Index

Above-resonance circulators, gyromagnetic space of, UHF circulator fabrication, 487–488

Apex-coupled triangular planar resonator, quality factor using, 299–308

Augmented eigenvalues, complex gyrator circuit of three-port circulator (using gyromagnetic resonators with sixfold symmetry), 384–387

Augmented scattering matrix, eigenvalues, scattering matrix of junction circulators with Chebyshev characteristics, 452–455

Chebyshev characteristics. See Scattering matrix

Circulation adjustment, scattering matrix of junction circulators with Chebyshev characteristics, 455–457

Circulator definition, by cyclic substitutions, scattering matrix of m-port junction, 71–72

Circumferential magnetic walls, 201–202. See also Triplet radial and circumferential magnetic walls

Cloverleaf resonators, 145–164
cutoff space of isotropic with fourfold symmetry, 151–153
with threefold symmetry, 149–151

field patterns in, 153–161
finite element method, 147–148

complex gyrator, 387–389
complex gyrator circuit of three-port circulator (using gyromagnetic resonators with sixfold symmetry), 387–389

complementary and eigenvectors of m-port symmetric planar junction circulator, 378–380

complex gyrator circuit, 387–389
complex gyrator circuit of three-port circulator (using gyromagnetic resonators with sixfold symmetry), 387–389

complex gyrator, 339–361. See also Gyromagnetic resonator augmented eigenvalues, 384–387
complex gyrator circuit, 387–389

Chebyshev characteristics.

Complex admittance, synthesis of, one-port topology, 139–141

Experimental evaluation of, weakly magnetized circulators fabrication, 520–525

finite element formulation, 274–277

frequency response, 351–353

Triplet radial and circumferential magnetic walls

Circulator definition, by cyclic

The Stripline Circulator: Theory and Practice. By J. Helszajn
Copyright © 2008 John Wiley & Sons, Inc.

