CROSS INDEX OF CRYSTAL OSCILLATOR SUBJECTS

The subjects related to the design of crystal oscillators are separated into five categories for cross-indexing. These categories appear in the following order:

I. OSCILLATOR FUNDAMENTALS

II. FUNCTIONAL CHARACTERISTICS OF CRYSTAL OSCILLATORS
(Factors to consider in selection of oscillators—alphabetical listing.)

III. CIRCUIT ANALYSES OF BASIC CRYSTAL OSCILLATORS
(Quantitative relations which are fundamental as points of departure in attacking particular problems of design.)

IV. DESIGN OF CRYSTAL OSCILLATORS

V. CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS
(Alphabetical indexing of principal factors to consider when designing for optimum or special performance characteristics.)

The primary subjects contained in the above categories are listed without line indentation. (Alphabetical listings are followed only in categories II and V above.) Subheads under the primary subjects are indented and preceded by a dot (.). Second order subheads are doubly indented and preceded by two dots (..).

CROSS INDEX OF CRYSTAL-OSCILLATOR SUBJECTS

SUBJECT	PARAGRAPH NUMBER BY OSCILLATOR EQUATION, FIGURE, OR BIBLIOGRAPHY NUMBER WHEN INDICATED (All except Bibliography numbers apply to Section I unless otherwise shown.)																							
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						PARALLEL MODE				SERIES MODE														
													Transformer-Coupled				Impedance-Inverting							
	Physical	*Electronic*	*Crystal*	*Parallel Mode*	*Series Mode*	*Pierce*	*Miller*	*Multivibrator Type*	*Duplex—Electrode*	*Meacham Bridge*	*Capacitance Bridge*	*Butler*	*Basic (Grounded-Cathode)*	*Grounded-Grid*	*Grounded-Plate*	*Transitron*	*Transitron*	*Pierce*	*Miller*	*Grounded Cathode Two-Stage-Feedback*	*Modified Colpitts*	*Transistor*			
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•Free, forced, forced-free	264																							
•LC-controlled, electromechanically-controlled		6, 7																						
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•Constant-amplitude requirements	265 266	236 267	232 236 267	232 236 594	593																			
••Amplitude build-up	266	236 267 268	232 236 267	232 236 586	586																			
••Amplitude limiting	266	236 267 268 585-598	232 236 267	232 236 585	585																			
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•Generalized crystal circuit			231-233 236	231-233 236 586	586																			
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Amplitude		273	300-303 308 311	275 308	275 355	277 286 291 293-295 300-303 312 320-322	328 330 336 339 340	348 349	352	356 362	356 365 370-372	356 376 379	356 392 405	356 406 411 414 415 417-420	356 421	356	356 429	356 430 431	356 432	356	356	540 541 544 554 572	438 538	438
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Amplitude dependence on load			300 309 322			286 295 300 309 312 321 322 567	339 340						401	411-415							436	540	538	436

FUNCTIONAL CHARACTERISTICS OF CRYSTAL OSCILLATORS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
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Amplitude stability		273 294 306	296 297 299-303 308 322 581 595	322		283 284 294-297 299-303 306 321 322			352	357 360	368	379		412-415							436			436
Amplitude tolerance			308 309 582			290 293 295 303 312-316 566 567	336 343		352	357 360 361		379 568	402	412-415								540		
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Dependability of starting		268 273 306	294 297 289 300 308	276		277 282 291 294 296 297 299 300 323	339 340	346 348		363	364 374	376 379 387 391		406 414	421	424 425	429			434		540		

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Economy of manufacture			296 304 308 560 561 564 573	275	275 355	277 296	328 339	349		363		376 379 384 387	392	414									530	
Economy of operation			294 296 304 322			277 294 296 312 322	322 328 339					387										541	442 455 508	570
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Frequency range—operable, practical, optimum (See also Bandwidth.)		306 354	296 305 322 565	275 276	275 276 355	277 290 291 295 296 301 303 566 567	344		351 352	356 357 363	356 364 369- 375	356 376 387 391 568	356 392 405	356 406 414	356 421	356 423 425	356 428 429	356 428 430 431	356 428	356 433	356 436 437	539 543 544 551	438- 442 455 463 530 537 538	354 436 438- 440

FUNCTIONAL CHARACTERISTICS OF CRYSTAL OSCILLATORS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Frequency stability		354	269 273 274 296-298 305 309 310 314 315 581	269 273 275	275 355 356	277 279 283 284 296-298 301 302 309 310 314 315 322 566 567	328 330 332 339 341-343	269 347 349		356 357 363	356 368	356 376 380 387 391 568	269 356 392 405	356 406 415 417-420	356 421	356 425	356 428 429	356 428 430 431	356 428 432	269 356	356	541 570 572	438 439 462	438 439 570
Frequency tolerance		354	305 310 317 582	317	355 356	277 291 310 317	328 332 339	347 349		356 357	356 373	356 387 391 568	356 392 405	356 406 414 417-420	356 421	356	356 429	356 430 431	356 432	356	356	541 552	438 439 462	438 439
Harmonic output		596-598	304 305 308 311 322 582	322		277 304 305 311 321 322	329			356 359	356	356 376 387 388	356	356	356	356	356	356 431	356	356 435	356 437	541 572	442 530	
Installation (airborne, shipboard, ground, etc)			311 560			311	339							414								541		
Location of load			322	322		277 283 309 321 322 328 566 567	322 328	349		356 363	356 370 371 375 388-390	356 376	356 392	356 406 407 417-420	356 421	356 423	356 429	356 430 431	356 432	356 433 435	356 437	540		
Output power		294	294 296 305 322	275	275 355	277 284 286 294-295 305 311 322 566 567	305 322 328 330 333 339 340 343	349		356	356 370-372	356 376 568	356 392 404 405	356 406 408 412-415 417-420	356 421	356	356 429	356 430 431	356 432	356	356	541 572	438 454 538	438

