the antenna and is then distributed to the various channel receivers. An extra output on the pre-amplifier is used to receive the signals from the CDI transmission.

In the test, the mobile transmitter is tuned to the channel as before and is used to transmit a 1kHz test tone signal from the mobile back to the Mt. Ada Base Station. At the Base Station the 1kHz test tone from the mobile is recorded as before for later processing.

The Base Station is also equipped with a spectrum analyzer which is used to set the CDI level and to monitor the amplitude of the incoming mobile transmissions as the car is driven around the coverage area. The spectrum analyzer set at the right frequency and detector bandwidth, and the output is used to record variations in the mobile signal level. This is correlated with S/N performance in later analysis.

The chart recordings are also used to monitor when CDI is not transmitting to monitor normal control of the mobile power levels and to monitor "splatter" from the adjacent mobile channel into the CDI receiver bandwidth. These are used to analyze potential CDI outages.

Figure 25(a) shows variations of the recorded Mobile power levels at the Mt. Ada site. Figure 25(b) shows splatter from the mobile into the CDI receive channel 15kHz away.

The above set ups were used to test both Outbound and Inbound interference from the CDI base transmission and User transponder transmission in the reference cell. A final round of tests was conducted to test interference in the Adjacent channel cell and in the Re-use cells for the Outbound signal. Though the potential for interference is greatest in the reference cell the other two cells have potential interference that was checked for completeness.

The CDI transmission was made from the reference cell, Mission Valley as before. The mobile channel with 1kHz test tone was transmitted from the Adjacent-channel cell and the mobile run around the Adjacent-channel cell to record signal quality. The recordings were processed as in the Reference-cell tests. The Re-use cell tests were done with the same test set up as the Adjacent channel cell; the mobile channel with the 1kHz test tone was transmitted from the Re-use Base Station to a mobile run around the Re-use cell.

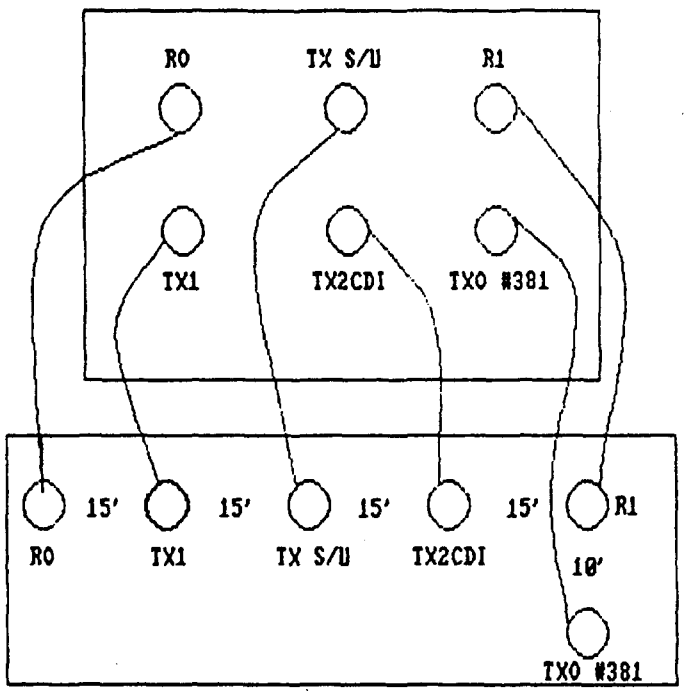
As a final check, interference was recorded between the cellular allocations themselves. For this test, the CDI transmitter was turned off in the Reference cell and the Reference cell mobile channel was turned on and driven with a recorded voice tape. The

mobile was driven around in the Re-use cell as before to record interference from the distant Reference cell transmissions. The experiment was repeated in the Adjacent channel cells.

On these tests, the CDI transmitter is expected to show no interference. It is pointed toward the Reference Base Station and away from the adjacent Re-use cells; it is also much closer to the Reference Base Station.

The inbound interference between the cellular system itself was not checked. For this test, an additional mobile would be needed. it is known in the cellular industry that this interference mode is serious and effects cell frequency coordination procedures. However, the CDI system has much less interference potential since its User Transceivers are low power. If they are at the edge of the Reference cell, they would be located on the Reference cell side of buildings or use directional antennas directed towards the Reference cell.

The test set-ups for the remaining tests are recorded on Figures 27, 28, 29 and 31.




ANTENNA ARRAY (MISSION VALLEY)

FIGURE 15(a)

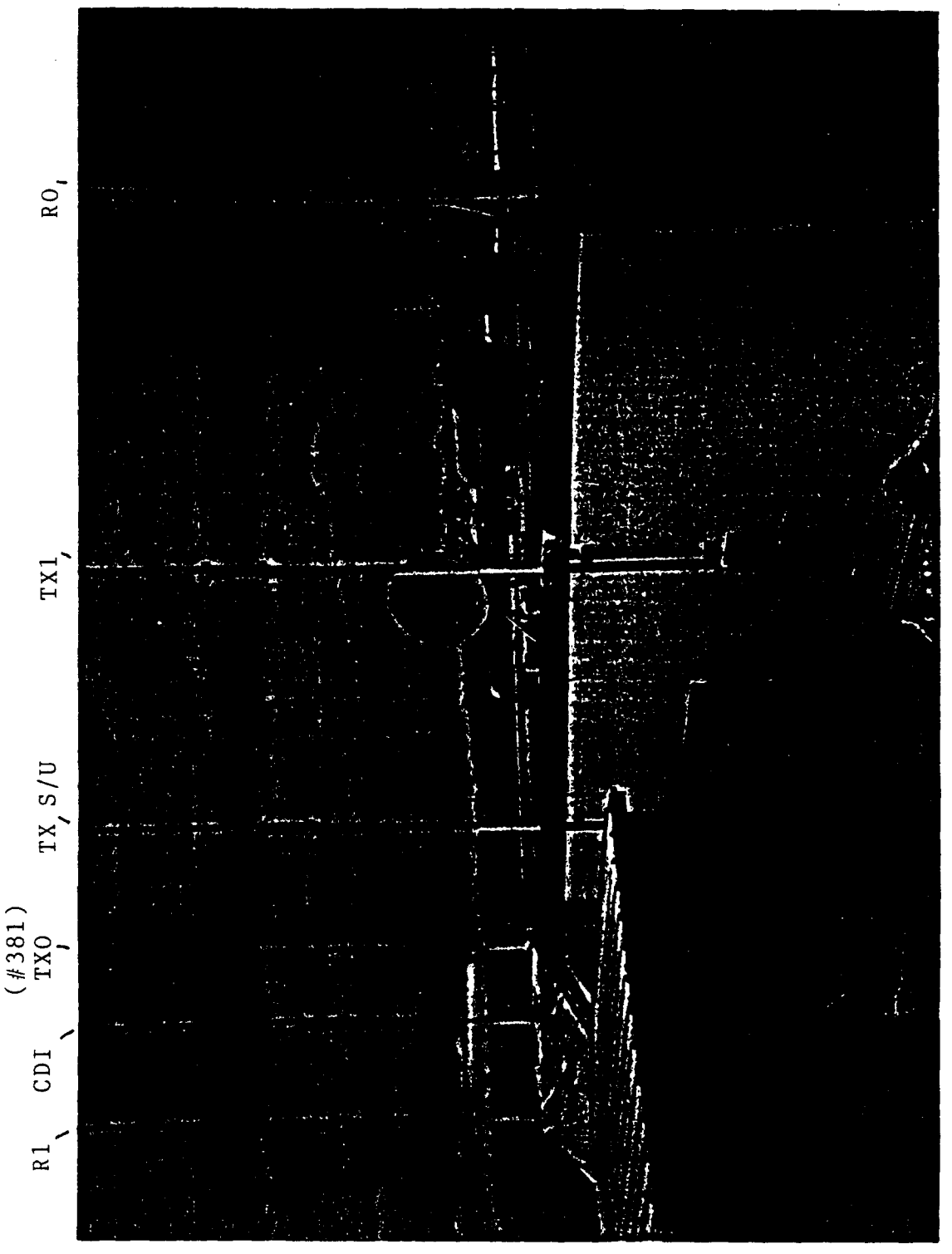



FIGURE 15(b)

