	1030.000	RF		967.000	1 LO			-
	1030.000	RF		967.000	1 LO			6,7
			AN/ARN-504-(V)					
	1030.000	RF		1093.000	1 LO			-
	1030.000	RF		1093.000	1 LO			6,7
AN/R-1047A/A			AN/ARC-552A					
	163.000	-IM2,1		386.000	1 RF			-
	169.000	-IM2,1		398.000	1 RF			-
	163.000	-IM3,2		304.500	1 RF			-
	172.000	-IM3,2		318.000	1 RF			-
AN/ARN-59(V)			AN/ARC-505A					
	0.991	-IM2,1		2.124	1 RF			-
	1.645	-IM2,1		3.432	1 RF			-
	1.000	+IM2,1		2.142	1 RF			4
	1.751	+IM2,1		3.643	1 RF			3,4
	0.643	-IM3,1		2.214	1 RF			-
	1.571	-IM3,1		4.996	1 RF			3
	0.647	+IM3,1		2.224	1 RF			3,4
	1.649	+IM3,1		5.230	1 RF			3,4
	1.283	-IM3,2		2.066	1 RF			3

Figure 4.5b Narrowband Output, Version 4.2 (cont'd)

NARROW BAND TEST COMBINATIONS FOR CH124

VICTIM	FREQUENCY (MHZ)	VICTIM RESPONSE	SOURCE	FREQUENCY (MHZ)	SOURCE EMISSION	RESULT GROUND	RESULT AIR	ERROR #
AN/ARN-59(V)			AN/ARC-505A					
	1.691	-IM3,2		2.678	1 RF			3
	1.289	+IM3,2		2.075	1 RF			3,4
	1.751	+IM3,2		2.768	1 RF			3,4
	0.464	-IM4,1		2.280	1 RF			3
	1.522	-IM4,1		6.515	1 RF			-
	0.466	+IM4,1		2.291	1 RF			4
	1.579	+IM4,1		6.743	1 RF			4
AN/APN-117			AN/ARN-504 (V)					
	4300.000	RF		1075.000	4 RF			-
	4300.000	-IM1,4		1075.000	1 RF			-
	4300.000	+IM1,4		1075.000	1 RF			-
AN/ARN-504-(V)			AN/ARC-552A					
	968.000	RF		322.700	3 RF			-
	1018.000	RF		339.200	3 RF			1
	968.000	RF		242.000	4 RF			-
	1018.000	RF		254.400	4 RF			-
	968.000	-IM1,3		322.700	1 RF			1
	1018.000	-IM1,3		339.200	1 RF			1
	968.000	-IM1,4		242.000	1 RF			-
	1018.000	-IM1,4		254.400	1 RF			-
AN/ARN-504-(V)			AN/ARC-552A					
	1156.000	RF		385.300	3 RF			-
	1195.000	RF		398.200	3 RF			1
	1157.000	RF		289.300	4 RF			-
	1207.000	RF		301.700	4 RF			-
	1157.000	RF		231.400	5 RF			-
	1207.000	RF		241.300	5 RF			1
	1153.000	+IM1,3		385.300	1 RF			1
	1192.000	+IM1,3		398.200	1 RF			1
	1154.000	+IM1,4		289.300	1 RF			1
	1204.000	+IM1,4		301.700	1 RF			1
AN/ARN-504-(V)			AN/ARC-552A					
	1031.000	RF		343.700	3 RF			-
	1081.000	RF		360.200	3 RF			1
	1031.000	RF		257.800	4 RF			-
	1081.000	RF		270.200	4 RF			-
	1031.000	-IM1,3		343.700	1 RF			-
	1081.000	-IM1,3		360.200	1 RF			1

Figure 4.5c Narrowband Output, Version 4.2 (cont'd)

NARROW BAND TEST COMBINATIONS FOR CH124

VICTIM	FREQUENCY (MHZ)	VICTIM RESPONSE	SOURCE	FREQUENCY (MHZ)	SOURCE EMISSION	RESULT GROUND	RESULT AIR	ERROR #
AN/ARN-504-(V)			AN/ARC-552A					
	1031.000	-IM1,4		257.800	1 RF			-
	1081.000	-IM1,4		270.200	1 RF			-
			AN/APX-77A					
	1060.000	-IM2,2		1090.000	1 RF			1
			AN/APN-117					
	1027.000	-IM4,1		4300.000	1 RF			-
AN/ARN-504-(V)			AN/ARC-552A					
	1094.000	RF		364.700	3 RF			-
	1144.000	RF		381.200	3 RF			1
	1094.000	RF		273.500	4 RF			-
	1144.000	RF		285.900	4 RF			1
	1128.000	RF		225.500	5 RF			1
	1148.000	RF		229.500	5 RF			1
	1091.000	+IM1,3		364.700	1 RF			1
	1141.000	+IM1,3		381.200	1 RF			1
	1091.000	+IM1,4		273.500	1 RF			1
	1141.000	+IM1,4		285.900	1 RF			1
			AN/APX-77A					
	1090.000	RF		1090.000	1 RF			-
	1120.000	+IM2,2		1090.000	1 RF			1
			AN/APN-117					
	1123.000	+IM4,1		4300.000	1 RF			1
AN/ARN-504-(V)			AN/APX-77A					
	1090.000	RF		1030.000	1 LO			-

Figure 4.5d Narrowband Output, Version 4.2 (cont'd)

are from the EMC database presented in Chapter 3, with the sample size set to two and the maximum image order set to five, that is, $2 \geq (P+Q=\text{image order}) \geq 5$. Version 4.2 generates a total of 116 frequency combinations, 69 of which are in error. An additional column has been added to the right of Figures 4.5a-d with an appropriate error number in each cell which refers the reader to a specific error category defined below. Cells which have a dash instead of an error number correspond to frequency combinations that are correct.

Error #1: Frequency Pair Does Not Maximize Interference

In general, there can be many source channels that will interfere with the same victim channel, and vice versa. However, the code should select the frequency pair that provides the most severe response. This type of error occurs because Version 4.2 does not test side channels of the source for a more severe response before terminating the computations for an interaction. The following example, taken from Figure 4.5a, illustrates the problem.

Example 5.1:

Victim Name: AN/ARC-552A	Source Name: AN/ARC-505A
Source Channel: 226.4MHz	Source Channel: 28.306MHz
Source Response: RF	Source Emission: 8 RF

Possible Source Channels: 28.294MHz $\rightarrow$ 28.306MHz
Most Severe Response: 28.300MHz

The channels of the AN/ARC-505A, in the frequency band extending from 28.294 to 28.306MHz, have their 8^{th} harmonics rounding to 226.4MHz. Therefore, when the AN/ARC-552A is tuned to 226.4MHz all of the 13 channels in that frequency band can be considered as potential sources of EMI. However, it is apparent that in order to maximize interference the code should select 28.300MHz as the source channel because this has the closest 8^{th} harmonic to 226.4MHz.

Error #2: Source/Victim Interaction Not Possible

When testing for interference between two systems, the code should consider only the source candidates that are converted to the IF band of the victim system since only these frequencies will be processed by the receiver. The following example, taken from Figure 4.5a, illustrates the problem.

Example 5.2:

Victim Name: AN/APX-77A	Source Name: AN/ARC-552A
Victim Channel: 1030MHz	Source Channel: 343.3MHz
Victim Response: RF	Source Emission: 3 RF

The 3^{rd} harmonic of 343.3MHz is at 1029.9MHz. Since the LO of the AN/APX-77A operates at 1090MHz it converts 1029.9MHz to 60.1MHz (1090MHz - 1029.9MHz = 60.1MHz). The IF band of the AN/APX-77A is fixed at 60.0MHz (see Figure 3.3) and, therefore, the two channels will not interfere.

Error #3 Frequencies Do Not Correspond To System Channels

In general, when the channel spacing is different from the dial setting, Version 4.2 generates frequency combinations which do not correspond to actual channels of the equipment under test. All frequency combinations should correspond to system channels and should be displayed to their correct decimal places as dictated by the dial setting. In fact, the user should be allowed to set the channel spacing to any value greater than the dial setting in order to accommodate for programable (pre-set) systems having a constant channel spacing. The following example, taken from Figure 4.5b, illustrates the problem.

Example 5.3:

Victim Name: AN/ARN-59(V)
Victim Channel: 1.571MHz
Victim Response: -IM3,1
Dial Setting: 1KHz
Channel Spacing: 3KHz

Source Name: AN/ARC-505A
Source Channel: 4.996MHz
Source Emission: 1 RF
Dial Setting: 1KHz
Channel Spacing: 1KHz

Correct Victim Channel: 1.570MHz
Correct Source Channel: 4.995MHz

or

Correct Victim Channel: 1.573MHz
Correct Source Channel: 5.004MHz

The AN/ARN-59(V) has a channel spacing of 3KHz starting at 0.190MHz. Hence, the assigned victim frequency does not correspond to an actual channel of the AN/ARN-59(V). Furthermore, the assigned source/victim pair does not provide the most severe response. The correct channels should be 1.570MHz and 4.995MHz or, 1.573MHz and 5.004MHz for the AN/ARN-59(V) and the AN/ARC-505A, respectively. These frequencies, in addition to providing the most severe response, correspond to actual system channels.

Error #4: Wrong Image Region

Version 4.2 does not properly account for the image region when S is stated opposite to the sign of the receiver, S≠SIGN. Although the coincidence is displayed as "$(-1)^{S \neq SIGN}$ IM P,Q", the code erroneously performs the calculations for "$(-1)^{S=SIGN}$ IM P,Q". The following example, taken from Figure 4.5b, illustrates the problem.

Example 5.4:

Victim Name: AN/ARN-59(V)
Victim Channel: 1.000MHz
Victim Response: +IM2,1

Source Name: AN/ARC-505A
Source Channel: 2.142MHz
Source Emission: 1 RF

For +IM2,1: Correct Victim Channel: 1.000MHz
Correct Source Channel: 2.427MHz or 2.428MHz

For -IM2,1: Correct Victim Channel: 1.000MHz
Correct Source Channel: 2.142MHz or 2.143MHz

The sign of the AN/ARN-59(V) is negative (S=1), that is the IF is subtracted from the LO to determine a system channel. Although the interaction is stated as +IM2,1, the code erroneously attempts to determine the image interaction that corresponds to the sign of the receiver (-IM2,1).

Error #5: Primitive Intermediate Frequency Algorithm

When testing for IF interference, Version 4.2 assigns the victim IF as the centre of the IF band regardless of whether the victim receiver has a fixed or variable IF. Therefore, although the sample size is set to two, the code only identifies one (incorrect) interaction.

Error #6: Primitive Local Oscillator Algorithm

When testing for LO interference, Version 4.2 employs a primitive algorithm. The source frequencies identified almost never correspond to actual system channels.

Error #7: Redundant Interaction

Version 4.2 occasionally repeats interactions when the sample size is greater than or equal to two. Although the code checks if two consecutive interactions are identical it fails to detect certain interactions because it does not account for numerical errors.

In addition to the above errors, Version 4.2 fails to detect every interaction. This is supported by the fact that Version 5.0 generates 162 frequency combinations for the same aircraft, all of which are correct. Figures 4.6a-f depict the narrowband results of Version 5.0. Note that every frequency in Figures 4.6a-f corresponds to an actual system channel and is displayed according to the tuning accuracy of its corresponding system. Furthermore, every frequency coincidence pair provides the most severe response. Minor modifications in the display of the narrowband results have also been implemented. The revised algorithm can now display frequencies below the VLF (Very Low Frequency) range (see AN/APN-117 vs POWER SYS 400HZ in Figure 4.6c). Also, pagination has been added and the titles have been centred.

Finally, Figures 4.7a-c display the spectrum chart for the CH124 Sea King helicopter. Version 5.0 also includes a minor modification to the spectrum chart which corrects a deficiency that prevented the display of the LO range of receivers when the first LO setting was greater than the last LO setting, i.e., FLOMIN > FLOMAX (see Figure 4.7a).

NARROWBAND TEST COMBINATIONS FOR CH124 PAGE 1

VICTIM	FREQUENCY (MHZ)	VICTIM RESPONSE	SOURCE	FREQUENCY (MHZ)	SOURCE EMISSION	RESULT GROUND	RESULT AIR
AN/ARC-552A			AN/ARC-505A				
	226.4	RF		28.300	8 RF		
	238.4	RF		29.800	8 RF		
	229.1	RF		25.456	9 RF		
	265.0	RF		29.444	9 RF		
	231.6	RF		23.160	10 RF		
	291.4	RF		29.140	10 RF		
	233.8	RF		21.255	11 RF		
	317.5	RF		28.864	11 RF		
	235.8	RF		19.650	12 RF		
	343.4	RF		28.617	12 RF		
	237.7	RF		18.285	13 RF		
	369.0	RF		28.385	13 RF		
	238.3	RF		17.021	14 RF		
	377.6	RF		26.971	14 RF		
	238.3	RF		15.887	15 RF		
	377.6	RF		25.173	15 RF		
	238.3	RF		14.894	16 RF		
	377.6	RF		23.600	16 RF		
	238.3	RF		14.018	17 RF		
	377.6	RF		22.212	17 RF		
	238.3	RF		13.239	18 RF		
	377.6	RF		20.978	18 RF		
	238.3	RF		12.542	19 RF		
	377.5	RF		19.868	19 RF		
	238.3	RF		11.915	20 RF		
	377.6	RF		18.880	20 RF		
	230.8	IF		20.800	1 RF		
	228.7	IF		28.700	1 RF		
			AN/APX-77A				
	390.0	-IM 3, 1		1090	1 RF		
			AN/ARN-504-(V)				
	370.0	-IM 3, 1		1030	1 RF		
	397.0	-IM 3, 1		1083	1 RF		
	360.0	+IM 3, 1		1040	1 RF		
	390.0	+IM 3, 1		1130	1 RF		
	299.0	-IM 4, 1		1051	1 RF		
	313.0	-IM 4, 1		1137	1 RF		
	279.0	+IM 4, 1		1029	1 RF		
	300.0	+IM 4, 1		1140	1 RF		

Figure 4.6a Narrowband Output, Version 5.0

VICTIM	FREQUENCY (MHZ)	VICTIM RESPONSE	SOURCE	FREQUENCY (MHZ)	SOURCE EMISSION	RESULT GROUND	RESULT AIR
AN/ARC-557A			AN/R-1047A/A				
	226.0	RF		166.000	1 LO		
	232.8	RF		172.750	1 LO		
AN/APX-77A			AN/ARC-552A				
	1030	RF		257.5	4 RF		
	1030	-IM 1, 4		257.5	1 RF		
	1030	+IM 1, 4		287.5	1 RF		
			AN/APN-117				
	1030	-IM 4, 1		4300	1 RF		
			AN/ARN-504-(V)				
	1030	RF		1030	1 RF		
	1030	+IM 1, 1		1150	1 RF		
	1030	-IM 2, 2		1060	1 RF		
	1030	+IM 2, 2		1120	1 RF		
			AN/ARN-504-(V)				
	1030	RF		967	1 LO		
			AN/ARN-504-(V)				
	1030	RF		1093	1 LO		
AN/R-1047A/A			AN/ARC-552A				
	163.000	+IM 1, 1		283.0	1 RF		
	172.000	+IM 1, 1		292.0	1 RF		
	163.000	-IM 2, 1		386.0	1 RF		
	169.000	-IM 2, 1		398.0	1 RF		
	163.000	+IM 2, 2		253.0	1 RF		
	172.000	+IM 2, 2		262.0	1 RF		
	163.000	-IM 3, 2		304.5	1 RF		
	172.000	-IM 3, 2		318.0	1 RF		
	163.000	+IM 3, 2		364.5	1 RF		
	172.000	+IM 3, 2		378.0	1 RF		
			AN/ARC-505A				
	164.500	RF		23.500	7 RF		

Figure 4.6b Narrowband Output, Version 5.0 (cont'd)

