INTERNATIONAL TELECOMMUNICATION UNION

**RADIOCOMMUNICATION STUDY GROUPS**

**Delayed Contribution**
**Document 6E/69-E**
**19 March 2001**
**English only**

Received: 19 March 2001

Subject: Question ITU-R 107/10

**United States of America**

# FIELD TEST RESULTS FOR DIGITAL SYSTEM C

This paper presents recent field tests assessing the performance of Digital System C. The field tests were conducted to further verify the results of previous field tests conducted in Washington, D.C. and Las Vegas, Nevada. These most recent field tests were conducted in San Francisco, California to test system performance and robustness in the challenging terrain environment that exists in that market.

## 1 Test Procedures

Tests were conducted using Digital System C operating in the hybrid mode. The desired hybrid signal is comprised of an analog FM host and a baseline digital signal. The analog FM host signal, present in all tests, is unchanged. The total power in the baseline digital signal is 22 dB below the total power in the analog host.

The test station, KLLC, is a class C FM commercial radio station which broadcasts 82.0 kW Effective Radiated Power ("ERP"), with a transmitter power output of 20 kW at 97.3 MHz in the San Francisco, California metropolitan area. The transmitter is located at 37$^{o}$ 51' 03" N latitude and 122$^{o}$ 29' 51" W longitude.

## 2 Route Selection

These field tests were conducted using loops chosen by the National Radio Systems Committee (an industry committee sponsored by the National Association of Broadcasters and the Consumer Electronics Association) in 1995 and were used at that time for testing non-IBOC DSB systems. Due to its severe multipath and terrain shielding conditions, San Francisco presents one of the most challenging radio markets in the United States. The NRSC designed six test loops to cover a variety of conditions that would challenge existing analog systems and DSB systems. The loops were designed specifically to encounter the following problems:

- Terrain "shadowing", which occurs at numerous locations in the mountainous San Francisco Bay area.
- Specular multipath, which is common in areas with tall buildings that produce strong singular reflections with deep nulls.
- Diffuse multipath, which is common in areas bordered by mountains that produce an infinite number of reflectors and wideband nulls.

The tests loops also provided a variety of geographic conditions including:

- City streets (structure shadowing).
- Pacific Coastline (extreme instantaneous terrain elevation changes).
- High Desert (large plain areas bordered by mountains).
- Rolling hills.

Digital System C's robust performance largely overcomes many of the terrain-related challenges that have always plagued traditional analog systems. Although no transmission system can provide satisfactory performance in areas of little or no signal, Digital System C continues to supply high quality audio in areas of severe analog impairment. The following describes digital system performance over the six San Francisco routes.

# 3 Results

## 3.1 Perimeter Loop

Much of this loop is characterized by extreme and abrupt elevation changes that shadow the KLLC transmission and produce multipath induced impairments. At a point adjacent to the Mt. Sutro transmitting tower, there is a short distance where the receiver front end overloads. This causes a momentary blend to analog. The rest of the route, however, is characterized by robust digital reception.

## 3.2 Downtown Loop

This loop was characterized by severe multipath. Observation of dynamic signal profile shows numerous instances of a complete loss or corruption of one of the digital carrier sets. Despite these severe impairments, there is no loss of the digital signal. The route continues up Mount Sutro, and rounds the base of the "candelabra" transmitting tower located there. High levels of radio frequency energy from the numerous radiators on this tower have the tendency to "overload" or produce intermodulation products in the digital receiver. Despite potential impairments, the signal remained locked in digital except for one or two blends to analog. The remainder of the loop is very steep and unimproved, but digital reception continued uninterrupted.

## 3.3 West Loop

The KLLC West Loop begins near the Pacific Coast Highway. The signal is significantly shadowed by extreme terrain elevation fluctuations near the shoreline. Shortly after the Pacific coastline comes into view, abrupt terrain shadowing causes loss of the digital signal and severe impairment of the analog. The remainder of the route along the ocean is intermittently shadowed with compromised analog performance. Even so, the digital system blends to digital at numerous locations along the beach. As Route 92 heads inland, it becomes completely terrain shadowed and the analog signal becomes unintelligible. As the elevation increases, line of sight to the transmitter is regained, with a corresponding acquisition of digital signal. Route 92 turns into Highway 101, and the digital signal is relatively unimpaired until shadowed by Mt. Bruno as the route turns west (shortly after the airport). The remainder of the route remains unimpaired, with robust digital reception.

### 3.4 South Loop

The KLLC South loop begins in an area with no terrain shadowing as the KLLC signal path is consistently over water. The route then heads south, following a sea-level plain, and also experiences no shadowing. The digital signal remains robust and unimpaired, despite relatively low signal levels, as the end of section of the loop is as far from the transmitter as any other point in the report (75 kilometers). The signal level at this point is only 40 dBu, a point at which analog reception is severely compromised.

### 3.5 East Loop

The KLLC East loop begins at the far Western end of the San Francisco Bay Bridge. Because the Eastbound lanes of the bridge are the lower lanes of a double-decker span, the KLLC signal suffers extreme multipath from the bridge superstructure. Despite this harsh RF environment, only two blends occurred. The route then passes through a mountain range via a tunnel, which is approximately 1 kilometer in length. The first shadowing induced blends occur in this tunnel, which shields all RF - FM or GPS. After emerging from the East end of the tunnel, the route is severely shadowed by the mountain range. This area, near the city of Walnut Creek, has poor FM analog reception. Nevertheless, the digital signal remains primarily digital. Here, the system maximizes audio quality by gracefully blending back and forth from digital to analog. As the loop heads south, the analog signal levels increase dramatically. This is due to an on-channel booster installed by KLLC to provide coverage to an area that is normally completely terrain shadowed (see Exhibit 6). Unfortunately, the booster does not repeat the digital carriers, and does not increase digital coverage. After a few kilometers, the signal path is no longer terrain obstructed, and digital reception continues unimpaired until the route ends.

### 3.6 North Loop

The KLLC North loop circles the area around the North Bay and the southern part of the Sonoma Valley. The KLLC signal is virtually unobstructed by terrain, as the signal travels across water for the majority of the loop. Correspondingly, digital reception was unimpaired, with no blends to analog.

## 4 Summaries of Results

Exhibits 1 thru 8 summarize these results. These maps color code the audio mode of the digital receiver along each of the six KLLC field test loops. Map 7 overlays data on a color coded terrain elevation matrix and Map 8 uses a computerized prediction of received signal strength. The audio mode colors signify two main regions of digital coverage:

- Region 1 (green) indicates the portion of the radial where digital audio is uninterrupted.
- Region 2 (red) indicates the portion of the radial where the audio has blended to analog.

The suite of test data is presented via strip-chart recording. The strip-chart recording, comprised of data logged by the Field Test PC application, is shown in Charts 1 thru 6. The strip chart displays the variation of selected parameters with time over the entire length of the loop. [1] The "X" axis of

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[1]
- Desired signal strength, in dBu (red).
- Upper (blue) and lower (yellow) first adjacent signal strength, in dBu.
- Upper (black) and lower (magenta) second-adjacent signal strength, in dBu.
- Distance from the transmitter, in km (orange).
- Receiver audio mode, digital or analog (green).

the chart displays elapsed time. The “Y” axis displays both signal strength in dBu (left scale) and distance from transmitter in km (right scale).

The traces of the first adjacents do not accurately represent the actual interference environment over much of the radial, since the digital sidebands are included in adjacent channel measurements.  The upper and lower first adjacent traces are each about 25 dB below the desired signal, because this is the level of each digital sideband relative to its host.

Also, the transition from Region 1 (digital) to Region 2 (blend) occurs as a result of a significant drop in received signal strength.  When cross-referenced to the corresponding terrain profile, it is clear that blending begins at a point that experiences extreme terrain shadowing. In fact, the signal profile closely approximates the terrain profile, indicating that signal strength is proportional to elevation.

Charts 1 thru 6 indicate that the digital receiver begins to blend at desired signal levels of about 45 dBu.  Exhibit 8 shows that blends for most radials commence in the center of the light-blue region, which corresponds to a 45 dBu signal level.  Therefore, actual field measurements verify that the signal-strength prediction map of Exhibit 8 is indeed accurate.

Besides showing that the digital receiver begins to blend at a signal level of about 45 dBu, Exhibit 8 illustrates that the edge of digital coverage lies beyond the 40 dBu signal level, and that solid, unperturbed digital coverage extends to the 50 dBu signal level.  It can be shown from Exhibit 8 that digital coverage is comparable to existing analog coverage.