579
Complex gyrator circuit(s) (Continued)
gyromagnetic planar disk resonator, 250–252
lumped element circulator, 224–226
negative permeability gyromagnetic resonator, 340–343
negative permeability tracking solution, 346–351
nondegenerate resonator modes
circulation solution using, 344–346
standing wave solution using, 346
100% circulator, 353–357
overview, 339–340, 377–378
radial/lumped element resonators, wideband planar circulator
synthesis using narrow coupling angles, 364–369
symmetrical m-port gyromagnetic resonator, eigenvalues of, 382–384
of three-port circulator (using gyromagnetic resonators with sixfold symmetry), 377–389
three-port circulator with threefold symmetry, open-circuit parameters of, 380–382
tracking and semitracking circulators, 319–323
tracking solution, 387
UHF circulator fabrication, 504–506
very strongly magnetized junction, impedance poles of, 343–344
weakly magnetized junction circulator, stripline circulator, 532–534
Complex gyrator immittance. See also Impedance matrix
resonant in-phase eigen-network, 116–118
of three-port circulator, impedance matrix, 113–116
Composite resonators. See also specific composite resonators
gyromagnetic, complex gyrator circuit, 357–361
stripline circulator, 13–15
Constituent lumped element circulator, inductance of, 228–229
Constituent problem regions, of six-port junction having two degrees of threefold symmetry, impedance pole approach, 400–403
Constituent resonator, unloaded quality factors, 205–207
Contour integral method, finite element formulation, 277–283
Coupled circulator, quarter-wave, stripline circulator, 16–17
Coupled disk insulator, spatial shape demagnetizing factors, 56–59
Cutoff space
of cloverleaf resonators, 145–164
(See also Cloverleaf resonators)
iso/otropic with fourfold symmetry, 151–153
with threefold symmetry, 149–151
irregular hexagonal resonator, 301–304
of wye gyromagnetic planar resonator, 166–169
gyromagnetic cutoff space, 177–179
Cyclic substitutions, circulator definition by, scattering matrix of m-port junction, 71–72
Damping, tensor permeability, 27–30
Degenerate counterrotating eigen-network, impedance matrix, 122–125
Degenerate counterrotating eigenvalue evaluation, eigenvalue adjustment, 100–102
Degree-1 three-port junction circulator, quarter-wave coupled reciprocal stripline junctions, 440–442
Degree-2 circuits, quarter-wave coupled reciprocal stripline junctions, 442–444
Degree-2 circuits, quarter-wave coupled reciprocal stripline junctions, 442–444
Degree-2 circulator quarter-wave coupled reciprocal stripline junctions, 444–447
stripline circulator, 537–541
Degree-2 lumped element circulator, 230–234
Degree-2 one-port topology, 143–144
Degree-3 circuits, quarter-wave coupled reciprocal stripline junctions, 442–444
Degree-3 circulator, synthesis of, tracking and semitracking circulators, 332–335
Degree-3 lumped element circulator, 234–235
Degree-\(n\) network, frequency response of, quarter-wave coupled reciprocal stripline junctions, 439–440
Demagnetizing factors. See Spatial shape demagnetizing factors
Diagonalization, eigenvalue adjustment, 97–98
Disk insulator
  coupled, spatial shape demagnetizing factors, 56–59
  flat, spatial shape demagnetizing factors, 50–56
Disk resonator, susceptance slope parameters, 310–312
Dissipation eigenvalues, eigenvalue adjustment, 98–99
Dissipation matrix, scattering matrix of \(m\)-port junction, 76–77
Distributed/lumped element resonators, quarter-wave coupled circulators, wideband planar circulator synthesis using narrow coupling angles, 369–371
Distributed radial/lumped element resonators, mixed, wideband planar circulator synthesis using narrow coupling angles, 372–373
Dominant mode charts, triplet radial and circumferential magnetic walls, 186–190
Drop-in techniques, packaging techniques and, 12
Duplexing, junction circulators using, stripline circulator, 21–22
Edge mode circulator, stripline circulator, 18–20
Effective permeability, gyrotropy and, tensor permeability, 32–34
Eigen-networks
  four-port single junction stripline circulator, 414–416
  quarter-wave coupled reciprocal stripline junctions, 434–436
Eigenfunctions
  equilateral triangle, triangular planar resonator, 286–291
  normalized, finite element formulation, 271–272
Eigenvalue(s)
  augmented, complex gyrator circuit of three-port circulator (using gyromagnetic resonators with sixfold symmetry), 384–387
  augmented scattering matrix, scattering matrix of junction circulators with Chebyshev characteristics, 452–455
  complex gyrator immittance, resonant in-phase eigen-network, 116–118
  four-port single junction stripline circulator, 414–416
  of immittance matrices, impedance matrix, 111–113
  input impedance, one-port topology, 133–135
  of \(m\)-port symmetric planar junction circulator, complex gyrator circuit of three-port circulator (using gyromagnetic resonators with sixfold symmetry), 378–380
  scattering matrix, scattering matrix of junction circulators with Chebyshev characteristics, 450–452
  of symmetrical \(m\)-port gyromagnetic resonator, complex gyrator circuit of three-port circulator (using gyromagnetic resonators with sixfold symmetry), 382–384
  tracking and semitracking circulators, 316–319
Eigenvalue adjustment, 85–108
  degenerate counterrotating eigenvalue evaluation, 100–102
diagonalization, 97–98
dissipation eigenvalues, 98–99
eigenvectors, 90–95
four-port single junction stripline circulator, 412–414
gyromagnetic resonators, split frequencies of, 104–105
importance of, 86–87
Eigenvalue adjustment (Continued)
in-phase eigenvalue evaluation, 102–103
phase angle of, 105–106
overview, 85
scattering matrix of m-port
junction, 95–97
three-port circulator, 87–90
triple pole circulator, 107–108
Eigenvalue diagrams, of semi-ideal
circulation, unloaded quality
factors, 203–205
Eigenvalue evaluation, lumped element
circulator, 222–224
Eigenvalue solution, gyromagnetic planar
disk resonator, 247–249
Eigenvectors
eigenvalue adjustment, 90–95
four-port single junction stripline
circulator, 414–416
of m-port symmetric planar junction
circulator, complex gyrator circuit
of three-port circulator (using
gyromagnetic resonators with
sixfold symmetry), 378–380
Electric field patterns, triangular planar
resonator, 294–298
Equilateral triangle, eigenfunctions of,
triangular planar resonator, 286–291
Equivalent circuit
of three-port circulator, impedance
matrix, 118–121
of three-port junction, quarter-wave
coupled reciprocal stripline
junctions, 432–434
Experimental evaluation, complex gyrator
circuits, weakly magnetized
circulators fabrication, 520–525
Experimental mode charts, triplet radial
and circumferential magnetic
walls, 200
External $Q$-factors, unloaded quality
factors, 207–208
Fay and Comstock solution, triplet radial
and circumferential magnetic walls,
193–195
Ferrites
frequency doubling in, stripline