VICTIM	FREQUENCY (MHZ)	VICTIM RESPONSE	SOURCE	FREQUENCY (MHZ)	SOURCE EMISSION	RESULT GROUND	RESULT AIR
AN/R-1047A/A			AN/ARC-505A				
	172.375	RF		24.625	7 RF		
	163.000	RF		20.375	8 RF		
	172.000	RF		21.500	8 RF		
	163.000	RF		16.300	10 RF		
	172.000	RF		17.200	10 RF		
	162.250	RF		14.750	11 RF		
	170.500	RF		15.500	11 RF		
	164.125	RF		12.625	13 RF		
	169.000	RF		13.000	13 RF		
	164.500	RF		11.750	14 RF		
	169.750	RF		12.125	14 RF		
	166.000	RF		10.375	16 RF		
	172.000	RF		10.750	16 RF		
	167.875	RF		9.875	17 RF		
	168.625	RF		8.875	19 RF		
	163.000	RF		8.150	20 RF		
	172.000	RF		8.600	20 RF		
AN/ARN-59(V)			AN/ARC-505A				
	1.720	+IM 1, 1		2.005	1 RF		
	1.747	+IM 1, 1		2.032	1 RF		
	0.991	-IM 2, 1		2.125	1 RF		
	1.645	-IM 2, 1		3.433	1 RF		
	0.856	+IM 2, 1		2.139	1 RF		
	1.621	+IM 2, 1		3.669	1 RF		
	0.643	-IM 3, 1		2.214	1 RF		
	1.573	-IM 3, 1		5.004	1 RF		
	0.553	+IM 3, 1		2.229	1 RF		
	1.555	+IM 3, 1		5.235	1 RF		
	1.282	-IM 3, 2		2.066	1 RF		
	1.693	-IM 3, 2		2.682	1 RF		
	1.195	+IM 3, 2		2.077	1 RF		
	1.681	+IM 3, 2		2.806	1 RF		
	0.463	-IM 4, 1		2.280	1 RF		
	1.522	-IM 4, 1		6.516	1 RF		
	0.394	+IM 4, 1		2.288	1 RF		
	1.507	+IM 4, 1		6.740	1 RF		
AN/APN-117	4300	IF	POWER SYS 400Hz	0.38 KHz	1 RF		
	4300	RF	AN/ARN-504-(V)	1075	4 RF		

Figure 4.6c Narrowband Output, Version 5.0 (cont'd)

VICTIM	FREQUENCY (MHZ)	VICTIM RESPONSE	SOURCE	FREQUENCY (MHZ)	SOURCE EMISSION	RESULT GROUND	RESULT AIR
AN/APN-117			AN/ARN-504-(V)				
	4300	-IM 1, 4		1075	1 RF		
	4300	+IM 1, 4		1075	1 RF		
AN/ARN-504-(V)			AN/ARC-552A				
	966	RF		322.0	3 RF		
	1017	RF		339.0	3 RF		
	966	RF		241.5	4 RF		
	1016	RF		254.0	4 RF		
	966	-IM 1, 3		322.0	1 RF		
	1020	-IM 1, 3		340.0	1 RF		
	966	+IM 1, 3		364.0	1 RF		
	1020	+IM 1, 3		382.0	1 RF		
	964	-IM 1, 4		241.0	1 RF		
	1018	-IM 1, 4		254.5	1 RF		
	964	+IM 1, 4		272.5	1 RF		
	1018	+IM 1, 4		286.0	1 RF		
			AN/APX-77A				
	964	+IM 1, 1		1090	1 RF		
	995	+IM 2, 2		1090	1 RF		
			AN/APN-117				
	996	+IM 4, 1		4300	1 RF		
AN/ARN-504-(V)			AN/ARC-552A				
	1155	RF		385.0	3 RF		
	1194	RF		398.0	3 RF		
	1156	RF		289.0	4 RF		
	1206	RF		301.5	4 RF		
	1155	RF		231.0	5 RF		
	1204	RF		240.8	5 RF		
	1155	-IM 1, 3		343.0	1 RF		
	1209	-IM 1, 3		361.0	1 RF		
	1152	+IM 1, 3		384.0	1 RF		
	1194	+IM 1, 3		398.0	1 RF		
	1154	-IM 1, 4		257.0	1 RF		
	1208	-IM 1, 4		270.5	1 RF		
	1154	+IM 1, 4		288.5	1 RF		
	1208	+IM 1, 4		302.0	1 RF		

Figure 4.6d Narrowband Output, Version 5.0 (cont'd)

VICTIM	FREQUENCY (MHZ)	VICTIM RESPONSE	SOURCE	FREQUENCY (MHZ)	SOURCE EMISSION	RESULT GROUND	RESULT AIR
AN/ARN-504-(V)	1184	-IM 2, 2	AN/APX-77A	1090	1 RF		
	1154	-IM 4, 1	AN/APN-117	4300	1 RF		
AN/ARN-504-(V)			AN/ARC-552A				
	1029	RF		343.0	3 RF		
	1080	RF		360.0	3 RF		
	1030	RF		257.5	4 RF		
	1080	RF		270.0	4 RF		
	1029	-IM 1, 3		343.0	1 RF		
	1083	-IM 1, 3		361.0	1 RF		
	1026	+IM 1, 3		384.0	1 RF		
	1068	+IM 1, 3		398.0	1 RF		
	1028	-IM 1. 4		257.0	1 RF		
	1082	-IM 1, 4		270.5	1 RF		
	1028	+IM 1, 4		288.5	1 RF		
	1082	+IM 1, 4		302.0	1 RF		
	1058	-IM 2, 2	AN/APX-77A	1090	1 RF		
	1028	-IM 4, 1	AN/APN-117	4300	1 RF		
AN/ARN-504-(V)			AN/ARC-552A				
	1092	RF		364.0	3 RF		
	1143	RF		381.0	3 RF		
	1092	RF		273.0	4 RF		
	1142	RF		285.5	4 RF		
	1125	RF		225.0	5 RF		
	1145	RF		229.0	5 RF		
	1092	-IM 1, 3		322.0	1 RF		
	1146	-IM 1, 3		340.0	1 RF		
	1092	+IM 1, 3		364.0	1 RF		
	1146	+IM 1, 3		382.0	1 RF		
	1090	-IM 1, 4		241.0	1 RF		
	1144	-IM 1, 4		254.5	1 RF		

Figure 4.6e Narrowband Output, Version 5.0 (cont'd)

NARROWBAND TEST COMBINATIONS FOR CH124 PAGE 6

VICTIM	FREQUENCY (MHZ)	VICTIM RESPONSE	SOURCE	FREQUENCY (MHZ)	SOURCE EMISSION	RESULT GROUND	RESULT AIR
AN/ARN-504-(V)	1090 1144	+IM 1, 4 +IM 1, 4	AN/ARC-552A	272.5 286.0	1 RF 1 RF		
	1090 1121	RF +IM 2, 2	AN/APX-77A	1090 1090	1 RF 1 RF		
	1122	+IM 4, 1	AN/APN-117	4300	1 RF		
	1090	RF	AN/APX-77A	1030	1 LO		

Figure 4.6f Narrowband Output, Version 5.0 (cont'd)

NARROWBAND FREQUENCY SPECTRUM CHART FOR CH124

AN/ARC-552A		
TUNED FREQUENCY (REC)	225.000 -	399.900 MHZ
TUNED FREQUENCY (TX)	225.000 -	399.900 MHZ
HARMONIC 2	450.000 -	799.800 MHZ
HARMONIC 3	675.000 -	1199.700 MHZ
HARMONIC 4	900.000 -	1599.600 MHZ
HARMONIC 5	1125.000 -	1999.500 MHZ
HARMONIC 6	1350.000 -	2399.400 MHZ
INTERMED FREQUENCY	20.000 -	29.900 MHZ
LOCAL OSCILLATOR	200.000 -	370.000 MHZ
AN/ARC-505A		
TUNED FREQUENCY (REC)	2.000 -	29.999 MHZ
TUNED FREQUENCY (TX)	2.000 -	29.990 MHZ
HARMONIC 2	4.000 -	59.980 MHZ
HARMONIC 3	6.000 -	89.970 MHZ
HARMONIC 4	8.000 -	119.960 MHZ
HARMONIC 5	10.000 -	149.950 MHZ
HARMONIC 6	12.000 -	179.940 MHZ
HARMONIC 7	14.000 -	209.930 MHZ
HARMONIC 8	16.000 -	239.920 MHZ
HARMONIC 9	18.000 -	269.910 MHZ
HARMONIC 10	20.000 -	299.900 MHZ
HARMONIC 11	22.000 -	329.890 MHZ
HARMONIC 12	24.000 -	359.880 MHZ
HARMONIC 13	26.000 -	389.870 MHZ
HARMONIC 14	28.000 -	419.860 MHZ
HARMONIC 15	30.000 -	449.850 MHZ
HARMONIC 16	32.000 -	479.840 MHZ
HARMONIC 17	34.000 -	509.830 MHZ
HARMONIC 18	36.000 -	539.820 MHZ
HARMONIC 19	38.000 -	569.810 MHZ
HARMONIC 20	40.000 -	599.800 MHZ
INTERMED FREQUENCY	14.500 -	15.499 MHZ
	2.001 -	3.000 MHZ
LOCAL OSCILLATOR	12.500 -	8.500 MHZ
	10.000 -	32.000 MHZ

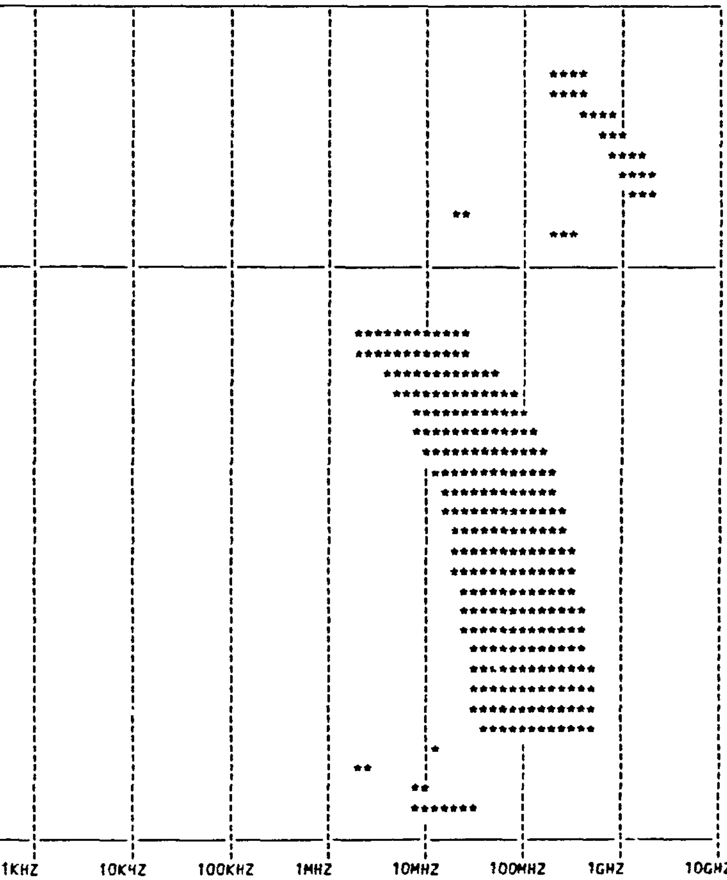

Figure 4.7a Narrowband Spectrum Chart, Version 5.0

NARROWBAND FREQUENCY SPECTRUM CHART FOR CH124

AN/APX-77A		
TUNED FREQUENCY (REC)	1030.000 -	1030.000 MHZ
TUNED FREQUENCY (TX)	1090.000 -	1090.000 MHZ
HARMONIC 2	2180.000 -	2180.000 MHZ
HARMONIC 3	3270.000 -	3270.000 MHZ
HARMONIC 4	4360.000 -	4360.000 MHZ
HARMONIC 5	5450.000 -	5450.000 MHZ
HARMONIC 6	6540.000 -	6540.000 MHZ
INTERMED FREQUENCY	60.000 -	60.000 MHZ
LOCAL OSCILLATOR	1090.000 -	1090.000 MHZ
AN/APS-503		
TUNED FREQUENCY (REC)	9375.000 -	9375.000 MHZ
TUNED FREQUENCY (TX)	9375.000 -	9375.000 MHZ
HARMONIC 2	10000.000 -	10000.000 MHZ
HARMONIC 3	10000.000 -	10000.000 MHZ
HARMONIC 4	10000.000 -	10000.000 MHZ
HARMONIC 5	10000.000 -	10000.000 MHZ
HARMONIC 6	10000.000 -	10000.000 MHZ
INTERMED FREQUENCY	58.000 -	62.000 MHZ
LOCAL OSCILLATOR	9315.000 -	9315.000 MHZ
AN/R-1047A/A		
TUNED FREQUENCY (REC)	162.250 -	173.500 MHZ
INTERMED FREQUENCY	60.000 -	60.000 MHZ
LOCAL OSCILLATOR	222.250 -	233.500 MHZ
POWER SYS 400Hz		
TUNED FREQUENCY (TX)	0.001 -	0.001 MHZ
HARMONIC 2	0.001 -	0.001 MHZ
HARMONIC 3	0.001 -	0.001 MHZ
HARMONIC 4	0.002 -	0.002 MHZ
HARMONIC 5	0.002 -	0.002 MHZ
HARMONIC 6	0.002 -	0.003 MHZ

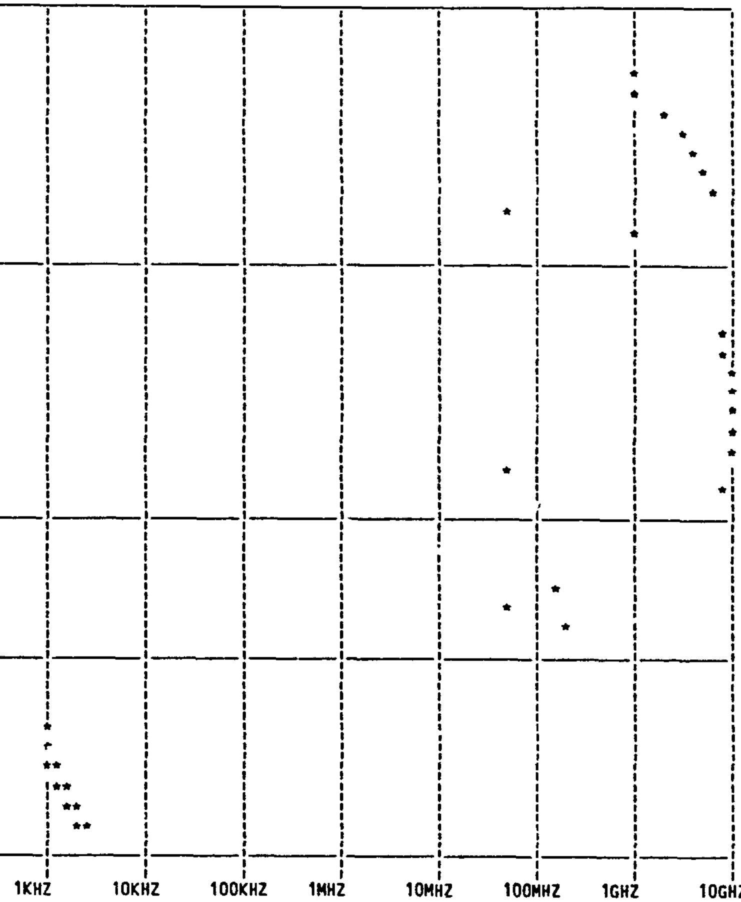

Figure 4.7b Narrowband Spectrum Chart, Version 5.0 (cont'd)

NARROWBAND FREQUENCY SPECTRUM CHART FOR CH124

AN/ARN-59(V)		
TUNED FREQUE (REC)	0.190 -	1.750 MHZ
INTERMED FREQUENCY	0.141 -	0.144 MHZ
LOCAL OSCILLATOR	0.332 -	1.892 MHZ
AN/APN-117		
TUNED FREQUENCY (REC)	4300.000 -	4300.000 MHZ
TUNED FREQUENCY (TX)	4300.000 -	4300.000 MHZ
HARMONIC 2	8600.000 -	8600.000 MHZ
HARMONIC 3	10000.000 -	10000.000 MHZ
HARMONIC 4	10000.000 -	10000.000 MHZ
HARMONIC 5	10000.000 -	10000.000 MHZ
HARMONIC 6	10000.000 -	10000.000 MHZ
INTERMED FREQUENCY	0.000 -	0.006 MHZ
LOCAL OSCILLATOR	4300.000 -	4300.000 MHZ
AN/ARN-504-(V)		
TUNED FREQUENCY (REC)	962.000 -	1213.000 MHZ
TUNED FREQUENCY (TX)	1025.000 -	1150.000 MHZ
HARMONIC 2	2050.000 -	2300.000 MHZ
HARMONIC 3	3075.000 -	3450.000 MHZ
HARMONIC 4	4100.000 -	4600.000 MHZ
HARMONIC 5	5125.000 -	5750.000 MHZ
HARMONIC 6	6150.000 -	6900.000 MHZ
INTERMED FREQUENCY	60.500 -	65.500 MHZ
	60.500 -	65.500 MHZ
	60.500 -	65.500 MHZ
	60.500 -	65.500 MHZ
LOCAL OSCILLATOR	1025.000 -	1087.000 MHZ
	1088.000 -	1150.000 MHZ
	1088.000 -	1150.000 MHZ
	1025.000 -	1087.000 MHZ

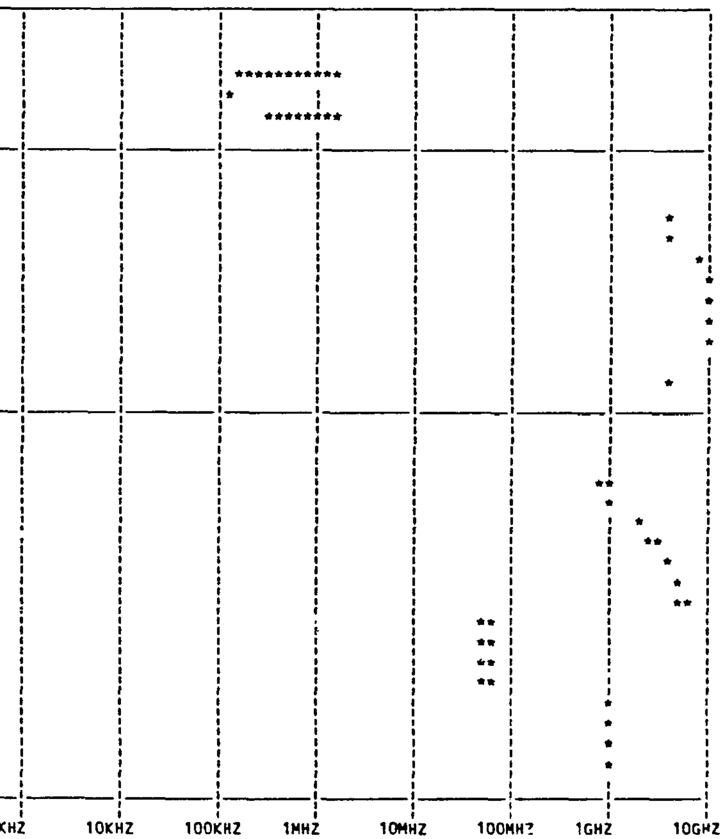

Figure 4.7c Narrowband Spectrum Chart, Version 5.0 (cont'd)

Chapter 5.0

SPECIFICATION OF DISTINCT SOURCE FREQUENCIES

5.1 Introduction

Version 5.0 addresses and corrects the algorithmic deficiencies of Version 4.2 which severely crippled the utility of the code. Although the contributions of Version 5.0 have resulted in the development of an error-free and useful inter-system EMI analysis/prediction tool, numerous extensions to the code can be defined to further enhance the utility of the code. These extensions address practical issues that arise during EMC testing and analysis.