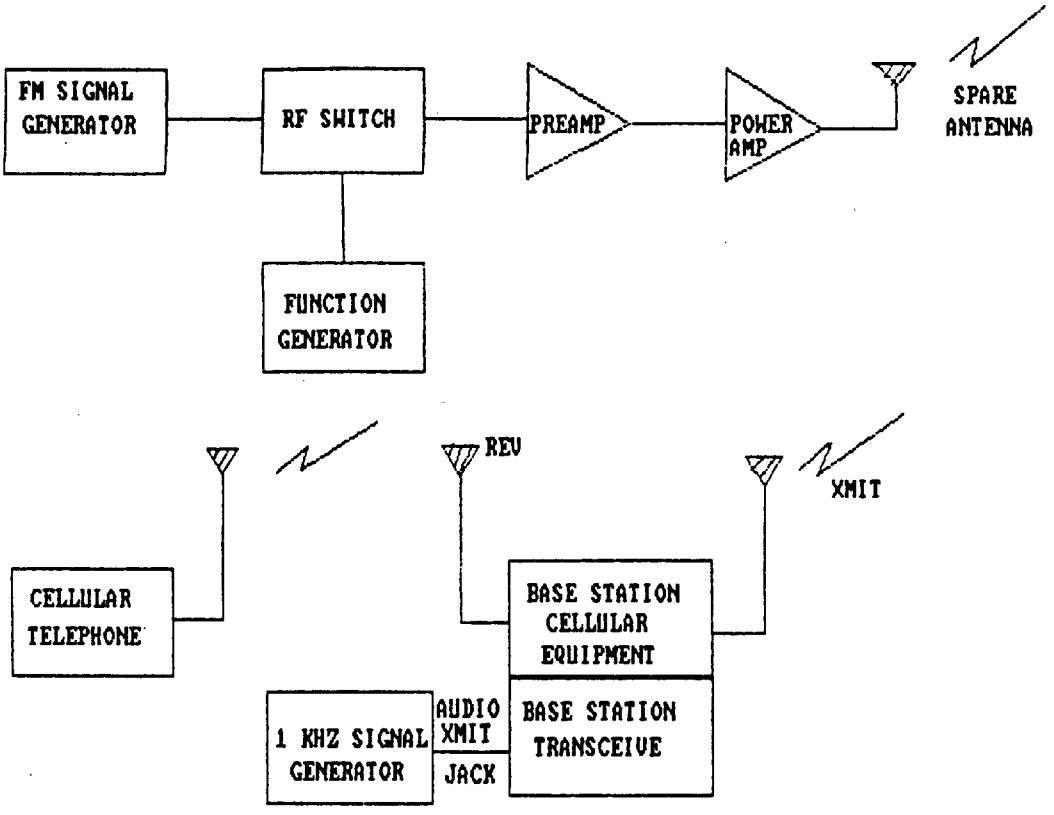



FIGURE 16
MISSION VALLEY BASE STATION
TEST EQUIPMENT

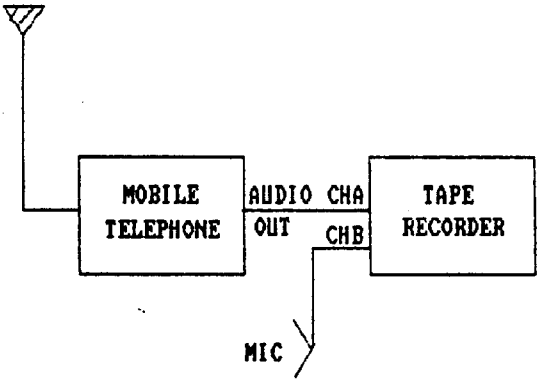



FIGURE 17
CO-CHANNEL MOBILE
TEST EQUIPMENT

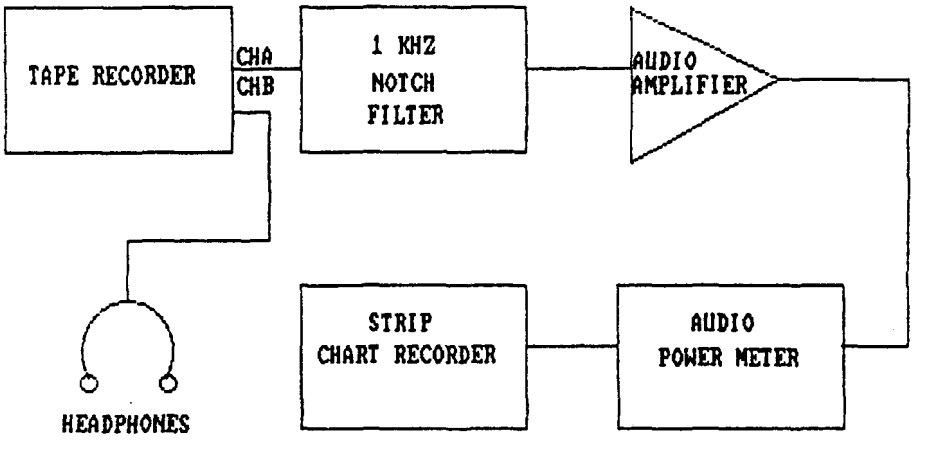



FIGURE 18

DATA REDUCTION

TEST EQUIPMENT

3/7/89 6:30pm
Gordy @ motel Mt-Ada
SAT no modulation

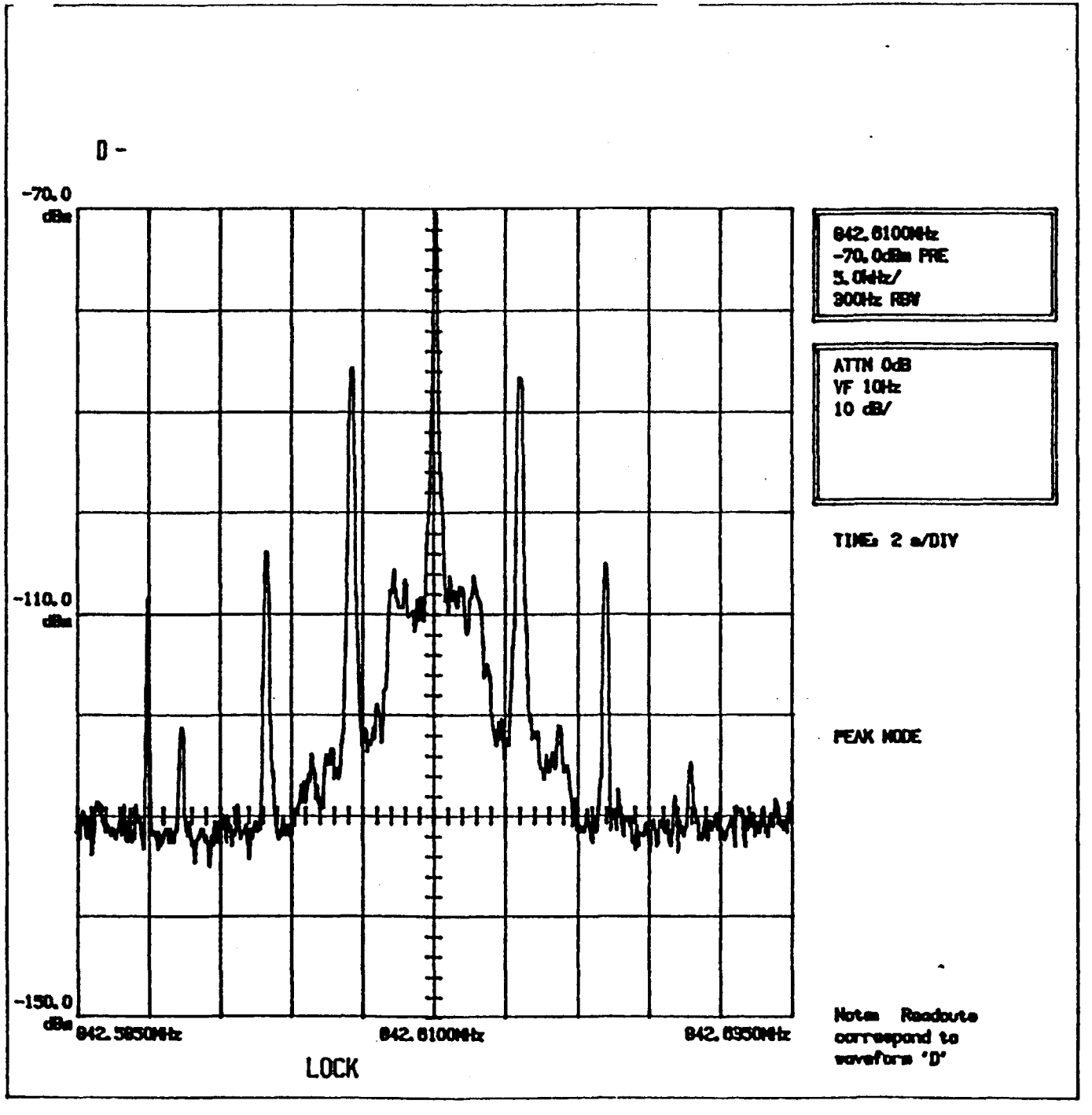



FIGURE 19

3/7/89 6 pm

Gordy @ Motel

1KHz tone.

