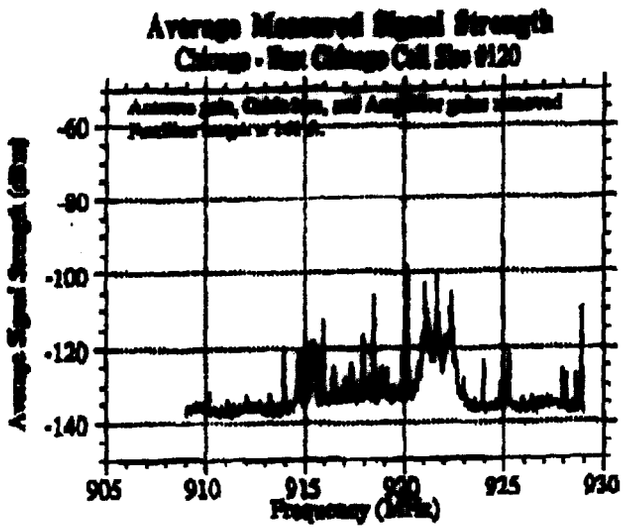
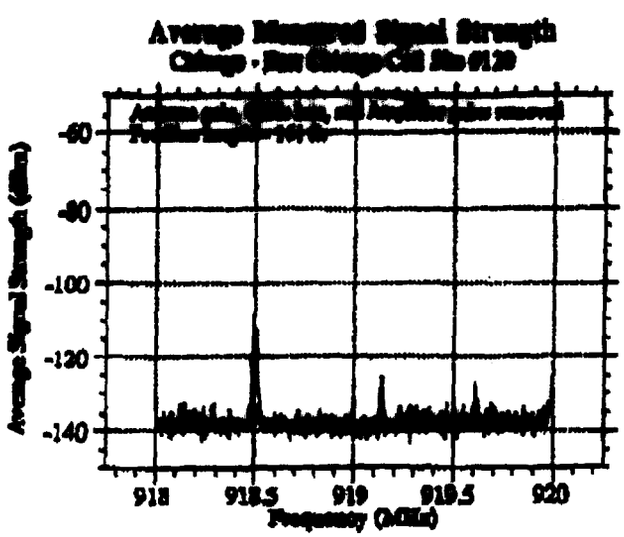
Figure 13. Interference Measurement at LMS Receive Site.

[redacted]



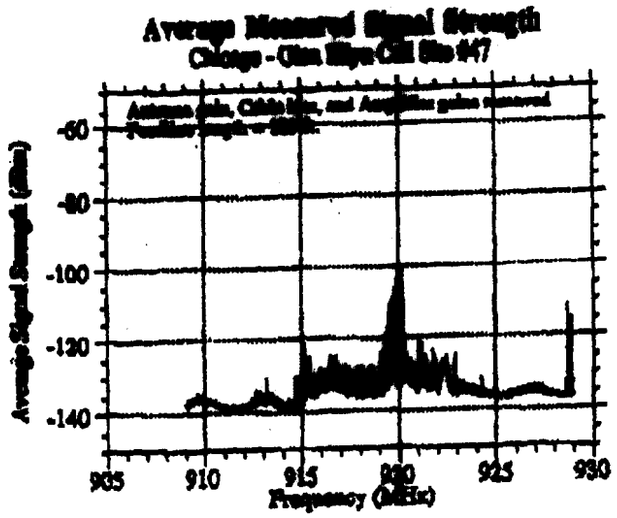
[redacted]



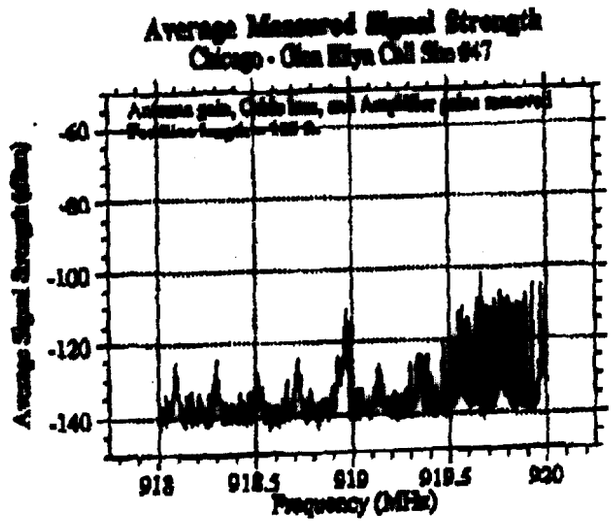
Parameters: Resolution BW: 10 kHz Video BW: 3 kHz

Figure 14. Interference Measurement at LMS Receive Site.

