A Method for Demonstrating the Impact of Multipath Distortion on Modulation and Demodulation Techniques Proposed for Standardization

by
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Abstract

One of the critical decisions which will face the IEEE 802.11 committee in the near future is the choice of a modulation technique to be used at the air interface. Extensive work has been done to characterize the nature and type of distortion that electromagnetic signals propogating through the air in an indoor environment will experience. The impact of multipath distortion on the complex envelope of the signal arriving at a station has been graphically illustrated through three dimensional representations of actual data taken in the indoor radio environment. The purpose of this brief analysis is to illustrate the impact of this distortion on a specific modulation and demodulation technique. This effort is undertaken not only for the purposes of this specific illustration but also as a template for the type of analysis which must ultimately be performed on any modulation/demodulation technique that is considered for standardization.

The specific technique chosen for analysis in this paper is the MSK form of CPFSK, however, the use of this technique as an example should not be construed as an introduction by the author of this type of modulation as a candidate for standardization. It is chosen for illustrative purposes only.

▩ The Transmitted Signal Model

A modulation technique often mentioned for use in this environment is the MSK (minimum-shift keying) form of CPFSK (continuous phase frequency shift keying). The transmitted waveform for any CPFSK modulation technique can be modeled with the equations detailed in the following cells (note the cell below should be executed after the cell which initializes the vector information if no errors are to be produced):

```
theta=Table[Pi h Sum[information[[n]],{n,1,Floor[k]}],{k,1,31}];
```

```
s[t_]:=a Cos[(2 Pi carrierfrequency t)+ theta[[window[t]]]
 + Pi/(2 bitperiod) information[[window[t]+1]] (t-(window[t]-1) bitperiod)]
```

where information[[window+1]] is the an element of a list containing the information signal for a given each bit time period and where theta[[window]] is the sum of all information bits from the beginning of time until period n-1 scaled by Pi h. For the purposes of this the following definitions are made. The amplitude a is set arbitrarily equal to unity, the modulation index h is set to 1/2 to provide an MSK signal, the bit period is set to one and the carrier frequency to 2 arbitrarily and a binary {+1,-1} information stream consisting of a 31 bit m-sequence is arbitrarily chosen. The following cells handle this initialization. The zero placed at the beginning of the information sequence is used to set the cumulative phase "theta" equal zero for information delivered before the beginning of time.

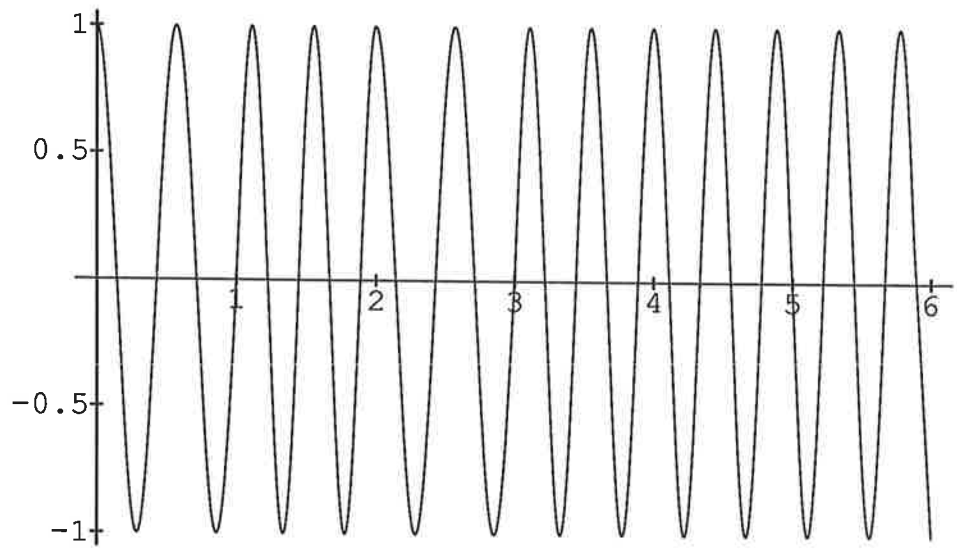
```
a=1
h=1/2
carrierfrequency=2
bitperiod=1
gencode[5,1,1,tinformation]
information=Join[{0},tinformation]
```

```
{0, -1, 1, -1, 1, 1, 1, -1, 1, 1, -1, -1, -1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, -1, 1, -1, -1, -1, -1, 1}
```

The information sequence listed above is an m-sequence of length 31 which is generated by a functions called gencode which appears in the appendix of this document.

Having made these definitions a plot of the transmit signal is presented as a sanity check. It should be noted that, for this plot, the carrier frequency has been set to two times the bit rate. This gives the two frequencies transmitted as 1.75 and 2.25. The following plot illustrates the expected waveform over the first six information bits.

```
Plot[s[t],{t,0,6},PlotPoints->50,PlotStyle->Thickness[.001]]
```



Multipath DistortionEffects Model

The previous section of this document developed the ability to generate transmit waveforms. The multipath distortion model of a typical indoor radio environment is known to be complicated and probably best described in terms of a representative group of experimentally obtained complex impulse response samples. Given these experimentally obtained samples the next step in the process being described here would be to convolve the transmit signal obtained above with the experimental complex impulse response samples and to use the resulting waveforms as input to the proposed demodulator. This approach although quite possible given the work done to date will not be taken in this paper. When the candidates for modulation techniques to be adopted are down to the final cut perhaps such an analysis would be appropriate, but for now a more heuristic approach intended to illustrate the basic effects of multipath distortion will be undertaken.

In this approach a simple four ray model for the arriving signal will be used. Each of the arriving rays will be parameterized by a value for excess delay (delay as counted from the first arriving trace of signal) and amplitude subject to the constraint that the sum of all the arriving ray amplitudes will equal the amplitude of the original transmitted signal. These parameters will be stored in a list each element of which will be {amplitude factor,excess delay}. Just to make it a little more exciting the values for amplitude factor and excess delay will be chosen by random number generators. The excess delay will be chosen to be uniformly distributed between zero and a parameter called delaymax and the amplitude will be chosen for the first ray as uniformly distributed between zero and one, for the second ray as uniformly distributed between zero and (1-first amplitude), for ray three as uniformly distributed between zero and (1-first amplitude-second amplitude) and for ray four as (1-first amplitude-second amplitude-third amplitude). The cells which follow set up the list "multipath"

```
delaymax=3
generatemultipathprofile:=multipath={{a1=Random[Real,1],Random[Real,delaymax]},
    {a2=Random[Real,1-a1],Random[Real,delaymax]},
    {a3=Random[Real,1-a1-a2],Random[Real,delaymax]},
    {1-a1-a2-a3,Random[Real,delaymax]}}
```

