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Effects of the Mark XII and Mark XV Identification Friend or Foe (IFF) Systems on the ATCRBS Ground System

Robert Pomrink
Ralph Yost

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16. Abstract

The Federal Aviation Administration is responsible for the safe operation of the National Airspace System (NAS) which uses the radio navigation L-band 960-1215 (megahertz) MHz. The military Mark XII and Mark XV Identify Friend or Foe (IFF) systems are used on the same frequencies as the FAA's Air Traffic Control Radar Beacon System (ATCRBS). Therefore, electromagnetic compatibility (EMC) testing is required to determine the interference effects of the Mark XII and its replacement, the Mark XV system, on the air traffic control beacon interrogator (ATCBI-5). The purpose of this test effort was to determine if the Mark XV has any greater effect on the ATCBI-5 receiver than the Mark XII.

The Mark XII and Mark XV were operated at pulse repetition frequency (PRF's) of 167, 333, and 500. The Mark XII is normally operated at a PRF of 333, while the Mark XV is expected to be operated at a PRF of 167. Both systems transmit on the 1090 MHz receive frequency of the ATCBI-5. No data were collected for signal levels greather than -30 decibels above 1 milliwatt (dBm).

The Mark XII system tests did not indicate noticeable effects on the ATCBI-5. However, when the Mark XV tests were conducted, the data showed that the ATCBI-5 performance was noticeably degraded, especially as the PRF was increased. Those performance parameters that were affected include receiver quantized pulses, sensor receiver and processor (SRAP) lead edge count, bracket decodes, and desired target quality scores.

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INTRODUCTION

PURPOSE.

The purpose of this effort was to determine the impact on the Air Traffic Control Radar Beacon System (ATCRBS) ground interrogator/receiver when subjected to signals from the United States Military Identification Friend or Foe (IFF) Mark XII and Mark XV systems. Specifically, this report deals with how the Mark XII and Mark XV systems affect the performance of the ATCRBS ground system.

BACKGROUND.

The United States military currently uses the Mark XII IFF system throughout the United States when conducting certain military exercises. The Mark XII system was designed and authorized to operate on the same frequency as the Federal Aviation Administration's (FAA) ATCRBS ground system: 1030 megahertz (MHz) uplink and 1090 MHz downlink. The military is currently developing the Mark XV as a replacement for the Mark XII. As part of this development, the military requires an extension of the limits on their designated time and geographic areas of aircraft flight using the Mark XV. Since it is the FAA's responsibility to insure the safety and integrity of the national airspace, the extension of flight limitations using the Mark XV could not be granted until data were collected to show the electromagnetic compatibility (EMC) effects of the Mark XII and Mark XV on the air traffic control beacon interrogator (ATCBI-5). One premise for granting an extension of the flight limitations is that the Mark XV cannot have a greater interference effect on the ATCBI-5 than the Mark XII.

DESCRIPTION OF EQUIPMENT

ATCRBS GROUND EQUIPMENT DESCRIPTION.

The ATCRBS is designed with the primary function of surveillance of cooperative aircraft for air traffic control (ATC) purposes. The system requires aircraft transponders and ground interrogator equipment to determine aircraft position. Aircraft identity and altitude are derived from coded transponder replies to the ground interrogations.

The ATCRBS is a cooperative system which consists of (1) a ground-based rotating directional antenna system, (2) interrogator/receiver (ATCBI-5), (3) a sensor, receiver and processor (SRAP) which processes the pulse information, (4) the ATC computer system, automated radar terminal system (ARTS) IIIA, and (5) active aircraft transponders.

The ground-based interrogations are radio frequency (RF) pulse groups transmitted by the ground equipment on 1030 MHz to interrogate all aircraft within the area of coverage. Upon receiving an interrogation, the aircraft transponder transmits a coded reply pulse train back to the ground station at a frequency of 1090 MHz.

Depending on the pulse spacing of the interrogation pulse groups (mode 3/A - 8 microseconds, mode C - 21 microseconds), the aircraft reply contains the aircraft identity selected by the pilot (mode 3/A) or the aircraft altitude as measured by the onboard barometric altimeter and encoded for mode C transmission. The ground-based equipment can then automatically decode the information and determine the aircraft range, azimuth, identity, and altitude.

Figure 1 is a block diagram of the receiver portion of the ATCBI-5/SRAP. The ATCBI-5 is the interrogator/receiver portion of the ATCRBS. The interrogator provides periodic beacon synchronous triggers (time zero triggers) and corresponding periodic interrogation. These interrogations are time-shared between mode 3/A and mode C. The interrogators are normally operated in a one-to-one mode interlace pattern where the interrogation pattern is mode 3/A, C, 3/A, C, etc.

The receiver accepts 1090 MHz replies from the directional antenna and passes these replies through a mixer, intermediate frequency (IF) amplifier, several video amplifiers, a band pass filter, a quantizer, and then output via a limiter/driver. A sensitivity time control (STC) is applied to the IF amplifier to desensitize the receiver for a fixed amount (generally 30 decibels (dB)) at zero range and then allows the receiver to recover at the rate of space attenuation (6 dB/double the range). This STC function prevents saturation of the IF amplifier from close-in aircraft replies.

The output pulses of the ATCBI-5 receiver are passed through a defruiter (interference blanker MX8757/UPX). The defruiter's function is to allow only replies that are synchronous with the interrogation to pass on to the processors. Eliminating asynchronous replies is achieved by delaying all the pulses by one pulse repetition frequency (PRF) interval and then comparing them with those in the next PRF interval of the same mode (mode 3/A, mode C). The pulses that are not coincident in each period are eliminated.

The SRAP consists of two distinct units: the radar data acquisition subsystem (RDAS) and the beacon data acquisition subsystem (BDAS).

The function of RDAS is to detect and transfer aircraft target and weather data derived from search radar video returns. The BDAS provides detection and transfer of aircraft target data derived from beacon transponder replies supplied from the output of the defruiter. The BDAS also correlates and merges radar and beacon target report data and outputs the target report data and weather data to ARTS IIIA input/output processors and then to an ATC display.

Associated with each ATCBI-5 equipment is a beacon test target generator (TTG). The TTG is a controlled source of 1090 MHz aircraft-like replies to interrogations from the ATCBI-5 interrogator. The TTG is triggered from beacon triggers and the reply code, range, azimuth, and number of replies per aircraft are controlled by front panel controls. The TTG allows for generating 16 targets, all at the same range and reply code and uniformly distributed in azimuth through 360°. The TTG was used in this test effort as the source of desired targets.

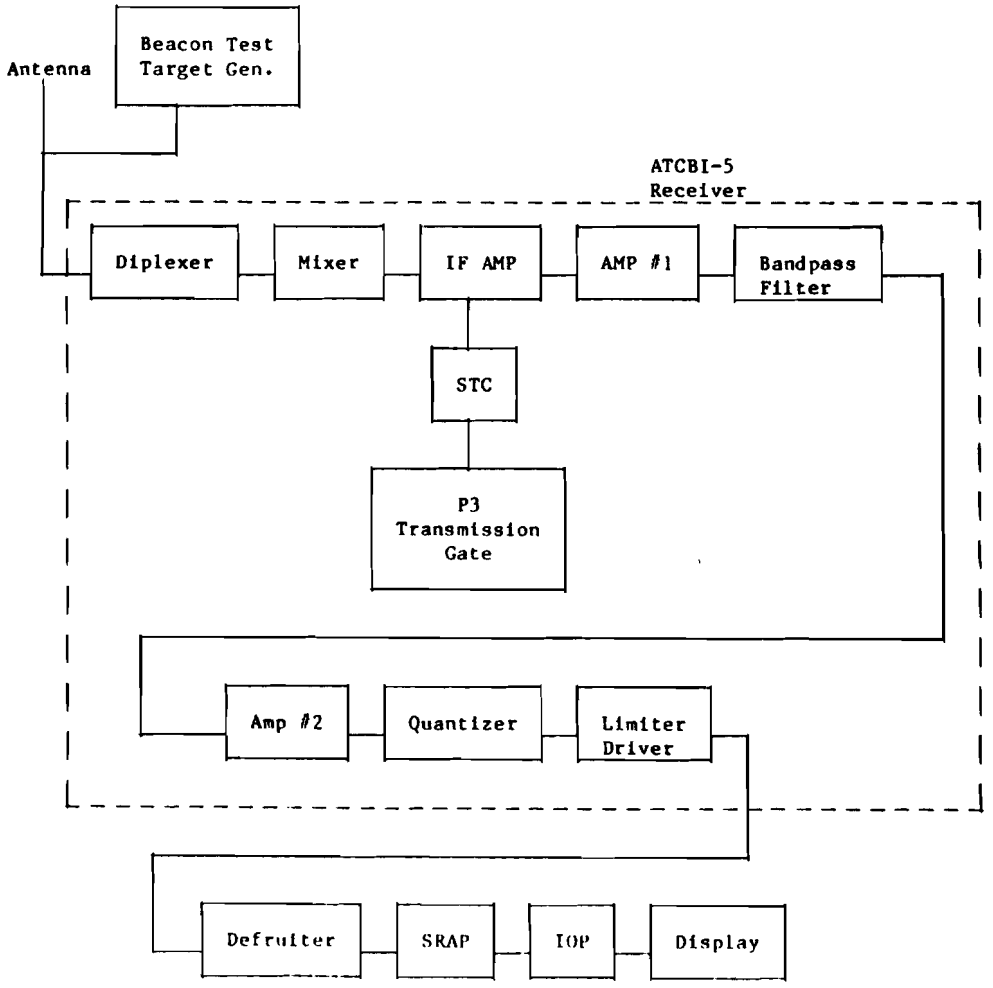

FIGURE 1. BLOCK DIAGRAM OF THE RECEIVER PORTION OF THE ATCBI-5/SRAP SYSTEMS

MARK XII/MARK XV SYSTEM DESCRIPTION.

The Mark XII and Mark XV are military IFF systems which operate in the L-Band (960-1215 MHz). Specifically, the Mark systems utilize a ground-based interrogator which transmits on 1030 MHz and receives airborne replies at 1090 MHz. The Mark XV is a replacement version of the Mark XII and has somewhat different transmission characteristics than the Mark XII. The Mark XII is operated at a typical PRF of 333 while the Mark XV is expected to be operated at a typical PRF of 167.

Like the ATCRBS and Mode S system, both Mark systems can operate in mode 3/A and mode C at 1030/1090 MHz. However, during military exercises the Mark systems use mode 4 which has a different waveform characteristic than ATCRBS. For example, the Mark XII mode 4 downlink replies (1090 MHz) have a short duration three-pulse waveform, while the Mark XV uses a very long duration waveform. Comparison of the Mark XII and Mark XV mode 4 replies along with the ATCRBS mode 3/A or mode C replies is shown in figure 2.

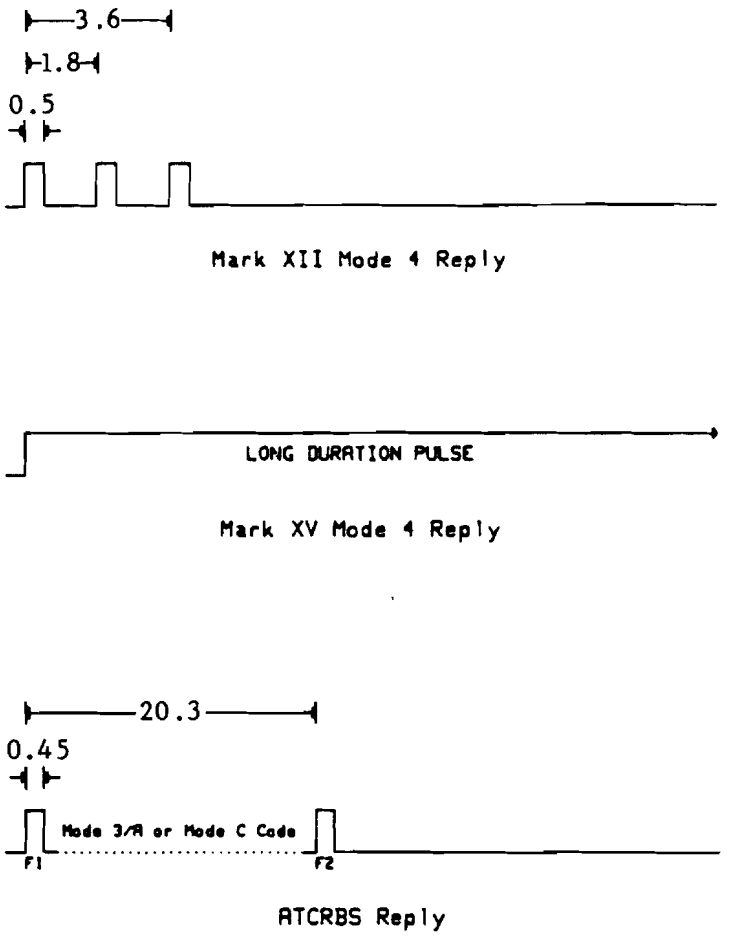

FIGURE 2. COMPARISON OF MARK XII AND MARK XV MODE 4 REPLIES TO THE ATCRBS MODE 3/A OR MODE C REPLIES

DISCUSSION

METHOD OF APPROACH.

Due to the Mark XV systems downlink transmissions on 1090 MHz and the FAA's responsibility to ensure that the aeronautical radio navigation systems operate at the required performance level, EMC testing must be performed on the ATCRBS ground system which receives on 1090 MHz. These tests were designed to determine the interference effects of the Mark XV, as compared to those of the Mark XII, at each level of signal processing within the ATCRBS.

The Mark XV/ATCBI-5 EMC tests were performed at the ATCBI-5 site at the FAA Technical Center. Prior to the testing, the ATCBI-5/SRAP systems located at this site were inspected to ensure that they were operating in accordance with FAA specifications.

In order to properly test the EMC of the Mark systems and the ATCBI-5/SRAP/ ARTS IIIA systems, the following steps were performed. First, the performance parameters that indicate the effect of interference at each processing level within the ATCRBS ground system were determined. Second, test equipment was configured to measure the ATCBI-5/SRAP performance parameters. Finally, data collection software was designed and developed to remotely program and control test equipment as well as collect and process data; also, beacon target report data were collected and processed using existing ARTS IIIA software. Through the successful completion of these tasks, an automated test equipment system was developed to measure the performance of the ATCRBS ground system operating in an extraneous pulse environment.

ATCRBS PERFORMANCE PARAMETERS.

The following performance parameters within the ATCBI-5/SRAP/ARTS IIIA systems were chosen to measure the effect the Mark XII and Mark XV have on the ATCRBS ground system: (1) receiver quantized pulses, (2) SRAP quantized pulses, (3) lead edge pulses, (4) total bracket decodes, (5) desired bracket decodes, (6) beacon targets with quality scores of six and seven, (7) beacon targets with correct range, azimuth, identity, and altitude. The block diagram of the ATCRBS ground system (figure 3) shows the system processing level where each performance parameter is located.

The first performance parameter measured was receiver quantized pulses. Receiver quantized pulses are the demodulated video outputs of the ATCBI-5 which will be sent to the defruiter for further processing. This parameter was monitored to give an indication of the amount of extraneous pulse interference passed and/or rejected by the ATCBI-5 receiver.

The next parameter measured was the SRAP quantized pulses. The SRAP quantizer is the first processing circuitry within the SRAP. This circuitry reshapes pulses from the defruiter and rejects pulses with a width less than 0.15 microseconds. When compared to the receiver quantized pulses, this parameter indicates how effective the defruiter is in eliminating undesired pulses.

The output of the SRAP quantizer is sent to the lead edge circuitry. The lead edge circuit outputs a pulse at the lead edge of each pulse input to it. If a wide pulse (greater than 0.621 microseconds) is detected, the lead edge circuit will output another pulse at the trail edge of the wide pulse since the lead edge circuit assumes a wide pulse to be overlapped ATCRBS pulses. All pulses that pass the lead edge circuit criteria are considered to be valid ATCRBS reply pulses. Therefore, this parameter is monitored to indicate either the number of "valid" ATCRBS reply pulses generated from interference or the number of "desired" ATCRBS reply pulses eliminated by interference.

The lead edge pulses are then output to the bracket decode detector. The bracket decode circuitry measures the separation of the F1 and F2 reply pulses. If these pulses are determined to be 20.3 microseconds apart, this circuit outputs a "bracket decode" pulse which identifies the pulse train in question as a valid ATCRBS reply. When a bracket decode pulse is generated, the SRAP obtains azimuth and range data and decodes the information bits between F1 and F2 into the mode 3/A or mode C information, whichever is appropriate at the time, for that reply. The output of the bracket detector is known as "total bracket decodes." The total bracket decode count is used to give an indication of the number of replies which are caused by an extraneous pulse environment.

To identify which decodes are caused by interference and which decodes can be attributed to the desired signal, a video pulse from the desired target generator is delayed until bracket detection time and then sent to a dual input logical "AND" gate. The second input to the "AND" gate is total bracket decodes from the output of the bracket decode circuitry. The output of the "AND" gate is desired bracket decodes. Through this technique, desired bracket decodes can be obtained and compared to total bracket decodes. This will indicate the number of decodes generated and/or the number of desired decodes eliminated by the interfering source.

The next performance parameter measured is quality score. The quality score indicates the number of replies greater than four that are received for a specified beacon target. When an extraneous pulse environment is injected into the ATCBI-5, a reduction in the quality score for a beacon target indicates that some desired replies were eliminated by this interference. The quality score information is obtained from ARTS IIIA data reduction software.

The final measure of performance of the ATCRBS ground system is the number of beacon targets with correct range, azimuth, identity, and altitude. This information is obtained from the ARTS IIIA computer which determines the percentage of correct beacon targets detected over a specified number of antenna scans. These data give an indication of the ability of the ATCRBS to correctly display desired targets when the system is subjected to interference.

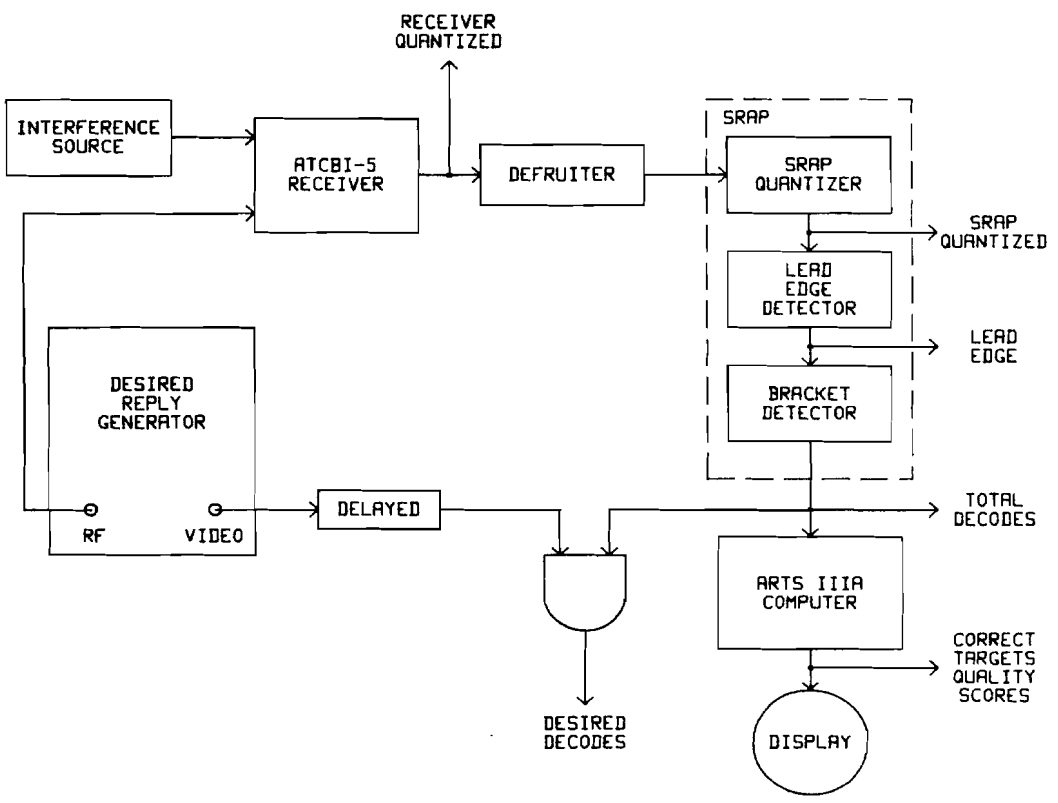

FIGURE 3. BLOCK DIAGRAM OF THE ATCRBS GROUND SYSTEM

TEST CONFIGURATION.

The test equipment configuration used to collect performance data on the ATCBI-5/SRAP systems is shown in figure 4. The desired and interfering signals used in testing were generated by ATCRBS reply generator number 1 and the Mark XV/XII waveform generators, respectively. ATCRBS reply generator number 1 generated a ring of 16 ATCRBS targets having an identity code of 7730, an altitude of 20,100 feet, a range of 34 nautical miles, a run length of 11 replies, and an equal distribution in azimuth around this ring. The Mark XV/XII waveform generators generated their respective MODE 4 reply as the interfering signal.