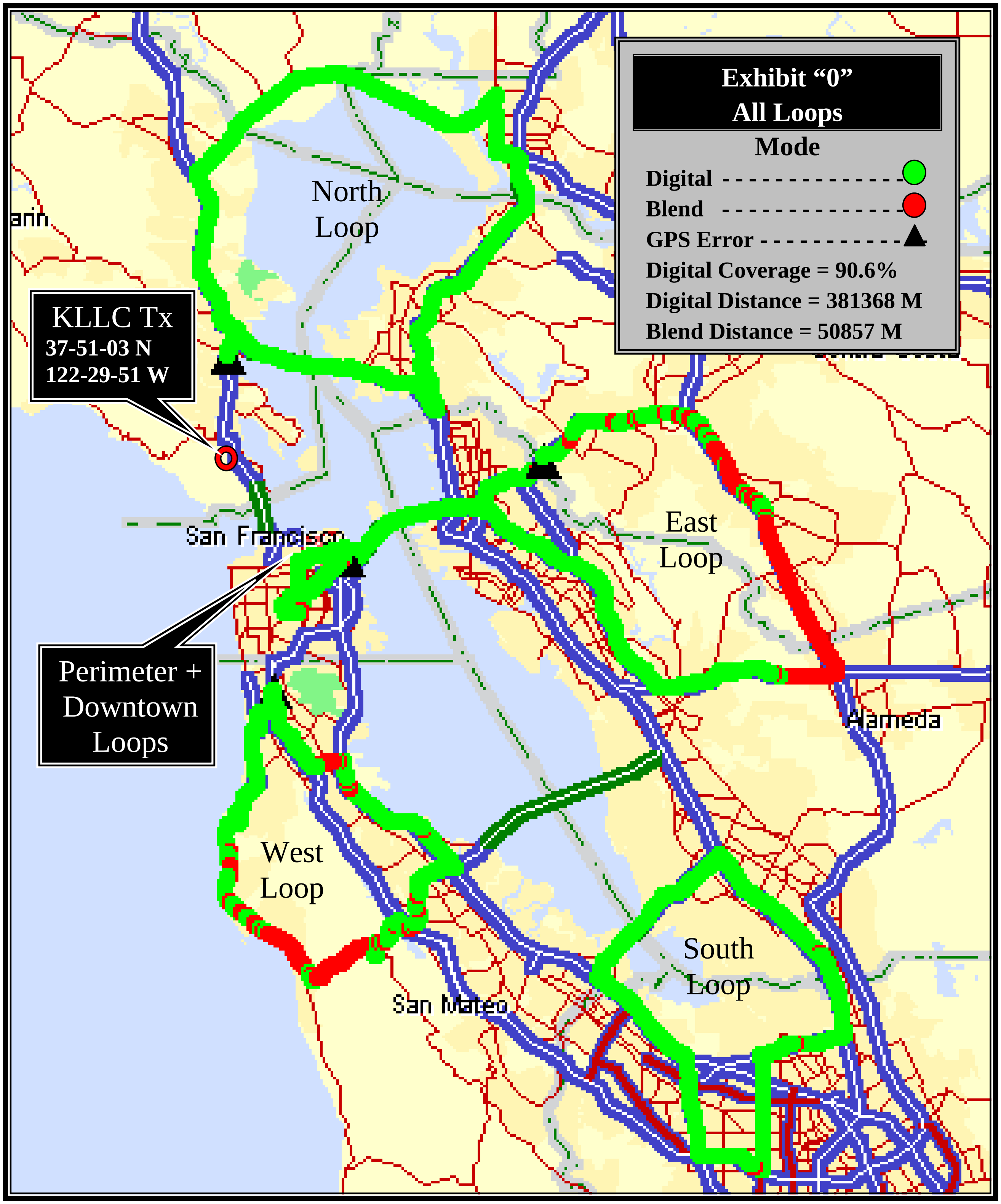


Exhibit "0"
All Loops
Mode
Digital
Blend
GPS Error
Digital Coverage = 90.6%
Digital Distance = 381368 M
Blend Distance = 50857 M
KLLC Tx
37-51-03 N
122-29-51 W
North Loop
East Loop
West Loop
South Loop
Perimeter + Downtown Loops
San Francisco
San Mateo
Alameda

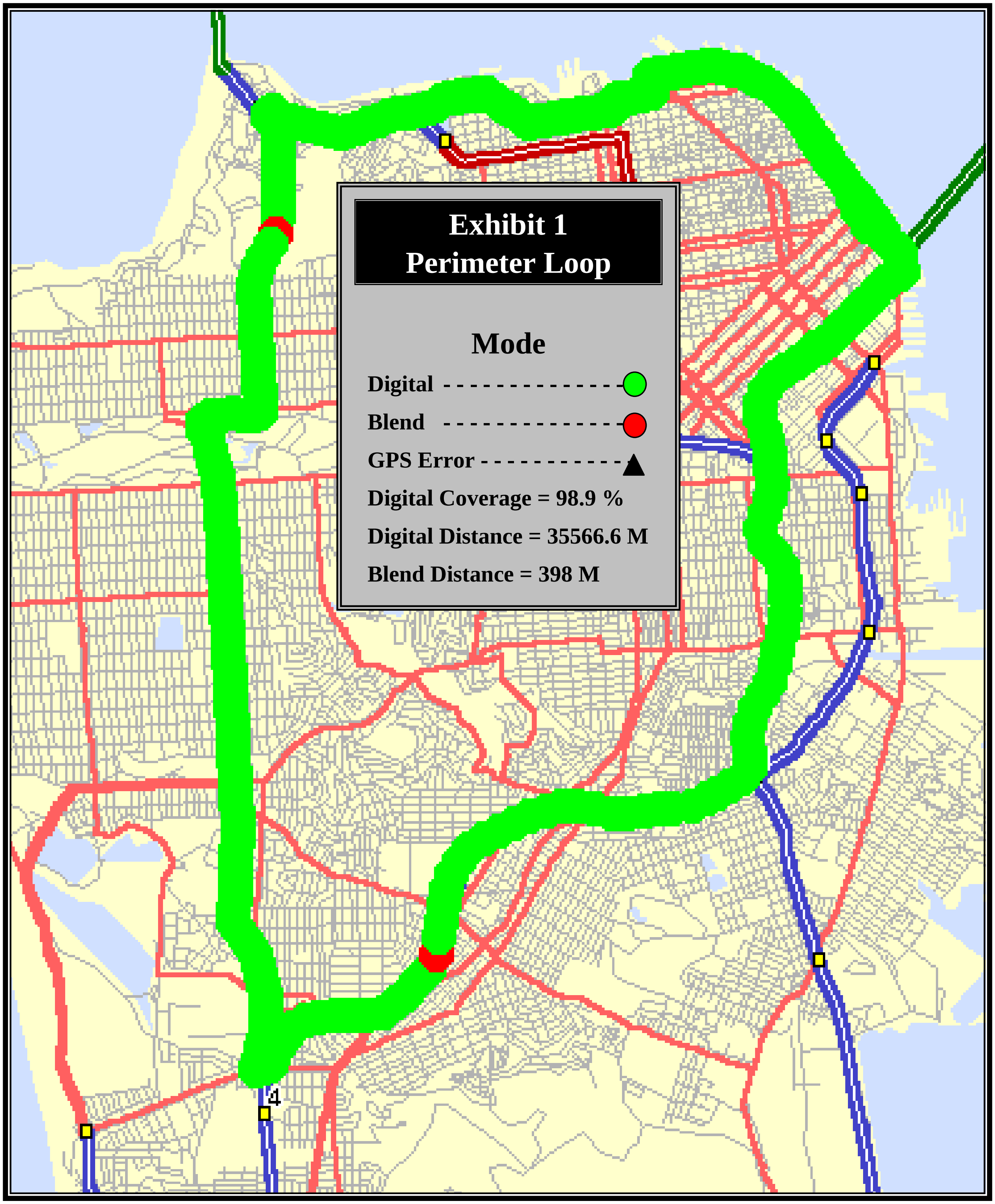


Exhibit 1
Perimeter Loop
Mode
Digital
Blend
GPS Error
Digital Coverage = 98.9 %
Digital Distance = 35566.6 M
Blend Distance = 398 M

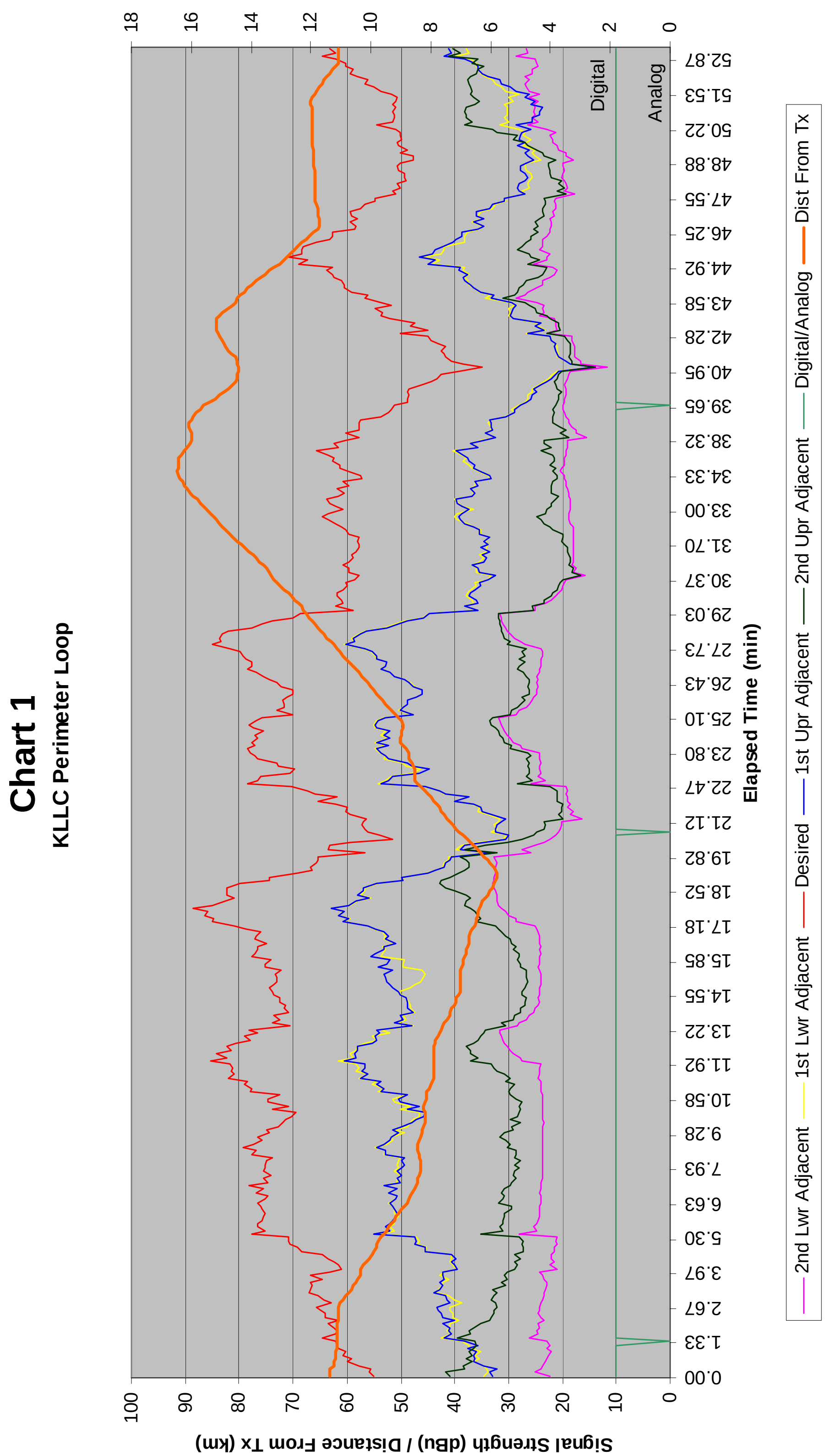


Chart 1
KLLC Perimeter Loop
Signal Strength (dBu) / Distance From Tx (km)
Elapsed Time (min)
Digital
Analog
2nd Lwr Adjacent
1st Lwr Adjacent
Desired
1st Upr Adjacent
2nd Upr Adjacent
Digital/Analog
Dist From Tx