[redacted]



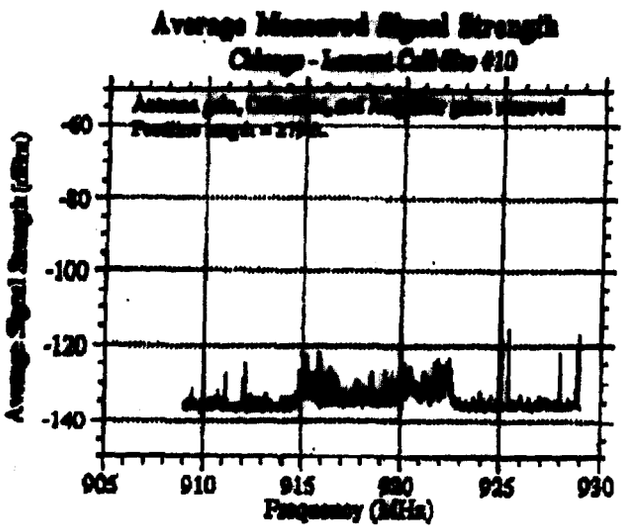
[redacted]



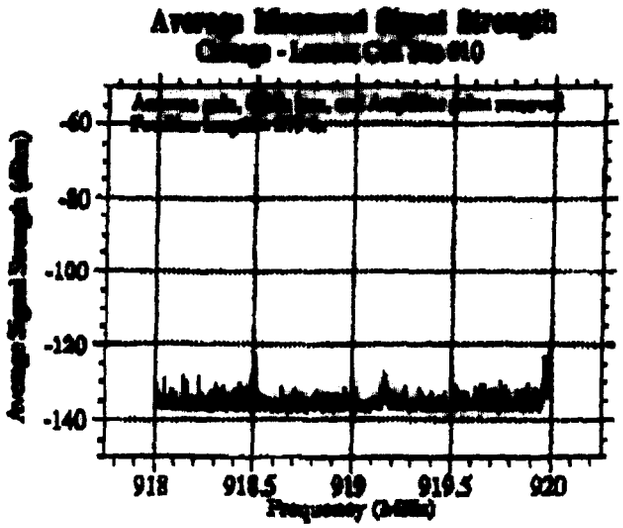
Parameters: Resolution BW: 10 kHz Video BW: 3 kHz

Figure 15. Interference Measurement at LMS Receive Site.

[redacted]



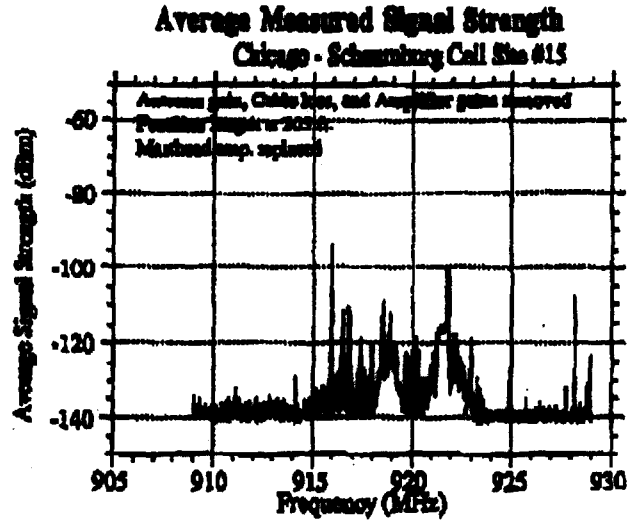
[redacted]



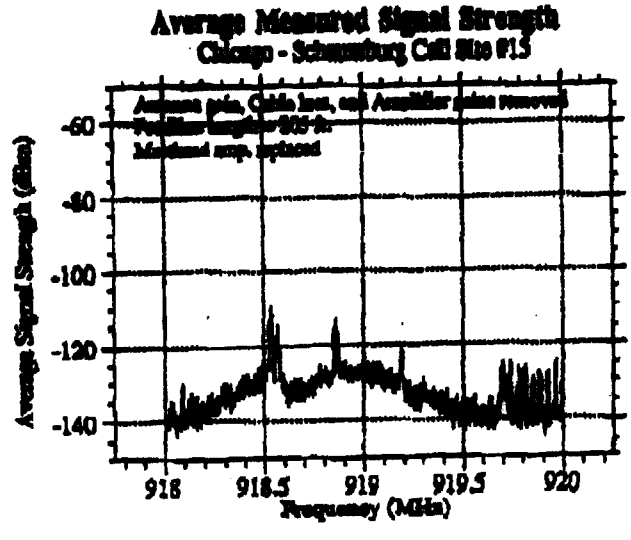
Parameters: Resolution BW: 10 kHz Video BW: 3 kHz

Figure 16. Interference Measurement at LMS Receive Site.