circulator, 552–553
magnetization values of, tensor
permeability, 41–42
Field patterns, cloverleaf resonators,
153–161
Finite element formulation, 267–283
complex gyrator circuit, 274–277
contour integral method, 277–283
Green’s function analysis using,
268–271
normalized eigenfunction, 271–272
overview, 267–268
procedure, 272–274
Finite element method (FEM)
cloverleaf resonators, 147–148
transverse demagnetizing factor, 63
Flat disk insulator, spatial shape
demagnetizing factors, 50–56
Flux density, magnetic field intensity
and, spatial shape demagnetizing
factors, 49–50
Four-port single junction stripline
circulator, 17–18, 407–429
eigenvalue adjustment, 412–414
eigenvectors, eigenvalues, and
eigen-networks, 414–416
overview, 407–408
phenomenological adjustment, 416–417
similarity transformation, 409–412
standing wave solutions, of planar
X resonators, 417–426
symmetry properties, 408–409
TM-field mode patterns, 417–424
UE loaded disk magnetized resonators,
frequencies of, 426–429
Fourfold symmetry
cutoff space of isotropic cloverleaf
resonators with, 151–153
field patterns in cloverleaf resonators
with, 158–161
Frequency doubling, ferrites, stripline
circulator, 552–553
Frequency response. See also Quarter-wave
coupled reciprocal stripline junctions
with capacitive turning, quarter-wave
coupled circulator, 461–463
complex gyrator circuit, 351–353
quarter-wave coupled circulators,
tracking and semitracking
circulators, 335–337
quarter-wave coupled reciprocal stripline junctions, 431–447
UE loaded disk magnetized resonators, four-port single junction stripline
circulator, 426–429
very weakly magnetized circulator, gyromagnetic planar disk
resonator, 256
weakly magnetized circulator, gyromagnetic planar disk
resonator, 254–256
Frequency variation
eigenvalue adjustment, gyromagnetic
resonators, 104–105
quarter-wave coupled circulator,
scattering matrix of junction
circulators with Chebyshev
characteristics, 459–460
Gain-bandwidth product, lumped element
circulator, 226–228
Gap effects, stripline circulator, 541–543
Green’s function, 257–265
finite element formulation, 268–271
matrix, 257–261
overview, 257
wave impedance matrix, 262–265
Gyrator circuit
complex, finite element formulation,
274–277
one-port topology, 135–136
Gyrator conductance
impedance matrix, 127–129
triangular planar resonator, 308–310
Gyrator network, impedance
matrix, 129–130
Gyromagnetic cloverleaf
resonators, 162
split cutoff space of, with threefold
symmetry, 162–164
Gyromagnetic cutoff space, wye
gyromagnetic planar resonator,
177–179
Gyromagnetic planar disk resonator,
239–256
complex gyrator circuit, 250–252
eigenvalue solution, 247–249
mode chart, 240–244
overview, 239–240
single pole circulation solution,
252–254
three-port junction circulator, impedance
matrix of, 245–247
very weakly magnetized
circulator, frequency response
of, 256
weakly magnetized circulator, frequency
response of, 254–256
Gyromagnetic resonator. See also
Complex gyrator circuit(s); UHF
circulator fabrication; Wye
gyromagnetic planar resonator
complex gyrator circuit of three-port
circulator using, with sixfold
symmetry, 377–389
composite, complex gyrator
circuit, 357–361
negative permeability, complex gyrator
circuit, 340–343
power ratings of, stripline
circulator, 15
split frequencies of, eigenvalue
adjustment, 104–105
UHF circulator fabrication,
485–509
Wye gyromagnetic planar resonator,
165–182
Gyromagnetic space, of above-resonance
circulators, UHF circulator
fabrication, 487–488
Gyrotropy
effective permeability and, tensor
permeability, 32–34
magnetic insulators, stripline
circulator, 7–8
Hexagonal insulator, irregular, 60–61.
See also Irregular hexagonal
insulator
Higher order mode charts, triplet radial and
circumferential magnetic walls,
190–193
Immittance matrices, eigenvalues of,
impedance matrix, 111–113
Immittance plane, three-port junction in,
passband frequencies, stripline
circulator, 545–548
Impedance matrix, 109–130. See also Complex gyrator immittance; Junction circulator
complex gyrator immittance resonant in-phase eigen-network, 116–118
of three-port circulator, 113–116
degenerate counterrotating eigen-network, 122–125
equivalent circuit, of three-port circulator, 118–121
gyrator conductance, 127–129
gyrator network, 129–130
immittance matrices, eigenvalues of, 111–113
impedance pole approach, Wye resonators, 403–405
in-phase eigen-network, 125–126
overview, 109–111
quality factor, 121–122
split eigen-networks, 126–127
three-port junction circulator, gyromagnetic planar disk resonator, 245–247
Impedance pole(s), very strongly magnetized junction, complex gyrator circuit, 343–344
Impedance pole approach, 391–406
constituent problem regions of six-port junction having two degrees of threefold symmetry, 400–403
open-circuit parameters, of junction with two degrees of threefold symmetry, 396–400
overview, 391–392
quarter-wave coupled circulator, short-circuit parameters of, 405–406
standing wave solution, 392–393
symmetry properties, 393–395
Wye resonators, 3 × 3 impedance matrix, 403–405
Impedance zero, triplet radial and circumferential magnetic walls, 202
In-phase eigen-network impedance matrix, 125–126
resonant, complex gyrator immittance, 116–118
In-phase eigenvalue evaluation
eigenvalue adjustment, 102–103
phase angle of, eigenvalue adjustment, 105–106
Inductance, constituent lumped element circulator, 228–229
Input immittance, one-port topology, open-circuit parameters, 132–133
Input impedance, one-port topology, eigenvalues, 133–135
Insertion loss
of junction circulators, unloaded quality factors, 213–218
for quarter-wave long stepped impedance transducers, stepped impedance transducers synthesis, 466–468
of UHF circulators, unloaded quality factors, 218
Insertion phase shift, scattering matrix of m-port junction, 78–79
Irregular hexagonal insulator, spatial shape demagnetizing factors, 60–61
Irregular hexagonal resonator, 299–307. See also Spatial shape demagnetizing factors; Triangular planar resonator; UHF circulator fabrication
cutoff space, 301–304
overview, 299–301
planar, mode charts of, UHF circulator fabrication, 496–499
split frequencies, 304–307
transmission phase angle degree-1 circulator, 313–314
UHF circulator fabrication, 485–509
Isotropic cloverleaf resonators
cutoff space:
with fourfold symmetry, 151–153
with threefold symmetry, 149–151
Junction circulator(s). See also Impedance matrix; Unloaded quality factors adjustment, stripline circulator, 2–7
duplexing with, stripline circulator, 21–22
impedance matrix of, 109–130
network definition of, scattering matrix of m-port junction, 73–75
quality factor, 121–122
single-port amplifiers with, stripline
circulator, 21
standing wave solution of, using wye
gyromagnetic resonator, 169
terminal planes, scattering matrix
of m-port junction, 77–78
unloaded quality factors, 203–220