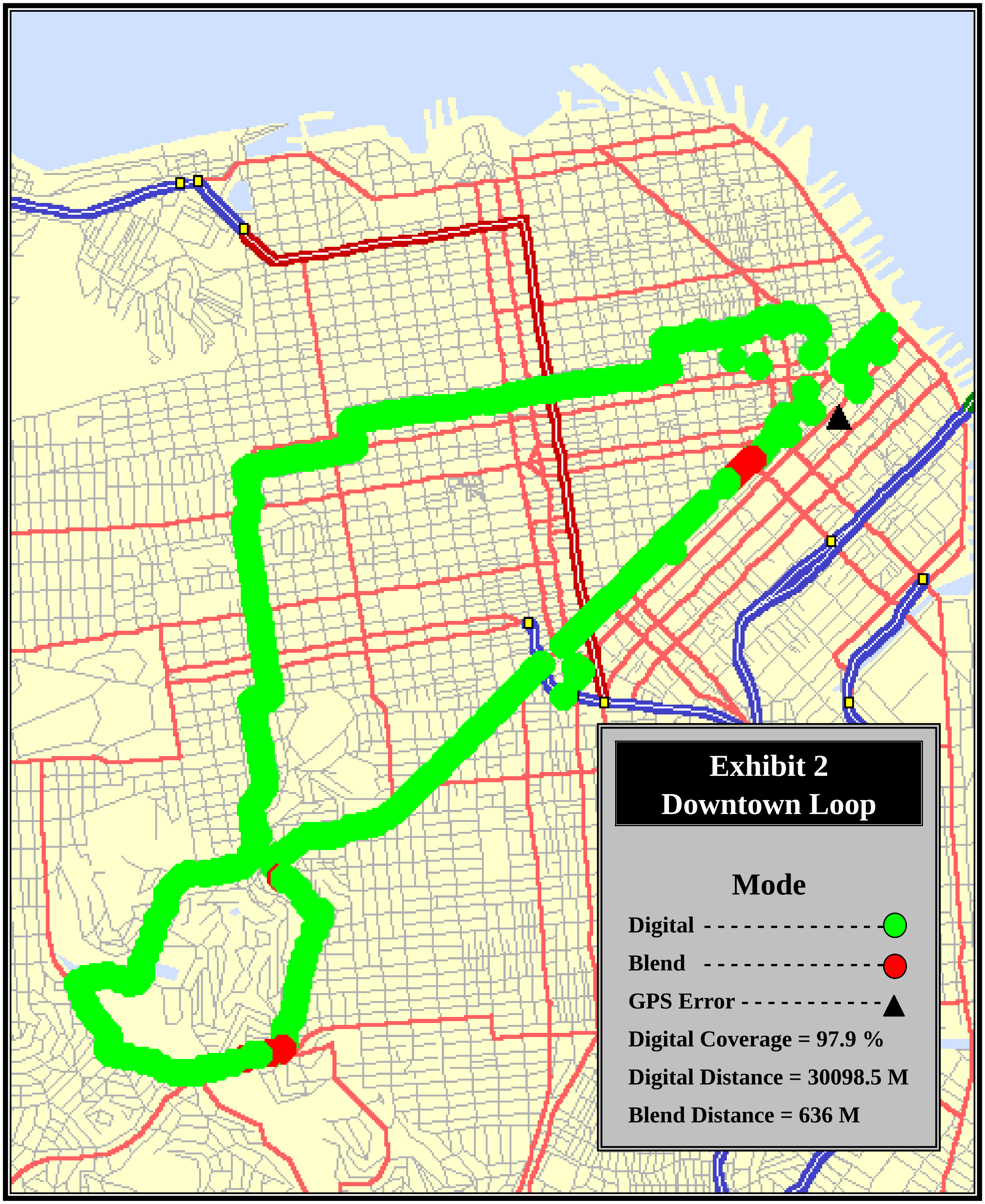


Exhibit 2
Downtown Loop
Mode
Digital
Blend
GPS Error
Digital Coverage = 97.9 %
Digital Distance = 30098.5 M
Blend Distance = 636 M

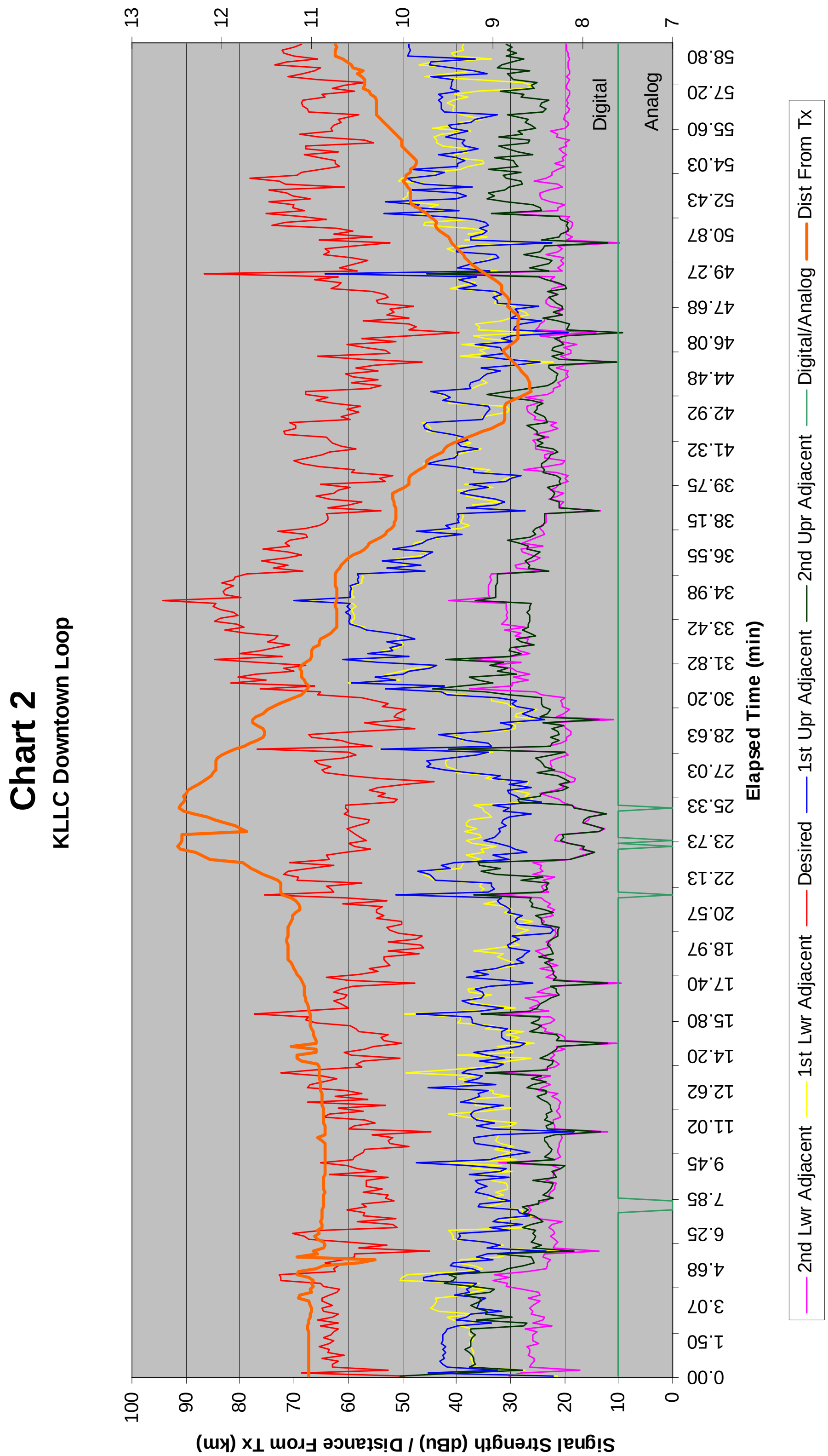


Chart 2
KLLC Downtown Loop
Signal Strength (dBu) / Distance From Tx (km)
Elapsed Time (min)
Digital
Analog
2nd Lwr Adjacent
1st Lwr Adjacent
Desired
1st Upr Adjacent
2nd Upr Adjacent
Digital/Analog
Dist From Tx