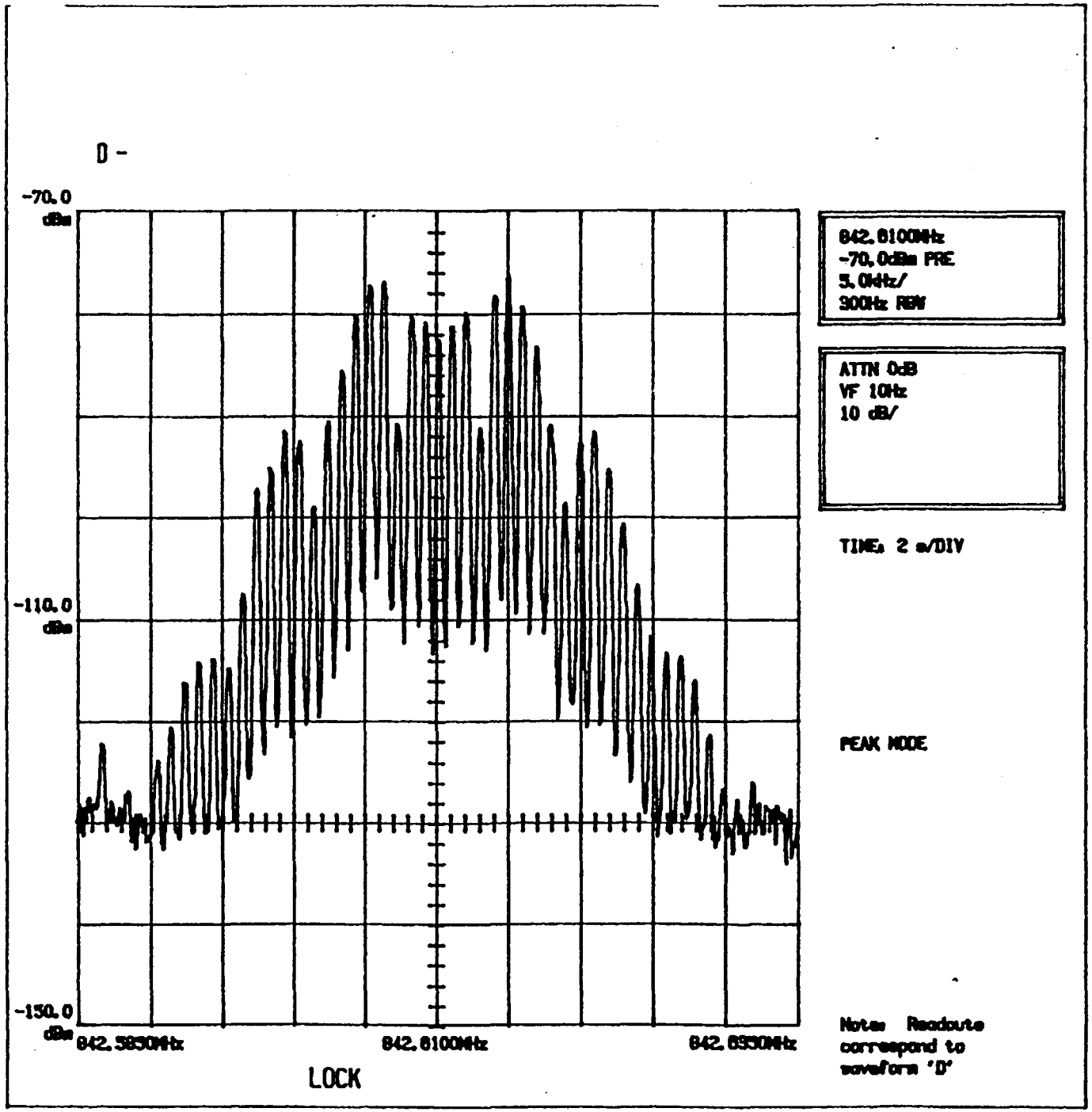



FIGURE 20

3/7/89 6 pm
Gordy @ motel
Harvard test sentences

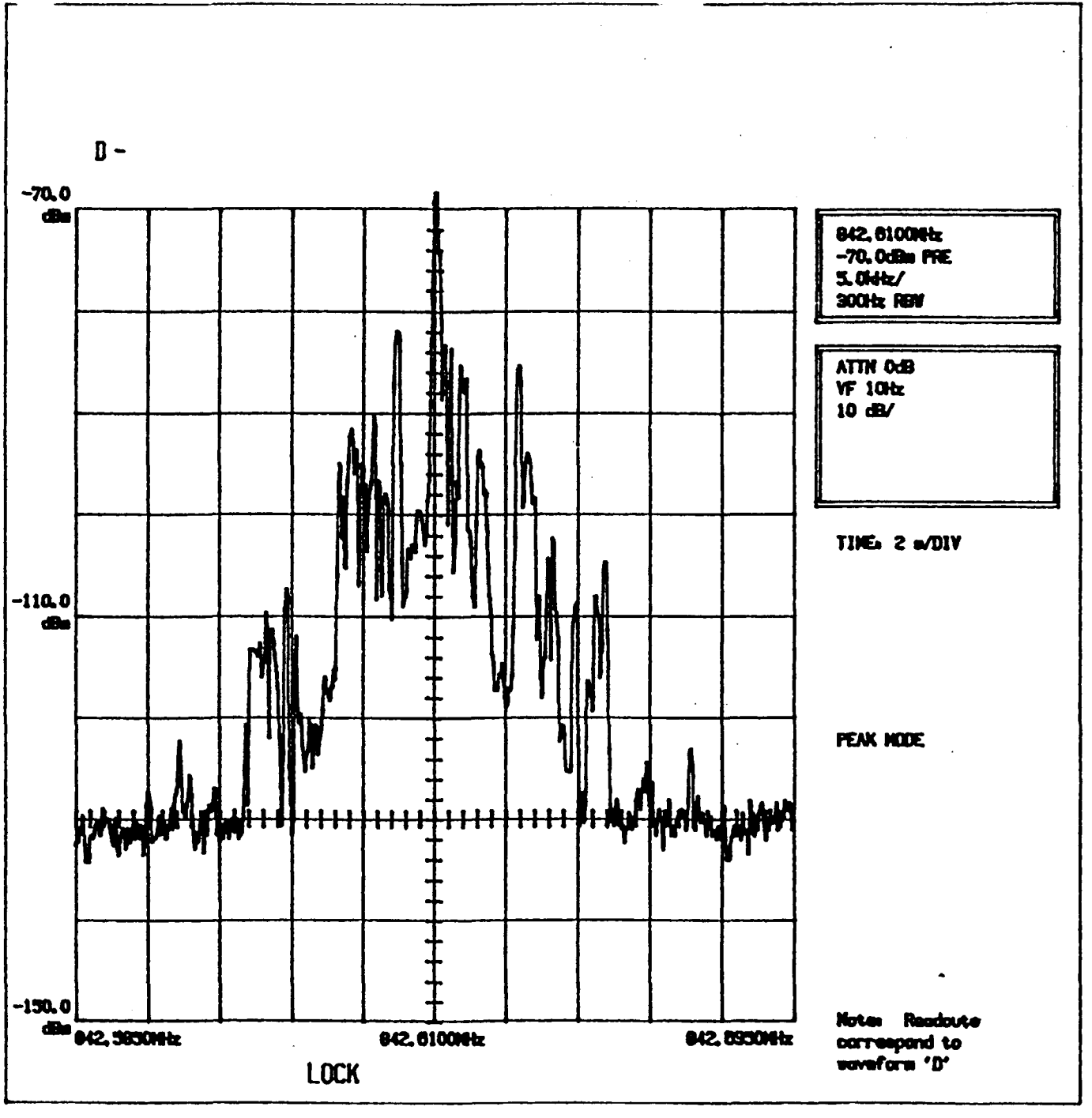