The signal inputs to the ATCBI-5 receiver were controlled through the use of an RF switch and programmable attenuators, which were driven by the attenuator/switch driver, in conjunction with a hybrid coupler. The RF switch was used to control the input of the desired signal to the receiver while the programmable attenuators controlled the Mark XV/XII signal level into the receiver. Coupling of the desired and interfering signals into the direct antenna port of the ATCBI-5 was accomplished by using a hybrid coupler.

Five of the performance parameters outlined in the previous section were measured using Hewlett Packard (HP) 5000 series counters. Receiver quantized pulses were measured directly from the ATCBI-5, while SRAP quantized pulses and lead edge pulses were measured directly from the SRAP. Since the amplitude of the total bracket decode pulses from the SRAP were low, the total bracket decode pulses were regenerated using the 7D15 unit in oscilloscope number 1. The output of the 7D15 unit, total bracket decodes, was then measured with a counter and also used as one of the "AND" gate inputs to the 7D15 unit in oscilloscope number 2. The other input to the desired bracket decodes "AND" gate was obtained by using the 7B53A in oscilloscope number 2 to generate a single video pulse and to delay this pulse until bracket detection time for each reply pulse train input. The output of the 7D15 unit in oscilloscope number 2, desired decodes, was then measured with a counter.

Another HP 5000 series counter was used to determine the occurrence of the azimuth reference pulse (ARP). The function of this counter was to start/stop the five performance parameter counters to obtain counts over an entire scan.

When an external trigger was required, reply generator number 2 functioned as the triggering mechanism for the Mark XV/XII interference source. Oscilloscope number 3 was used to monitor the triggering of the interference source as it relates to the desired reply pulse train.

The HP 300 series computer, through use of the HP interface bus, functioned as the system controller. The computer was used to control and program the performance parameter counters and to control the signal input to the ATCBI-5. This computer system also collected and processed the performance parameter data which were measured with the counters.

Finally, the ARTS IIIA system, located in the Terminal Systems Support Facility, collects and processes beacon target report data.

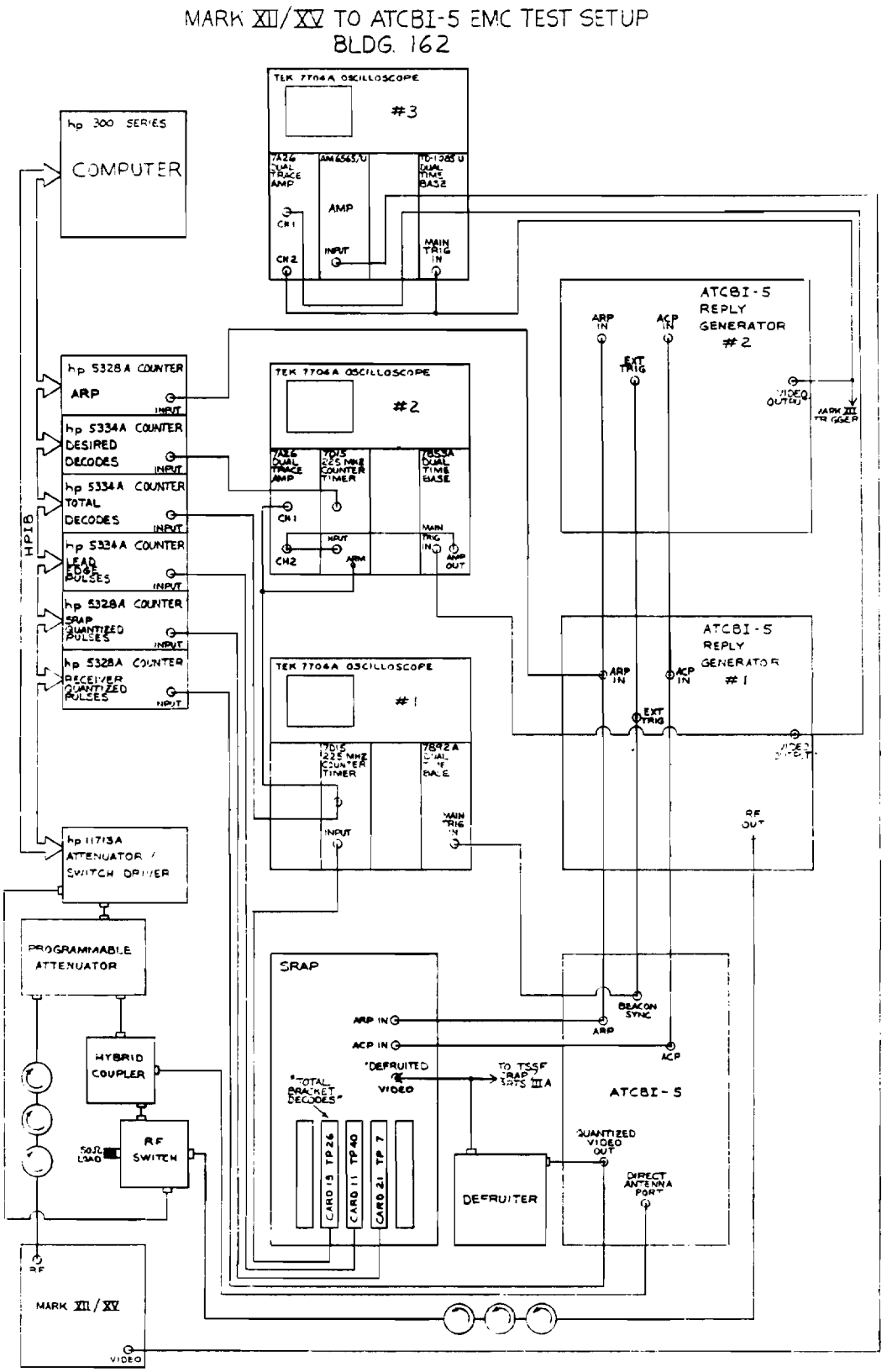

FIGURE 4. TEST EQUIPMENT CONFIGURATION

DATA COLLECTION METHOD.

Two software packages were required for the Mark XV/ATCBI-5 EMC data collection effort. The software designed and developed on the HP 300 series computer, hereafter referred to as "the 300 series software," was used to control the input of signals to the ATCBI-5 and to collect performance data on the ATCBI-5/SRAP systems. ARTS IIIA data collection software was used to collect data on beacon target reports.

Upon execution of the 300 series software, the initialization of the data collection process was performed. The test conditions, Mark XV/XII interfering signal levels, and data storage file names were input to the computer. After these inputs, the test equipment used for data collection was initialized for remote programming and control. Then the software fully attenuates all signal inputs to the ATCBI-5 for three scans to indicate a change in test conditions. Upon completion of these three blank scans (reception of three ARP's by the ARP counter), the interfering and desired signals were injected into the ATCBI-5/ SRAP/ARTS IIIA systems.

After initialization, the data collection process for each interfering signal level began. When the next ARP was received, the performance parameter counters were programmed to start counting. At the completion of a scan, next ARP, the counters were stopped and data were removed from the counters and processed by the program. The counters were then reset to start counting when the next ARP occurred. This process continued until 30 scans of performance parameter data were obtained from the counters. Then all input signals to the ATCBI-5 were fully attenuated for three scans to distinguish changes in the Mark XII/XV signal levels. After these blank scans, the RF output of the Mark XII/XV was changed to the next signal level to be tested, and the data collection process was restarted.

As a result of this process, 63 scans were required to collect data for each Mark signal level tested under a particular condition. Three blank scans at the beginning of each signal level followed by 30 scans of data collection interlaced with 30 scans of zero counter data collection were necessary to obtain the desired data. The 30 scans of zero counter data collection were required to allow time for the collection and processing of data after each of the data collection scans.

After testing was completed at a particular Mark XV/XII signal level, the mean value and the standard deviation for each performance parameter within the ATCBI-5/ SRAP systems were computed, using the 30 data samples, and then output to a printer. This real-time processing and data display were necessary to ensure that the test setup was functioning properly. If any abnormalities were noted in the data sent to the printer, the malfunction in the test setup was corrected before a significant amount of incorrect data were collected. Therefore, real-time processing reduced test time and placed greater confidence in the data collected.

When testing was completed for a particular test condition, the data were stored on disk. The mean value and standard deviation of each ATCBI-5/SRAP performance parameter, as well as Mark signal levels, test times, and test conditions, were stored on a 3.5-inch microdisk. Due to the storage limitations of the microdisk, a 14-megabyte HP9134 hard disk was used to store all of the raw data along with the processed data stored on the microdisk. This data storage scheme avoids the use of large numbers of microdisks and provides for rapid recall if future data analysis is required.

The ARTS IIIA data collection program processed and collected information on individual beacon target reports. Since the ARTS IIIA software collected data continuously, data were collected over a period of 60 scans for each Mark XV/XII interfering signal level tested. These data were stored on disk for future reduction and analysis.

After the Mark XV/ATCBI-5 EMC testing was completed, a data reduction program for the ARTS IIIA computer system was used to obtain the quality score and correct target performance measurements for the beacon target data.

TEST RESULTS AND ANALYSIS.

INTERFERENCE EFFECTS FROM THE MARK SYSTEMS OPERATING AT A PRF OF 167. The performance of the ATCBI-5 was virtually unaffected by the injection of Mark XII signals at a PRF of 167. Figure 5 shows plots of data collected when the Mark systems were injected into the ATCBI-5 at a PRF of 167. The increase in the number of pulses measured at the output of the victim receiver (figure 5a) nearly doubled (see table 1 under "Receiver Quantized" column heading). Further examination of tables 1 and 2 and figure 5 indicates that all other performance parameters measured were unchanged. Table 2 shows the summarized data from the ARTS IIIA data reduction program which tabulates the blip scan and quality score information used to generate the bar graphs for figures 5f, 5g, and 5h.

As can be seen from the data plots in figure 5 and tables 1 and 2, the Mark XV has a different effect on some ATCRBS performance parameters than the Mark XII. The data show that when the Mark XV was operated at a PRF of 167, its wide pulses passed through the ATCBI-5 receiver and increased the number of receiver quantized pulses (relative to the baseline with no interference) by approximately 1,100 percent, with the highest number occurring at -70 dBm. However, figures 5b and 5c show that the defruiter effectively eliminated most of these additional pulses. SRAP quantized and lead edge counts showed maximum increases of 2 and 4 percent, respectively. Figures 5a and 5c illustrate that the Mark XV has a greater effect on the receiver quantized and lead edge parameters than the Mark XII. Total and desired bracket decodes were basically unchanged (figures 5d and 5e). The slight drop in total bracket decodes that occurs when the Mark XV is at -80 dBm is translated further down the processing line as a reduction in desired targets with quality scores of six and seven (see figure 5f). Figure 5g shows about a 15 percent reduction in the number of desired targets with quality scores of just seven due to Mark XV interference (at RF levels -30 dBm to -80 dBm). These changes in quality score data indicate an elimination of the number of correct beacon replies used to make up a target report. Correct detection of desired target azimuth, range, identity, and altitude codes (collectively known as "blip scan") remained essentially unchanged. Figure 5h shows the blip scan data, indicating no reduction in the number of correct desired targets as seen by the ARTS IIIA, even though fewer replies were used to make up these targets.

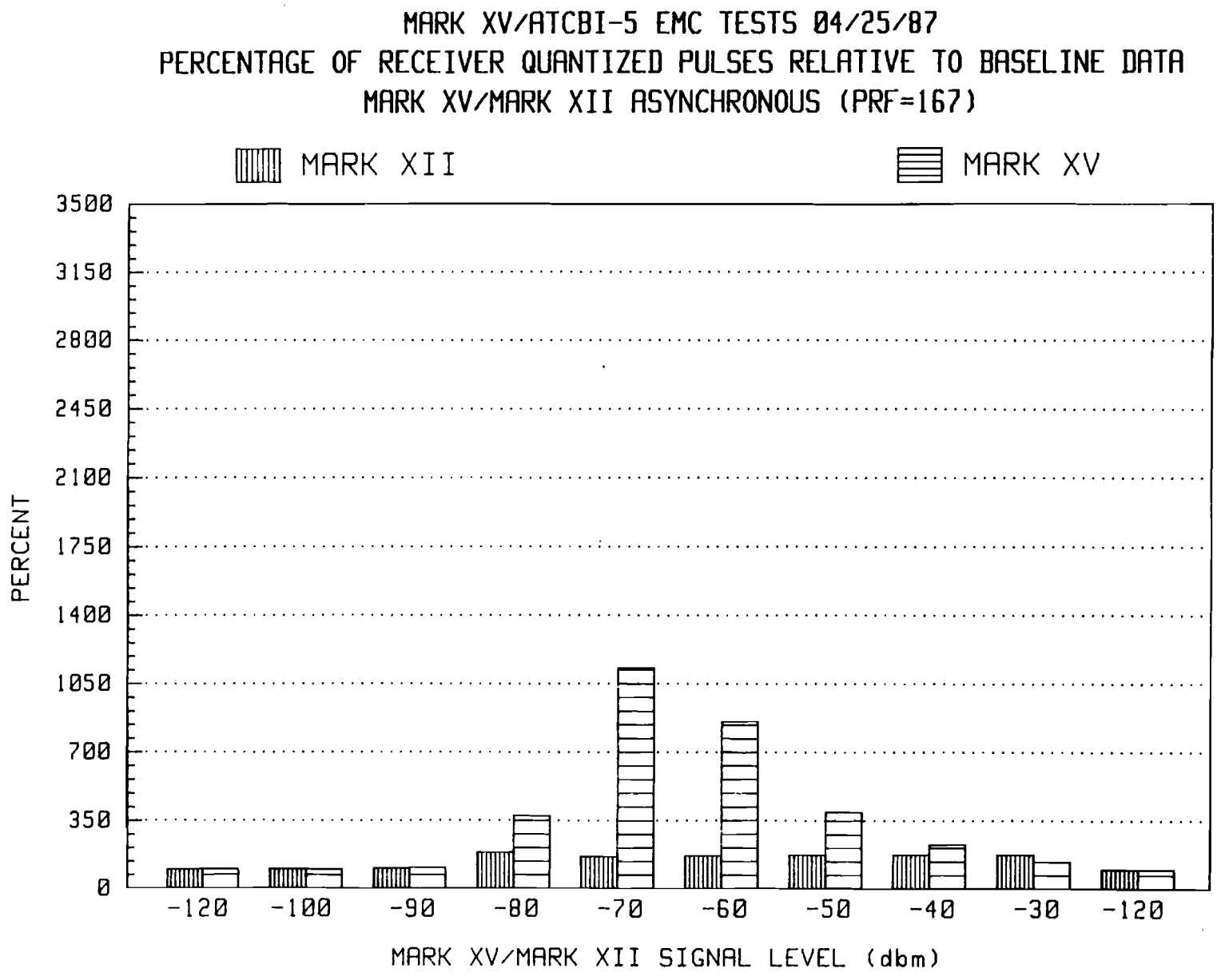

FIGURE 5a. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 167 (1 of 8)

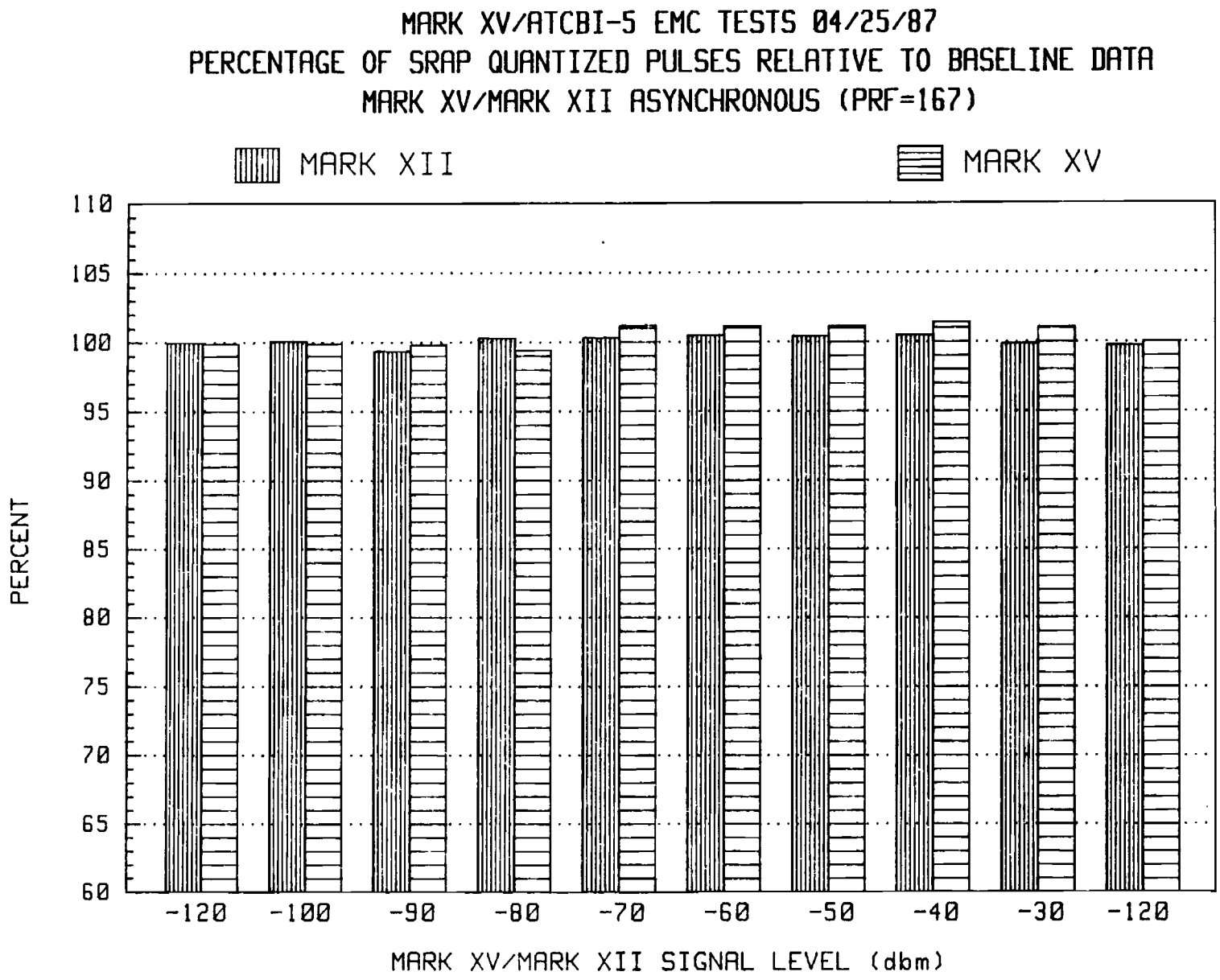

FIGURE 5b. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 167 (2 of 8)

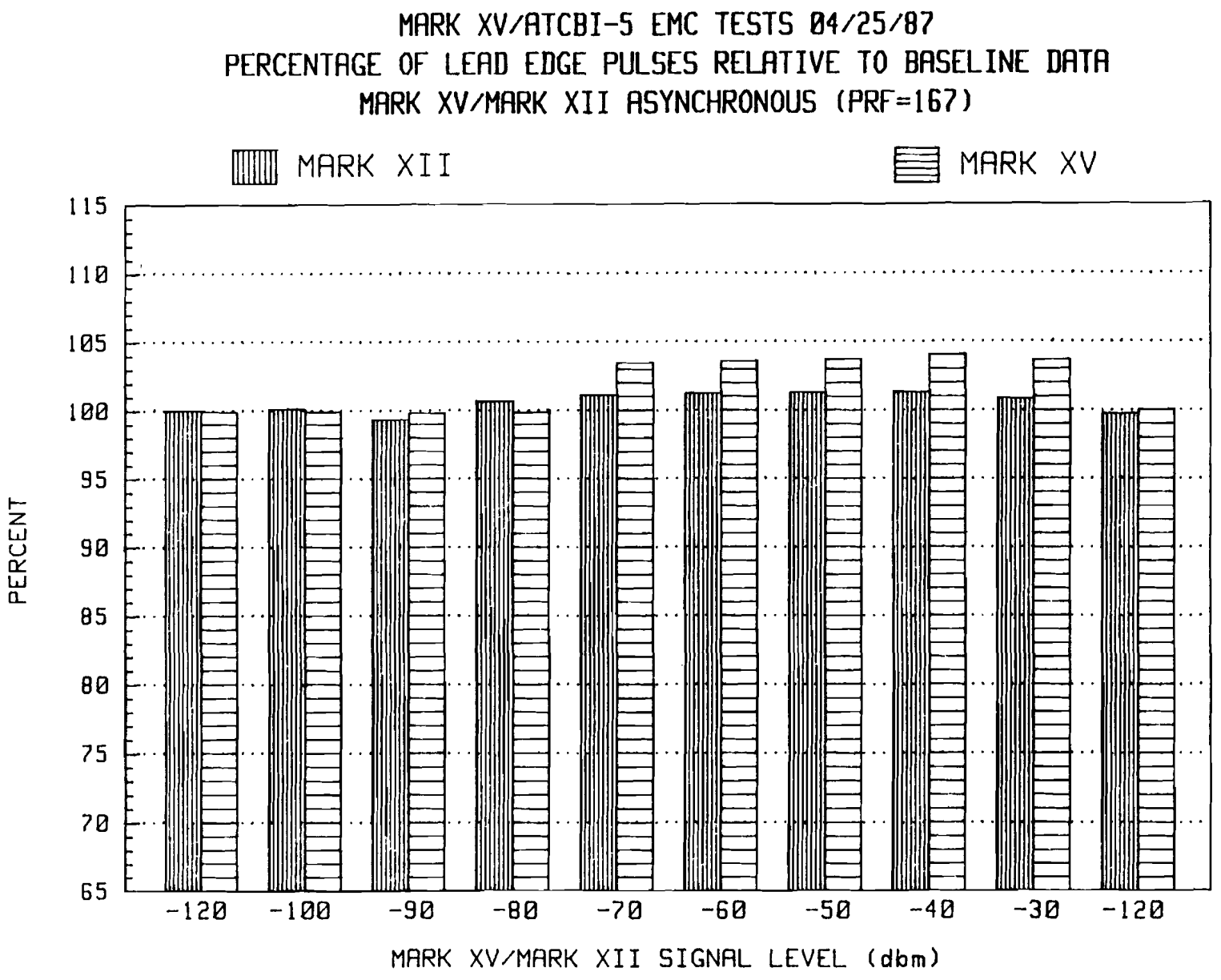

FIGURE 5c. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 167 (3 of 8)