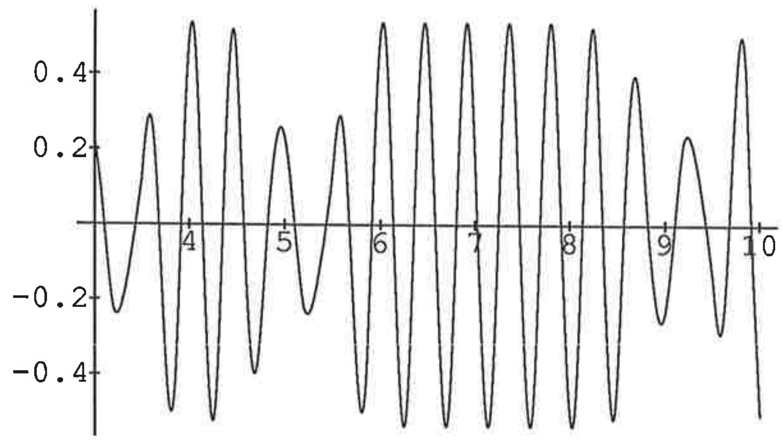
Given this profile a receive signal is the generated by simply by summing four versions of the transmit signal, each scaled by the appropriate amplitude factor and time shifted by the appropriate excess delay factor. The cells which follows defines the received signal according to this approach. Note that when using the function receive signal, it should not be called with a value of time that is less than delaymax as this would require access to information that is present before the begining of time.

```
generatemultipathprofile

{{0.296166, 0.94734}, {0.0533105, 0.349085}, {0.314922, 2.7758}, {0.335601, 2.37179}}

receivesignal[t_]:=multipath[[1,1]]  s[t-multipath[[1,2]]]+multipath[[2,1]]
s[t-multipath[[2,2]]]+multipath[[3,1]]  s[t-multipath[[3,2]]]+multipath[[4,1]]
s[t-multipath[[4,2]]];
```

Although it is difficult to determine what the received waveform should look like after going through a particular multipath profile, two examples of multipath profiles and their associated receive signal are plotted below as examples of the process.

```
multipath={{0.171006, 2.19623}, {0.471617, 2.49391}, {0.311085, 2.85078}, {0.046293, 2.40142}}
```

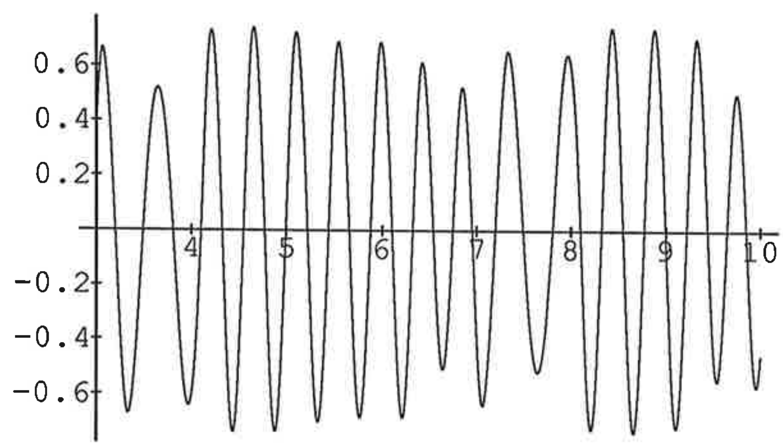
Plot[receivesignal[t],{t,delaymax,10},PlotPoints->100,PlotStyle->Thickness[.001]]



generatemultipathprofile

{{0.222604, 0.326215}, {0.725153, 1.08105}, {0.0246201, 1.5547}, {0.0276231, 2.64433}}

Plot[receivesignal[t],{t,3,10},PlotPoints->100,PlotStyle->Thickness[.001]]



Demodulator Model-The Port to Spice

As the reader is certainly aware, some software packages are better suited to do do certain functions than others. The generation of FSK signals other than a carrier modulated by a single tone frequency is non-trivial in SPICE. Likewise the generation of a dynamic simulation of the time domain operation of a filter is non-trivial in *Mathematica*. For this reason, the signal generated in the previous sections of this document will now be placed into a table including a time stamp and a value stamp and exported through a text editor to SPICE for further processing. The table will be used to generated a piecewise linear signal to excite a demodulator modeled in SPICE. In order to provide a degree of realism, the time scale of the signal will be set so that the carrier frequency of 2 cycles per unit time which is set above will be scaled to give 1 cycle/50 nanoseconds. This will make the carrier frequency 20MHz with the deviation being 2.5 MHz or 22.5 MHz and 17.5 MHz as the two signaling frequencies. The signal will be sampled 20 times per unit time (20 times per cycle) for the purposes of avoiding aliasing and making a relatively smooth piecewise approximation. The multipath profile used for the plots contained in this paper are those listed above.

```
Table[N[{(time-3)/(1  10^7),  receivesignal[time]},5],{time,3,23,.05}];

%>>tospice.tmp
```

In order to compare the results of the analysis with and without multipath present another set of data is necessary which is the tranmsitted signal without any distortion term. This data is collected in the following cell.

