EXECUTIVE SUMMARY

This report describes mobile communication link measurements made at Ft. Hood, Coryell County, Texas, in support of the Flexible Interoperable Transceiver (FIT) program. Ft. Hood is the second of four locations measured, the other three being Edwards Air Force Base, CA (completed), Fort Polk, LA (pending) and Camp Lejeune, NC (pending). The goal of the measurement series is to define communication link characteristics at different frequencies over a representative cross section of military training centers.

The measurements were made using the Institute for Telecommunication Sciences (ITS) multiple channel impulse response system (see Report, Section 3). The primary figures of merit used to characterize wireless communication links are basic transmission loss (L_{BT}) and delay statistics. Three frequencies were considered: 440 MHz, 1360 MHz, and 1920 MHz. 440 MHz is representative of several current ground-to-ground communication links (JRTC-IS, PRIME, PLRS). 1360 MHz is proposed for the next generation FIT system. 1920 MHz has similar characteristics to the 1710-1850 MHz band, which is also under consideration for FIT. By comparing the 1360 MHz and 1920 MHz basic transmission loss and delay statistics to those for 440 MHz, the viability of using higher frequencies for future military communications and the associated system requirements can be assessed. At Ft. Hood a second 1360 MHz receiver channel was added. This channel was used to monitor a “low” 1360 MHz receive antenna. The purpose of this experiment was to measure the difference in received signal using a hand held “low” antenna (ground soldier) versus a vehicle-mounted antenna. As before, all channels are measured simultaneously.

Two transmitter sites and a common receiver vehicle route were selected. At both transmit sites the antennas were elevated using a 10-m mast on a Humvee provided by TEXCOM. Site 1 was located on Anderson Mountain directly north of Copperas Cove. Ground elevation at this site is 360 m. The transmitter elevation including mast was 370 m. This site had a view of the training range to the ridge-line of the Manning Mountains just north of the Manning Mountains Road. In general, Anderson Mountain had good views of the range except when obscured by vegetation (cypress trees) or valleys cut by streams. Some of these obstructions would presumably not exist for the second transmit site at Pidcoke. Pidcoke (Site 2) is located near the intersection of Antelope Road and the State Highway, which forms the western boundary of the Military Reservation. The elevation at Pidcoke is approximately 275 m. The 10-m Humvee mast was used to place the antennas at 285 m elevation. Photographs and maps of the transmitter and receiver locations are in the figures from Section 2 of the report.

Data were collected simultaneously at three frequencies. The major question answered by the survey is the effect of frequency translation on radio propagation parameters. To quantify propagation impairments caused by frequency translation, the impulse response data were analyzed and the following metrics tabulated:

1. Linear curve fit parameters n (path loss exponent) and B (multiplier) are tabulated for basic transmission loss (L_{BT}) versus distance for three frequencies. The path loss exponent, n, is the critical parameter. For line of sight propagation with loss only due to signal spreading (free space loss, L_{FS}), $n = 2$. In areas with obstructions caused by terrain, vegetation, or buildings, n typically varies between 2 and 4 due to diffraction, attenuation and multipath interference. Column 1, Tables ES1 and ES2 summarize the n and B parameters (see Report, Section 4 for more details). By substituting these parameters into the curve fit equation, a best fit approximation of path loss versus distance can be calculated for the different frequencies and transmitters. These curves are then used in conjunction with the free space loss curve to determine additional loss over free space ($\Delta L_{BT/FS}$). They are also used to determine signal loss due to frequency translation from 440 MHz to higher frequencies ($\Delta L_{BT/440}$).

2. The difference between the linear fit estimates and ideal free space values is designated $\Delta L_{BT/FS}$. These data indicate the additional loss over the basic free space loss. The $\Delta L_{BT/FS}$ data range is approximately 15 to 30 dB for Anderson Mountain and 20 to 40 dB for Pidcoke. This difference is most likely due to the transmitter elevations. The Anderson Mountain transmitter was at an elevation of 370 m which is about 120 m above the survey area. The Pidcoke transmitter was at an elevation of 285 m or about 35 m above the survey area. This difference compares to a $\Delta L_{BT/FS}$ range of 10 to 20 dB for the high transmitter at Edwards Air Force Base (EAFB) and 20 to 40 dB for the low transmitter at EAFB. At EAFB the low transmitter was only 5 m above the survey area, while the high transmitter was also 120 m above the survey area. At Ft. Hood the high unobstructed transmitter (Anderson Mountain) had a larger $\Delta L_{BT/FS}$ than the high transmitter at EAFB and a slightly smaller loss than the obstructed low transmitter at EAFB. The received signal from Pidcoke was about equal with the received signal from the lower transmitter at EAFB. The additional losses versus distance for these higher transmitters at Ft. Hood are most likely due to obstructions caused by vegetation and terrain. Tables ES1 and ES2 and Report, Section 4 summarize these data for Ft. Hood.