Consider, for example, the narrowband tables which contain source/victim frequency combinations and two empty columns for ground and air results to be entered during EMC testing. The code generates the frequency combinations according to the sampling equations described in Chapter 4.0. Therefore, the EMC test engineer tunes to the sampled channels, measures the level of EMI, and records the results in the two right-most columns of the tables. The sampled source frequencies, however, may not correspond to authorized test frequencies for a given EMC test site. Although the ground tests can be performed in shielded hangars or anechoic chambers, the air tests introduce a problem. Furthermore, modern hangars and anechoic chambers are scarce.

Therefore, Version 5.2 has been developed to allow the specification of distinct source frequencies which correspond to authorized test frequencies for a given EMC test site.

Finally, Version 6.0 includes graphics and is presented in Chapter 6.0.

5.2 Version 5.2

Version 5.2 is an extension to the previous revisions and includes an additional option which allows the specification of distinct source frequencies. In this option, the user inputs the system name of the offending transmitter and a maximum of ten test frequencies which correspond to channels of the system under test, and to authorized frequencies for a given EMC test site. The code tests only for interference between the specified source channels (and their harmonics up to a set limit as specified in the transmitter data file) and every receiver, excluding the receivers that belong to the same system as the offending transmitter. Therefore, this option does not test for local oscillator interference which involves only receivers.

Figures 5.1a-c illustrate a sample printout of Version 5.2. The code tests the AN/ARC-505A transmitter against every receiver, except its own. The specified source channels in Figures 5.1a-c correspond to the first ten source frequencies of Figure 4.6a in Chapter 4. Note that the code, in addition to re-generating the same source/victim frequency combinations of Figure 4.6a, will also display all the possible frequencies that interact with the specified test frequencies and their harmonics. As stated earlier, however, no LO interactions are present in the output.

This option has also been proven to be particularly effective as a debugging aid and provides the means of comparing the performance of the CAETS program to that of other programs.

Therefore, Version 5.2 provides a practical extension to the CAETS program since it allows the user to specify distinct source frequencies which correspond to authorized test frequencies for a given EMC test site.

NARROWBAND TEST COMBINATIONS FOR CH124

VICTIM	FREQUENCY (MHZ)	VICTIM RESPONSE	SOURCE	FREQUENCY (MHZ)	SOURCE EMISSION	RESULT GROUND	RESULT AIR
AN/ARC-552A			AN/ARC-505A				
	226.4	RF		28.300	8 RF		
	254.7	RF		28.300	9 RF		
	283.0	RF		28.300	10 RF		
	311.3	RF		28.300	11 RF		
	339.6	RF		28.300	12 RF		
	367.9	RF		28.300	13 RF		
	396.2	RF		28.300	14 RF		
	228.3	IF		28.300	1 RF		
			AN/ARC-505A				
	238.4	RF		29.800	8 RF		
	268.2	RF		29.800	9 RF		
	298.0	RF		29.800	10 RF		
	327.8	RF		29.800	11 RF		
	357.6	RF		29.800	12 RF		
	387.4	RF		29.800	13 RF		
	229.8	IF		29.800	1 RF		
			AN/ARC-505A				
	229.1	RF		25.456	9 RF		
	254.6	RF		25.456	10 RF		
	280.0	RF		25.456	11 RF		
	305.5	RF		25.456	12 RF		
	330.9	RF		25.456	13 RF		
	356.4	RF		25.456	14 RF		
	381.8	RF		25.456	15 RF		
	225.5	IF		25.456	1 RF		
			AN/ARC-505A				
	235.6	RF		29.444	8 RF		
	265.0	RF		29.444	9 RF		
	294.4	RF		29.444	10 RF		
	323.9	RF		29.444	11 RF		
	353.3	RF		29.444	12 RF		
	382.8	RF		29.444	13 RF		
	229.4	IF		29.444	1 RF		
			AN/ARC-505A				
	231.6	RF		23.160	10 RF		

Figure 5.1a Narrowband Output, Version 5.2

VICTIM	FREQUENCY (MHZ)	VICTIM RESPONSE	SOURCE	FREQUENCY (MHZ)	SOURCE EMISSION	RESULT GROUND	RESULT AIR
AN/ARC-552A			AN/ARC-505A				
	254.8	RF		23.160	11 RF		
	277.9	RF		23.160	12 RF		
	301.1	RF		23.160	13 RF		
	324.2	RF		23.160	14 RF		
	347.4	RF		23.160	15 RF		
	370.6	RF		23.160	16 RF		
	393.7	RF		23.160	17 RF		
	233.2	IF		23.160	1 RF		
			AN/ARC-505A				
	233.1	RF		29.140	8 RF		
	262.3	RF		29.140	9 RF		
	291.4	RF		29.140	10 RF		
	320.5	RF		29.140	11 RF		
	349.7	RF		29.140	12 RF		
	378.8	RF		29.140	13 RF		
	229.1	IF		29.140	1 RF		
			AN/ARC-505A				
	233.8	RF		21.255	11 RF		
	255.1	RF		21.255	12 RF		
	276.3	RF		21.255	13 RF		
	297.6	RF		21.255	14 RF		
	318.8	RF		21.255	15 RF		
	340.1	RF		21.255	16 RF		
	361.3	RF		21.255	17 RF		
	382.6	RF		21.255	18 RF		
	231.3	IF		21.255	1 RF		
			AN/ARC-505A				
	230.9	RF		28.864	8 RF		
	259.8	RF		28.864	9 RF		
	288.6	RF		28.864	10 RF		
	317.5	RF		28.864	11 RF		
	346.4	RF		28.864	12 RF		
	375.2	RF		28.864	13 RF		
	228.9	IF		28.864	1 RF		
			AN/ARC-505A				
	235.8	RF		19.650	12 RF		

Figure 5.1b Narrowband Output, Version 5.2 (cont'd)

NARROWBAND TEST COMBINATIONS FOR CH124 PAGE 3

VICTIM	FREQUENCY (MHZ)	VICTIM RESPONSE	SOURCE	FREQUENCY (MHZ)	SOURCE EMISSION	RESULT GROUND	RESULT AIR
AN/ARC-552A			AN/ARC-505A				
	255.5	RF		19.650	13 RF		
	275.1	RF		19.650	14 RF		
	294.8	RF		19.650	15 RF		
	314.4	RF		19.650	16 RF		
	334.1	RF		19.650	17 RF		
	353.7	RF		19.650	18 RF		
	373.4	RF		19.650	19 RF		
	393.0	RF		19.650	20 RF		
			AN/ARC-505A				
	228.9	RF		28.617	8 RF		
	257.6	RF		28.617	9 RF		
	286.2	RF		28.617	10 RF		
	314.8	RF		28.617	11 PF		
	343.4	RF		28.617	12 RF		
	372.0	RF		28.617	13 RF		
	228.6	IF		28.617	1 RF		

Figure 5.1c Narrowband Output, Version 5.2 (cont'd)

Chapter 6.0

NARROWBAND GRAPHICS

6.1 Introduction

The CAETS program provides an effective tool to analyze and predict EMI in communication systems and significantly reduces the time required to prepare an aircraft EMC test plan. However, for a typical EMC database, the code produces more data than can be tested. Therefore, Version 6.0 includes graphics and is intended to simplify the selection of optimum test frequencies and to aid the user in the analysis and prediction of EMI in communication systems.

Specifically, for image and harmonic interference, the code displays the computed test frequencies along with their complete response, while for local oscillator and intermediate frequency interference, the code displays the system characteristics of the equipment under test.

This chapter examines the various templates for image and harmonic interference, as well as for local oscillator and intermediate frequency interference, and discusses the algorithms that generate the image and harmonic lines. Also, various graphics options are briefly examined. The EMC database described in Chapter 3 was used for the examples illustrated in this chapter.

6.2 Image Templates

Figure 6.1 through 6.3 illustrate the image response of a fixed-IF receiver, a variable-IF receiver, and a fixed-tuned system, respectively. In these figures, the source axis (X-axis) and victim axis (Y-axis) extend from the minimum to the maximum tuning frequencies of the equipment under test. Furthermore, the frequency marks on the axes correspond to channels of the equipment under test, and are displayed according to the tuning accuracy of their corresponding system. The computed test frequencies are represented by square placemarks on the image lines which are identified as ± IM P,Q. The entire set of image lines in every figure represents the complete image response of the victim receiver under test, clipped against the minimum and maximum tuning frequencies of the corresponding source transmitter. The following sections describe the manner in which the code generates these responses.

6.2.1 Templates for Fixed-IF and Fixed-Tuned Receivers

Figure 6.1 depicts a sample template for image coincidence between the AN/ARC-552A source transmitter and the AN/ARN-504-(V) victim receiver. Each image line in Figure 6.1 is defined by two endpoints (X1,Y1) and (X2,Y2) and is clipped against the window limits defined by the minimum and maximum

