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INTRODUCTION:

This is the seventh edition of "Q-Curves for Iron Powder Cores." It is an application supplement to Micrometals RF Catalog—Iron Powder Cores for RF Applications. (Refer to page 38 for a brief description of the full product line.)

The information provided in this supplement will help the designer select the best core and winding for high Q inductor requirements with a minimum of experimentation. It provides practical guidelines regarding the interaction of core size, core material, and winding considerations as they affect Q versus frequency characteristics. For those interested in a theoretical treatment of the subject, the following two excellent books are recommended: THE THEORY AND DESIGN OF INDUCTANCE COILS by V.G. Welsby and HIGH FREQUENCY MAGNETIC MATERIALS by W.J. Polydoroff. Both are published by John Wiley & Sons.

For this supplement, the following relationships are important:

The Q of an inductor is represented by the following expression:

$$Q = \frac{2\pi fL}{R}$$

Where: f = frequency
L = inductance
R = effective series resistance due to both copper and iron loss

To calculate the number of turns required for a desired inductance use the following formula:

$$\text{Required turns} = \left[\frac{\text{desired L (nH)}}{A_L\ (\text{nH}/N^2)}\right]^{1/2}$$

A_L in nH/N^2 is listed for all cores in Micrometals Catalog #3.

Generally, when designing an inductor for high Q it is best to optimize the coil for Q and then select an appropriate resonating capacitor for the resultant inductance rather than to select a desired inductance and then sacrifice Q in order to achieve that inductance.

The interrelationships between frequency, Q, inductance, core size, and winding considerations are discussed in more detail on pages 3 and 4.

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GENERAL MATERIAL PROPERTIES FOR RF CORES

Mix #	Basic Iron Powder	Material Permeability (μo)	Temperature[1] Stability (+) (ppm/°C)	Resonant Circuit Frequency Range (MHz)
1	Carbonyl C	20	280	.15-3
2	Carbonyl E	10	95	.25-10
3	Carbonyl HP	35	370	.02-1
4	Carbonyl J	9.0	280	3-40
6	Carbonyl SF	8.5	35	3-40
7	Carbonyl TH	9.0	30	1-25
8	Carbonyl GQ4	35	255	.02-1
10	Carbonyl W	6.0	150	15-100
12**	Synthetic Oxide	4.0	170*	30-250
15	Carbonyl GS6	25	190	.15-3
17	Carbonyl	4.0	50	20-200
42	Hydrogen Reduced	40	550	.03-.80
0	Phenolic	1	0	50-350

[1]Temperature stability values listed are for closed magnetic structures.
*Non-linear
**Mix 17 was developed as a temperature stable alternative to Mix 12 and is recommended for all new designs.

Note: For information on Mix #'s 8, 18, 26, 28, 33, 40 and 52 see Micrometals Catalog 4 for Power Conversion and Line Filter Applications.

PART NUMBER

Type of core: T-Toroid

Dominate Dimension in 100th of inches

T 80 - 2

Micrometals Iron Powder mix No.

Code area for additional characteristics.

ENGINEERING KITS

For a wide selection of iron powder cores for engineering design and evaluation, the kits described below are available at a modest charge.

ENGINEERING KIT #20
Mixes 1, 3, 15 Frequency: 20 KHz - 3 MHz
T12, T16, T20, T25, T30, T37, T44, T50, T68
17 items, 170 pieces

ENGINEERING KIT #21
Mixes 1, 3, 15 Frequency: 20 KHz - 3 MHz
T80, T94, T106, T130, T157, T184
10 items, 44 pieces

ENGINEERING KIT #22
Mixes 2, 6, 7 Frequency: 250 KHz- 30 MHz
T7, T10, T12, T16, T20, T22, T25, T27,
T30, T37, T44, T50, T51, T60, T68
34 items, 340 pieces

ENGINEERING KIT #23
Mixes 2, 6, 7 Frequency: 250 KHz - 30 MHz
T72, T80, T94, T106, T130, T157, T175,
T184, T200, T225, T300, T400
20 items, 60 pieces

ENGINEERING KIT #24
Mixes 10, 17, 0 Frequency: 10 MHz - 250 MHz
T5, T7, T10, T12, T20, T22
T25, T27, T30, T37, T44, T50, T68
34 items, 340 pieces

ENGINEERING KIT #25
Mixes 2, 6, 8, 10, 0 Frequency: 30 MHz - 1000 MHz
(Broadband Transformer Applications)
BLN814, BLN1728, BLN1728A
12 items, 120 pieces

PARAMETERS AFFECTING Q VERSUS FREQUENCY CHARACTERISTICS

CORE CONSIDERATIONS:

Core Material: The table on page 2, "General Magnetic Properties," provides information about the iron powder mixes for RF applications. The column "Resonant Circuit Frequency Range" shows the general frequency range over which a given core material, in the toroidal configuration, will produce the highest Q relative to the other materials.

Inductance Value: The frequency at which the Q peaks is dependent on its inductance. As inductance increases, by adding turns, Q will peak at a lower frequency. The Q value may increase or decrease as the number of turns is varied. Page 30 illustrates this characteristic.

Core Size: Large cores will produce higher Q than small cores, (Page 13). The optimum Q for a large core will occur at a lower frequency than the optimum Q for a small core. (Figure A).

Core Shape: The toroidal core is the most efficient configuration for high Q RF inductors. Its self-shielding geometry also limits stray magnetic fields. A comparison of various core shapes is shown on page 33.

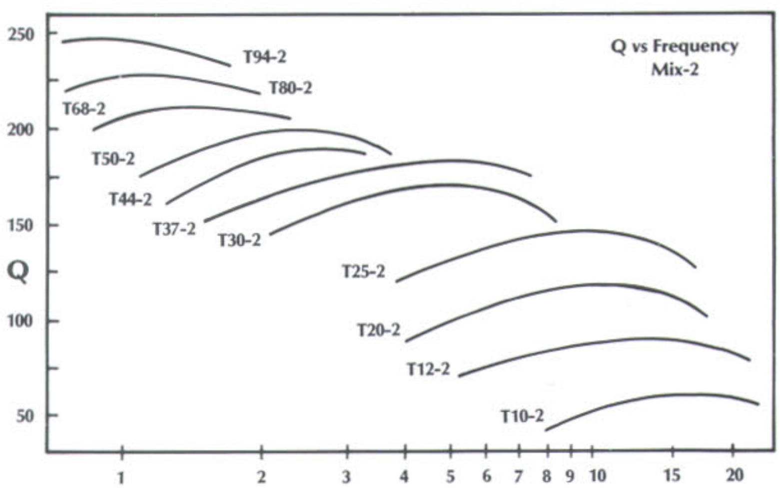

FIG. A

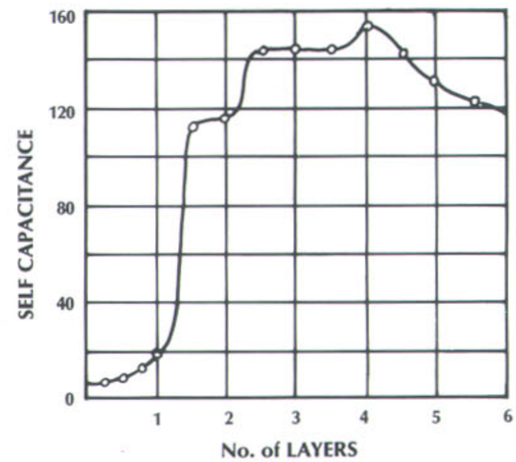

FIG. B CAPACITANCE OF TOROIDAL WINDINGS AS A FUNCTION OF THE NUMBER OF LAYERS

WINDING CONSIDERATIONS:

In arriving at the best winding for a given coil there are two characteristics to be minimized: resistance and capacitance.

Resistance: At low frequency the resistance of copper wire is the same as its DC resistance. As frequency increases, "skin effect" causes an increase in the AC resistance proportional to the square root of frequency. Litz wire can be used to reduce the AC resistance. Litz wire is strands of small insulated wire completely interwoven and connected in parallel at the ends. (15/44 Litz wire is 15 strands of #44 awg) Page 9 illustrates how the use of Litz wire reduces winding resistance resulting in higher Q. Litz wire is effective at frequencies up to about 3 MHz. Above this frequency, the advantage of reduced resistance using Litz wire is more than offset by the disadvantage of increased capacitive losses created by the stranding.

Self-capacitance: The effects of self-capacitance on Q increases with frequency squared. In a winding, self-capacitance results from the capacitance of adjacent turns as well as capacitance from the winding to the core. The turn-to-turn capacitance is affected by the number of turns, the wire size and the positioning of the turns. For a toroidal coil, one of the primary factors controlling the capacitive build-up is the number of winding layers. Figure B illustrates that the addition of even a partial second layer winding dramatically increases the turn-to-turn self-capacitance. Figure C illustrates this affect on Q.

Distribution of Winding: Apparent inductance is increased by both self-capacitance and leakage inductance. Normally, these effects are quite small. However, in low inductance, high frequency applications (above 25 MHz), where both the number of turns and resonating capacitor are small, these effects can be significant, (Figure D). Due to these effects, many of the inductance values shown throughout this supplement vary from theory.

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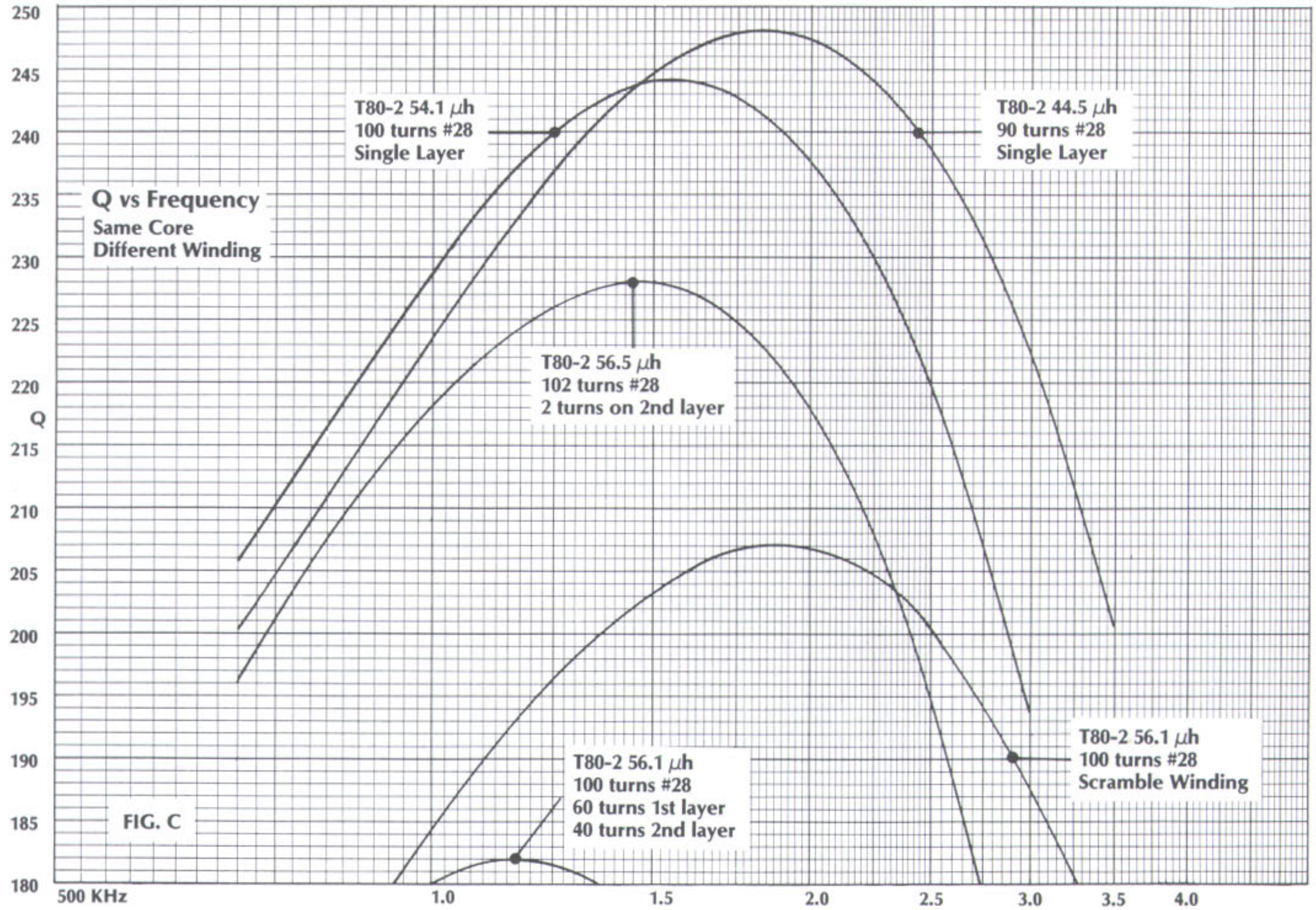

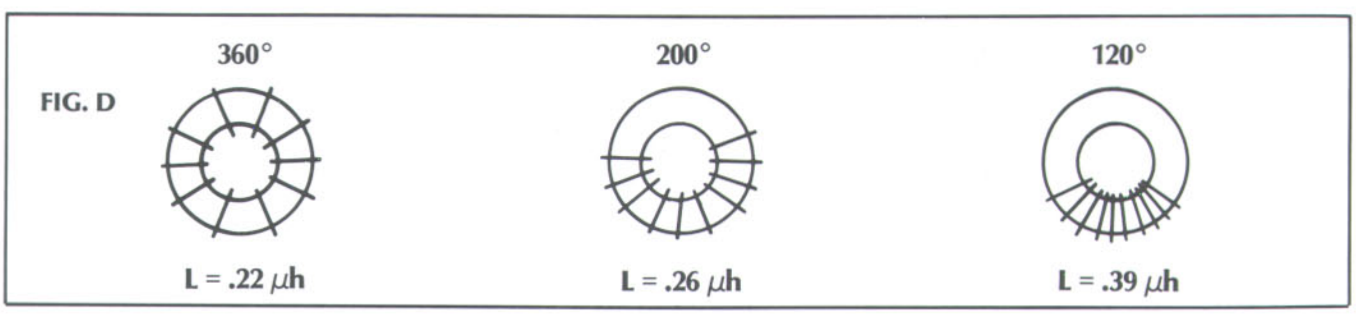

SUMMARY OF WINDING CONSIDERATIONS:

For frequencies less than 3 MHz:

1. Resistive considerations outweigh capacitive considerations.
2. The use of Litz wire and multiple layers can be useful in reducing resistive losses and thus improving Q.

For frequencies greater than 3 MHz:

1. Capacitive considerations outweigh resistive considerations.
2. Single-layer windings will maximize Q. Use the largest practical wire size.

Broadband Transformers:

The useful frequency range for iron powder core materials is greatly increased when used in broadband transformers where optimum Q is not the primary objective. Please refer to "IRON POWDER CORES FOR BROADBAND APPLICATIONS" in Catalog 3 for additional information.