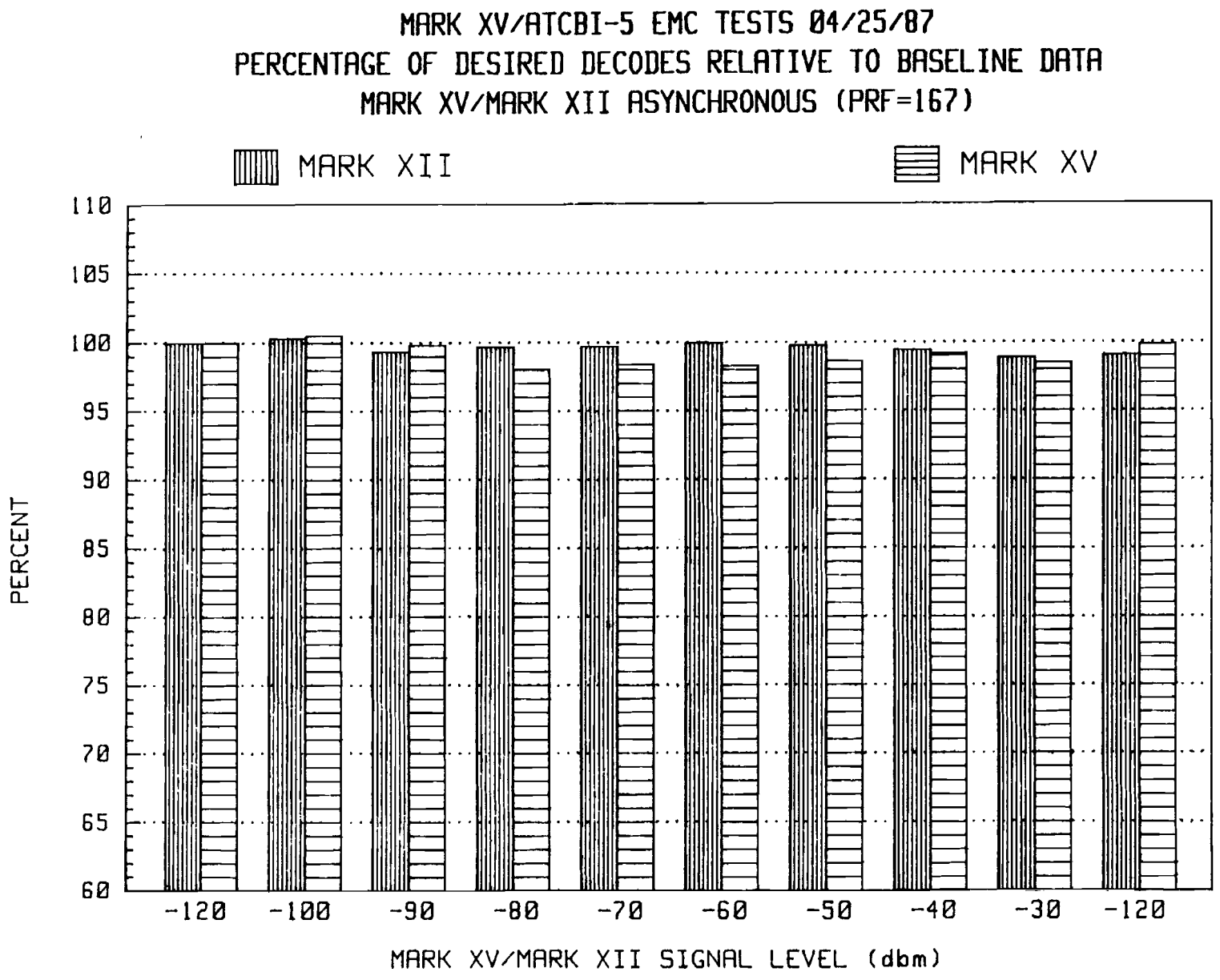

FIGURE 5d. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 167 (4 of 8)

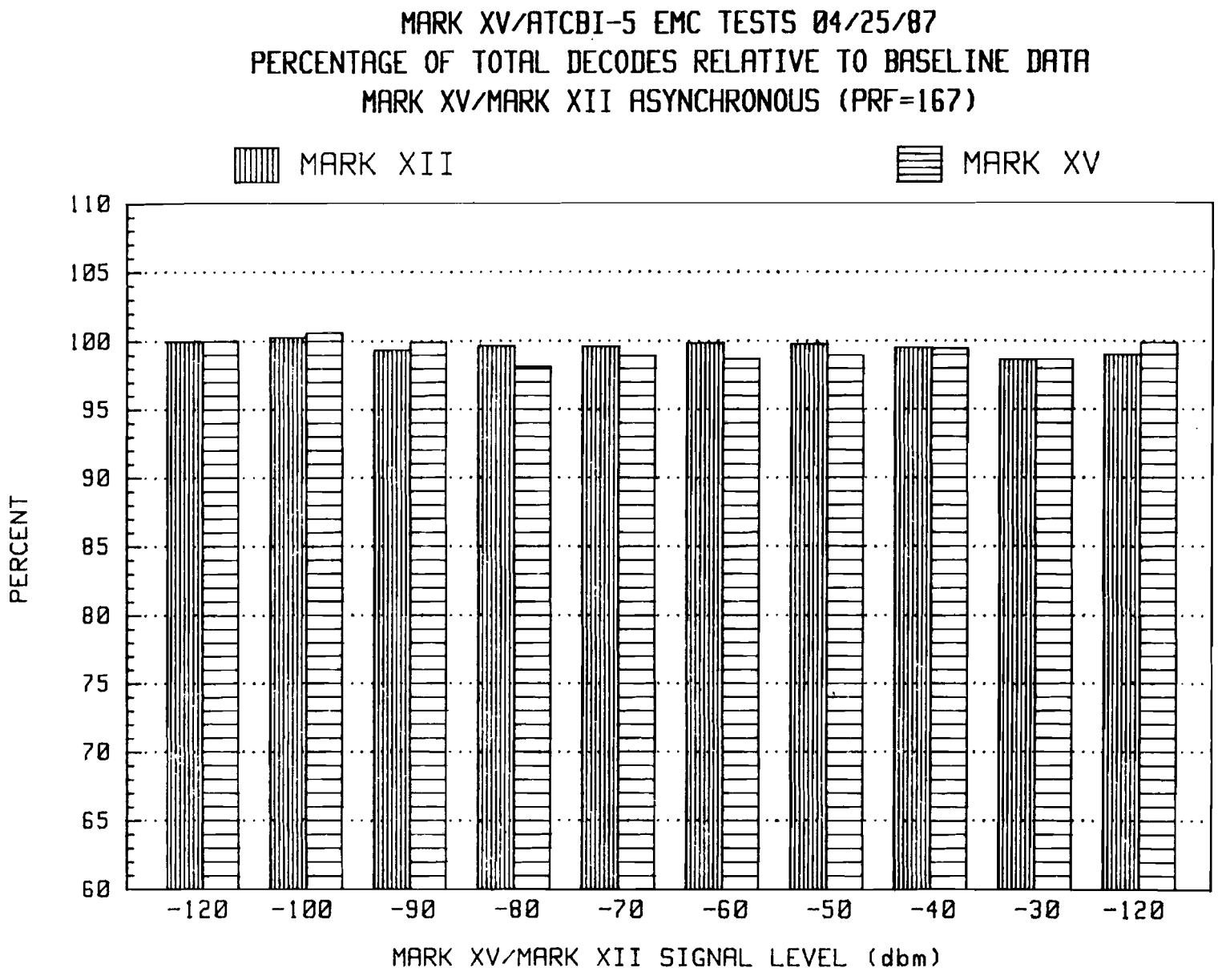

FIGURE 5e. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 167 (5 of 8)

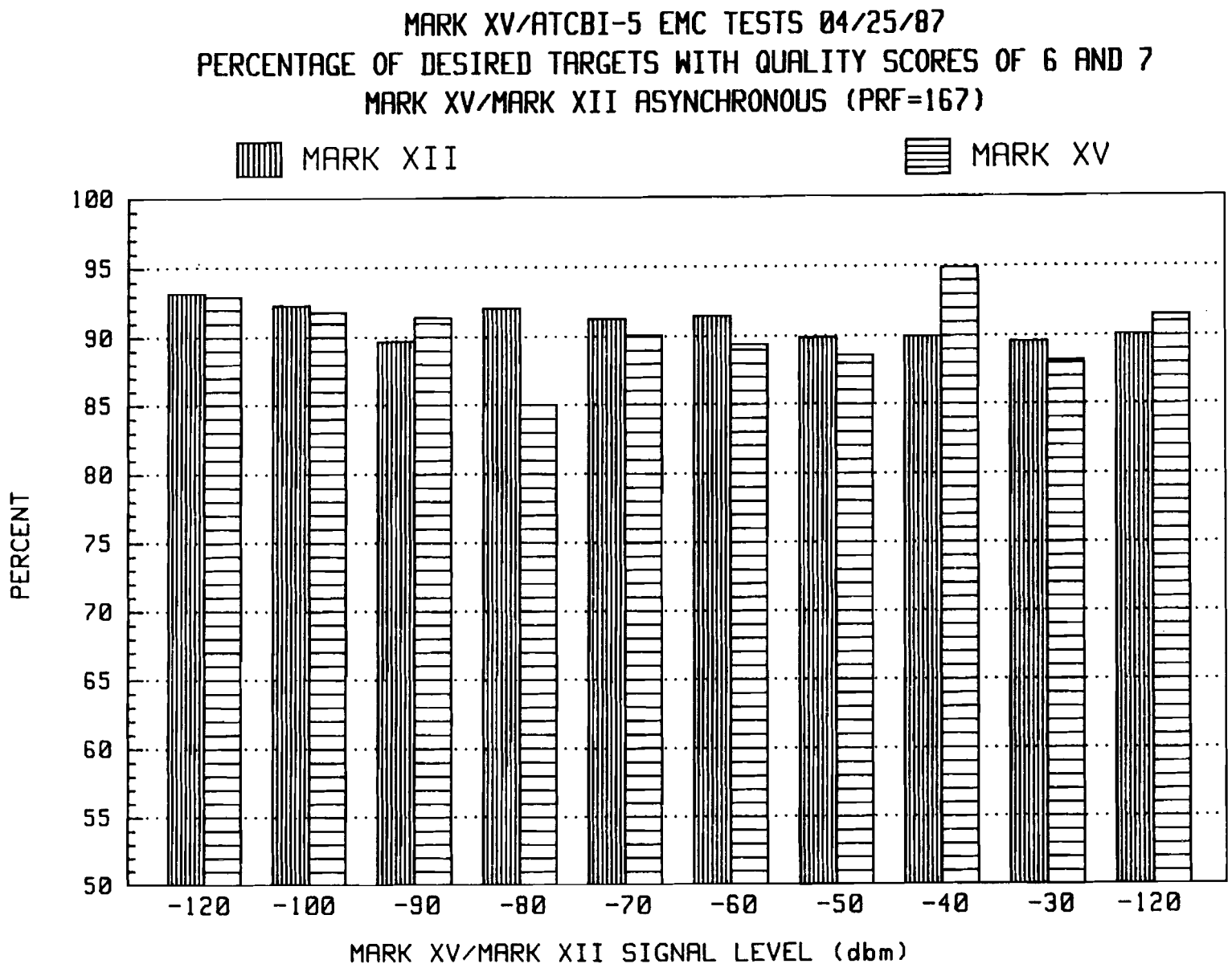

FIGURE 5f. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 167 (6 of 8)

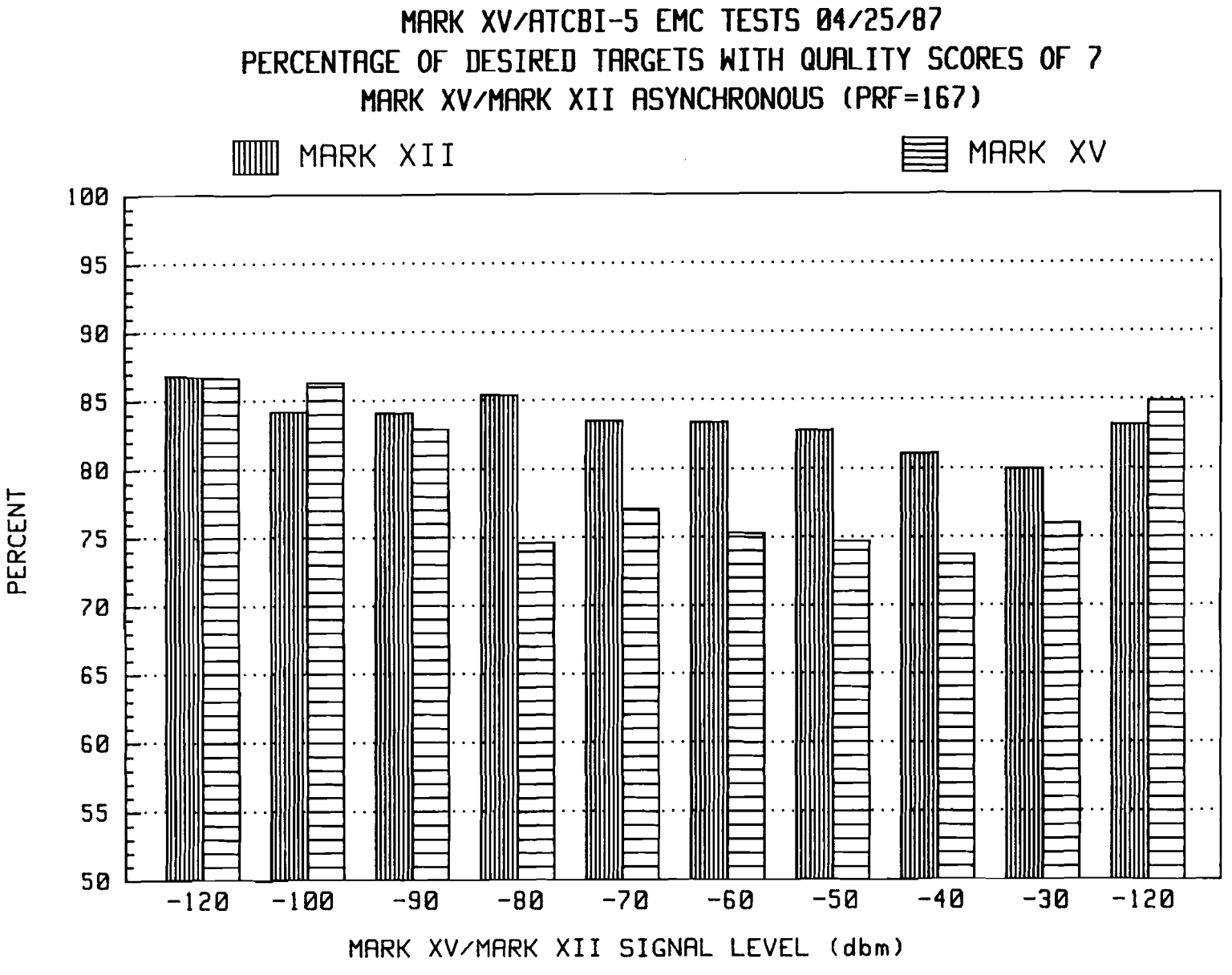

FIGURE 5g. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 167 (7 of 8)

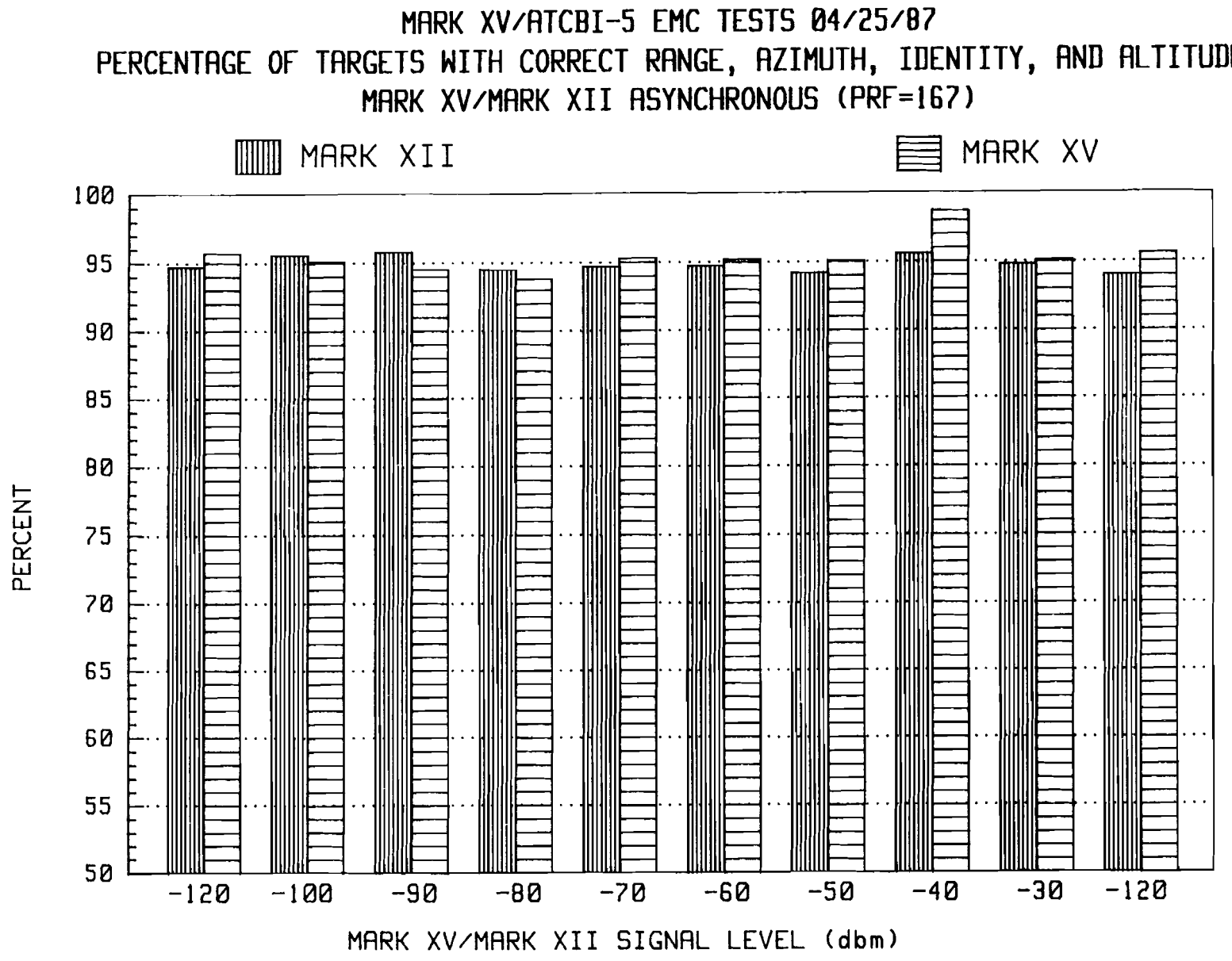

FIGURE 5h. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 167 (8 of 8)

TABLE 1. ATCBI-5/SRAP PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 167

Signal Level (dBm)	Desired Decodes		Total Decodes		Lead Edge		Receiver Quantized		SRAP Quantized	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
-120	173	4	175	4	1786	18	2126	17	1786	1
-30	173	3	175	3	1806	20	3727	21	1788	2
-40	174	4	176	3	1814	13	3724	22	1800	1
-50	174	3	177	3	1814	21	3692	22	1798	2
-60	175	3	177	3	1813	17	3642	27	1799	1
-70	174	4	176	4	1811	15	3553	22	1796	1
-80	174	3	176	3	1803	16	3959	40	1796	1
-90	173	3	176	3	1779	18	2218	18	1779	1
-100	175	3	178	3	1792	14	2131	14	1792	1
-120	175	3	177	3	1791	13	2130	12	1791	1

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Signal Level (dBm)	Desired Decodes		Total Decodes		Lead Edge		Receiver Quantized		SRAP Quantized	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
-120	174	4	177	4	1791	22	2130	21	1791	22
-30	172	4	175	4	1856	34	2954	34	1810	24
-40	173	3	176	3	1863	28	4822	58	1817	17
-50	172	3	175	3	1857	27	8402	105	1812	17
-60	172	4	175	4	1855	33	18279	179	1811	24
-70	172	5	175	5	1853	37	24086	216	1812	25
-80	171	5	174	5	1788	28	8002	76	1780	28
-90	174	4	177	3	1788	15	2304	19	1788	15
-100	175	3	178	3	1789	20	2129	19	1789	20
-120	175	3	177	3	1789	17	2128	17	1789	17

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TABLE 2. ARTS IIIA PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 167

Signal Level (dBm)	Quality of 7 (Percent)	Quality of 6 (Percent)	Quality of 7 + 6 (Percent)	Blip Scan (Percent)
-120	83.2	6.9	90.1	94.0
-30	80.0	9.6	89.6	94.8
-40	81.1	8.9	90.0	95.6
-50	82.5	7.4	89.9	94.2
-60	83.4	8.1	91.5	94.7
-70	83.5	7.8	91.3	94.7
-80	85.4	6.7	92.1	94.5
-90	84.1	5.6	89.7	95.8
-100	84.2	8.1	92.3	95.6
-120	86.8	6.4	93.2	94.7

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Signal Level (dBm)	Quality of 7 (Percent)	Quality of 6 (Percent)	Quality of 7 + 6 (Percent)	Blip Scan (Percent)
-120	84.9	6.6	91.5	95.6
-30	76.0	12.2	88.2	95.1
-40	73.7	21.2	94.9	98.7
-50	74.7	13.9	88.6	95.1
-60	75.3	14.1	89.4	95.2
-70	77.1	13.0	90.1	95.3
-80	74.6	10.4	85.0	93.8
-90	82.9	8.5	91.4	94.5
-100	86.3	5.5	91.8	95.1
-120	86.7	6.2	92.9	95.7

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INTERFERENCE EFFECTS FROM THE MARK SYSTEMS OPERATING AT A PRF OF 333. Figure 6 shows plots of data collected when the Mark systems were operated at a PRF of 333, which is the PRF normally used for Mark XII operation. Tables 3 and 4 contain the data used to generate these plots. The data indicate an increase in receiver quantized pulse count from the Mark XII operating at a PRF of 333 as compared to operating at a PRF of 167. But a comparison of figures 6a and 6b indicates that the data return to near baseline values as measured at the SRAP quantizer, indicating that the defruiter successfully eliminated most of the extraneous pulses resulting from the Mark XII interference. The other system performance parameters remained relatively unchanged.