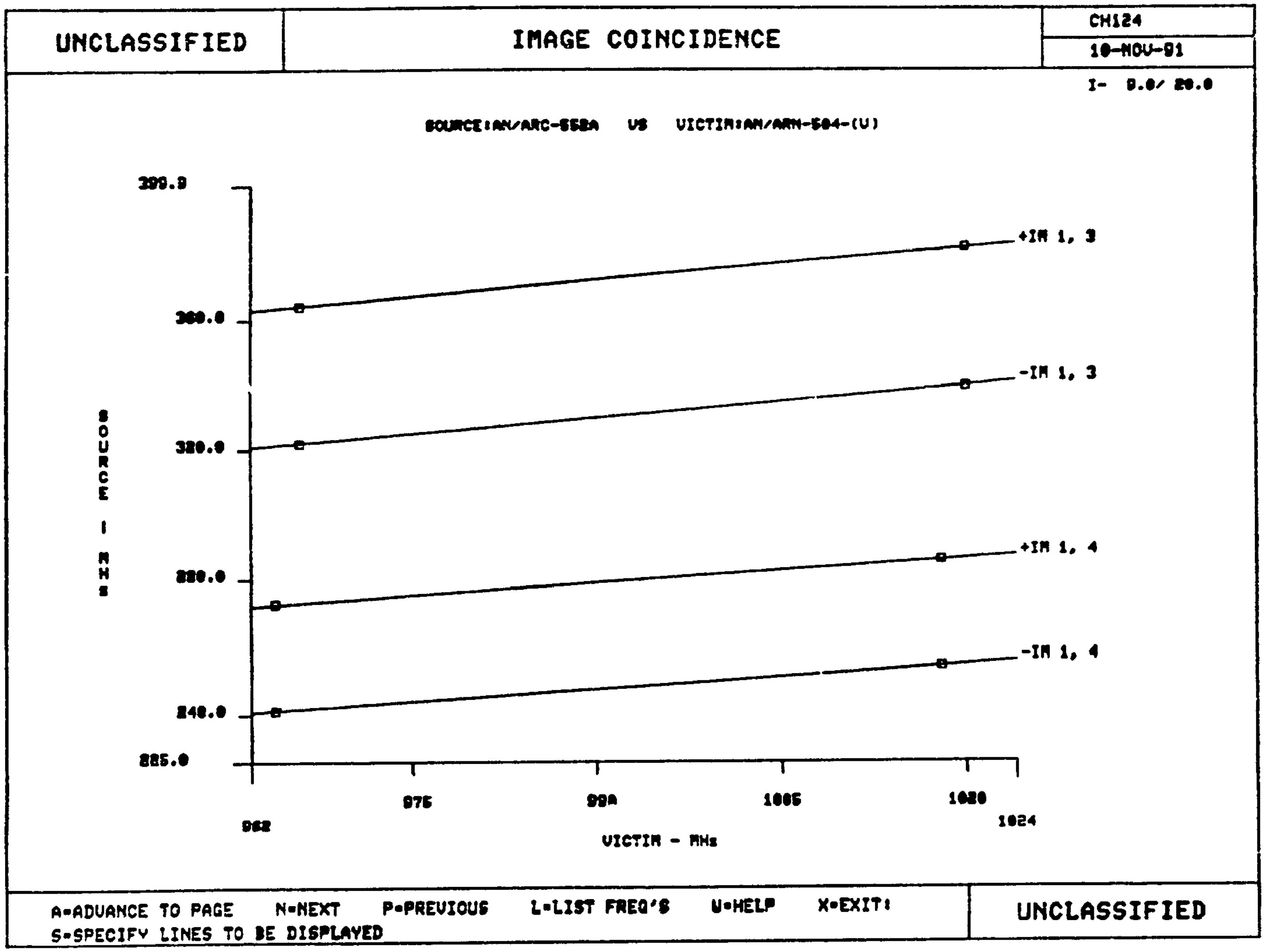

Figure 6.1 Template for Image Coincidence for Fixed-IF Receivers

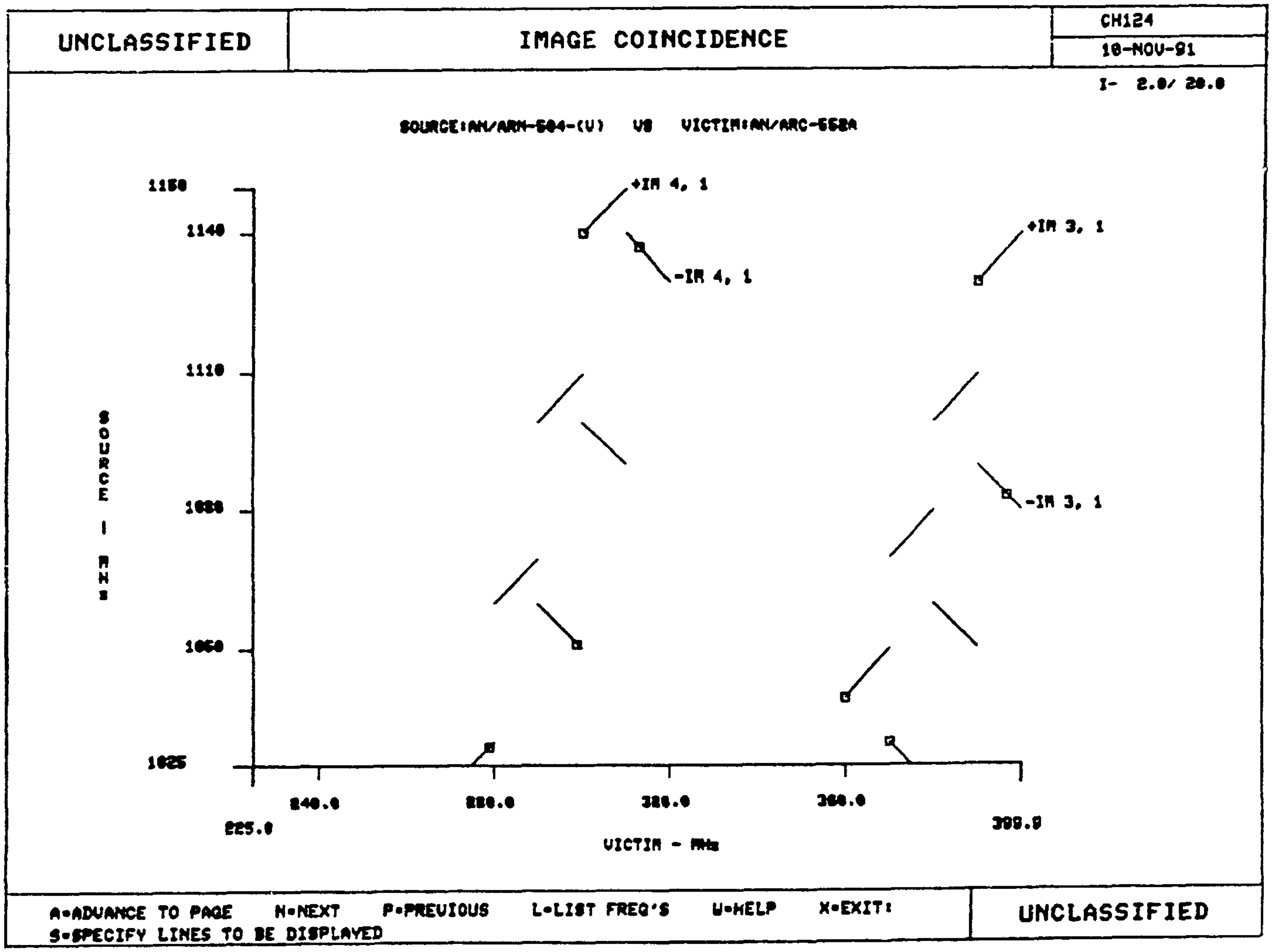

Figure 6.2 Template for Image Coincidence of Variable-IF Receivers

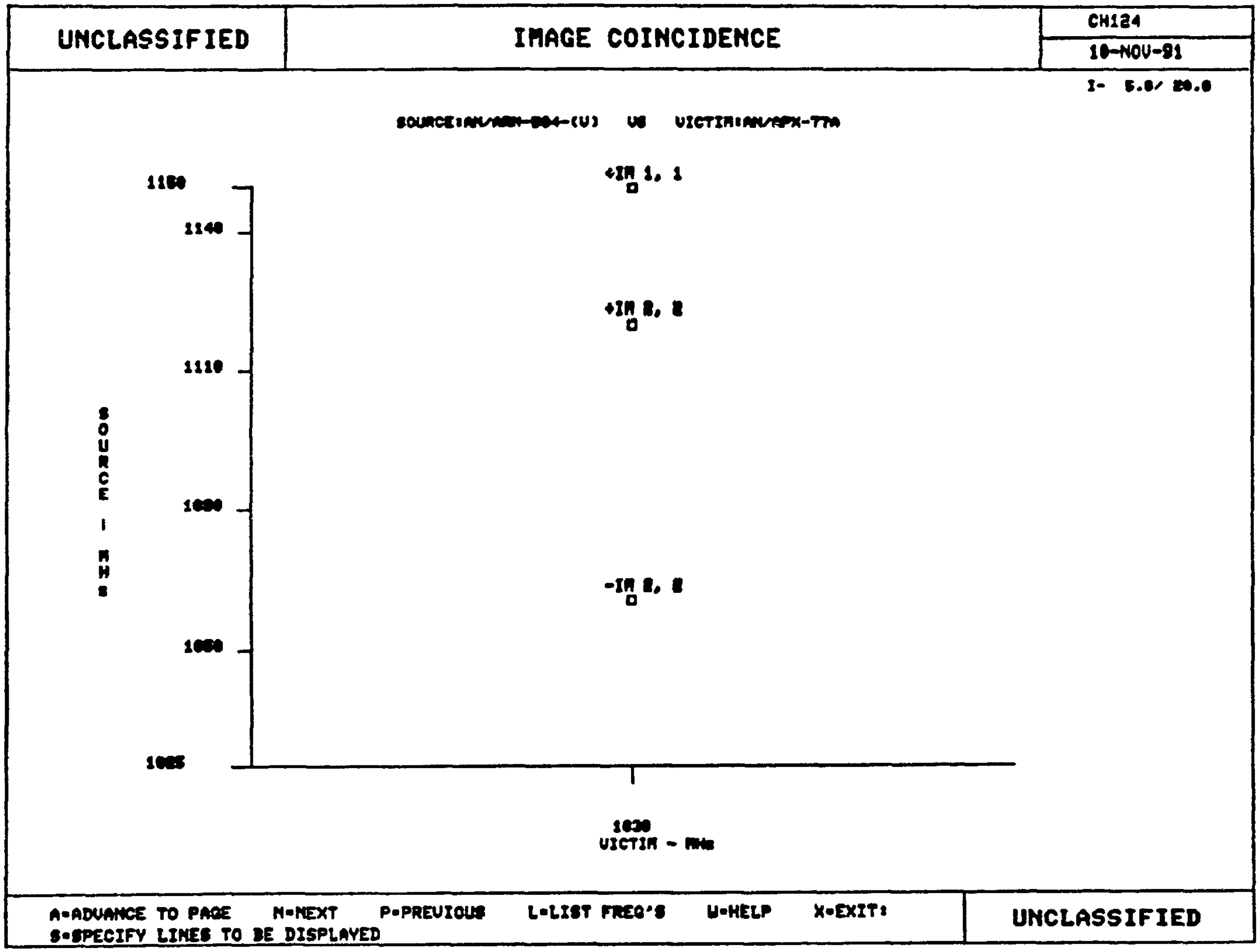

Figure 6.3 Template for Image Coincidence for Fixed-Tuned Receivers

operating frequency limits of the equipment under test.

Given P, Q and S, the endpoint coordinates of an image line for fixed-IF receivers, are defined as follows:

$$(X1,Y1)=(abs(FLOMIN+(-1)^{SIGN}*V),FA) \tag{6.1}$$

$$(X2,Y2)=(abs(FLOMAX+(-1)^{SIGN}*V),FB) \tag{6.2}$$

where

$$FA=\frac{(P*FLOMIN+(-1)^{S}*V)}{Q} \tag{6.3}$$

and

$$FB=\frac{(P*FLOMAX+(-1)^{S}*V)}{Q} \tag{6.4}$$

The above expressions are derived from Eq. (2.3) where variables SIGN and S correspond to the sign of the victim receiver and the sign of the image region under test, respectively, and variable V corresponds to the fixed IF value, which is usually the centre frequency of the IF band of the victim receiver (see Table 3.1 in Chapter 3).

Essentially, X1 and X2 in Eqs. (6.1) and (6.2) correspond to the minimum and the maximum tuning frequencies of the receiver, while Y1 and Y2 are the corresponding image frequencies of X1 and X2, respectively. Therefore, the code generates each image line by its endpoints and clips it against the window limits defined by the minimum and maximum tuning frequencies of the equipment under test.

Note that all image lines must fall completely within the first quadrant. Since the X-coordinates of the endpoints are always non-negative, this implies that FA and FB must be non-negative. Therefore, if an image line falls completely within the fourth quadrant (FA and FB < 0), the line is reflected about the X-axis ($Y=0$) onto the first quadrant by taking the absolute value of the Y-coordinates. However, if the product FA*FB is negative, one endpoint of an image line belongs to the first quadrant while the other belongs to the fourth quadrant and the code reflects only the negative portion of the image line (image reflection). This is done by generating the line as defined previously, clipping it against the window limits, and repeating this process for the reflected line defined by (X1,-Y1) and (X2,-Y2). Image reflection can occur only when the LO range (or its p^{th} harmonics) overlaps the IF range of a receiver (albeit, poor receiver structure design).

For interactions involving a fixed-tuned system, i.e., a system that operates at a single frequency, each computed test frequency is identified individually. Figure 6.3 depicts the image response of the AN/ARN-504-(V) source transmitter with the AN/APX-77A victim receiver. Since the AN/APX-77A operates only at 1030MHz, variables FLOMIN and FLOMAX in Eqs. (6.1) through (6.4) are equal and correspond to the LO setting of the victim receiver, i.e., FLOMIN=FLOMAX=1090MHz.

6.2.2 Template for Variable-IF Receivers

The image response of a variable-IF receiver is more complex. Consider the interaction between the AN/ARN-504-(V) source transmitter and the AN/ARC-552A victim receiver depicted in Figure 6.2. Note that the AN/ARC-552A receiver has a variable IF and, therefore, the image lines are discontinuous. That is, each image interaction now consists of several line segments. For example, the -IM3,1 interaction consists of three line segments, the +IM3,1 consists of four line segments, et cetera. Each line segment corresponds to a particular LO setting of the victim receiver and has a positive slope if the sign of the image region is the same as the sign of the receiver under test, and a negative slope otherwise. Since the sign of the AN/ARC-552A receiver is positive, the +IMP,Q interactions slope upwards, while the -IMP,Q slope downwards.

Because of the variability of the IF range, each victim LO setting defines a line segment extending from (Xlo1,Ylo1) to (Xlo2,Ylo2) given as follows:

$$(Xlo1, Ylo1) = (abs(FLO + (-1)^{SIGN} * FIFMIN), FA) \qquad (6.5)$$

$$(Xlo2, Ylo2) = (abs(FLO + (-1)^{SIGN} * FIFMAX), FB) \qquad (6.6)$$

where

$$FA=\frac{P*FLO+(-1)^{S}*FIFMIN}{Q} \qquad (6.7)$$

and

$$FB=\frac{P*FLO+(-1)^{S}*FIFMAX}{Q} \qquad (6.8)$$

The previous expressions are derived from Eq. (2.3) where f_{IF} is a free variable and can assume any value within the IF band defined by FIFMIN and FIFMAX, and FLO represents the victim LO setting. Therefore, each image interaction comprises a collection of line segments, one for every victim LO setting. Each line segment is individually clipped against the window limits defined by the minimum and maximum tuning frequencies of the equipment under test.

Image reflection in variable-IF receivers is applied to every line segment in a similar manner to image reflection in fixed-IF receivers. This is illustrated in the following example. Figure 6.4 depicts the complete -IM3,1 image response of a victim receiver, RX, which is not part of the EMC database described in Chapter 3. The tuning range of the receiver extends from 420.00 to 430.00MHz, the LO range extends from 100.0 to 110.0MHz in steps of 0.5MHz, and the IF band extends from 320.00 to 320.49MHz. The design structure of the receiver is poor since the third harmonics of the LO range overlap the IF range.

The image region depicted in Figure 6.4 is calculated by applying Eqs. (4.1) and (4.2) in Chapter 4 which yield:

F1 = abs(FB) = abs(3*100 - 320.49) MHz = 20.49MHz

and F2 = abs(FC) = abs(3*110 - 320) MHz = 10MHz

However, since the product FB*FC is negative, the lower frequency limit, F2, is set to zero, i.e.,

F1 = 20.49MHz and F2 = 0

Therefore, it is apparent that if a transmitter is operating at or below the HF band (3 to 30MHz) it will interfere with the receiver in the -IM3,1 mode. Furthermore, since the LO stepping is 0.5MHz there are 21 image line segments in total. Each line segment corresponds to a specific LO setting. Note that the last image segment on the RHS of the graph is almost entirely clipped and corresponds to the last LO setting, FLO=FLOMAX=110MHz.

In Figure 6.4, the code generates each line segment by applying Eqs. (6.5) through (6.8) and then clips each segment against the minimum and maximum tuning limits of the equipment under test. For example, the endpoints of the last image segment are determined by applying Eqs. (6.5) through (6.8) as follows:

Xlo1 = abs(110+320) MHz = 430MHz

Ylo1 = (3*110-320) MHz = 10MHz

and

Xlo2 = abs(110+320.49) MHz = 430.49MHz

Ylo2 = (3*110-320.49) MHz = 9.51MHz

Therefore, the last line segment extends from (430,10)MHz to (430.49,9.51)MHz. However, since the victim receiver extends from 420 to 430MHz, only the left endpoint of the line segment is retained. Note that the slope of the line segment is negative since the sign of the receiver is opposite to the sign of the image region under test.

Repeating the same procedure for the first LO setting, FLO=FLOMIN=100MHz, we obtain:

Xlo1 = abs(100+320) MHz = 420MHz

Ylo1 = (3*100-320) MHz = -20MHz

and

Xlo2 = abs(100+320.49) MHz = 420.49MHz

Ylo2 = (3*100-320.49) MHz = -20.49MHz

Since FA and FB are negative, the line segment appears in the fourth quadrant. Therefore, the code reflects the line segment onto the first quadrant by taking the absolute value of the Y-coordinates of the endpoints. However, this will also change the sign of the slope. Finally, this process is repeated for the remaining LO settings in order to obtain the complete image response depicted in Figure 6.4.

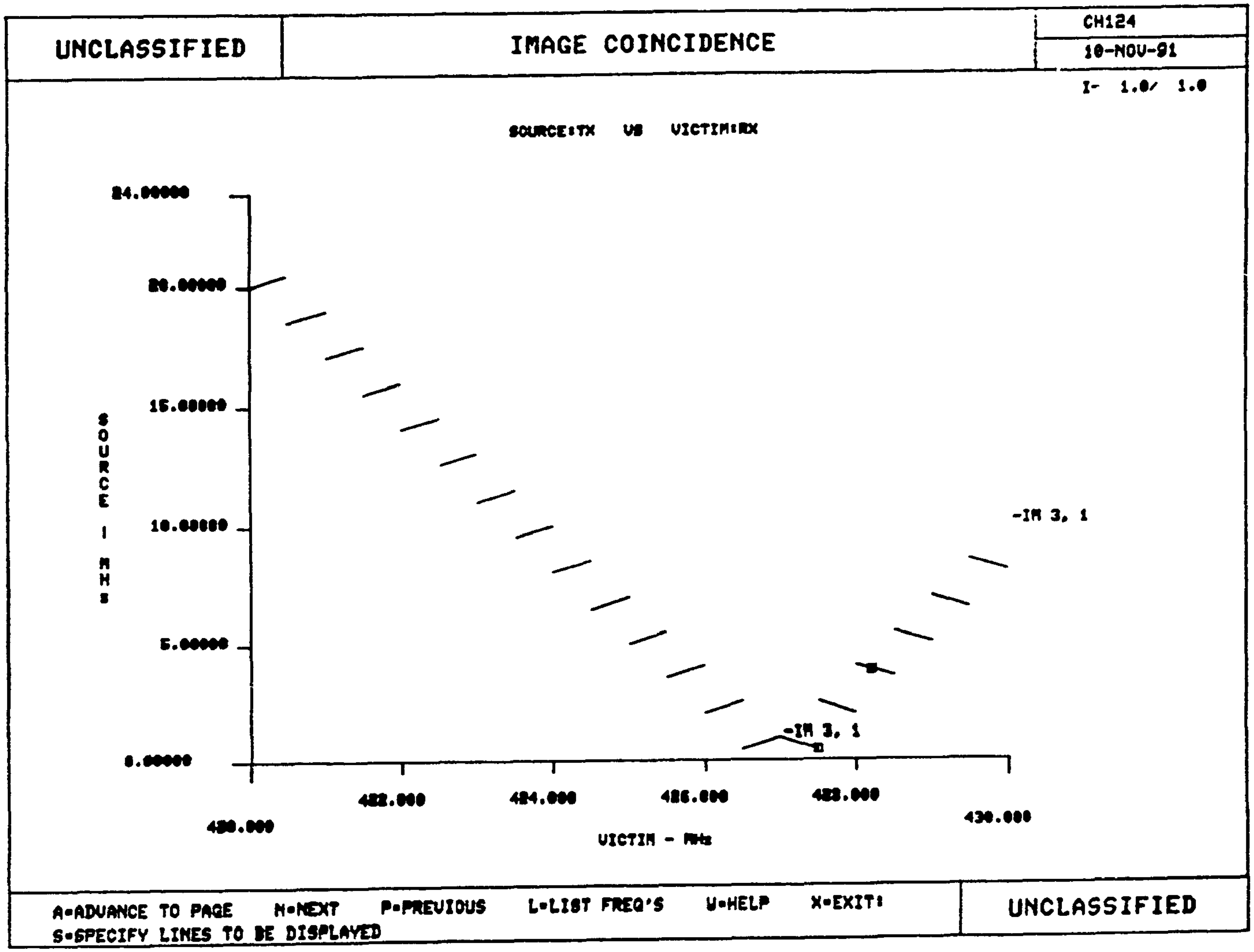

Figure 6.4 Image Reflection in Variable-IF Receivers

6.3 Harmonic Templates

Figure 6.5 depicts a sample template for harmonic interference between the AN/ARC-505A source transmitter and the AN/ARC-552A victim receiver. The template is identical to the one for image interference for fixed-IF receivers except that the harmonic lines are identified as 'nRF' instead of '±IMP,Q', where variable 'n' represents the harmonic order.