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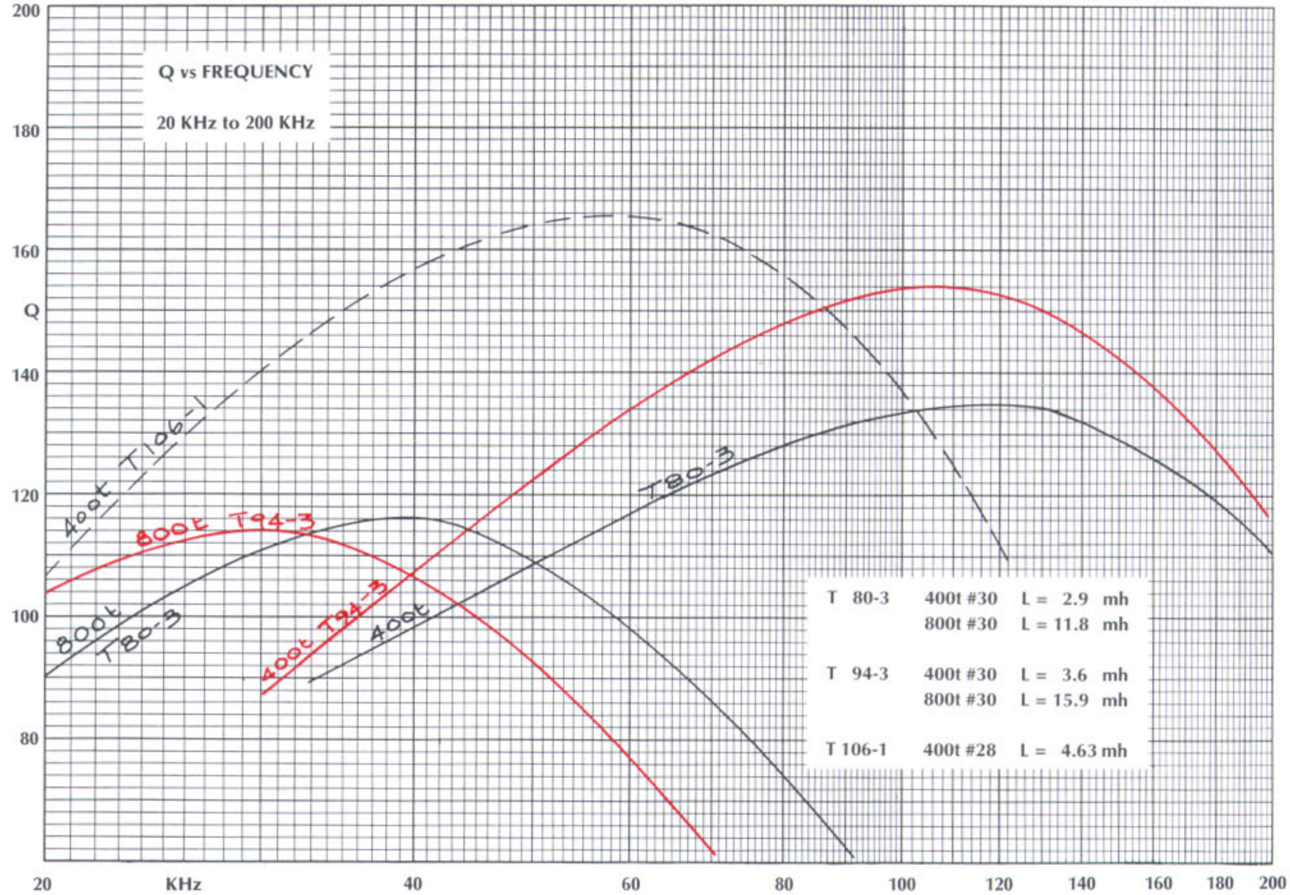
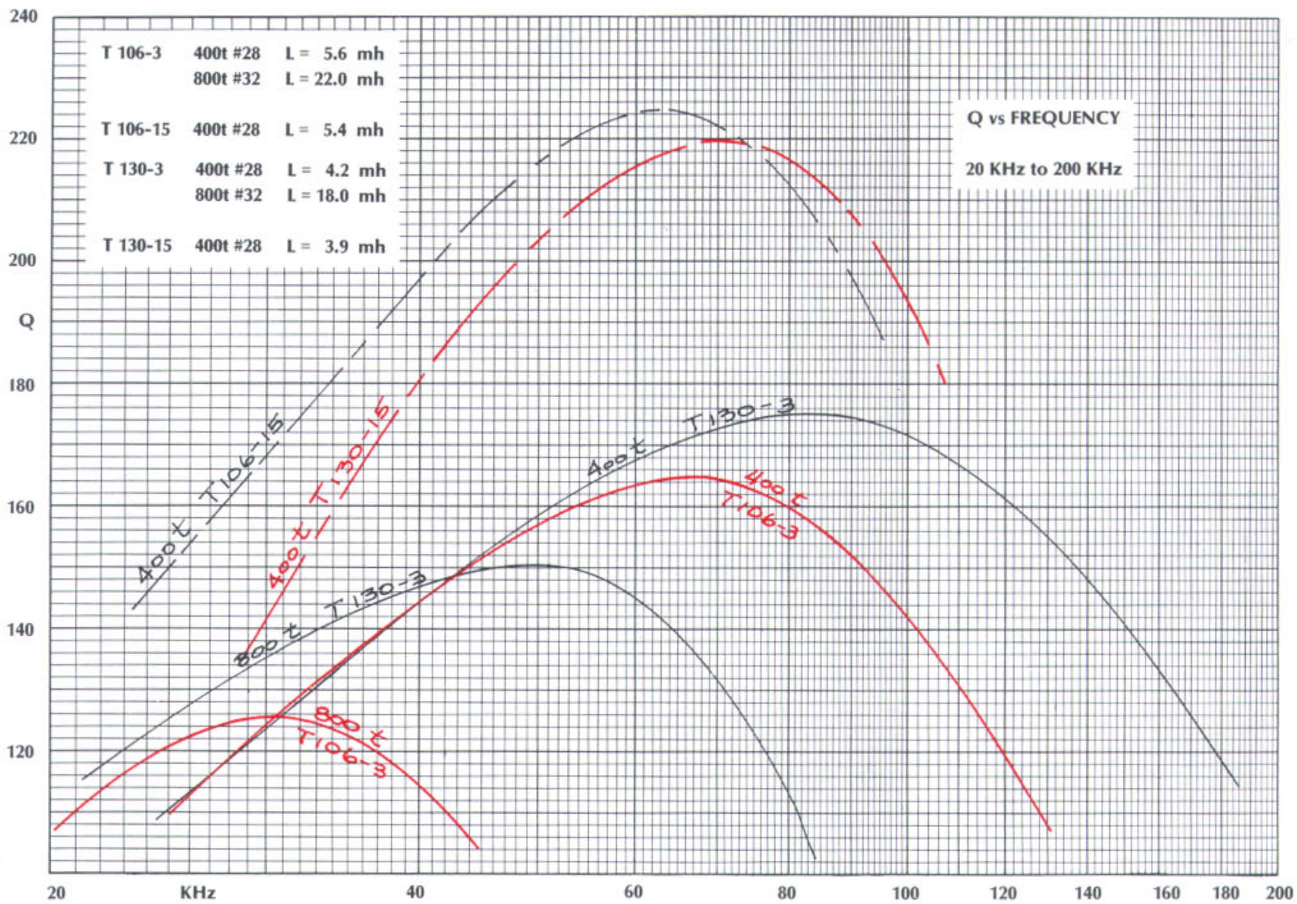
20 KHz to 200 KHz





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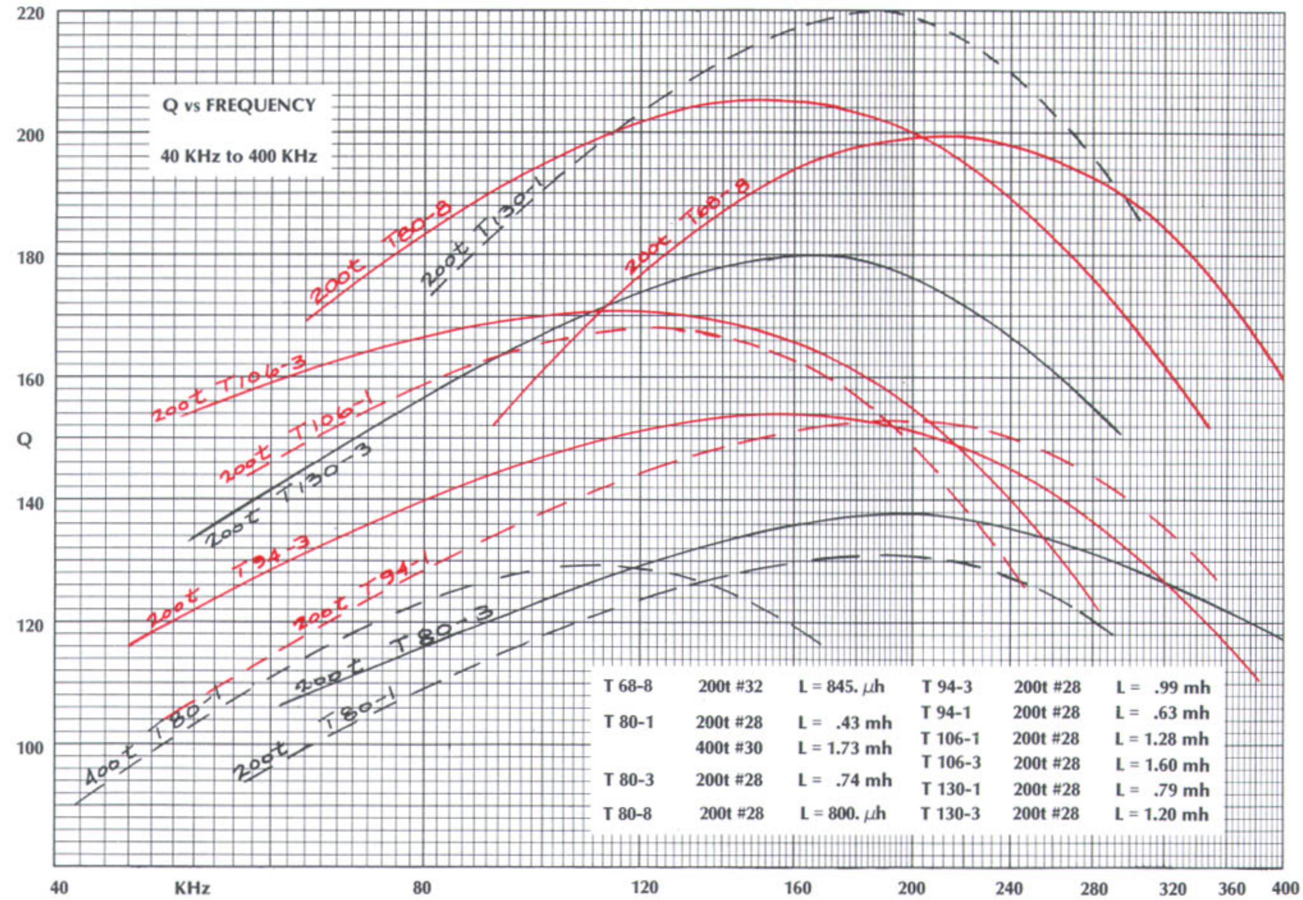

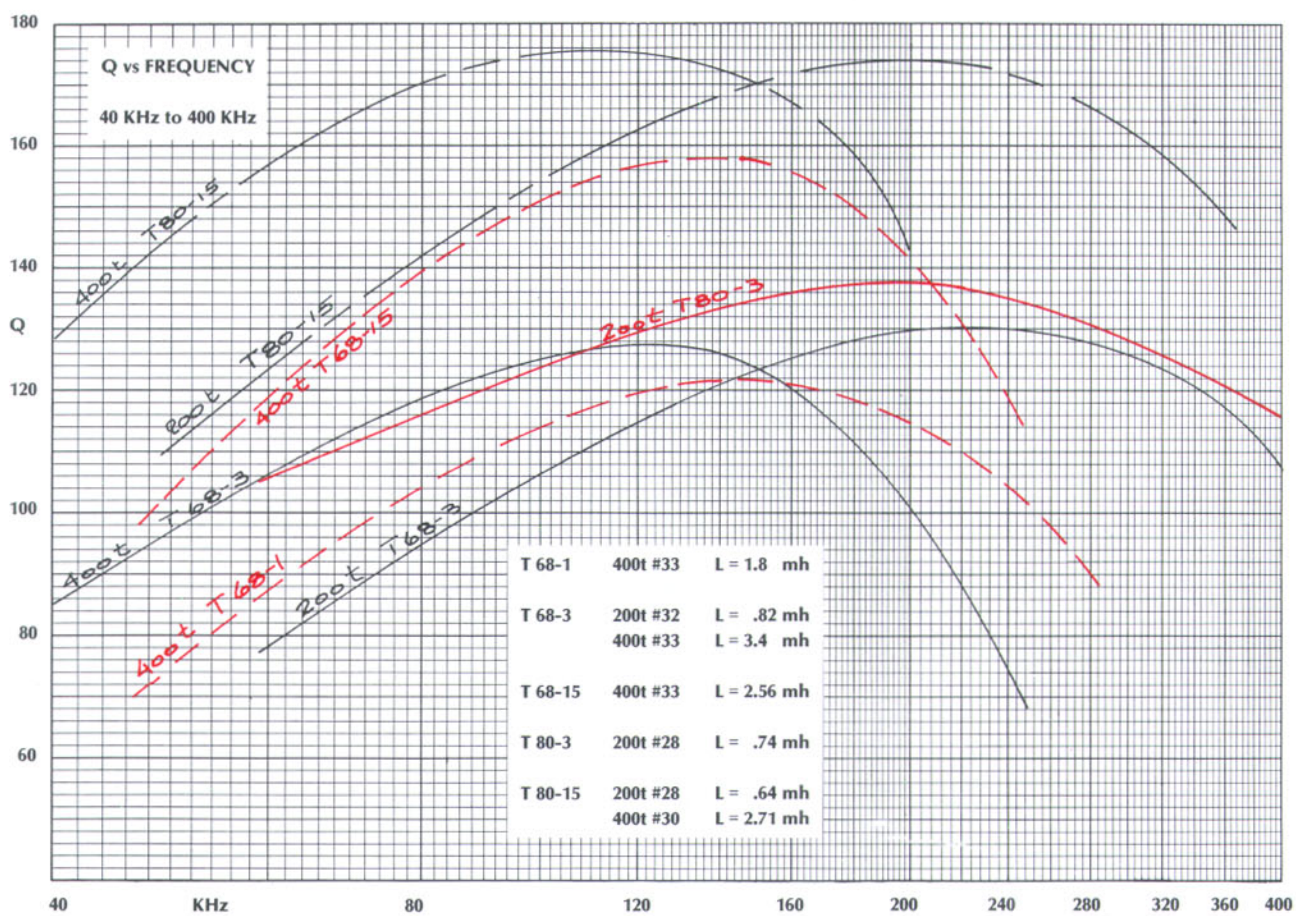

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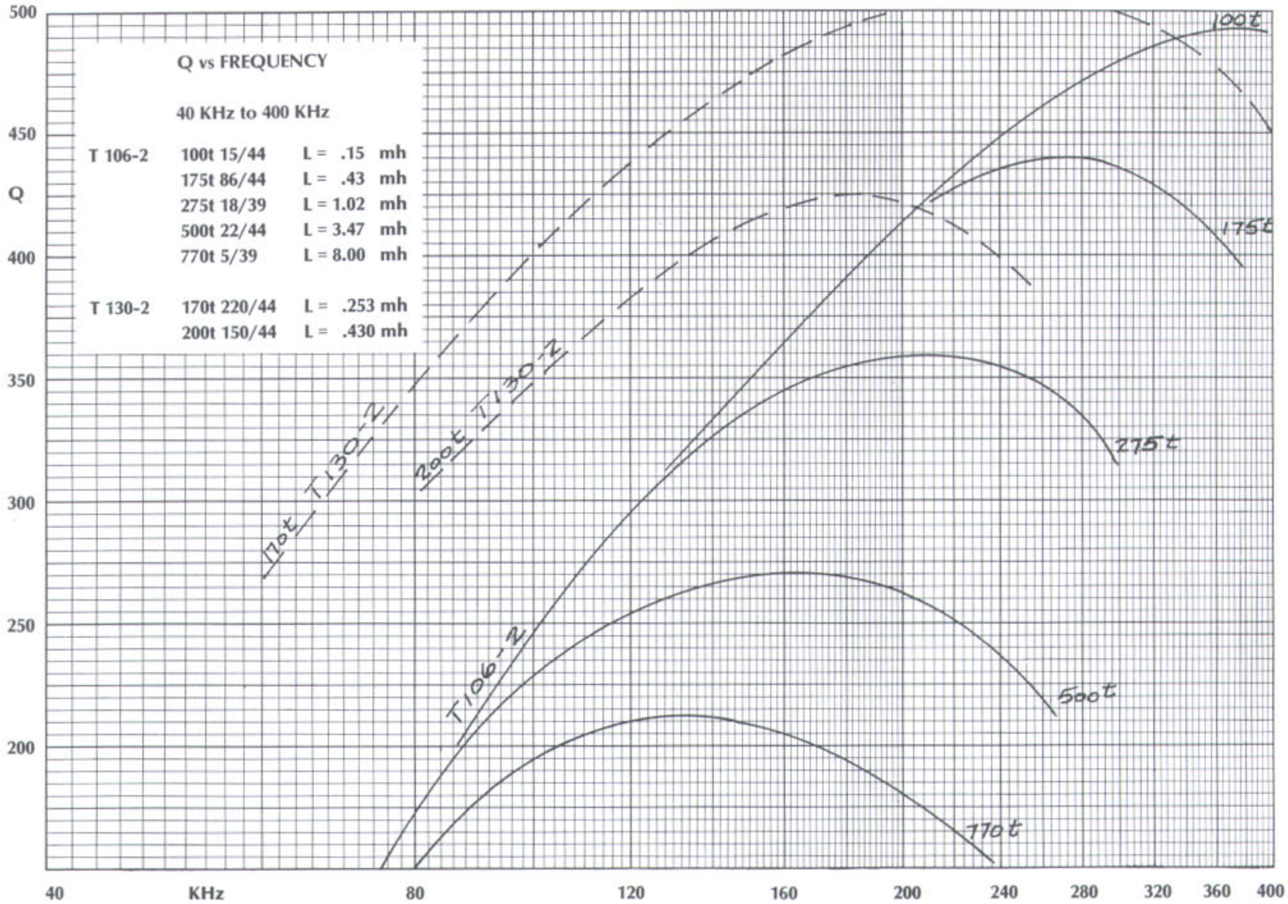
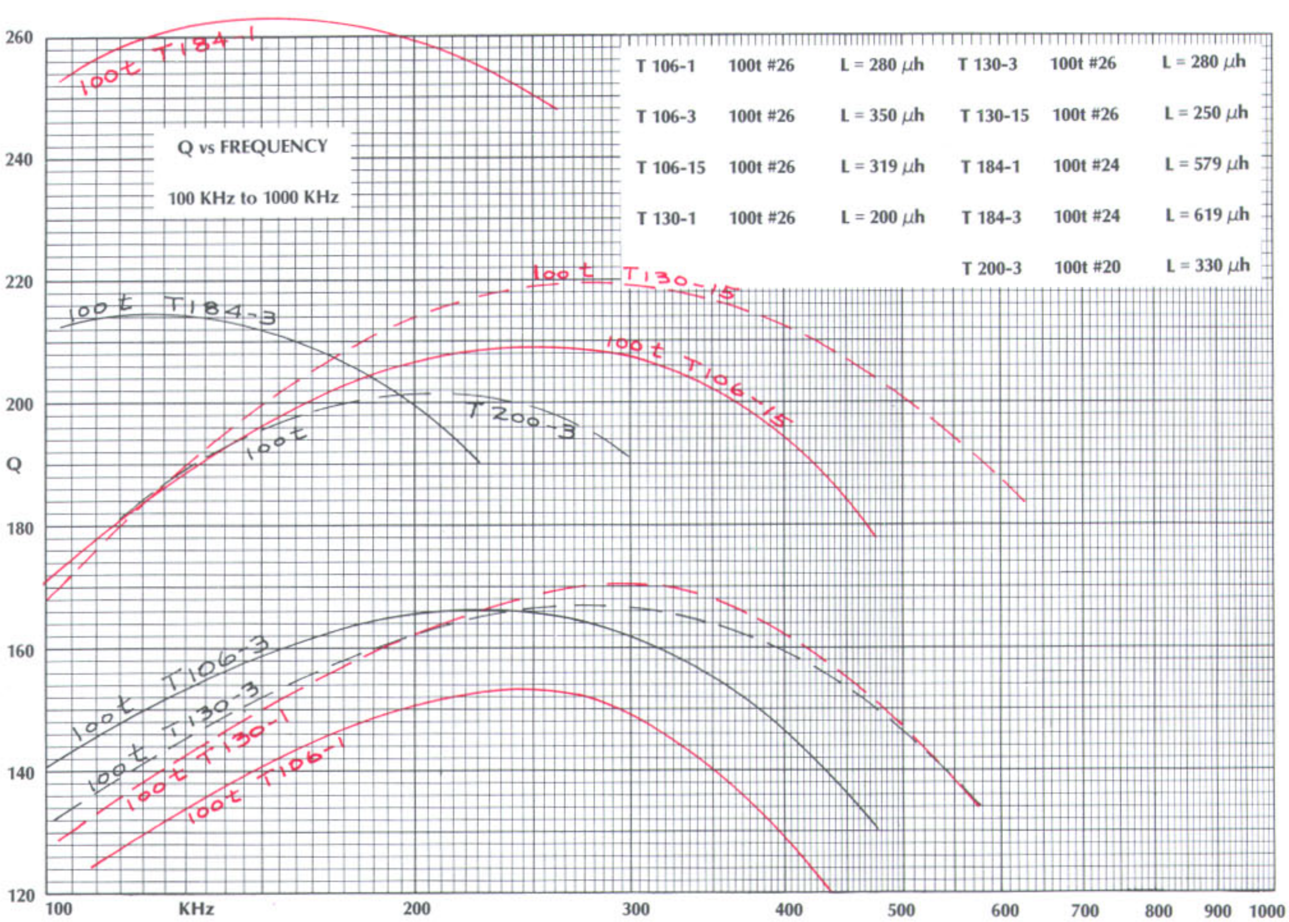
40 KHz to 1000 KHz





