Appendix A

Geometries of the Example Quad-Ridged Horns

Ridge Profile		Horn Profile	
x	y	x	y
122.81	12.18	122.81	0
122.81	0	122.81	29.18
27.71	0	125.43	211.29
27.71	12.18	132.37	393.39
2.9	12.18	143.92	575.5
2.9	29.18	160.25	757.6
5.27	194.02	180.71	939.71
11.69	358.86	205.83	1121.81
22.14	523.69	235.04	1303.92
36.57	688.53	268.09	1486.02
55.56	853.36	305.37	1668.13
78.38	1018.2	346.01	1850.23
104.92	1183.04	390.13	2032.34
135.08	1347.87	437.48	2214.44
169.28	1512.71	487.5	2396.55
206.8	1677.55	540.37	2578.65
247.46	1842.38	595.42	2760.76
291.11	2007.22	652.41	2942.86
328.26	2139.09	711.17	3124.97
367.15	2270.96	771.16	3307.07
407.67	2402.83	832.18	3489.17
449.68	2534.69	893.83	3671.28
493.07	2666.56	951.33	3853.38
537.7	2798.43	967.97	3894.83
583.45	2930.3	990.97	3931.99
630.16	3062.17	1019.18	3963.01
677.72	3194.04	1051.17	3986.32
725.96	3325.91	1085.35	4000.76
774.76	3457.78	1120	4005.6
823.96	3589.65	1153.38	4000.61
873.41	3721.52		
918.08	3853.38		
951.33	3853.38		
893.83	3671.28		
832.18	3489.17		
771.16	3307.07		
711.17	3124.97		
652.41	2942.86		
595.42	2760.76		
540.37	2578.65		
487.5	2396.55		
437.48	2214.44		
390.13	2032.34		
346.01	1850.23		
305.37	1668.13		
268.09	1486.02		
235.04	1303.92		
205.83	1121.81		
180.71	939.71		
160.25	757.6		
143.92	575.5		
132.37	393.39		
125.43	211.29		
122.81	29.18		
122.81	12.18		

Table A.1: $x - y$ coordinates of the ridge and horn profiles of the very high gain QRFH for $f_{lo} = 0.5$ GHz. Dimensions are in millimeters.

Ridge Profile		Horn Profile	
x	y	x	y
77.22	7.71	77.22	0.00
77.22	0.00	77.22	18.41
16.79	0.00	77.65	65.63
16.79	7.71	79.52	112.85
2.71	7.71	83.32	160.07
2.71	18.41	89.39	207.28
2.94	42.02	98.02	254.50
3.73	65.63	109.44	301.72
5.16	89.24	123.86	348.93
7.25	112.85	141.48	396.15
10.05	136.46	162.48	443.37
13.58	160.07	187.00	490.59
17.85	183.67	215.22	537.80
22.88	207.28	247.27	585.02
28.69	230.89	283.29	632.24
35.30	254.50	323.40	679.45
42.71	278.11	345.03	703.06
50.94	301.72	355.00	712.71
60.00	325.33	365.70	720.75
69.90	348.93	376.59	726.78
80.64	372.54	387.12	730.50
92.24	396.15	396.77	731.71
104.71	419.76	405.05	730.37
118.04	443.37	411.55	726.53
132.26	466.98		
147.37	490.59		
163.36	514.19		
180.26	537.80		
198.07	561.41		
216.79	585.02		
236.43	608.63		
256.99	632.24		
278.49	655.85		
300.92	679.45		
324.28	703.06		
336.14	703.06		
345.03	703.06		
323.40	679.45		
283.29	632.24		
247.27	585.02		
215.22	537.80		
187.00	490.59		
162.48	443.37		
141.48	396.15		
123.86	348.93		
109.44	301.72		
98.02	254.50		
89.39	207.28		
83.32	160.07		
79.52	112.85		
77.65	65.63		
77.22	18.41		
77.22	7.71		

Table A.2: $x - y$ coordinates of the ridge and horn profiles of the high-gain QRFH for $f_{lo} = 0.7$ GHz. Dimensions are in millimeters.