Harmonic coincidence is described by Eq. (2.6). Therefore, each harmonic line is defined by the endpoint coordinates (X1,Y1) and (X2,Y2) given below:

$$(X1, Y1) = (FRMIN, FRMIN/L) \tag{6.9}$$

$$(X2, Y2) = (FRMAX, FRMAX/L) \tag{6.10}$$

where variable L represents the harmonic order under test.

Harmonic lines always fall onto the first quadrant. The code simply clips each line against the window limits defined by the minimum and maximum tuning frequencies of the equipment under test.

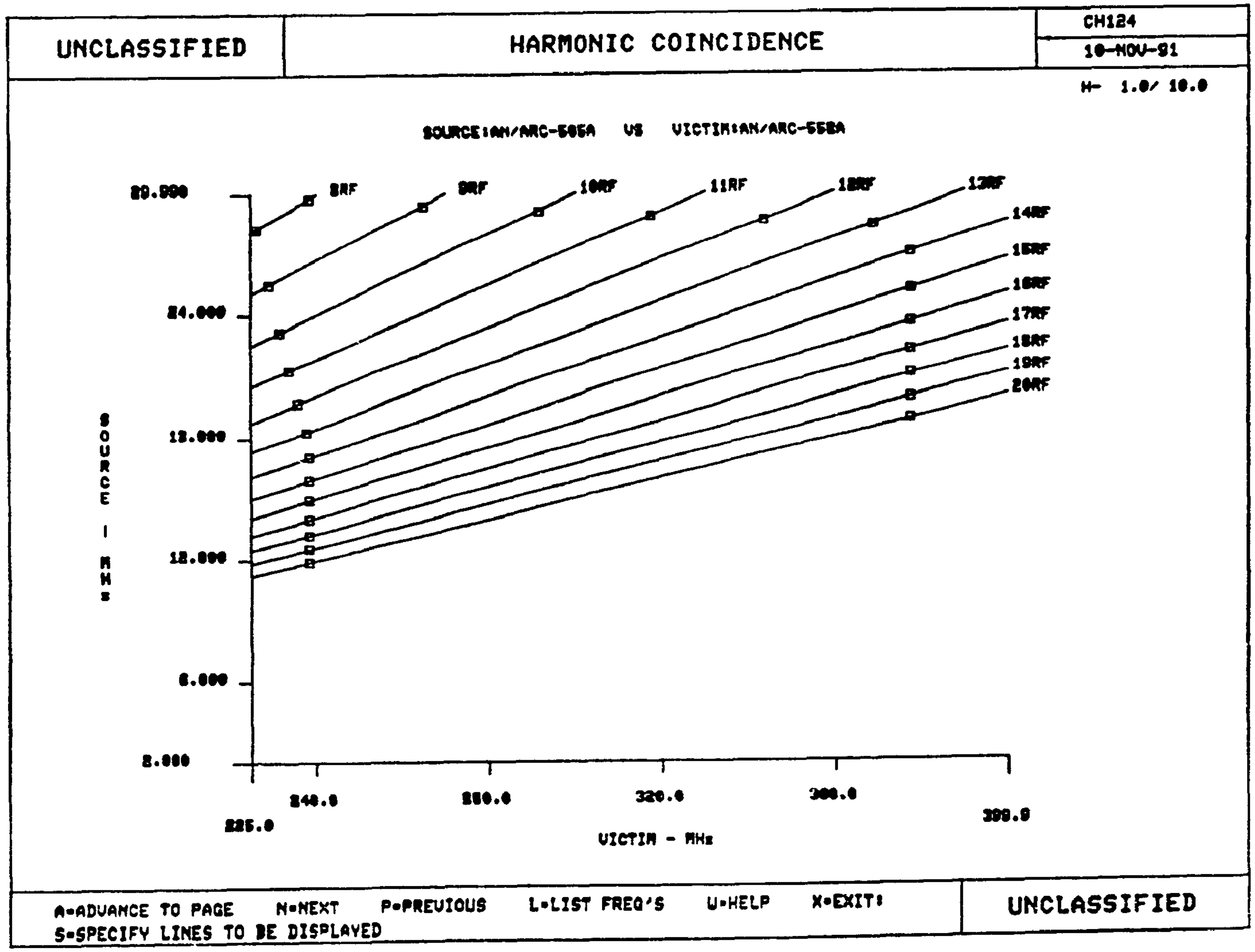

Figure 6.5 Template for Harmonic Interference

6.4 Local Oscillator and Intermediate Frequency Templates

For local oscillator and intermediate frequency interference, the code displays the system characteristics of the equipment under test. The computed test frequencies, however, are not displayed. Figure 6.6 depicts a sample template for local oscillator interference between the AN/R-1047A/A source receiver and the AN/ARC-552A victim receiver. The top half of the graph displays the system characteristics of the offending receiver while the bottom half displays those of the victim receiver. Essentially, the code displays the tuning range, the LO range and the IF range of the equipment under test. The code highlights the overlap region in the centre of the figure. The overlap region is defined as the intersection of the LO range of the offending receiver with the tuning range of the victim receiver.

Figure 6.7 depicts a sample template for intermediate frequency interference between the AN/ARC-505A source transmitter and the AN/ARC-552A victim receiver. This template is similar to that for local oscillator interference except that the code displays only the tuning range of the offending system. The overlap region is defined as the intersection of the tuning range of the offending transmitter with the IF band of the victim receiver.

The algorithm for generating these templates is straightforward and does not warrant further discussions.

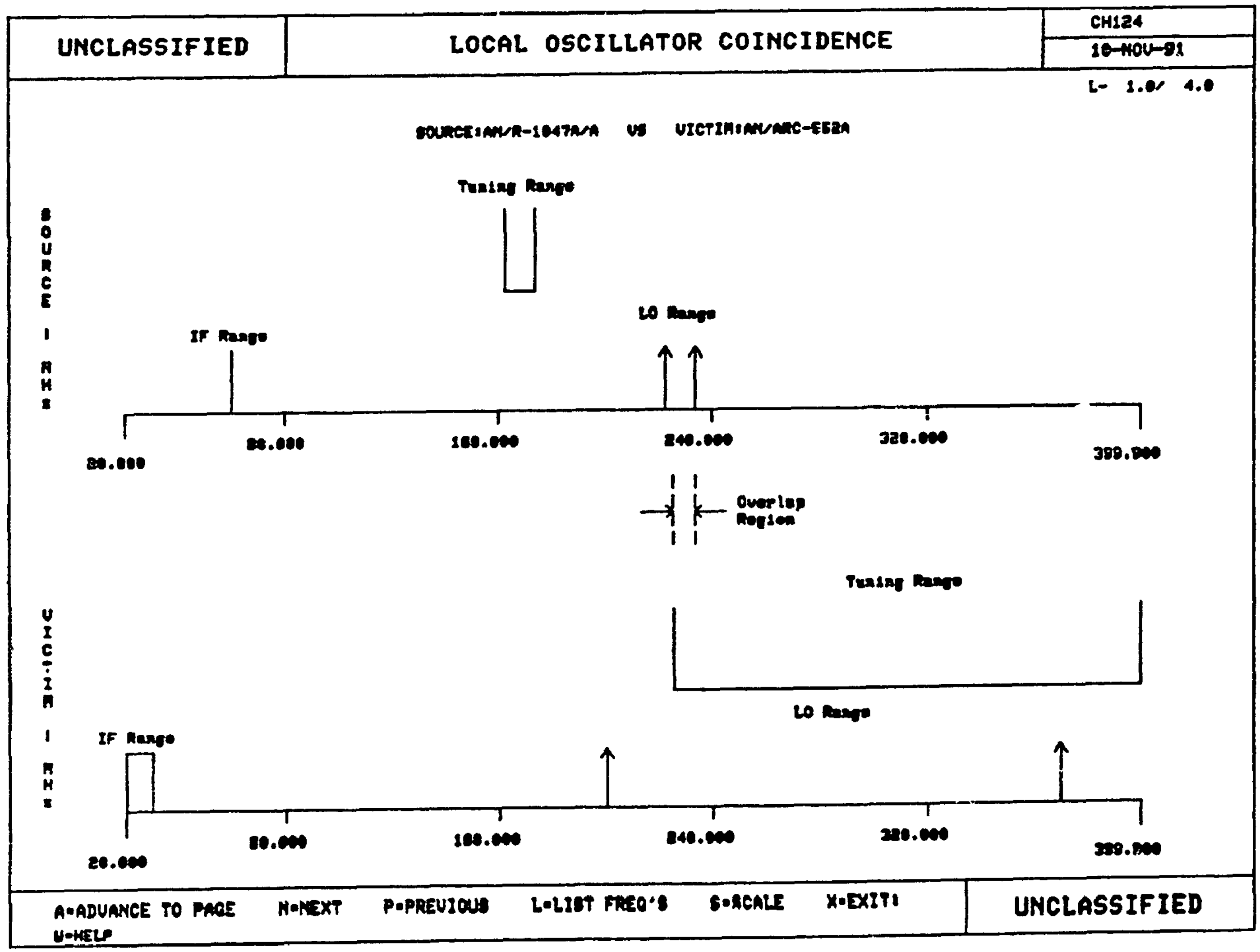

Figure 6.6 Template for Local Oscillator Interference

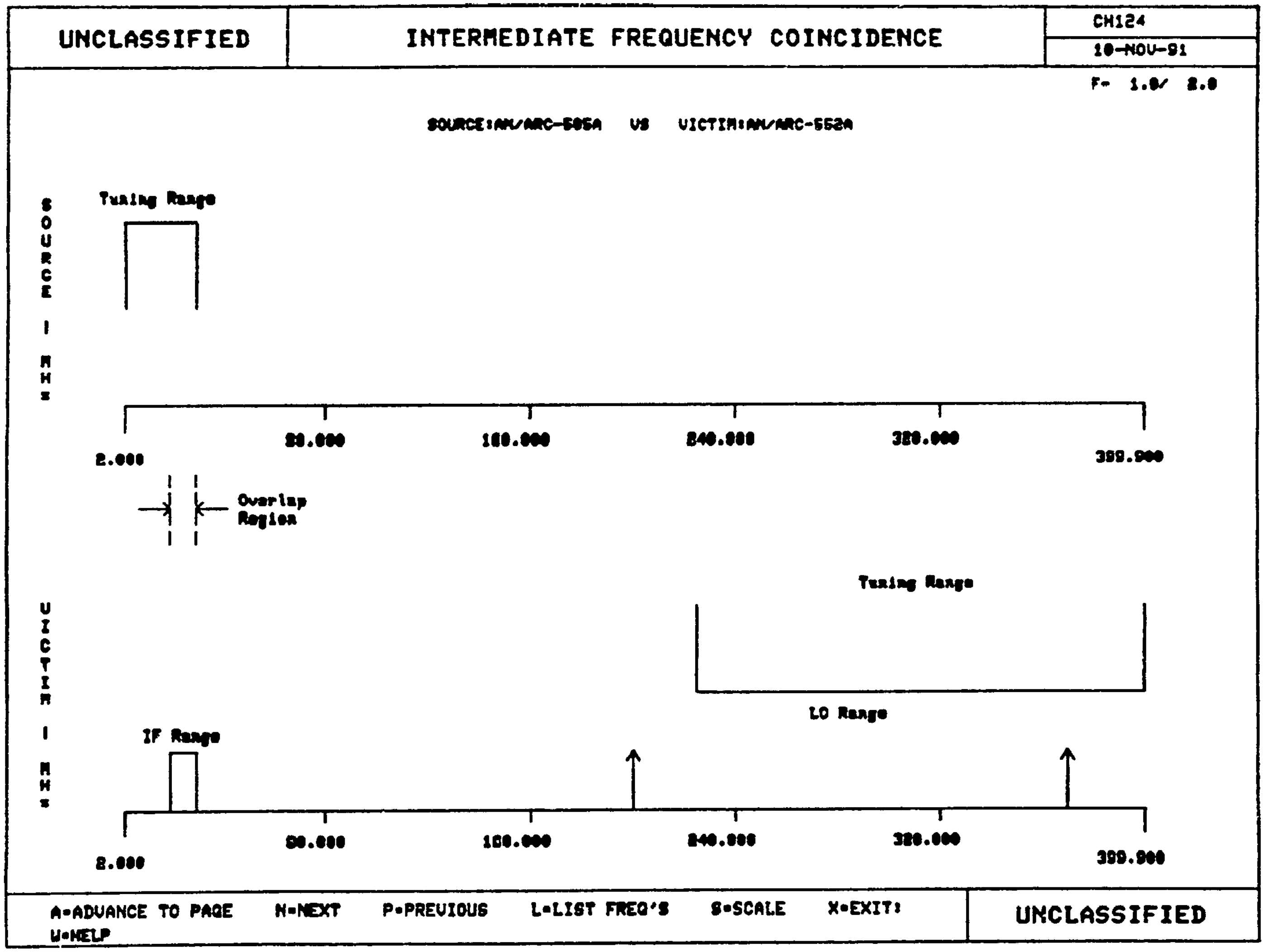

Figure 6.7 Template for Intermediate Frequency Interference

6.5 Display Options

In order to improve the visualization of the system characteristics and to assist the user in the analysis of spurious EMI, several display options have been included in the graphics option. These options appear at the bottom of Figures 6.1 through 6.7 and are described in the following sections. In addition to these options, a summary of the interactions is available from the main graphics menu.

6.5.1 Summary

This option provides a summary of all the interactions for a particular aircraft. A sample printout for the CH124 aircraft is shown in Figure 6.8. It comprises of a listing of all victim systems and their corresponding offending systems, an interference code which describes the mode by which the source and the victim systems interfere (H- Harmonic; I- Image; F- Intermediate Frequency; L- Local Oscillator), the page number where the interaction is stored, and the total number of sampled test frequencies for that particular mode. A page, herein, is referred to as the locus of all the interactions involving the same victim and source systems, and interfering in the same mode. For example, the 'F- 1.0/ 2.0' field at the top right-hand corner of Figure 6.7 indicates to the user that the current page is the first page of a total of two pages. This page is also shown in the second line of the first column under the first block in Figure 6.8.

Therefore, the user can locate a desired interaction found in the summary by simply invoking the pertinent interference mode from the main graphics menu and advancing to the appropriate graphics page.

6.5.2 Cluttered Display Windows

When the sample size, the maximum image order or the harmonic order are large integers, a display window may become cluttered. The user can reduce the clutter by specifying a set of lines to be displayed, thus making the display more legible. Figure 6.9 depicts the complete image response for the AN/ARC-505A source transmitter and the AN/ARN-59(V) victim receiver. Notice that the image lines are closely spaced at the lower portion of the graph. Figure 6.10, on the other hand, depicts the same interacting system pair but only -IM2,1 and +IM1,1 are shown. This option is available only for image and harmonic templates.

6.5.3 Logarithmic and Linear Scale

When the system characteristics of the equipment under test span several decades of frequencies, it is advantageous to use a logarithmic scale to avoid very wide or very narrow frequency ranges. Figure 6.11 depicts the system characteristics of the POWER SYS 400Hz source and the AN/APN-117 victim receiver on a linear scale. Notice that the system characteristics appear to be fixed at a particular frequency. Figure 6.12, however, depicts the same system characteristics on a logarithmic scale where it is evident that the IF band of the receiver and the tuning range of the transmitter span a range of frequencies. This option is available only for local oscillator and intermediate frequency templates.

6.5.4 List/Display Sampled Frequencies

For image and harmonic interference, the code displays the computed test frequencies in relationship to the source and the victim tuning ranges. For local oscillator and intermediate frequency coincidence, the computed test frequencies are not displayed. However, the code provides a list of the sampled test frequencies for every interference template. Figure 6.13 depicts the frequency combinations for the image interference shown in Figure 6.9. Note that each frequency combination corresponds to a particular square placemark shown in Figure 6.9.

Therefore, it is evident that the graphics option of Version 6.0 is indeed an essential tool in the analysis and prediction of EMI in communication systems. Furthermore, the visualization of the computed test frequencies in relationship to the source and victim tuning limits as well as the visualization of the system characteristics, aid the user in the selection of optimal test frequencies since the user is now equipped with the complete response of the equipment under test.