[redacted]



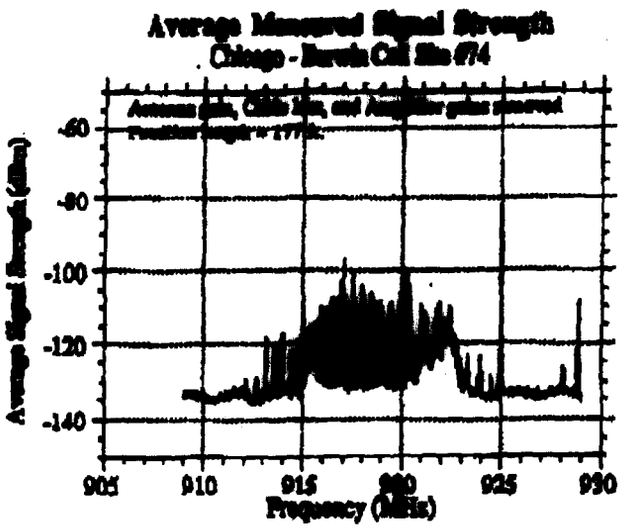
[redacted]



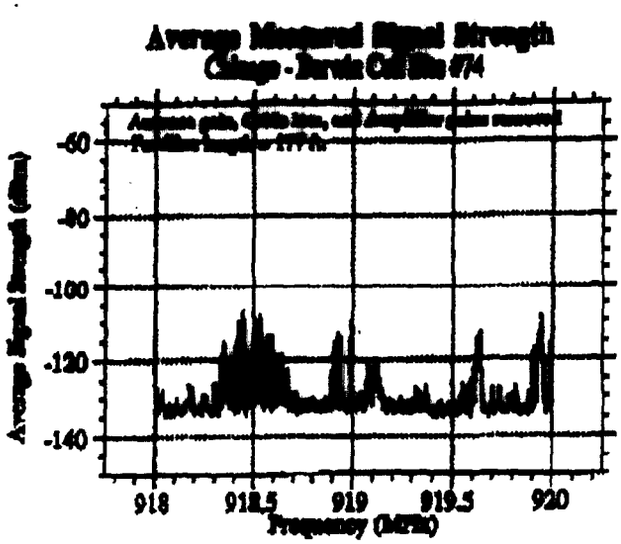
Parameters: Resolution BW: 10 kHz Video BW: 3 kHz

Figure 17. Interference Measurement at LMS Receive Site.

[redacted]



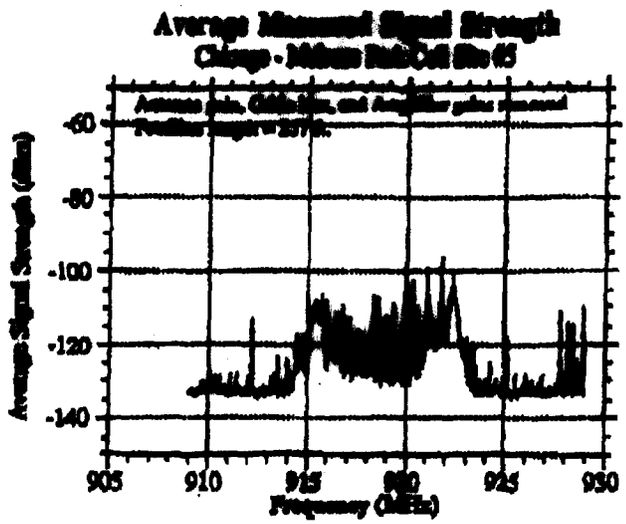
[redacted]



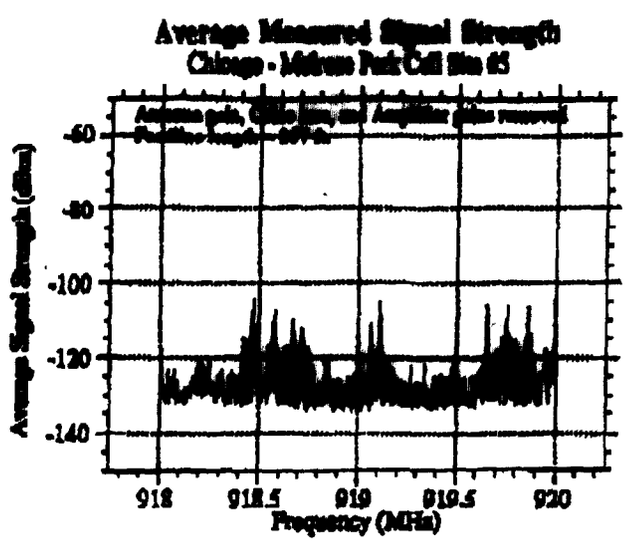
Parameters: Resolution BW: 10 kHz Video BW: 3 kHz

Figure 18. Interference Measurement at LMS Receive Site.