The data collected with the Mark XV operating at a PRF of 333 are also shown in figure 6 and tables 3 and 4. The number of pulses at the output of the receiver quantizer (figure 6a) was approximately double the value measured for Mark XV at a PRF of 167. When the Mark XV peaked at an RF level of -70 dBm, the number of quantized pulses rose to a level of 2,100 percent above that of the baseline data. However, the Mark XII only increased the receiver quantized count 200 percent over the baseline value. After passing the defruiter (figure 6b, SRAP quantized pulses), the pulse count was only 2 to 3 percent higher than the baseline. But, for Mark XV RF levels -30 to -70 dBm, the lead edge count showed a 7 percent increase over baseline and about the same amount of increase over the Mark XII data, as seen in figure 6c. This increase in the lead edge pulse count indicates that the long pulse duration reply of the Mark XV is interpreted differently by the SRAP lead edge circuit than by the Mark XII reply pulses. The long Mark XV pulse appears to the lead edge circuit as additional overlapped ATCRBS pulses that pass all of the circuit's measurement criteria for pulse overlap and result in an increase in the lead edge circuit output pulse count. It is important to note that the lead edge circuit output pulses are assumed by the rest of the SRAP to be valid ATCRBS pulses and are then input to the bracket detection circuit. Figures 6d and 6e show the desired and total bracket decodes that were reduced by less than 2 percent for all Mark XV signal levels except -80 dBm, which caused a 5 percent reduction in both decode counts. Examination of figures 6f and 6g quality scores of desired targets show that, again, when the Mark XV is at -80 dBm, the greatest effect in performance is noted: quality score reductions of 10 and 20 percent, respectively. Notice, also from figures 6f and 6g, the difference in the data between the Mark XV and Mark XII as an interfering source. The Mark XV clearly eliminates more desired target replies than the Mark XII. The blip scan data in figure 6h indicate that targets were correctly detected by the ARTS IIIA when subjected to interfering signals from the Mark XV, even though there was a reduction in the number of correct replies used to make up the targets.

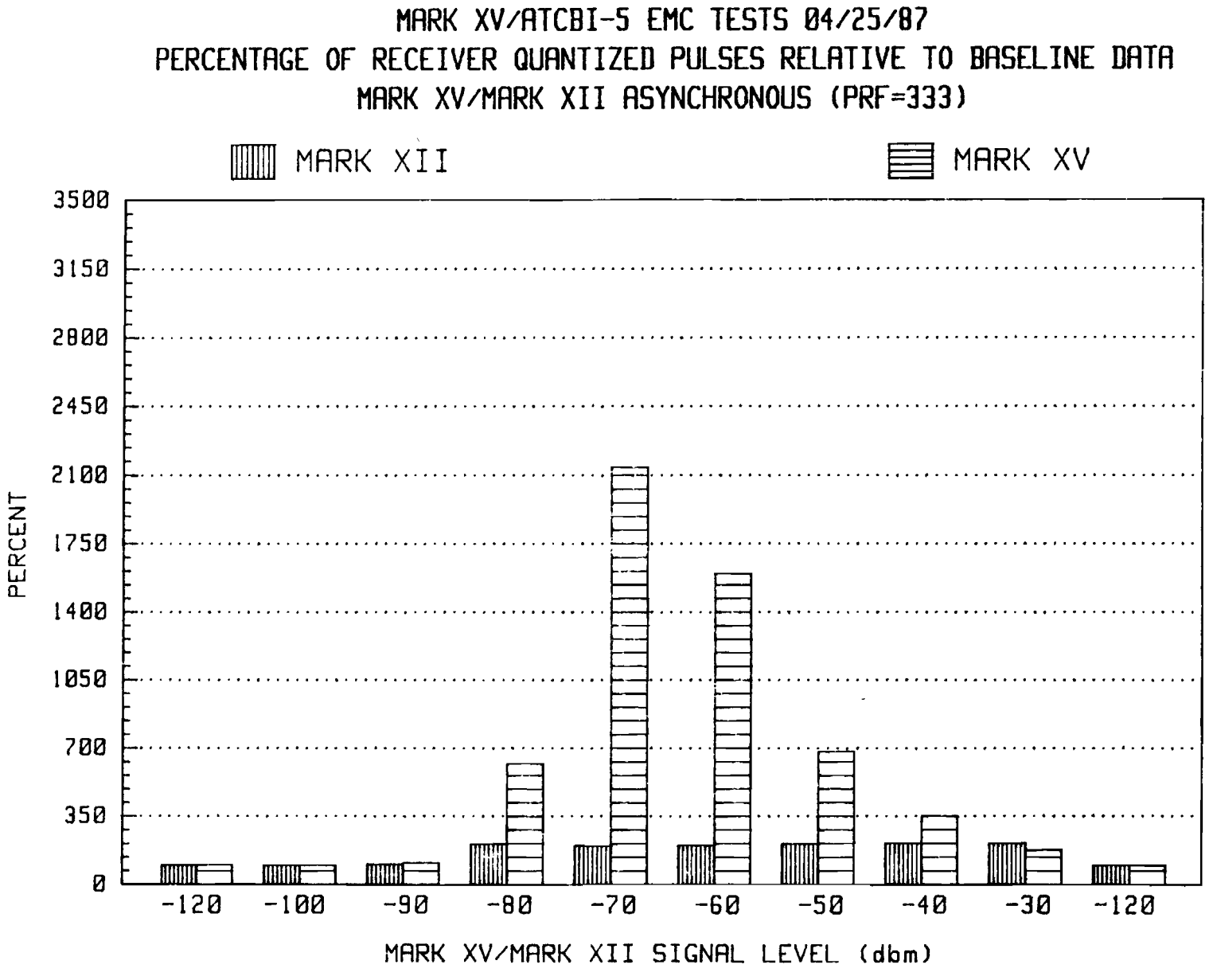

FIGURE 6a. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 333 (1 of 8)

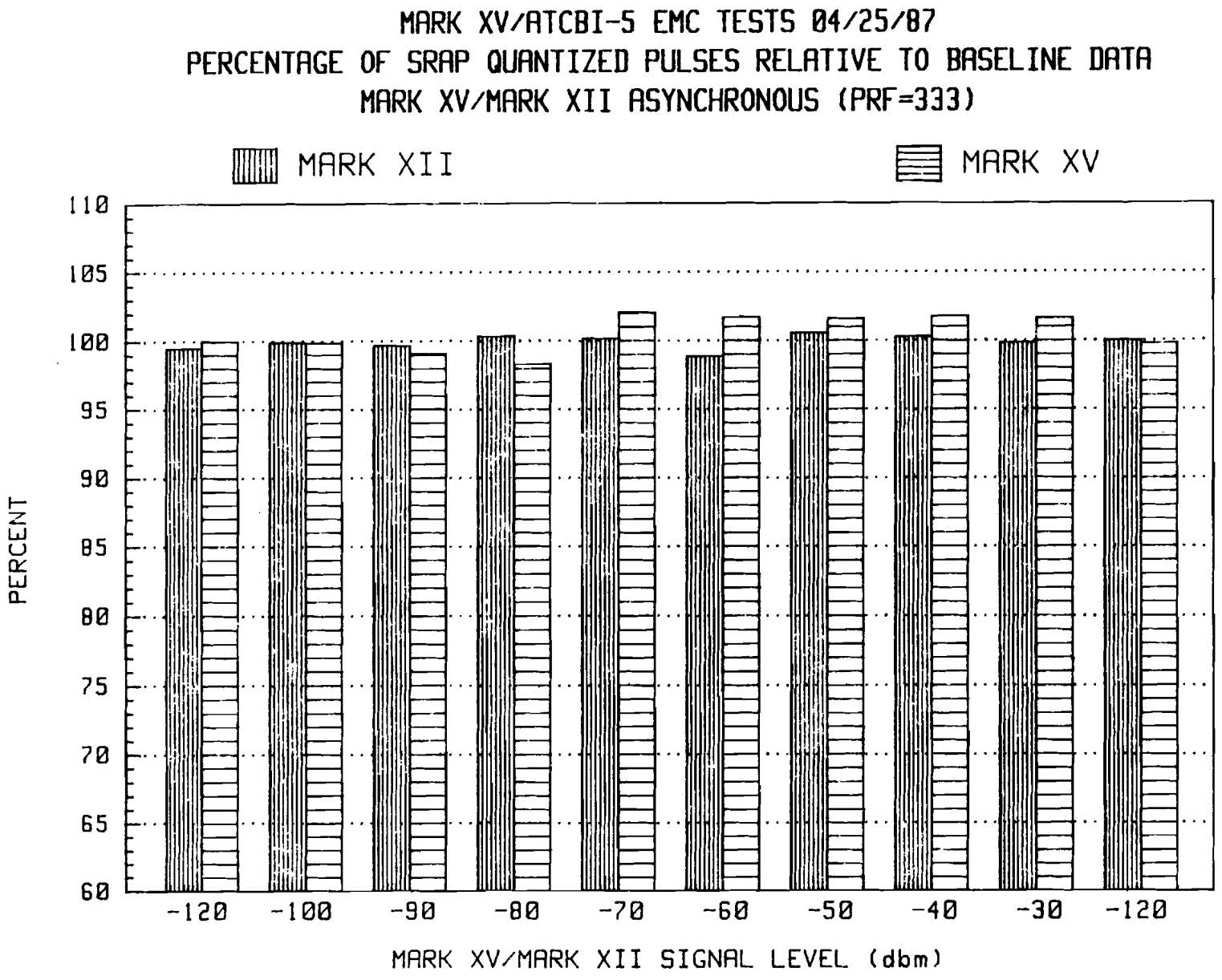

FIGURE 6b. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 333 (2 of 8)

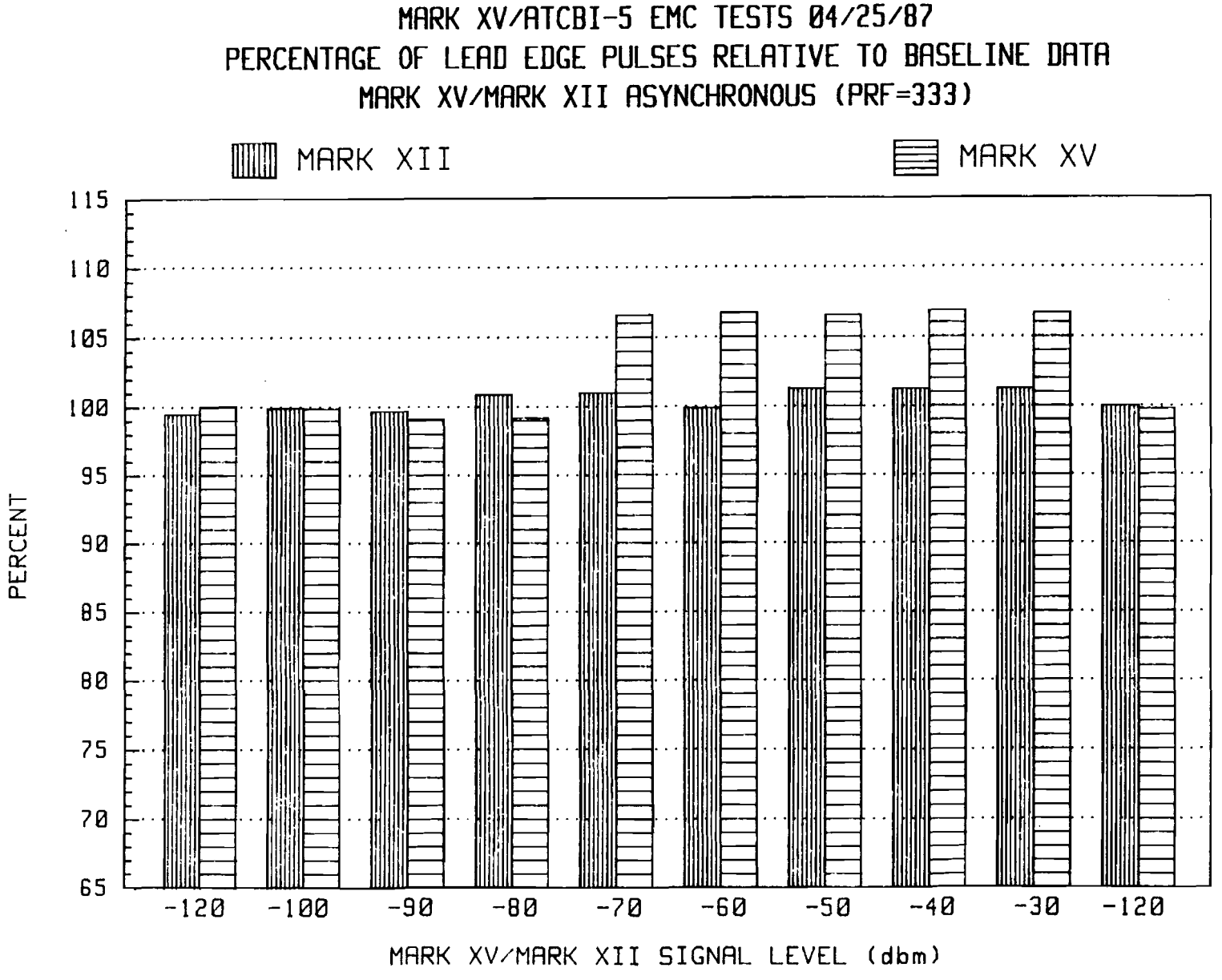

FIGURE 6c. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 333 (3 of 8)

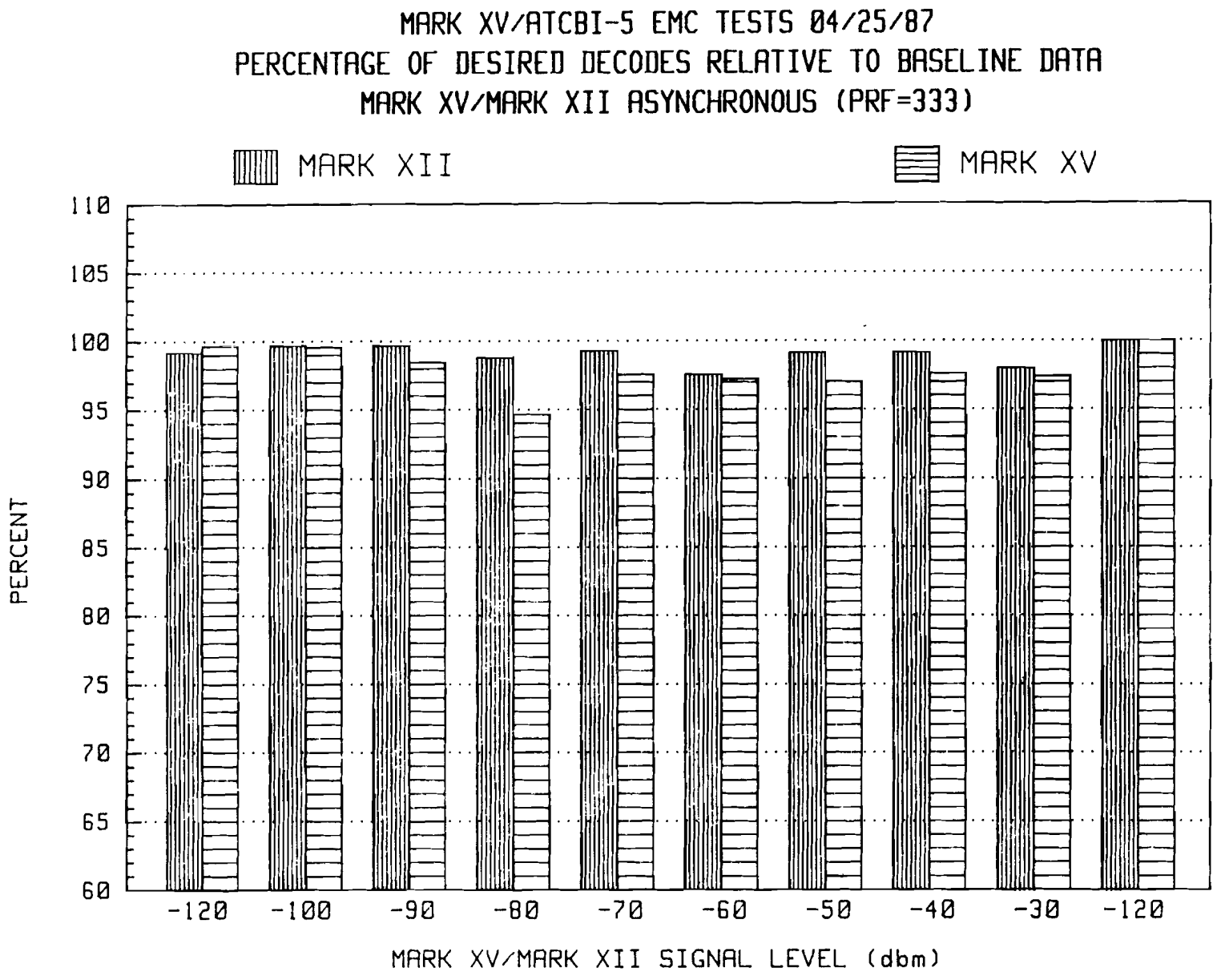

FIGURE 6d. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 333 (4 of 8)