UNCLASSIFIED	SUMMARY OF COINCIDENCES	CH124 10-NOV-91

S- 1.0/ 1.0

VICTIM/ SOURCE	# OF SAMPLES	VICTIM/ SOURCE	# OF SAMPLES	VICTIM/ SOURCE	# OF SAMPLES
		H- 5. AN/ARN-504-(V)	(1)	I-19. AN/APX-77A	(1)
1-AN/ARC-558A		I- 8. AN/ARN-504-(V)	(2)	I-20. AN/APN-117	(1)
H- 1. AN/ARC-505A	(26)	6-AN/ARN-504-(V)		L- 4. AN/APX-77A	(1)
F- 1. AN/ARC-505A	(2)	H- 6. AN/ARC-552A	(4)		
I- 1. AN/APX-77A	(1)	I- 9. AN/ARC-552A	(8)		
I- 2. AN/ARN-504-(V)	(8)	I-10. AN/APX-77A	(2)		
L- 1. AN/R-1047A/A	(2)	I-11. AN/APN-117	(1)		
2-AN/APX-77A		7-AN/ARN-504-(V)			
H- 2. AN/ARC-552A	(1)	H- 7. AN/ARC-552A	(6)		
I- 3. AN/ARC-558A	(2)	I-12. AN/ARC-552A	(8)		
I- 4. AN/APN-117	(1)	I-13. AN/APX-77A	(1)		
H- 3. AN/ARN-504-(V)	(1)	I-14. AN/APN-117	(1)		
I- 5. AN/ARN-504-(V)	(3)	8-AN/ARN-504-(V)			
L- 2. AN/ARN-504-(V)	(1)	H- 8. AN/ARC-552A	(4)		
L- 3. AN/ARN-504-(V)	(1)	I-15. AN/ARC-552A	(8)		
3-AN/R-1047A/A		I-16. AN/APX-77A	(1)		
I- 6. AN/ARC-558A	(10)	I-17. AN/APN-117	(1)		
H- 4. AN/ARC-505A	(18)	9-AN/ARN-504-(V)			
4-AN/ARN-59(V)		H- 9. AN/ARC-552A	(6)		
I- 7. AN/ARC-505A	(18)	I-18. AN/ARC-552A	(8)		
5-AN/APN-117		H-10. AN/APX-77A	(1)		
F- 2. POWER SYS 400Hz	(1)				

N=NEXT X=EXIT:

UNCLASSIFIED

Figure 6.8 Summary for CH124 Aircraft

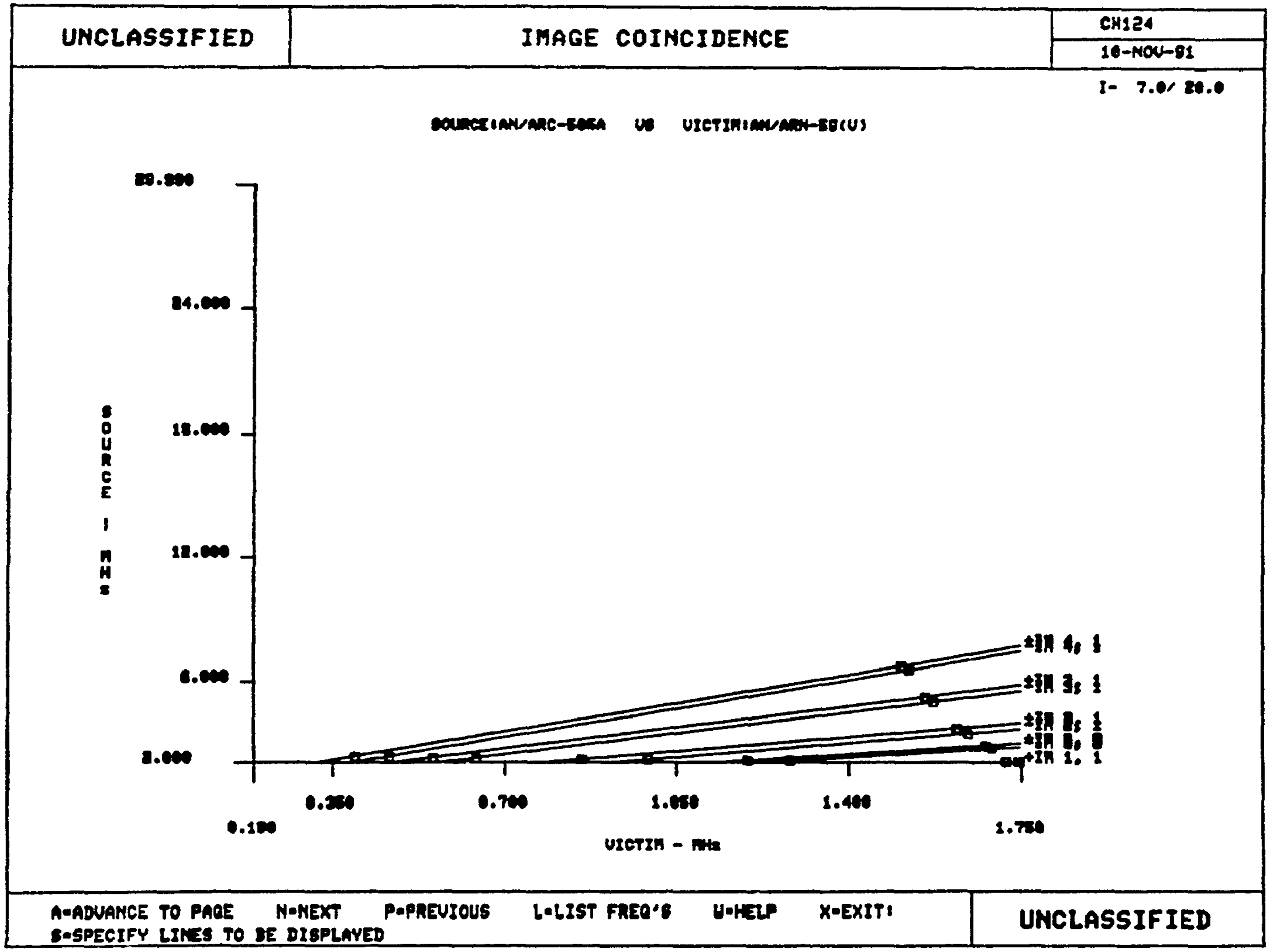

Figure 6.9 Cluttered Display Window

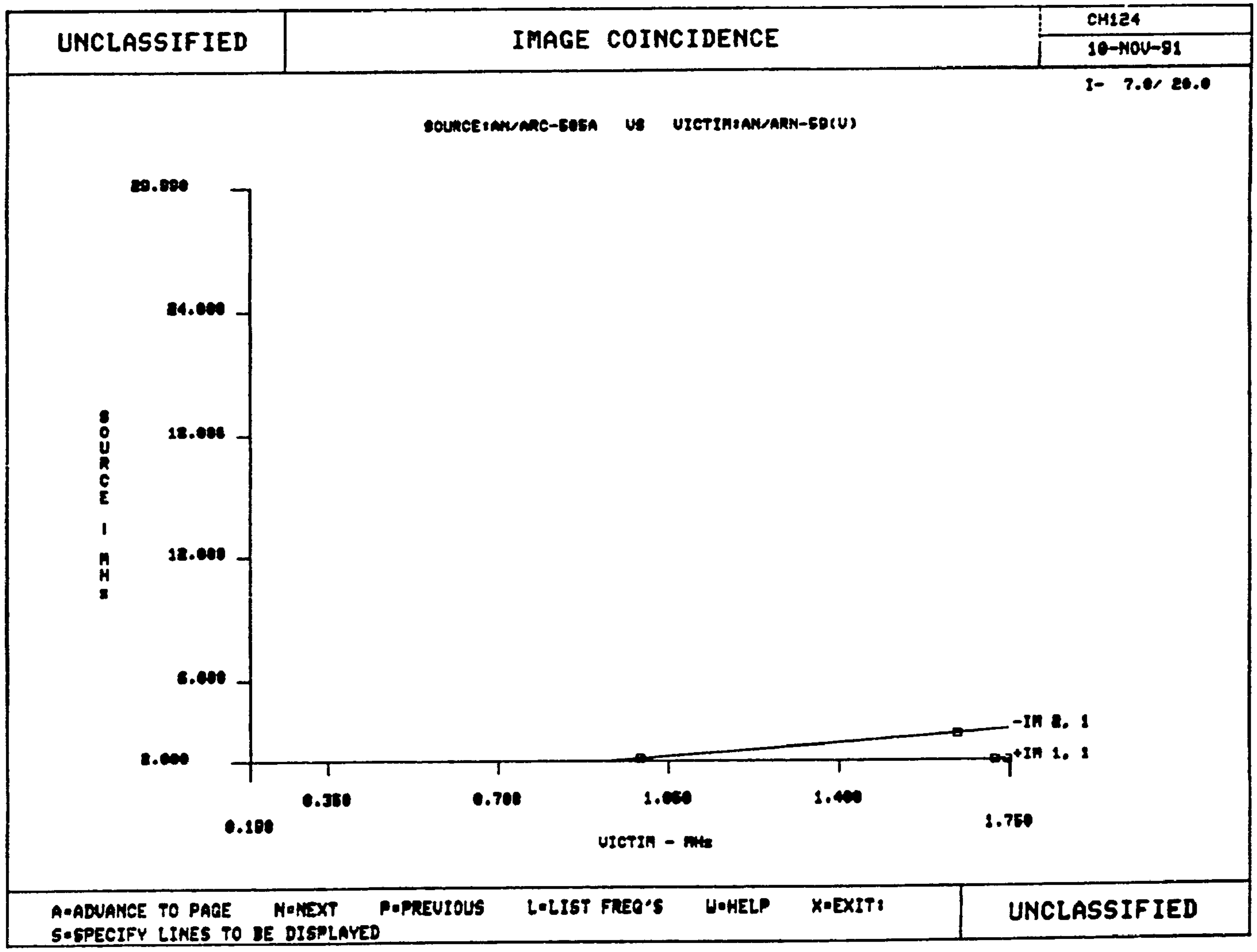

Figure 6.10 De-Cluttered Display Window

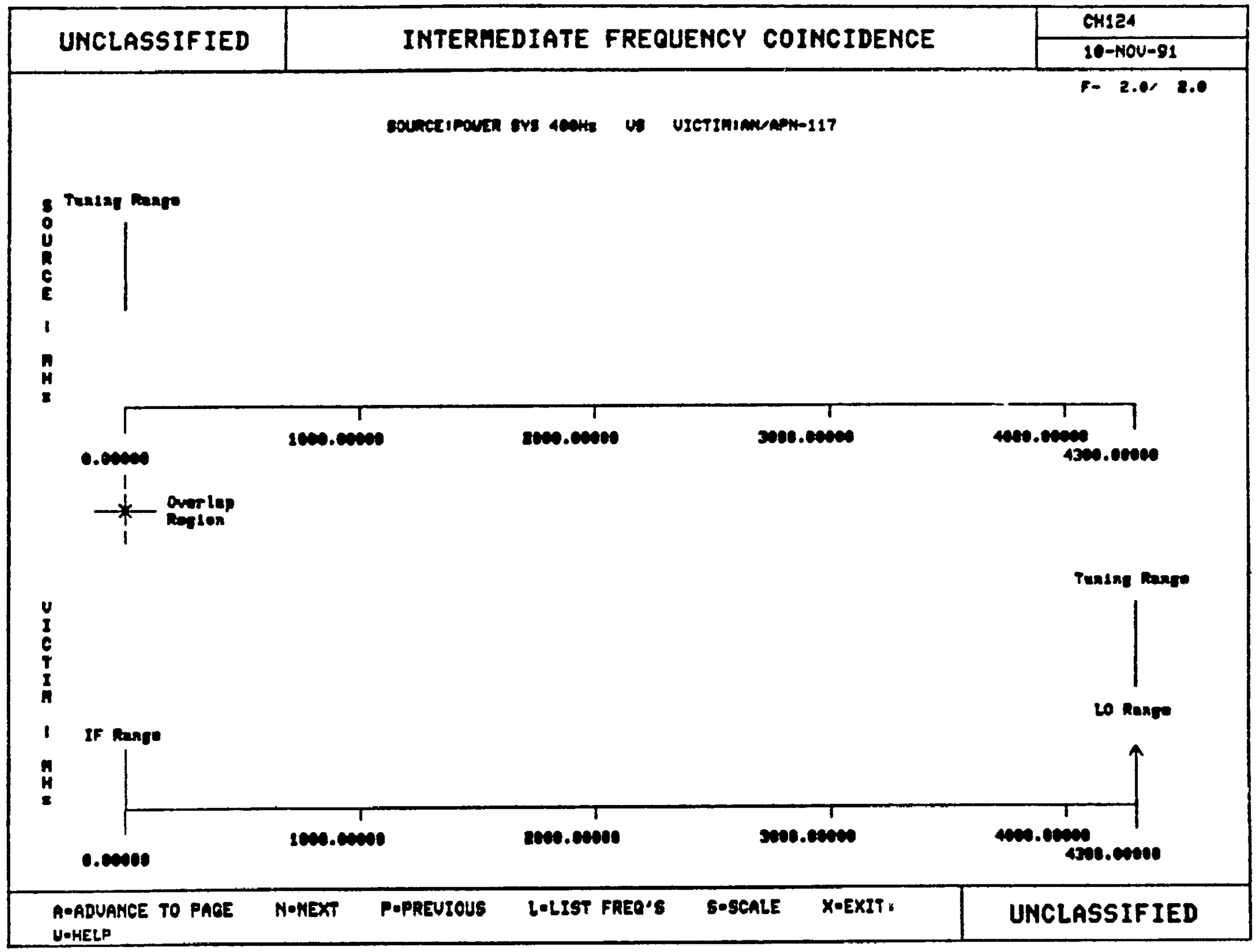

Figure 6.11 Linear Scale

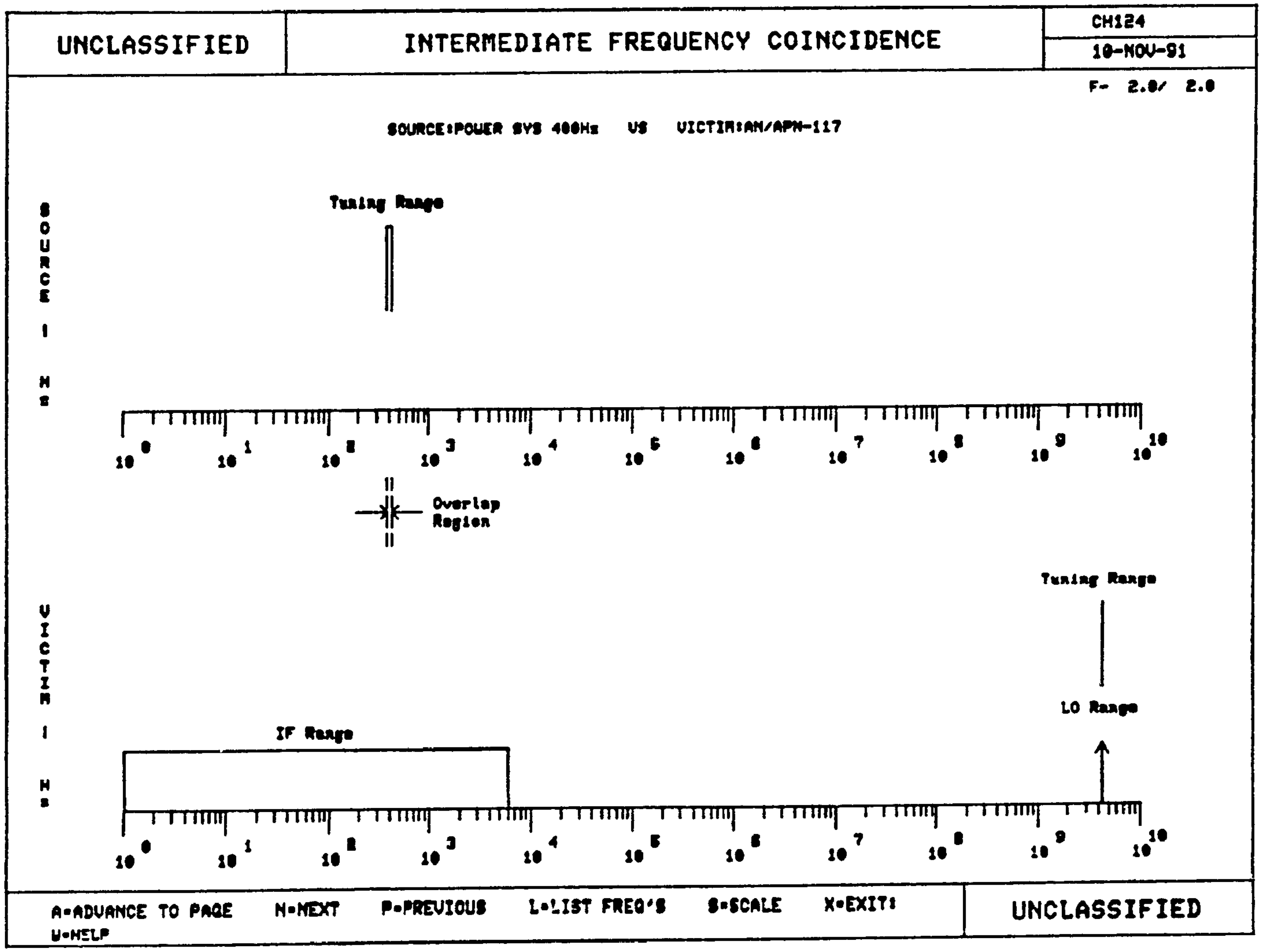

Figure 6.12 Logarithmic Scale

UNCLASSIFIED	IMAGE COINCIDENCE	CH124 10-NOV-91

I- 7. 1/ 7. 1

SOURCE:AN/ARC-505A VS VICTIM:AN/ARN-59(V)

