

## LIST OF FIGURE

Figure 2.1 FMCW radar vital signs detection diagram.....	6
Figure 2.2 FMCW Radar Waveform .....	7
Figure 2.3 The line of radiators (broadside) if all antenna elements are fed in phase .....	8
Figure 2.4 Phased array antenna principle .....	9
Figure 2.5 Components of the Butler Matrix.....	11
Figure 2.6 Symbol for directional couplers .....	12
Figure 2.7 SIW Parameters .....	14
Figure 2.8 (a) Waveguide dielectric. (b) Rectangular Waveguide.....	15
Figure 3.1 Illustrations of multi-target detection .....	19
Figure 3.2 Proposed Method .....	20
Figure 3.3 Proposed research of SIW Beamforming .....	21
Figure 3.4 Butler Matrix Output Phase .....	22
Figure 3.5 Basic parameters of SIW Transmission .....	24
Figure 4.1 Scheme of Designing and Simulating SIW Parameters .....	26
Figure 4.2 BM Simulation Diagram .....	26
Figure 4.3 Diagram of the testing and data collection process .....	27
Figure 4.4 Prototype measurement (a) Illustration of BM measurements using VNA. (b) Documentation of the measurements .....	28
Figure 4.5 (a) Illustration Butler Matrix Horizontal radiation pattern testing process in the laboratory. (b) Documentation of the experiment Butler matrix H-Plane radiation pattern measurement configuration .....	29
Figure 4.6 Integration of FMCW radar devices with Butler matrix .....	30
Figure 4.7 Prototype beamforming with SIW techniques on FMCW radar. (a) Parts of beamforming FMCW Radar. (b) Integration of Butler Matrix .....	31
Figure 4.8 The experiment of Beamforming target detection. (a) Illustration of the experimental setup side view. (b) Illustration of radar position setup. (c) Documentation of the experiment.....	33

Figure 4.9 Breath detection testing using FMCW radar .....	33
Figure 4.10 The experiment of multi-target detection. (a) Illustration of the experimental In the first scenario. (b) Illustration of the second scenario.....	34
Figure 4.11 Documentation of the experiment in the first scenario.....	35
Figure 4.12 Documentation of the experiment in the second scenario .....	36
Figure 5.1 Results of radiation 4 element antenna .....	38
Figure 5.2 Structure of Antenna Array .....	39
Figure 5.3 Results of 3D radiation pattern antenna with phase differences.....	39
Figure 5.4 S-parameters of the SIW transmission line design .....	41
Figure 5.5 Phase of the SIW transmission line design.....	41
Figure 5.6 Results of E-fields distribution at frequency 24GHz.....	41
Figure 5.7 Proposed analysis scheme for each component.....	42
Figure 5.8 Proposed 90° HC structure in SIW.....	43
Figure 5.9 (a) Simulation results of $S_{11}$ , $S_{21}$ , $S_{51}$ , $S_{61}$ , $S_{33}$ , $S_{43}$ , $S_{73}$ , and $S_{83}$ . (b) Simulation results of phase differences between output ports and results phase output ports .....	44
Figure 5.10 E-Field distribution of hybrid coupler feed by port 1 and port 3 .....	45
Figure 5.11 Proposed -45° phase shifter and crossover structure in SIW.....	45
Figure 5.12 Simulated S-parameters and phase of crossover .....	46
Figure 5.13 Simulated S-parameters and phase of -45° phase shifter .....	47
Figure 5.14 E-Field distribution of phase shifter -45° and crossover. (a) With input port 1 and port 2. (b) With input port 1 and port 3 .....	47
Figure 5.15 Proposed 0° phase shifter and crossover structure in SIW .....	48
Figure 5.16 Simulated S-parameters and phase of 0° phase shifter.....	49
Figure 5.17 Simulated S-parameters and phase of crossover .....	49
Figure 5.18 E-Field distribution of 0° phase shifter and crossover (a) With input port 1 and port 2. (b) With input port 1 and port 3.....	50
Figure 5.19 A combination of a 90° hybrid coupler with a -45° phase shifter and a crossover on the SIW transmission line.....	51
Figure 5.20 Simulated S-parameters port 1, port 2, port 3, and port 4 of 90° hybrid coupler, -45° phase shifter, and crossover .....	51
Figure 5.21 Results of E-fields distribution at the second part .....	52
Figure 5.22 Results of Phase.....	52
Figure 5.23 A combination of parts 1, 2, and 3 on the SIW transmission line .....	53