Kittel line
low-field losses in unsaturated magnetic
insulator, 35–37
magnetic bias points above and below,
37–38
temperature stability of magnetic
insulators, stripline circulator,
555–561
tensor permeability, 34–35
UHF circulator fabrication, 485–486,
492–496

Landau-Lifshitz (LL) damping term, 42–45
Loaded Q-factors, unloaded quality factors,
207–208
Low-field losses, in unsaturated magnetic
insulator, tensor permeability, 35–37
Lowpass matching circuit, lumped element
circulator, 236–237
Lumped element circulator, 221–237.
See also Radial/lumped element
resonators
complex gyrator circuit of, 224–226
constituent, inductance of, 228–229
degree-2, 230–234
degree-3, 234–235
eigenvalue evaluation, 222–224
gain-bandwidth product of, 226–228
lowpass matching circuit, 236–237
magnetic variables of, 229–230
overview, 221–222
quasi, 235–236
Lumped element resonator
distributed, quarter-wave coupled
circulators, wideband planar
circulator synthesis using narrow
coupling angles, 369–371
distributed radial/lumped element
resonators, mixed, wideband planar
circulator synthesis using narrow
coupling angles, 372–373
mixed distributed radial/lumped element
resonators, wideband planar
circulator synthesis using narrow
coupling angles, 372–373
quasi lumped element circulator,
235–236
radial/lumped element resonators,
complex gyrator circuits using,
wideband planar circulator
synthesis using narrow coupling
angles, 364–369
M-port gyromagnetic resonator,
eigenvalues of symmetrical, complex
gyrator circuit of three-port circulator
(using gyromagnetic resonators with
sixfold symmetry), 382–384
M-port junction. See Scattering matrix
M-port symmetric planar junction
circuit, eigenvalues and
eigenvectors of, complex gyrator
circuit of three-port circulator (using
gyromagnetic resonators with sixfold
symmetry), 378–380
Magnetic field intensity, flux density
and, spatial shape demagnetizing
factors, 49–50
Magnetic insulators
gyrotropy in, stripline circulator, 7–8
spinwave instability in, stripline
circulator, 550–552
temperature stability of, Kittel line,
stripline circulator, 555–561
Magnetic variables
lumped element circulator,
229–230
UHF circulator fabrication, 502–504
Magnetization values, of ferrites, tensor
permeability, 41–42
Mixed distributed radial/lumped element
resonators, wideband planar circulator
synthesis using narrow coupling
angles, 372–373
Mode charts
- dominant mode charts, triplet radial and circumferential magnetic walls, 186–190
- experimental mode charts, triplet radial and circumferential magnetic walls, 200
- gyromagnetic planar disk resonator, 240–244
- higher order mode charts, triplet radial and circumferential magnetic walls, 190–193
- of irregular hexagonal planar resonator, UHF circulator fabrication, 496–499