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Output voltage		306	294 299- 303 322	275	275 355	277 284 286 293- 295 299- 303 308- 316 318 321 322 566 567	328 336 340 343	349		361 362	366 368 370	379 568		420		425					437	572	454 538	
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Temperature range requirements			304 582			277		349	353	357	364 373	387		414								540 541 572		
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CIRCUIT ANALYSES OF BASIC CRYSTAL OSCILLATORS (Quantitative relations which are fundamental as points of departure in attacking particular problems of design.)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
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••Bibliography numbers		154	149 154 212	149 212	212	149 211 212	211 212 618					211 212												
•Complex-function, impedance-linear-parameter method																								
••Qualitative discussion		267 289	267	289		267 289	267 289	331														458		
••Application illustrated		289		289		281 289	289	331 332 336														458		
••Bibliography numbers		211 466		426		232 426 533	232 426														211 212 697			211 212 697
•Linear-differential-equation method *(Not used or discussed in this handbook as means for solving over-all circuit, although differential equations are employed occasionally in restricted steady-state problems.)*		289	203 213 239	243 287 288	240 241	287 288				360														
••Bibliography numbers		211 332	232 750 823	232 750 823		232 823	232 750 823																	
•Loop-gain, loop-phase method (For similar analysis of loop-phase relations, see Phasor method below.)																								
••Qualitative discussion		267	267			280		345 347 348	351	357 360 363	365- 368	377 380	393 394	407 409	422					433		540 542 543		
••Application illustrated			267		267	281		348		360 361		378 383 388	367 394- 395	410	422					434		540 543		

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•Negative-resistance method																								
••Qualitative discussion			231-233 236 267	231-233 586-595	586-595	278-280										425	429					545 546 549		
••Application illustrated				233		233 278-282	233					378				425	429					547		
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•Phasor (vector) method																								
••Qualitative discussion		267-273	267-273	268-273		280 282 283	280 282	345 347		358														
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••Bibliography numbers		35	70 232			70 232	70 232																	
Amplitude considerations																								
•Derivation of loop-gain equation						284 289	289 331 336	348		359 360 363		378 388	395 396	410 411		424 425	425 426	289 426 427	289 331 426 427	434	289 436	548		289 436

CIRCUIT ANALYSES OF BASIC CRYSTAL OSCILLATORS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Loop-gain equation		267 (1)				284 (1,2, 5) 289 (2)	331 (2,4) 335 (1) 336 (1,7)	348 (1,6)		359 (3,4) 336 (2) 361 (10)		378 (1,21, 24, 25, 26) 388 (1,2)	395 (1,9) 396 (3)	410 (1,6, 7) 411 (1,2)	422 (1)	424 (1) 425 (3)				434 (1,5)		540 (1) 548 (2,3)		
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•A-C current and voltage limitations due to presence of crystal unit in circuit			294			277 282 284 286 290 293-295 300 303 312-316	277 336 339	349		361 362		379 387	402 403	412 415								540		
•Bias voltage limitations due to presence of crystal unit in circuit			245 294 303	271		282 286 293-295 300 303 312-315	339			359 362		379	405	412 413 415										
•Fixing electrical characteristics of limiter (vacuum tube, thermistor, etc) from loop-gain equation, crystal-unit limitations, and desired class of operation		267 294	294 300 305 322	273		284-286 290 293-295 303 308 312-316 322	333-336 339			361 362		379 388	401-404	411-413 415	425	429				434		540		
•Output amplitude estimated from equilibrium parameters of limiter		267 294				282 290 293-295 303 312-316	336 339			361 362		379	402-404	412 413 415								540		

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•Amplitude variation with effective resistance of crystal unit			226-237 294 300 308 309	214 230-237	229	290 293-295 300-303 308 309 312-316	336 343			361 362		379 387	401-403	411-413 415							436	540		436
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•Amplitude-stability equation										360 (6, 10, 11, 12, 13, 14, 18)														
•Interpretation of amplitude-stability equation and/or discussion of basic requirements for optimum amplitude stability		267 294 306	294 296 299 300 306 308	273		284 291 294 296 299 300 308	340 343		352	357 360-363	368 370-372	379	401-403	412 413 415								540		
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•Qualitative analysis and simplification of loop-phase requirements		267-273		269		268-273 280 282 283 289	268-273 328 332	269 345 347	351	357	268-273 365-368	380 383	267 269 393 394	407 409	380 383 421 422	423 424	423 424 429	268-273 427 430 431	268-273 427 432	269 433	268-273 436	540	440	268-273 440
•Derivation of loop-phase equation		270 272 281		270 272 281		270 272 281 289	270 272 281 289 331					383			383	424	424	270 272 281	270 272 281		270 272 281	548		270 272 281

CIRCUIT ANALYSES OF BASIC CRYSTAL OSCILLATORS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Loop-phase equation		267 (2) 270 (1) 281 (1,2, 3,4)		270 (1) 281 (1,2, 3,4)		270 (1) 281 (1,2, 3,4, 6, 11, 12) 289 (3)	331 (3,5)					383 (5)	267 (1)		383 (5) 422 (5)	424 (2)						548 (1)		
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•Frequency-stability equation				287 (1)		287 (1,2, 3,4, 5) 288 (2)	338 (1,2, 3,4, 5)			358 (4,5, 8, 10, 11, 12) 359 (5,6, 8,9)		241 (2)	399 (1,2)	413 (3)										
•Interpretation of frequency-stability equation and/or discussion of basic requirements for optimum frequency stability		298	245 251-261 269 298 309 310 593-598	273 287 288	355	277 279 281 283 284 287 288 298 309 310	332 333 335 336 338 341 342	346 347		357 359 361 363	368 371-373	379-386 393	396-400 404	406 413 415 419		424	426 429	426	426	433 435			438 439	438 439
Bibliography numbers for amplitude, frequency, and stability analyses		69 154 211 466 571 640 789	212 213 318 872	89 149 232 532	108 127 211 212 233	70 149 211 212 231 232 426 533 649 823 843	70 211 212 231 232 426 649 750 823 843			211 231 523	653	128 211 212	211 212	128 212	212	113 211 212 554	211 212	212	212	211	89 211	151	329	89 211