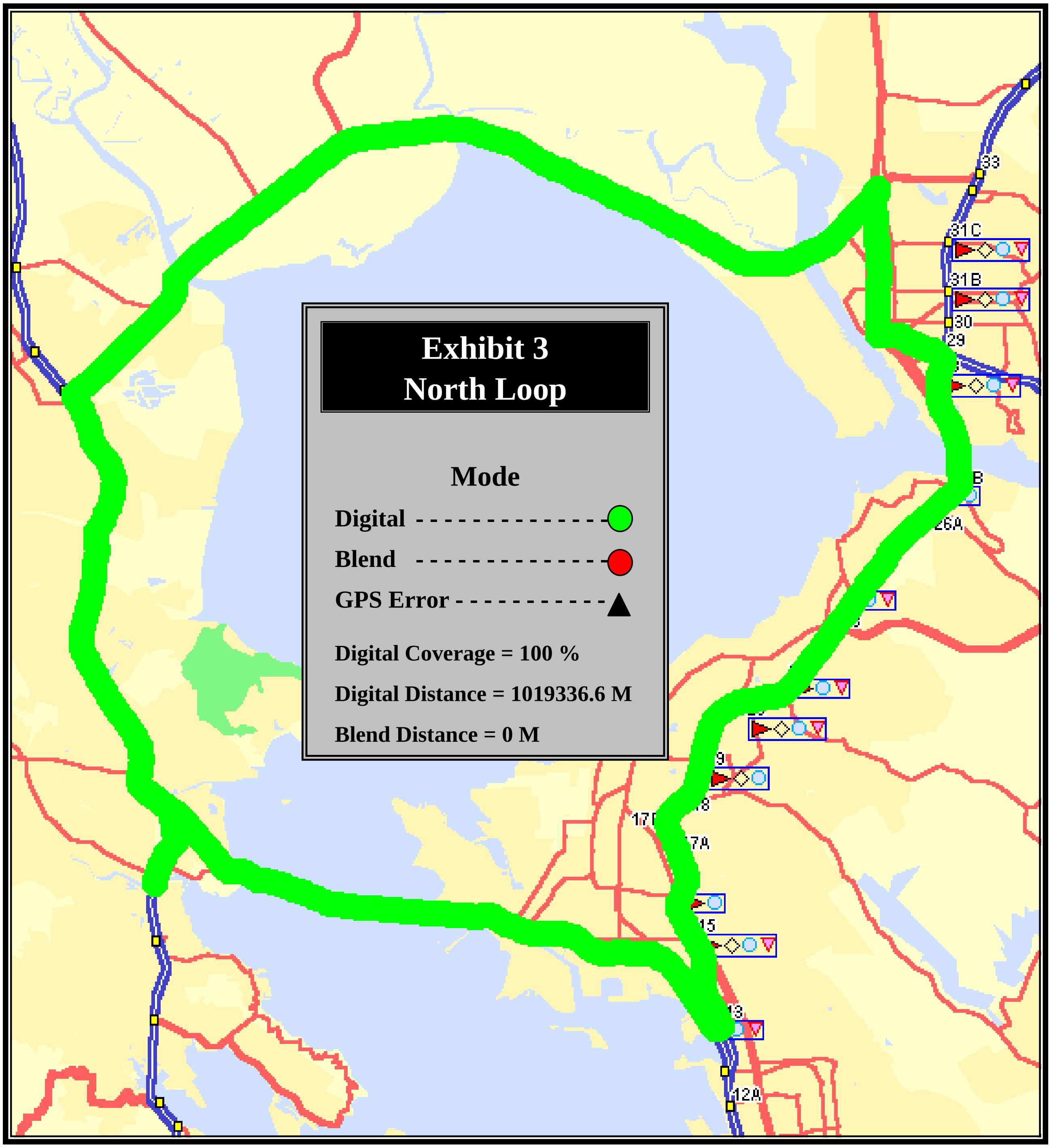


Exhibit 3
North Loop
Mode
Digital
Blend
GPS Error
Digital Coverage = 100 %
Digital Distance = 1019336.6 M
Blend Distance = 0 M
33
31C
31B
30
29
26A
15
13
12A

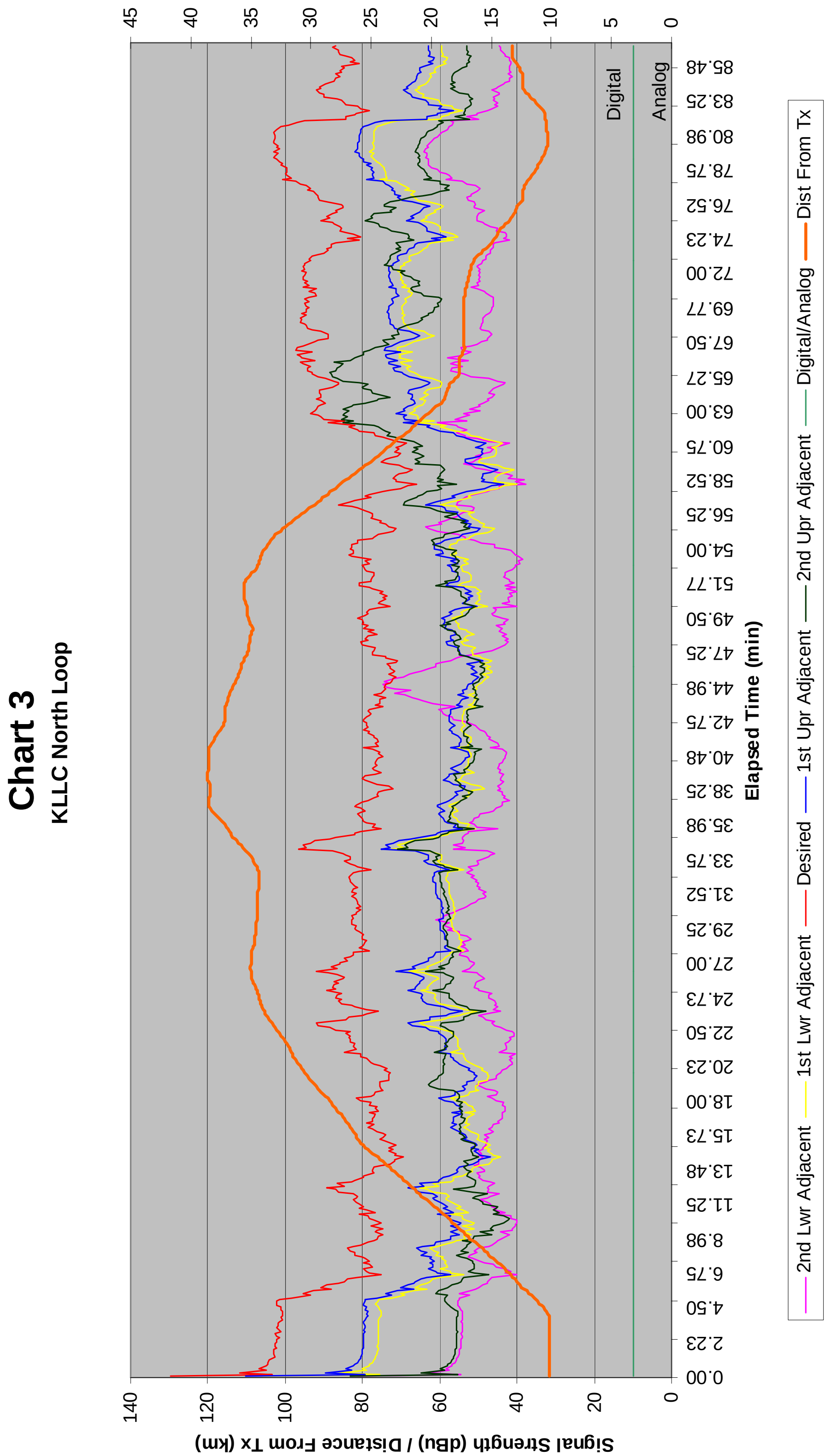


Chart 3
KLLC North Loop
Signal Strength (dBu) / Distance From Tx (km)
140
120
100
80
60
40
20
0
45
40
35
30
25
20
15
10
5
0
Digital
Analog
Elapsed Time (min)
0.00
2.23
4.50
6.75
8.98
11.25
13.48
15.73
18.00
20.23
22.50
24.73
27.00
29.25
31.52
33.75
35.98
38.25
40.48
42.75
44.98
47.25
49.50
51.77
54.00
56.25
58.52
60.75
63.00
65.27
67.50
69.77
72.00
74.23
76.52
78.75
80.98
83.25
85.48
2nd Lwr Adjacent
1st Lwr Adjacent
Desired
1st Upr Adjacent
2nd Upr Adjacent
Digital/Analog
Dist From Tx