Moderately magnetized gyromagnetic resonator, stripline circulator, 536–537

Negative permeability gyromagnetic resonator, complex gyrator circuit, 340–343
Negative permeability tracking solution, complex gyrator circuit, 346–351
Network definition, of junction circulator, scattering matrix of m-port junction, 73–75
Network parameters
- quarter-wave long stepped impedance transducers, stepped impedance transducers synthesis, 471–477
- short-line impedance transducers, stepped impedance transducers synthesis, 479–483
Nondegenerate resonator modes:
- circulation solution using, complex gyrator circuit, 344–346
- standing wave solution using, complex gyrator circuit, 346
Nonideal loads, specifications with, scattering matrix of m-port junction, 79–82
Nonlinear devices, third-order intermodulation products, 561–564
Normalized eigenfunction, finite element formulation, 271–272

100% circulator, complex gyrator circuit, 353–357

One-port topology, 131–144
- complex admittance, synthesis of, 139–141
- degree-2, 143–144
- gyrator circuit, 135–136
- input immittance, open-circuit parameters, 132–133
- input impedance, eigenvalues, 133–135
- overview, 131–132
- real part condition, 136–139
- split frequencies, 141–143
- 1–2 GHz device, wideband planar circulator synthesis using narrow coupling angles, 373–375
Open walls, stripline circulator, 548–550
Open-circuit parameters. See also Impedance pole approach
- impedance pole approach, 391–406
- input immittance, one-port topology, 132–133
- of junction with two degrees of threefold symmetry, impedance pole approach, 396–400
- of three-port circulator with threefold symmetry, complex gyrator circuit of three-port circulator (using gyromagnetic resonators with sixfold symmetry), 380–382
- wye gyromagnetic planar resonator, 179–181

Packaging techniques, drop-in techniques and, 12
Parallel plate waveguide model
- stripline circulator, 9–12
- weakly magnetized circulators fabrication, 512–515
Partial magnetization. See Unsaturated magnetic insulator
Passband frequencies, three-port junction in immittance plane, stripline circulator, 545–548
Permeability tensor. See Tensor permeability
Phase angle, of in-phase eigenvalue, eigenvalue adjustment, 105–106
Phenomenological adjustment, four-port single junction stripline circulator, 416–417
Phenomenological damping, tensor permeability, 27–30
Planar resonators, stripline circulator, 8–9
Planar X resonators, standing wave solutions of, four-port single junction stripline circulator, 417–426
Power ratings, of gyromagnetic resonator, stripline circulator, 15

Quality factor(s)
apex-coupled triangular planar resonator, 299–308
impedance matrix, 121–122
measurement of unloaded split, 208–210
triplet radial and circumferential magnetic walls, 195–200
UHF circulator fabrication, 507–509
unloaded, external, and loaded, 207–208

Quarter-wave coupled circulator(s)
distributed/lumped element resonators using, wideband planar circulator synthesis using narrow coupling angles, 364–369
frequency response of, tracking and semitracking circulators, 335–337
scattering matrix of junction circulators with Chebyshev characteristics, 457–459
frequency response, with capacitive turning, 461–463
frequency variation, 459–460
short-circuit parameters of, impedance pole approach, 405–406
stripline circulator, 16–17
Quarter-wave coupled reciprocal stripline junctions, 431–447
degree-1 three-port junction circulator, 440–442
degree-2 and degree-3 circuits, 442–444
degree-2 circulator, 444–447
degree-n network, frequency response of, 439–440
eigen-networks, 434–436
equivalent circuit of three-port junction, 432–434
overview, 431–432
reflection coefficient, 436–439
Quarter-wave long stepped impedance transducers
insertion loss function, stepped impedance transducers synthesis, 466–468
network parameters, stepped impedance transducers synthesis, 471–477
r-plane synthesis, stepped impedance transducers synthesis, 468–471
Quasi lumped element circulator, 235–236