DESIGN OF CRYSTAL OSCILLATORS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
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Design procedure illustrated						311-316	336		352		371		404	414-420	421 422		429	430	432				439 443 447	439
Bibliography numbers		211 466	108 149 212 213 678 781 840	781	108 212	91 149 211 212 533 649	91 211 212 618 649		840	211 523	653	128 211 212	211 212	211 212	212	113 211 212 554	211 212	212	212	211 840	89 211 840	151	329	89 211 697 840

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Alphabetical indexing of principal factors to consider when designing for optimum or special performance characteristics.)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
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•Of crystal oscillator			228 294	232 233 232 233 236 237 273 275	254 275 355	277 283 284 286 289 291 293-295	328 336 338 339		352	360-362	364-366 368 370-372	376 379 387	392 402 403 405	411 412 414-420	421	423	429	430 431	432	433	436	540 541	438 440	254 438 440
•Of crystal unit (See also Methods of Mounting Crystal Blanks in Crystal Holders — paragraphs 1-132 to 1-170.)			227 228	230-237	229	312					374	387 388	402 403 405											
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•Discussion of			227 228	230-237	229					361														
•Parameters for indicating activity quality			226-237																					
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••Effective resistance (R_e)			584	232		300 309 312-316	333 336	348	353	361 362			393 394 401-403 405	412							436			436
••Equivalent series-arm conductance (1/R)			228-231	230 231	229							379	393 394 401-403 405	412			426	426	426			540		
••Figure of merit (M)			235																					
••Gridleak current			220 228			284			352		368										220			220
••Maximum effective Q (Q_{em})			234 235																					

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Amplitude		268 294 306	249 294 296 304 305 308 311 315 322	27[illegible]	275 355	277 278 282 284 286 291 293-296 308-318 322 566 567	322 328 333 336 339 340	348 349	352	356 360-362	356 365-368 370 371	356 376 379 387 388 568	356 392 397 399-405	356 406 411-420	356 421	356	356 429	356 430 431	5[illegible] 3[illegible]	356 434	356 436	540 541 572	438 454 527	438
Amplitude range		294	308-310		355	291 295 308-310 312 321 566 567	336 339	348 349	352	361 362	366 368 371	376 379 568		411-413	421			431				540 541	527	
•Expected, due to variation in effective resistance of crystal unit			232 249 300-303 308 309	3[illegible] 3[illegible]		233 237 290 294 295 300-303 308 309 312-316	233 237 308 336 343			[illegible]61 [illegible]62		379 387	401 402	412-415							3[illegible]			436
•Limitations of, due to specified drive level of crystal unit			258 294 311			277 282 284 286 290 293-295 301-303 311-316	328 336 339 344			361 362	37[illegible]	379 387	397 401-404	412 413 415 416					434				
•Of fully loaded circuit			309			286 295 309	339 340	349			37[illegible] 37[illegible]	387		417-420										
•Of nonloaded circuit						278 284 286 293 295 312-316	336 340			6[illegible]	366 370 371												438	3[illegible]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•With automatic gain control			308			308 315																		
•With manual gain control			301- 303 311			291 294 295 301- 303 311 318	337 340				366	387												
•With no gain control						286 293 295 312- 315						379 387	402	412 413										
•With overdrive of crystal unit			339				339				372			416										
Amplitude stability	263 265 266	294	294			283 284 294				357 360 361	368		393											
•Under variations of load	265		315 322	212 214		291 312 315 321 322 326	340		352				401 402	411 412										
•With automatic gain control			308 315			308 315	308																	
•With gridleak bias		306	296 297 299- 303			296 297 299- 303						379		412										
•With grid limiting		294	214	273		294																		
•With load electron-coupled			322			322					375													
•With tri-tet operation			214 322			321 322	322																	
•With variation in gain of stage										360	373	379										540		
Bandwidth		354			355	295 566 567	344	347	351 352	356 357 363	356 370- 375	356 376 381 568	356 404- 405	356 406	356	356	356 428	356 428	356 428	356 433	356	539	455 525- 529	220 354
•Broad-band circuit			247 309 310 311 322	275	275 355	277 278 309 310 311 322 323					374	376 377 381- 385 387	392 398 402 404 405	406 418		423 425				433			438- 440	438- 400

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Narrow-band circuit			247 309		355	277 283 308	328 344				365 372 375		404 405	417			428	428	428	435			451-454	
•Of crystal units (See also Crystal element characteristics.)			139 246-248	276 317		305 309							405											
•Single-frequency circuit			247 309 322			277 283 291 322			353	357 358 363	364 371			419 420					432	435			451 455	
•With adjustable tuning		306 354	246-248 322	276 317		291 301 303 317 322	328 329 339 344	350	352	363	364-368 370-375	376						431			436		439	220 354 436 439
•With overtone crystal units				276	355	277					364-366 370-375	376 387 391	392 402 404 405											
Bandwidth and selectivity parameters of crystal unit			197 246-248	276							368 374													
Bias		288				288 312	337							411 415								540 549-553 555		
•Automatic gain control		337	308 310 315			308 315	337																505 510	
•Cathode			307			307	337			359 362		379 382 387								434	220			220
•Class A		298	305 308	273		284 308 312 314 315 322				359 362		376 379 387	401	411 412						434			537	
•Class AB				273		312 315 322								412										
•Class B		294	296 300 311	273		293 294 296 311 312 322								412 417										

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Class C		294	296 299 300 311	273		282 284 293 294 296 311 312	337 339					376 387 388	392 401- 403	406 420	421						437		438	438
•"Class D"		298	298			298	342																	
•Effect of crystal resistance				271		297 312- 316															220			
•Effect of gridleak resistance		306	282 296- 298 307 308			282 296- 308 313	341					379												
•Fixed		294	294 296 300 305	271 273		294- 296	339																	
•For frequency multiplication			322			322																	474 537	
•Gridleak		306	296- 308	273		282 286 293 295- 316	339 343		352			379 382 388	405	411 412							220		474 537	220
•Limitations of, due to specified crystal drive level			294			282 293- 295 303 312- 316	339					379		412 415							220- 224			220- 224
•Reactance tube (afc)								350													437		484 492	
Build-up of oscillations	266	267 268 294	232 236 275 294 296 299 304 305	232 236 273 276 308 586- 595	355 586- 595	294 296 299 308 315	337 339 340	346		357 363	364- 367	377 379	401	411		425	429			434		540	455 484 489 532- 535 537	
Buffer amplifier			304 305 308			304 305 308 323																	522 538	
Capacitance						290 291					365- 368													