[redacted]



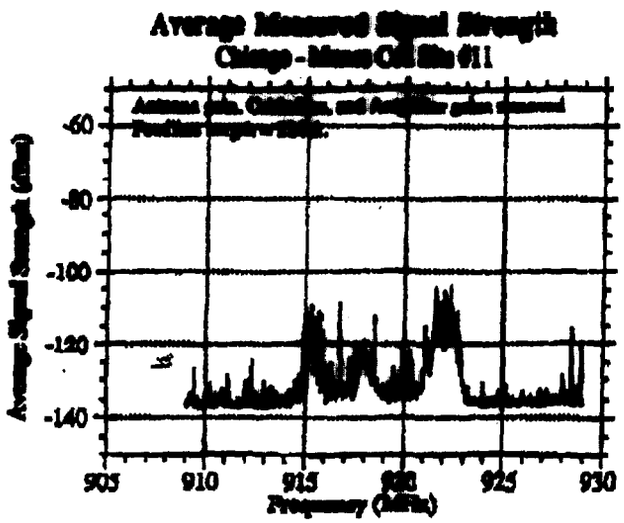
[redacted]



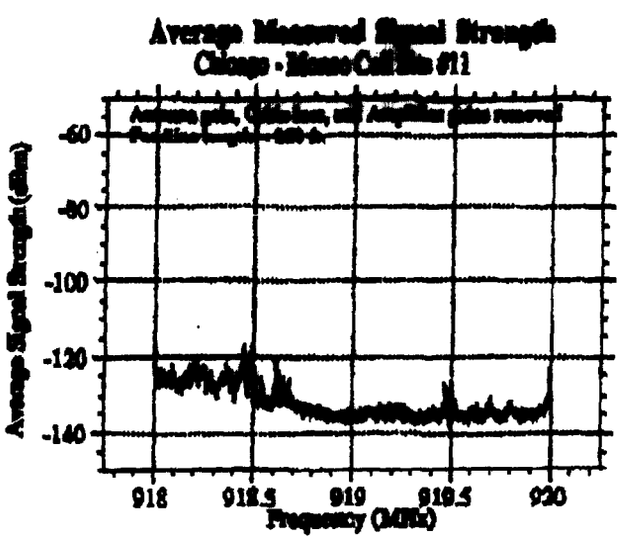
Parameters: Resolution BW: 10 kHz Video BW: 3 kHz

Figure 19. Interference Measurement at LMS Receive Site.

[redacted]

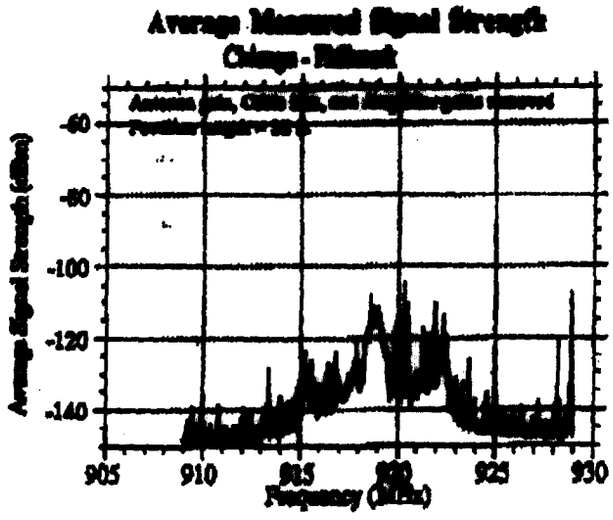


[redacted]

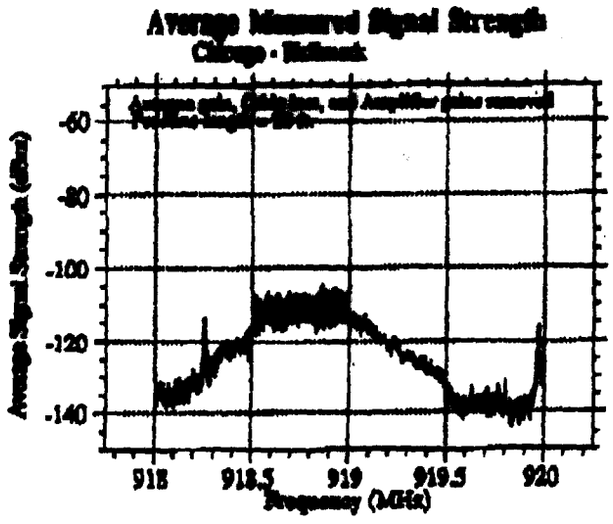


Parameters: Resolution BW: 10 kHz Video BW: 3 kHz

Figure 20. Interference Measurement at LMS Receive Site.



[redacted]



[redacted]

Parameters: Resolution BW: 10 kHz Video BW: 3 kHz

ORIGINAL

MobileVision

Further Analysis of Interference of Part 15 Devices and LMS Wideband Systems

Probability of Interference

G K Smith

June 22th, 1994

Issue 1.4

METS, Inc.

Executive Summary

This paper uses "worse case" conditions and shows the following.

It is highly unlikely that indoor consumer Part 15.247 and 15.249 devices, such as cordless phones, will cause interference to LMS systems. Over 200 Part 15.247 cordless phones per square mile, and over 2220 Part 15.249 cordless phones per square mile, are acceptable as far as the LMS service is concerned.

The number of outdoor, pole mounted, Part 15.247 devices is severely limited, in the case of devices using direct sequence spread spectrum, and limited, for devices using frequency hopping, by their mutual interference with other such devices. The number of such systems, deployed in any given area, will not be restricted by the presence of an LMS site, even if the device is asked to move.