Radial/lumped element resonators, complex gyrator circuits using, wideband planar circulator synthesis using narrow coupling angles, 364–369
Radial magnetic walls, UHF circulator fabrication, 500–502
Real part condition
one-port topology, 136–139
UHF circulator fabrication, 506–507
Reentrant magnetic circuits, spatial shape demagnetizing factors, 61–62
Reflection coefficient, quarter-wave coupled reciprocal stripline junctions, 436–439
Relative permeability tensor, 24
Resonant frequencies, of UE loaded disk magnetized resonators, wye gyromagnetic planar resonator, 169–177
Resonant in-phase eigen-network, complex gyrator immittance, 116–118
Resonator(s). See also specific resonators composite, stripline circulator, 13–15
gyromagnetic, power ratings of, stripline circulator, 15
switched, stripline circulator, 12–13
Scalar permeabilities, tensor permeability, 30–31
Scattering matrix
of junction circulators with Chebyshev characteristics, 449–463
circulation adjustment, 455–457
Scattering matrix (Continued)
eigenvalues
augmented scattering
matrix, 452–455
scattering matrix, 450–452
overview, 449
quarter-wave coupled circulator,
457–459
frequency response, with
capacitive turning, 461–463
frequency variation, 459–460
of m-port junction, 67–83 (See also
Eigenvalue adjustment)
cyclic substitutions, circulator
definition by, 71–72
dissipation matrix, 76–77
eigenvalue adjustment, 86–87,
95–97
insertion phase shift, 78–79
network definition, of junction
circulator, 73–75
overview, 67–68
properties of, 68–71
semi-ideal circulator, 75–76
specifications, with nonideal
loads, 79–82
swept frequency description of
scattering parameters, 82–83
terminal planes, of junctions, 77–78
unitary condition, 72–73
of semi-ideal circulators, unloaded
quality factors, 218–220
Second-order intermodulation, stripline
circulator, 553–555
Semi-ideal circulator(s)
eigenvalue diagrams of, unloaded quality
factors, 203–205
scattering matrix of, unloaded quality
factors, 218–220
scattering matrix of m-port
junction, 75–76
Semitracking circulators. See Tracking and
semitracking circulators
Short-circuit parameters, quarter-wave
coupled circulator, impedance pole
approach, 405–406
Short-line impedance transducers, network
parameters, stepped impedance
transducers synthesis, 479–483
Short-line matching network, r-plane
synthesis, stepped impedance
transducers synthesis, 477–479
Short UE, wye gyromagnetic planar
resonator, 181–183
Side-coupled Wye resonators, impedance
pole approach, 391–406. See also
Impedance pole approach
Side-wall-coupled triangular planar
resonator, 308
Similarity transformation, four-port
single junction stripline circulator,
409–412
Single junction circulator, four-port,
stripline circulator, 17–18
Single pole circulation solution,
gyromagnetic planar disk resonator,
252–254
Single-port amplifiers, junction circulators
with, stripline circulator, 21
Sixfold symmetry. See Complex gyrator
circuit(s)
Six-port junction, constituent problem
regions of, having two degrees of
threefold symmetry, impedance pole
approach, 400–403
Slot-hole. See Triplet radial and
circumferential magnetic walls
Spatial shape demagnetizing factors,
47–66. See also Irregular hexagonal
resonator; Triangular planar resonator
disk
coupled disk insulator, 56–59
flat disk insulator, 50–56
irregular hexagonal insulator, 60–61
magnetic field intensity and flux
density, 49–50
overview, 47–49
partial magnetization, 63–66
reentrant magnetic circuits, 61–62
transverse demagnetizing
factor, 63
Specifications, with nonideal loads,
scattering matrix of m-port
junction, 79–82
Spinwave instability, in magnetic insulators,
stripline circulator, 550–552
Spinwave manifold, tensor permeability,
38–41
Split cutoff space, of gyromagnetic
cloverleaf resonators with threefold
symmetry, 162–164
Split eigen-networks, impedance
matrix, 126–127
Split frequencies
of gyromagnetic resonators, eigenvalue
adjustment, 104–105
irregular hexagonal resonator, 304–307
one-port topology, 141–143
Split \( Q \)-factors
experimental data, 210–213
measurement of unloaded, 208–210
Standing wave solution. See also Wye
gyromagnetic planar resonator
of circulators using cloverleaf
resonators, 164
impedance pole approach, 392–393
of junction circulators using wye
gyromagnetic resonator, 169
of planar X resonators, four-port single
junction stripline circulator,
417–426
of wye gyromagnetic planar resonator,
165–182
Stepped impedance transducers synthesis,
465–483
insertion loss function, for quarter-wave
long stepped impedance
transducers, 466–468
network parameters
quarter-wave long stepped impedance
transducers, 471–477
short-line impedance transducers,
479–483
overview, 465
t-plane synthesis:
for quarter-wave long stepped
impedance transducers,
468–471
short-line matching
network, 477–479
Stored energy, triangular planar
resonator, 298–299
Stripline circulator, 1–22, 531–564.
See also specific stripline circulators
composite resonators, 13–15
defined, xv, 1
degree-2 circulator, 537–541
described, 1–2
drop-in and packaging techniques, 12
duplexing using junction
circulators, 21–22
degree mode circulator, 18–20
ferrites, frequency doubling
in, 552–553
four-port single junction circulator,
17–18
gap effects, 541–543
junction circulator adjustment, 2–7
Kittel line, temperature stability of
magnetic insulators, 555–561
moderately magnetized gyromagnetic
resonator, 536–537
open walls, 548–550
overview, 531–532
parallel plate waveguide model, 9–12
passband frequencies, three-port
junction in immittance
plane, 545–548
planar resonators, 8–9
power ratings, of gyromagnetic
resonator, 15
quarter-wave coupled circulator, 16–17
second-order intermodulation, 553–555
single-port amplifiers using junction
circulators, 21
spinwave instability in magnetic
insulators, 550–552
suspended planar resonator, 543–545
switched resonators, 12–13
third-order intermodulation products,
nonlinear devices, 561–564
very weakly magnetized gyromagnetic
resonator, 534
weakly magnetized gyromagnetic
resonator, 534–536
weakly magnetized junction circulator,
complex gyrator circuit,
532–534
Strongly magnetized junction, impedance
poles of, complex gyrator
circuit, 343–344
Susceptance slope parameters, triangular
and disk planar resonators,
310–312
Susceptibility tensor, 25–27
INDEX