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Cathode			307			307 566						383 388		407 417 419										
•Dynamic						278- 282 287- 290	332	350										430						
•Grid			296			278 284 287 288 290 291 293 294 296- 298 301 312 322 323	328 334 336	345 348		358 359		381- 383	398- 400 404	406 413				430	432	435			439	354 439
•Load (See Load capacitance of crystal unit.)																								
•Negative (C_n)						278- 282 287- 289												430						
•Optimum grid-to-plate ratio (C_p/C_g) (See also Gain, optimum.)						284- 286 290 291 293- 295 298 301 303 308- 310 312- 316 318												430						
•Oven			279 4-73			279 321 323																		

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Plate (C_p)			309			277 278 280 281 284 287- 290 291 293 294 298 300 309 312	329 332 338 340			358 359		381 389	393 394 398- 400 404	407 413 419				430	432					
•Plate-to-grid (C_{pg})			279 311			277- 279 287 295 311 320- 323	329 332 334 336	345			371		393 394					430	432	435				
•Shunting crystal			182 184 185 187 188 190- 196 201 219 252	208 211 212 230 231 233 243 276	205- 207 355	278 279 287 300 305 320- 323 566	332 334 336	348 350			365 367 368	376 381 385 388 391	393 394 405	406 412 414 417- 419	422	424 425	426	429	430	432 435				354
•Stray			188 201 311 598	233 276	189 355	278 279 287 289 290 292 311 318 320- 323	332 334 336 339	345 347	351	357	365 372	381 387- 389	392- 394			423 425		429	430					
•Stray, measurement of			292			290 292																		188
Capacitors						318					369	389												2-90
•Fixed, r-f bypass			245 303 307 320			303 307 320 321 324			352			382 389												220
•Fixed, tuning			245		355	290 318	329 336	345- 347	352		369	389	393							432				

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Variable			245 322 581			291 294 298 301 318 321 322 566	329 338		352	358 363	365- 369	389						429	431		436		439 513	220 436 439
Cathode bias			305 307			307	337			359		387								434				
Choke, r-f						292								406 407								551		
•To reduce circuit losses		294	296 297 307 309			277 294 296 297 309	339																	
Class A operation		298	305 308	273 276		284 308 312 314 315 322				359 362		376 379 387	401	411 412						434				
Class AB operation				273 276		312 315 322								412 415										
Class B operation		294	296 300 311	273 276		293 294 296 300 311 312 322								412 417										
Class C operation		294	296 299 300 311	273 276		282 284 293 294 296 300 311 312	337 339					376 387 388	392 401- 403	406 420	421						437		438	438
"Class D" operation		298	298			298	342															553 555		
Coils, inductors										358	365 369													

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•RFC		294	296 297 307 309			277 292 294 296 297 309	339	350				390		406 407								551		
•To antiresonate with unwanted capacitance			248		355		329	347			365	376 381-383 385 388 391	394	406 417 418	422	425								248
•Transformer										358 362 363	365-369 371-373	390	393 394	406 407 411 417-420	421							542		
•Tuning		306	322			277 283 298 322 323	328 329 338 340 343 344	350		363	365 367 369 374	389 515	267 393	406 407 417-420	421	425	426 427	426 427	426 427		436	542	438 513 515 516	220 436 438
•V-H-F											365 369 371-374			417-420										
Crystal calibration (See also 2-66 to 2-151)										357														438-440
Crystal calibrator circuits																								
•Figure numbers						135 (D,E, Z) 137 (F,G, L,M, V) 138 (B, D)	149 (D, F,G) 151 (C) 153 (E-J) 186					175 (K, L)						187		184	185 (A-D)		186 187	159 186 187
•Principal requirements of																							438-440	438-440
Crystal check points																							439 440	439 440

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Crystal current				216 232 233 594	205 210 249 594	233 237 277 284 286 289 290 293 294 300 301 303 312- 317 323	233 237 332 339	3[illegible]5 3[illegible]8	353	361 362	366- 368	377- 379	393 394	412								540 542 543		188 220 259
Crystal element characteristics			89- 119 192- 200 246 247 254 256 259- 261 305	208 209 212 217 276 317	207 217 253- 255				351	357 358 363	364- 368 374	391	396	413 414			42[illegible]	42[illegible]	2[illegible]					438
Crystal impedance meters			274																		436			
•Application					2[illegible]				352				40[illegible] 41[illegible]								436			188 220- 225 436
•Design f											373 374										220 436			220 436
•Figure numbers																					106 185 (A- C)			106 185 (A- C)
•Military Standard test sets (See also paragraphs 2-66 to 2-151.)													40[illegible] 41[illegible]								436			25 220 236
Crystal oscillators, early development of			17- 22	27[illegible]					351															
Crystal oscillators, types of			274 275 449 560 586	276 345 351 354	345 351 355 356 449																	539		

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Crystal parameters (See Parameters of crystal unit.)																								
Crystal power			181 186 230 249-252 256-261 303	214 215 230-233 237	249	284 286 293 295 296 301-303 312-316 319 324 566 567	333 336 339 340			359 361 362	370 372	379 387 397 399-404 568	401 402	408 412 413 415 420	421				432	434				220 221 224
Crystal unit, major factors determining selection of (See also Crystal element characteristics.)																								
•Availability							339				374			414										
•Drive level			181 256-261 311	214 301-303		277 278 282 284 286 293 311-316 566 567	333 336 339 340 344		353	359 361 362	370	379 387 568	392 397 399-404	412 413 415	421				432			540		
•Frequency range		354		276		277 278 295 301-303	336		351	357	370-375	376 387	392 402 403	413 414	421		429	430 431	432	433		539		354
•Frequency tolerance		354	215 257-260	276		277 278 291				357		376 387 568	392 404	413 414	421		429	430 431	432				438	354 438
•Load capacitance		354		317		278	332	348	352															354
•Maximum effective resistance			228 261 583	214 230	229	278 293-295 300 303 312-316 566 567	333 336 339	348	353	361 362	368	376 377 379 385-387 568	393 394 396 401-403	411-414	421	423 425	429	430 431	432	433		540		
•Maximum shunt capacitance											365	385	394	414 419	422	424	426 429	426 430	426 432					