The number of incidents that will arise when it will be necessary to resolve interference from a Part 15 device will be isolated, limited to outdoor Part 15.247 type devices, and will not effect the numbers of such Part 15 devices that can be deployed.

- the LMS service will not effect the ability of Part 15 devices to continue to operate in the 902 - 928 MHz band.

This paper supports the practical experiance of the LMS providers which has shown that the cases of Part 15 interference are very isolated.

1. Introduction and Summary

Initial calculations of the theoretical interference between Part 15 and wideband LMS systems were presented in Annex 2 to the "Further Comments of MobileVision", March 15, 1994[1]. For each of the possible mechanisms of interference, figures were derived for the relevant near-far-ratio (NFR) pertaining to that case[2]. In that paper it was noted that the actual interference that would be experienced would be a statistical one related to the probabilities associated with:

a) the distance of the LMS mobile from the fixed site,
b) the distance of the Part 15 radio from the LMS fixed site,
c) the mobile transmitting,
d) the Part 15 radio transmitting

In addition to the above, the following probabilities need to be considered:

e) the number of Part 15 devices in an area
f) the usage of the Part 15 devices (proportion of time when transmitting).

This paper looks further into the understanding these effects in order to assess the realistic interference that may be experienced.

The results show that devices that transmit on a low duty cycle, even Part 15.247, can be virtually ignored. About 8000 indoor 15.247 devices, in an LMS area, transmitting 1% of the time, in the LMS sub-band, are required before the LMS system will experience a 10% probability of loss of location. This equates to over 200 such devices per square mile, in suburban areas. The density will be higher in urban areas by up to four times.

The effect of intermittent transmissions on the "interference threshold" are analyzed and discussed, and the following definition is proposed:

Interference from a Part 15 device shall be considered above the interference threshold if the total field strength at an LMS site, across the licensed LMS sub-band, exceeds 59 μV/m, (equivalent to -101 dBm at an isotropic antenna), or, in the case when the Part 15 device is transmitting less than 10% of the time, in any 10 second period, 186 μV/m (equivalent to -91 dBm at an isotropic antenna).

[1]"Interference Analysis of Part 15 Devices and LMS Wideband Systems - Initial Calculations", G K Smith, March 8th, 1994.
[2]The NFR values derived were worse case. See Section 3 of this paper.

This definition effectively allows the Part 15 interference to desensitize the LMS site by 10 dB, in the case of constantly transmitting devices. This is equivalent to increasing the density of Part 15 devices fourfold because the coverage area is reduced by four. For devices that only transmit intermittently, the interference is relaxed a further 10 dB.

Calculations are also carried out into the number of Part 15 devices that can co-exist with each other. The results show that the number of pole mounted Part 15 devices that can co-exist, under similar conditions, is much less, in the case of direct sequence spread spectrum devices, and less, in the case of frequency hopping devices, as those that can share with the LMS system.

From these results it is clear that the effect of the LMS systems will not cause any decrease in the number of Part 15 devices in the field, and similarly the number of cases where the LMS system operators will require the co-operation of a Part 15 user/supplier in order to resolve any harmful interference will be very limited.

The results show that there will be only isolated cases when co-operation will be required in order to resolve any interference problem, and that the market potential of Part 15 devices will be unaffected. This is consistent with the practical findings of the LMS operators.

2. Expressions for Probability of Blocking.

Appendix A to this paper derives the following expressions:

The probability, *Pb*, that the wanted LMS signal is blocked is:

$$P_b = 1 - \sum_{n=0}^{N} \left(1 - \frac{1}{2(NFR)^2} \right)^n \frac{(NF_t)^n}{n!} e^{-NF_t} \qquad \text{(A)}$$

Where *NFR* is the near far ratio,
N is the total number of Part 15 devices in the area,
Ft is the average proportion of time that the Part 15 device is transmitting

In order to obtain a location using time of arrival techniques, it is necessary to have at least four stations reporting. In order to obtain accurate location in practical conditions, the more stations reporting the better so as to compensate for the effects of blocking and multipath. There are, of course, financial and practical constraints on the site layout.

If there are *S* sites that receive the location burst, then the location will be lost if less than four sites are not blocked. If each site has a probability of P_b that it is blocked, then the probability that *s* or more sites are blocked is, (from the binomial distribution):

$$P_{(s+)} = \sum_{s}^{S} \frac{S!}{s!(S-s)!} P_b^s (1 - P_b)^{S-s} \qquad \text{(B)}$$

For example, Table 1A shows the value of P_b required for a 10% probability of loss of location against the number of sites, *S*.

Table 1A
Required probability of site blocked, Pb for 10% lost locations

No sites	4	5	6	7
Pb=	0.026	0.115	0.2	0.28
P(no loc)	0.10	0.10	0.10	0.10

From Table 1A it can be seen that if there are 6 sites that receive the location burst, then 10% of the locations will be lost if the probability of blocking of each site is 20%.