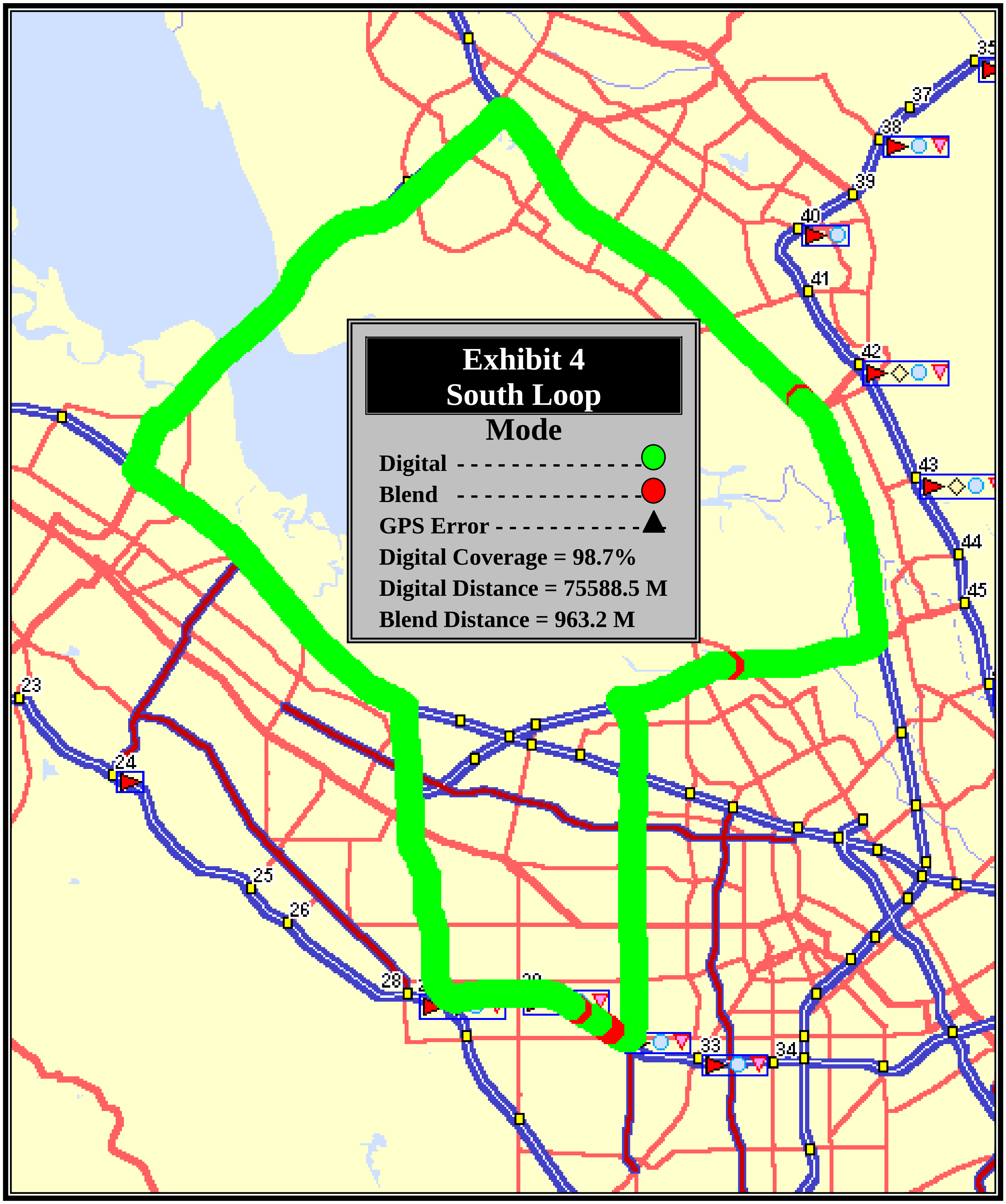
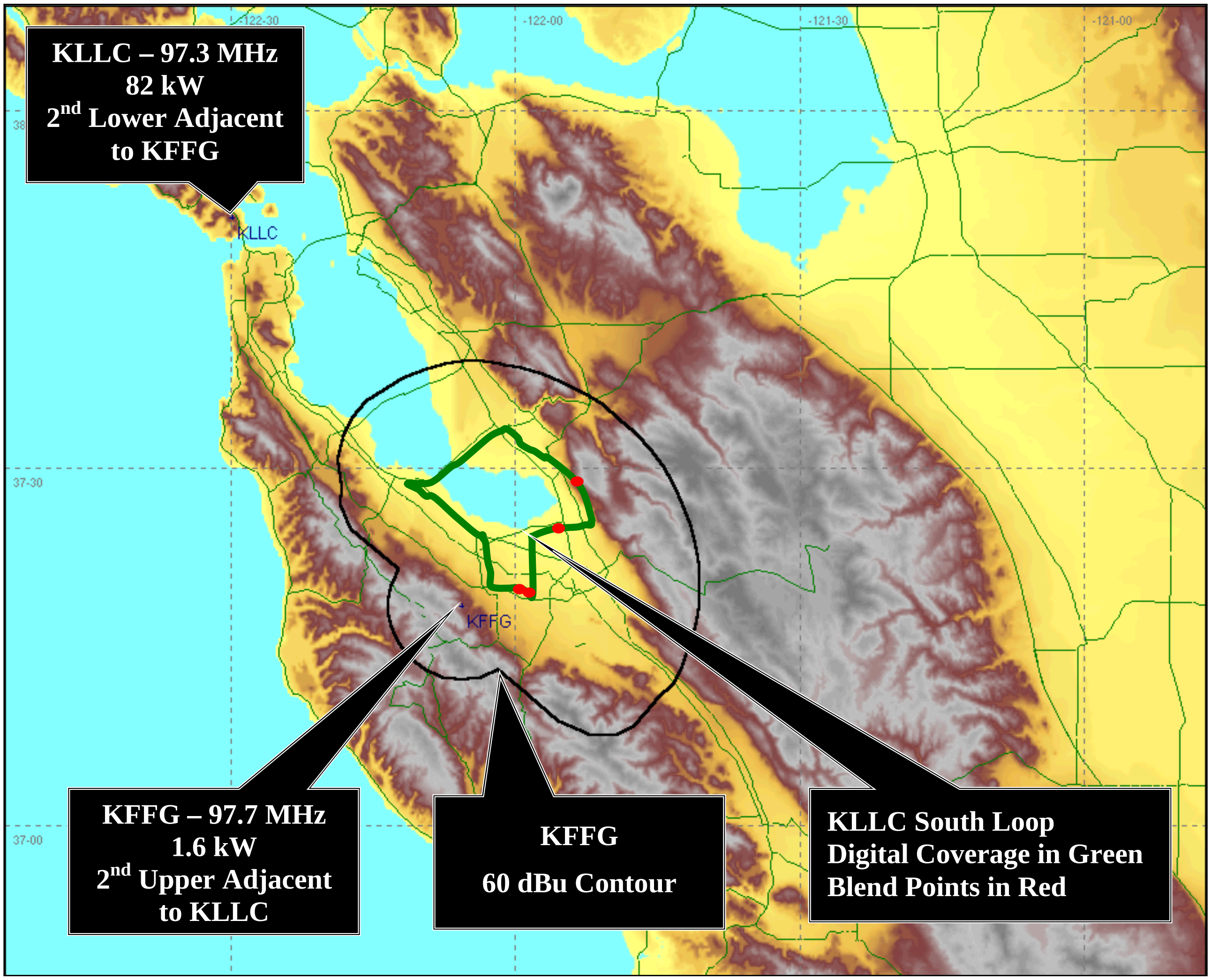


Exhibit 4
South Loop
Mode
Digital
Blend
GPS Error
Digital Coverage = 98.7%
Digital Distance = 75588.5 M
Blend Distance = 963.2 M
23
24
25
26
28
33
34
35
37
38
39
40
41
42
43
44
45

**Exhibit 4A – KLLC South Loop – 2nd Adjacent Interferer**



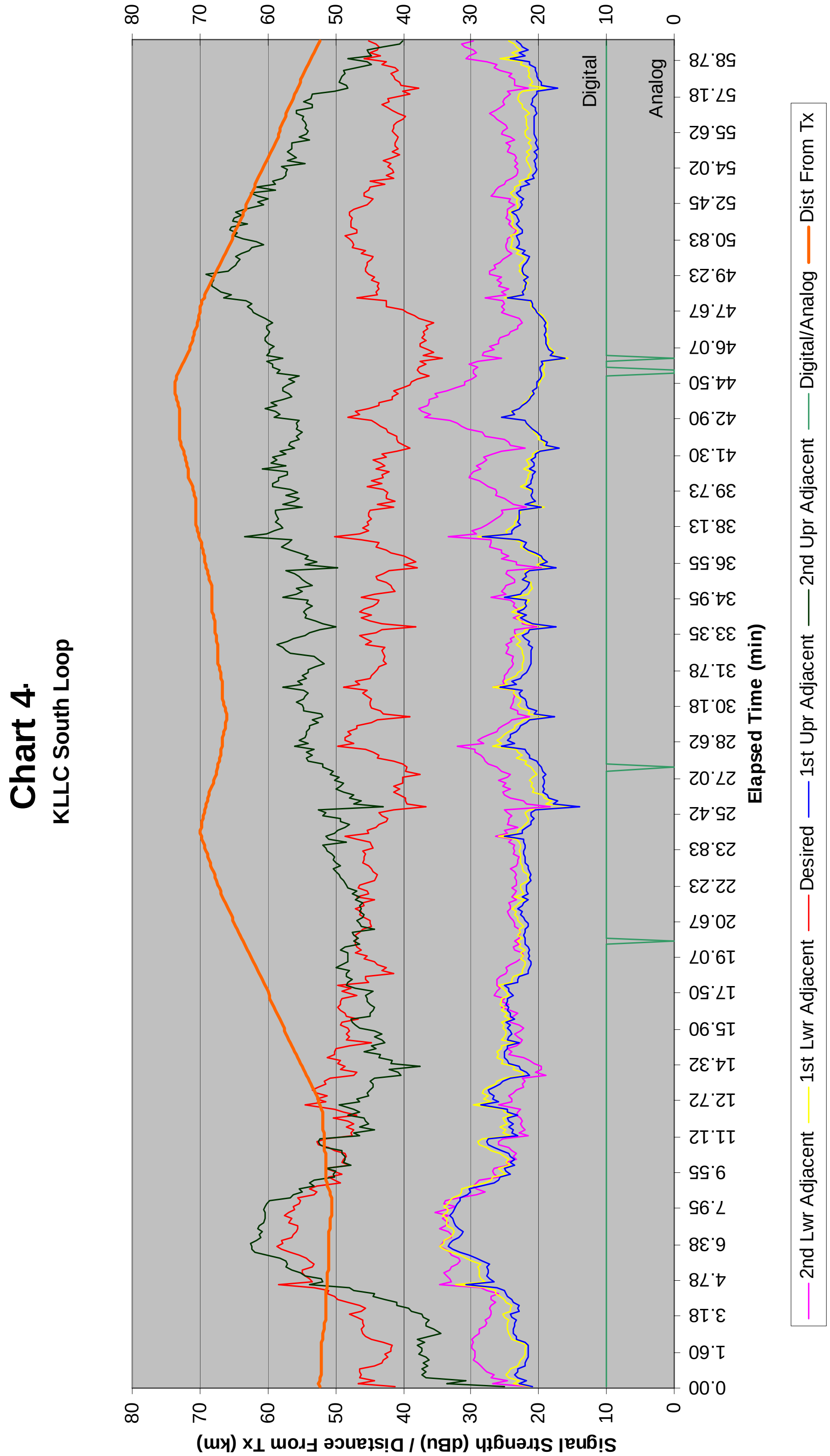


Chart 4
KLLC South Loop
Signal Strength (dBu) / Distance From Tx (km)
Elapsed Time (min)
Digital
Analog
2nd Lwr Adjacent
1st Lwr Adjacent
Desired
1st Upr Adjacent
2nd Upr Adjacent
Digital/Analog
Dist From Tx