3. The difference between the 1360 and 1920 MHz linear fit estimates and the 440 MHz linear fit estimate is designated $\Delta L_{BT/440}$. These numbers can be used to determine the extra transmit power, system sensitivity, diversity gain, or BER versus signal to noise requirements of the proposed higher frequency systems. The $\Delta L_{BT/440}$ data range over approximately 7 to 12 dB for the 1360 MHz van roof data and 11 to 15 dB for the 1920 MHz data. For this metric there is no noticeable difference between the two transmitter sites (see Tables ES1 and ES2 and Report, Section 4). For comparison, the $\Delta L_{BT/440}$ data for EAFB varies from 5 to 15 dB for the 1360 MHz data and 10 to 20 dB for the 1920 MHz data. So we see that there is 3 to 5 dB less differential loss due to frequency translation at Ft. Hood than at EAFB.

4. An alternative to curve fitting the measured data is to bin the L_{BT} data. This is done versus distance, and the mean and standard deviation for each bin are calculated as well as the 90% and 99% probability levels (i.e. 99% of the L_{BT} data are less than this level). 99% L_{BT} levels range from 98 to 167 dB for Anderson Mountain and from 105 to 167 dB for Pidcoke. The larger values were limited by the dynamic range of the measurement system. The maximum range before this limit was reached using the 1360 MHz high receiver was about 15 km for Anderson Mountain and about 10 km for Pidcoke. These data give the upper bounds for the measured transmission loss L_{BT} and indicate maximum signal loss on the link required to ensure a certain channel availability probability (see Tables ES3 and ES4 and Report, Section 4). The difference between the mean and the 99% level can also be added to the curve fit to extend the curve fit requirements to the 99% availability level. 99% L_{BT} levels ranged from 126 to 163 dB in Cell 1 (low transmitter) at EAFB and from 117 to 157 dB in Cell 2 (high transmitter) at EAFB.

5. Delay statistics are necessary for design of a digital system. They are used to determine equalizer requirements for elimination of inter-symbol interference. In general, delay increases with frequency and with the presence of scattering objects (low transmitter). Two figures of merit are the delay spread and the maximum delay. Tables ES5 through ES8 summarize the delay statistics for different probability levels. In these tables the maximum mean and delay spread are given versus frequency. For instance, at 90% probability, the maximum delay is 0.93 μs for both Anderson Mountain and Pidcoke at 440 MHz. At 1920 MHz and 90% probability, the maximum delay ranges between 1.18 μs at Pidcoke down to 0.65 μs at Anderson Mountain. These data are based on average power delay profiles (APDPs) with a 20 dB interval of discrimination (ID). A 20 dB ID means that the impulse peak to noise is > 23 dB and only echoes within 20 dB of the peak are included in the statistics, see Report, Section 5 for more details). For comparison, the delay spreads at EAFB are up to 2.2 μs for 440 MHz and up to 4.1 μs for 1920 MHz. We see a decrease in multipath at Ft. Hood versus EAFB that probably is due to the lack of large metal hangers and multistory office buildings in the training area at Ft. Hood. The few buildings seen while driving the range at Ft. Hood were a small mock village which appeared to consist only of wooden buildings.

6. Simultaneous impulse response measurements at 1360 MHz were made using two receive antennas placed at different heights. This experiment was designed to measure possible signal degradation between higher vehicle-mounted antennas and lower antennas carried by foot soldiers. The low antenna was approximately 0.5 m above the ground and towed behind the recording vehicle. The high antenna was 2.5 m above the ground and situated on the van roof. Measurements indicated that the low antenna suffered a 2 to 3 dB decrease in average received signal strength. These results were determined using curve fitting (see Report, Section 4 and Figures 4.19 and 4.20).