FIGURE 21

3/7/89
Run #2

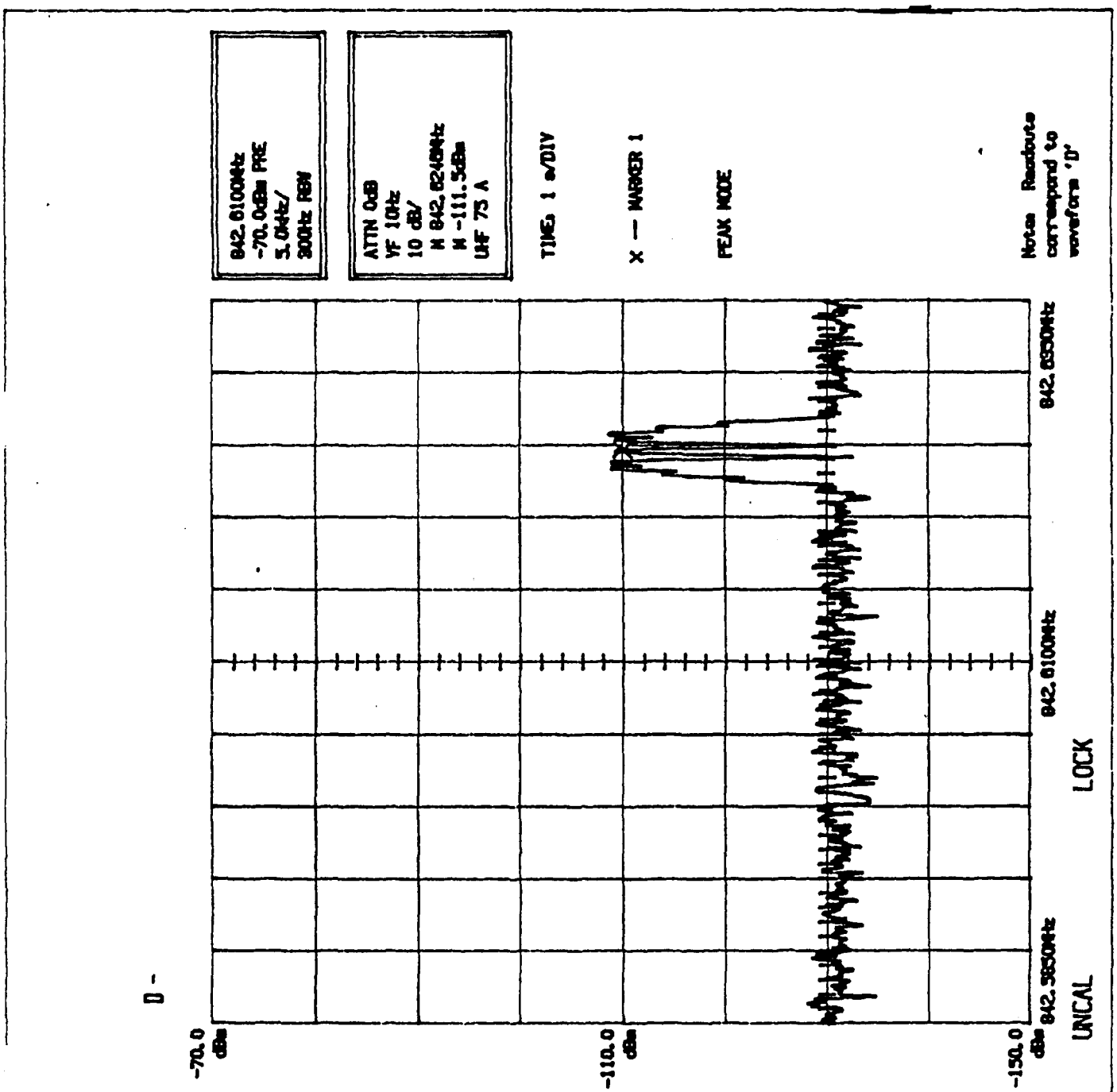



FIGURE 22

3/7/89

Run #3

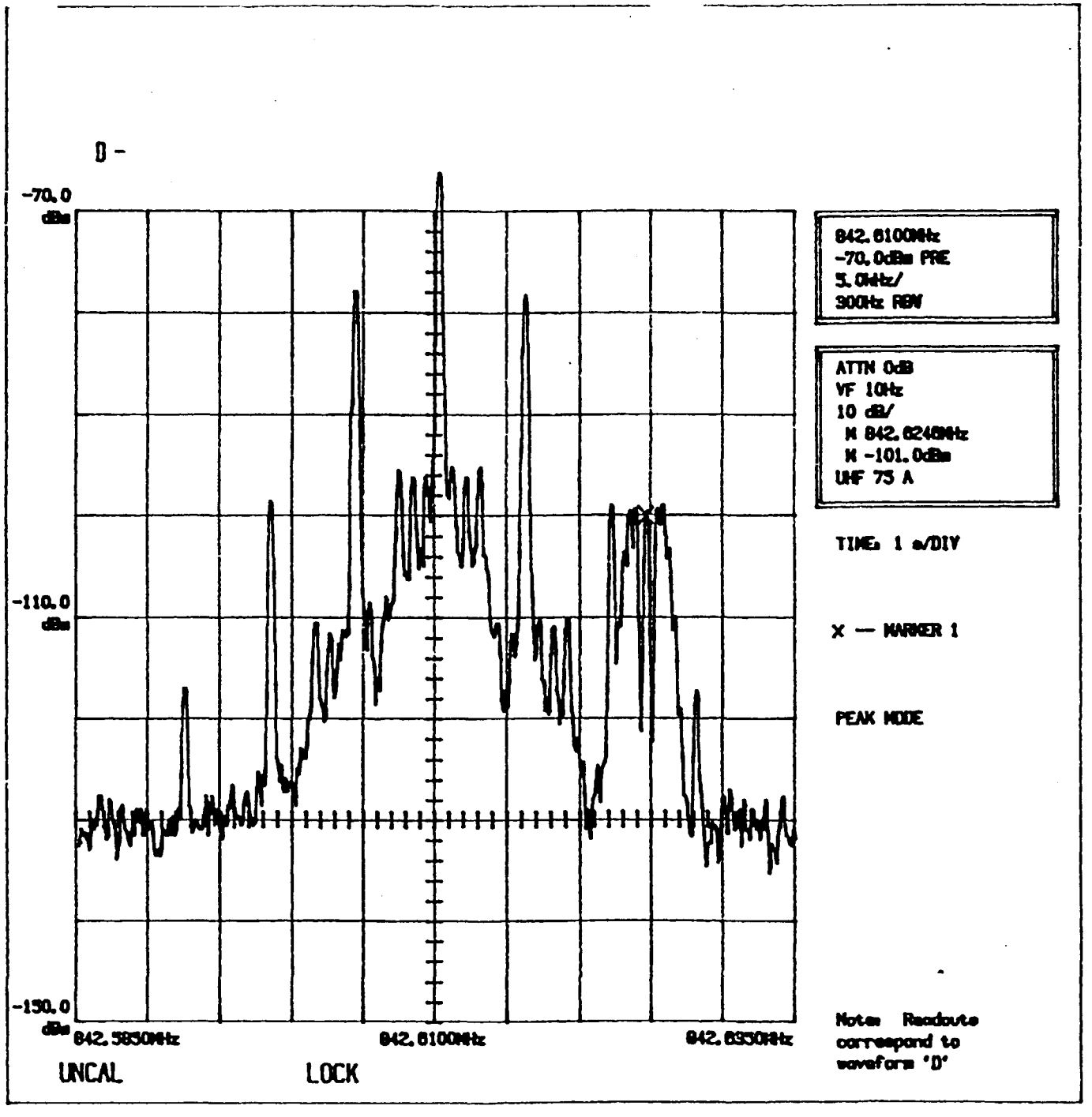