Suspended planar resonator, stripline circulator, 543–545
Swept frequency description, of scattering parameters, 82–83
Switched resonators, stripline circulator, 12–13
Symmetrical \( m \)-port gyromagnetic resonator, eigenvalues of, complex gyrator circuit of three-port circulator (using gyromagnetic resonators with sixfold symmetry), 382–384
Symmetry properties
  four-port single junction stripline circulator, 408–409
  impedance pole approach, 393–395

\( T \)-plane synthesis
  for quarter-wave long stepped impedance transducers, stepped impedance transducers synthesis, 468–471
  short-line matching network, stepped impedance transducers synthesis, 477–479

Temperature stability
  Kittel line, permeability tensor, 495–496
  of magnetic insulators, Kittel line, stripline circulator, 555–561

Tensor permeability, 23–45
  approximate relationships of, UHF circulator fabrication, 488–491
  characteristics of, 24–27
damping, 27–30
effective permeability and gyrotropy, 32–34
ferrites, magnetization values
  of, 41–42
  Kittel line, 34–35
  low-field losses in unsaturated magnetic insulator, 35–37
  magnetic bias points above and below, 37–38
temperature stability of, 495–496
overview, 23
relative, 24
scalar permeabilities, 30–31
spinwave manifold, 38–41
uniform linewidth origin, 42–45

Terminal planes, of junctions, scattering matrix of \( m \)-port junction, 77–78
Terminated circulator. See One-port topology
Third-order intermodulation products, nonlinear devices, 561–564
Three eigen-network theory, tracking and semitracking circulators, 323–327
Threefold symmetry. See also Triplet radial and circumferential magnetic walls
  constituent problem regions of six-port junction having two degrees of, impedance pole approach, 400–403
cutoff space of isotropic cloverleaf resonators with, 149–151
  field patterns in cloverleaf resonators with, 153–157
  junction with two degrees of, open-circuit parameters, impedance pole approach, 396–400
  split cutoff space of gyromagnetic cloverleaf resonators with, 162–164
  three-port circulator with, open-circuit parameters of, complex gyrator circuit of three-port circulator (using gyromagnetic resonators with sixfold symmetry), 380–382

Three-port circulator. See also Eigenvalue adjustment; Impedance matrix complex gyrator immittance of, impedance matrix, 113–116
eigenvalue adjustment, 87–90
equivalent circuit of, impedance matrix, 118–121
  with threefold symmetry, open-circuit parameters of, complex gyrator circuit of three-port circulator (using gyromagnetic resonators with sixfold symmetry), 380–382

Three-port junction circulator
equivalent circuit of, quarter-wave coupled reciprocal stripline junctions, 432–434
  immittance plane, passband frequencies, stripline circulator, 545–548
  impedance matrix of, gyromagnetic planar disk resonator, 245–247
TM-mode field patterns
four-port single junction stripline
circulator, 417–424
triangular planar resonator, 291–294

Tracking and semitracking circulators,
315–337
complex gyrator circuit, 319–323
eigenvalues, 316–319
overview, 315–316
quarter-wave coupled circulators,
frequency response of, 335–337
semitracking circulation solutions,
329–332
synthesis of degree-3 circulator,
332–335
synthesis of semitracking circulators,
327–329
three eigen-network theory, 323–327