INTER-ACTION #	VICTIM FREQUENCY (MHz)	VICTIM RESPONSE	SOURCE FREQUENCY (MHz)	SOURCE RESPONSE
1	1.720	+IM 1, 1	2.005	1RF
2	1.747	+IM 1, 1	2.038	1RF
3	0.991	-IM 2, 1	2.185	1RF
4	1.245	-IM 2, 1	3.433	1RF
5	0.856	+IM 2, 1	2.139	1RF
6	1.621	+IM 2, 1	3.069	1RF
7	0.643	-IM 3, 1	2.214	1RF
8	1.573	-IM 3, 1	5.004	1RF
9	0.553	+IM 3, 1	2.229	1RF
10	1.555	+IM 3, 1	5.235	1RF
11	1.222	-IM 3, 2	2.068	1RF
12	1.693	-IM 3, 2	2.082	1RF
13	1.195	+IM 3, 2	2.077	1RF
14	1.681	+IM 3, 2	2.806	1RF
15	0.483	-IM 4, 1	2.280	1RF
16	1.582	-IM 4, 1	6.516	1RF
17	0.394	+IM 4, 1	2.288	1RF
18	1.507	+IM 4, 1	6.740	1RF

N=NEXT H=HELP L=DISPLAY FREQ'S:	UNCLASSIFIED

Figure 6.13 Frequency List

Chapter 7.0

CONCLUSION

7.1 Review of Thesis

The objective of this thesis was to describe the modifications and improvements, as well as two practical extensions to the Computer Aided EMC Test Plan System (CAETS) program. The original CAETS program, Version 4.2, was developed by Bell Northern Research to assist the Department of National Defense (DND) and their contractors in the preparation of EMC test plans. However, Version 4.2 produced a proportionally large number of invalid test combinations in the victim/source tables and minor errors in the spectrum charts. These deficiencies, coupled with poor presentation of the output, insufficient documentation, primitive user interface, and lack of graphics severely limited the utility of the code.

After extensive diagnosis of the code, major modifications to the algorithm and structure of the CAETS program were planned, implemented and tested. The improvements described in this thesis shall be presented to DND and industry and shall be released in three successive revisions.

Version 5.0 includes major modifications to the narrowband algorithm as well as improvements in presentation of the output, documentation, and user interface. A comparison between Version 4.2 and Version 5.0 reveals that the earlier revision, in addition to providing incorrect victim/source frequency coincidences, fails to detect all the possible interactions. This is supported by the fact that Version 4.2 generates only 116 frequency samples (69 of which are in error) for the CH124 aircraft database, while Version 5.0 detects 162 frequency samples for that same aircraft (the sample size and the maximum image order were set to two and five, respectively). The efficiency of the narrowband algorithm has also been drastically improved. Consequently, the execution time required to generate the narrowband output has been reduced by at least a factor of ten.

Because of the scarcity of special test facilities, Version 5.2 was developed to allow the specification of distinct source frequencies corresponding to authorized frequencies for given EMC test sites. This revision has also proven to be particularly effective as a debugging aid and provides the means of comparing the performance of CAETS to that of other programs. Version 5.2 is quite likely to become the stable version of the code for several years.

The CAETS program provides an effective tool to analyze and predict EMI in communication systems and significantly reduces the time required to prepare an EMC test plan. However, for a typical EMC database, the code produces more data than can be tested and the user cannot see directly the frequency relationships of the interacting systems. Hence, Version 6.0 has been developed to provide the visualization of the relationship of the computed test frequencies to the victim and source operating frequency ranges, as well as the visualization of the system characteristics of the equipment under test. These features simplify the selection of optimum test frequencies and aid the user in the analysis and prediction of EMI in communication systems. The code remains to be tested by operational EMC test groups to determine whether indeed the objectives of improved visualization and as an aid to frequency selection are being fulfilled.

7.2 Suggestions for Improvements and Extensions

Although the work presented in this thesis has resulted in the development of an error-free and useful inter-system EMI prediction tool, numerous improvements and extensions to the code can be defined to further improve the utility of the code.

Because the degree of accuracy at which the narrowband equipment has been specified reflects the validity of the narrowband results obtained, proper equipment modelling is an essential requirement. However, typographical errors are especially common in formatted input databases which, in addition to providing erroneous results, will cause unpredictable behaviour of the program execution. Therefore, an input validation program along with an increase in the field lengths of the input variables comprising the EMC database, which would allow for a more accurate specification of these variables, would be desirable. Furthermore, an extended EMC database comprising most modern narrowband systems would be an asset. Presently, only a very small fraction of a plethora of modern narrowband systems has been modelled.

The CAETS program, Version 6.0, requires a Tektronix 4015 (or compatible) to run the graphics option. This hardware restriction, however, severely limits the portability of the code. Due to the availability of personal computers with high resolution displays, it is recommended that the development of a graphics version that runs on high resolution monitors (CGA, VGA, EGA, etc.) be instigated as soon as possible. This can be accomplished by replacing the Tektronix 4015 graphics library with its PC-equivalent.

Finally, the code should be extended to allow the prediction of the degree of performance degradation or EMI margin between two interfering narrowband systems. This can be easily achieved by linking the CAETS program to other existing EMC packages such as Antenna-to-Antenna Propagation with Graphics (AAPG) which account for the amount of energy coupled between two antennas.

In conclusion, it is hoped that this work will serve as an encouragement to the author and others to pursue the possible implementations and extensions identified herein. It is believed that the code in its various versions will provide an effective and reliable EMC analysis tool for EMC test plans and their executions.

REFERENCES

[1] "Definitions and System of Units, Electromagnetic Interference and Compatibility Technology," MIL-STD-463A, June 1, 1977, p.13.

[2] W. Rotkiewicz, "Electromagnetic Compatibility in Radio Engineering," Studies in Electrical and Electronic Engineering, Vol. 6., (Amsterdam: Elsevier Scientific Publishing Company, 1982), p.122.

[3] L.P. Inglis, "Compatibility of Man in the Microwave Environment," IEEE Electromagnetic Compatibility Symposium Record, Asbury Park, N.J., June 17-19, 1969.

[4] W.G. Duff, "Fundamentals of Electromagnetic Compatibility," Vol. 1, A Handbook Series on Electromagnetic Interference and Compatibility, (Gainesville, VA: Interference Control Technologies, Inc., 1988), p.9.3.

[5] "Electromagnetic Compatibility Requirements, Systems," MIL-E-6051D, Sept. 7, 1967, p.11.

[6] MIL-E-6051D, p.15.

[7] J.F. Spina, "The EMC Concept for Weapon Systems," Lecture Series No. 116, AGARD Lecture Series on Electromagnetic Compatibility, (London: Technical and Reproduction Ltd., Aug. 1981), p.1-2.

[8] M.J.L. Drolet, "Advances in Path Loss Algorithm in the Antenna-to-Antenna Propagation with Graphics (AAPG) EMC Analysis Program," Thesis in the Department of Electrical and Computer Engineering, Concordia University, Montreal, Quebec, Aug. 1989.

[9] "CAETS Program Description," Bell Northern Research Report No.: EM Eng 5E34, Dec. 1985, p.13.

[10] "CAETS User's Manual: Theory and System Description for a Computer Aided EMC Test Planning System," Bell Northern Research Report No.:5134-EME-84-01, Nov. 1984, p.1.

[11] G.T. Capraro, and J. Perini, "A Graphical Approach to the Intermodulation and Spurious Response Problem," Vol. EMC-16, No. 1, IEEE Trans. on Electromagnetic Compatibility, Feb. 1974, pp.38-43.

[12] F.W. Heather, "Applications of Nomographs for Analysis and Prediction of Receiver Spurious Response EMI," IEEE International Symposium on Electromagnetic Compatibility, Wakefield, MA, Aug. 20-22, 1985, pp.390-398.

[13] S.J. Erst, "Receiving Systems Design," (Dedham, MA: Artech House, Inc., 1984), pp.118-123.

[14] C. Christopoulos, and S.J. Kubina, "Assessment of CAETS Status," Concordia University, Electromagnetic Compatibility Laboratory Technical Notes, TN-EMC-91-01, July 25, 1991.

[15] "Analysis of a CH124A Sea King Helicopter Electromagnetic Compatibility," Vol. 1, IMP Report No. : CH124A / R210, Feb. 8, 1989.

[16] "Report on CAETS Electromagnetic Compatibility Analysis of the CP121 Tracker," Vol. 1, IMP Report No. : CP121 / R181, Feb. 27, 1889.

[17] "Version Description Document, Computer Aided Electromagnetic Compatibility Test System, Version 4.2," Dept. of National Defence, Ottawa, June 25 1987, pp.3-7.

[18] F.G. Stremler, "Introduction to Communication Systems," Second Edition, (Reading, MA: Addison-Wesley Publishing Company, Dec. 1982), p.236.

[19] E.L. Bronaugh, and W.S Lambdin, "Electromagnetic Interference Test Methodology and Procedures," Vol. 6, A Handbook Series on Electromagnetic Interference and Compatibility, (Gainesville, VA: Interference Control Technologies, Inc., 1988), p.12.29.

[20] W.G. Duff, "Electromagnetic Compatibility in Telecommunications," Vol. 7, A Handbook Series on Electromagnetic Interference and Compatibility, (Gainesville, VA: Interference Control Technologies, Inc., 1988), p.2.3.

[21] W.W. Everett, "Topics in Intersystem Electromagnetic Compatibility," HRW Series on Electrical Engineering, Electronics and Systems, (US: Holt, Rinehart and Winston, Inc., 1972), p.49.

APPENDIX

The following section provides a brief description of the changes implemented to the CAETS program by the author during the thesis project. These changes have resulted in the addition of approximately 8,000 lines of FORTRAN code to the original CAETS program, and are presented below in three parts according to the version for which they have been realised. The extent of these changes is such that they preclude the inclusion of detailed information and a complete set of flowcharts. Instead, only a brief description of the changes implemented to the modules is included. Furthermore, only the modular flowchart for Version 6.0 is presented since it reflects the latest changes.

In addition to these modifications, several changes were implemented to the CAETS program, Version 4.2, in order to make the code run on a PC-386 workstation. David Gaudine, from the EMC Laboratory of Concordia University, implemented the changes necessary to make the code executable and was responsible for the initial *grooming* of the code. For example, several arrays were dimensioned to 600 in some modules and to 601 in others. Since the arrays were in COMMON blocks, COMMON block alignment was incorrect. To guarantee consistency, all COMMON blocks had to be removed from the source file and placed in separate INCLUDE files.

In addition, several COMMON block variables have been renamed to avoid confusion. For example, the variable N was declared in three different COMMON blocks, for three different purposes. This did not cause any errors, since no module used more than one of these COMMON blocks. However, it was very confusing, especially since sometimes N implied *source* and sometimes *victim*.

Furthermore, Version 4.2 did not contain any OPEN statements. Presumably some VAX system-dependent method was used to find the input files. Now, OPEN statements are used and all output can be directed either to a file for editing (PRINTER.LST default), or to a printer.

Finally, several format statements have been changed to eliminate the use of overprinting which cannot be viewed easily when examining the output file with a text editor. These changes form part of Version 5.0.

Version 5.0

The changes to the CAETS program have resulted in the omission of certain modules and the inclusion of new ones. Specifically, modules <CAETS>, <RESPNS>, <ASSIGN>, <ORDER>, <NBPRT>, <SPECTR>, <PRTOUT> and <FILING> have been modified, modules <ADJCHA>, <IFLO>, <TOLER> and <COMMON> have been added, and modules <INTERF> and <ASIGN2> have been omitted. Module <INTERF> has been incorporated into modules <RESPNS> and <COMMON>, while module <ASIGN2> has been incorporated into module <ASSIGN>. Figures A-1 through A-4 depict the modular flowchart of Version 6.0 (Version 5.0 does not include module <GRAPH> in Figure A-1).

Module <CAETS>

Module <CAETS> has been modified to prompt the user for the sample size, and the maximum image order or the maximum values for P and Q. The user, therefore, can now control the maximum image order and the sample size without re-editing, compiling and linking the program's source code.

Module <RESPNS>

This module has been modified to incorporate local oscillator interference which was previously handled by module <INTERF>. The new module, however, no longer calculates the overlap region. It simply loops through every Rx/Tx and Rx/Rx system pair and calls module <COMMON> to test for overlap which in turn calls module <ASSIGN>, to store the interaction, if an interference is detected. Finally, the limits defining the image region have been corrected since the old limits were not valid when S was stated opposite to the sign of the receiver.

Module <ASSIGN>

The revised module assigns relevant information to narrowband arrays for both Rx/Tx and Rx/Rx interactions. Module <ASIGN2>, which previously handled the Rx/Rx interactions, has been omitted. Also, a message is printed at the terminal when over 30,000 narrowband interactions are detected to inform the user that certain narrowband arrays need to be increased. Instead of aborting the calculations, however, Version 5.0 considers only the first 30,000 interactions and proceeds with the algorithm.

Module <ORDER>

Module <ORDER> has been re-written to provide correct frequency coincidences that correspond to system channels. Also, the efficiency of the module has been drastically improved by accurately determining the victim LO range without ever having to step through the entire first LO range. Once the victim LO range has been determined the module proceeds to test every LO setting within the victim LO range. If the module does not determine any candidate LO setting it tests adjacent source channels and resumes the search for a victim

LO. The new module, however, terminates the calculations for an interaction only when both, lower and upper, frequency limits of the overlap region have been exceeded. If only one of the frequency limits, FMIN or FMAX, has been exceeded, the code continues the search in the opposite direction. Previously, the code would abort the interaction if either one of the limits was exceeded.

In calculating the intermediate frequency to which the source channel is converted, the old module employed the wrong equation. This deficiency has been eliminated. However, module <IFLO> now determines the victim IF. Also, the code will correctly account for variable and fixed-IF receivers.

Before terminating any interaction, the new module calls module <ADJCHA> to test adjacent source channels for a more severe response. This is necessary in order to provide frequency coincidences that maximize interference, since there can be many source channels that correspond to a specific victim channel, and vice versa.

When calculating the image region stated opposite to the sign of the receiver, i.e., S*SIGN, the old module would either provide the wrong interaction or omit the interaction altogether. This deficiency has been eliminated and the new module correctly accounts for both image regions.

Finally, the Rx/Rx interactions are not considered separately from the Rx/Tx interactions. The improved module handles all interactions together.

Module <NBPRT>

The enormous amount of data produced in the 'Narrowband' option made it difficult for the user to scan through the victim/source tables in order to check the validity of the results. As such, all frequency coincidences are now displayed according to the dial setting of their corresponding system. This in effect eliminates trailing zeros which, in addition to making the data less legible, delude the user regarding the accuracy of the systems under test.

The POWER SYS 400Hz system presented a new problem to the CAETS program since the code was unable to display frequency coincidences below the VLF range. Module <NBPRT> has been modified to account for this situation. Frequencies below 1.0MHz with at least four digits of accuracy, or frequencies below 1.0KHz, are now displayed as XXX.XX KHz with trailing zeros deleted, instead of XXX.XXX MHz.

In addition, pagination has been added and the titles have been centred on narrowband tables. Also, the Rx/Rx and the Rx/Tx combinations for the same victim receiver are grouped together.

Module <SPECTR>

A minor modification has been made in module <SPECTR> to correct a display error of the local oscillator range. When the first local oscillator stepping of a receiver was negative, the module would not display the LO range.