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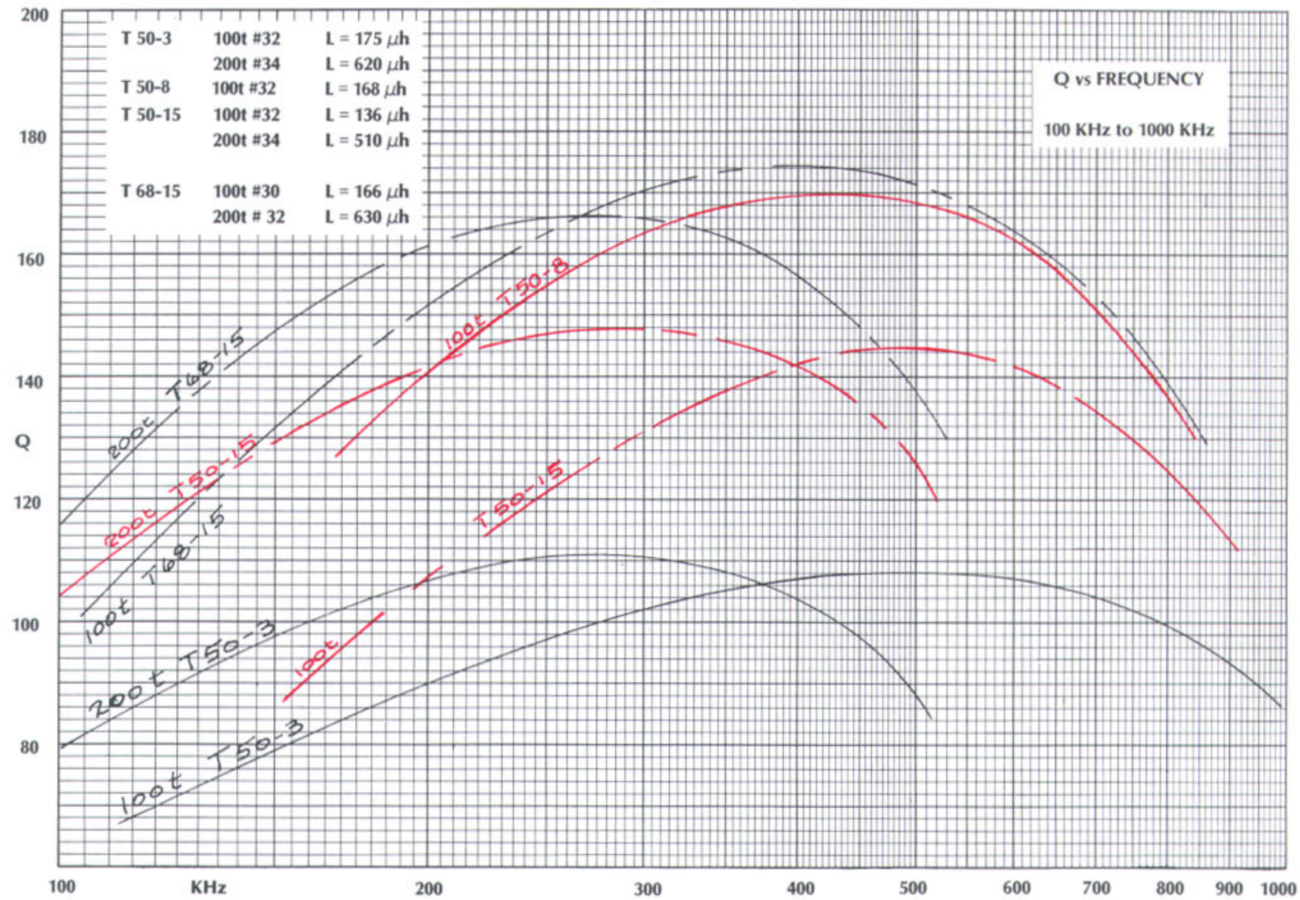

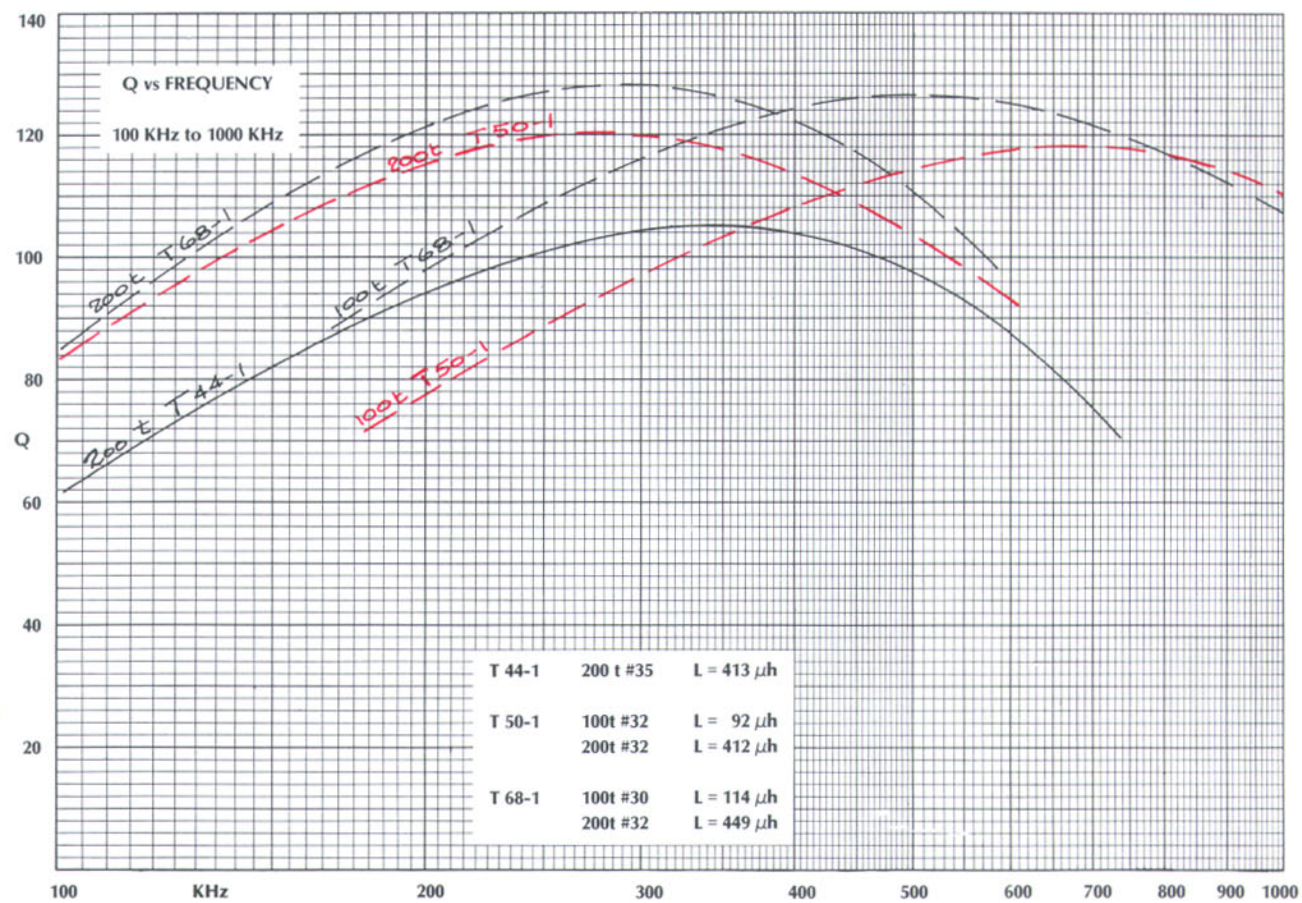

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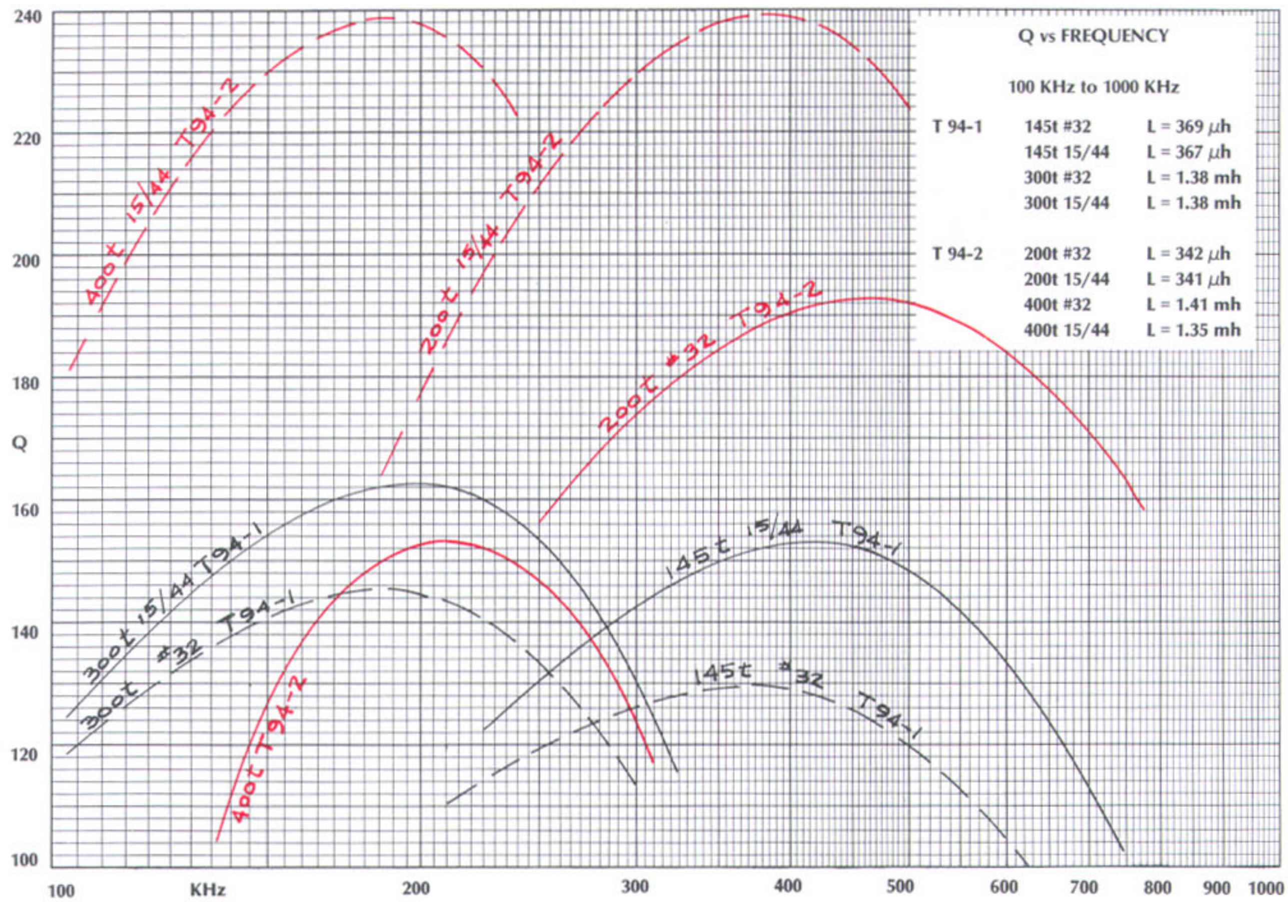