FIGURE 23

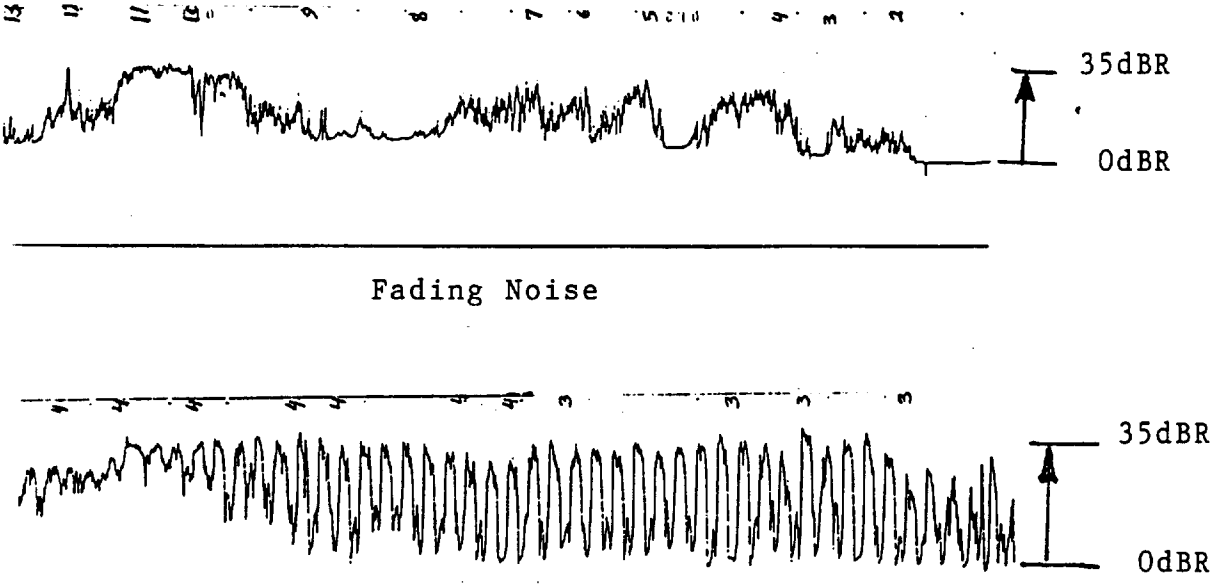
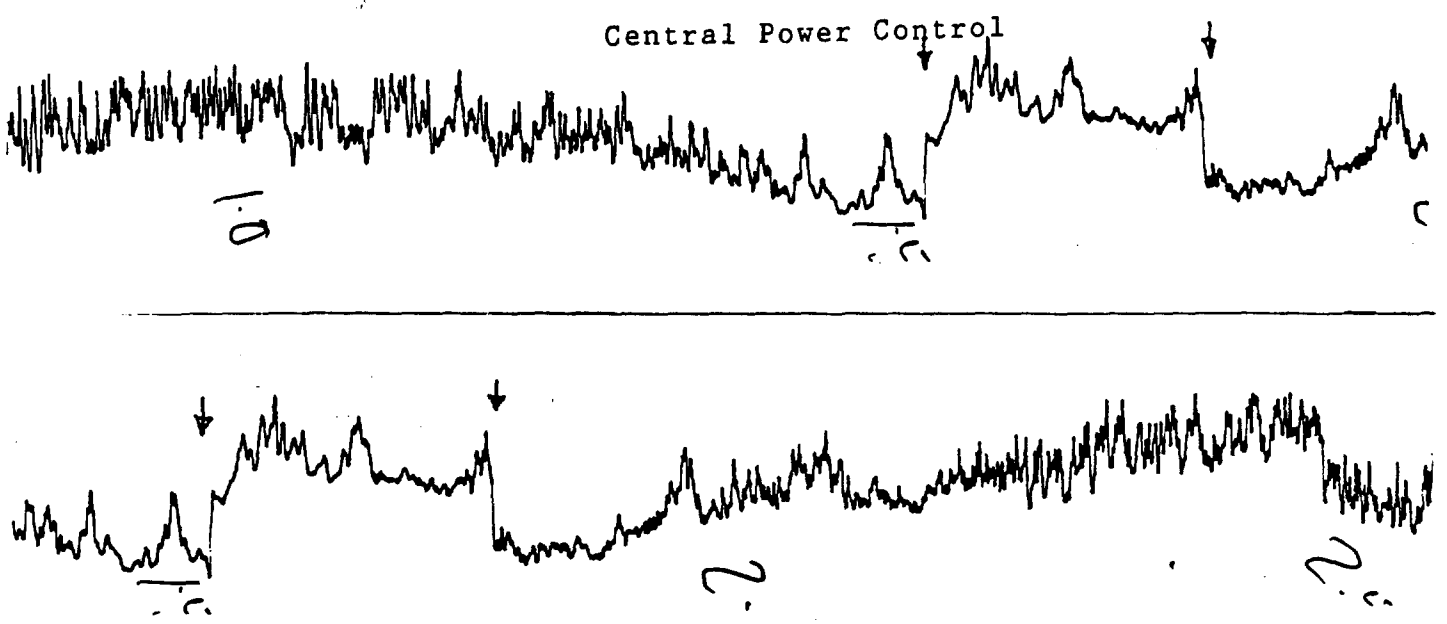
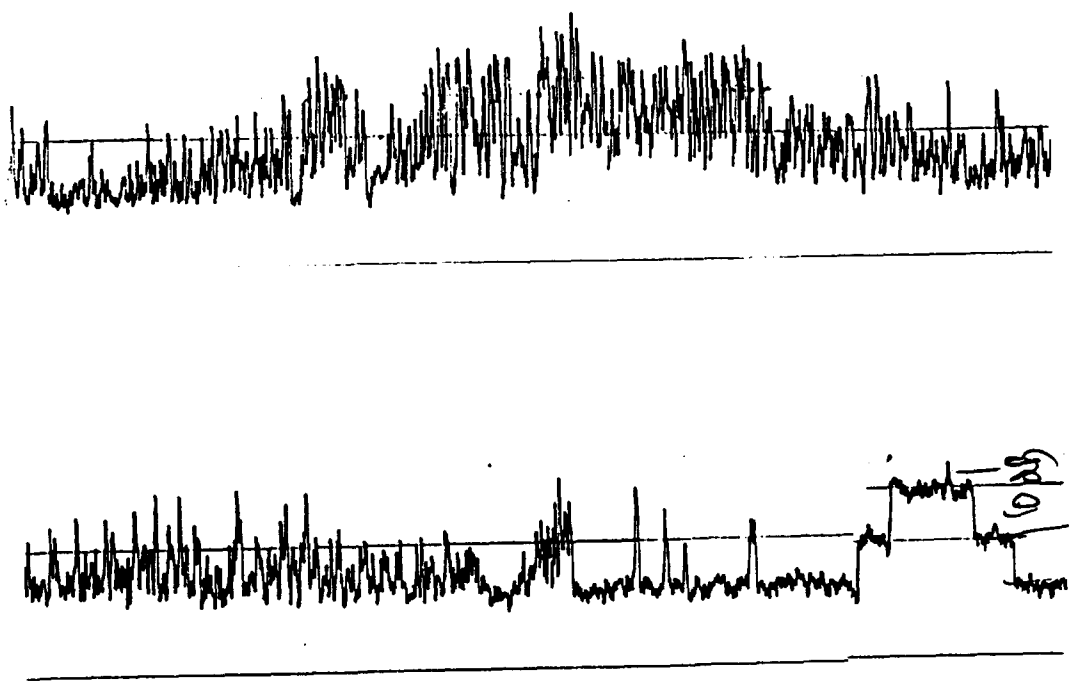