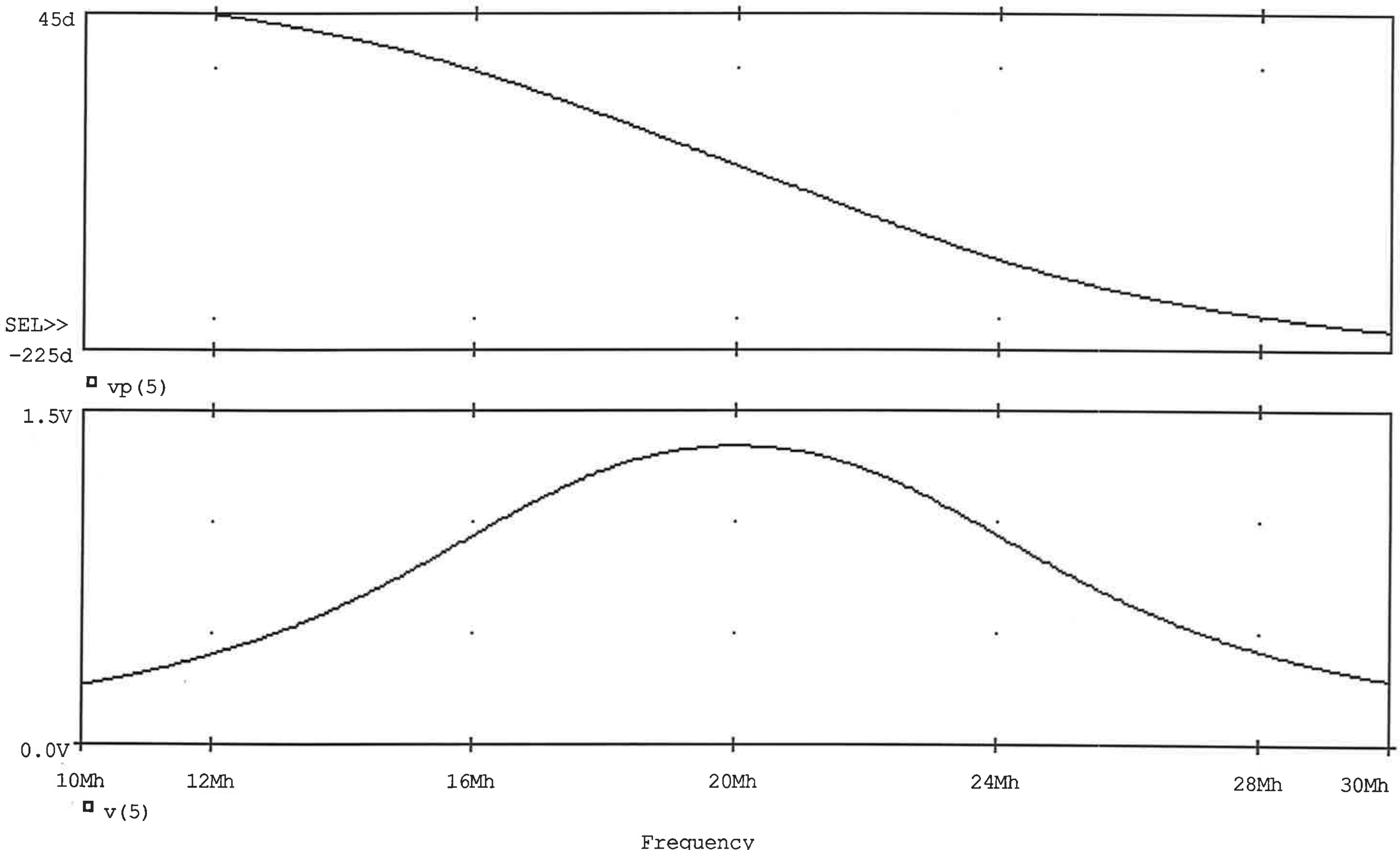
```
Table[N[{(time-3)/(1  10^7),  s[time]},5],{time,3,25,.05}];

%>>tospice1.tmp
```

For anyone who works with the Apple Macintosh MPW system the following commands the conversion between the *Mathematica* output format and the SPICE piecewise linear function format:

```
#This next set of commands changes from Mathematica to SPICE
Find •
replace -c ∞ /([0-9])®1.'*'/ '®1.0*'
Find •
replace -c ∞ /([0-9])®1.([0-9]+)®2'*10^-9,'/ '®1.®2N'
Find •
replace -c ∞ /([0-9])®1.([0-9]+)®2'*10^-7,'/ '.®1®2U'
Find •
replace -c ∞ /([0-9])®1.([0-9]+)®2'*10^-8,'/ '®1®2.N'
Find •
replace -c ∞ /.0«3»([0-9]+)®1,/ '.®1M'
Find •
replace -c ∞ /[,∂{∂}]+/ ' '
Find •
replace -c ∞ /([0-9 MNU.-]+)®1∂n([0-9 MNU.-]+)®2∂n/ '®1 ®2'∂n
Find •
replace -c ∞ /[ ]+/ ' '
Find •
replace -c ∞ /∂n/  ∂n'+'
```

The phase shift network for the quadrature detector is set up to have a center frequency of 20 MHz and is built around a symmetric transformation of a 4MHz Bessel low pass to 20MHz The post quadrature demodulator filter is also a Bessel low pass filter. The diagram on the next page illustrates the characteristics of the quadrature filter. The SPICE codes used for the simulation is as follows:

```
*Evaluation of FSK with Quadrature Detectors
*This voltage source generates the modulated waveform

*This is the signal with multipath

V1 1 0 AC 1 PWL
+0. 0.37532 5.0N 0.64253 10.N 0.60647 15.N 0.36029 20.N 0.0040821 25.N -0.35468
+ 30.N -0.60713 35.N -0.66068 40.N -0.51131 45.N -0.24411 50.N 0.05422 55.N 0.30735
+ 60.N 0.46816 65.N 0.51881 70.N 0.46011 75.N 0.29672 80.N 0.052628 85.N -0.22764
+ 90.N -0.47899 95.N -0.62656 .10U -0.60816 .105U -0.40155 .11U -0.0023215 .115U 0.46777
+ .12U 0.71809 .125U 0.62744 .13U 0.23707 .135U -0.26842 .14U -0.64882 .145U -0.72281
+ .15U -0.45459 .155U 0.028895 .16U 0.50125 .165U 0.73381 .17U 0.61779 .175U 0.2099
+ .18U -0.29654 .185U -0.6616 .19U -0.71288 .195U -0.42737 .20U 0.057954 .205U 0.51185
+ .21U 0.7192 .215U 0.58342 .22U 0.17189 .225U -0.31699 .23U -0.64923 .235U -0.6673
+ .24U -0.36513 .245U 0.10976 .25U 0.52776 .255U 0.68777 .26U 0.51382 .265U 0.091755
+ .27U -0.37101 .275U -0.656 .28U -0.62663 .285U -0.297 .29U 0.17496 .295U 0.56308
+ .30U 0.68137 .305U 0.47316 .31U 0.038221 .315U -0.41504 .32U -0.66941 .325U -0.60302
+ .33U -0.24766 .335U 0.22148 .34U 0.55074 .345U 0.58783 .35U 0.33468 .355U -0.06514
```



QUADRATURE FILTER CHARACTERISTICS

"*Evaluation of FSK with Quadrature Detectors" 03/08/91 14:54:14 27.0°

PROBE 3.08a (Evaluation) from MicroSim Corp.