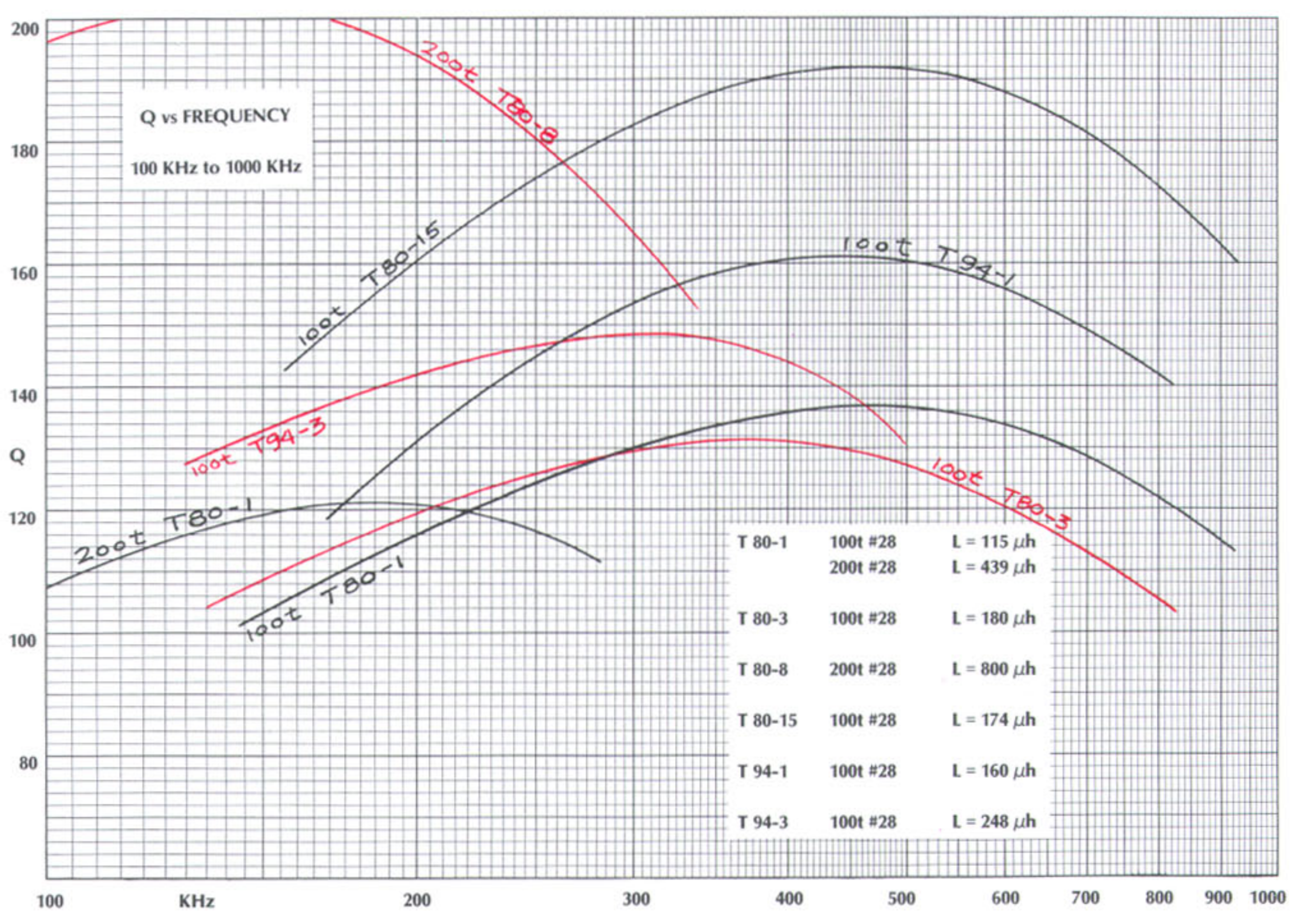

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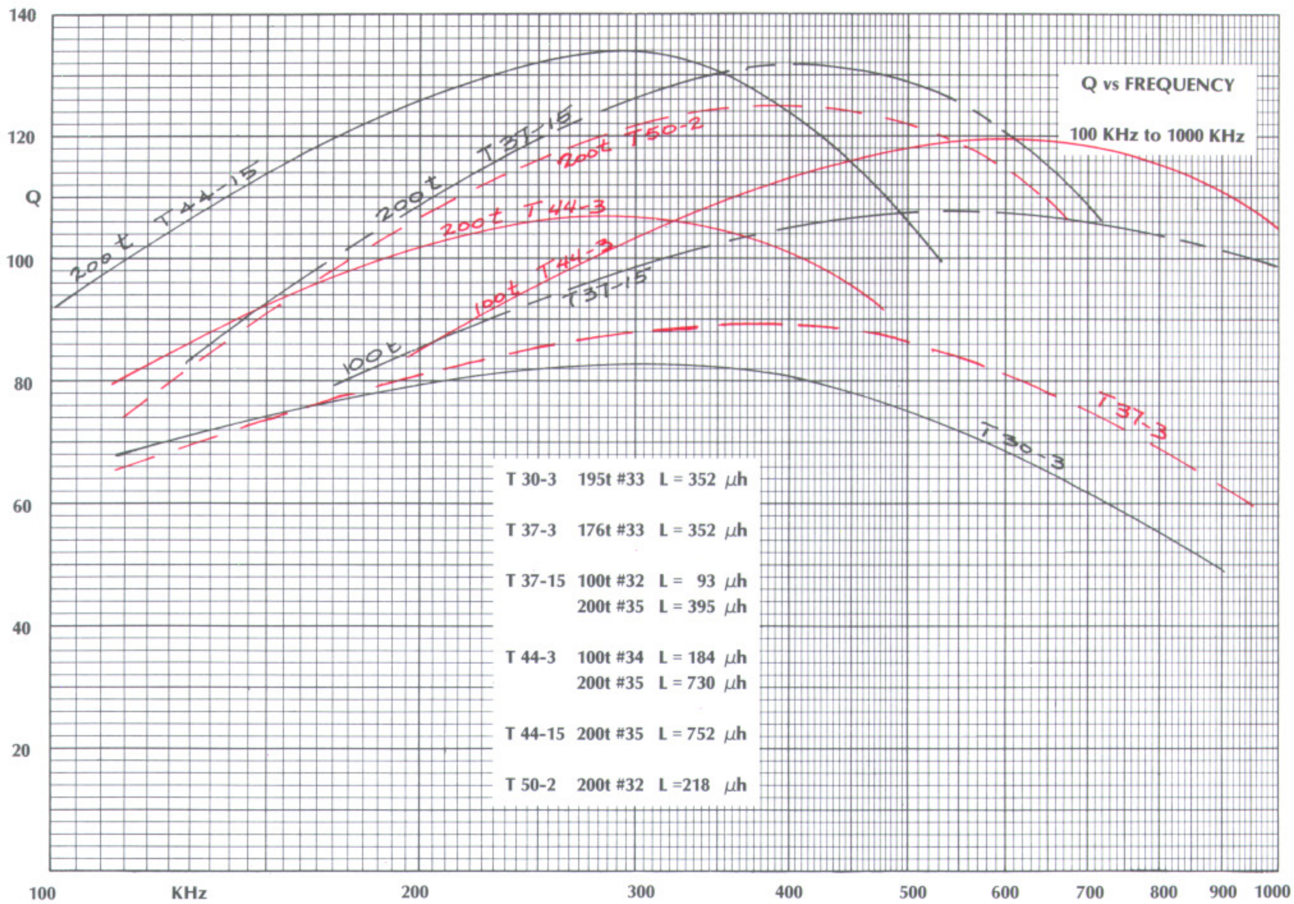

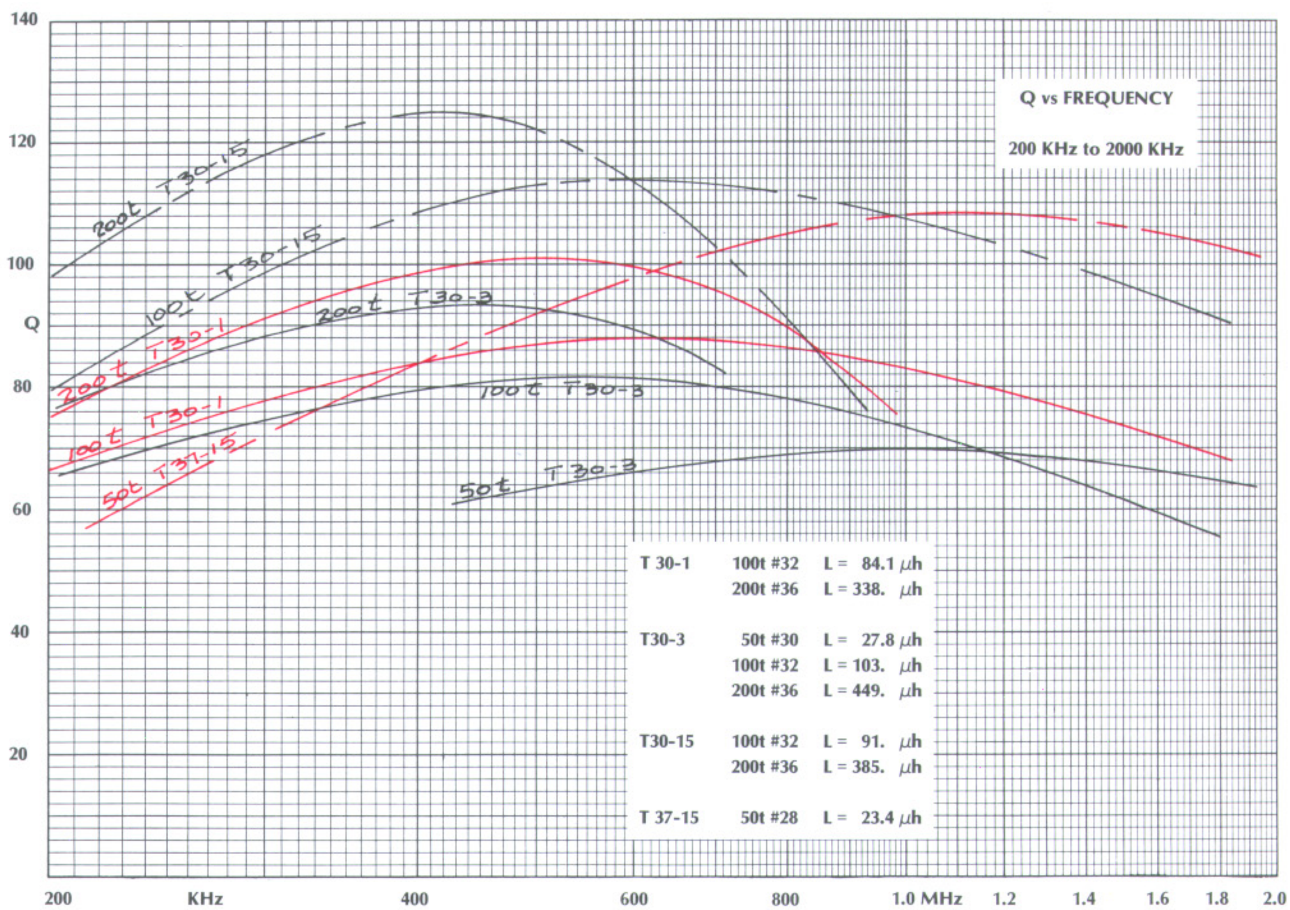

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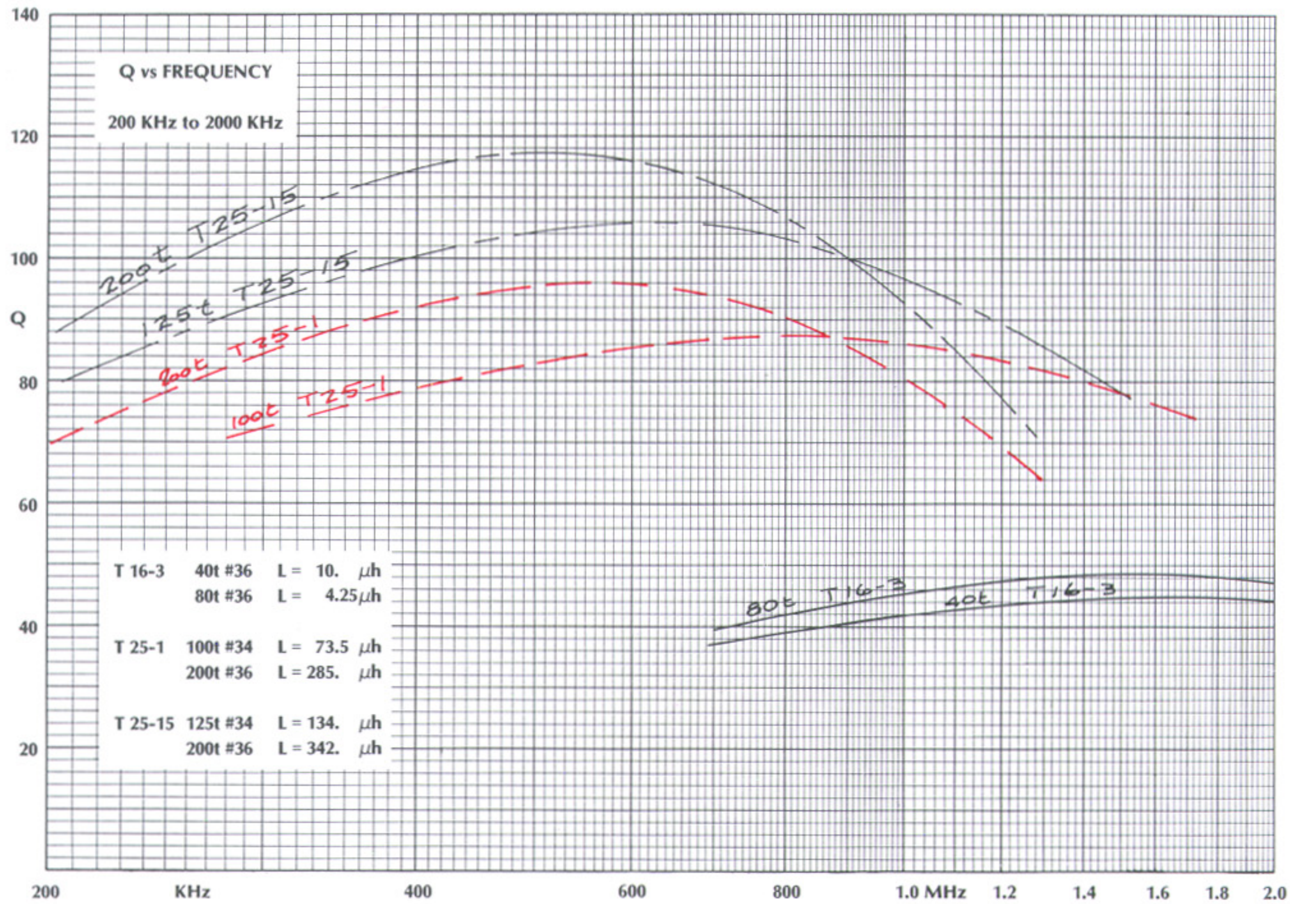

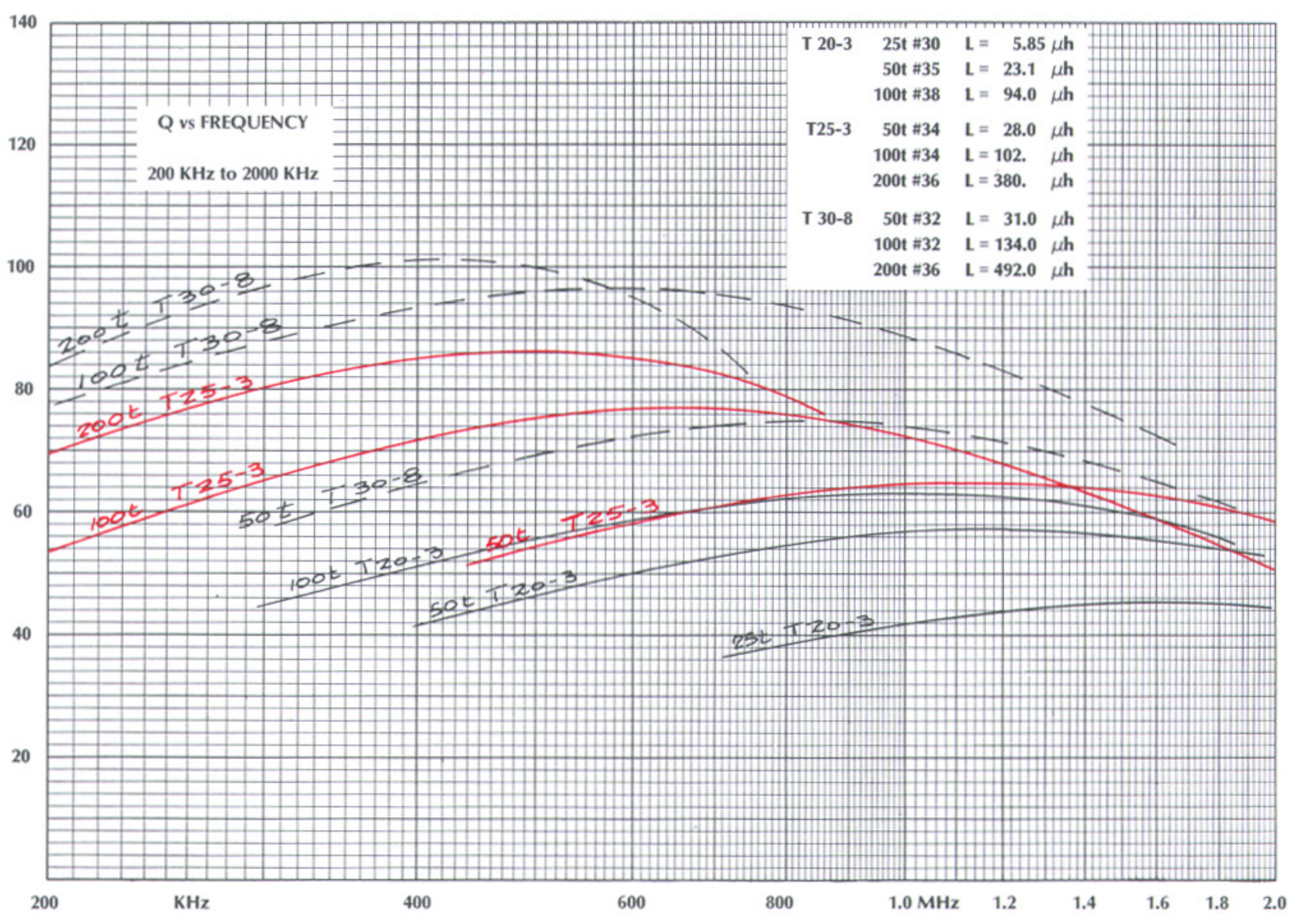

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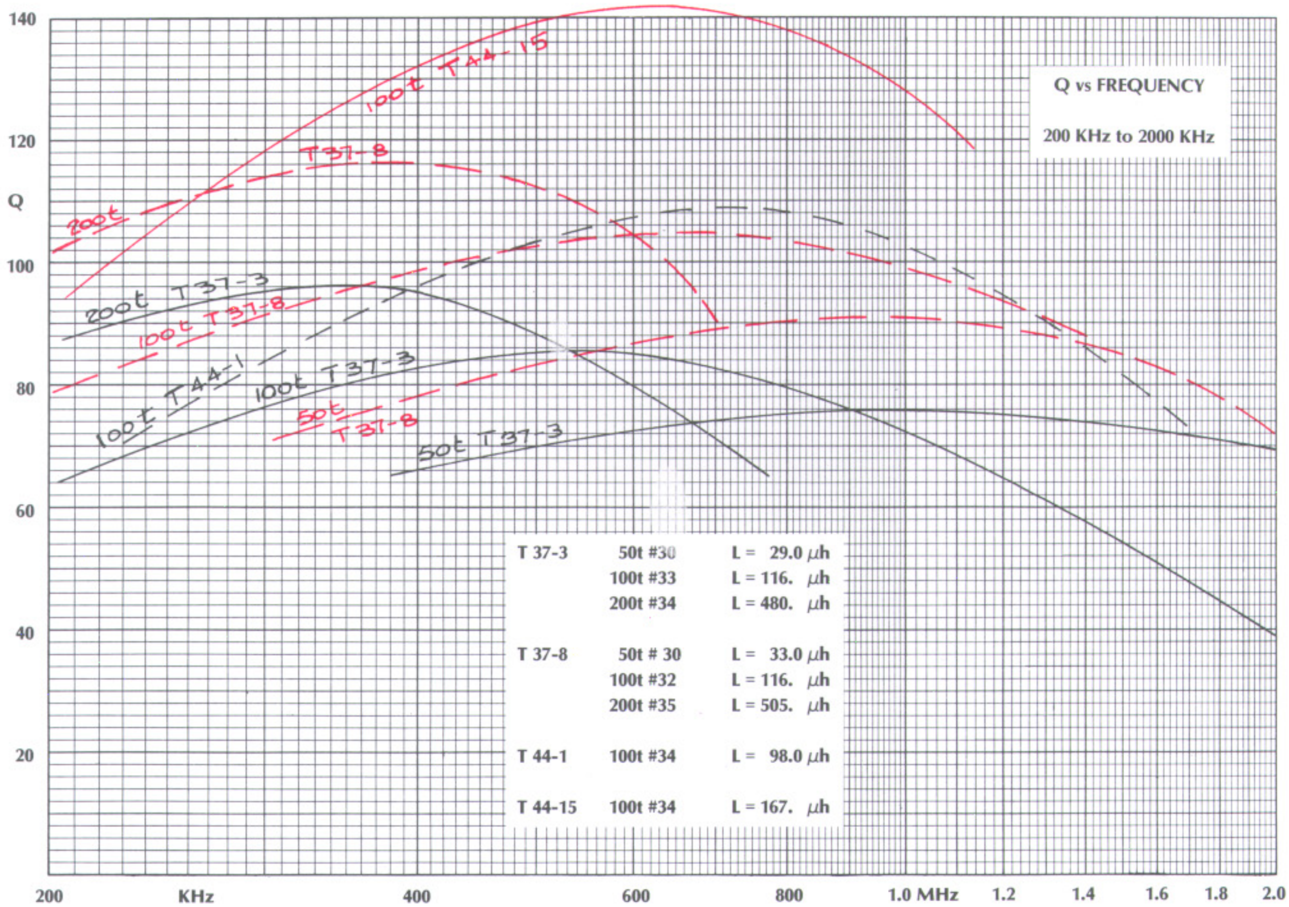