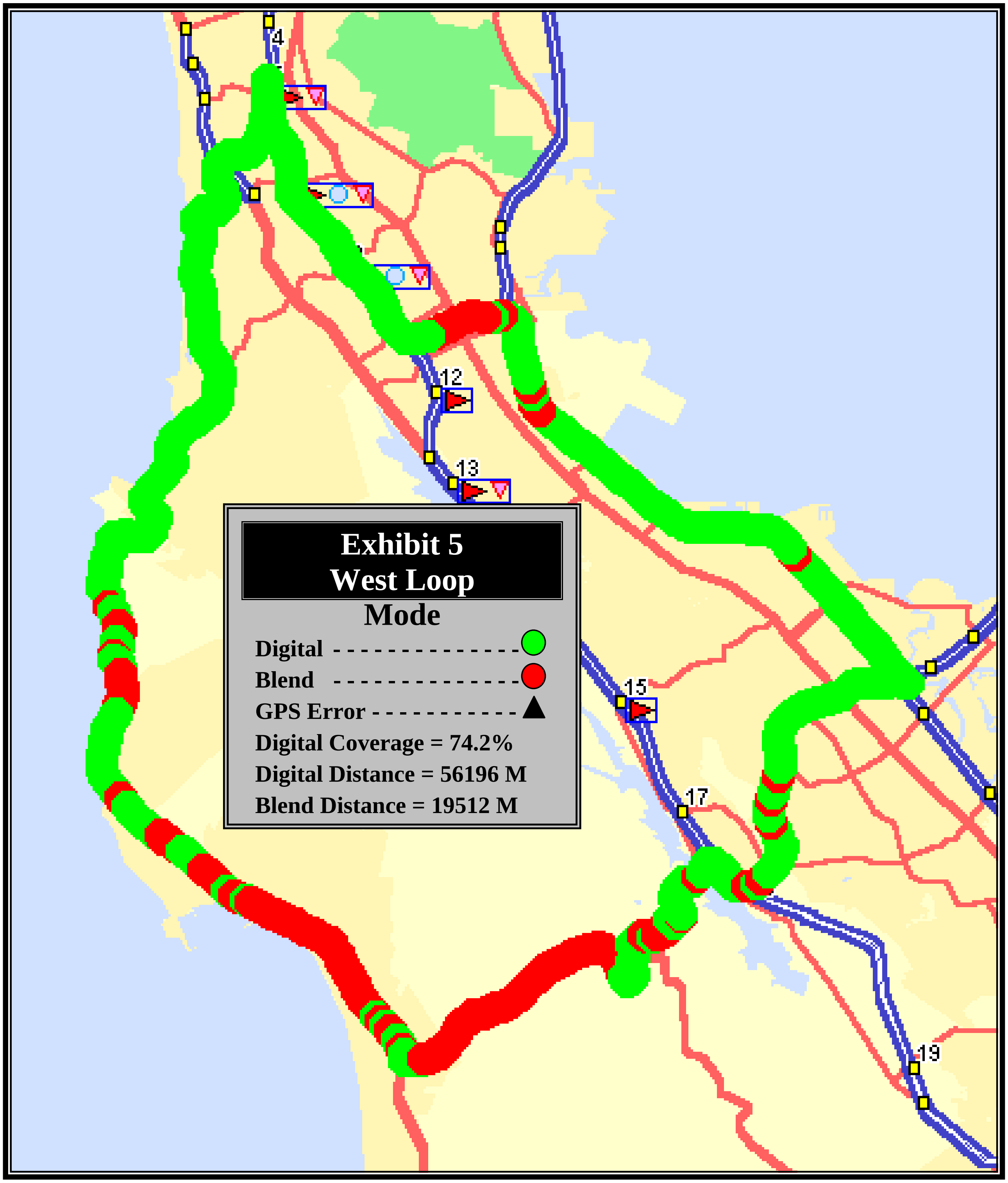


Exhibit 5
West Loop
Mode
Digital
Blend
GPS Error
Digital Coverage = 74.2%
Digital Distance = 56196 M
Blend Distance = 19512 M
4
12
13
15
17
19

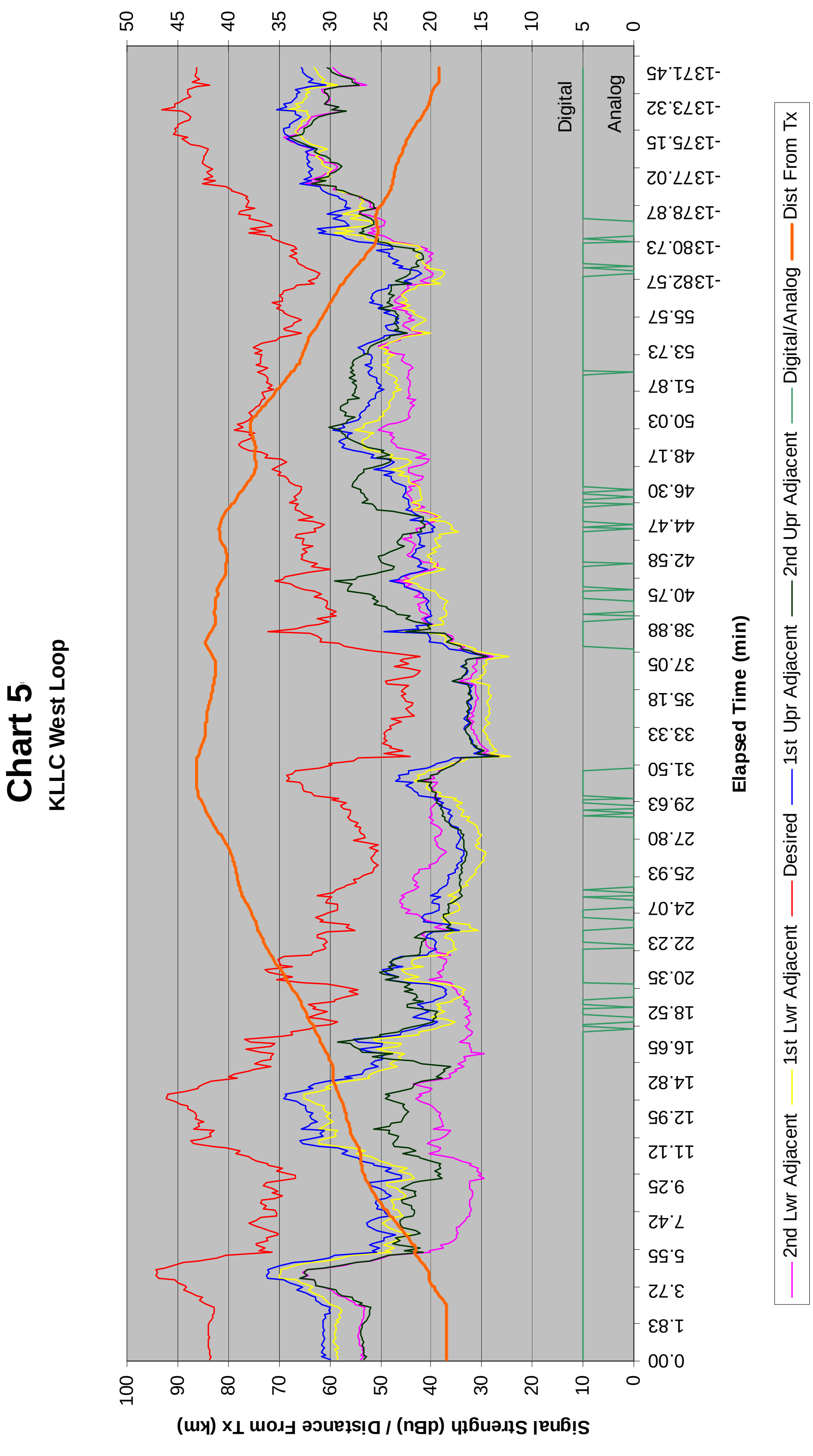
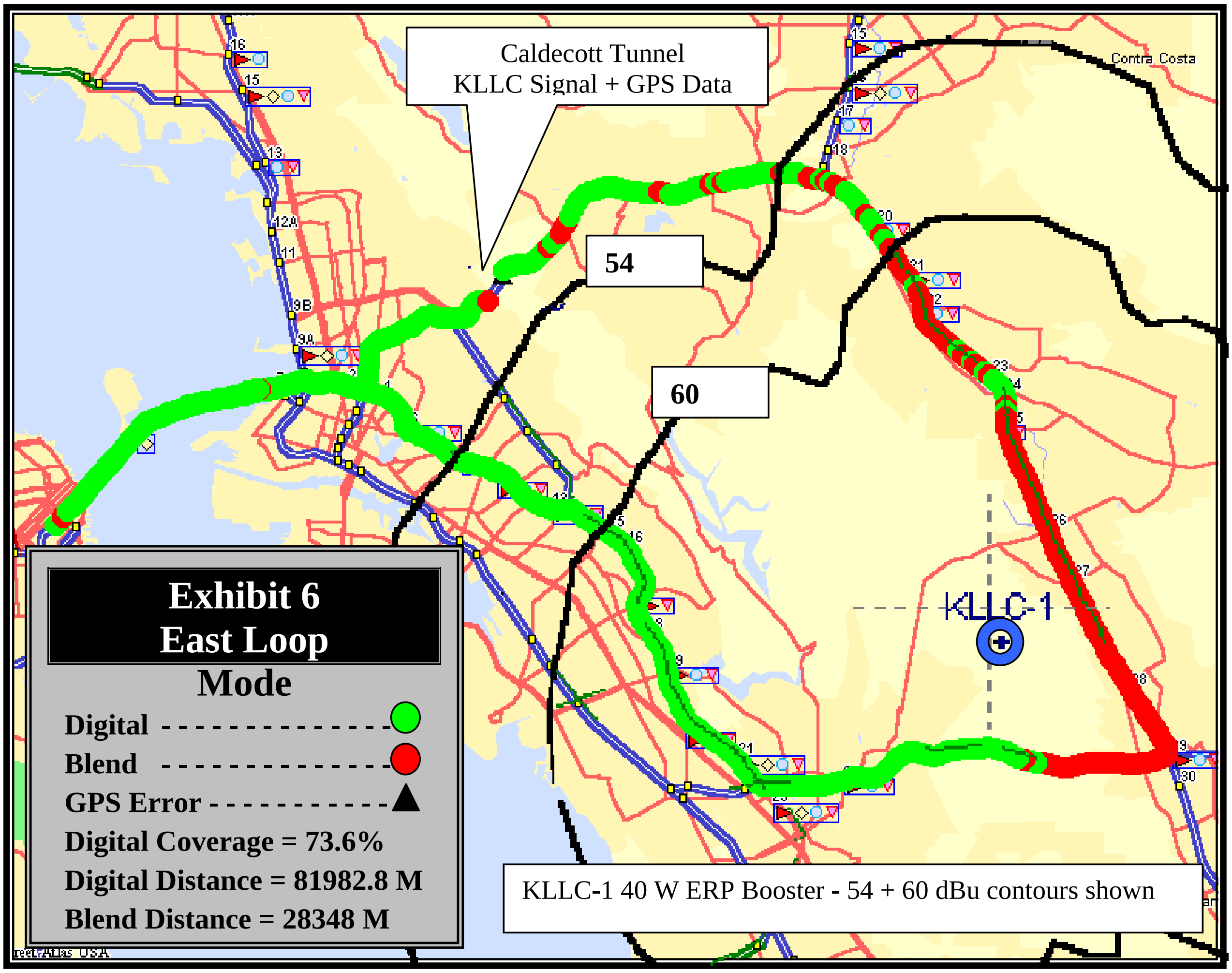