+ .36U -0.40185 .365U -0.50528 .37U -0.32907 .375U 0.02809 .38U 0.37395 .385U 0.52104
+ .39U 0.38289 .395U 0.020218 .40U -0.38659 .405U -0.62583 .41U -0.57109 .415U -0.32168
+ .42U 0.023082 .425U 0.3624 .43U 0.59643 .435U 0.63976 .44U 0.49068 .445U 0.23141
+ .45U -0.057207 .455U -0.30428 .46U -0.46489 .465U -0.51881 .47U -0.46011 .475U -0.29672
+ .48U -0.052628 .485U 0.22764 .49U 0.47899 .495U 0.62656 .50U 0.60816 .505U 0.40155
+ .51U 0.0023215 .515U -0.46777 .52U -0.71809 .525U -0.62744 .53U -0.23707 .535U 0.26842
+ .54U 0.64882 .545U 0.72281 .55U 0.45459 .555U -0.028895 .56U -0.50125 .565U -0.73381
+ .57U -0.61779 .575U -0.2099 .58U 0.29654 .585U 0.6616 .59U 0.71288 .595U 0.42737
+ .60U -0.057954 .605U -0.51185 .61U -0.7192 .615U -0.58342 .62U -0.17189 .625U 0.31699
+ .63U 0.64923 .635U 0.65141 .64U 0.33424 .645U -0.11108 .65U -0.4587 .655U -0.54272
+ .66U -0.33643 .665U 0.038339 .67U 0.37478 .675U 0.4978 .68U 0.34127 .685U -0.014885
+ .69U -0.38445 .695U -0.56872 .70U -0.45812 .705U -0.09093 .71U 0.31872 .715U 0.57051
+ .72U 0.65562 .725U 0.54826 .73U 0.27901 .735U -0.073685 .74U -0.40622 .745U -0.62018
+ .75U -0.65155 .755U -0.49002 .76U -0.18552 .765U 0.17742 .77U 0.49315 .775U 0.66713
+ .78U 0.64489 .785U 0.42959 .79U 0.082719 .795U -0.29306 .80U -0.58442 .805U -0.70195
+ .81U -0.60826 .815U -0.33026 .82U 0.048367 .825U 0.41273 .83U 0.65215 .835U 0.69432
+ .84U 0.52753 .845U 0.20369 .85U -0.17821 .855U -0.50306 .86U -0.67468 .865U -0.64497
+ .87U -0.42844 .875U -0.085632 .88U 0.28241 .885U 0.56722 .89U 0.68486 .895U 0.60066
+ .90U 0.33943 .905U -0.021834 .91U -0.37666 .915U -0.62048 .92U -0.68143 .925U -0.54155
+ .93U -0.24206 .935U 0.12387 .94U 0.42046 .945U 0.57245 .95U 0.56306 .955U 0.41952
+ .96U 0.1934 .965U -0.059096 .97U -0.28865 .975U -0.45535 .98U -0.52718 .985U -0.48122
+ .99U -0.31126 .995U -0.039106 0.001M 0.27832 0.001005M 0.55458 0.00101M 0.68559 0.001015M 0.51477
+ 0.00102M 0.092273 0.001025M -0.38275 0.00103M -0.68355 0.001035M -0.66414 0.00104M -0.32982 0.001045M 0.1642
+ 0.00105M 0.58568 0.001055M 0.73536 0.00106M 0.53969 0.001065M 0.087821 0.00107M -0.40645 0.001075M -0.70888
+ 0.00108M -0.6763 0.001085M -0.32469 0.00109M 0.17858 0.001095M 0.59463 0.0011M 0.72684 0.001105M 0.51431
+ 0.00111M 0.060261 0.001115M -0.41779 0.00112M -0.69228 0.001125M -0.63415 0.00113M -0.27402 0.001135M 0.21334
+ 0.00114M 0.5934 0.001145M 0.68453 0.00115M 0.44491 0.001155M -0.0079904 0.00116M -0.45447 0.001165M -0.67871
+ 0.00117M -0.57568 0.001175M -0.1968 0.00118M 0.27639 0.001185M 0.61713 0.00119M 0.66216 0.001195M 0.38988
+ 0.0012M -0.069221 0.001205M -0.49515 0.00121M -0.68381 0.001215M -0.5448 0.00122M -0.14472 0.001225M 0.3247
+ 0.00123M 0.63853 0.001235M 0.64639 0.00124M 0.3445 0.001245M -0.12247 0.00125M -0.53075 0.001255M -0.6847
+ 0.00126M -0.51055 0.001265M -0.091755 0.00127M 0.37101 0.001275M 0.656 0.00128M 0.62663 0.001285M 0.297
+ 0.00129M -0.17496 0.001295M -0.56308 0.0013M -0.68137 0.001305M -0.47316 0.00131M -0.038221 0.001315M 0.41504
+ 0.00132M 0.66941 0.001325M 0.60302 0.00133M 0.24766 0.001335M -0.22637 0.00134M -0.59193 0.001345M -0.67384
+ 0.00135M -0.43286 0.001355M 0.015548 0.00136M 0.4565 0.001365M 0.67871 0.00137M 0.57568 0.001375M 0.1968
+ 0.00138M -0.27639 0.001385M -0.61713 0.00139M -0.66216 0.001395M -0.38988 0.0014M 0.069221 0.001405M 0.49515
+ 0.00141M 0.68381 0.001415M 0.5448 0.00142M 0.14472 0.001425M -0.3247 0.00143M -0.63853 0.001435M -0.63049
+ 0.00144M -0.31361 0.001445M 0.12378 0.00145M 0.46169 0.001455M 0.53965 0.00146M 0.33317 0.001465M -0.038339
+ 0.00147M -0.37478 0.001475M -0.4978 0.00148M -0.34127 0.001485M 0.014885 0.00149M 0.38445 0.001495M 0.56872
+ 0.0015M 0.45812 0.001505M 0.09093 0.00151M -0.31872 0.001515M -0.57051 0.00152M -0.65562 0.001525M -0.54826
+ 0.00153M -0.27901 0.001535M 0.073685 0.00154M 0.40622 0.001545M 0.62018 0.00155M 0.65155 0.001555M 0.49002
+ 0.00156M 0.18552 0.001565M -0.17742 0.00157M -0.49315 0.001575M -0.66713 0.00158M -0.64489 0.001585M -0.42959
+ 0.00159M -0.082719 0.001595M 0.29306 0.0016M 0.58442 0.001605M 0.70195 0.00161M 0.60826 0.001615M 0.33026
+ 0.00162M -0.048367 0.001625M -0.4127 0.00163M -0.65215 0.001635M -0.67843 0.00164M -0.49663 0.001645M -0.20238
+ 0.00165M 0.10915 0.001655M 0.358 0.00166M 0.49729 0.001665M 0.51488 0.00167M 0.42467 0.001675M 0.24383
+ 0.00168M 0.0029572 0.001685M -0.25534 0.00169M -0.47537 0.001695M -0.59501 0.0017M -0.56269 0.001705M -0.3604
+ 0.00171M 0.019719 0.001715M 0.46501 0.00172M 0.69523 0.001725M 0.59631 0.00173M 0.21071 0.001735M -0.28145
+ 0.00174M -0.64735 0.001745M -0.71212 0.00175M -0.44254 0.001755M 0.036453 0.00176M 0.50328 0.001765M 0.73381
+ 0.00177M 0.61779 0.001775M 0.2099 0.00178M -0.29654 0.001785M -0.6616 0.00179M -0.71288 0.001795M -0.42737
+ 0.0018M 0.057954 0.001805M 0.51185 0.00181M 0.7192 0.001815M 0.58342 0.00182M 0.17189 0.001825M -0.31699
+ 0.00183M -0.64923 0.001835M -0.65141 0.00184M -0.33424 0.001845M 0.11108 0.00185M 0.4587 0.001855M 0.54272
+ 0.00186M 0.33643 0.001865M -0.038339 0.00187M -0.37478 0.001875M -0.4978 0.00188M -0.34127 0.001885M 0.014885
+ 0.00189M 0.38445 0.001895M 0.56872 0.0019M 0.45812 0.001905M 0.09093 0.00191M -0.31872 0.001915M -0.57051