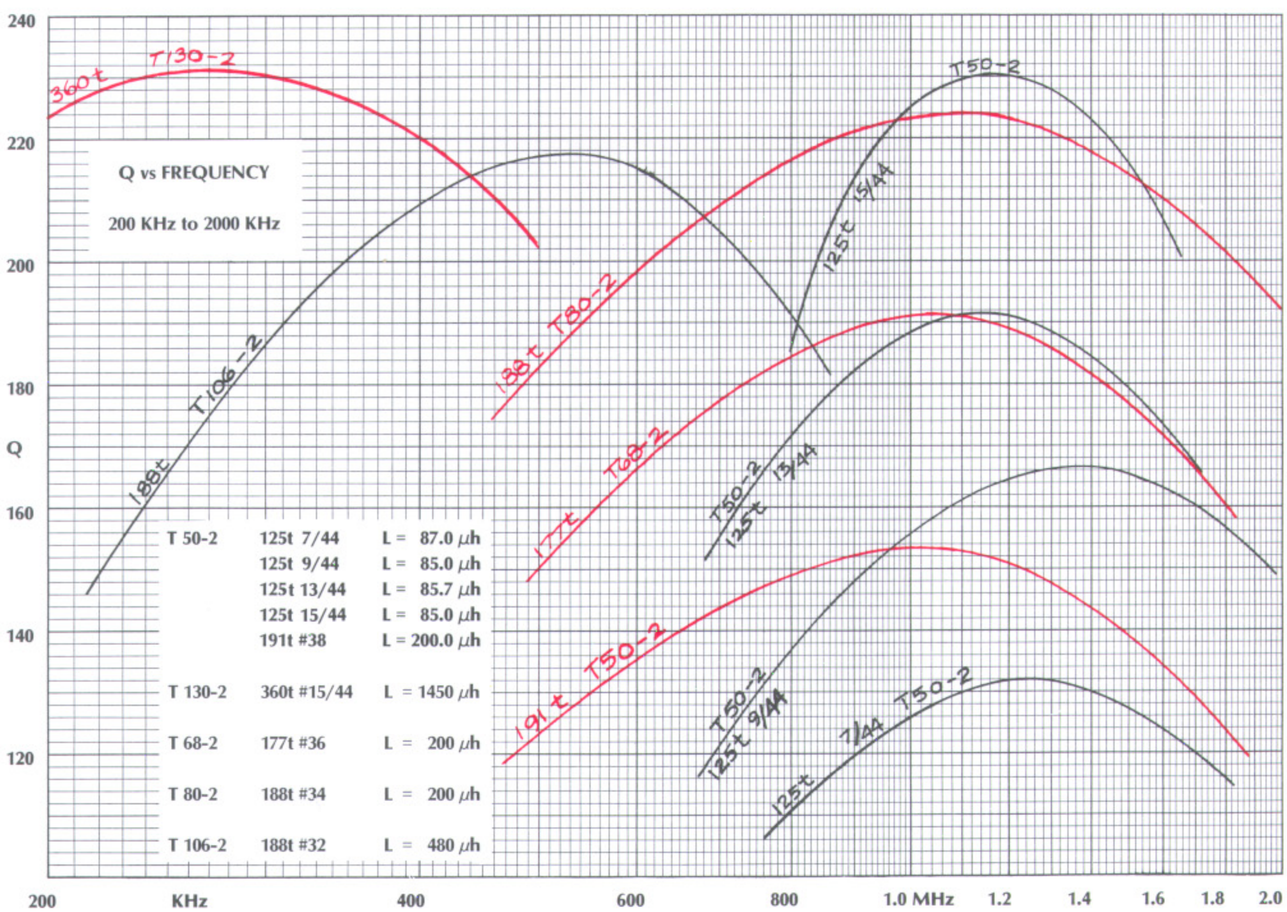

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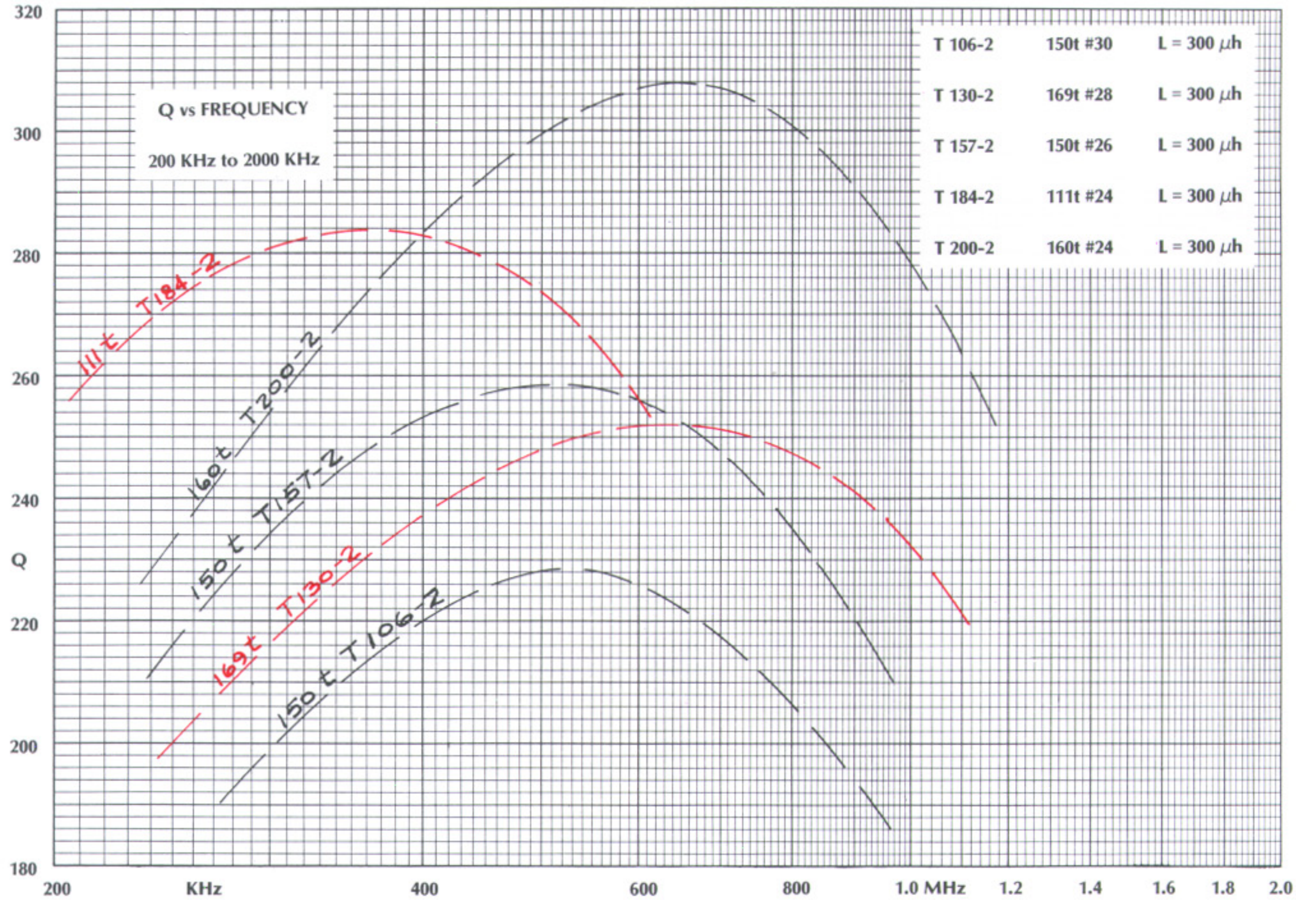
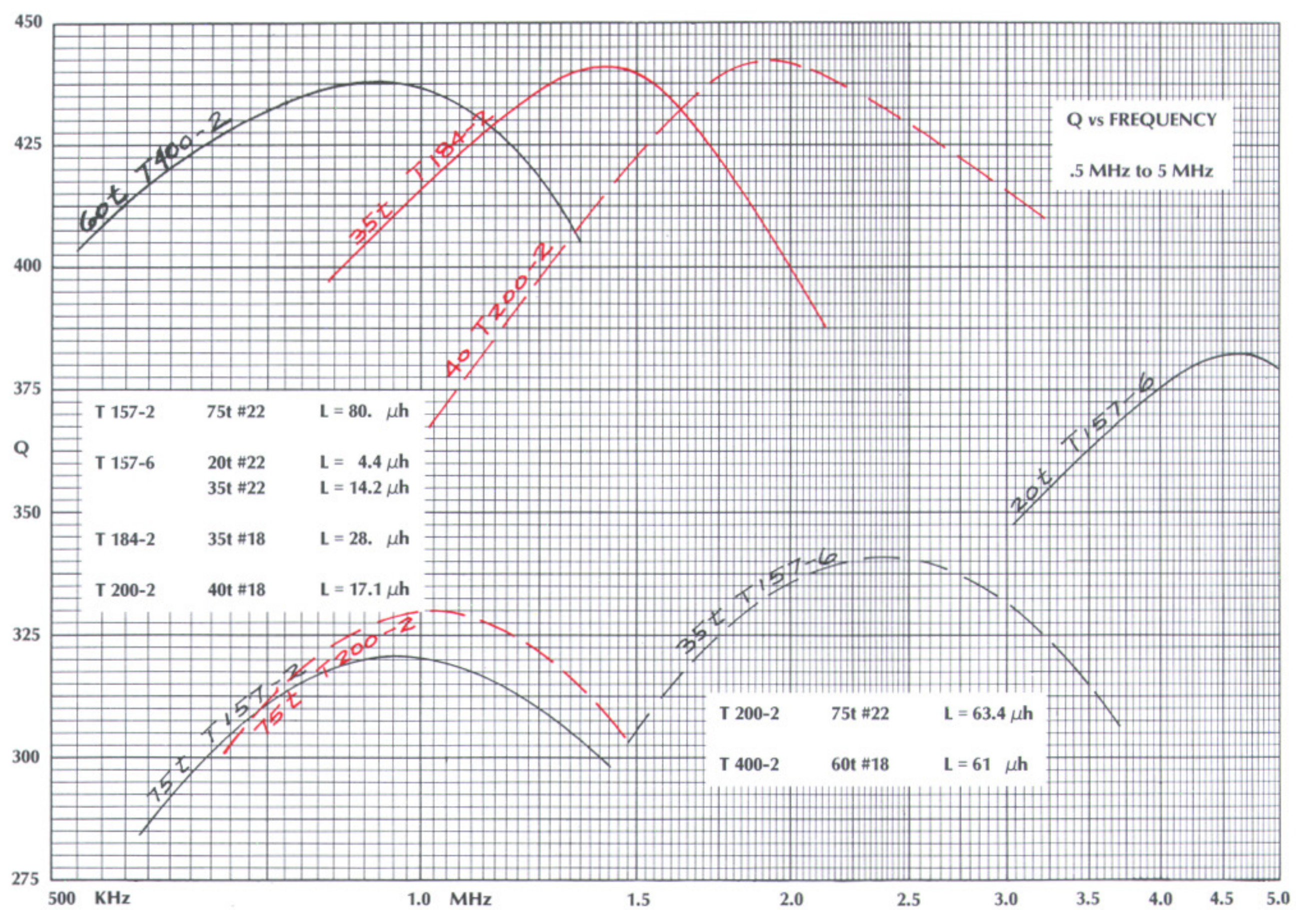
200 KHz to 5000 KHz





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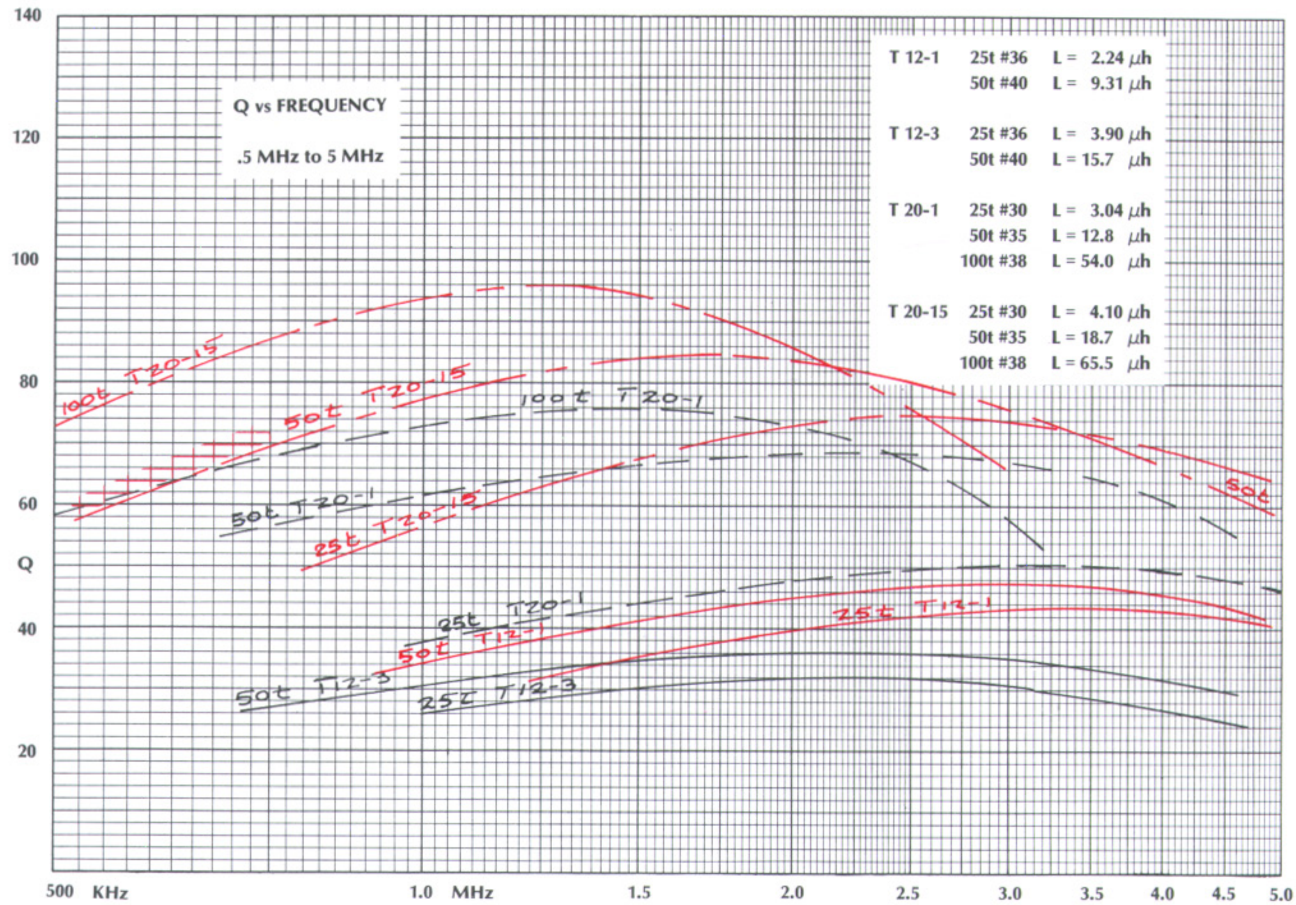