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Mode of operation																								
••Fundamental, overtone				276	355	277	339		351		364 365	376 377 387	392 403 405	407 414			428	428	428	433				
••Parallel, series		354	594	214 276		277		350	351			387	393 403 405			425	428 429	428 430 431	428 432	433		550 551		
•Mounting method			24 132- 170 178 258 320 577- 579			320 566 567	339		351		365	381 385 568	393 394	414								570 571 572		570
•Operating temperature range			22 23 252- 255 304 582			277		349	353		373	387		414								540 541 572		
•Relative performance characteristics			226- 261 305	317		287 288	339 343			357 362	365	386	393 394 396	414									438	438
•Special test specifications			25 317 320 581 582			285 286 295 300 320	332 339 344	351		357 362	365 368			414			426	426	426				438	438
•Type of holder			24 171 320 579			320	339				365	381 385	393 394	414										
•See Section II for full description of Military Standards and Military Test Specifications for recommended crystal units.																								
Crystal voltage																								
•A-C			143 248- 250 320	232- 234		320 324	336 339 340 343	345 348		361 362	365 366 368		393							436				220 436

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Effect on feedback Q (Q_f)				233 244 270-273		279 281 289 297 298	332	348														556		
•Effect on frequency stability			250 597	210-212 214	206 207 240-242	279 281	332 333	348		359	368	376	396 399	406 413-415										
•Expected range of values			199 200 202 205 209 294	217 271		278 290 294 295 300 301 312-316	332 336 339 343	348		361 362		379 387	401 402	412 414-416	422	425						549 551		
•Maximum value			216 300 303	271 584	584	278 285 290 293 295 300 303 312-316	333 339	348	353	362		379 385 387	401-403	411-415						433 434				
•Minimum expected value			199 200	271		290 295 301 312-316				362		379	401	412 415										
•Most probable value			199 200			295	333			362		379	402 403											
•Reducing the effects of changes in			254-256 261 308 309 595	214 271		278 295 308 309 320	332 333	348		361 362			401 402	412 413 415							436	553 555-559		436
Efficiency of circuit			248 296	276		284 296 312	339	349				376	405	420								541 544		
Electron-coupled circuits			279 322			279 322 327 567																		

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Advantages of			320 322	214		320 322 565	322 439				375	387			421			431					439	439
•Design features of			322			322 327 510 567	439				375	388 390			421			431					439	439
•Figure numbers						137 138 139 247 2-2 2-6 2-18 2-22 2-28 2-32 2-54 2-56	139 152 186				172 (C)	174 (A) 175 (I) 2-26 2-66			180 (C)			182 (D)					186 187	186 187
Feedback circuit		267- 273		269- 273		279 281 295 297 324		348		357		377 386	267		421	423						540 542 546		
•Effect on state of oscillation		269- 273 298 306	245 294 298 590- 594	233 237 244 273 291	240- 242	277 278 282 284 289 294 298 321 322	277 328 332 334 336 339 341	345- 347		360	365- 368	386	393 394 402	412 415			429				220 436	540 542		220 436
Feedback Q (Q_f)		271- 273	294	271- 273		277- 284 289 294 295 297 298 321 323	277 332	347														543 556		
Filament voltage			313 315																					
•Effect of variation of			315			315	315																	
First crystal oscillator			17 18						351															

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Frequency adjustment			211 246 247 322	215- 217 273 317	217 355	277 291 298 317 321 322	328 329 337 339 341 344	350	352	363	364- 369 371 374	376 387- 389		417 418				431			436 437		439 445 455 458 464 509 513 517 528 531	436 439 2-66 to 2-151
Frequency division									353														438 440 445 450	438 440 2-92 2-94 2-118 2-133 2-134
•Regenerative frequency divider																							440	440
Frequency-mixing circuits		598				279 327		350				389 390											440- 538	440 443 2-122 2-124 to 2-135
•Figure numbers						135 (J,L- Q,Z) 138 2-2 2-22 2-54 2-56	152 (A,D, J,K) 153 (H- J)																187- 221	187- 190 2-76 to 2-82
Frequency multiplier circuits		7	322	276		322 325 326	322 339				375	376 387 388 390			421			431					438- 538	438- 440 2-111 to 2-117
•Figure numbers						136 (E,H, I) 137 (C-N, U,V) 138 (B, D) 139 2-6 2-28	139 149 (F,G) 150 (A-C) 151 (H,K) 152 (A,B, D-G, I-K) 153 (H-J)				172 (C)	174 (A) 175 (A-F, H,I, L) 2-26 2-66			180 (C)			182 (D) 187					186- 221	186 187

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•High Q in crystal circuit			186 217 250 274 297	212-214 216	207 240 241	277 282 297 308					367 368	376 379 381 385 386	393 396-399 404	413		425				435		549		
•High Q_f		270	294			277 279 282 284 294 295	332																	
•Increasing plate-circuit resistance			310			277 282 284 294 297 298	333 337										429							
•Large gridleak resistance			296-298			277 282 296-298	341	348				387	398											
•Low crystal drive			181 252 256-261 314	276		277 282 284 295 324						379 387	401 402	413										
•Maintaining resistive plate circuit		269 271				277 282-284 323	332	347 348		357	368	376 377 380-385 387	393 394											
•Minimizing effects of distributed impedances		269	186-189 245 252		205 207 217	279	339	347		357 363	365 369 371 372 374	376 380-385 387-389	393 394	417-420	424									219
•Minimizing effects of variations in																								
••Grid capacitance			245			295 298				359	373	381-383	392 399 400 404	406										
••Load capacitance			245	211-213 217 243 244		284 295 298 301 318 566	332				368													