FIGURE 24
Example of Data Reduction




(a) Incoming Mobile Signal



(b) Splatter in CDI
Receiver Channel

FIGURE 25
Power at Mt. Ada Test Site

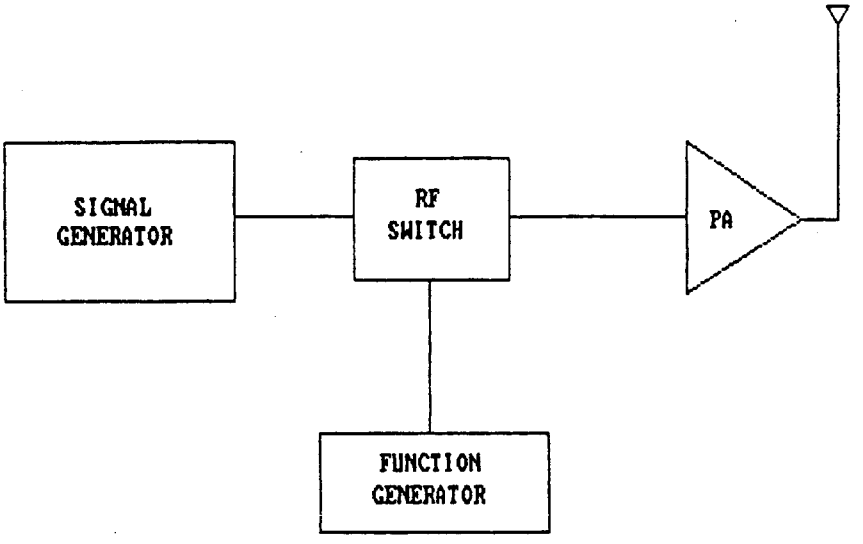



FIGURE 26

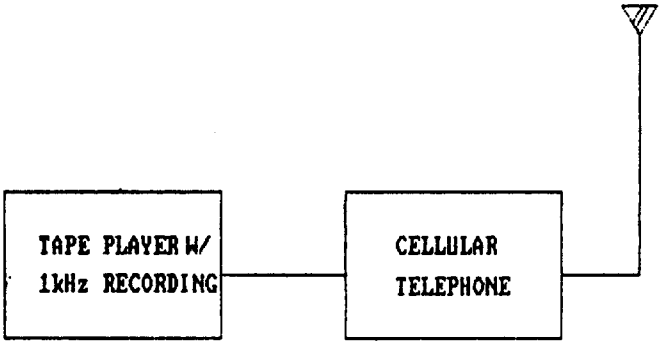



FIGURE 27

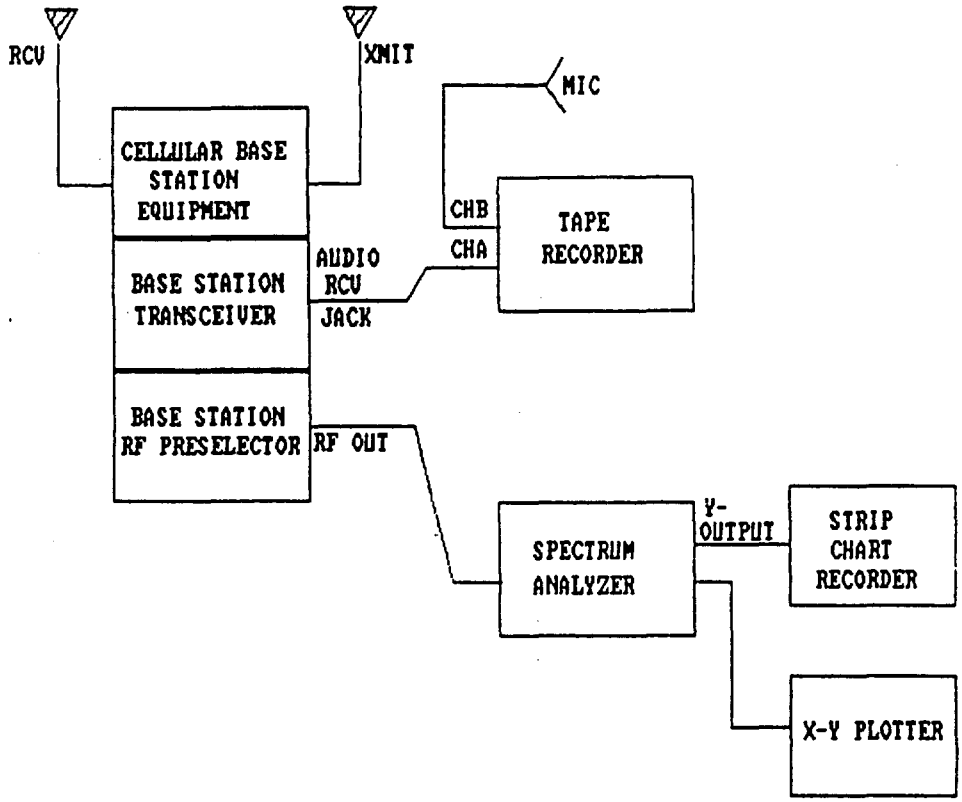
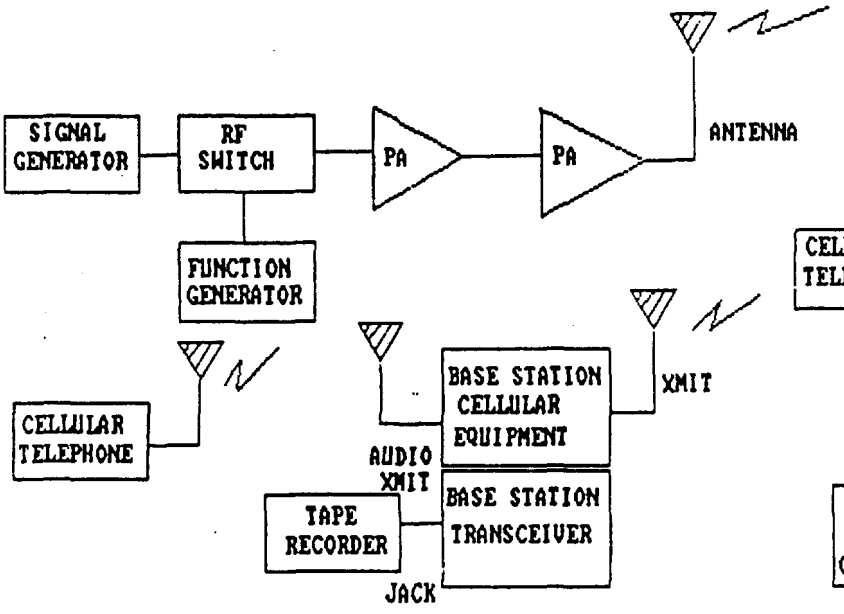
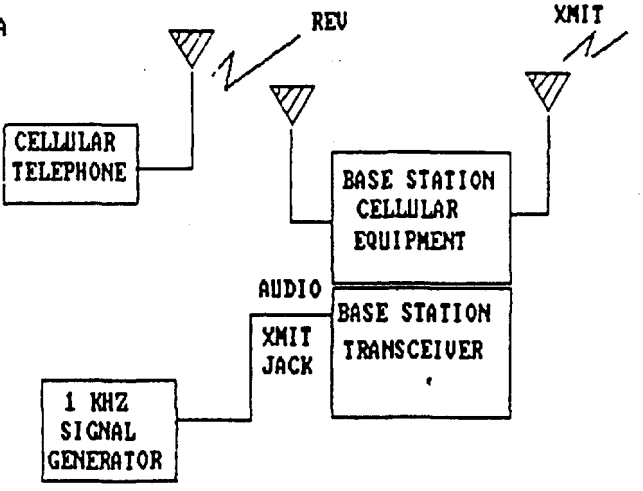



FIGURE 28.
MT. ADA BASE STATION
TEST EQUIPMENT



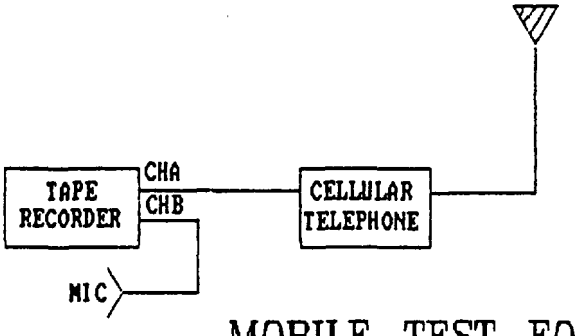

MISSION VALLEY
BASE STATION
TEST EQUIPMENT

FIGURE 29




SORRENTO VALLEY/CARLSBAD
BASE STATION
TEST EQUIPMENT

FIGURE 30




MOBILE TEST EQUIPMENT

FIGURE 31

OUTBOUND REUSED ADJACENT
FORWARD CHANNEL TEST EQUIPMENT

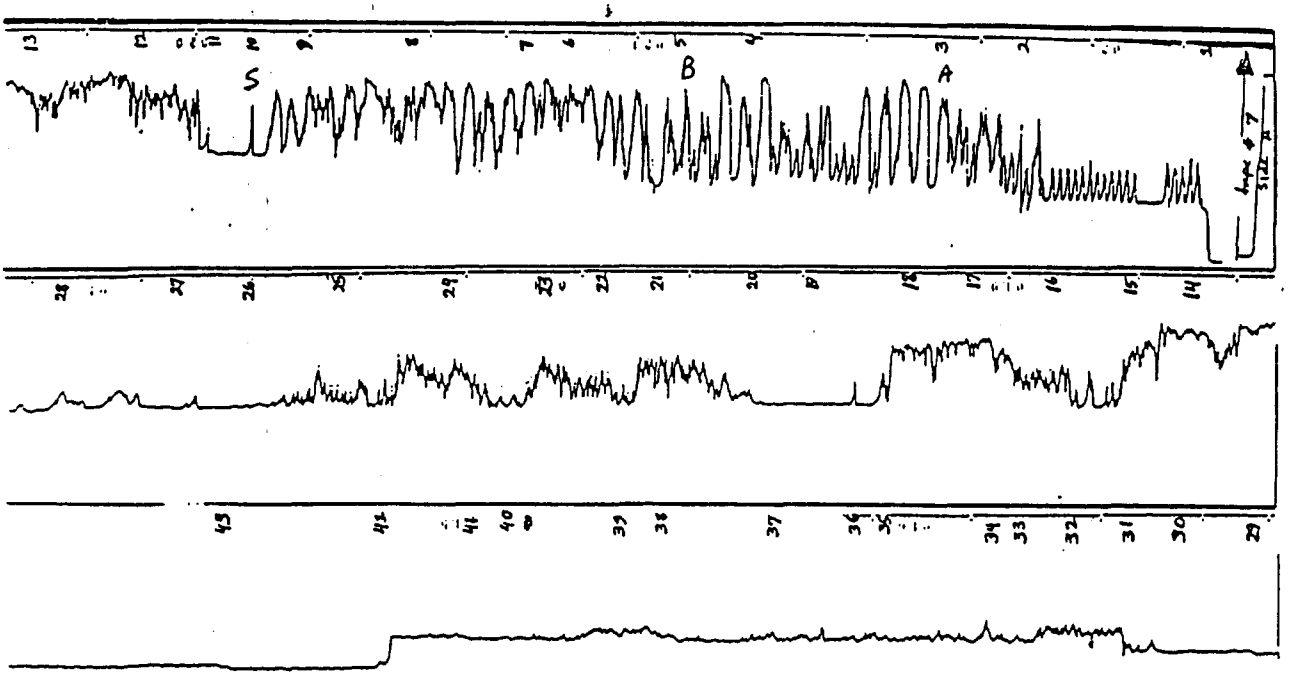
## IV TAPE RECORDS

For completeness, the audio test tapes have been recorded entirely on Chart recordings and indexed on Logs. The formats are illustrated by Figures 32. Figure 32(a) shows the beginning of the Chart recording of the audio tape, 32(b) shows the Log of comments recorded on the voice track of the audio tape.