Table ES1. Curve Fit Parameters, Free Space Loss and 440 MHz Loss Compared to Basic Transmission Loss Collected Using Anderson Mountain Transmitter Site

	L_{BT} Linear Fit Parameters		Distance (km)					
			2.0			20		
F (MHz)	n	B (km^{-1})	L_{FS} (dB)	$\Delta L_{BT/FS}$ (dB)	$\Delta L_{BT/440}$ (dB)	L_{FS} (dB)	$\Delta L_{BT/FS}$ (dB)	$\Delta L_{BT/440}$ (dB)
440	3.3	848	91.3	15.6	N/A	111.3	28.7	N/A
1360	3.5	1010	101.1	15.8	10.1	121.1	31.3	12.4
1920	3.1	4107	104.1	16.4	13.7	124.1	27.3	11.4

Table ES2. Curve Fit Parameters, Free Space Loss and 440 MHz Loss Compared to Basic Transmission Loss Collected Using Pidcoke Transmitter Site

	L_{BT} Linear Fit Parameters		Distance (km)					
			1.0			10.0		
F (MHz)	n	B (km^{-1})	L_{FS} (dB)	$\Delta L_{BT/FS}$ (dB)	$\Delta L_{BT/440}$ (dB)	L_{FS} (dB)	$\Delta L_{BT/FS}$ (dB)	$\Delta L_{BT/440}$ (dB)
440	3.4	1451	85.3	22.2	N/A	105.3	36.2	N/A
1360	3.9	854	95.1	19.5	7.1	115.1	38.6	12.2
1920	3.1	9932	104.1	24.2	14.8	118.1	34.8	11.4

Table ES3. Anderson Mt. Basic Transmission Loss (L_{BT}): Free Space Loss (L_{FS}) and Measured Mean (Avg), 90%, and 99% Probability Levels

		L_{BT} (dB): 440 MHz				L_{BT} (dB): 1360 MHz (trailer)				L_{BT} (dB): 1360 MHz (van)				L_{BT} (dB): 1920 MHz		
D (km)	L_{FS} *(dB)*	Avg	90%	99%	L_{FS} *(dB)*	Avg	90%	99%	L_{FS} *(dB)*	Avg	90%	99%	L_{FS} *(dB)*	Avg	90%	99%
0.7	82.8	92.2	96.9	98.8	92.6	106.0	120.7	125.3	92.6	104.3	114.6	119.6	95.6	105.6	110.4	112.6
1.8	90.3	106.8	113.9	114.1	100.1	117.7	125.8	126.3	100.1	116.2	119.7	120.1	103.1	123.9	127.1	128.4
2.8	94.2	110.1	120.3	122.1	104.0	121.9	130.0	133.2	104.0	121.1	132.6	138.2	107.0	125.6	137.6	139.1
3.8	96.9	112.5	126.5	130.3	106.7	128.1	144.9	149.9	106.7	125.2	145.1	152.7	109.7	127.8	144.1	148.9
4.8	99.0	119.8	125.2	127.1	108.8	135.6	147.5	156.5	108.8	136.4	152.9	160.7	111.8	137.6	146.6	155.8
5.8	100.6	120.2	131.3	137.2	110.4	135.8	152.0	159.0	110.4	131.5	150.3	155.9	113.4	132.5	149.6	154.2
6.9	102.0	127.2	142.1	145.0	111.8	141.7	165.7	166.8	111.8	141.9	165.2	166.4	114.8	144.3	161.9	164.3
7.9	103.2	121.3	129.6	138.1	113.0	136.8	151.7	162.5	113.0	128.8	142.2	161.1	116.0	130.0	141.7	150.7
8.9	104.3	129.9	140.7	146.3	114.1	145.8	159.7	165.9	114.1	141.7	162.7	166.0	117.1	140.6	156.1	161.3
9.9	105.2	131.0	135.4	138.5	115.0	145.1	154.7	160.5	115.0	142.8	154.3	162.1	118.0	142.5	149.9	155.0
10.9	106.1	148.5	156.2	158.2	115.9	161.3	166.6	167.3	115.9	162.6	166.2	166.9	118.9	158.8	165.9	166.9
12.0	106.9	147.3	159.3	160.7	116.7	160.8	166.7	167.3	116.7	159.5	166.4	167.1	119.7	158.6	166.4	167.1
13.0	107.6	140.3	149.9	158.0	117.4	157.5	166.3	167.2	117.4	158.0	165.9	166.9	120.4	156.9	165.7	166.7
14.0	108.2	136.2	144.5	151.1	118.0	151.8	164.5	166.7	118.0	151.7	165.2	166.3	121.0	147.9	159.0	164.1
15.0	108.8	134.8	157.3	159.3	118.6	154.1	166.6	167.5	118.6	142.7	166.4	167.2	121.6	144.0	166.2	167.1
16.0	109.4	129.2	145.2	158.6	119.2	141.0	161.5	166.7	119.2	140.0	164.9	166.5	122.2	140.6	160.6	166.5
17.1	110.0	132.6	151.3	153.9	119.8	154.7	166.0	167.1	119.8	149.6	165.8	166.8	122.7	147.2	165.5	166.7
18.1	110.5	131.5	144.8	151.4	120.3	149.0	165.8	167.1	120.3	147.7	165.6	166.6	123.3	146.3	163.4	165.9
19.1	110.9	142.4	150.8	152.8	120.7	160.3	166.7	167.3	120.7	157.6	166.3	167.0	123.7	154.7	166.3	166.9
20.1	111.4	145.2	158.5	160.2	121.2	159.4	166.7	167.5	121.2	159.9	166.3	167.0	124.2	157.9	166.3	167.0