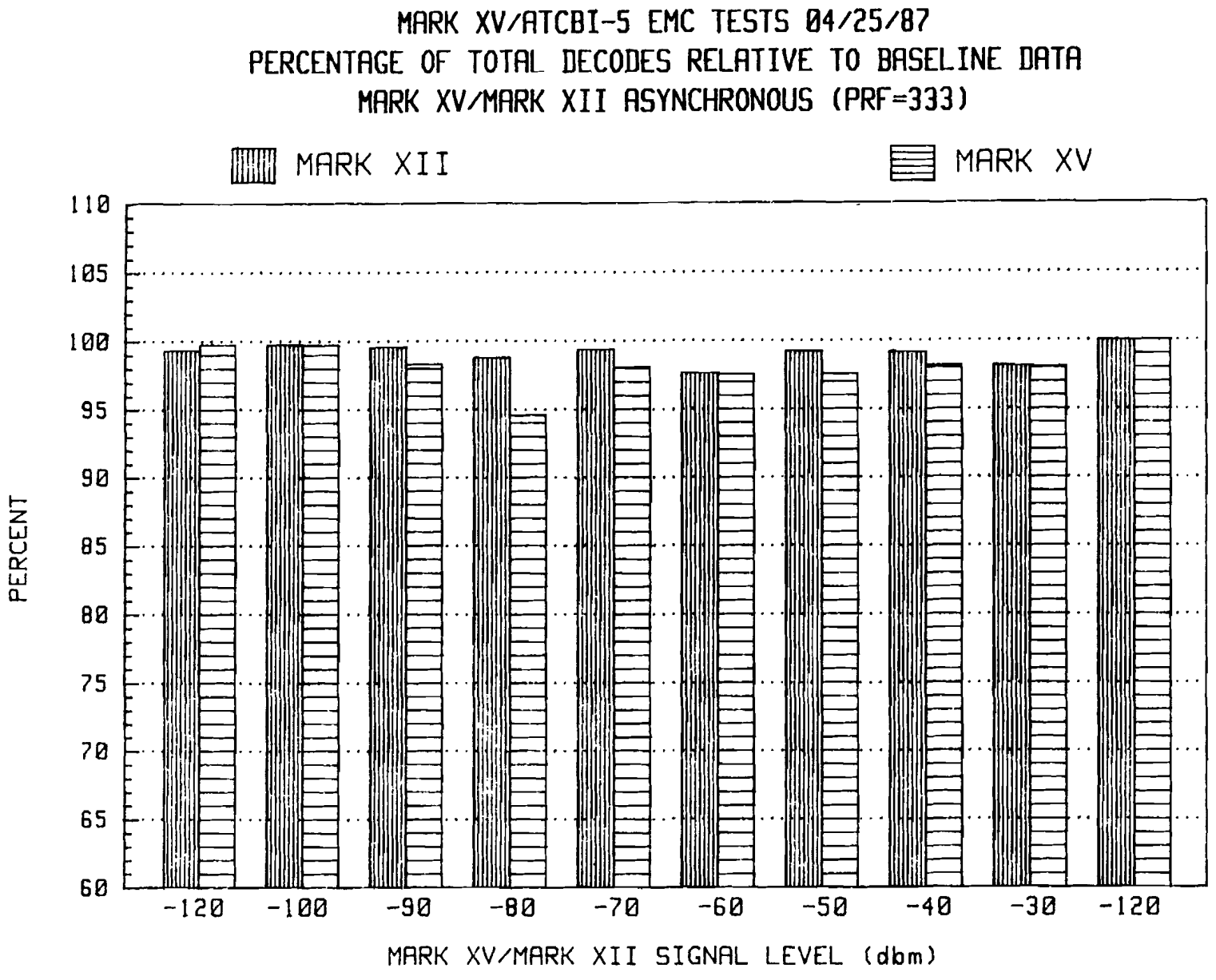

FIGURE 6e. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 333 (5 of 8)

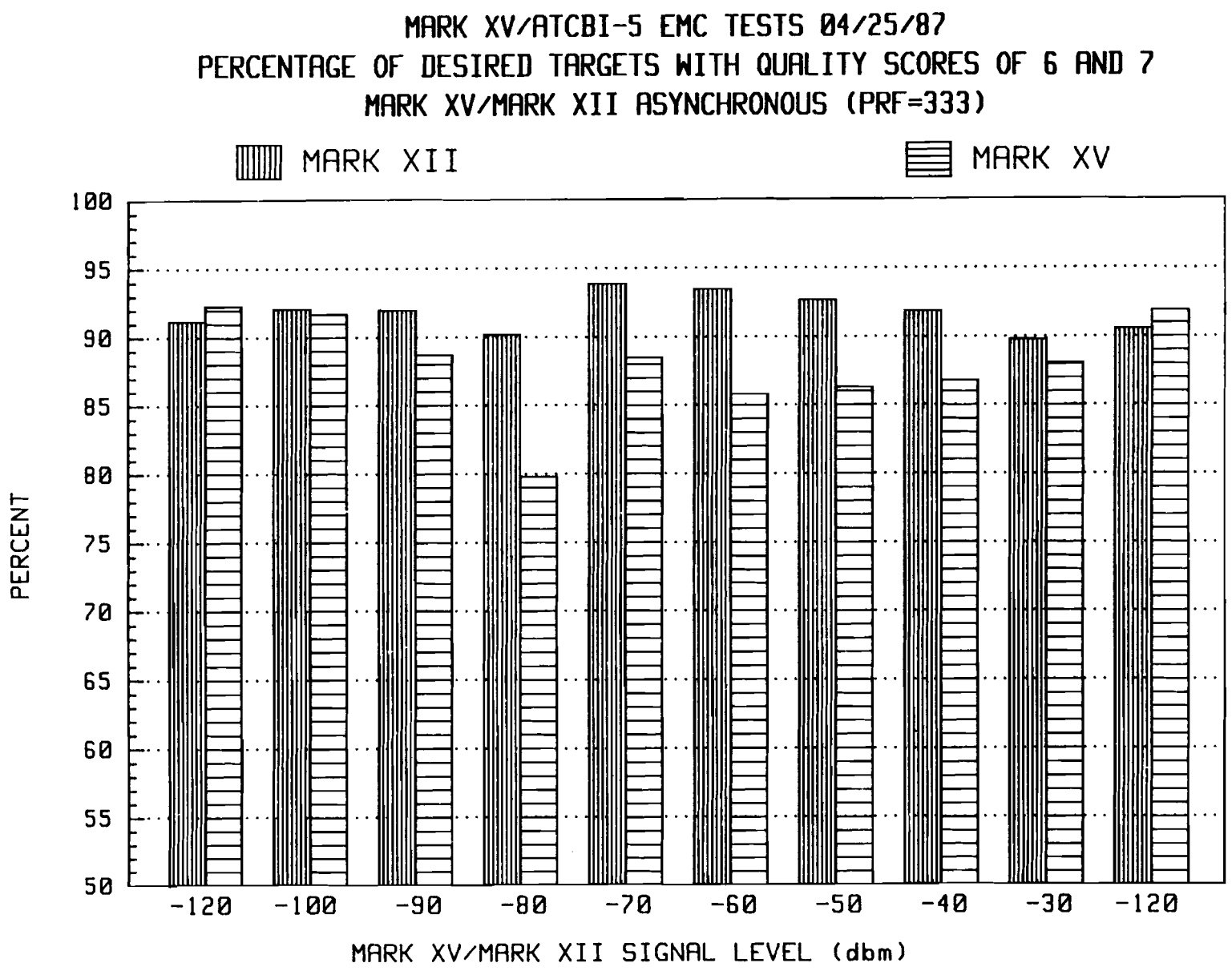

FIGURE 6f. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 333 (6 of 8)

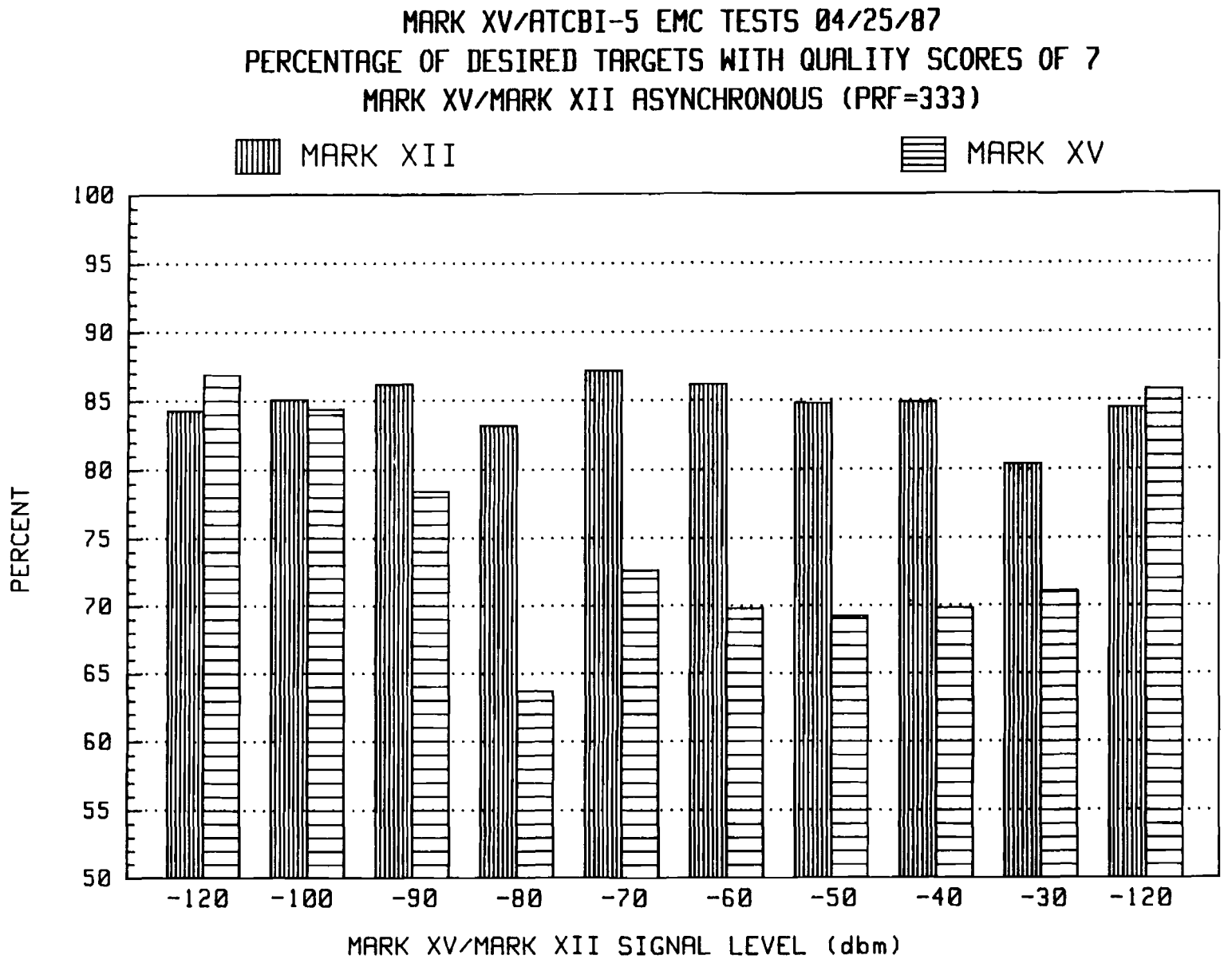

FIGURE 6g. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 333 (7 of 8)

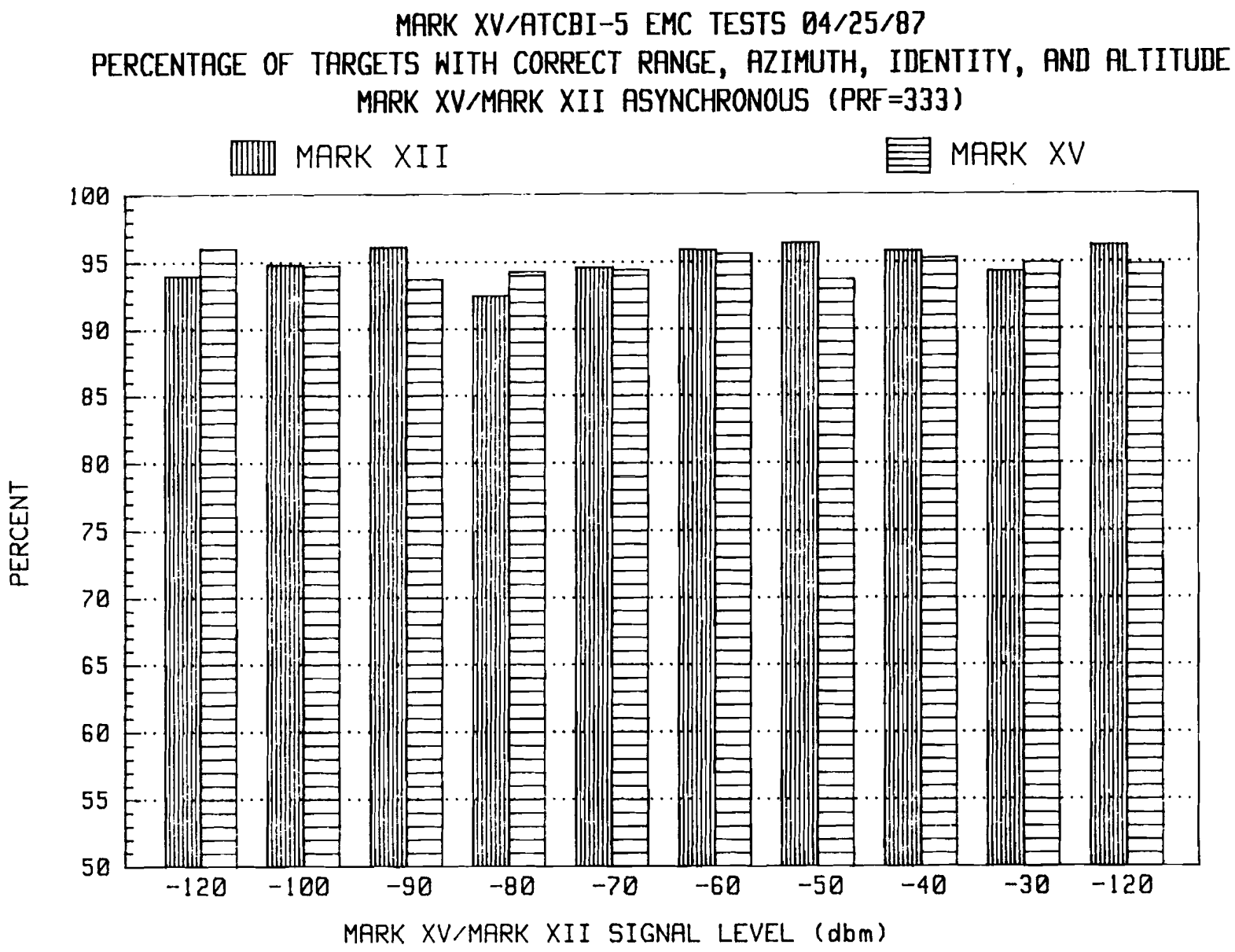

FIGURE 6h. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 333 (8 of 8)

TABLE 3. ATCBI-5/SRAP PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 333

Signal Level (dBm)	Desired Decodes		Total Decodes		Lead Edge		Receiver Quantized		SRAP Quantized	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
-120	176	3	178	3	1797	15	2135	15	1979	16
-30	172	4	175	4	1820	24	4508	29	1795	28
-40	174	3	177	3	1820	25	4493	28	1802	25
-50	174	3	177	3	1821	22	4460	23	1808	22
-60	172	13	174	14	1795	130	4301	291	1777	122
-70	175	3	177	3	1816	17	4230	25	1801	15
-80	174	4	176	4	1813	18	4452	32	1804	19
-90	175	3	177	3	1792	16	2223	20	1792	16
-100	175	3	178	3	1796	18	2134	18	1796	18
-120	174	3	177	3	1788	14	2126	15	1788	14

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Signal Level (dBm)	Desired Decodes		Total Decodes		Lead Edge		Receiver Quantized		SRAP Quantized	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
-120	175	3	178	3	1791	16	2130	14	1791	18
-30	171	3	174	3	1714	21	3795	38	1823	19
-40	171	3	174	3	1917	23	7481	68	1826	20
-50	170	3	173	3	1912	18	14588	125	1823	16
-60	170	3	173	3	1915	18	34176	267	1825	18
-70	171	4	174	4	1912	25	45809	345	1831	25
-80	166	4	168	4	1780	20	13255	128	1764	19
-90	173	3	175	3	1778	18	2387	24	1778	18
-100	174	3	177	3	1792	18	2134	17	1792	18
-120	175	4	177	4	1794	14	2140	26	1794	14

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TABLE 4. ARTS IIIA PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 333

Signal Level (dBm)	Quality of 7 (Percent)	Quality of 6 (Percent)	Quality of 7 + 6 (Percent)	Blip Scan (Percent)
-120	84.5	6.1	90.6	96.2
-30	80.4	9.4	89.8	94.3
-40	84.9	7.0	91.9	95.8
-50	84.8	7.9	96.4	96.4
-60	86.2	7.3	93.5	95.9
-70	87.1	6.7	93.9	94.6
-80	83.2	7.0	90.2	92.5
-90	86.2	5.8	92.0	96.1
-100	85.1	7.0	92.1	94.8
-120	84.3	6.9	91.2	94.0

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Signal Level (dBm)	Quality of 7 (Percent)	Quality of 6 (Percent)	Quality of 7 + 6 (Percent)	Blip Scan (Percent)
-120	85.8	6.1	91.9	94.8
-30	71.1	17.0	88.1	94.9
-40	69.8	17.0	86.8	95.3
-50	69.2	17.1	86.3	93.7
-60	69.8	16.0	85.8	95.6
-70	72.6	15.9	88.5	94.4
-80	63.7	16.1	79.8	94.3
-90	78.4	10.3	88.7	93.7
-100	84.4	7.3	91.7	94.7
-120	86.9	5.4	92.3	96.0

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INTERFERENCE EFFECTS FROM THE MARK SYSTEMS OPERATING AT A PRF OF 500. When the Mark XII was operated at a PRF of 500, the only performance parameters affected were receiver quantized pulse count and SRAP lead edge pulse count. Tables 5 and 6 show the data which were plotted in figure 7. Receiver quantized data indicate approximately a 300 percent increase in pulses which are passed through the ATCBI-5 receiver when subjected to interfering signals from the Mark XII at a PRF of 500. However, examination of figure 7a, SRAP quantized pulse count, indicates a return to near baseline values demonstrating good interference protection from the defruiter. One of the most critical parameters, SRAP lead edge pulse count, indicates a 3 percent rise in values for Mark XII signal levels greater than -80 dBm. The other performance parameters show a negligible change for this test condition.

Although the Mark XV is intended to be used at relatively low PRF's, the Mark XV simulator used for the EMC tests is capable of operating up to a PRF of 500. Figure 7 and tables 5 and 6 also show the data that were collected for the Mark XV operating at a PRF of 500. Figure 7a shows an increase in receiver quantized pulses of 3,150 percent over the baseline (no interference) reference when the Mark XV signal was at -70 dBm. An obvious observation from figure 7a is that at higher RF levels, the data show less of an effect. Figure 7b again illustrates the effectiveness of the defruiter in eliminating unwanted pulse interference from the Mark XV; the SRAP quantizer data indicate a relatively stable state with the exception of the Mark XV at -80 dBm. The SRAP lead edge pulse count data in figure 7c indicate a 10 percent increase over baseline and an 8 percent increase over Mark XII data for Mark XV RF levels from -30 to -70 dBm. Desired and total bracket decodes (figures 7d and 7e) experienced a reduction from baseline value for Mark XV RF levels -30 to -80 dBm with the greatest change (8 percent) occurring at -80 dBm. Figures 7d and 7e show the difference in the data trends for the Mark XV as compared to the Mark XII. In figures 7f and 7g, the quality scores of desired targets were most affected when the MARK XV was at -80 dBm. Full baseline data recovery of these parameters does not occur until the Mark XV is at -100 dBm. Figure 7f shows a reduction of 25 percent in the occurrence of quality scores of six and seven for desired targets when the Mark XV is at -80 dBm. The reduction in quality score data below six or seven is directly attributed to the elimination of desired target replies. Finally, figure 7h shows a plot of the blip scan data taken when the Mark systems were operated at a PRF of 500. The data there indicate that the number of desired targets correctly detected was not reduced appreciably, with the maximum reduction occurring when the Mark XV was operated at -30 dBm.