On Figure 32(a), time runs from right to left, starting at the top of the page. It continues on the next strip from left to right again and so on down the page. This slow chart speed is 25mm/min. The numbers shown on the Chart correspond to the Log comments from the voice track of the audio tape. "1", for example, is "starting of tape"; "2" is "right of Bank building and stationary; "3" is "starting moving, 25mph, etc.

Each tape is indexed thoroughly in the above fashion. In addition, each audio tape is chart recorded at High Chart speed, 10mm/sec., to show fine detail for analysis. Figure 32(c) shows samples of the high-speed charts.

All test tapes are processed in this way. The Charts at Low-speed and the Logs are given in Appendix A. The charts are selected and analyzed in the following sections.

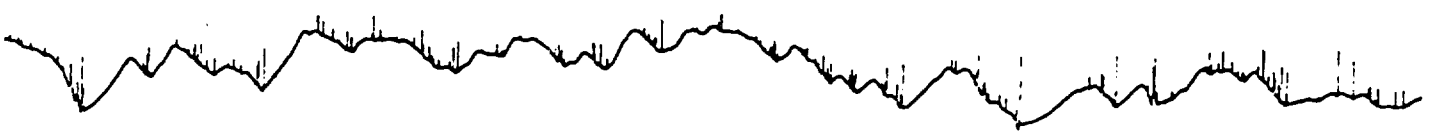



(a) Slow speed Recording

driving the toward Carlsbad ~ 35 miles
805 N → 5-N → to Carlsbad

| Chart Index | Comment Number | Comments 1KHZ + |
|---|---|---|
| 39.0–39.1 | 1 | 000 ~~Stationary~~ Starting of tape |
| 38.2–38.3 | 2 | 007 right at bank building & stationary |
| 37.1 37.2 | 3 | 020 starting moving ( 25 miles/hour ( the list will be repeated transmitting from the same antenna |
| 36.7–36.8 | 4 → 28 | 48 heading free & way heading East |
| 36.3 | 5 | 099 turn tape off until Carlsbad signal captures my ~~channel~~ receiver |
| 35.9 | 6 | 008 I-52 junction 4.9 miles ~~Next~~ N of 7-8 I will set odometer 000 at 805 starting hearing tone of Carlsbad |
| 35.2–35.3 | 7 | 060 5.05 " |
| 34.9 | 8 | 076 6.5 " |
| ~34.4 ~~35.5~~ | 9 | 087 ~~miles~~ 7.5 mile |
| ~34.1 | 10 | 92 → 98 8.0 mile Myer Mesa Blvd – Serranto rd exit |
| ~33.9 | 11 | 98 ~~Capture~~ Carlsbad Signal Capturing the receiver now |
| 33.5–33.6 | 12 | 104 9.0 miles |
| 32.9–33.0 | 13 | 115 10.0 " |
| 32.3–32.4 | 14 | 126 11.0 " ← turning the volume down (do don't want to distort the tape) |
| 32.0–32.1 | 15 | 133 11.5 " |
| ~31.7 | 16 | 129 12.2 " Carmel Valley rd exit |
| 31.2–31.3 | 17 | 130 13.0 " |

(b) Data Log



(c) High Speed Recording

FIGURE 32
Examples of Tape Records

## V OUTBOUND REFERENCE CELL TESTS

The Outbound links transmit signals from the Base stations to the Cellular Mobiles or CDI User transponders.

The CDI system operates its 2kb/s data carrier 15kHz off from the Cellular Voice carrier. In order to avoid interference to the cellular service, the CDI carrier is run at a level well below the voice carrier. The margin for protection of the Cellular service depends on the way the CDI Base site antenna is installed.

Three different transmitting configurations were tested. On one of them the CDI signal was transmitted from the same antenna used for the Cellular Voice-channel 15kHz away. On the second configuration, the CDI signal was transmitted on an antenna with the same polarization and antenna gain pattern, but located physically over 30 feet away from the antenna used for the Cellular Voice Signal. The third configuration tested was cross-polarization antenna; they CDI signal was transmitted from a horizontally polarized antenna located next to the vertically polarized antenna used for the Cellular Voice transmission. (see section IX).

When the same antenna is used, the CDI signal must be 20dB below the carrier level of the Cellular signal. When an antenna with the same characteristics, but located separately on the Base site is used, the CDI signal must be 25dB below the Cellular signal. When the cross-polarized antenna is used, the CDI signal must be 20dB below the Cellular carrier.

Any of these three installation strategies may be used. In an operational system, the choice should be made to suit the convenience of the Cellular and CDI operators. Use of the same antenna requires a low-loss coupler to combine the CDI signal to the Cellular signal before they are sent to the antenna. The coupler can be very lossy for the CDI signal and essentially transparent to the Cellular signal since the CDI signal to be radiated is 20dB lower in power than the Cellular signal. This technique may be preferred on sites, such as Mt. Ada, where the access to the antennas is difficult and expensive.

The separate, but identical, vertical antenna would have less interaction with the Cellular transmitter, but will require installation of a second antenna on the site, located near enough to have nearly identical coverage patterns. The lower power level will cause less margin for reception of signals by the CDI User units and will result in somewhat greater loss of data. However, the margins are still adequate. The CDI system uses an efficient data management protocol to overcome the sporadic loss of data due to splatter of energy from the adjacent Cellular channel.

The cross-polarization system will still require the installation of a separate antenna. The CDI signal level, however, can be higher than the vertical option above by at least 5dB. The added advantage is that the cross-polarization also protects the CDI signal from the Cellular signal. The CDI receiver receives about 11dB cross-polarization protection on the average. (See Section IX.) The allowed higher power plus the receive cross-polarization protection give about 16dB better results for the CDI system.

The Field tests covered a wide range of terrain in the Mission Valley test sites. The equipment described in Section II was used to record interference from the CDI system to test mobiles run over the area of the cell. The logs of these runs are contained in Appendix A. Figure 33 shows the roads used to obtain an extensive pattern of coverage over the cell. The pattern approximated radials both in flat areas and into mountainous areas. In open areas and among urban high-rise canyons.

Initial tests showed that the results are insensitive to the range of the CDI bandwidths being considered 1.5 to 3.0kHz occupied bandwidth and to the frequency tolerance that will be maintained by the CDI system, ± 250Hz. The main effect was due to the control of differential fading of the two signals.

Figure 34 shows the sensitivity performance of a typical Cellular mobile receiver to a CDI signal located 15kHz away from the Cellular transmission. The receiver selectivity is such that in this static test, the CDI Data signal could be only 5dB lower than the Cellular Voice signal even allowing room for frequency error. (The "Nominal" level in this test is 10dB lower than the Cellular carrier) However, the operational Cellular installation is not static. The signals Fade due to multipath in the transmission from the Base station to the Cellular mobiles.

Figure 35 shows the fading problem. As a mobile goes through a multipath area, signals from two directions cause deep fades. In many locations, fades as deep as 20 to 25dB are encountered. These cause the typical "picket fence" noise bursts experienced by all Cellular users. If the Cellular and CDI signals do not fade together the relative amplitudes of the two will change. If the phase of fading of the two signals is off by 5° out of 360°, the unwanted signal, say the CDI signal, will rise about 7dB higher relative to the Cellular signal when the Cellular signal is on the depth of the fade. The protection would have to be increased by 7dB. If the error is much larger the full margin of about 20dB would typically be lost.

The phase error is proportional to da•Dr/R : where da is the separation of the antennas transmitting the two signals. If the same antenna is used, the signals fade together. Dr is the separation of the two points causing the multi-path reflections. Dr may be the width of a major building or the distance between buildings on opposite sides of a street. R is the distance from

Base station to mobile. The differential fading is much more severe near the Base station than far from it.