Ridge Profile		Horn Profile	
x	y	x	y
28.05	7.04	28.05	0.00
28.05	0.00	28.05	11.50
11.37	0.00	28.61	21.97
11.37	7.04	29.32	32.44
0.65	7.04	30.21	42.91
0.65	11.50	31.32	53.38
1.06	16.74	32.73	63.85
1.51	21.97	34.50	74.32
2.02	27.21	36.72	84.79
2.59	32.44	39.52	95.26
3.22	37.68	43.04	105.73
3.93	42.91	47.46	116.20
4.72	48.15	53.03	126.67
5.61	53.38	60.02	137.14
6.59	58.62	68.82	147.60
7.70	63.85	79.89	158.07
8.94	69.09	86.45	163.31
10.32	74.32	88.10	164.34
11.86	79.55	89.94	164.99
13.59	84.79	91.88	165.21
15.51	90.02	93.81	164.99
17.67	95.26	95.65	164.35
20.08	100.49	97.30	163.31
22.77	105.73	98.68	161.93
25.78	110.96		
29.14	116.20		
32.90	121.43		
37.10	126.67		
41.80	131.90		
47.05	137.14		
52.92	142.37		
59.47	147.60		
66.80	152.84		
74.99	158.07		
84.15	163.31		
86.45	163.31		
79.89	158.07		
68.82	147.60		
60.02	137.14		
53.03	126.67		
47.46	116.20		
43.04	105.73		
39.52	95.26		
36.72	84.79		
34.50	74.32		
32.73	63.85		
31.32	53.38		
30.21	42.91		
29.32	32.44		
28.61	21.97		
28.05	11.50		
28.05	7.04		

Table A.3: $x - y$ coordinates of the ridge and horn profiles of the medium-gain QRFH for $f_{lo} = 2$ GHz. Dimensions are in millimeters.

Ridge Profile		Horn Profile	
x	y	x	y
17.84	4.75	17.84	0.00
17.84	0.00	17.84	7.89
6.93	0.00	17.84	13.61
6.93	4.75	17.86	19.33
0.53	4.75	17.93	25.05
0.53	7.89	18.09	30.77
1.03	16.91	18.35	36.49
1.53	25.93	18.79	42.21
2.03	34.95	19.42	47.93
2.53	43.97	20.27	53.65
3.04	53.00	21.45	59.37
3.66	62.02	22.94	65.09
4.69	71.04	24.82	70.81
5.54	75.25	27.15	76.53
6.82	79.46	29.93	82.25
8.68	83.67	33.31	87.97
11.30	87.88	37.26	93.69
14.82	92.09	41.84	99.41
19.31	96.30	47.18	105.13
24.74	100.51	53.24	110.85
30.93	104.72	60.17	116.57
37.55	108.93	67.99	122.29
44.12	113.14	76.68	128.01
50.11	117.35	80.91	130.41
54.95	121.56	85.23	132.23
58.17	125.77	89.42	133.38
64.59	131.63	93.26	133.80
72.64	134.89	96.57	133.46
81.33	135.14	99.18	132.40
87.82	132.94	100.95	130.65
85.23	132.23		
80.91	130.41		
76.68	128.01		
67.99	122.29		
60.17	116.57		
53.24	110.85		
47.18	105.13		
41.84	99.41		
37.26	93.69		
33.31	87.97		
29.93	82.25		
27.15	76.53		
24.82	70.81		
22.94	65.09		
21.45	59.37		
20.27	53.65		
19.42	47.93		
18.79	42.21		
18.35	36.49		
18.09	30.77		
17.93	25.05		
17.86	19.33		
17.84	13.61		
17.84	7.89		
17.84	4.75		

Table A.4: $x - y$ coordinates of the ridge and horn profiles of the low-gain QRFH for $f_{lo} = 2.3$ GHz. Dimensions are in millimeters.