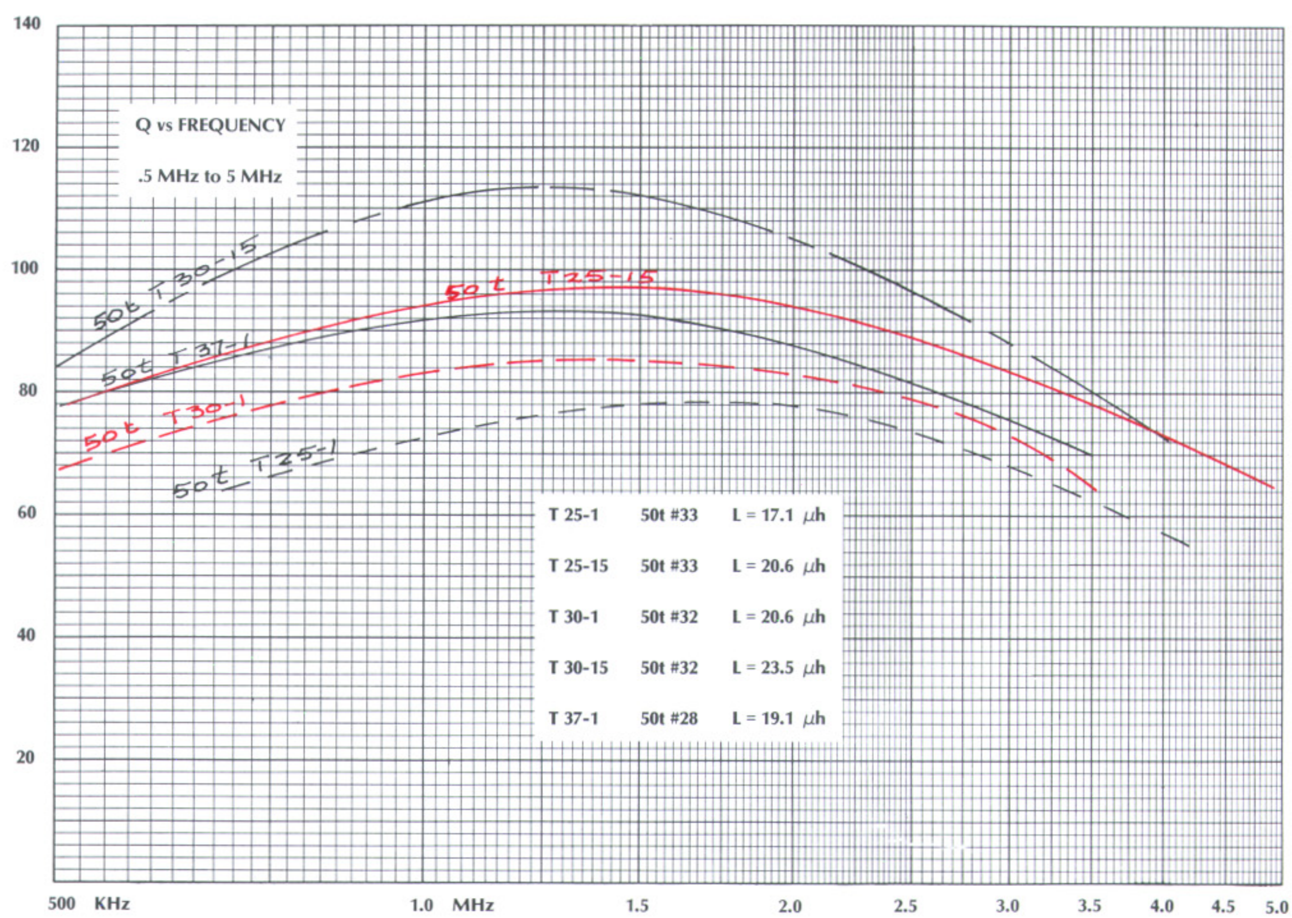

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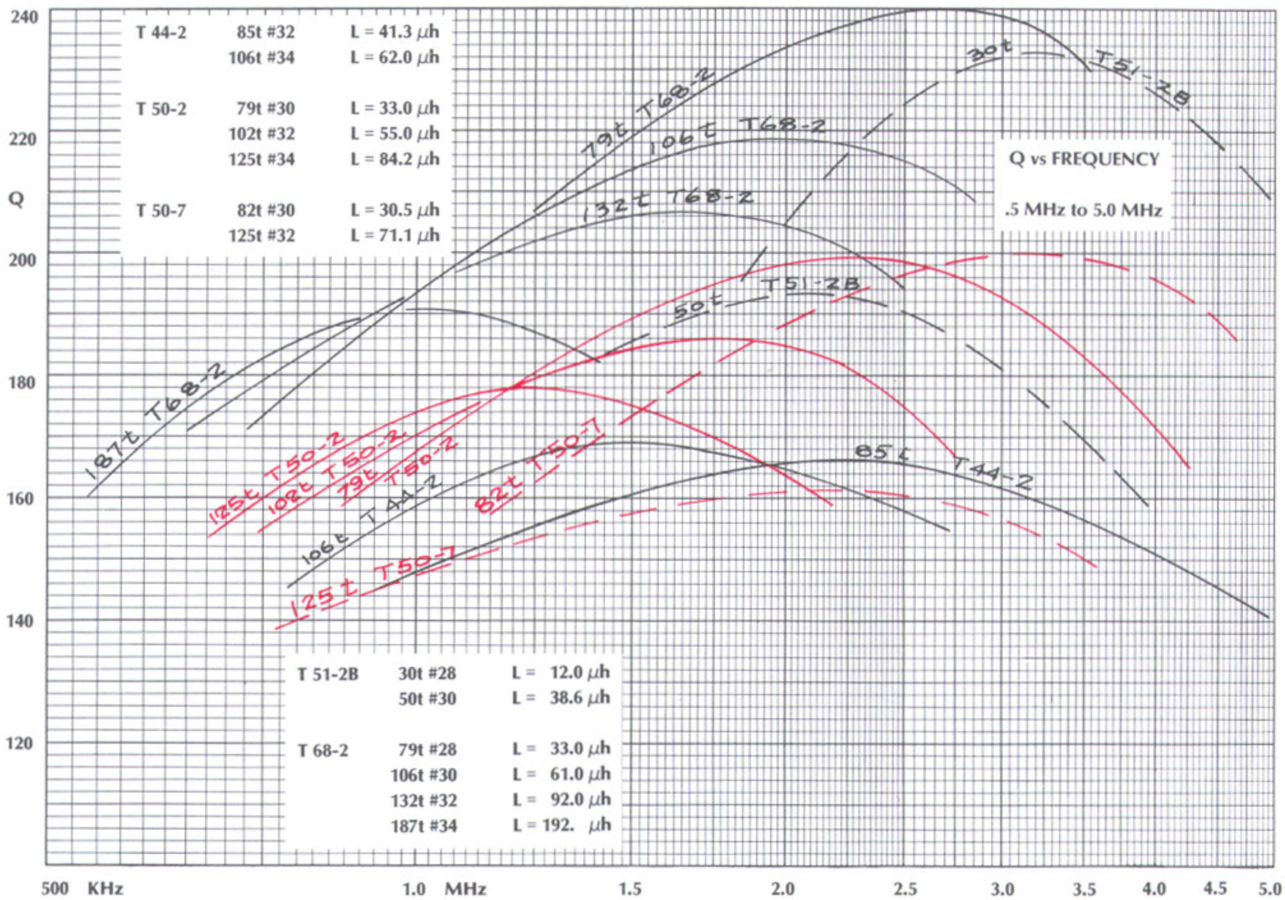
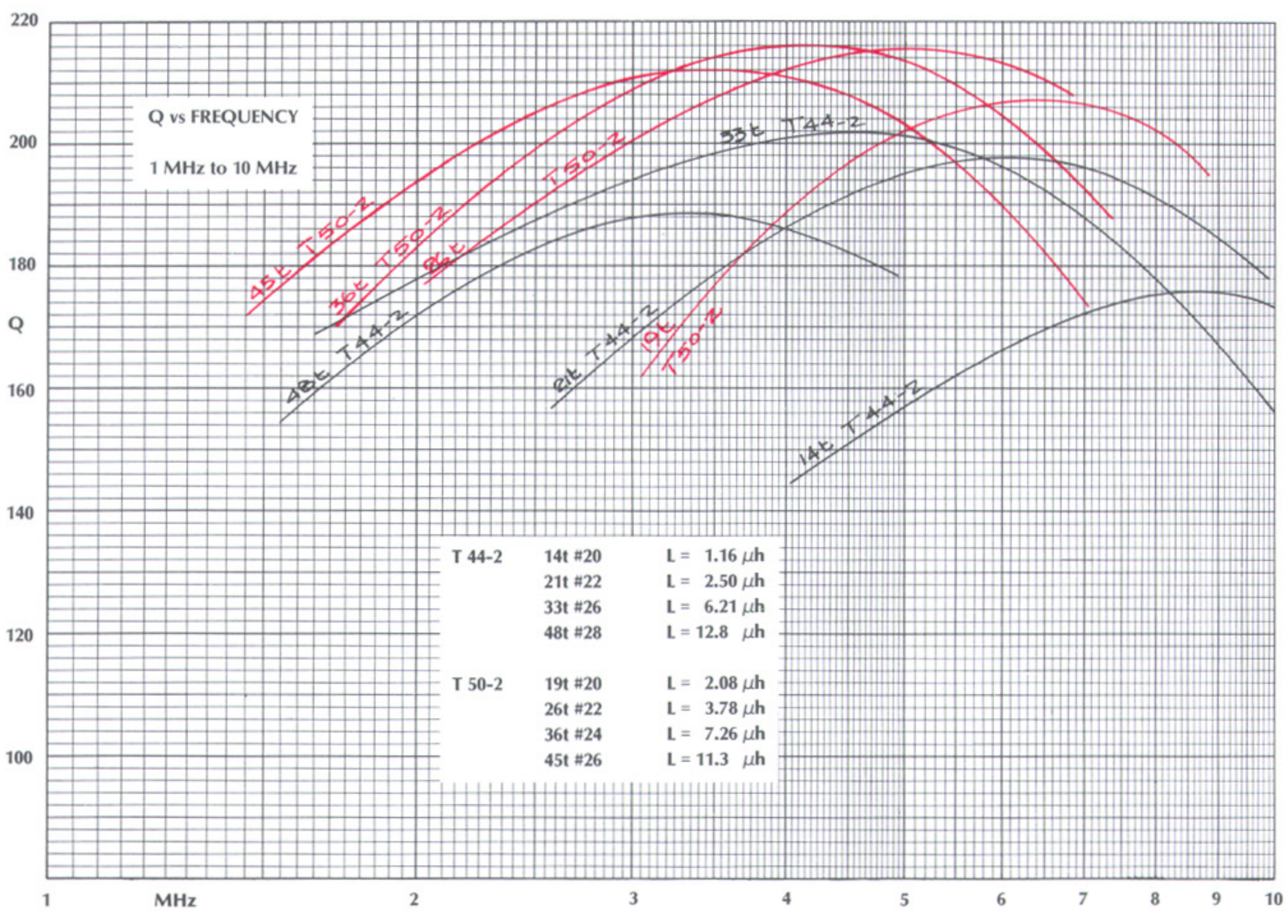
.5 MHz to 10 MHz





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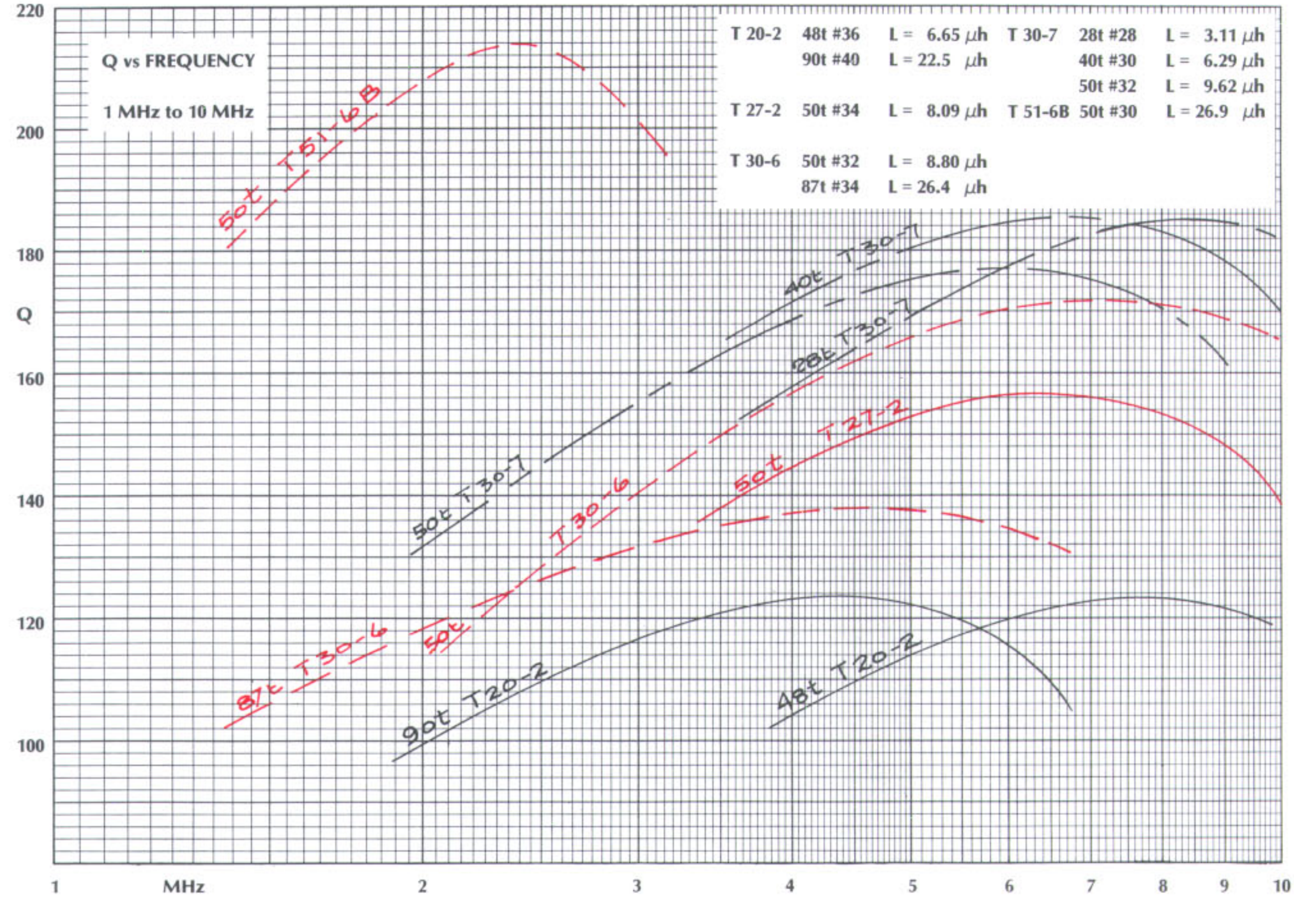