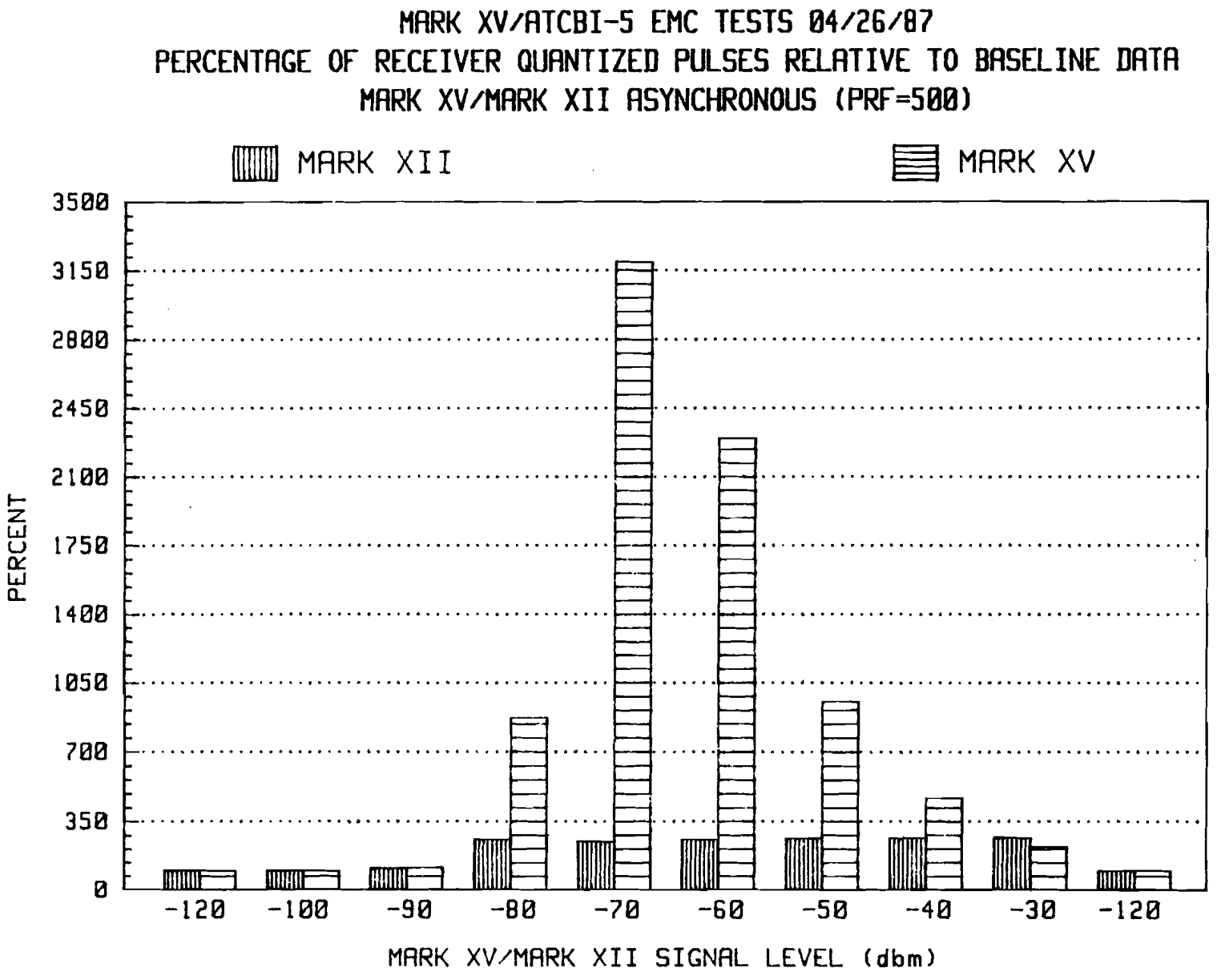

FIGURE 7a. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 500 (1 of 8)

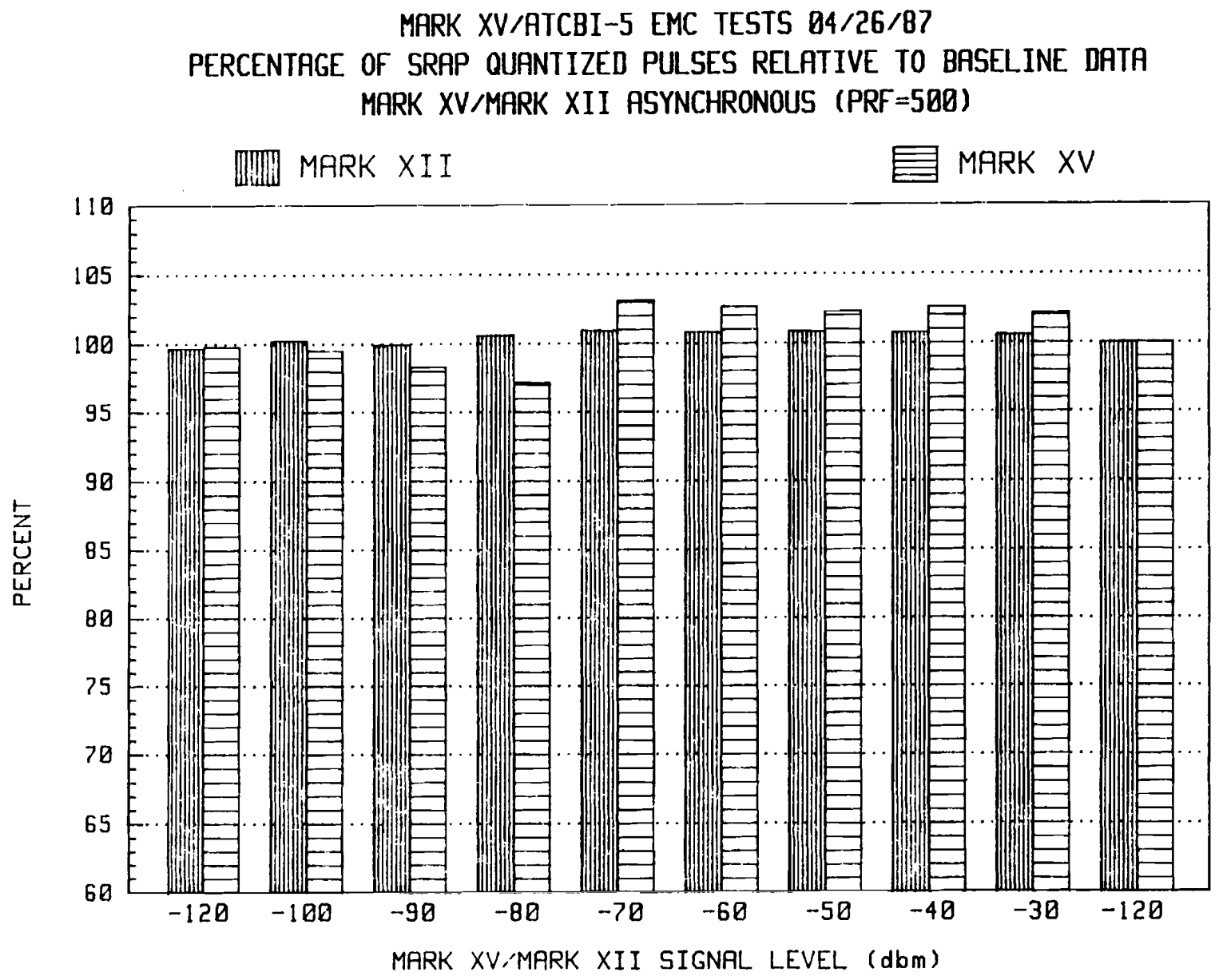

FIGURE 7b. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 500 (2 of 8)

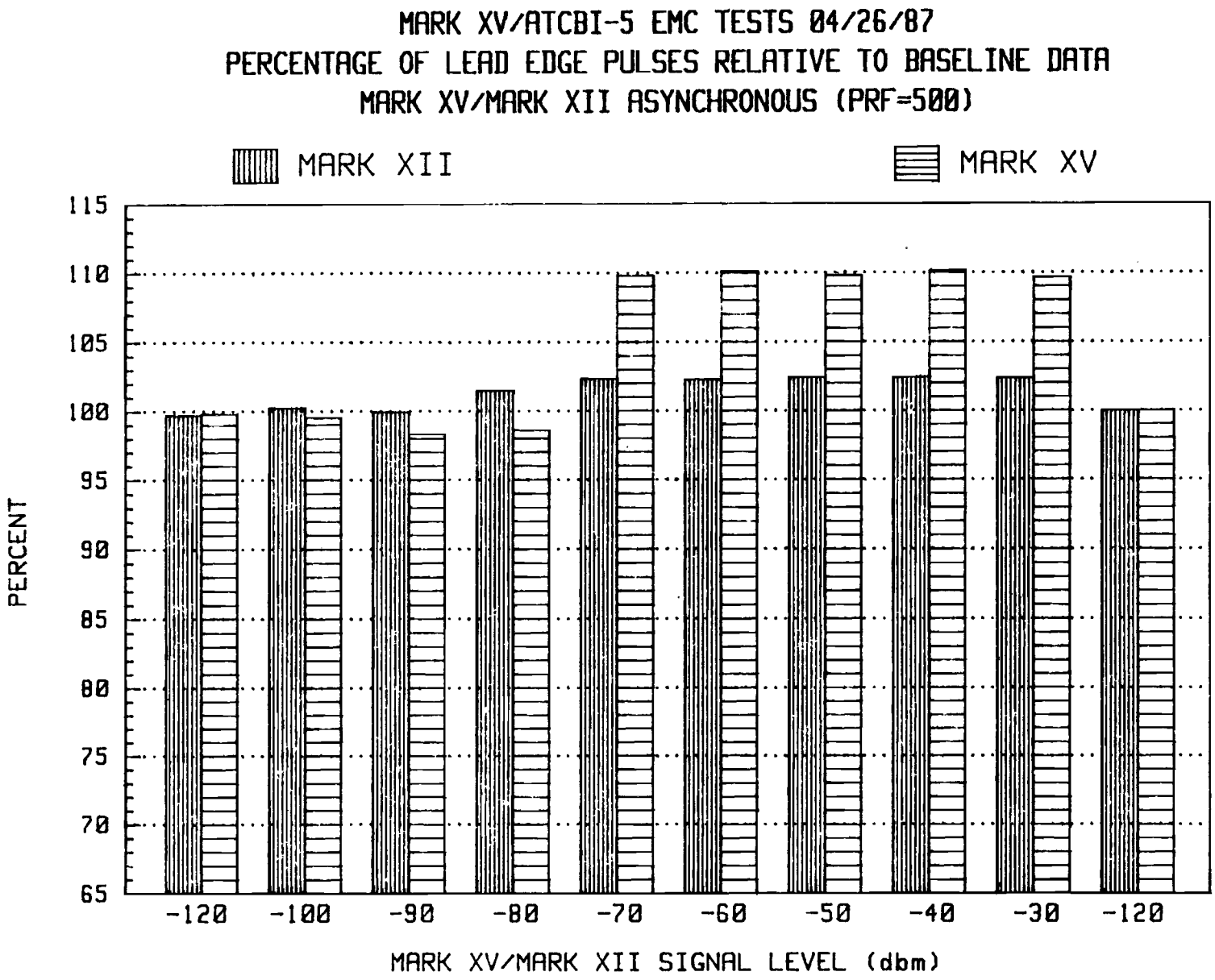

FIGURE 7c. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 500 (3 of 8)

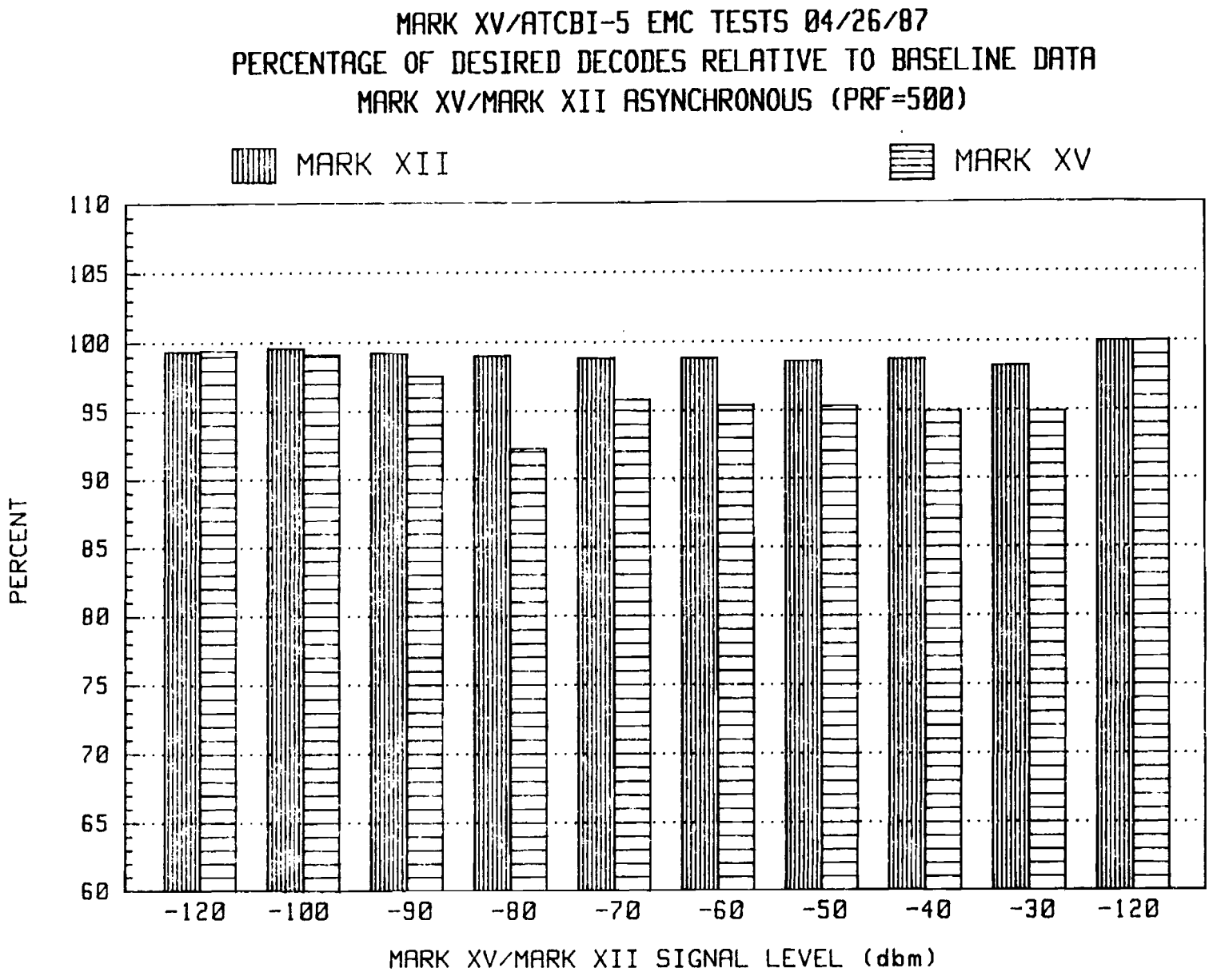

FIGURE 7d. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 500 (4 of 8)

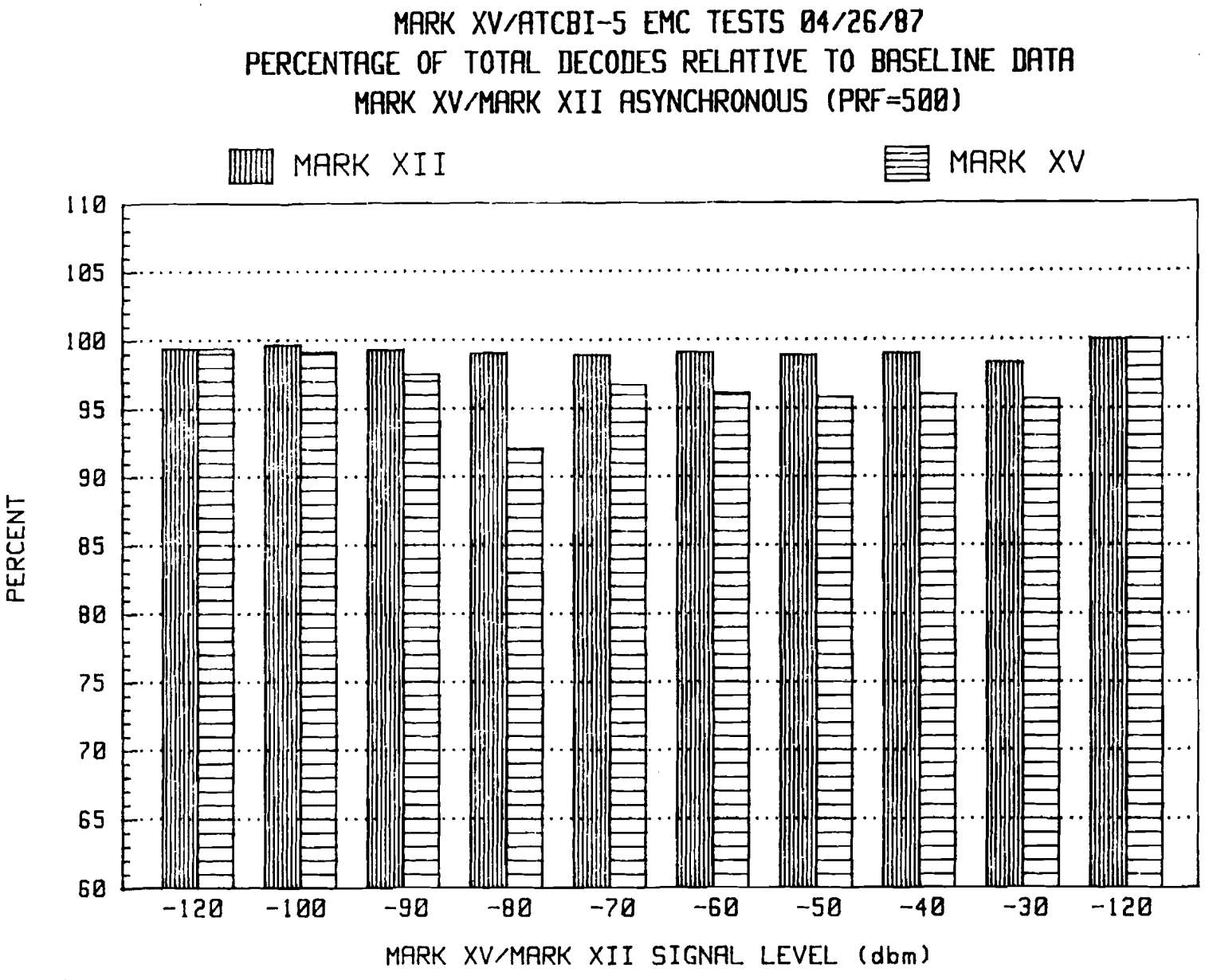

FIGURE 7e. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 500 (5 of 8)

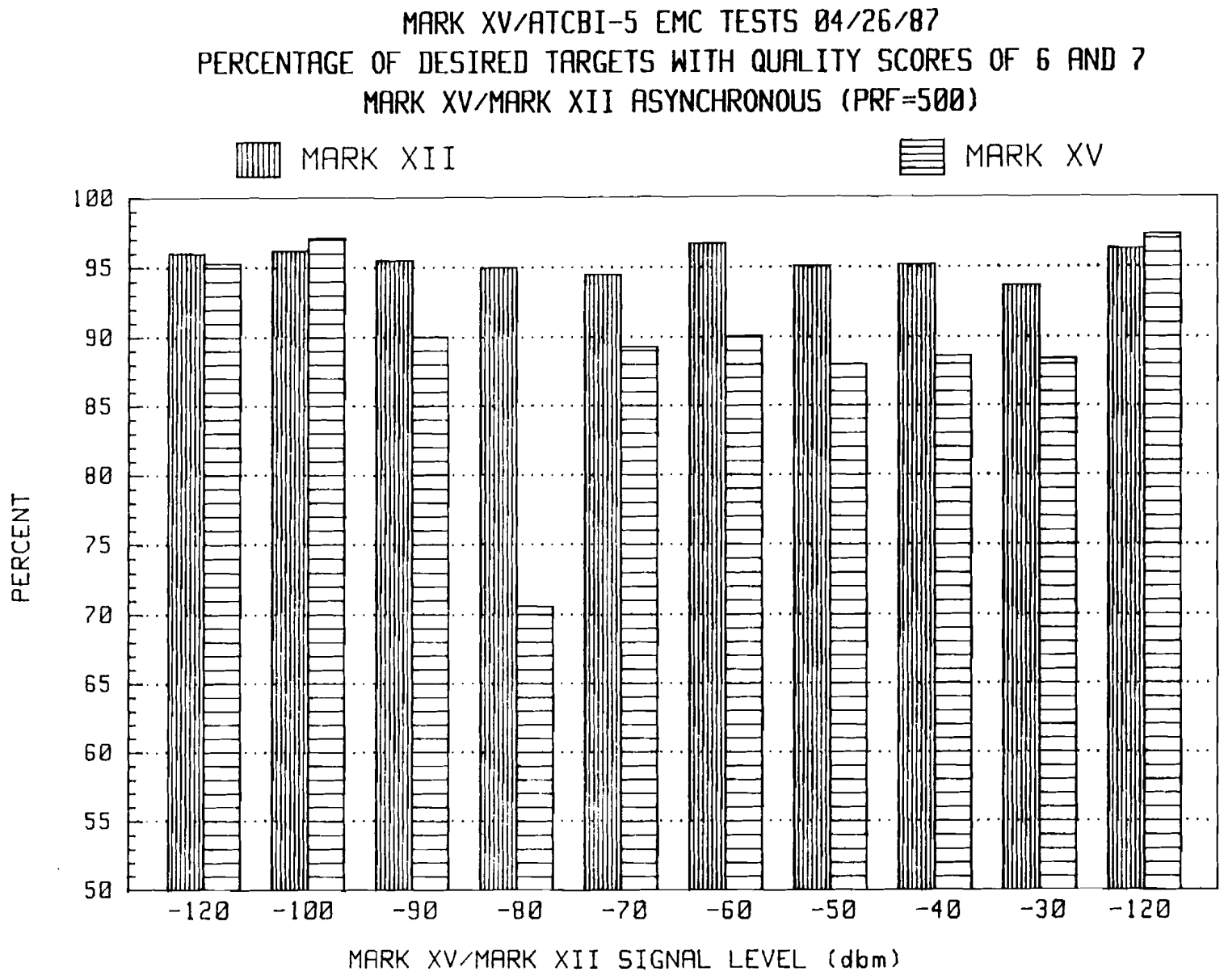

FIGURE 7f. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 500 (6 of 8)