+ 0.00192M -0.65562 0.001925M -0.54826 0.00193M -0.27901 0.001935M 0.068788 0.00194M 0.36504 0.001945M 0.53417
+ 0.00195M 0.55337 0.001955M 0.44042 0.00196M 0.24018 0.001965M -0.0039923 0.00197M -0.24654 0.001975M -0.44224
+ 0.00198M -0.54733 0.001985M -0.52568 0.00199M -0.36198 0.001995M -0.076597

*This is the signal with no multipath

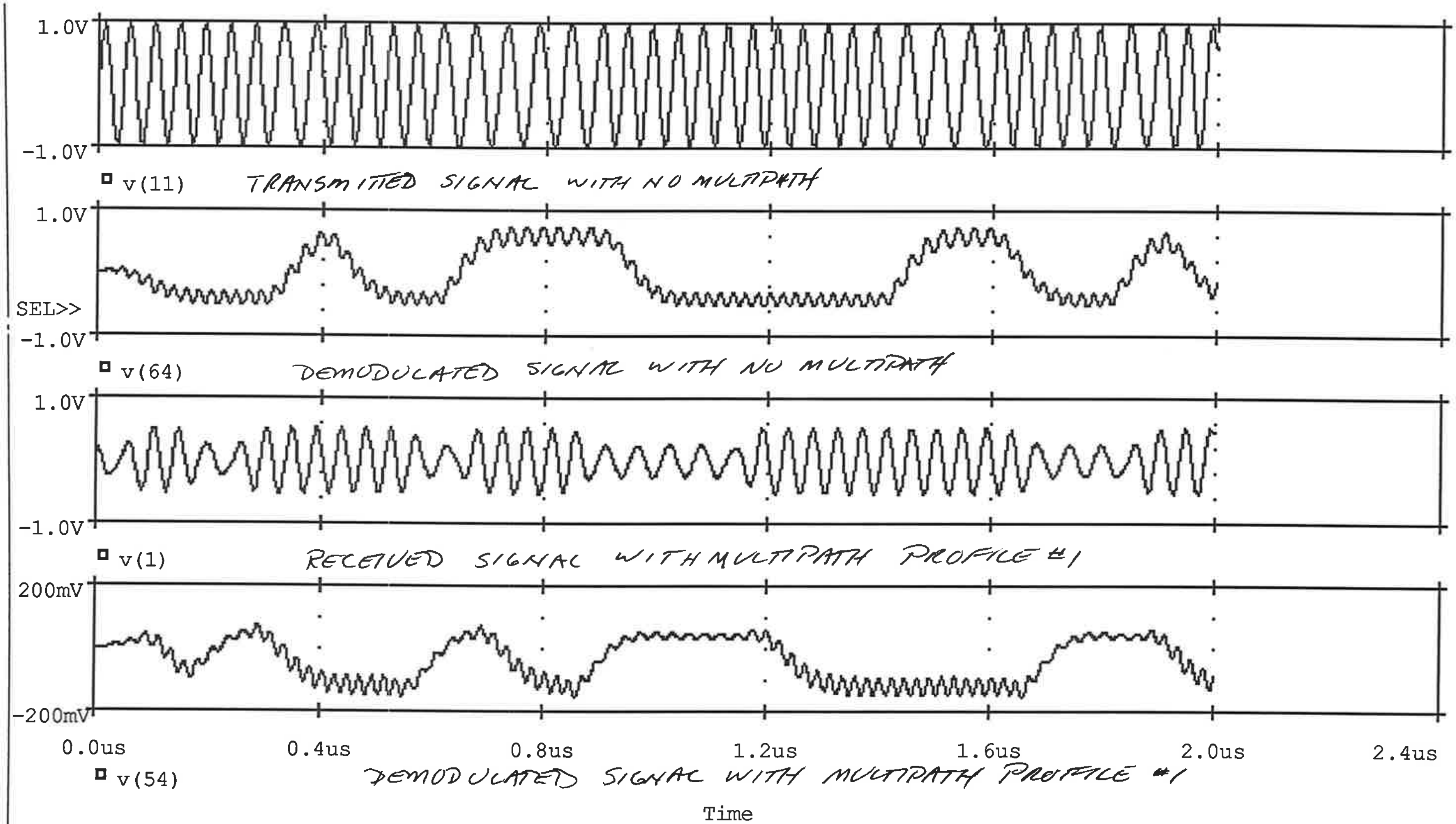
V2 11 0 AC 1 PWL
+0. 0. 5.0N 0.64945 10.N 0.98769 15.N 0.85264 20.N 0.30902 25.N -0.38268
+30.N -0.89101 35.N -0.97237 40.N -0.58779 45.N 0.078459 50.N 0.70711
+55.N 0.99692 60.N 0.80902 65.N 0.23345 70.N -0.45399 75.N -0.92388
+80.N -0.95106 85.N -0.5225 90.N 0.15643 95.N 0.76041 .10U 1.
+.105U 0.76041 .11U 0.15643 .115U -0.5225 .12U -0.95106 .125U -0.92388
+.13U -0.45399 .135U 0.23345 .14U 0.80902 .145U 0.99692 .15U 0.70711
+.155U 0.078459 .16U -0.58779 .165U -0.97237 .17U -0.89101 .175U -0.38268
+.18U 0.30902 .185U 0.85264 .19U 0.98769 .195U 0.64945 .20U 0 .205U -0.64945
+.21U -0.98769 .215U -0.85264 .22U -0.30902 .225U 0.38268 .23U 0.89101
+.235U 0.97237 .24U 0.58779 .245U -0.078459 .25U -0.70711 .255U -0.99692
+.26U -0.80902 .265U -0.23345 .27U 0.45399 .275U 0.92388 .28U 0.95106
+.285U 0.5225 .29U -0.15643 .295U -0.76041 .30U -1. .305U -0.85264
+.31U -0.45399 .315U 0.078459 .32U 0.58779 .325U 0.92388 .33U 0.98769
+.335U 0.76041 .34U 0.30902 .345U -0.23345 .35U -0.70711 .355U -0.97237
+.36U -0.95106 .365U -0.64945 .37U -0.15643 .375U 0.38268 .38U 0.80902
+.385U 0.99692 .39U 0.89101 .395U 0.5225 .40U 0 .405U -0.64945 .41U -0.98769
+.415U -0.85264 .42U -0.30902 .425U 0.38268 .43U 0.89101 .435U 0.97237
+.44U 0.58779 .445U -0.078459 .45U -0.70711 .455U -0.99692 .46U -0.80902
+.465U -0.23345 .47U 0.45399 .475U 0.92388 .48U 0.95106 .485U 0.5225
+.49U -0.15643 .495U -0.76041 .50U -1. .505U -0.76041 .51U -0.15643
+.515U 0.5225 .52U 0.95106 .525U 0.92388 .53U 0.45399 .535U -0.23345
+.54U -0.80902 .545U -0.99692 .55U -0.70711 .555U -0.078459 .56U 0.58779
+.565U 0.97237 .57U 0.89101 .575U 0.38268 .58U -0.30902 .585U -0.85264
+.59U -0.98769 .595U -0.64945 .60U 0 .605U 0.5225 .61U 0.89101 .615U 0.99692
+.62U 0.80902 .625U 0.38268 .63U -0.15643 .635U -0.64945 .64U -0.95106
+.645U -0.97237 .65U -0.70711 .655U -0.23345 .66U 0.30902 .665U 0.76041
+.67U 0.98769 .675U 0.92388 .68U 0.58779 .685U 0.078459 .69U -0.45399
+.695U -0.85264 .70U -1. .705U -0.85264 .71U -0.45399 .715U 0.078459
+.72U 0.58779 .725U 0.92388 .73U 0.98769 .735U 0.76041 .74U 0.30902
+.745U -0.23345 .75U -0.70711 .755U -0.97237 .76U -0.95106 .765U -0.64945
+.77U -0.15643 .775U 0.38268 .78U 0.80902 .785U 0.99692 .79U 0.89101
+.795U 0.5225 .80U 0 .805U -0.5225 .81U -0.89101 .815U -0.99692 .82U -0.80902
+.825U -0.38268 .83U 0.15643 .835U 0.64945 .84U 0.95106 .845U 0.97237
+.85U 0.70711 .855U 0.23345 .86U -0.30902 .865U -0.76041 .87U -0.98769
+.875U -0.92388 .88U -0.58779 .885U -0.078459 .89U 0.45399 .895U 0.85264
+.90U 1. .905U 0.76041 .91U 0.15643 .915U -0.5225 .92U -0.95106
+.925U -0.92388 .93U -0.45399 .935U 0.23345 .94U 0.80902 .945U 0.99692
+.95U 0.70711 .955U 0.078459 .96U -0.58779 .965U -0.97237 .97U -0.89101
+.975U -0.38268 .98U 0.30902 .985U 0.85264 .99U 0.98769 .995U 0.64945
+0.001M 0 0.001005M -0.64945 0.00101M -0.98769 0.001015M -0.85264
+0.00102M -0.30902 0.001025M 0.38268 0.00103M 0.89101 0.001035M 0.97237
+0.00104M 0.58779 0.001045M -0.078459 0.00105M -0.70711 0.001055M -0.99692
+0.00106M -0.80902 0.001065M -0.23345 0.00107M 0.45399 0.001075M 0.92388
+0.00108M 0.95106 0.001085M 0.5225 0.00109M -0.15643 0.001095M -0.76041
+0.0011M -1. 0.001105M -0.76041 0.00111M -0.15643 0.001115M 0.5225