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
••Load resistance		21 271 322	245 322	214		322							402											
••Plate capacitance		322	245 322		242	322				359	373	381	399 400 404	413										
••Plate resistance		20 271 298	245 298 310 311			277 282- 284 294 298 310 311 323	332 335 337 342	347 348			368 373	380- 385	402 403											
••Plate voltage		20 298	245 298			277 282- 284 298 323	332 341 342	347			368 369	380- 385	403											
•• Temperature (See also Ovens, and Temperature control.)			22 23 252- 261	215		277						387										554		
••Tube gain		298	245			282- 284 294 298	332			363	373	380- 385											474	
•Minimizing harmonics		322 595	245 249 304 305 308 311			277 308 311 321 322	329 343			359 363		387								435		558	438	438
•Minimizing grid losses		271 294	296- 298 301 306 307 308	273		277 282 284 294- 298 307 308 321	332 336 339 341	348		359		387	392		421									
•Minimizing load						277 278 298 567	336 341					379	392											
•Minimizing transit time											369	381 382 383 387			421									
•Neutralizing circuits			245 326			326	339					383 387 389	392- 394	406 419	422					435				

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Optimum relations among stability parameters	266	298	302 310 562	210 273	245	285 298 302 310	332 337 342			359 361 362	368	377 379 387	392- 394 396- 404	413 415 419			426 429	426 430 431	426 432			553 555	474	
•Plate phase stabilization		269 530				282 283 323						383	394										530	
•Suppressing parasitic and free-running oscillations			426								365 373 389	381		406	421	424	426	426	426	435		554	458	
Frequency stability versus amplitude stability	263		245 296 297 322 581	214 315		283 284 296 297 315 322	330			360 361	366 368		401	406 415 417- 420										
Frequency stability versus output amplitude		595 596	245 249 294 296 301 302 581	214		277 282 284 286 294 296 330	277 328 330 341			356	356 371 372	356 379	356 392 397 404 405	356 413 417- 420	356 421	356	356 428	356 428	356 428	356	356			
Frequency synthesis				276																			441- 538	
•Estimation of all frequencies involved in synthesizing network																							440 442 445- 449 455- 461 464 519- 522 525- 529	
•Methods of synthesizing frequencies				276																			276 440- 442 455 463 508 509 512 517 530	440 443 2-124
•Stability of channel frequencies																							442 458 462	

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Total number of channels																							442 455 463 509 512 517 537 538	
Frequency tolerance (See also paragraphs 2-8, 2-18.)	263	354	245 252 304 305 310 317 582	215 276 317	355 356	277 278 310 311 317	328 339	347 349		356 357	356	356 387 568	356 392 404 405	356 406 414	356 421	356	356 429	356 430 431	356 432	356	356	552	438 439 462	354 438 439
Gain of																								
•Autotransformer											365 368		393- 395 397 398 401- 404	407 408 410- 414 417- 420	421 422									
•Cathode follower												378 383		409 410	378 383 421 422									
•Conventional vacuum-tube amplifier		268 269	233 237			282 284 286 308 311	328 333- 336 339	345 348		360	365		395							434				
•Electron coupling			322	214		322	322																	
•Grounded-grid amplifier												378		409 410									513 523	
•Grounded-plate amplifier			322			321 322						378												
•Thermistor bridge										357 358 360														
Gain control (See also Amplitude range.)				214						360			402 403											
•Automatic			308 310 315	214		308 315	308			360														
•By loading			309			295 309 321			352	363				412 415										
•Gridleak				214 273								379											474	

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Manual			301-303 311			294 295 298 301-303 311 318	340			362	365 366	387									220	540		220
•With load isolated			322			322															220			
Gain, optimum			308 322 562	233 237 273		284 286 290 291 293-295 301 303 308 311-316 322	328 333-336 339	348		360-362	368	379 387	392-394 397-399 402-404	411 413 415						434		540		
Grid choke		294	294 297 307			294 297	339																	
Gridleak bias (See Bias.)																								
Gridleak current		294	296 300 307		254	284 294 296 300	339		352	359	365	379		407							220			220 254
Gridleak resistance (R_g)			296-307			296-307		345 348								425								
•Effect on amplitude stability			296-308	273		296-308						379												
•Effect on frequency stability			245 296-298	273		281 282 296-298	341 342																	
•Effect on oscillator keying			296 304 305			296 304 305																		
•Effect on output control		306	296 301-303 305	273		296 301-303 315	340 341																	
•Value of		306	296-308			277 278 282 296-308 311 313	333 341	348	352			387 398		417-420	422								438	438

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Grid losses			296 297 307 308			296 297 308	331																	
•Effect on feedback Q (Q_f)				271 273		281 282 284 297 298 321	332																	
•Effect on grid capacitance		298				298																		
•Effect on oscillator stability			308	214 271 273 296 297		282 284 296 297 300- 303 321	332 341				367 368		392											
•Effect on state of oscillation			305	214 271 273		278 281 282 284 287 321	332 333 339 341				367 368		392 395											
•Input loss of vacuum tube			305			295							392 395		421									
•Minimized by grid choke		294	294 296 297 307			294 296 297	339																	
Grounded-grid circuits												377 378 382		406- 420								523	
•Figure numbers												174 175 2-4 2-8 2-10 2-20 2-24 2-26 2-30 2-38 2-40 2-66		179 2-12		181 2-14 2-16 2-48	182 (B)						215	
Grounded-plate circuits		322	320 322			320- 322 566 567						377 378			421 422						437			