Chart 5
KLLC West Loop
Signal Strength (dBu) / Distance From Tx (km)
Elapsed Time (min)
Digital
Analog
2nd Lwr Adjacent
1st Lwr Adjacent
Desired
1st Upr Adjacent
2nd Upr Adjacent
Digital/Analog
Dist From Tx


Caldecott Tunnel
KLLC Signal + GPS Data
54
60
Contra Costa
KLLC-1
Exhibit 6
East Loop
Mode
Digital
Blend
GPS Error
Digital Coverage = 73.6%
Digital Distance = 81982.8 M
Blend Distance = 28348 M
KLLC-1 40 W ERP Booster - 54 + 60 dBu contours shown

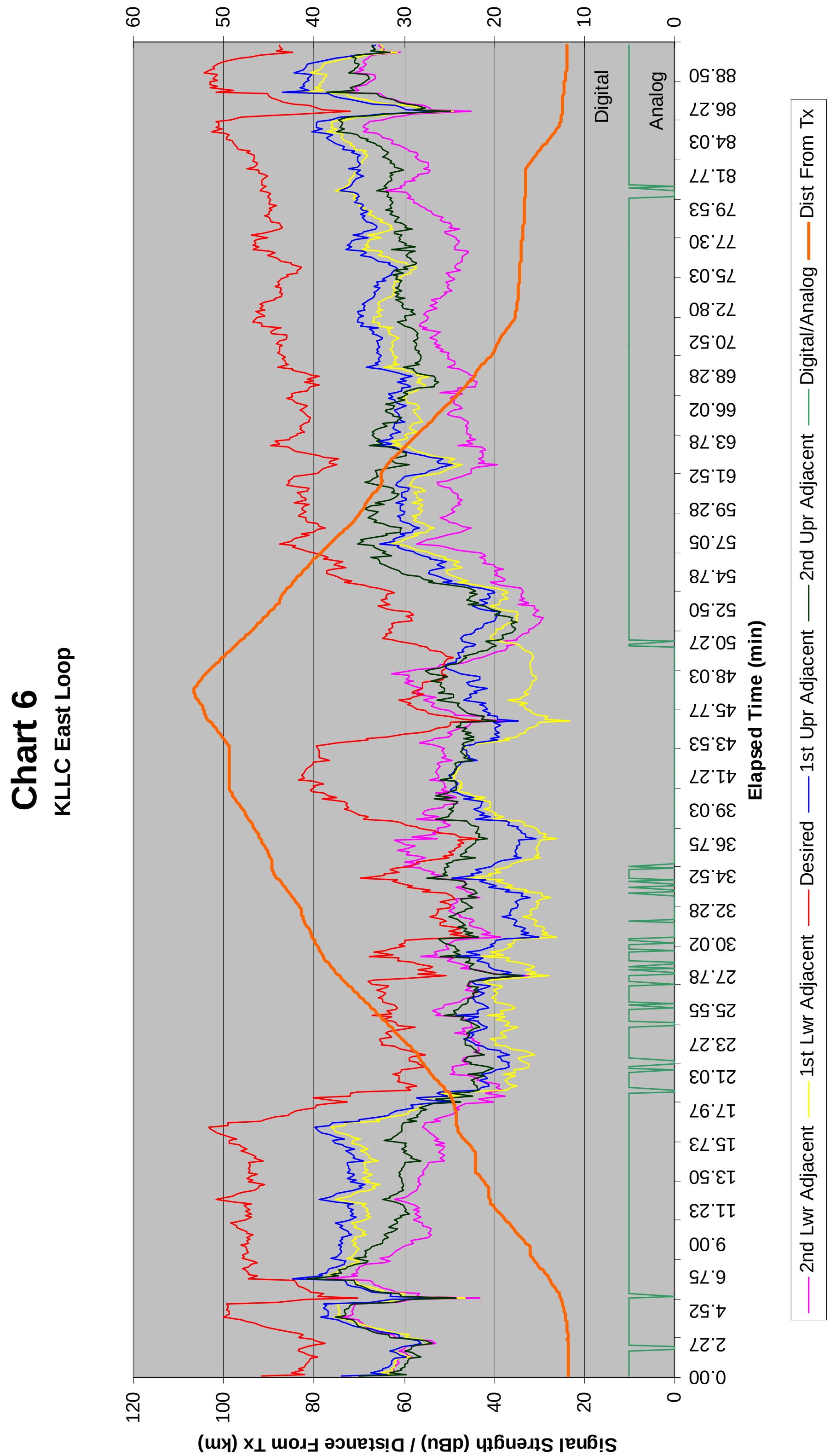
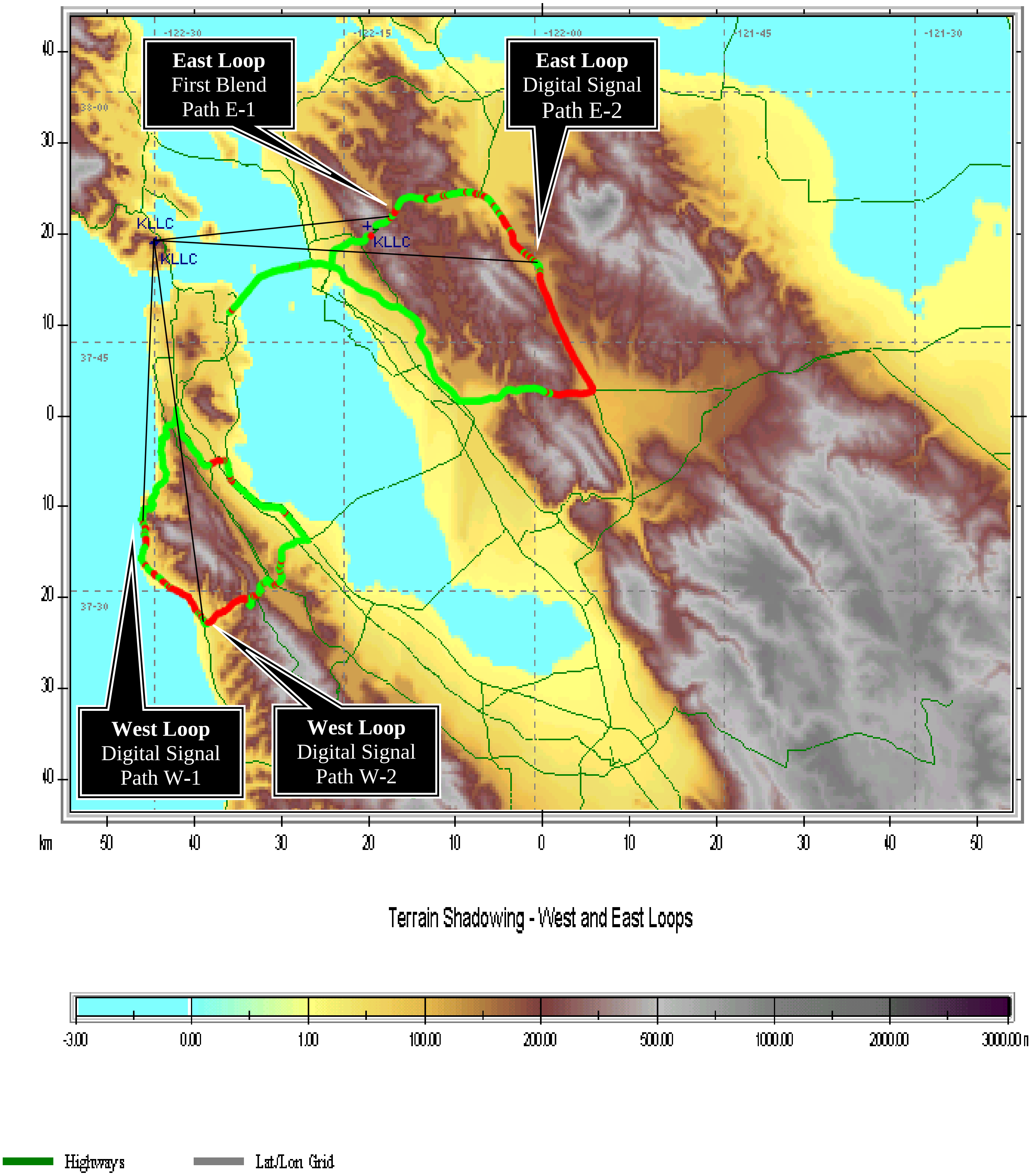