+0.00112M 0.95106 0.001125M 0.92388 0.00113M 0.45399 0.001135M -0.23345
+0.00114M -0.80902 0.001145M -0.99692 0.00115M -0.70711 0.001155M -0.078459
+0.00116M 0.58779 0.001165M 0.97237 0.00117M 0.89101 0.001175M 0.38268
+0.00118M -0.30902 0.001185M -0.85264 0.00119M -0.98769 0.001195M -0.64945
+0.0012M 0 0.001205M 0.64945 0.00121M 0.98769 0.001215M 0.85264
+0.00122M 0.30902 0.001225M -0.38268 0.00123M -0.89101 0.001235M -0.97237
+0.00124M -0.58779 0.001245M 0.078459 0.00125M 0.70711 0.001255M 0.99692
+0.00126M 0.80902 0.001265M 0.23345 0.00127M -0.45399 0.001275M -0.92388
+0.00128M -0.95106 0.001285M -0.5225 0.00129M 0.15643 0.001295M 0.76041
+0.0013M 1. 0.001305M 0.76041 0.00131M 0.15643 0.001315M -0.5225
+0.00132M -0.95106 0.001325M -0.92388 0.00133M -0.45399 0.001335M 0.23345
+0.00134M 0.80902 0.001345M 0.99692 0.00135M 0.70711 0.001355M 0.078459
+0.00136M -0.58779 0.001365M -0.97237 0.00137M -0.89101 0.001375M -0.38268
+0.00138M 0.30902 0.001385M 0.85264 0.00139M 0.98769 0.001395M 0.64945
+0.0014M 0 0.001405M -0.5225 0.00141M -0.89101 0.001415M -0.99692
+0.00142M -0.80902 0.001425M -0.38268 0.00143M 0.15643 0.001435M 0.64945
+0.00144M 0.95106 0.001445M 0.97237 0.00145M 0.70711 0.001455M 0.23345
+0.00146M -0.30902 0.001465M -0.76041 0.00147M -0.98769 0.001475M -0.92388
+0.00148M -0.58779 0.001485M -0.078459 0.00149M 0.45399 0.001495M 0.85264
+0.0015M 1. 0.001505M 0.85264 0.00151M 0.45399 0.001515M -0.078459
+0.00152M -0.58779 0.001525M -0.92388 0.00153M -0.98769 0.001535M -0.76041
+0.00154M -0.30902 0.001545M 0.23345 0.00155M 0.70711 0.001555M 0.97237
+0.00156M 0.95106 0.001565M 0.64945 0.00157M 0.15643 0.001575M -0.38268
+0.00158M -0.80902 0.001585M -0.99692 0.00159M -0.89101 0.001595M -0.5225
+0.0016M 0 0.001605M 0.64945 0.00161M 0.98769 0.001615M 0.85264
+0.00162M 0.30902 0.001625M -0.38268 0.00163M -0.89101 0.001635M -0.97237
+0.00164M -0.58779 0.001645M 0.078459 0.00165M 0.70711 0.001655M 0.99692
+0.00166M 0.80902 0.001665M 0.23345 0.00167M -0.45399 0.001675M -0.92388
+0.00168M -0.95106 0.001685M -0.5225 0.00169M 0.15643 0.001695M 0.76041
+0.0017M 1. 0.001705M 0.76041 0.00171M 0.15643 0.001715M -0.5225
+0.00172M -0.95106 0.001725M -0.92388 0.00173M -0.45399 0.001735M 0.23345
+0.00174M 0.80902 0.001745M 0.99692 0.00175M 0.70711 0.001755M 0.078459
+0.00176M -0.58779 0.001765M -0.97237 0.00177M -0.89101 0.001775M -0.38268
+0.00178M 0.30902 0.001785M 0.85264 0.00179M 0.98769 0.001795M 0.64945
+0.0018M 0 0.001805M -0.5225 0.00181M -0.89101 0.001815M -0.99692
+0.00182M -0.80902 0.001825M -0.38268 0.00183M 0.15643 0.001835M 0.64945
+0.00184M 0.95106 0.001845M 0.97237 0.00185M 0.70711 0.001855M 0.23345
+0.00186M -0.30902 0.001865M -0.76041 0.00187M -0.98769 0.001875M -0.92388
+0.00188M -0.58779 0.001885M -0.078459 0.00189M 0.45399 0.001895M 0.85264
+0.0019M 1. 0.001905M 0.76041 0.00191M 0.15643 0.001915M -0.5225
+0.00192M -0.95106 0.001925M -0.92388 0.00193M -0.45399 0.001935M 0.23345
+0.00194M 0.80902 0.001945M 0.99692 0.00195M 0.70711 0.001955M 0.078459
+0.00196M -0.58779 0.001965M -0.97237 0.00197M -0.89101 0.001975M -0.38268
+0.00198M 0.30902 0.001985M 0.85264 0.00199M 0.98769 0.001995M 0.64945