Ridge Profile		Horn Profile	
x	y	x	y
16.67	4.86	16.67	0.00
16.67	0.00	16.67	7.61
6.51	0.00	16.69	14.86
6.51	4.86	16.73	22.11
0.58	4.86	16.78	29.35
0.58	7.61	16.88	36.60
0.74	11.11	17.04	43.85
0.90	14.61	17.30	51.09
1.06	18.11	17.74	58.34
1.22	21.61	18.46	65.59
1.38	25.11	19.65	72.83
1.54	28.60	21.62	80.08
1.70	32.10	24.88	87.33
1.86	35.60	30.27	94.57
2.02	39.10	39.19	101.82
2.18	42.60	53.97	109.06
2.34	46.10	64.66	112.69
2.50	49.59	67.15	113.36
2.66	53.09	69.63	113.69
2.83	56.59	71.96	113.66
3.00	60.09	74.03	113.27
3.20	63.59	75.73	112.54
3.42	67.09	76.99	111.51
3.69	70.58	77.73	110.23
4.06	74.08		
4.57	77.58		
5.33	81.08		
6.48	84.58		
8.23	88.07		
10.89	91.57		
14.94	95.07		
21.00	98.57		
30.01	102.07		
43.21	105.57		
47.92	106.43		
45.65	105.44		
34.17	98.19		
27.23	90.95		
23.04	83.70		
20.51	76.46		
18.98	69.21		
18.05	61.96		
17.49	54.72		
17.15	47.47		
16.95	40.22		
16.83	32.98		
16.75	25.73		
16.71	18.48		
16.68	11.24		
16.67	4.86		

Table A.5: $x - y$ coordinates of the ridge and horn profiles of the very low gain QRFH for $f_{lo} = 2.3$ GHz. Dimensions are in millimeters.

Appendix B

Sample MATLAB Codes for QRFH Design

```
% prepCST.m
% Main interface to write QRFH geometry defined in MATLAB to CST
%
% The inputs are the geometric parameters listed in "Prmtrs" variable
% The program then generates the ridge & horn profiles using four
% custom functions: genProfile.m, genRidgeProfile.m, genHornProfile.m, and
% mergeProfiles_new.m
%
% If the user elects to upload geometry to CST by setting "writeCST" equal
% to one, the program writes the parameters to CST as well as to a text
% file.
%
% If the user elects to run the EM simulation by setting "doSave" equal
% to one, the program runs the simulation engine and once complete:
% 1) downloads the S-parameters and far-fields to MATLAB; 2) writes the
% results to disk using the functions: CST_saveFF.m and CST_saveSpar.m;
% 3) plots the results for user evaluation using the function plotCSTRun.m

clear

prj_path = 'D:\CST';
prj_fname = 'qrfh.cst';

% PARAMETER SETUP %
p_name = {
    'rpInd'         , 'hpInd'           ,...
    'rp_ai'         , 'hp_ai'           ,...
    'rp_ao'         , 'hp_ao'           ,...
    'rp_L'          , 'hp_L'            ,...
```

```
    'rp_R'          , 'hp_R'            ,...
    'rp_p'          , 'hp_p'            ,...
    'rp_A'          , 'hp_A'            ,...
    'rp_g'          , 'hp_g'            ,...
    'alpha'         , 'curv_rad'        ,...
    'fin_depth'     , 'fin_thick'       ,...
    'fin_width'     , 'gap_w'           ,...
    'leg_width'     , 'fin_angle'       ,...
    'p1_h'          , 'p2_h'            ,...
    'tip_w'         , 'trans_L'         ,...
    'max_fin_t'     , 'aper_ang'        ,...
    'aper_Rx'       , 'aper_Rz'         ,...
    'donut_Ri'      , 'donut_L'         ,...
    'donut_offset'  , 'scaleFctr'       };

halfAng = 50; % Half-subtended angle

Prmtrs = [
    9               ; 9                 ;...
    NaN             ; NaN               ;...
    83.5            ; 85.8              ;...
    151.8           ; 151.8             ;...
    21.255e-3       ; 21.898e-3         ;...
    1               ; 1                 ;...
    1               ; 1                 ;...
    1               ; 1                 ;...
    45              ; -25               ;...
    7.04            ; NaN               ;...
    10.72           ; 1.3               ;...
    16.68           ; 0                 ;...
    0.914           ; 1                 ;...
    0.514           ; 4.466             ;...
    3               ; 0                 ;...
    8.7             ; 8.7               ;...
    0.7             ; 2                 ;...
    0               ; 1                 ];

writeCST = 0;
doSave = 1;

%% PERFORM SCALING PER THE VALUE OF "scaleFctr"
Prmtrs(3) = 0;
Prmtrs(4) = Prmtrs(21) + Prmtrs(23);
Prmtrs(20) = Prmtrs(29);