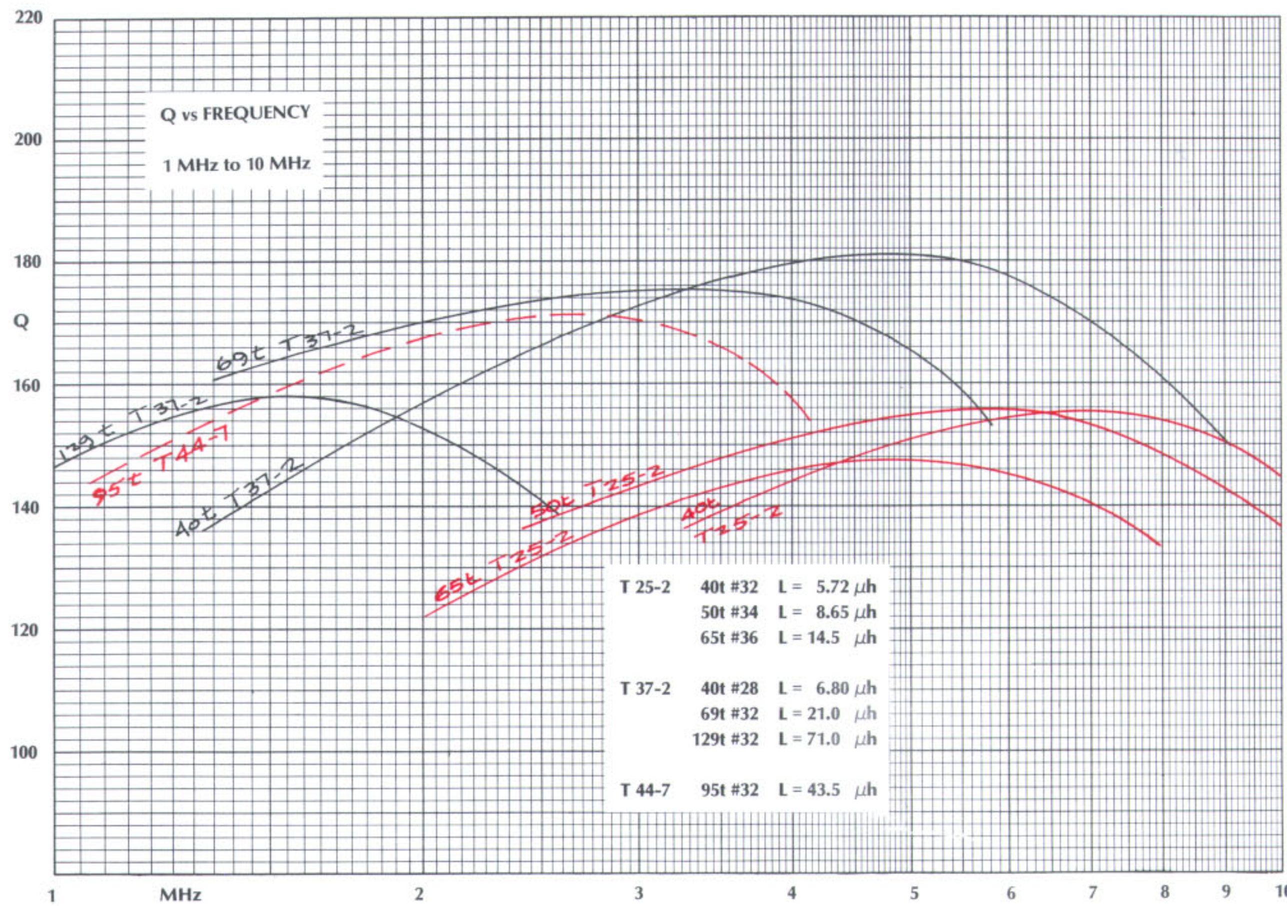

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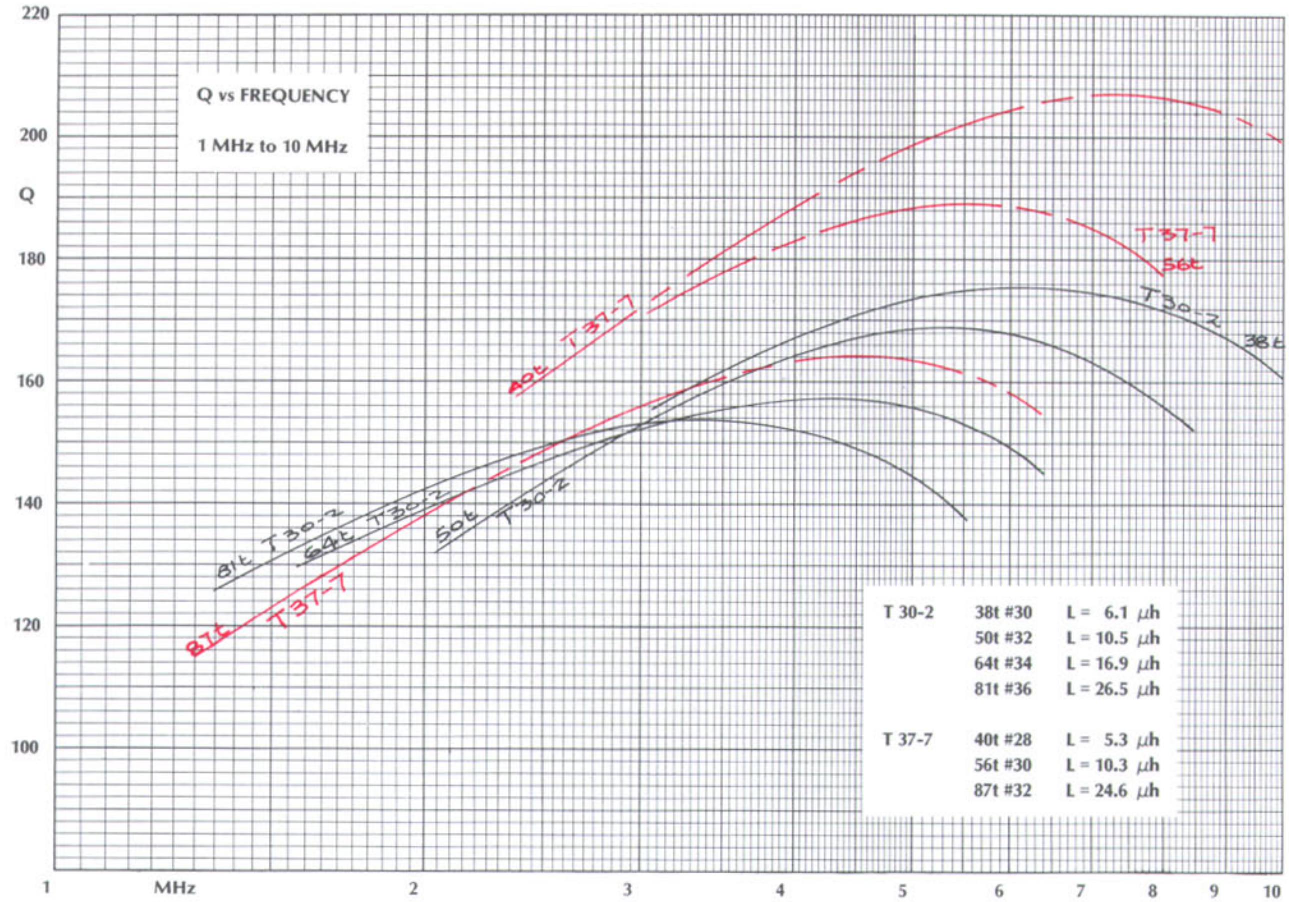
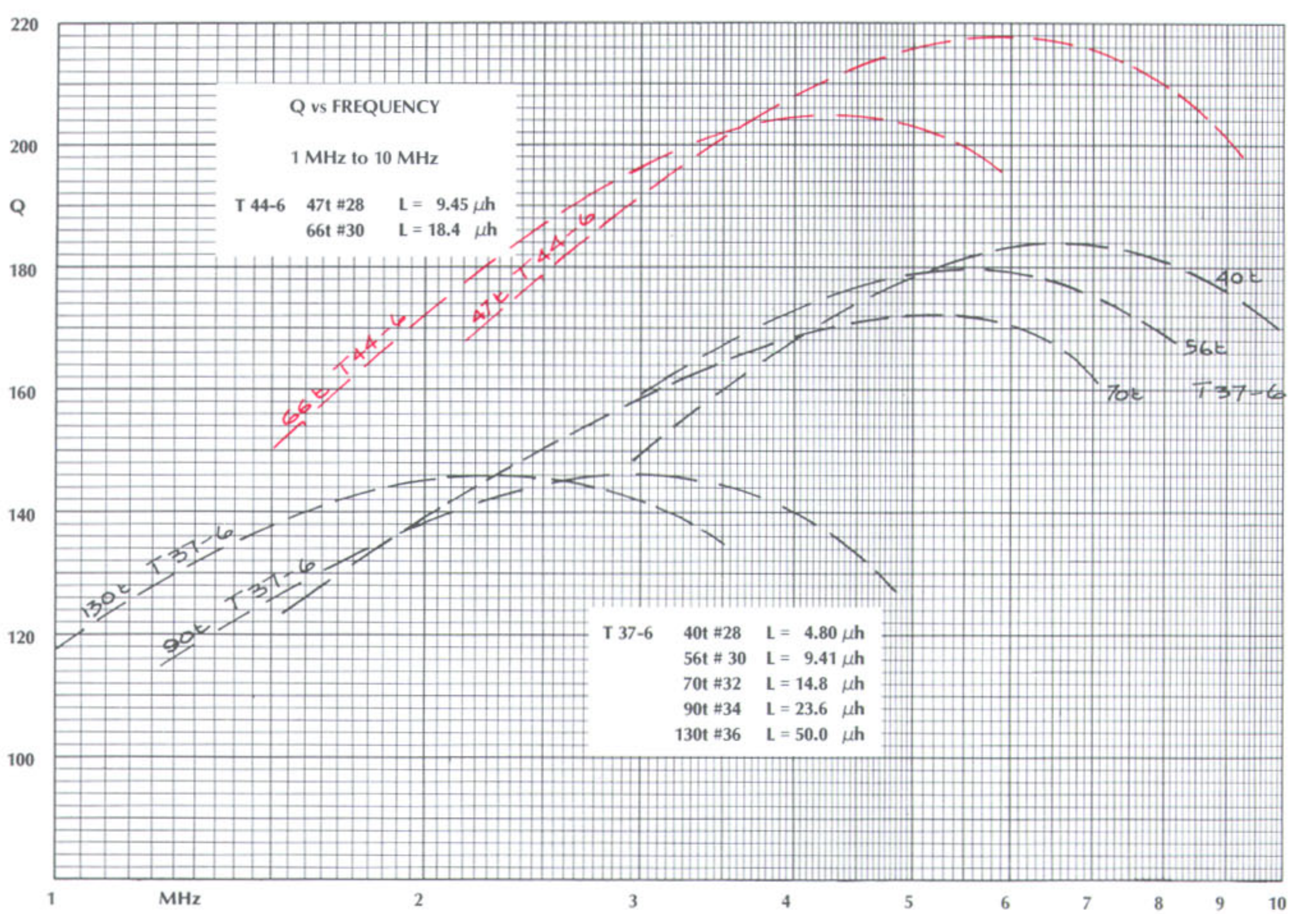
1 MHz to 10 MHz





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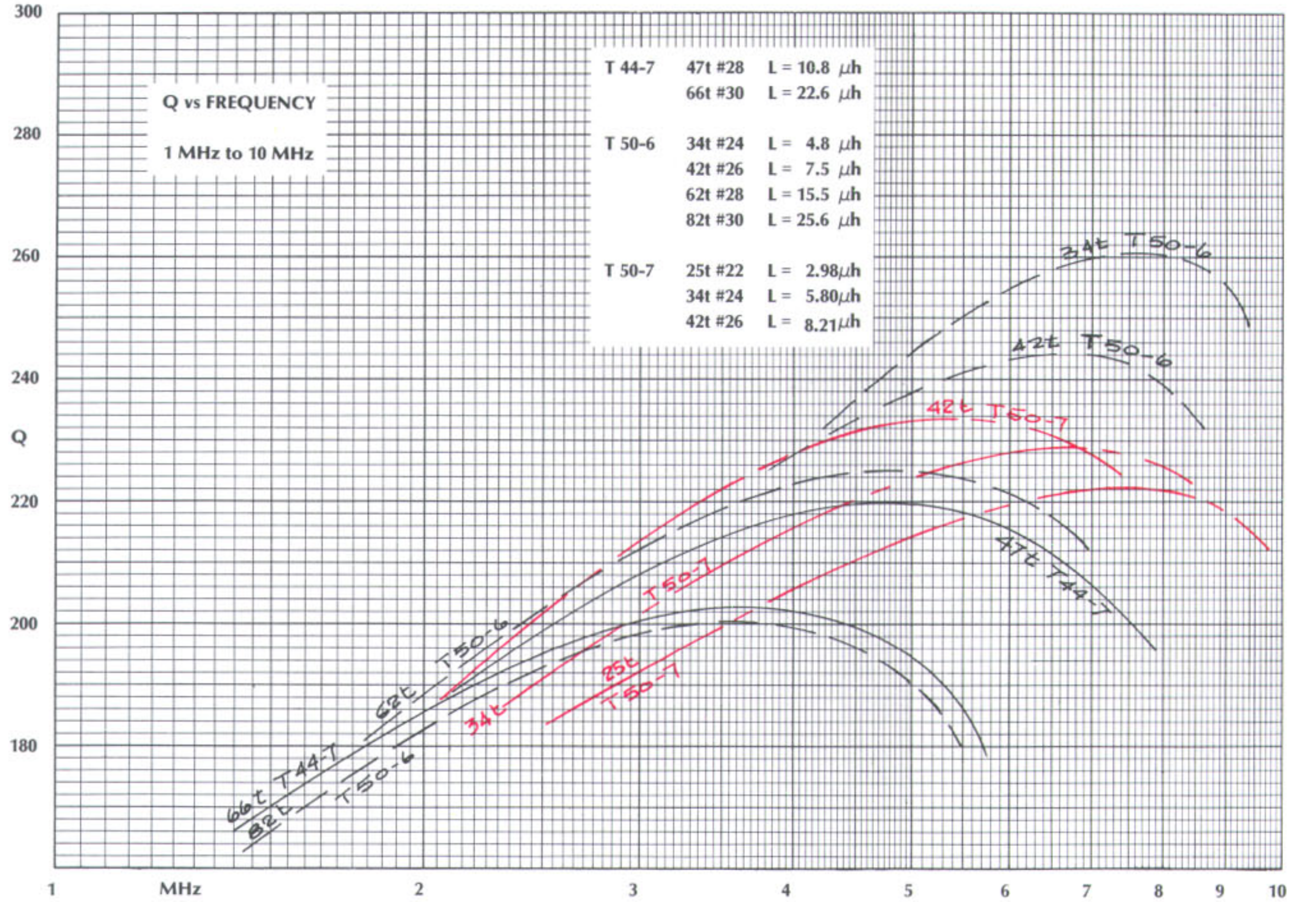