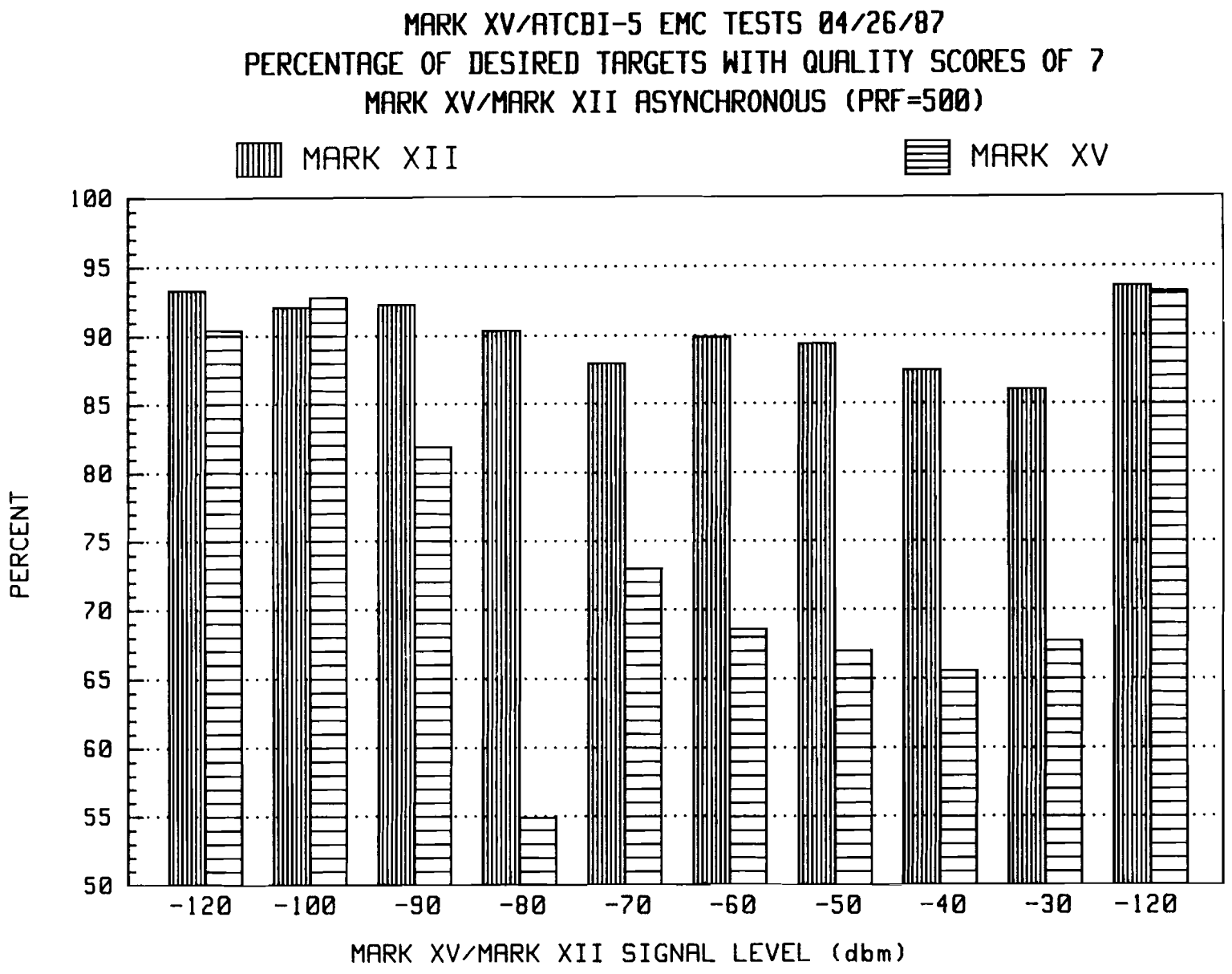

FIGURE 7g. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 500 (7 of 8)

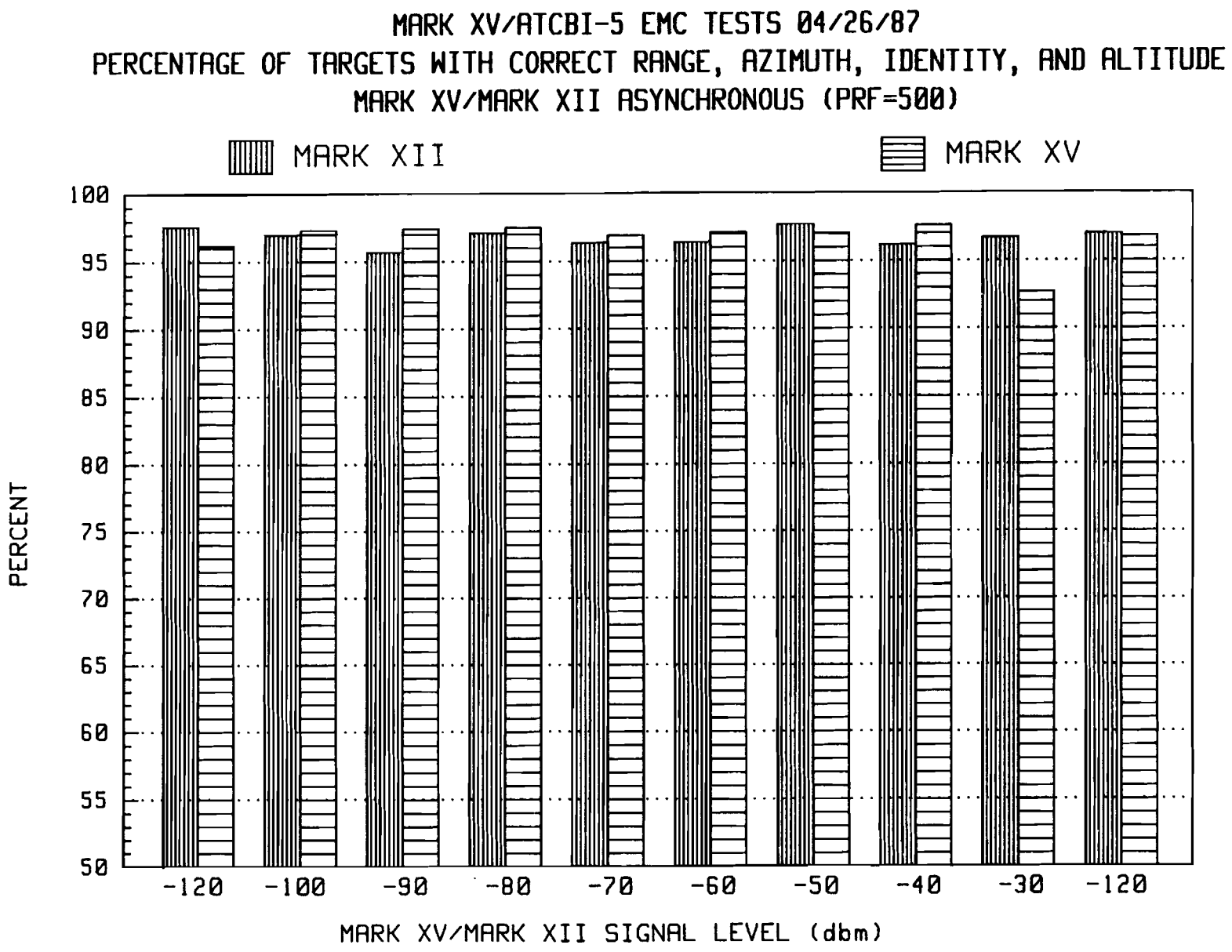

FIGURE 7h. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 500 (8 of 8)

TABLE 5. ATCBI-5/SRAP PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 500

Signal Level (dBm)	Desired Decodes		Total Decodes		Lead Edge		Receiver Quantized		SRAP Quantized	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
-120	178	2	181	2	1805	15	2139	15	1805	15
-30	175	4	177	4	1848	20	5706	21	1816	20
-40	176	3	179	2	1849	15	5699	18	1819	16
-50	176	2	179	2	1849	16	5627	16	1820	13
-60	176	3	179	3	1847	23	5520	22	1820	21
-70	176	2	179	2	1848	17	5301	17	1822	16
-80	176	2	179	2	1832	16	5552	33	1817	17
-90	177	3	179	3	1804	19	2393	21	1804	19
-100	177	3	180	2	1810	21	2144	21	1810	21
-120	177	2	179	2	1800	16	2134	16	1800	16

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Signal Level (dBm)	Desired Decodes		Total Decodes		Lead Edge		Receiver Quantized		SRAP Quantized	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
-120	178	3	181	2	1812	15	2145	16	1812	15
-30	169	3	173	3	1986	18	4709	33	1850	18
-40	169	3	173	3	1995	15	10091	54	1859	14
-50	170	4	173	4	1989	22	20471	64	1853	21
-60	170	4	174	4	1995	18	49269	109	1859	17
-70	171	4	175	3	1989	14	68488	150	1868	14
-80	164	4	166	4	1786	18	18707	130	1760	18
-90	174	3	176	3	1781	24	2487	23	1781	24
-100	176	2	179	2	1803	14	2141	12	1803	14
-120	177	3	179	3	1808	23	2143	22	1808	23

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TABLE 6. ARTS IIIA PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT A PRF OF 500

Signal Level (dBm)	Quality of 7 (Percent)	Quality of 6 (Percent)	Quality of 7 + 6 (Percent)	Blip Scan (Percent)
-120	93.6	2.7	96.3	96.8
-30	86.1	7.6	93.7	92.7
-40	87.5	7.7	95.2	97.6
-50	89.4	5.7	95.1	97.0
-60	89.9	6.8	96.7	97.1
-70	88.0	6.5	94.5	96.9
-80	90.4	4.6	95.0	97.5
-90	92.3	3.2	95.5	97.4
-100	92.1	4.1	96.2	97.3
-120	93.3	2.7	96.0	96.2

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Signal Level (dBm)	Quality of 7 (Percent)	Quality of 6 (Percent)	Quality of 7 + 6 (Percent)	Blip Scan (Percent)
-120	93.2	4.1	97.3	97.0
-30	67.7	20.7	88.4	96.7
-40	65.6	23.0	88.6	96.2
-50	67.0	21.0	88.0	97.7
-60	68.6	21.5	90.1	96.4
-70	73.0	16.3	89.3	96.4
-80	54.9	15.7	70.6	97.1
-90	81.9	8.1	90.0	95.7
-100	92.8	4.3	97.1	97.0
-120	90.4	4.9	95.3	97.6

Mark XV, Asynchronous, PRF - 500
Saturday, April 26, 1987

MARK XV VERSUS MARK XII INTERFERENCE EFFECTS ON THE ATCBI-5 WHEN THE MARK SYSTEMS OPERATE AT THEIR EXPECTED PRF. Figure 8 shows data plotted which provide a way of easily comparing the Mark XII and Mark XV systems interference effects on the performance of the ATCBI-5. The data plotted are the ATCBI-5 performance parameters measured when the Mark XII was operated at a PRF of 333 and the Mark XV was operated at a PRF of 167. Since these are the expected operational PRF's of the MARK XII/XV systems, this comparison of the two Mark systems is relevant to determining if both Mark systems have an equal interference effect on the ATCBI-5. Notice from figure 8a that at -70 dBm the number of receiver quantized pulses present when the Mark XV is the interfering source is increased by 1,100 percent (over the desired-only, no-interference case). When the Mark XII replaced the Mark XV as the interfering source, the number of receiver quantized pulses increased about 170 percent. Figure 8b shows data collected for the same test conditions at the first input to the SRAP, the SRAP quantizer. The data show a return to near baseline (no interference) values which indicate that the defruiter was effective in eliminating most of the interfering pulses. SRAP quantizer pulse counts differ by a maximum of 2 percent when the Mark XV data are compared to the Mark XII data. Figure 8c is a plot of the lead edge pulse count data. These data indicate a 4 percent increase in lead edge pulses when the Mark XV was injected into the ATCBI-5 as compared to the Mark XII. The Mark XII lead edge data more closely resembles the baseline data than the Mark XV data. Desired bracket decode data are shown in figure 8d; and from -30 to -80 dBm, there is some reduction in performance (about 2 to 3 percent) due to either the Mark XV or Mark XII systems. Both Mark systems have equal effect on the desired bracket decode count. The total bracket decodes measured are plotted in figure 8e. The data there show a close resemblance to baseline, differing by only about 2 to 3 percent, while the difference in total decodes from the Mark XV as compared to the Mark XII is negligible. Figure 8f shows the percentage of desired targets with quality scores of six and seven that occurred when each of the Mark systems were injected into the ATCBI-5. Notice that the Mark XV caused a 5 percent greater reduction in correct desired replies than the reduction caused by the Mark XII at -80 dBm, which is where the worst interference effect occurs. This effect from the Mark XV at -80 dBm can be noted throughout the test data presented. Figure 8g shows the percentage of desired targets with correct range, azimuth, identity, and altitude codes (blip scan). Again, the data collected when the Mark systems were at -80 dBm show the worst interference effect, a reduction in blip scan by about 3 percent. The rest of the blip scan data in figure 8g shows no appreciable reduction in blip scan.

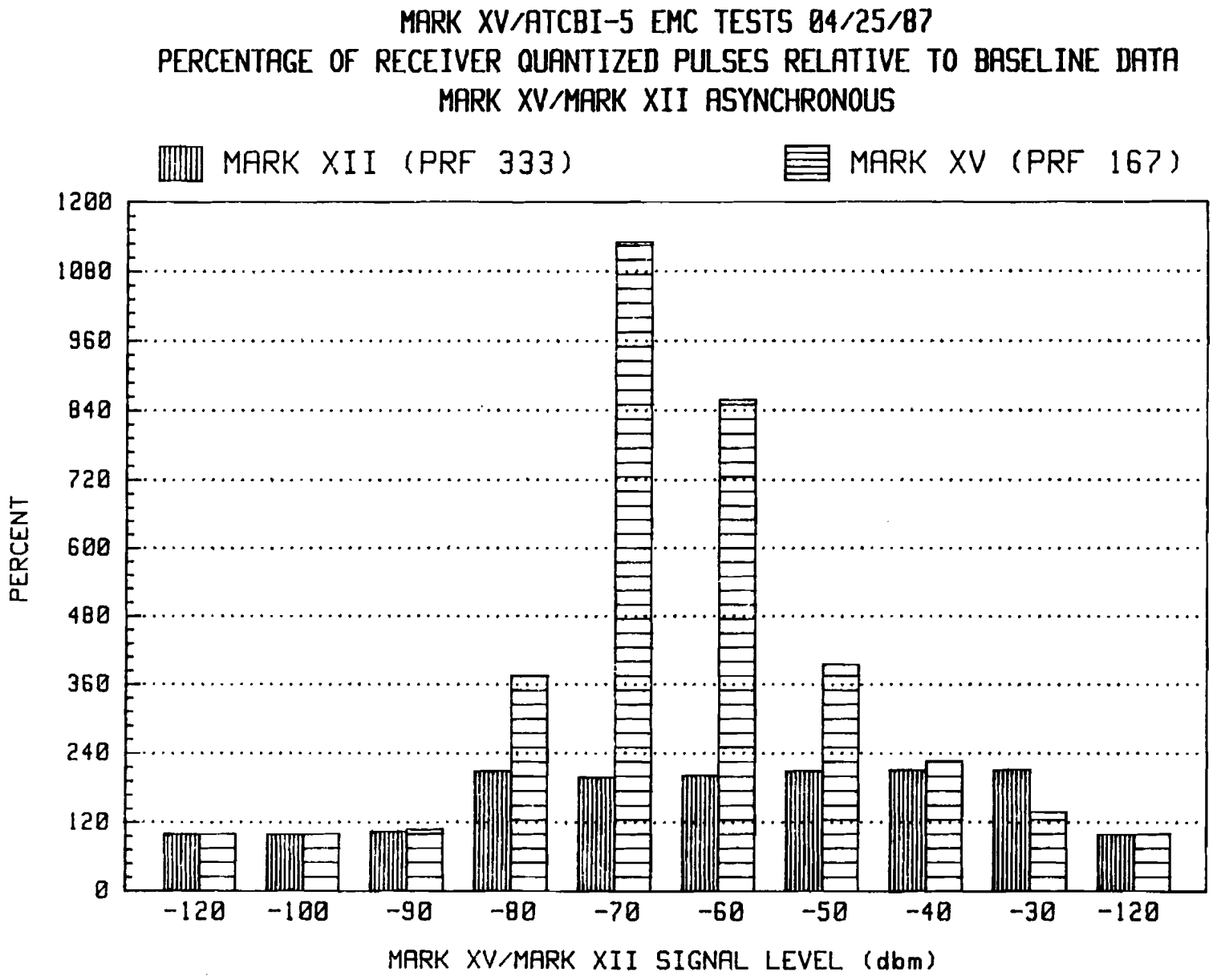

FIGURE 8a. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT THEIR EXPECTED PRF (1 of 7)

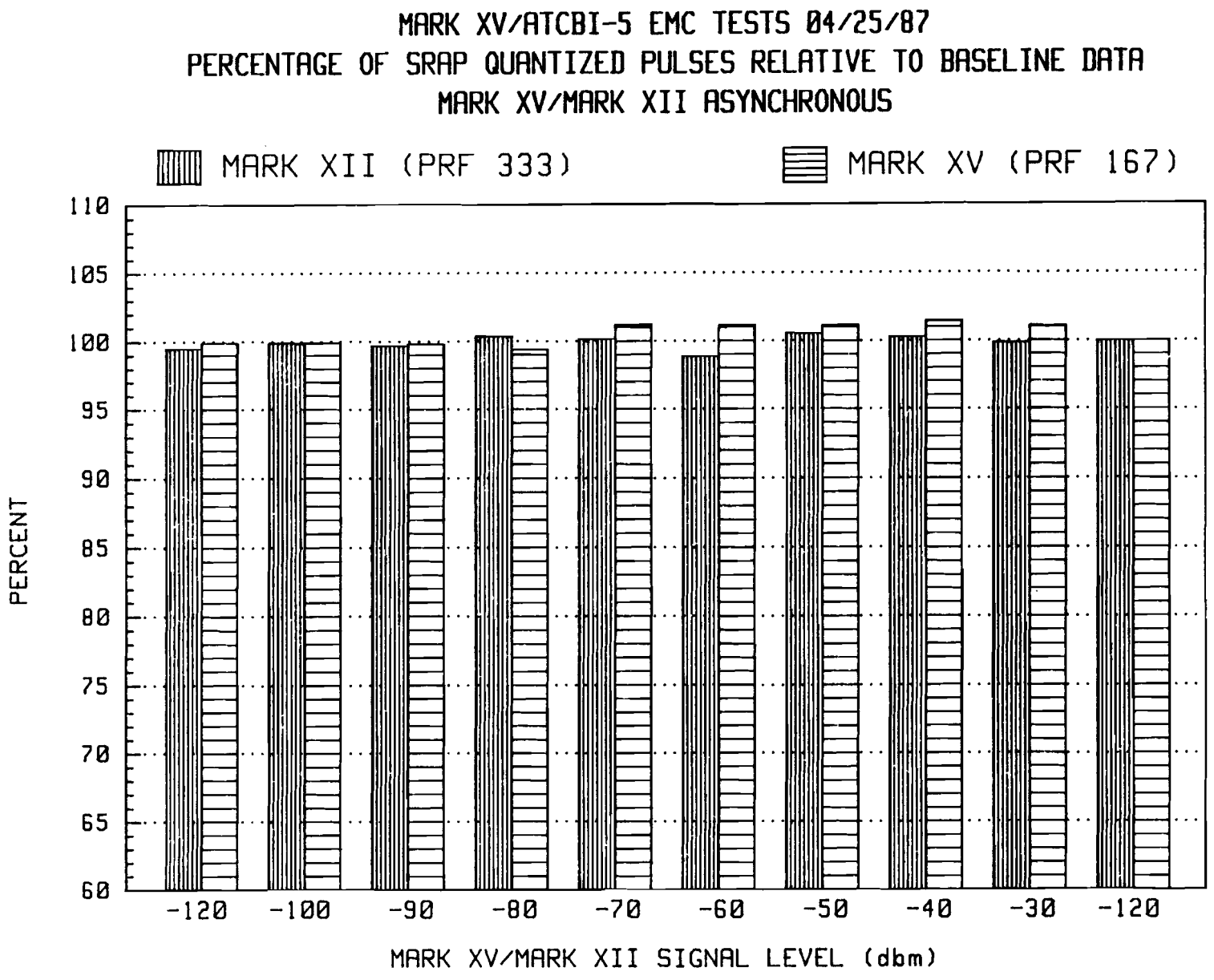

FIGURE 8b. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT THEIR EXPECTED PRF (2 of 7)