Module <PRTOUT>

Module <PRTOUT> has been modified to display a positive IF range in the receiver printout when the IF is added to the LO to determine a system channel, and a negative IF range when the IF is subtracted from the LO to determine a system channel. Version 4.2 would erroneously reverse the signs.

Module <FILING>

The stringent format specifications of module <FILING> in the 'Edit' option have been replaced by free format statements. A decimal point in every exponential-type entry is no longer required. Furthermore, error handling ability has been included to avoid abnormal program termination when inputting wrong data while editing an input file. The code will continue to loop until a correct value is entered.

Module <TOLER>

The CAETS narrowband algorithm can now handle frequency coincidences from below the VLF range up to the EHF range. Because the order of magnitude of the difference between two interacting channels can be as high as ten, all narrowband variables have been declared as double precision and a tolerance check has been included in every critical calculation. Specifically, module <TOLER> will test if two frequencies are identical, to within a certain tolerance. All narrowband modules that perform numerical calculations refer to module <TOLER> (see Figure A-1).

Module <IFLO>

Module <IFLO> calculates the IF that corresponds to a victim frequency and a victim LO. The module does not employ the 'V-W' equation in order to calculate the IF of a received channel. A heuristic approach is used instead which attempts to solve for IF in Eq. (4.22) in Chapter 4.

Module <COMMON>

Module <COMMON> tests whether or not two frequency regions overlap and measures the extent of the overlap region. If the call to the module was made by <RESPNS> then module <COMMON> will call <ASSIGN> to store the interaction, otherwise, it will inform the calling module of whether or not the frequency regions overlap.

When testing for intermediate frequency interference between two systems, if the operating range of the source overlapped the IF band of the victim, the old algorithm would assign the lower and upper frequency limits of the overlap region to the centre frequency of the IF band regardless of whether the receiver had a fixed-IF or a variable-IF band. The new algorithm, however, considers the entire IF band of the victim system. This deficiency was a problem primarily with variable-IF receivers since the code would always output at most one IF interaction per interacting system pair regardless of the sample size.

Module <ADJCHA>

The original CAETS program identified frequency coincidences that did not provide the most severe response. The algorithm would sample a source frequency and proceed to determine a suitable victim frequency. This approach does not always provide frequency pairs that will maximize interference since there can be many source frequencies that will correspond to a given victim frequency and vice versa. The improved algorithm calls module <ADJCHA> to test adjacent source channels for a more severe response before terminating the calculations for an interaction.

Version 5.2

The data structure requirements in implementing this revision have resulted in the modification of modules <CAETS> and <RESPNS>. Because the original data structure did not lend itself for the specification of distinct source frequencies, module <CAETS> overwrites the information retrieved from the transmitter data file and models every distinct frequency to be tested as a separate transmitter operating at a fixed channel and having zero channel spacing. The original information stored in the transmitter data file remains unaffected. The code proceeds to test for narrowband interference while module <RESPNS> is signalled to disable LO interference tests.

Version 6.0

The data structure requirements in implementing Version 6.0 have resulted in the inclusion 19 new modules and the modification of the CAETS main program. The new modular flowchart is depicted in Figures A-1 through A-4.

In Figures A-3 and A-4, GRAPG represents a collection of graphic modules which perform fundamental operations such as cursor movement and flushing of the output buffer, and output primitives (written by D. Gaudine).

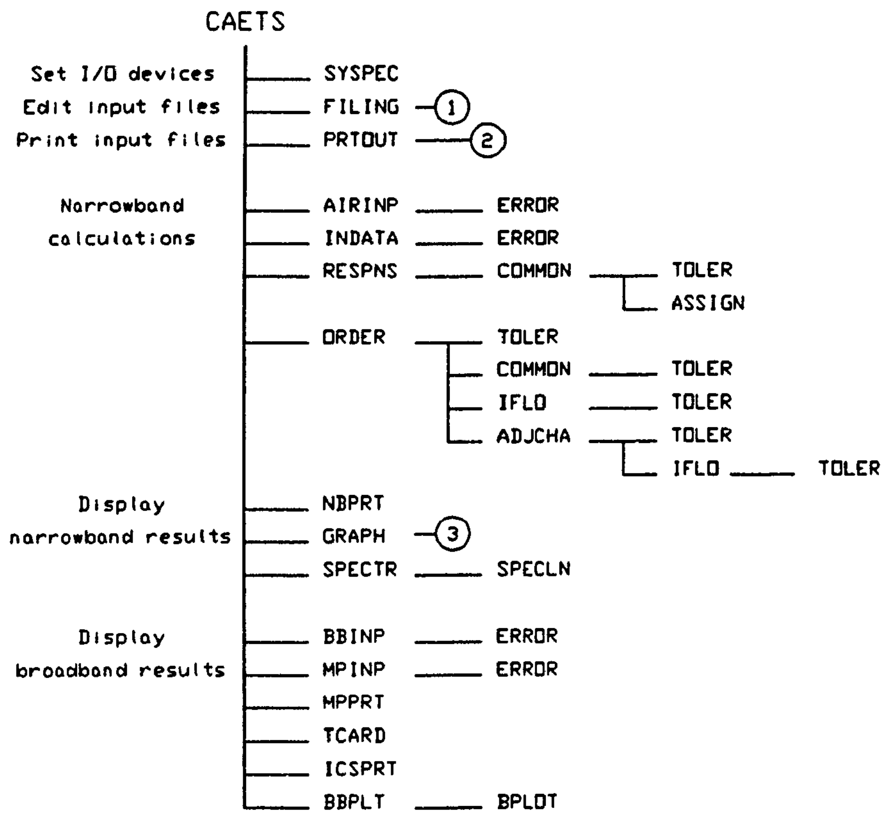

Figure A-1 CAETS Modular Flowchart, Version 6.0

Module <GRAPH>

Module <GRAPH> initializes the graphics and displays the main graphics menu. The user can select harmonic, image, IF or LO coincidences. A summary of all coincidences and a help menu are also available. Upon exiting the graphics option, module <GRAPH> erases the screen and exits the graphics mode.

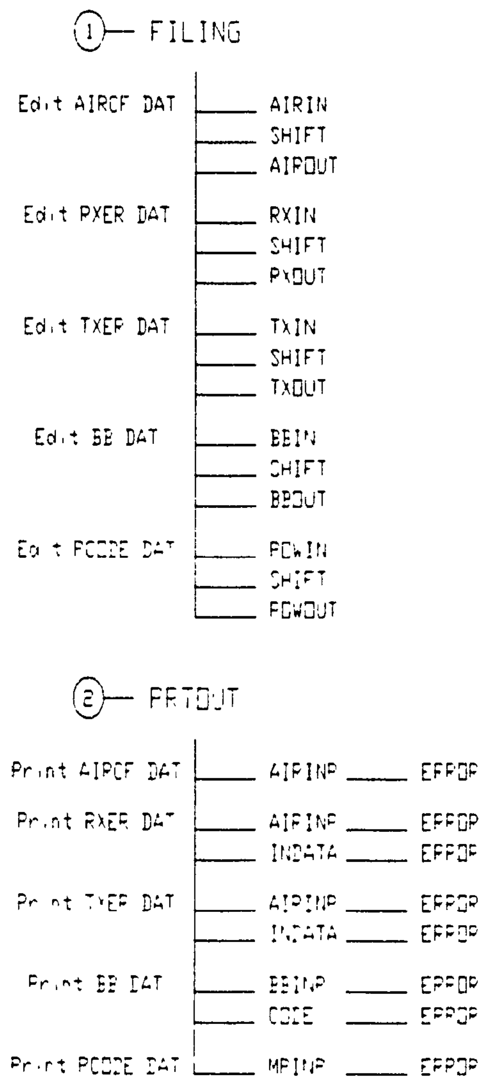

Figure A-2 CAETS Modular Flowchart, Version 6.0 (cont'd)

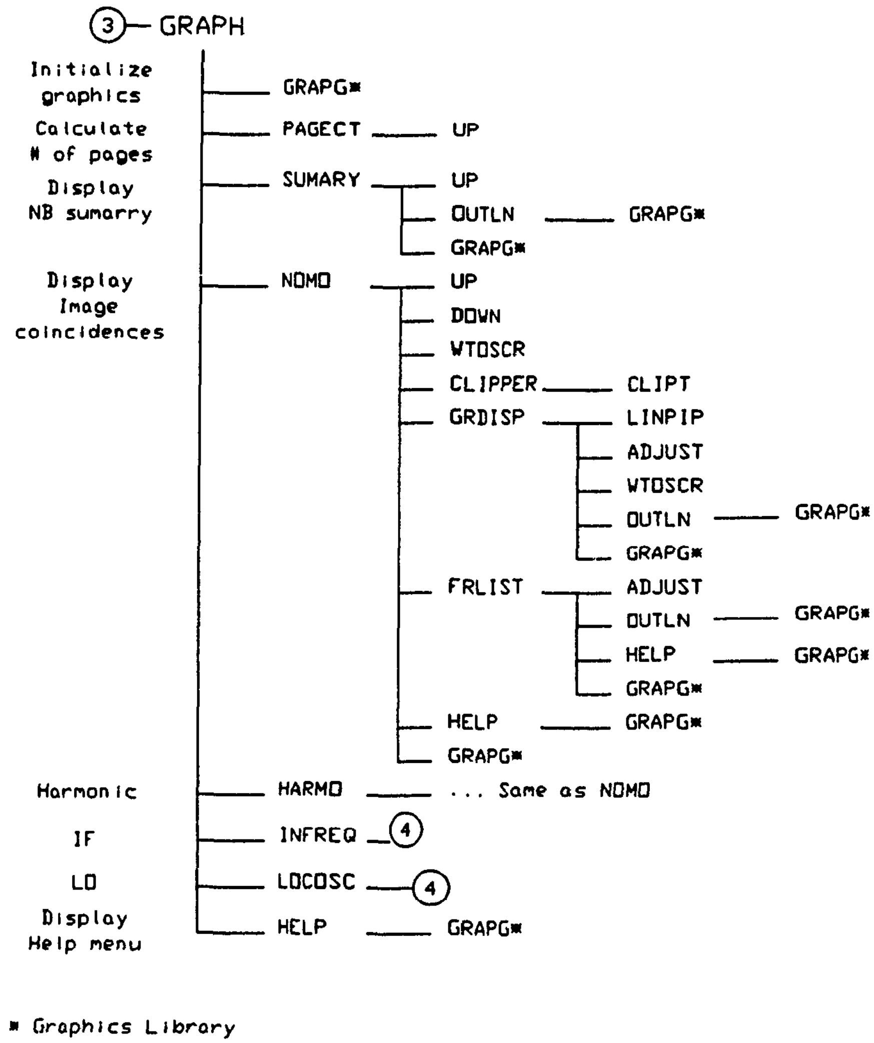

Figure A-3 CAETS Modular Flowchart, Version 6.0 (cont'd)

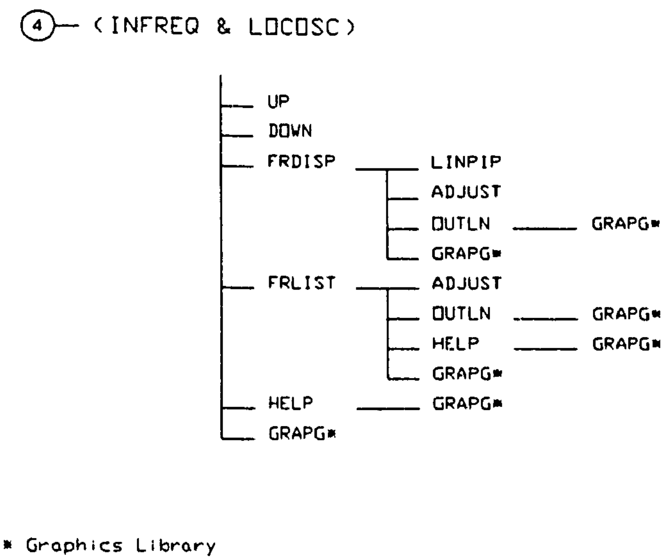

Figure A-4 CAETS Modular Flowchart, Version 6.0 (cont'd)

Module <PAGECT>

Module <PAGECT> calculates the total number of interacting system pairs for every interference mode (harmonic, image, LO and IF). That is, the module will calculate how many systems interfere through harmonic coincidence, how many through image coincidence, and so on. This information is used for pagination.

Module <SUMARY>

Module <SUMARY> generates and displays the narrowband summary (see Figure 6.8 in Chapter 6).

Module <HELP>

Module <HELP> retrieves from memory and echoes to the screen an appropriate help file. There are six help files in total and are labelled as HELP01.DAT through HELP06.DAT. Each file may consist of several pages (32 lines per page). These files can easily be modified to reflect updated revisions. The user merely edits the corresponding file with an editor and the code displays the file 32 lines at a time. If the code does not locate a help file it will display an error message.

Module <HARMO>

Module <HARMO> displays harmonic coincidences. The module reads the narrowband output arrays generated by module <ORDER> and displays the computed test frequencies along with their corresponding harmonic lines (for interactions involving fixed-tuned systems, only the computed test frequencies are displayed). The module also displays the menu located at the bottom of the screen and the page number at the top right-hand corner of all the harmonic templates.

Module <NOMO>

Module <NOMO> displays image coincidences. The module reads the narrowband output arrays generated by module <ORDER> and displays the computed test frequencies along with their corresponding image lines (for interactions involving fixed-tuned systems, only the computed test frequencies are displayed). The module also displays the menu located at the bottom of the screen and the page number at the top right-hand corner of all the image templates.

Module <GRDISP>

Module <GRDISP> generates the graphics templates for harmonic and image coincidences. The template consists of an outline box (generated by module <OUTLN> and contains the date, the aircraft name, the classification and the header), the interacting system names (SOURCE vs VICTIM), and the source and victim axes along with their divisions (generated by module <LINPIP>).

Module <INFREQ>

Module <INFREQ> displays IF coincidences. The module reads the narrowband output arrays generated by module <ORDER> but does not display the computed test frequencies. Instead, the module displays the system characteristics of the equipment under test. Specifically, the module displays the tuning range of the offending transmitter, and the IF, the LO and the tuning range of the victim receiver. The module also displays the menu located at the bottom of the screen and the page number at the top right-hand corner of all the IF templates.

Module <LOCOSC>

Module <LOCOSC> displays LO coincidences. The module reads the narrowband output arrays generated by module <ORDER> but does not display the computed test frequencies. Instead, the module displays the characteristics of the interacting systems. Specifically, the module displays the tuning range, the IF range and the LO range of the victim and offending receivers. The module also displays the menu located at the bottom of the screen and the page number at the top right-hand corner of all the LO templates.

Module <FRDISP>

Module <FRDISP> generates the graphics templates for LO and IF coincidences. The template consists of an outline box (generated by module <OUTLN> and contains the date, the aircraft name, the classification and the header), the interacting system names (SOURCE vs VICTIM) and the source and victim axes with their divisions (generated by module <LINPIP>). The code offers the choice of a linear or a logarithmic scale. When the linear scale is active, all divisions on the axes are displayed according to the dial setting of the system with the greatest tuning accuracy (module <ADJUST> deletes trailing zeros).

Module <FRLIST>

Module <FRLIST> lists the computed test frequencies of the equipment under test. Although the LO and IF templates do not display the computed test frequencies, a frequency list is available for all the templates.

Module <OUTLN>

Module <OUTLN> generates a graphical template consisting of an outline box, the date, the aircraft name under test and the classification.

Module <WTOSCR>

Module <WTOSCR> maps world coordinates onto screen coordinates for image and harmonic coincidence only. If either the source and/or the victim is fixed-tuned, the module will map every point to the centre of the axis that corresponds to the fixed-tuned system.

Module <ADJUST>

Module <ADJUST> displays every frequency according to the dial setting (i.e tuning accuracy) of its corresponding system. In essence, the module deletes trailing zeros.

Module <LINPIP>

Module <LINPIP> generates five (occasionally four or six) frequencies to be displayed as frequency divisions on the axes for image and harmonic templates. The frequencies are selected such that they fall within the operating limits of the equipment under test, and that the increment between two consecutive frequencies contains the least amount of significant digits. In essence, this guarantees that the frequency divisions will simplify the process of extrapolating coordinates of points from the screen.

Modules <UP> and <DOWN>

The graphics option divides the narrowband interactions into pages. A page, herein, is referred to as the locus of all interactions involving the same victim and source systems, and interfering in the same mode. This approach facilitates the process of scanning through the narrowband results. Module <UP> provides the page that follows the current page while module <DOWN> provides the previous one.

Modules <CLIPPER> and <CLIPT>

Every image and harmonic line is clipped against the window limits defined by the minimum and maximum operating frequency limits of the systems under test. Modules <CLIPPER> and <CLIPT> employ the Liang & Barsky line clipping algorithm.