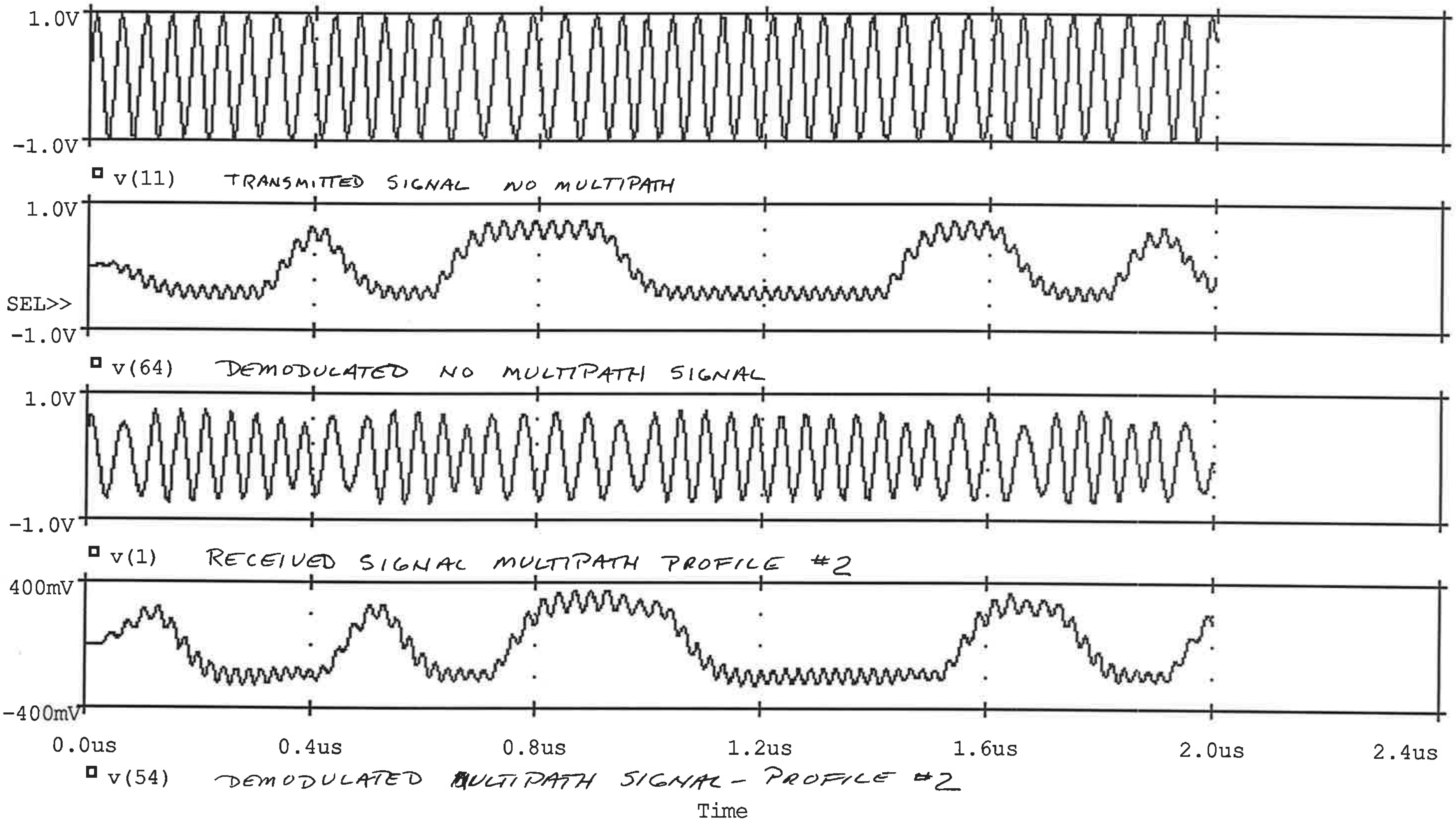
*THIS PROVIDES THE QUADRATURE FILTER FOR THE MULTIPATHED SIGNAL

RM1 1 2 183.917
LM1 2 0 .47995U
CM2 2 0 100P
RM2 2 0 10K
EM1 3 0 POLY(1) 2 0 0 1

```
RMX1 3 0 10MEG
LM2 3 4 .781624U
CM3 4 0 100P
RM3 4 0 180.595
EM2 5 0 POLY(1) 4 0  0 1
RMX2 5 0 10MEG

*THIS PROVIDES THE QUADRATURE FILTER FOR THE CLEAN SIGNAL

RC1 11 12 183.917
LC1 12 0 .47995U
CC2 12 0 100P
RC2 12 0 10K
EC1 13 0 POLY(1) 12 0  0 1
RCX1 13 0 10MEG
LC2 13 14 .781624U
CC3 14 0 100P
RC3 14 0 180.595
EC2 15 0 POLY(1) 14 0  0 1
RCX2 15 0 10MEG

*THIS SECTION DEMODULATES THE SIGNAL BY MULTIPLYING THE INCOMING SIGNAL
*BY THE QUADRATURE SIGNAL AND APPLYING A BESSEL LOW PASS FILTER

EMN 6 0 POLY(2) 1 0 5 0  0 0 0  0 1

RLM1S1 6 51 10K
RLM2S1 51 52 1OK
RLMS1A 54 53 RSCALE8 10K
RLMS1B 53 0 10K
CLM1S1 54 51 3.123P
CLM2S1 52 0 3.123P
ELMS1 54 0 POLY(2) 52 0 53 0  0  100000 -100000
.MODEL RSCALE8 RES(R=.268)

ECN 16 0 POLY(2) 11 0 15 0  0 0 0  0 1

RLC1S1 16 61 10K
RLC2S1 61 62 1OK
RLCS1A 64 63 RSCALE8 10K
RLCS1B 63 0 10K
CLC1S1 64 61 3.123P
CLC2S1 62 0 3.123P
ELCS1 64 0 POLY(2) 62 0 63 0  0  100000 -100000

.PROBE
.OPTION ITL5=0
.AC LIN 400 10MEG 30MEG
.TRAN 200N 2U
.END
```



"*Evaluation of FSK with Quadrature Detectors" 03/09/91 12:01:29 27.0°
PROBE 3.08a (Evaluation) from MicroSim Corp.



"*Evaluation of FSK with Quadrature Detectors" 03/09/91 11:09:40 27.0°
PROBE 3.08a (Evaluation) from MicroSim Corp.

The attached diagram illustrating the waveforms of the demodulated no-multipath signal (node 64) and the demodulated multipathed signal (node 54) as weel as the raw received signal in each case illustrate the impact of multipath on signals of this type demodulated by a quadrature demodultor. A preliminary view of these diagrams seems to indicate that the net result of multipath distortion on a system of this type are a reduction in the peak to peak amplitude of the demodulated signal as well as a DC shift of the demodulated signal.

In actual systems using this technique a limiter is typically employed prior to impressing the received signal onto the quadrature filter and the demodulator mixer. If this analysis was being done in an effort to determine suitability of this technique for standardization this limiter would need to be included in the simulation.

Another interesting analysis which would be performed if this analysis was to be applied to an actual candidate technique would be to continue the simulation for two complete m-sequence periods and to correlate the results. The resulting system impulse response would provide valuable insight into the suitablity of the technique as well as a sanity check on the accuracy of the evaluation.