<u>In this paper, the calculations have assumed 6 sites.</u>

3. Calculated NFRs

In Annex 2 to the "Further Comments of MobileVision", March 15, 1994[3] the near far ratios were calculated for the various interference cases. These values were "worse case" in that the propagation of the unwanted signals did not include any additional losses other than the theoretical minimum.

In practice, the following extra propagation losses would probably apply:

- *Blocking losses,*
  Blocking of the direct signal path is common and can add at least 10 dB to the propagation loss.

- *Wall penetration losses for more than one wall.*
  The mean attenuation, due to building walls is about 10 dB per wall.

- *Antenna directivity.*
  Directional antennas will reduce the transmitted power inthe direction of the LMS receive site.

- *Antenna efficiency, especially for hand-held devices,*
  Hand-held devices do not present a good earth plane to the antenna and thus the efficiency of such antennas is often in the order of -6 to -10 dBi.

- *LMS fixed site antenna gain at small distances.*
  High gain antennas are used at the LMS fixed sites, in the order of 9 to 12 dBi. The narrow beam, in the vertical plane, means that transmissions at close distances are not in the main beam of the antenna. For a 200 - 300 feet antenna height, the transmission must be about 1.5 miles away before it is in the main beam. At distances up to about 0.5 mile, the antenna gain is about -5 dBi and at 1 mile is about +5 dBi.

All the above would tend to improve the near far ratio and reduce the interference. To this extent, the original calculations can be recognized as "worse case" analysis.

[3]"Interference Analysis of Part 15 Devices and LMS Wideband Systems - Initial Calculations", G K Smith, March 8th, 1994.

The following values of near far ratio were calculated in the "Initial Calculations":

3.1. Indoor Part 15 and LMS fixed site reception

Part 15 Transmitted power in direction of LMS site	NFR
30 dBm	7.5
20 dBm	13.3
10 dBm	23.7
0 dBm	42.2

For the purposes of this paper, the effective transmitted power of an indoor Part 15.247 device as assumed to be 20 dBm in order to take account of building penetration loss (more than one wall), blocking, antenna efficiency, directivity, etc.

3.2. Outdoor Pole Mounted Part 15 and LMS fixed site reception[4]

Note: An outdoor device was assumed to have antenna heights of 30 feet.

Part 15 Transmitted power in direction of LMS site	NFR
30 dBm	1.9
20 dBm	3.4
10 dBm	6.0
0 dBm	10.6

For the purposes of this paper, the effective transmitted power of an outdoor Part 15.247 device as assumed to be 20 dBm in order to take account of antenna directivity, which will be used in the majority of applications.

[4]In the Draft, March 15, 1994, Table 10 is incorrect. the figures given here are correct.

3.2. Outdoor Ground Level Part 15 and LMS fixed site

The NFR for ground level outdoor Part 15 devices is calculated in Section 5 of this paper.

Part 15 Transmitted power in direction of LMS site	NFR
30 dBm	4.2
20 dBm	7.5
10 dBm	13.3
0 dBm	23.7

4. *Indoor Part 15 Devices*

4.1. Calculated Results

IT MUST BE NOTED THAT ALL THE TABLES AND CALCULATIONS REFER ONLY TO THE NUMBERS OF PART 15 DEVICES THAT ARE TRANSMITTING WITHIN THE LMS SUB-BAND AND WITHIN THE DESENSITIZED (i.e. reduced) RANGE OF THE LMS SITE. THE TOTAL NUMBER OF PART 15 DEVICES IN THE ISM BAND WILL BE MUCH HIGHER.

The fraction of time that a Part 15 device is transmitting, *Ft*, is important because the interference potential is directly related to the possibility that the Part 15 device is transmitting at the same time as an LMS mobile. For example Table 1 gives the results for the case when an indoor, 1W Part 15 device is transmitting, on average, 1% of the time. It can be seen that 10000 of this type of device, in an area, could result in a 14% loss of locations.

Table 1 - Probability of Blocking					
Part 15 Ft=1%					
Indoor Part 15.247					
N=	**1000**	**2500**	**5000**	**10000**	**12500**
NFR=	13.3	13.3	13.3	13.3	13.3
Ft=	0.01	0.01	0.01	0.01	0.01
Pb	0.028	0.068	0.132	0.246	0.326
P(no loc)	**0.0004**	**0.005**	**0.03**	**0.16**	**0.22**

As the value of *Ft* approaches unity, then the number of Part 15 devices in the area required to cause a 10% probability of loss of location, will reduce. This is shown in Table 2.

Table 2	**Number of indoor Part 15.247 devices for 10% probability of blocking.**					
Ft=	0.01	0.1	0.25	0.5	0.75	1
NFR=	13.3	13.3	13.3	13.3	13.3	13.3
N=	8000	800	320	160	110	80

Table 3 is the case for 1mW transmitted power which represents the indoor Part 15.249 devices.