Tracking solution, complex gyrator circuit
of three-port circulator (using
gyromagnetic resonators with sixfold
symmetry), 387

Transmission phase angle degree-1
circulator, irregular hexagonal
resonator, 315–314

Transverse demagnetizing factor, spatial
demagnetizing factors, 63

Triangular planar resonator, 285–299.
See also Irregular hexagonal
resonator; Spatial shape
demagnetizing factors
apex-coupled, quality factor
using, 299–308
eigenfunctions of equilateral
triangle, 286–291
electric field patterns, 294–298
gyrator conductance, 308–310
overview, 285–286
side-wall-coupled, 308
stored energy, 298–299
susceptance slope parameters, 310–312
TM-mode field patterns, 291–294

Triple pole circulator, eigenvalue
adjustment, 107–108

Triplet radial and circumferential magnetic
walls, 185–202. See also Threefold
symmetry
circumferential magnetic wall, 201–202
dominant mode charts, 186–190

experimental mode charts, 200
Fay and Comstock solution, 193–195
higher order mode charts, 190–193
impedance zero, 202
overview, 185–186
quality factor, 195–200

UE loaded disk magnetized resonators:
four-port single junction stripline
circulator, frequencies
of, 426–429
resonant frequencies of, wye
gyromagnetic planar
resonator, 169–177
short UE, wye gyromagnetic planar
resonator, 181–183
UHF circulator, insertion loss of, unloaded
quality factors, 218
UHF circulator fabrication, 485–509
above-resonance circulators,
gyromagnetic space
of, 487–488
complex gyrator circuit, 504–506
\( H_{ox}/M_s \) space, 491–492
Kittel line, 485–486, 492–496
magnetic variables, 502–504
mode charts, of irregular hexagonal
planar resonator, 496–499
overview, 485–486
permeability tensor, approximate
relationships of, 488–491
quality factors, 507–509
radial magnetic walls, 500–502
real part condition, 506–507
wave impedance and wavenumber,
486–487
Uniform linewidth, origin of, tensor
permeability, 42–45

Unitary condition, scattering matrix
of \( m \)-port junction, 72–73, 85
Unloaded quality factors, 203–220
constituent resonator, 205–207
eigenvalue diagrams, of semi-ideal
circulation, 203–205
experimental data, 210–213
insertion loss
of junction circulators, 213–218
of UHF circulators, 218
overview, 203
Unloaded quality factors (Continued)

$Q$-factors

measurement of unloaded split, 208–210
unloaded, external, and loaded, 207–208
scattering matrix, of semi-ideal circulators, 218–220

Unsaturated magnetic insulator, low-field losses in, tensor permeability, 35–37

Very strongly magnetized junction, impedance poles of, complex gyrator circuit, 343–344

Very weakly magnetized circulator. See also Weakly magnetized circulators fabrication

frequency response of, gyromagnetic planar disk resonator, 256

Very weakly magnetized gyromagnetic resonator, stripline circulator, 534

Wave impedance, wavenumber and, UHF circulator fabrication, 486–487

Wavenumber, wave impedance and, UHF circulator fabrication, 486–487

Weakly magnetized circulator, frequency response of, gyromagnetic planar disk resonator, 254–256

Weakly magnetized circulators fabrication, 511–530

commercial practice, 528–530
complex gyrator circuits, experimental evaluation of, 520–525
overview, 511–512
parallel plate waveguide model, 512–515
synthesis procedure, 526–528
very weakly magnetized problem region, 515–518

Weakly magnetized problem region, 518–519

Weakly magnetized gyromagnetic resonator, stripline circulator, 534–536

Weakly magnetized undersized junctions, wideband planar circulator synthesis using narrow coupling angles, 375–376

Wideband planar circulator synthesis using narrow coupling angles, 363–376

complex gyrator circuits, using radial/lumped element resonators, 364–369
mixed distributed radial/lumped element resonators, 372–373
1–2 GHz device, 373–375
overview, 363–364
quarter-wave coupled circulators, using distributed/lumped element resonators, 369–371
weakly magnetized undersized junctions, 375–376

Wye gyromagnetic planar resonator, 165–182. See also Impedance pole approach

cutoff space of, 166–169
gyromagnetic cutoff space, 177–179
impedance pole approach, 391–406
impedance pole approach, $3 \times 3$
impedance matrix, 403–405
open-circuit parameters, 179–181
overview, 165
resonant frequencies of UE loaded disk magnetized resonators, 169–177
short UE, 181–183
standing wave solution of junction circulators using, 169