```

```
scaleFctr = Prmtrs(36);
Prmtrs([3:8, 18:23, 25:29, 31:32, 34:35]) = ...
    Prmtrs([3:8, 18:23, 25:29, 31:32, 34:35]) / scaleFctr;
Prmtrs([9:10]) = Prmtrs([9:10]) * scaleFctr;

%% GENERATE PROFILES
ridgePrf = genProfile(Prmtrs(1), Prmtrs(3:2:15), 0);
ridgePrf = genRidgeProfile(ridgePrf, Prmtrs(28), Prmtrs(19), ...
    Prmtrs(21), Prmtrs(23), Prmtrs(18));

hornPrf = genProfile(Prmtrs(2), Prmtrs(4:2:16), 0);
hornPrf = genHornProfile(hornPrf, Prmtrs(31), Prmtrs(32), ...
    Prmtrs(28), Prmtrs(19), Prmtrs(4));

[prf, hornPrf] = mergeProfiles_new(ridgePrf, hornPrf);

if isempty(prf)
    error('Horn and fin do not intersect!');
end

%% SOME MISC STUFF
p_name = [p_name, 'xmax', 'ymax', 'zmax'];
Prmtrs = [Prmtrs; ...
          max(hornPrf(:,1)); max(hornPrf(:,1)); max(hornPrf(:,2))];
Prmtrs(Prmtrs == 0) = 1e-3;

%% ARE WE WRITING GEOM TO CST?
if writeCST

    time = datestr(now,30); time(end-1:end) = [] %%% TIME STAMP
    fid = fopen([prj_path '\' prj_fname(1:end-4), ...
        '_Parameters_' time '.txt'],'wt');
    prf_fname = [prj_path '\' prj_fname(1:end-4) '_' time];

    cst = actxserver('CSTSTUDIO.application');
    mws = invoke(cst, 'OpenFile',[prj_path '\' prj_fname]);
    solver = invoke(mws,'Solver');

    %%% WRITE GEOM PARAMETERS TO CST AND TXT FILE %%%
    rx_lbl = strtrim( cellstr( [num2str([1:length(prf)]')] ) );
    rx_lbl = cellfun(@(x) ['rx',x], rx_lbl, 'UniformOutput',false);
    ry_lbl = strtrim( cellstr( [num2str([1:length(prf)]')] ) );
    ry_lbl = cellfun(@(x) ['ry',x], ry_lbl, 'UniformOutput',false);

    hx_lbl = strtrim( cellstr( [num2str([1:length(hornPrf)]')] ) );
```

```
    hx_lbl = cellfun(@(x) ['hx',x], hx_lbl, 'UniformOutput',false);
    hy_lbl = strtrim( cellstr( [num2str([1:length(prf)]')] ) );
    hy_lbl = cellfun(@(x) ['hy',x], hy_lbl, 'UniformOutput',false);

    CST_writePar( mws, p_name, Prmtrs, fid);
    CST_writePar( mws, rx_lbl, prf(:,1), fid);
    CST_writePar( mws, ry_lbl, prf(:,2), fid);
    CST_writePar( mws, hx_lbl, hornPrf(:,1), fid);
    CST_writePar( mws, hy_lbl, hornPrf(:,2), fid);

    invoke( mws, 'RebuildForParametricChange' );
    fclose(fid);

    invoke(solver, 'HardwareAcceleration','True');

    %%% RUN SOLVER %%%
    if doSave
        solvOut = invoke(solver, 'Start');
        fname_SPar = [prj_path '\' prj_fname(1:end-4) '_' time];
        CST_saveFF(mws, [1 15], prj_path, prj_fname, time);
        CST_saveSPar(mws, fname_SPar);

        plotCSTRun(prj_path, prj_fname(1:end-4), time, halfAng);
        invoke( mws, 'Save');
        invoke( mws, 'Quit');
    end
end
```

```
function prf = genProfile(prfInd, in)

if prfInd <1 || prfInd > 13
    error('Profile index must be an integer between 1-12');
end

ai = in(1);      % radius at bottom
ao = in(2);      % radius at aperture
L = in(3);       % taper length

R = in(4);

p = in(5);       % power p
A = in(6);       % A
g = in(7);       % Gamma

len = 30;

z = linspace(0,L,len)';

% Linear
all(:,1) = ai + (ao - ai) * z/L;


% Sinusoid
all(:,2) = ai + (ao-ai)*( (1-A).*z/L + A.*sin(pi/2*z/L).^p );


% Tangential
all(:,3) = ai + (ao-ai)*( (1-A).*z/L + A.*tan(pi/4*z/L).^p );


% x^p
all(:,4) = ai + (ao-ai)*( (1-A).*z/L + A.*(z/L).^p );


% Exp
all(:,5) = ai*exp(log(ao/ai)*z/L);


%Hyperbolic
all(:,6) = sqrt(ai^2 + z.^2 * (ao^2 - ai^2)/L/L);