Table ES4. Pidcoke Basic Transmission Loss (L_{BT}): Free Space Loss (L_{FS}) and Measured Mean (Avg), 90%, and 99% Probability Levels

		L_{BT} (dB): 440 MHz				L_{BT} (dB): 1360 MHz (trailer)				L_{BT} (dB): 1360 MHz (van)				L_{BT} (dB): 1920 MHz		
D (km)	L_{FS} *(dB)*	Avg	90%	99%	L_{FS} *(dB)*	Avg	90%	99%	L_{FS} *(dB)*	Avg	90%	99%	L_{FS} *(dB)*	Avg	90%	99%
0.3	75.1	92.2	97.1	105.6	84.9	107.6	113.9	124.9	84.9	108.1	116.7	125.1	87.9	109.2	120.5	126.5
0.7	81.7	107.4	114.0	119.4	91.5	121.8	127.9	130.0	91.5	111.2	122.0	126.6	94.5	115.1	129.8	134.4
1.0	85.4	106.3	114.6	116.2	95.2	122.6	127.2	128.7	95.2	114.5	124.4	126.3	98.2	118.2	128.1	130.6
1.4	87.9	111.4	114.3	115.1	97.7	129.5	134.9	138.8	97.7	116.1	119.6	126.7	100.7	120.9	129.0	136.8
2.0	91.5	130.3	143.4	150.8	101.3	153.4	166.4	167.4	101.3	148.6	165.4	166.5	104.3	150.4	165.9	166.9
3.1	95.1	113.7	124.4	128.4	104.9	138.4	144.8	151.2	104.9	128.4	142.7	146.2	107.9	130.6	141.0	146.7
4.1	97.6	130.2	149.9	155.4	107.4	145.5	158.7	164.6	107.4	143.7	164.0	165.9	110.4	141.8	156.0	161.2
5.2	99.6	122.4	128.8	135.4	109.4	140.3	155.1	160.3	109.4	133.6	145.2	154.9	112.4	133.6	142.9	154.1
6.2	101.2	131.8	140.4	143.4	111.0	146.7	157.8	165.2	111.0	144.1	159.9	166.2	114.0	143.0	155.2	163.8
7.3	102.5	131.4	151.1	155.4	112.3	141.5	165.7	167.2	112.3	139.6	166.0	166.9	115.3	142.4	165.3	166.9
8.0	103.3	133.7	144.2	146.8	113.1	147.6	164.6	167.1	113.1	147.9	165.5	166.6	116.1	146.0	160.4	166.2
9.0	104.4	139.6	155.2	157.0	114.2	158.1	166.9	167.7	114.2	158.2	166.2	166.9	117.2	153.8	166.3	167.2
10.1	105.4	152.5	157.5	158.9	115.2	165.0	167.5	168.1	115.2	164.8	166.6	167.2	118.2	164.1	167.1	167.7
11.1	106.2	150.8	156.5	158.1	116.0	164.5	167.3	167.9	116.0	164.9	166.5	167.1	119.0	162.7	166.9	167.7
12.1	107.0	140.9	148.1	151.3	116.8	159.8	166.4	167.5	116.8	157.4	166.0	166.9	119.8	150.3	165.0	167.2
13.2	107.7	146.5	156.8	158.8	117.5	159.2	167.2	168.2	117.5	161.4	166.5	167.1	120.5	157.0	166.7	167.5
13.9	108.2	142.9	151.4	156.3	118.0	157.4	166.0	167.5	118.0	160.8	165.8	167.0	121.0	154.0	164.5	166.7