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Figure numbers						135 (R-Z) 137 (A-H, J-N, P-V) 138 (A,B, D) 139 243 247 2-6 2-18 2-28 2-32 2-54 2-56	139 151 (F,G) 152 (D-L)				172 (C)	174 175 (G,I, J,K) 2-4 2-8 2-10 2-20 2-24 2-30 2-38 2-40			180	181 2-14 2-16 2-48	182 (B)	182 (D)			185 (D)			
Harmonic of crystal (See also Crystal element characteristics.)	75-86		183 192 197	276	207				351	363	364 365 373 374	376 377 391	403 405	407 414 417 418			428	428	428					
•Overtone versus fundamental			253-255	276		277	339		351		364	376 377 387	392							433				
Harmonics of oscillator	265 266																							
•Generation of		595-598	245 304 311 322			311 322 325					375	376 387 388 390						431			437		438-441 455 464 473 478 519 530	438-440 2-111
•In output		595-598	245 249 304 305 311 322 582			311 322 325				356 359	356	356 388 390	356	356	356	356	356	356 431	356	356	356 437	541 551 558 572	438-440 445 537 538	438-440
•Reduction of		595	245 249 308 311 322			277 308 311 321 322	329 343			359		387								435		551 558	452 525-529	
Heterodyne circuits (See Frequency-mixing circuits.)																								
Impedance inversion		426	426-428																					

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Intermittent oscillations			282 297 305	593 594	593 594	282 297		345 346															531	
Keying		531	304 305																				531	
•Of crystal oscillator			149 304 305			304 305	305																	
LC oscillators		7 21 213 267-273 305 306 314 328										389												
•Crystal stabilized			274		355			350		357 363	364	377 387 389									220 436 437		455 491 530-538	220-224 436
•Figure numbers (Circuits indicated can operate as free-running oscillators if the crystal unit is shorted out, or else is removed.)								155 (B, C)		163 164	167 168 169 170 171 172	174 175 2-10 2-26 2-38 2-40 2-66	177 2-60 2-68	179 2-12 2-62	180	181 2-14 2-16 2-48	182 (B)	182 (C, D)	182 (E)	184 2-58	106 185		187 219 220 221	106 185 (A-C)
•Switching from crystal control to		306	396			296 306	339	350				389									220 436 437			220 436
Leads			182 184 187-189 201 217 245 579		205 207 355						365 369	376 387 389											523	219 2-122
Limiting action		585	585	585	585		339					379												
•In generalized oscillator		267 268 596-598	585-598	214 232 236 273	586-595	586-595																		
•Of plate varistor		294	294 305			294 295			352													558 559		

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Of thermistor		294 595	294 595							357 360 362												559		
•Of transistor			590-594																			540		
•Of transitron circuit			590-594													425	429					546		
•Of vacuum tube with agc			308 311			308 311	339																	
•Of vacuum tube with cathode bias		337	305				337					379												
•Of vacuum tube with fixed bias		294	294 300 305			294 295 300	339																	
•Of vacuum tube with grid-leak bias		282 306	296 300 311	214 232 273		282 284 296 300 311 315	339							411										
Load			230																					
•Coupling to		21 322	309 322		242	286 291 309 321 322 566 567	328 339 340	349	352	363	370 371 375	387-390		406 418						435	437		454 523	
•Effect on oscillator performance	265 266	21 269-272 281 322	238 245 298 305 309 322	214		277 278 280 281 284 286 291 295 298 309 314 322 567	322 332 333 336 339-343	345 348		363		387 389	392 393 405	406-408 411-413 415			429					540		
•Location of						298 321 322 567	328	349		356	356 370 371 375	356 376 387-390	356 393 405	356 406 407 417-420	356 421	356	356 429	356 430 431	356 432	356 433 435	356	540		
•Requirements of		281	582			280 281 289 291 322 567	332 333 336 339 344	348				387 388	393 397 404	406 407 412 415			429			433		540		

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Load capacitance of crystal unit (C_x)																								
•Analysis of						278-282 290 294	328 332																	
•As mathematical abstraction of generalized circuit				210 211 230-232		233 278 282	233																	
•Dynamic component introduced by vacuum tube						278 280-282 287 290	332	350																
•Effect of stray capacitance upon				233		278 279 287 290 311																		
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•Relation to frequency		354	225	210-217 233 317		290 291 298 317	328 332 340 341	350	352		367 368													218 221 223 354
•Relation to frequency stability		354		210-217 233 243 244 287 288 317		287 288 298 317	334				367 368											551		354

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Military Standard crystal units and holders (See Sections II and III, respectively, for complete descriptions of Military Standards for individual types of crystal units and crystal holders.)			25 133 188 200- 202 208 209 226 254 256- 258 260 261	212 217 222- 224 233 236 271	207 220 221	278 279 291 293 295 479 481 486 495 510 516	332 336 339 340		353			472 510 514 515	396 403	414 415									220- 224
Multiple frequency generation		7 306 596- 598	308 309 322	276		277 301 303 308 309 322	328 344			356	356 371 374 375	356 376 387- 390	356 404 405	356	356 421	256	356	356 431	356	356	220 356 436 437		436- 538 571	220 436 438- 440
Multistage oscillators		289						345- 350		363	373 374	376- 391 472 510 514 515								433- 435			440	440
Negative capacitance (See Capacitance.)																								
Negative resistance (See Resistance.)																								
Neutralizing circuits			245 326			326	339					383 387 389	392- 394	406 412 419	383 422					435				
Oscillator modifications		283 306	245 301 303- 309 311 428	214 271 273 428	428	271 277 279 282- 286 291 294 305- 309 311 317- 327 566 567	271 329 339	349 350	353	363	369- 375	376 382- 384 388- 391 568	394 404 405 416- 420		421	427		431 436 440		435	436 437		339 440	354 436