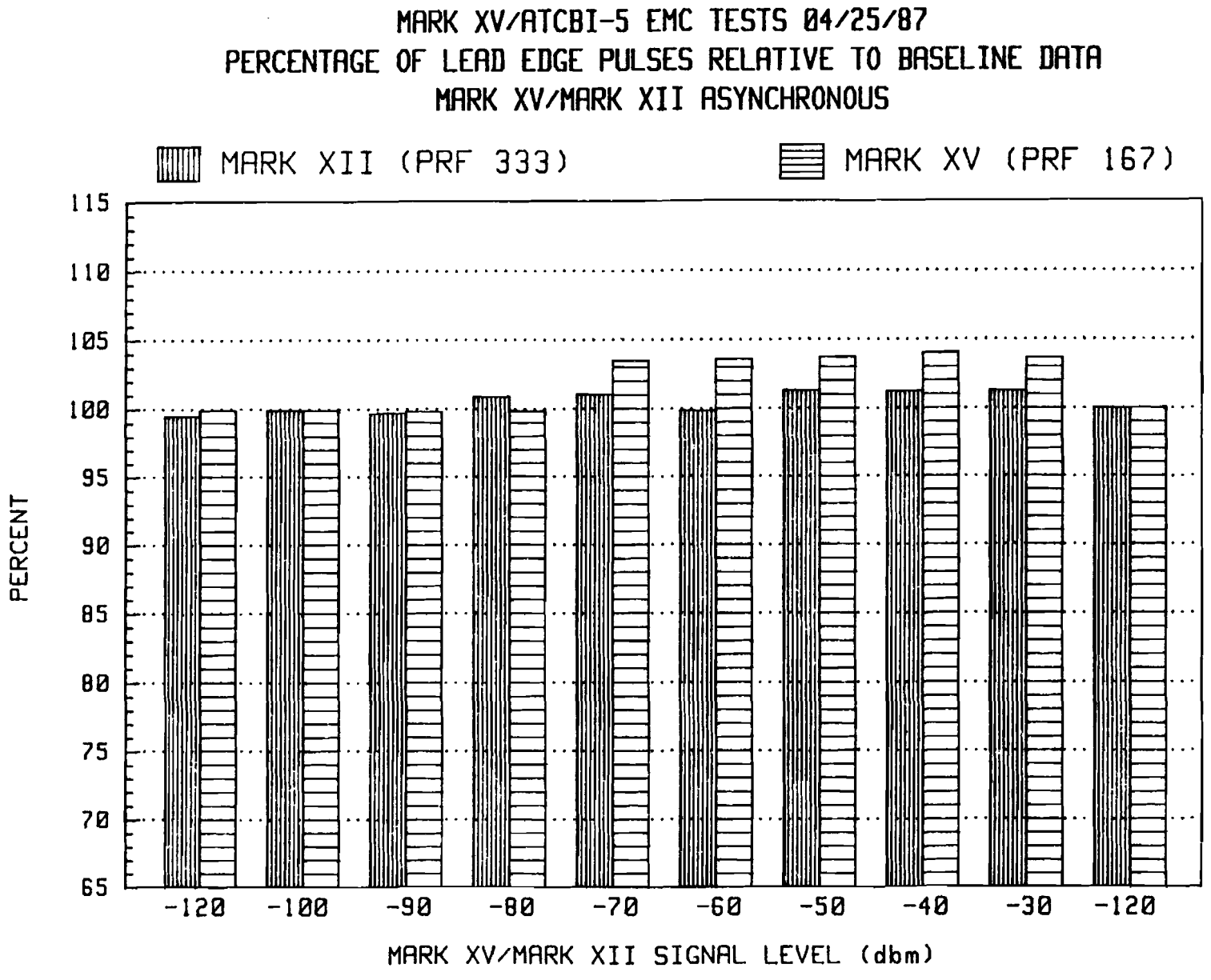

FIGURE 8c. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT THEIR EXPECTED PRF (3 of 7)

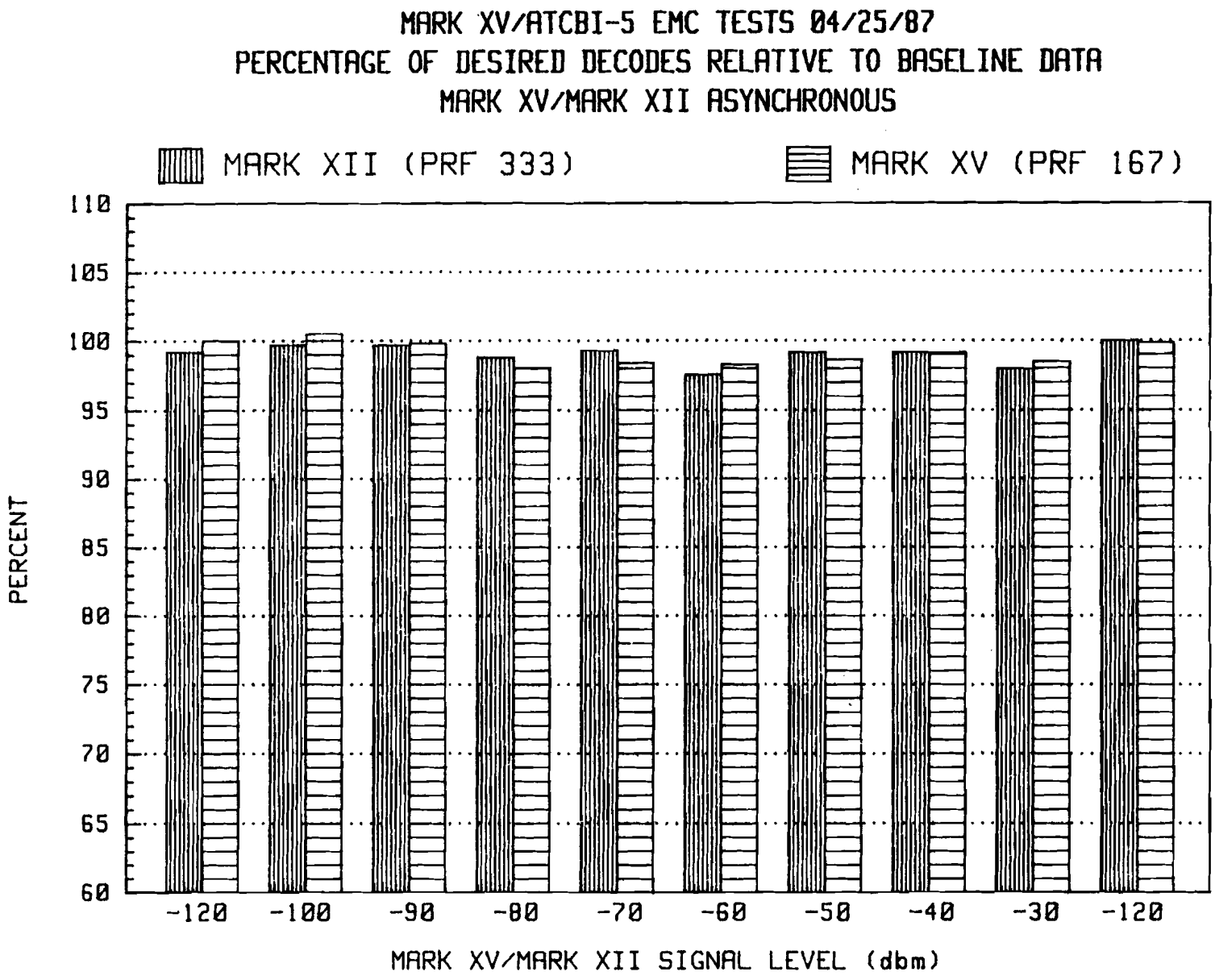

FIGURE 8d. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT THEIR EXPECTED PRF (4 of 7)

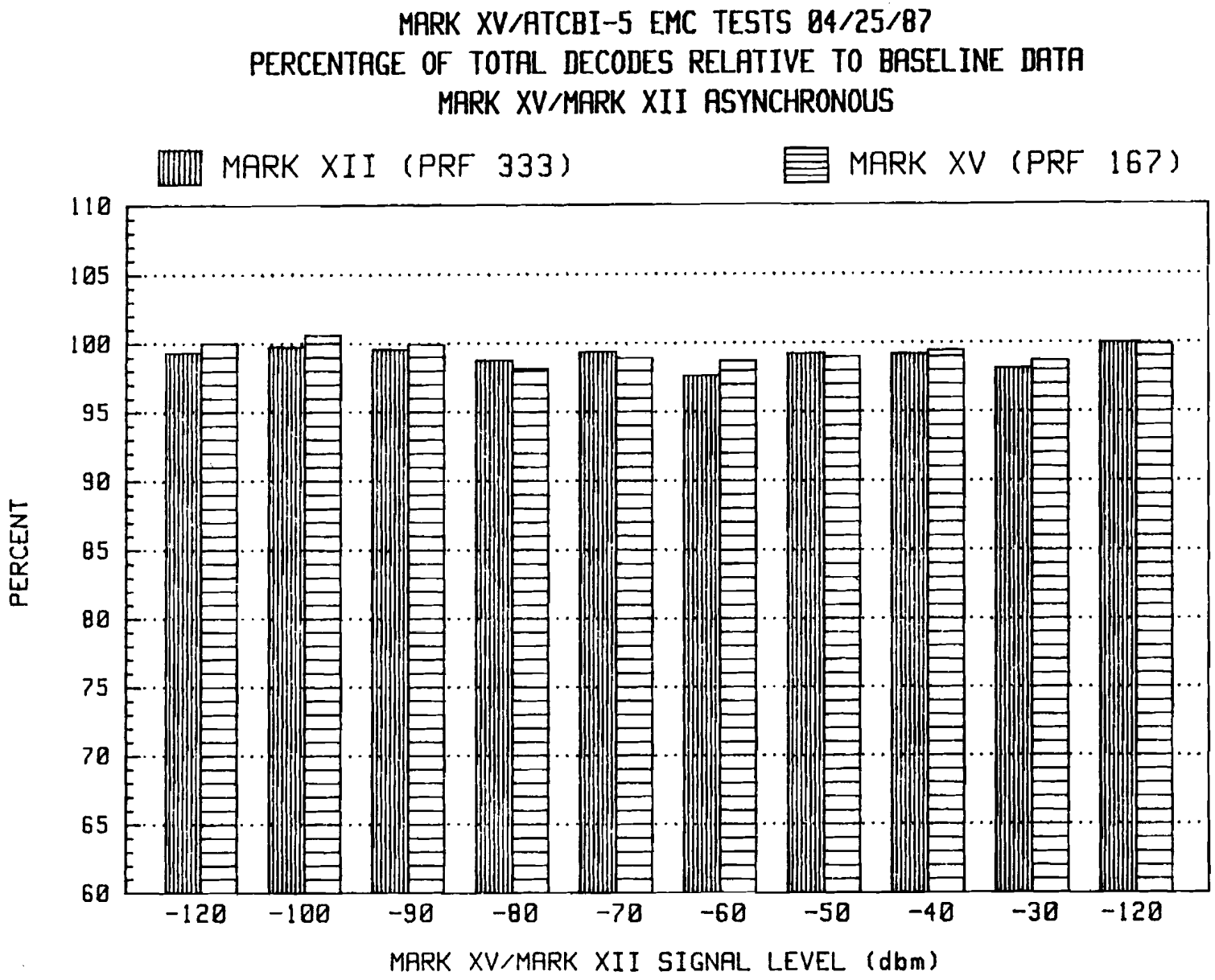

FIGURE 8e. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT THEIR EXPECTED PRF (5 of 7)

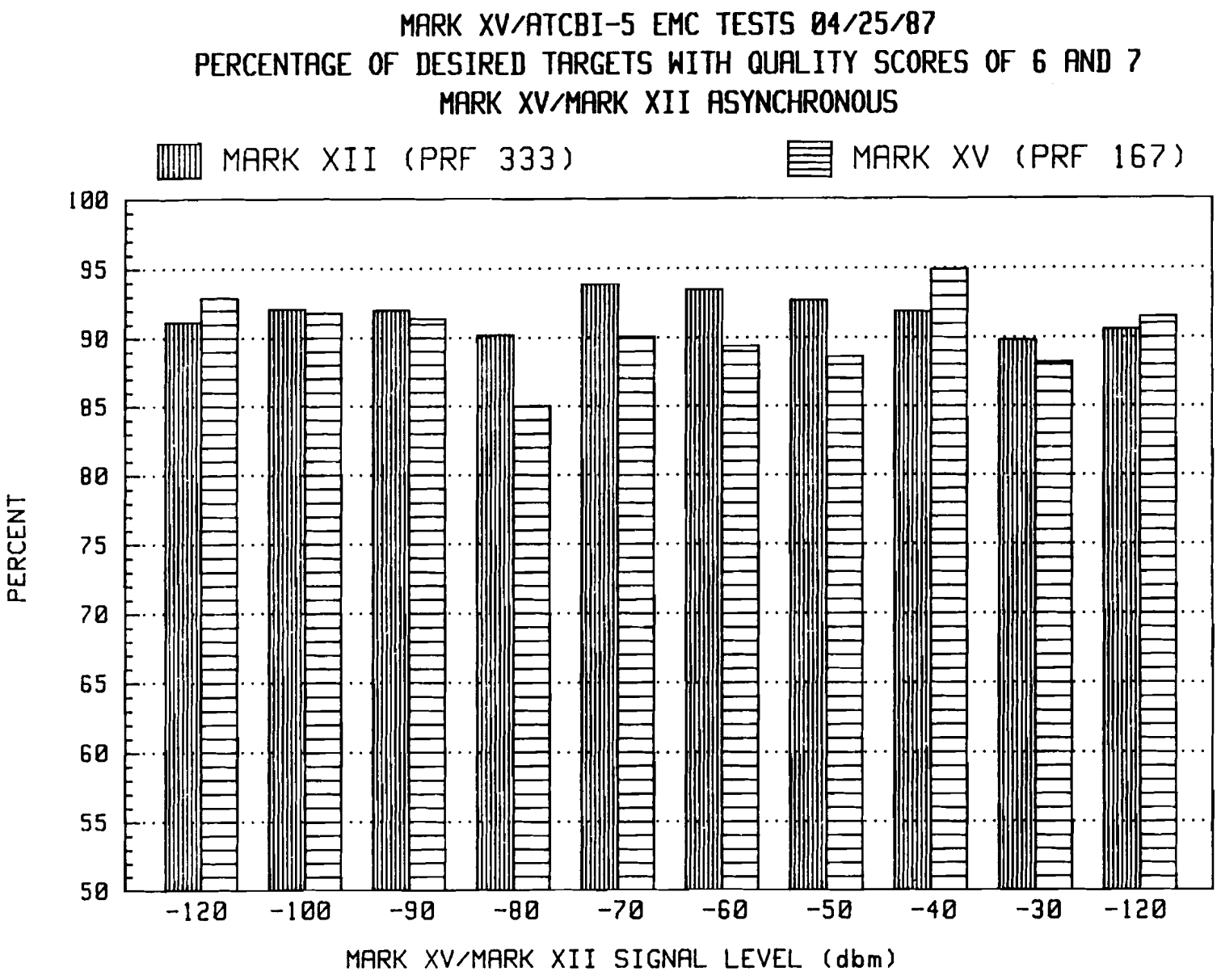

FIGURE 8f. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT THEIR EXPECTED PRF (6 of 7)

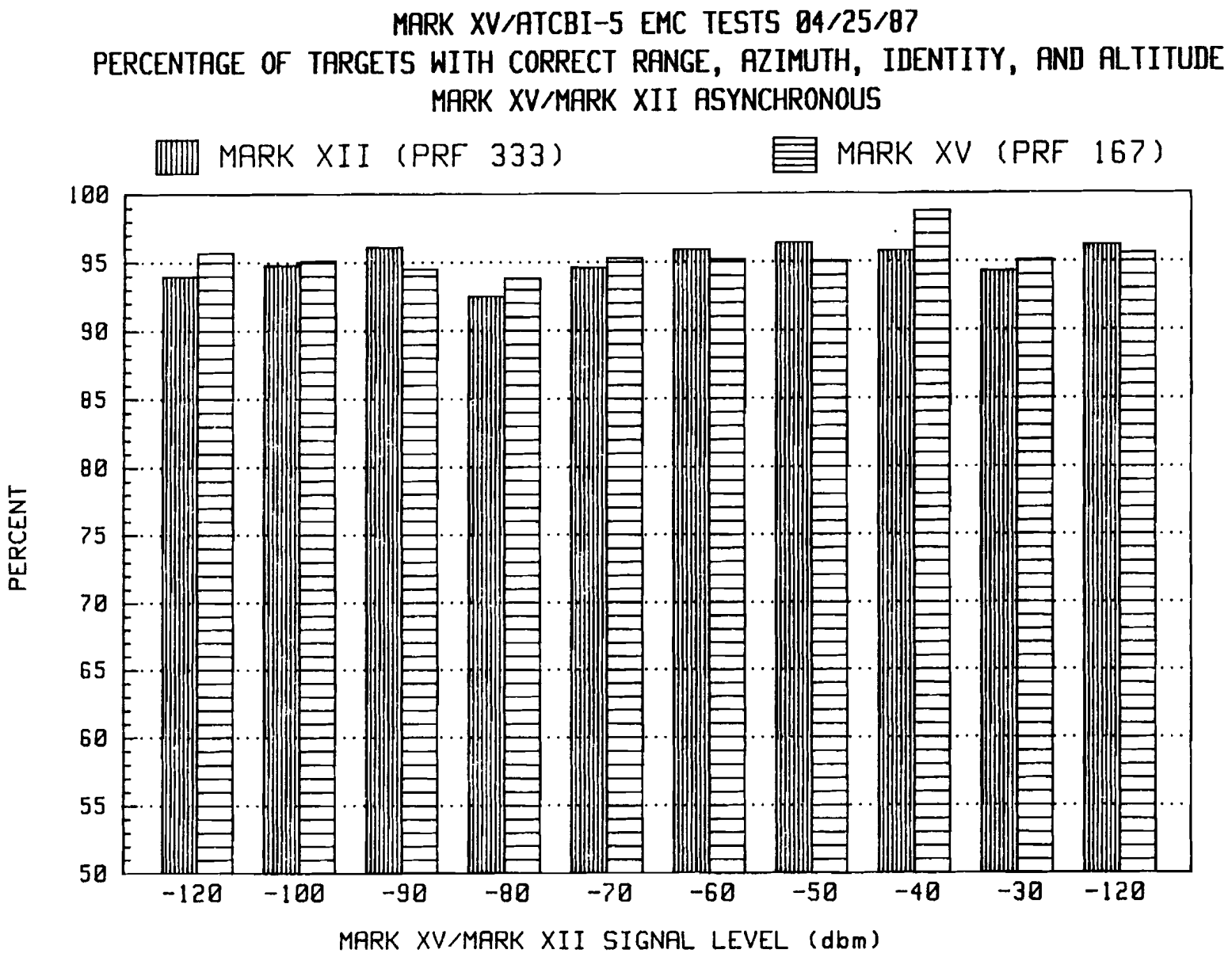

FIGURE 8g. PERFORMANCE PARAMETER MEASUREMENTS WHEN THE MARK SYSTEMS OPERATED AT THEIR EXPECTED PRF (7 of 7)

SUMMARY

EMC tests were performed on the ATCBI-5/SRAP/ARTS IIIA to measure the effects of the Mark XII and Mark XV systems. The main objective of the tests was to determine if the Mark XV had a greater interference effect on the ATCBI-5 than the Mark XII. For the tests, the Mark systems were operated at PRF's of 167, 333, and 500. The Mark XII, which is being replaced by the Mark XV, is normally operated at a PRF of 333. The Mark XV is expected to operate at a PRF of 167. Both Mark systems downlink replies at 1090 MHz. The ATCBI-5 receiver is tuned to 1090 MHz, thereby making it susceptible to interference from the Mark XV and Mark XII.

The Mark XII system, as tested, did not indicate noticeable interference effects on the performance of the ATCBI-5/SRAP/ARTS IIIA system. The absence of effect can most likely be attributed to the short message duration of the Mark XII Mode 4 reply in comparison to the ATCRBS 20.3-microsecond reply duration. No data were collected for Mark XII RF levels greater than -30 dBm or PRF's greater than 500.

When the Mark XII was replaced by the Mark XV as the interference source, the resulting data indicate that the Mark XV has a more noticeable effect on some of the ATCBI-5 performance parameters measured. The data indicate that as the PRF was increased, the performance of the ATCBI-5 was further degraded. Those performance measures that were affected include the ATCBI-5 receiver quantized pulse count, SRAP lead edge pulse count, bracket decodes, and desired target quality scores. The number of lead edge pulses increased accordingly as the PRF of the Mark XV was increased. No data were collected for Mark XV RF levels greater than -30 dBm or PRF's greater than 500.

A comparison of the test results from the Mark XV and the Mark XII tests indicate there is a difference in effect on the performance of the ATCBI-5 when all conditions for the two systems are the same. However, if the Mark XV will be operated at low PRF's as expected, interference effects on the ATCBI-5 will be minimized.

CONCLUSIONS

1. When both the Mark XII and Mark XV systems operate at the same pulse repetition frequency (PRF), the Mark XV has a greater interference effect on the air traffic control beacon interrogator (ATCBI-5)/sensor receiver and processor(SRAP)/automated radar terminal system (ARTS) IIIA systems than the Mark XII.

2. The greatest interference effect of the Mark XV on the ATCBI-5/SRAP/ARTS IIIA systems occurs with the Mark XV transmitting relatively low power levels of -70 and -80 dBm.

3. With the Mark XV/XII systems operating at their expected PRF's of 167 and 333, respectively, the Mark XV causes a significant increase in receiver quantized pulses, a maximum 2 percent increase in SRAP quantized pulses, a maximum 4 percent increase in lead edge pulses, negligible reduction in total and desired decodes, a maximum reduction of 5 percent in correct desired replies, and negligible reduction in correct targets as compared to the effects of the Mark XII on the Air Traffic Control Radar Beacon System (ATCRBS) ground system.

RECOMMENDATIONS

1. The Mark XV should be operated at low PRF's in order to minimize its impact on the performance of the ATCBI-5/SRAP/ARTS IIIA systems.

2. If Mark XV signal levels are determined to be greater than -30 dBm at the ATCRBS receiver directional antenna port, further electromagnetic compatibility (EMC) testing on the ATCBI-5/SRAP/ARTS IIIA systems will be necessary since no EMC data were collected for signal levels greater than -30 dBm.