Table 3 Number of indoor Part 15.249 devices for 10% probability of blocking.						
Indoor Part 15						
Ft=	0.01	0.1	0.25	0.5	0.75	1
NFR=	42.2	42.2	42.2	42.2	42.2	42.2
N=	74000	7400	3000	1500	1000	750

Table 3 shows clearly that there is no interference problem from indoor Part 15.249 devices.

4.2. Interpretation of Results.

The Tables 1 and 2 show the probable number of indoor Part 15.247 devices that can be tolerated in an area. Table 2 predicts that 800 indoor devices, transmitting 10% of the time, could be present in an area. Table 3 shows that 7400 indoor Part 15.249 devices can be present. It must be remembered that these quantities only represent those devices transmitting in the LMS sub-band and are related to the effect on the LMS system. In Section 7 of this paper, the number of Part 15 devices which can co-exist with other Part 15 devices will be analysed.

The area is the coverage area of one LMS site. The Tables represent a 20% probability of blocking of one site and thus the number of Part 15 devices refers to the number in tha coverage area of the LMS site, i.e. the area in which an LMS mobile expects to be able to communicate to the fixed site. This is further discussed in Section 8, and is approximately 200 square miles.

Tables 2 and 3 need further explanation. The probability formula assumes that there is an equal distribution of Part 15 devices and LMS mobiles over the area. Thus the distances of the transmitting mobiles, from the fixed site, varies. Therefore, even when there are Part 15 devices close to the fixed site, many of the mobile transmissions are received because their distances are within the near far ratio, i.e. they are relatively close to the fixed site. The 10% loss of location equates to a 20% probability of blocking at any one LMS site. This blocking therefore represents those vehicles at the outer edge of the area. The formula assumes a probability associated with how far the nearest Part 15 device is to the fixed site. Obviously, if a constantly transmitting Part 15 is very close, then the fixed site will be desensitized more than predicted. It is in this case that the LMS provider needs to be able to resolve the interference. The results show that the probability of this is low

The factor *Ft* can also be related to frequency hopping devices and represents the proportion of time that the device is transmitting in the LMS sub-band.

The effect of intermittent transmissions by the Part 15 devices is dramatic and the results show that very high numbers of these type of devices can be tolerated.

5. *Outdoor Part 15 Devices.*

An outdoor Part 15 device is assumed to have an antenna height of 30 feet.

5.1. Calculated Results

5.1.1. Pole Mounted Devices

Table 4 shows the calculated results for various values of *Ft*.

Table 4 Number of outdoor Part 15.247 devices for 10% probability of loss of location.

Ft=	0.01	0.1	0.25	0.5	0.75	1
NFR=	3.4	3.4	3.4	3.4	3.4	3.4
N=	540	54	21.6	10.8	7.2	5.4

5.1.2. Ground Level Devices

Table 4 refers to outdoor Part 15.247 devices that are transmitting at antenna heights of 30 feet. It is useful to also consider the case of Part 15 transmitters that are at ground level so as to represent a consumer type device that has been taken outdoors. The corresponding NFRs for this case are:

Outdoor Part 15 transmitter at ground level[5].			
Transmitted power	1W	100mW	1mW
NFR	4.22	7.5	23.7

Tables 5 and 6 give the results.

Table5 Number of outdoor Part 15.247 devices at ground level, for 10% probability of blocking.

Indoor Part 15

Ft=	0.01	0.1	0.25	0.5	0.75	1
NFR=	7.5	7.5	7.5	7.5	7.5	7.5
N=	2600	260	105	52	35	26

Table 6 Number of 1mW outdoor Part 15.249 devices at ground level, for 10% probability of blocking.

Indoor Part 15

[5]Assumed to be 6 ft, i.e. the same as the LMS mobile antenna height.

Ft=	0.01	0.1	0.25	0.5	0.75	1
NFR=	23.7	23.7	23.7	23.7	23.7	23.7
N=	23000	2300	920	460	350	230

5.2. Interpretation of Results

Tables 5 and 6 give the probable number of outdoor Part 15 systems in an area that can be tolerated by an LMS system. The results show that if the devices are transmitting infrequently, then larger numbers are required before the LMS system is affected.

It is clear, however, that the outdoor devices cause more concern to the LMS provider than the indoor. Outdoor devices that are transmitting constantly, in the LMS sub-band, can be significant interferers, and it is this type of device where it may be necessary to resolve the interference. If the outdoor device is transmitting infrequently, then the interference potential is greatly lessened.

Significantly more devices at ground level can be tolerated, especially if the device is transmitting intermittently.

Although the outdoor Part 15 device can cause interference problems to the LMS system, this type of device also will cause interference to other similar devices. Section 7 analyses this further.

6. Effect of Intermittent Transmissions by Part 15 Device.

As noted before, if the Part 15 device is transmitting intermittently, i.e. *Ft* is less than unity, then the interference to the LMS system is reduced. From Table 4 it is noted that for a NFR of 7.5 the number of Part 15 devices, N, is 45 for a probable loss of location, *P(no loc)* of 10%. The value of the NFR can be varied such that N and *P(no loc)* remain constant. The NFR is related to the received power of the Part 15 device, and hence the effect of intermittent transmissions can be assessed.