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Figure numbers		131	131 182	123 131 142		123 131 134 135 136 137 138 139 182 (C, D) 187 243 247	139 142 143 149 150 151 152 153 182 (E) 186 221	155	157 158	163 164	167 168 169 170 171 172	174 175 250	177	179	180	181 182 (B)	182 (B)	106 182 (C, D) 187	182 (E)	183 184	106 182 (C, D) 185	228 232 (B) 233 240 254 256 257	186 187 188 189 192 196 199-203 205 206 210-217 219-221	106 159 185 (A-C) 186 187
Output control		306 337	214 296 301-303 308 309 311		428	284 291 293-296 298 301-303 308 309 318	337		352	357 360-363	366	379 387 388	401 402	412 415 417-420						435	436	540 555-559	338-441 448	338-440 436
Output power		294 306	214 228 230 294 300 304-306 322 582	237 275	275 355	277 278 284 286 287 294 305 314 319 322	277 305 322 328 330 333 339 340	349		356	356 370 372	356 376	356 392 397 399 404 405	356 406 408 412-415 417-420	356 421	356	356 429	356 430 431	356 432	356	356	541 544	338 454 538	338
Output-to-crystal-power ratio			228	231 233 237			333 339 340						392 397 399 404	408 411 413 415 420	421				432					
Ovens (See also Section IV.)			22 23 215 252 253 279 317	317		279 317 479 481		349				387 472 514										571 572		
Packaged oscillators			560-584			566 567					371	568		406								569-572		570

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Parameters of crystal unit, determination of (See also Crystal element characteristics.)			184 185 188 190-204 208 209 217 246-250 584	210-212 216 230-237 243 244	205-207 229 240 241	279-300 305	337		351	362			396 405								436			218-225 436
Plate characteristics, requirements of		272	245 303 305 311	273		280-282 284-286 290 293-295 308 310-316	332 333 335 336 339 342	348		359 362	371-373	377 379 386 387	402-404	312 409 412 413 415		424 425	429			434				
Plate-circuit design		272 306	245 249 308-310	271 305		278 280 281 283 284 286 289 290 293 294 298 308-316 318 320-327 567	328 329 332-334 336 339 342	345-348	351	359 362 363	370-375	376 377 379 381 383 384 387-391	393 394 398 404 405	407-409 411 412 415 417-420	421 422	423-425	429	430 431	432	433-435	220 436 437		441-538	220 436
Plate d-c voltage			214 245 309 310 311	288		277 284 288 291 311	335					379												
•Magnitude of			245			290 293 298 302 309 310 312-316 566 567	336 339 340 341	348	352	362	369 372	379 384 387 391 568	403	412 415 417 418 420			429	430	432					

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Regulation of		298	245			277 298 309 310					369		403											
Plate resistance of vacuum tube (R_p)		268 270 272	232 311	271 273 288		277 280- 286 288- 290 293- 295 298 311 312 315	331- 333 335- 337 342	346 347		362	369	380 387	403							434				
Power delivered to crystal unit (See Crystal drive level, Crystal power, and in Section II, Test Level of Drive, Second Test Level of Drive.)																								
Power oscillators		21 294	149 249 258 294 300 322	273 276		286 300 305 322	300 305 322 339				372			420										
Purpose of oscillator, design factors influenced by		294 296	149 245 247- 250 252 253 258 311 322 562	214 232 273 276	355 356	277 286 291 296 305 306 311 322- 327	322 328 330 336 337 339 344	349 350	353	357 362 363	370- 375	376 387- 391	392 401 404 405	414 415 417- 420	421		429	431		433 435	220 436 437	539 541	338- 443 455 530	338 354 357 570
Q of crystal unit (effective, as well as actual)			139 186 190 199 200 202 227 249 250 274	213 214 217 231- 237 270		279 284 298 300	336					386	396	413						435				
Q of crystal circuit			300 305 306 584	216 270 283	249	280 283 289 300	331 332 336				367 368	386	396- 399 401- 404	413						433 435		543 549		

CRYSTAL OSCILLATOR DESIGN CONSIDERATIONS (Continued)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Q_f of feedback circuit		270 272 294	294	271 273 297		277- 284 289 294 295 297 298 321 323	277 332	347														543 556		
Replacement of crystals (See Interchangeability of crystal units.)																								
Resistance								347			369													
•Cathode		337	307			307	337	349	352	362		377 379 386- 388			422					434 435	220			220
•Collector, of transistor (r_c)																						540 548		
•Crystal-circuit			300 426 427 584	214 283 584	240- 242 249 355 584	279 289 297 298 300	331			360	367 368	379 386 387	393 396 401	413 415- 420	422		426 427 429	426 427	426 427	433 435	436			436
•Damping			426									381 382 385		418		424	426 429	426 430 431	426 432	433	436			436
•Distributed			182 186 189								368													
•Effective, of crystal unit (R_e, R_{em}—also R, R_m for series-mode crystals)			204 205 209 261 311 583 584	217 224 232 233 271 427 584 586	220 229 241 355 584 586	278- 281 284 285 290 293 295 297 300 301 303 311- 316 320	332 333 336 339		353	357 358 361 362	368	376 379 385 386 387 391	393 394 396 401- 405	406 409 411- 420	422	423- 425		427	427	433 434	436	540		436

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
•Effective, of grid circuit			308	273		297-300	331-333 336			358	368		393 395 398 404	406 413	421					435				
•Feedback circuit		269 270		271 273 297	240-242	279 284 289 297 298	328 332			357 361		379 386	393 395								436	540		436
•Gridleak (See Gridleak resistance.)																								
•Load		269 270 281	245 305 309 310 582	214		277 278 280 281 283 286 289 295 298 300 308-312 314	331 336 340	348 349		363	370	387 388	393 405	406-408 411-413 415 417-420	422	425	429	430 431	432	433 434	436	540		436
•Negative (ρ)			232 586-598	232 233 236 586 594	586-594	278 280						378				590 591			432			545-547 549 590 591		
•Plate-circuit (See also plate resistance of vacuum tube.)		269		271		277 280-284 288 311	333	345-348	352	359 362 363		377 381 387 390	393 395 398 404	408 409 412 413 415		425	429	430 431	432	433 434			339	339
•Screen-circuit			303			303 324			352			390		417-420							220			220
•Series-arm, of crystal unit (R, R_m)			182 185 190 199 200 202 204-207 218 228 261 305	214 216 230 231	205 220 229	300 305				357 358 361 362	367	379 385 386 387 391	393 394 396 401	406 409 411-420		424 425	426 429	426 430 431	426 432					
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