```

```
% Polynomial
all(:,7) = ai*(1-A) + (ao-ai) * (1-A).*(z/L) + ...
    A.*(ai + (p+1)*(ao-ai)*(1-p*z/(p+1)/L).*(z/L).^p);

% Asymmetric sine-squared
L1 = L/(1+g); L2 = g*L1;
ind = find(z<=L1); ind = ind(end);

all(:,8) = ai + 2*(ao-ai)/(1+g) *...
    [sin(pi/4*z(1:ind)/L1).^2;...
     g*sin(pi/4/L2 * (z(ind+1:end)+L2-L1)).^2 + (1-g)/2];


% original exponential
x2 = ao;
x1 = ai;
z1 = 0;
z2 = L;
c1 = (x2-x1) ./ ( exp(R.*z2) - exp(R.*z1) );
c2 = ( x1*exp(R.*z2) - x2*exp(R.*z1) ) ./ ...
        ( exp(R.*z2) - exp(R.*z1) );

x = c1 .* exp(R.*z) + c2;
all(:,9) = x;


% original elliptical
a = max([ao,L]); % semi-major axis
b = min([ao,L]); % semi-minor axis
dp = 0;

if ao > L,
    phi = 0;
    theta = linspace(-pi, -3*pi/2, len)';
else
    phi = pi/2;
    theta = flipud(linspace(0+dp, pi/2, len)');
end

xe = ao + a * cos(theta) * cos(phi) - b * sin(theta) * sin(phi);
ze = a * cos(theta) * sin(phi) + b * sin(theta) * cos(phi);


% original exponential modified to include linear portion
x2 = ao;
```

```
x1 = ai;
z1 = 0;
z2 = L;
c1 = (x2-x1) ./ ( exp(R.*z2) - exp(R.*z1) );
c2 = ( x1*exp(R.*z2) - x2*exp(R.*z1) ) ./ ...
        ( exp(R.*z2) - exp(R.*z1) );

all(:,11) = ai*(1-A) + (ao-ai) * (1-A).*(z/L) + A.*(c1 .* exp(R.*z) + c2);

% super quadric
a = ao - ai;
b = L;

phi = linspace(-pi,-3*pi/2, len)';

xs = a * sign(cos(phi)) .* abs(cos(phi)).^(1/p);
zs = b * sign(sin(phi)) .* abs(sin(phi)).^(1/p);

xs = xs - xs(1) + ai;
zs = zs - zs(1);

xs = A .* xs + (1-A) .* ( ai + (ao-ai) * (zs/L) );


% output
if prfInd ~= 10 && prfInd ~= 12
    prf = [all(:,prfInd), z];
elseif prfInd == 10
    prf = [xe, ze];
elseif prfInd == 12
    prf = [xs, zs];
end
```

```
function CST_writePar(mws, p_name, p_val, fid)

for ii = 1:length(p_val)
    invoke( mws, 'StoreParameter', p_name{ii}, num2str( p_val(ii),'%10.6f' ) );
    if ~isempty(fid)
        fprintf(fid, '%s\n', [p_name{ii} ' ' num2str(p_val(ii),'%10.6f')]);
    end
end
```