The analyses show and the data confirm that if the antennas are located within one foot of each other or are the same then an extra margin of 10dB (15 to be absolutely safe) is adequate. The CDI data signal should be located 15 to 20dB lower in power than the adjacent Cellular voice signal.

If separate antennas are used then the full fading margin of 20dB is needed to ensure no interference to the Cellular service. i.e.. The CDI system should be 25dB below the Cellular voice channel.

The analyses indicate that if a CDI cross-polarization antenna is co-located with the Cellular antenna, a reduced fading margin could also be obtained in addition to the expected improvement due to the cross-polarization isolation. However, the vértical beam shape of the vertically and horizontally polarized antennas could not be matched during the test. Thus, interference near the Base station could not be reliably measured. Therefore, the conservative conclusion is that only the cross-polarization isolation which was measured should be used. The CDI signals must be kept at 20dB lower than the Cellular signal.

The Field runs covered many weeks and many conditions. Figures 36 and 37 show a representative sample to illustrate the results.

In Figure 36, the mobile is run from under the Mission Valley Test site to well out on the edge of the cell. Point D on the run is within the 37dBu contour, but is near the edge where fading and signal loss begins to occur.

In Figure 36(a), the noise recording is made along route I-8. On the top curve the CDI signal is 15kHz away from the Cellular Voice signal and 10dB lower in amplitude. The test is run with the CDI signal using an antenna with vertical polarization located over 10 ft. from the Cellular Voice transmission antenna. The beam shape of the two antennas were the same.

At this level of CDI interferer, the CDI signal is 5dB lower than the value that gives no interference in a static situation. However, there is perceptible interference shown. The lower curve in Figure 36(a) shows the same stretch of freeway with the CDI signal turned off. There a measurable amount of interference occurs in this run, particularly when fading occurs at point (D) on the path. This natural interference level does not cause loss of signal, but it is definitely perceptible.

Tests were made with the CDI signal reduced to 15dB and 20dB below the Voice level. AT 20dB the interference was not noticeable. With the CDI carrier 25dB below the Cellular carrier, there was no perceptible difference between runs with the CDI signal on and the runs with no CDI transmissions.

Figure 36(b) shows interference in the vicinity underneath the Base site building. The top curve also shows interference with the CDI interferer only 10dB below the carrier. The bottom curve shows some interference, but very little when the CDI signal is off.

When the CDI carrier is reduced to 20 and 25dB below the Cellular carrier, the interference is not detected.

To test a wide range of terrain and multipath environments the test mobile was driven widely around the Mission-Valley coverage area. With the CDI signal 15kHz away from the Cellular Voice Channel and 25dB lower in power no interference could be detected.

In an earlier run, a test was made of the fading with both the CDI and the Cellular signal being transmitted from the same antenna. This was not done using the normal Cellular transmitters. The agreement with the Cellular operator would not allow the CDI transmitter to be connected to the same antenna as the operational Cellular channels. Therefore, a Motorola test set was used to simulate the Cellular transmission. In this test, the CDI level which caused perceptible interference was higher. This is a confirmation of the theoretical expectations. If the Cellular operator would permit a connection to the operational Cellular antenna this finding should be reviewed.

Figure 37 shows the effects of the cross-polarization tests. The run shown is the same as shown on Figure 36. The top curve and bottom curves are repeated for comparison. The top curve is the vertical test with the CDI carrier 10dB lower. Right under that is the run with the CDI signal on horizontal polarization and the effective radiated power 10dB lower . At this level, the actual interference level caused by the horizontal signals is systematically 8 to 10dB lower than that caused by the same level EIRP on the Vertical curve shown above.

The third curve has the CDI signal still horizontally polarized, but now 20dB lower. For comparison the run with no interferer on is shown at the bottom. The interference of the horizontally polarized CDI signal with its EIRP 20dB down is imperceptible.

(Note: on the chart the recording pen was hotter for the processing of the horizontal data runs. This caused "fur" to appear above the line. Audio checks confirm that the test run at the 20dB level has no perceptible interference.)

Because of the limitations of the horizontal antenna beam shape (see section IX) no valid measurements were made underneath the Base station.

In conclusion, the test results show confidently that the CDI signal can be run in the reference cell on a vertical antenna separate from the Cellular Voice channel as long as it is 25dB below the level of the Cellular channel and 15kHz away in frequency.

If the CDI signal uses the same antenna as the Cellular, then the CDI signal can be run only 20dB below the Cellular channel.

If a horizontal polarization antenna is used, the CDI signal can also be run 20dB below the Cellular channel power level. This can be done, however, only if care is taken to match the Cellular antenna pattern gain near the Base station. The gain must be reduced in the range of -20° to 40° below horizontal to approximate the beam shape of the normal Cellular antenna.

Points on Map:

A - Balboa Exit

B - I-52 Exit

C - Mira Mesa Blvd. Exit

D - Carmel Valley Road

E - Carlsbad Blvd. Alma Drive

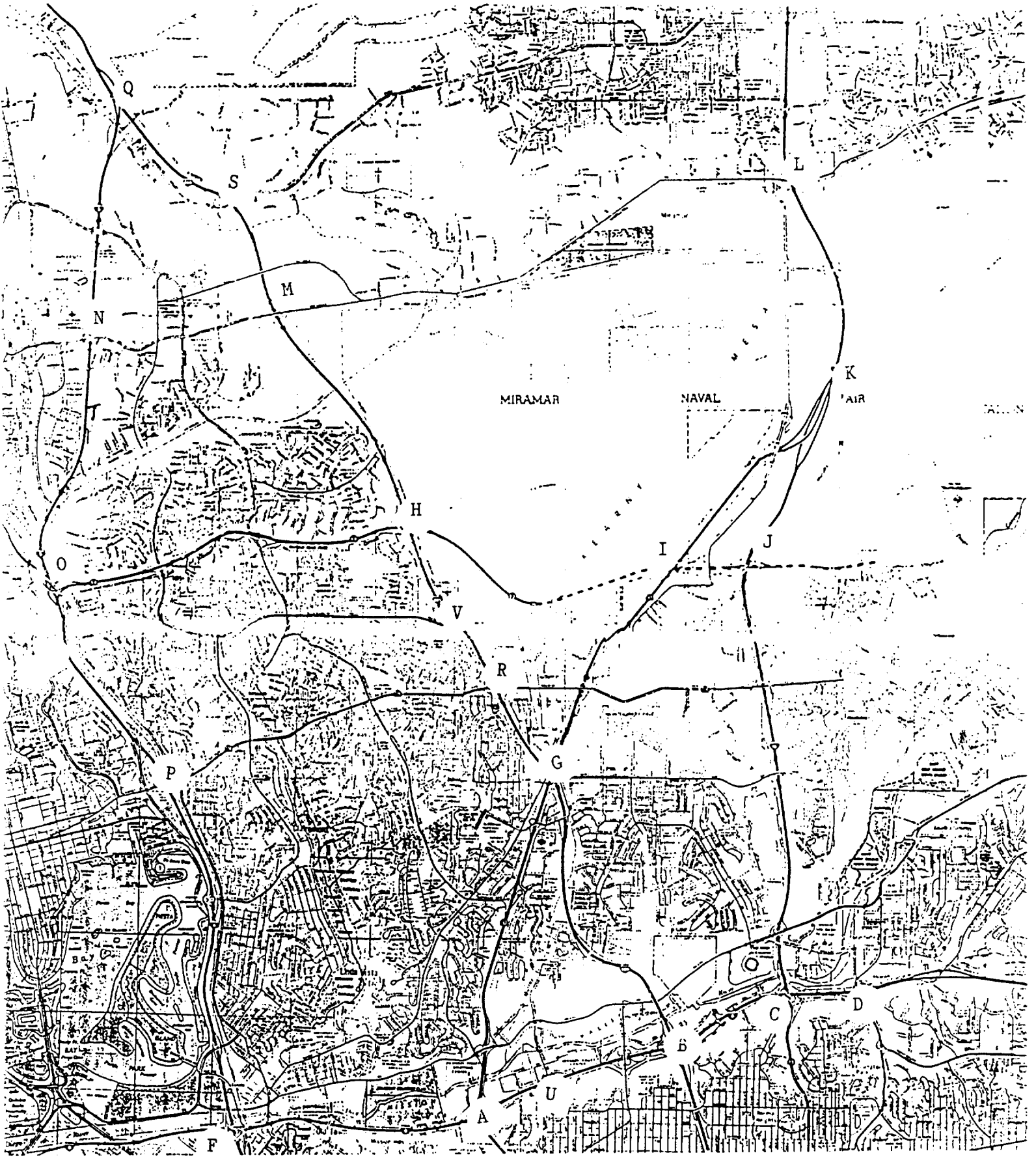



FIGURE 33

Map of Mission Bay Test Area