Figure 5.24 Simulated S-parameters port 1, port 2, port 3, and port 4 of 90° hybrid coupler, -45° phase shifter, and crossover .....	53
Figure 5.25 Results of E-fields distribution in the third part .....	54
Figure 5.26 The output phase result of combining 3 parts.....	54
Figure 5.27 Design of SIW 4 x 4 Butler Matrix .....	55
Figure 5.28 Simulated S-parameters 4 x 4 Butler Matrix .....	55
Figure 5.29 Results of E-fields distribution in 4 x 4 Butler Matrix .....	56
Figure 5.30 Results of phase 4 x 4 Butler Matrix .....	56
Figure 5.31 Design transition input port .....	58
Figure 5.32 Simulated S-parameters transition input port .....	58
Figure 5.33 Design of SIW 4 x 4 Butler Matrix with transition input port .....	59
Figure 5.34 Simulated S-parameters 4 x 4 Butler Matrix with transition input port .	59
Figure 5.35 Results of phase 4 x 4 Butler Matrix with transition input port .....	60
Figure 5.36 S-parameters results from measuring and simulation of the Butler Matrix .....	61
Figure 5.37 (a) Design of 24 GHz Series Fed Microstrip Patch Antenna Array. (b) Fabricated Antenna .....	61
Figure 5.38 (a) Simulated and measured reflection coefficients of the antenna. (b) VSWR of the antenna .....	62
Figure 5.39 Beam direction from simulation and measurement results of the antenna at 24GHz.....	63
Figure 5.40 Design of Beamforming with Antenna.....	64
Figure 5.41 Simulated isolation loss and reflection coefficients of the antenna.....	65
Figure 5.42 Simulated Radiation pattern of the BM .....	65
Figure 5.43 Comparison of antenna array radiation patterns with BM.....	66
Figure 5.44 Measurement isolation loss and return loss of the antenna. ....	67
Figure 5.45 Results from measuring and simulation the radiation pattern of the Butler Matrix .....	67
Figure 5.46 H-Plane Port 1 and Port 2 Beam direction from simulation and measurement results from BM.....	68
Figure 5.47 H-Plane Port 3 and Port 4 Beam direction from simulation and measurement results from BM.....	69
Figure 5.48 Magnitude response of output FMCW radar .....	72
Figure 5.49 Magnitude response of output in the frequency domain. ....	73

Figure 5.50 Time domain representation of phase detector output in ROI.....	73
Figure 5.51 Small displacement of phase detector output in ROI .....	74
Figure 5.52 Phase response radar without a target on port 1 .....	75
Figure 5.53 Magnitude response when target position is at $-40^\circ$ and $40^\circ$ .....	76
Figure 5.54 Phase response at port 2 with target position $-40^\circ$ .....	76
Figure 5.55 Comparison of phase response at port 2 between target position $-40^\circ$ and target position $40^\circ$ .....	77
Figure 5.56 Phase response at port 3 with target position $40^\circ$ .....	77
Figure 5.57 Comparison of phase response at port 3 between target position $40^\circ$ and target position $-40^\circ$ .....	78
Figure 5.58 Phase response at port 1 with target position $15^\circ$ .....	79
Figure 5.59 Comparison of phase response at port 1 between target position $15^\circ$ and target position $-15^\circ$ .....	79
Figure 5.60 Phase response at port 4 with target position $-15^\circ$ .....	80
Figure 5.61 Comparison of phase response at port 4 between target position $15^\circ$ and target position $-15^\circ$ .....	80
Figure 5.62 Phase response multi-target radar on port 1 .....	81
Figure 5.63 Phase response multi-target radar on port 2 .....	82
Figure 5.64 Phase response multi-target radar on port 3 .....	82
Figure 5.65 Phase response multi-target radar on port 4 .....	83
Appendix A.1 Phase response without a target on port 1 .....	90
Appendix A.2 Phase response without a target on port 2 .....	90
Appendix A.3 Phase response without a target on port 3 .....	91
Appendix A.4 Phase response without a target on port 4 .....	91
Appendix B.1 Measurement Tx Antenna.....	92
Appendix B.2 Laboratory Setup measuring Tx Antenna.....	92
Appendix C.1 Laboratory Setup measuring Butler Matrix.....	93
Appendix C.2 Measurement S-parameters Port 1 to Port 2 Butler Matrix .....	93
Appendix C.3 Measurement S-parameters Port 1 to Port 3 Butler Matrix .....	94
Appendix C.4 Measurement S-parameters Port 3 to Port 4 Butler Matrix .....	94
Appendix C.5 Measurement S-parameters Port 2 to Port 4 Butler Matrix .....	95
Appendix D.1 Laboratory Setup measuring Butler Matrix with Antenna.....	96
Appendix D.2 Measurement port 1 Butler matrix .....	96
Appendix D.3 Measurement port 2 Butler matrix .....	97

Appendix D.4 Measurement port 3 Butler matrix .....	97
Appendix D.5 Measurement port 4 Butler matrix .....	98
Appendix E.1 Anritsu MS46322A Vector Network Analyzer Series up to 43.5 GHz.....	99
Appendix E.2 Signal Analyzer KEYSIGHT N9020A MXA, 10 Hz to 26.5 GHz ....	99
Appendix E.3 KEYSIGHT MXG Analog signal generator N5183B, 9 kHz - 40 GHz.....	100
Appendix E.4 WR-34 Waveguide Standard Horn Antenna 22 GHz to 33 GHz .....	100