From "Interference Analysis of Part 15 Devices and LMS Wideband Systems - Initial Calculations", Section 5.3., the expression for calculating the NFR is given as :

$$40 \log dw/du = (Ptw + JM) - (Ptu - f) + 20 \log hw/hu \text{ (for hw,hu} \leq \text{30feet)}$$

where,	dw/du	is the NFR
	Ptw	is the transmitted power of the LMS mobile
	JM	is the jamming margin of the LMS system
	Ptu	is the transmitted power of the Part 15 device
	f	is the floor attenuation factor
	hw	is the height of the LMS mobile
	hu	is the height of the Part 15 device.

For the indoor Part 15 case,

Ptw = 40 dBm, JM = 15dB, f = 10dB and hw=hu=6ft

Hence, $Ptu = 65 - 40 \log NFR$ (indoor Part 15)

For the outdoor Part 15 case:

Ptw = 40 dBm, JM = 15dB, f = 0, hw = 6ft and hu = 30ft.

Hence, $Ptu = 41 - 40 \log NFR$ (outdoor Part 15)

Table 7 shows the values of NFR and Ptu for the various values of Ft:

Table 7	**NFR vs. Ft for constant N for 10% probability of loss of location.**					
Indoor Part 15						
Ft=	0.01	0.1	0.25	0.5	0.75	1
NFR=	1.3	4.2	6.7	9.4	11.9	13.3
N=	80	80	80	80	80	80
Ptu=dBm	60	40	32	26	22	20

From Table 7 , it can be seen that the equivalent power of a device that is transmitting, on average, only 1% of the time, is 40 dB less than its actual transmitted power. A device transmitting 50% of the time has an equivalent transmitted power of 6 dB less.

Hence, the time power reduction is *20 log (1/Ft)*

Thus the equivalent interfering received signal is *Ptu - 20 log (1/Ft).*
or *Ptu + 20 log Ft*

7. Interference Threshold

The calculations given in this paper give the numbers of devices that exist in an "area of unit radius" (see Annex A). The unit radius is the distance of an LMS mobile that would be expected to be received satisfactorily. In the absence of interference, this distance would be related to thermal noise, and interference, or desensitization of the receive site will reduce this area. A 10 dB desensitization of the receiver effectively reduces the radius of the unit circle by half (theoretically 1.8), and thus the area of the circle by four. Hence, by proposing an acceptable desensitization of 10 dB for the LMS receive sites, the number of Part 15 devices in a given area is increased by four, i.e. the Part 15 device density is increased fourfold, because the "area" is reduced by four.

In "Interference Analysis of Part 15 Devices and LMS Wideband Systems - Initial Calculations", Section 4, it is shown that a received interfering signal of -92 dBm will desensitize the LMS receiver by 10 dB. Assuming a 9 dBi receiving antenna, this is equivalent to a -101 dBm signal at the antenna. The effective received level is therefore:

$$Ptu\ (eff) = -101 + 20 \log Ft \text{ dBm}$$

The relationship between field strength, E, and received power, Pr, is:

$$E^2 = \frac{480\pi^2 \Pr}{\lambda^2} \text{ V/m}$$

For Pr = *Ptu (eff)* and 915 MHz

$$E = 10^{-(84.6-20\log Ft)/20} \text{ V/m}$$

For Ft = 1 $\quad E = 59\ \mu\text{V/m}$

The definition of "interference threshold" has been proposed to be equivalent to 10 dB desensitization, i.e. -101 dBm. As shown above, if the device is transmitting 50% of the time, then the received power could be -95 dBm for the same effect. The proposed "interference threshold, 59 µV/m, is intended to be a level below which interfering signals must be tolerated. If the interfering level at an LMS site exceeds the "interference threshold", then this allows the LMS provider to work with the Part 15 user/provider in order to resolve the interference.

A case can be made for relaxing this in the case of Part 15 devices that are transmitting infrequently. The problem is that if the level were relaxed, then if there were several infrequently transmitting devices, on the threshold, then the effect would be that the LMS site would be severely desensitized. For example, if the definition is relaxed to include the effect of transmission time, then if three

or four devices transmitting 50% of the time and being received at -95 dBm would definitely desensitize the LMS site. Yet each of those signals is within the new definition. On the other hand, if there were several devices transmitting only 1% of the time, then their received levels could definitely be above -101 dBm. Thus it is not practical to increase the interference threshold directly in line with the transmission duty cycle.

Therefore it is proposed that the definition of interference threshold takes account of Part 15 devices that transmit less than 10% of the time as follows:

Interference from a Part 15 device shall be considered above the interference threshold if the total field strength at an LMS site, across the licensed LMS sub-band, exceeds 59 μV/m, (equivalent to -101 dBm at an isotropic antenna), or, in the case when the Part 15 device is transmitting less than 10% of the time, in any 10 second period, 186 μV/m (equivalent to -91 dBm at an isotropic antenna).