Summary and Conclusions

The purpose of this submittal has been to provide a template for first cut evaluation of any air interface modulation scheme which might be proposed for adoption. If the scheme can survive this type of analysis its prospects for serving the needs of the standard are reasonably good. If the scheme can not survive even this level of scrutiny it should not be considered for adoption.

As indicated above this basic analysis should be enhanced when being applied to actual candidates for standardization. In addition to the addition of the post demodulation correlation step described above, another possible candidate for addition would be impulse noise and narrowband disturbances. Each of these impediments to communications can be added to the basic model described above final picture of the impact of various types of disturbers on a given modulation/demodulation candidate can be obtained.

Care has been taken in the preparation of this document to assure that the simulated results accurately depict reality. Of course, if anyone can see a hole in the technique illustrated or detects some abnormality in the presented results we would certainly be interested in finding out about these problem areas. Also, if someone has a specific multipath profile ("the multipath profile from hell") which they would like to see added to the evaluation this type of input is welcomed.

Appendix

This appendix contains a number of function definitions which are required used in the body of the text. Since these definitions are unrelated to the topic under discussion they have been relegated to an appendix. Items in this appendix are flagged as initialization cells in order to assure that they have been defined prior to there use in the body of the document.

```
gencode[length_,invocation_,phase_,name_]:=
(taps={{1,0},{0,1,0},{0,0,1,0},
 {{0,0,1,0,0},{1,1,1,0,0},{1,0,1,1,0}},
 {{0,0,0,0,1,0},{1,0,0,1,1,0},{1,0,1,1,0,0}},
 {{0,0,0,0,0,1,0},{0,0,0,1,0,0,0},{0,0,0,1,1,1,0},
 {0,0,1,1,1,0,0},{1,1,0,0,1,0,0},{1,0,1,0,0,1,0},
 {1,1,0,0,1,0,0},{1,1,1,0,1,1,0},{0,1,1,1,1,1,0}},
 {{0,0,0,1,1,1,0,0},{0,1,1,0,1,0,0,0},{0,1,1,0,0,1,0,0},
 {0,0,1,0,1,0,1,0},{0,1,1,0,0,0,1,0},{1,1,0,0,0,0,1,0},
 {1,1,1,0,0,1,1,0},{0,1,0,1,1,1,1,0}}};
name=Table[t,{t,1,2^length-1}];
uphase=phase;
state=Table[p=Floor[uphase/(2^(length+1-k))];
  uphase=uphase-Floor[uphase/(2^(length+1-k))]*(2^(length+1-k));
  p,{k,2,length+1}];
Do[If[state[[-1]]==1,state=Mod[state+taps[[length-1]][[invocation]],2];
   state=RotateRight[state,1],state=RotateRight[state,1]];
   name[[i]]=(2  state[[-1]]-1),{i,1,2^length-1}];
name)
```

```
window[t_]:=Floor[t/bitperiod]+1
```