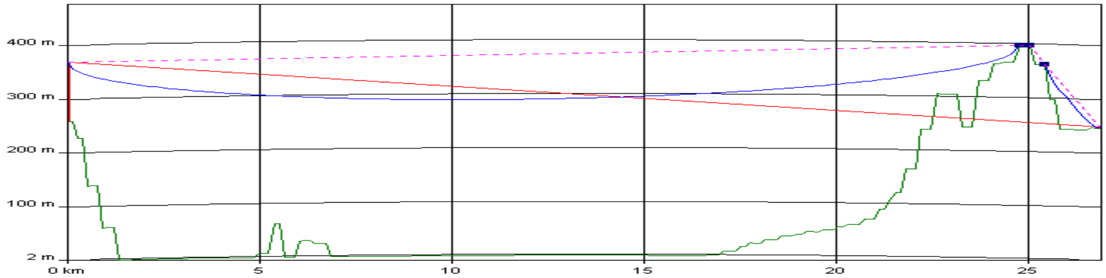
Chart 6
KLLC East Loop
Signal Strength (dBu) / Distance From Tx (km)
Elapsed Time (min)
Digital
Analog
2nd Lwr Adjacent
1st Lwr Adjacent
Desired
1st Upr Adjacent
2nd Upr Adjacent
Digital/Analog
Dist From Tx

## Exhibit 7 – San Francisco Terrain - West and East Loops

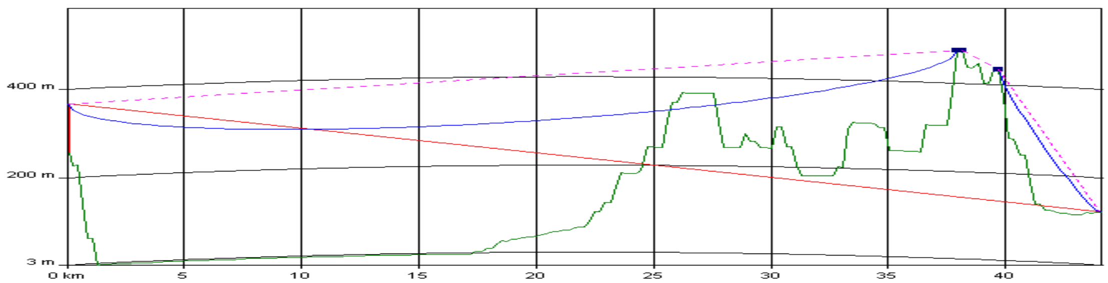


## Exhibit 7A - KLLC Terrain Profiles – West and East Loops

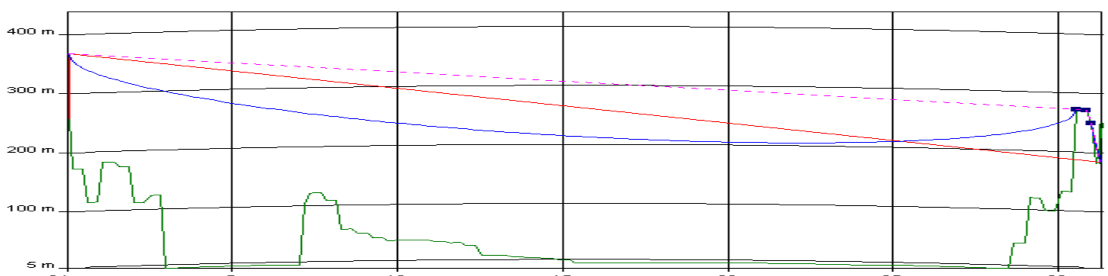
### Path W1 - KLLC West Loop – Point of First Blend



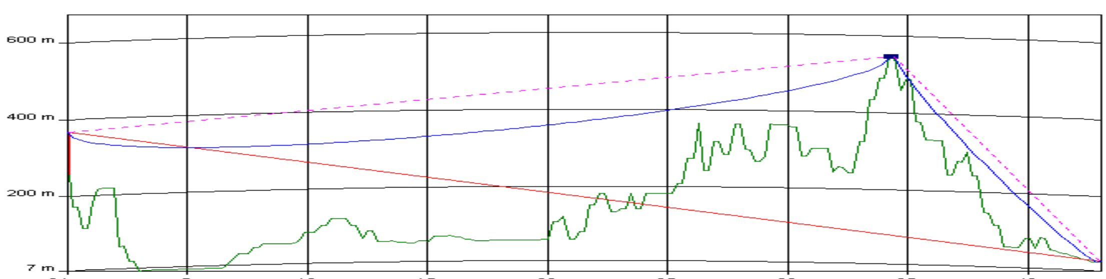

### Path W2 - KLLC West Loop – Digital Signal



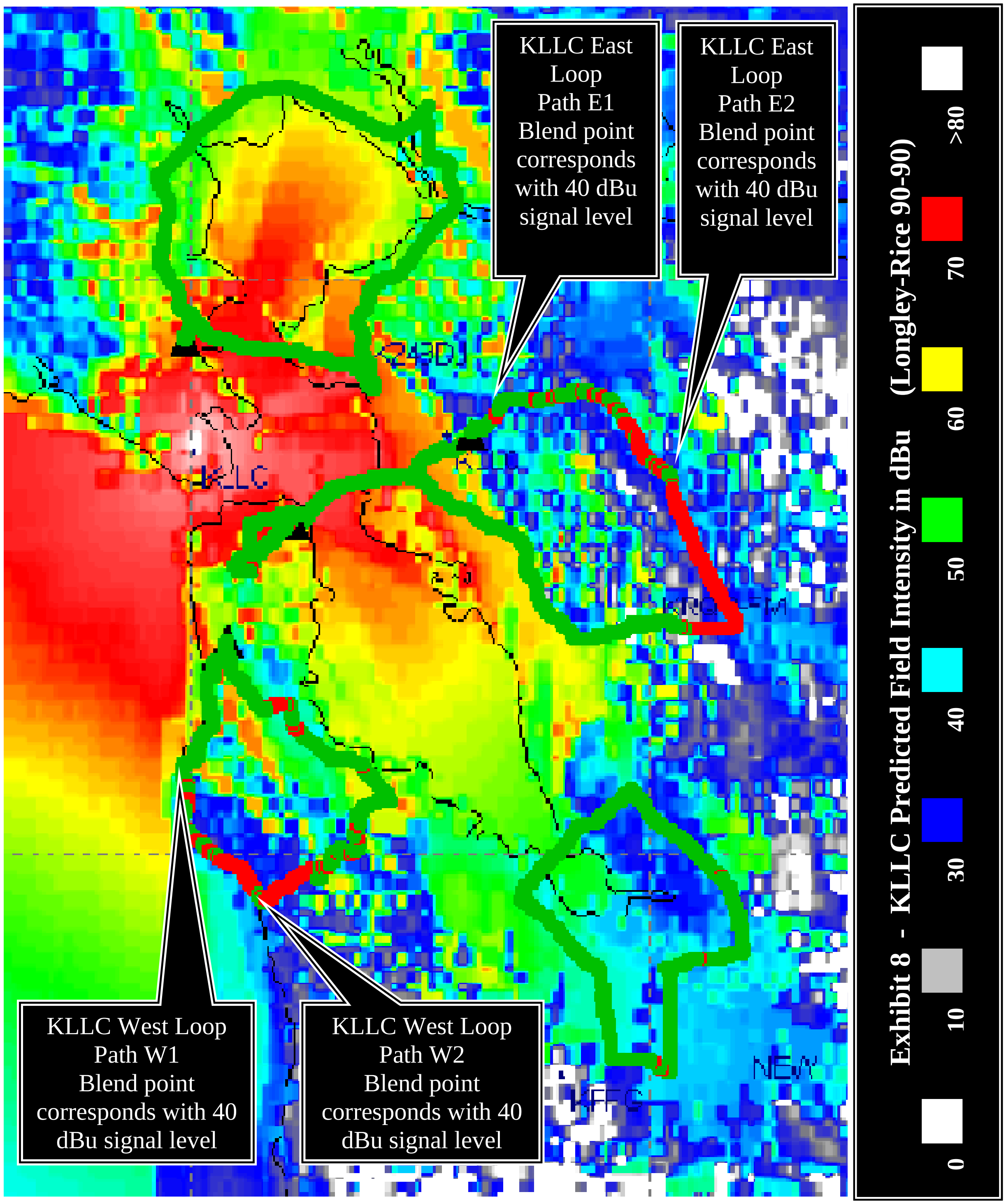

### Path E1 - KLLC East Loop – Point of First Blend




### Path E2 - KLLC East Loop – Digital Signal



## Exhibit 8 – KLLC Propogation Prediction

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