Table ES5. Anderson Mt.: Delay Statistics for APDPs with a 20 dB ID

	440 MHz			1360 MHz (Trailer)			1360 MHz (Van)			1920 MHz		
	69 % APDPs Valid			52 % APDPs Valid			52 % APDPs Valid			61 % APDPs Valid		
Prob. (%)	Delay (μs)			Delay (μs)			Delay (μs)			Delay (μs)		
	max	avg	spr	max	avg	spr	max	avg	spr	max	avg	spr
90.0	0.93	0.15	0.15	0.75	0.15	0.13	0.55	0.13	0.08	0.65	0.13	0.09
99.0	17.4	1.52	3.92	12.1	1.26	2.59	14.7	1.57	3.48	12.0	1.78	3.35
99.9	23.1	17.8	7.03	39.3	22.1	9.21	20.8	17.4	6.06	24.3	18.4	8.30

Table ES6. Anderson Mt.: Delay Statistics for APDPs with a 10 dB ID

	440 MHz			1360 MHz (Trailer)			1360 MHz (Van)			1920 MHz		
	81 % APDPs Valid			69 % APDPs Valid			67 % APDPs Valid			74 % APDPs Valid		
Prob. (%)	Delay (μs)			Delay (μs)			Delay (μs)			Delay (μs)		
	max	avg	spr	max	avg	spr	max	avg	spr	max	avg	spr
90.0	0.13	0.09	0.03	0.23	0.11	0.06	0.15	0.09	0.03	0.15	0.09	0.04
99.0	1.65	0.30	0.46	9.43	3.25	3.03	2.33	0.72	0.74	7.15	3.71	3.08
99.9	7.13	1.84	2.30	23.7	10.5	8.59	10.9	7.02	3.55	23.7	8.69	9.15

Table ES7. Pidcoke: Delay Statistics for APDPs with a 20 dB ID

	440 MHz			1360 MHz (Trailer)			1360 MHz (Van)			1920 MHz		
	60 % APDPs Valid			43 % APDPs Valid			42 % APDPs Valid			56 % APDPs Valid		
Prob. (%)	Delay (μs)			Delay (μs)			Delay (μs)			Delay (μs)		
	max	avg	spr	max	avg	spr	max	avg	spr	max	avg	spr
90.0	0.93	0.16	0.14	0.75	0.16	0.12	0.56	0.14	0.09	1.18	0.18	0.19
99.0	9.70	1.14	2.26	10.2	1.94	2.59	3.48	0.40	0.77	7.25	0.93	1.67
99.9	17.5	3.89	5.40	19.0	3.21	5.39	18.9	1.32	3.78	10.9	2.56	2.77

Table ES8. Pidcoke: Delay Statistics for APDPS with a 10 dB ID

	440 MHz			1360 MHz (Trailer)			1360 MHz (Van)			1920 MHz		
	76 % APDPs Valid			60 % APDPs Valid			59 % APDPs Valid			69 % APDPs Valid		
Prob. (%)	Delay (μs)			Delay (μs)			Delay (μs)			Delay (μs)		
	max	avg	spr	max	avg	spr	max	avg	spr	max	avg	spr
90.0	0.13	0.09	0.03	0.30	0.13	0.07	0.18	0.10	0.04	0.18	0.10	0.04
99.0	2.10	0.75	0.88	5.88	2.73	2.21	2.18	0.64	0.72	3.48	0.88	1.17
99.9	9.73	2.93	3.69	14.5	5.49	4.97	7.58	1.96	2.59	13.5	5.52	4.69