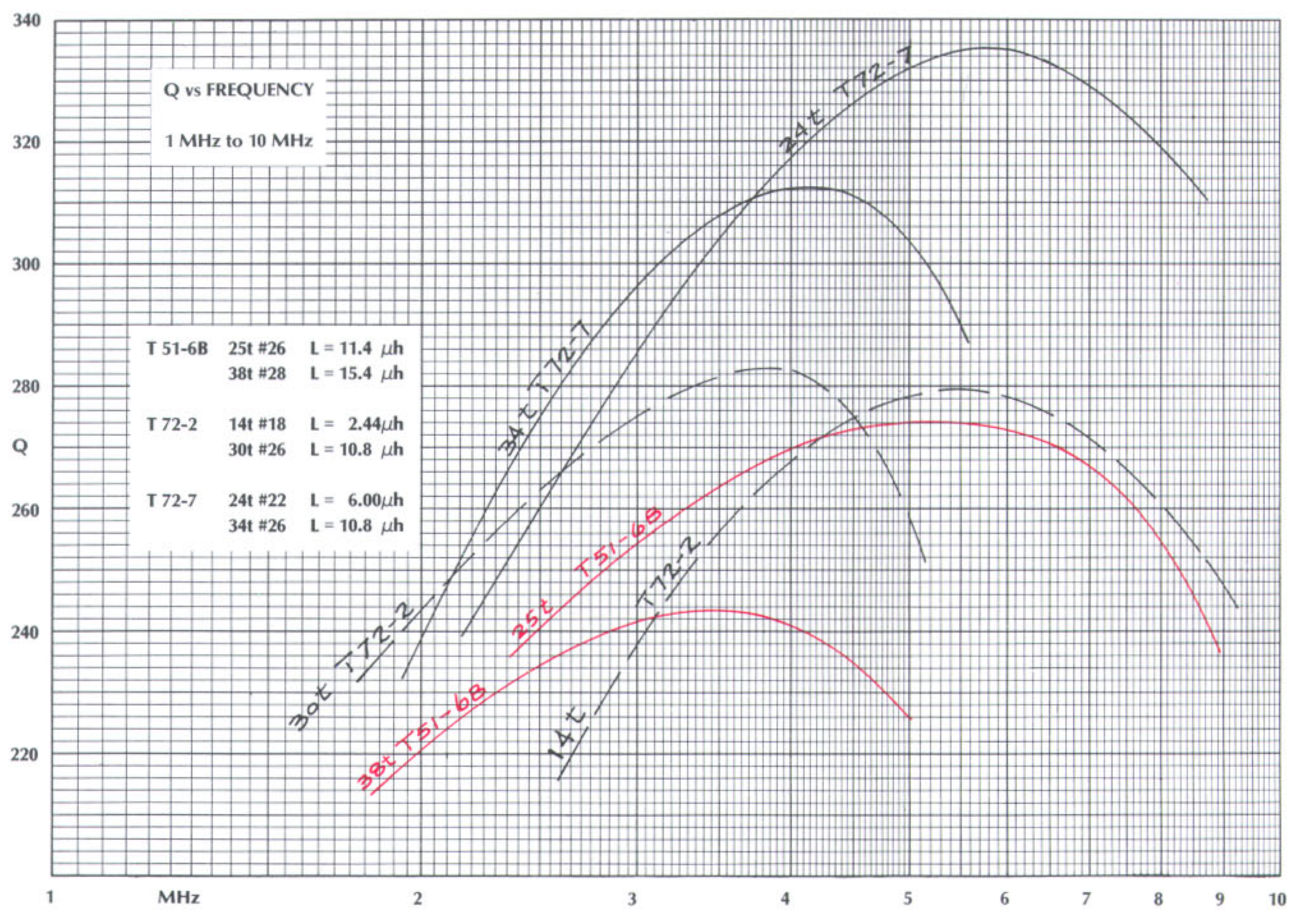

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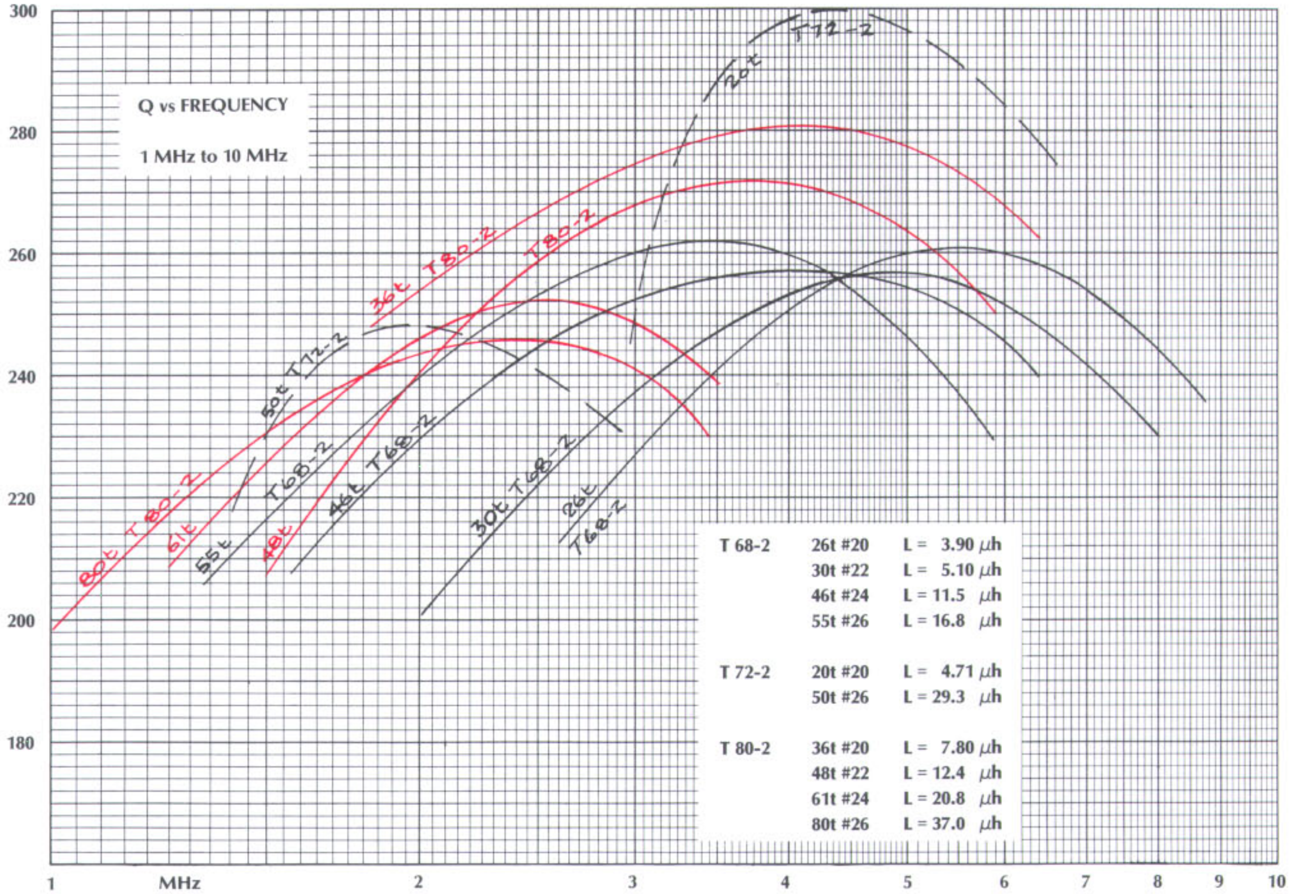
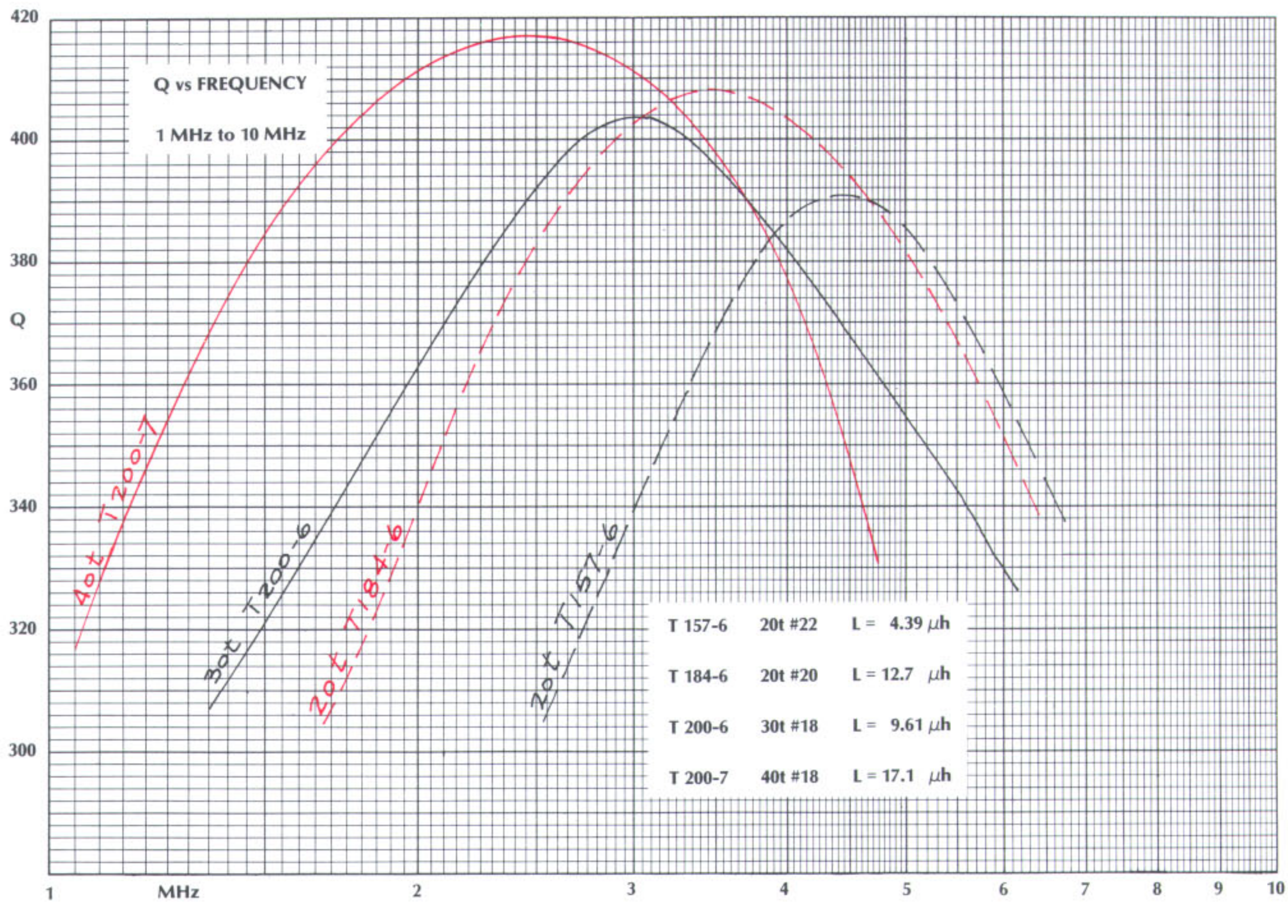
1 MHz to 10 MHz





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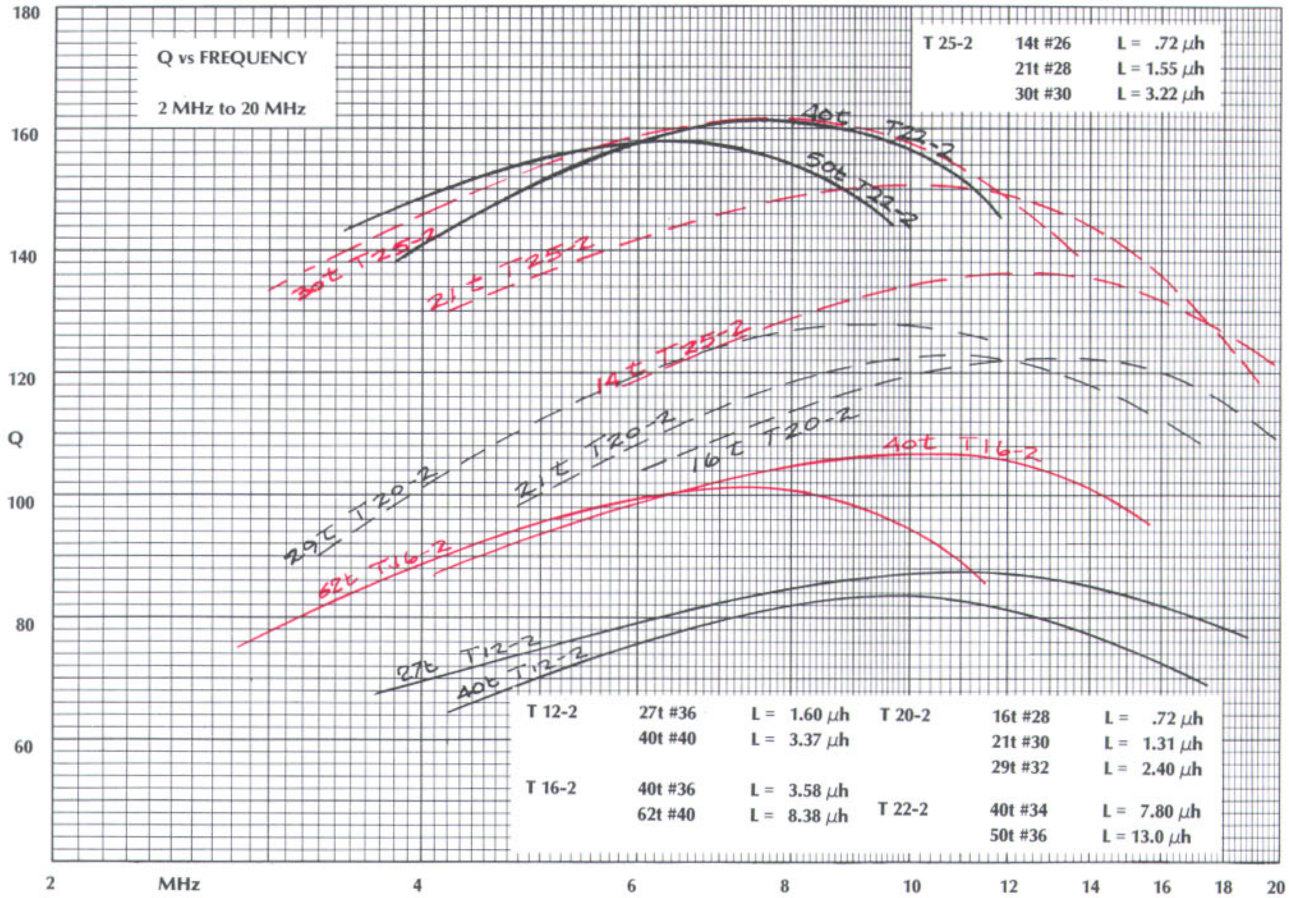

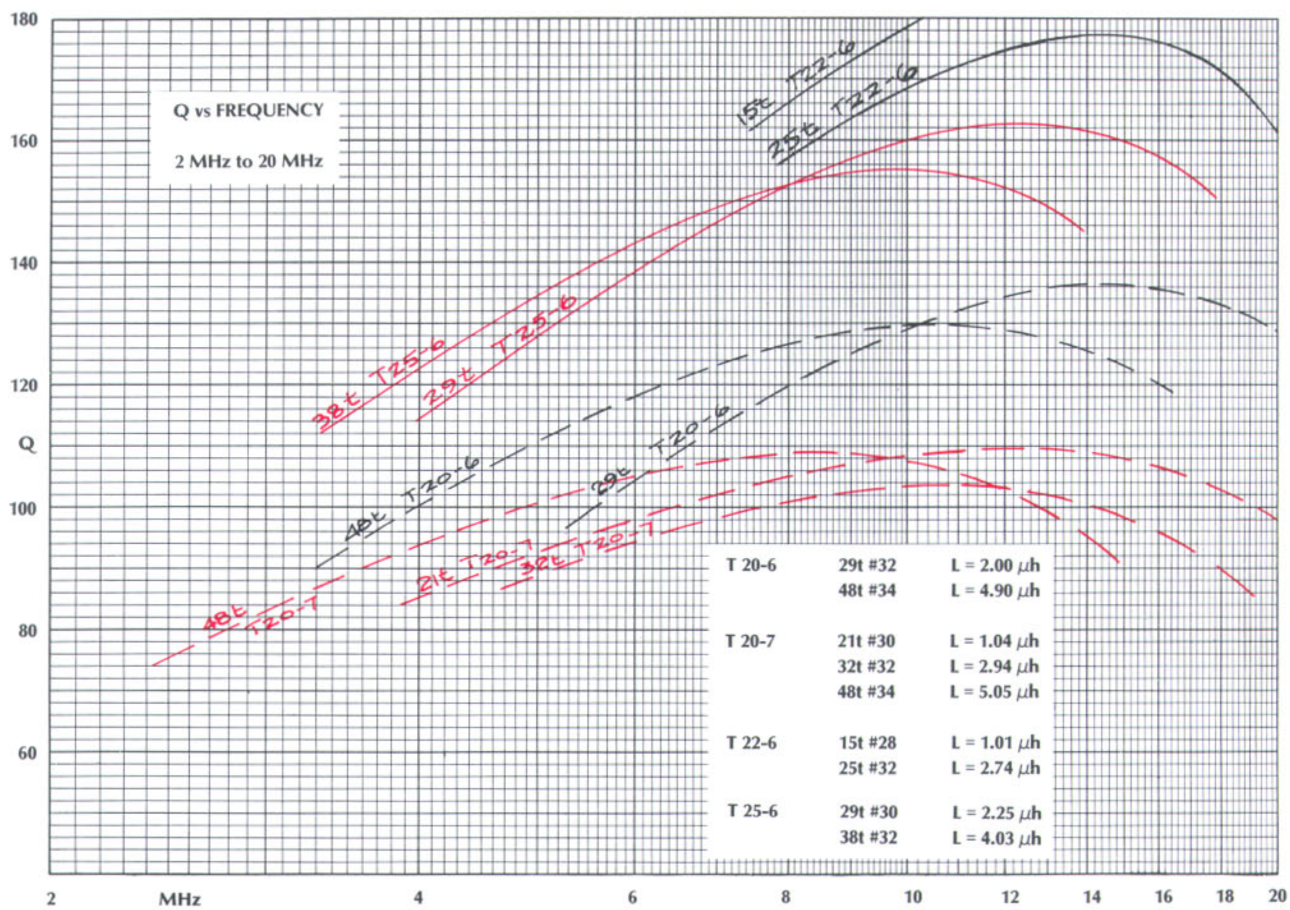

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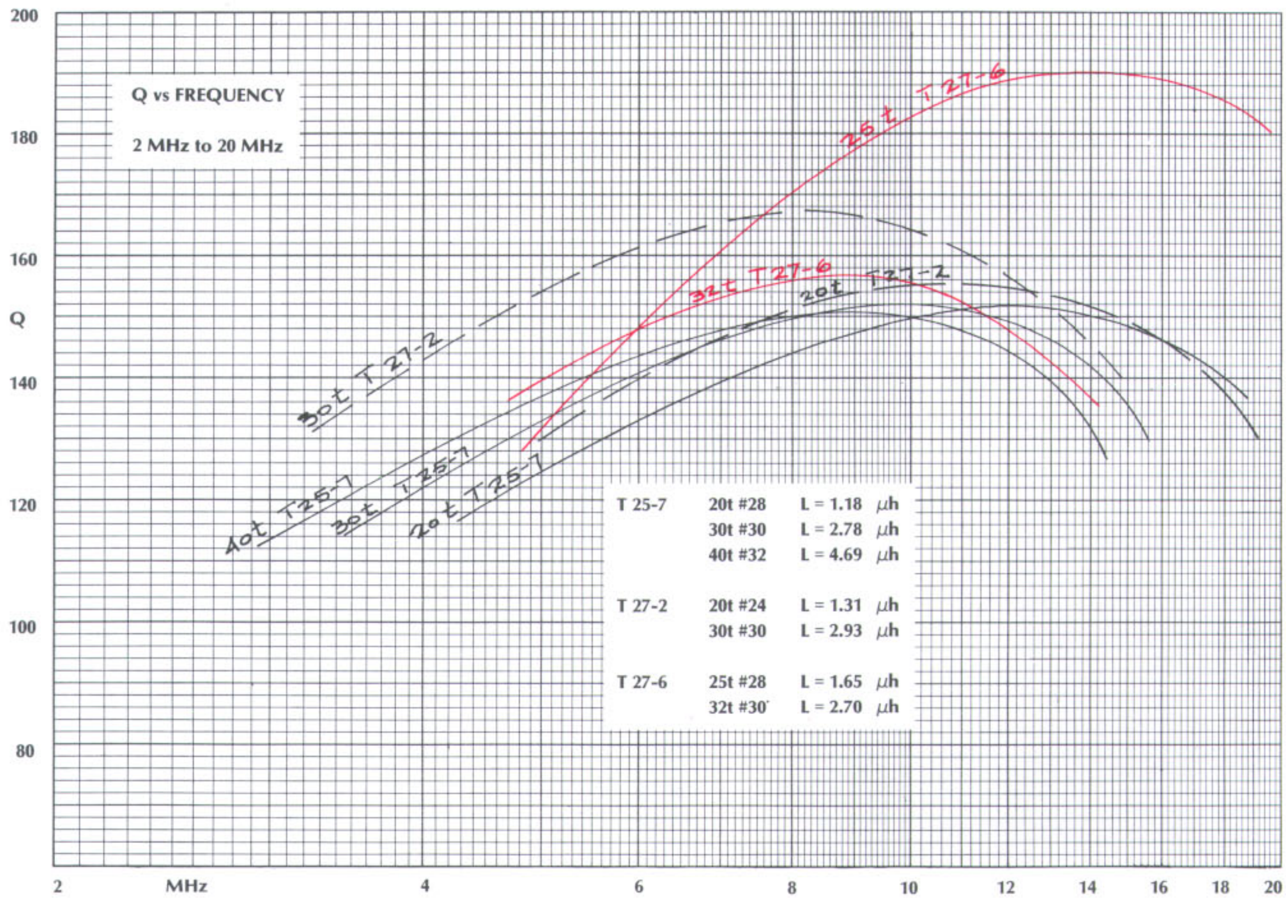

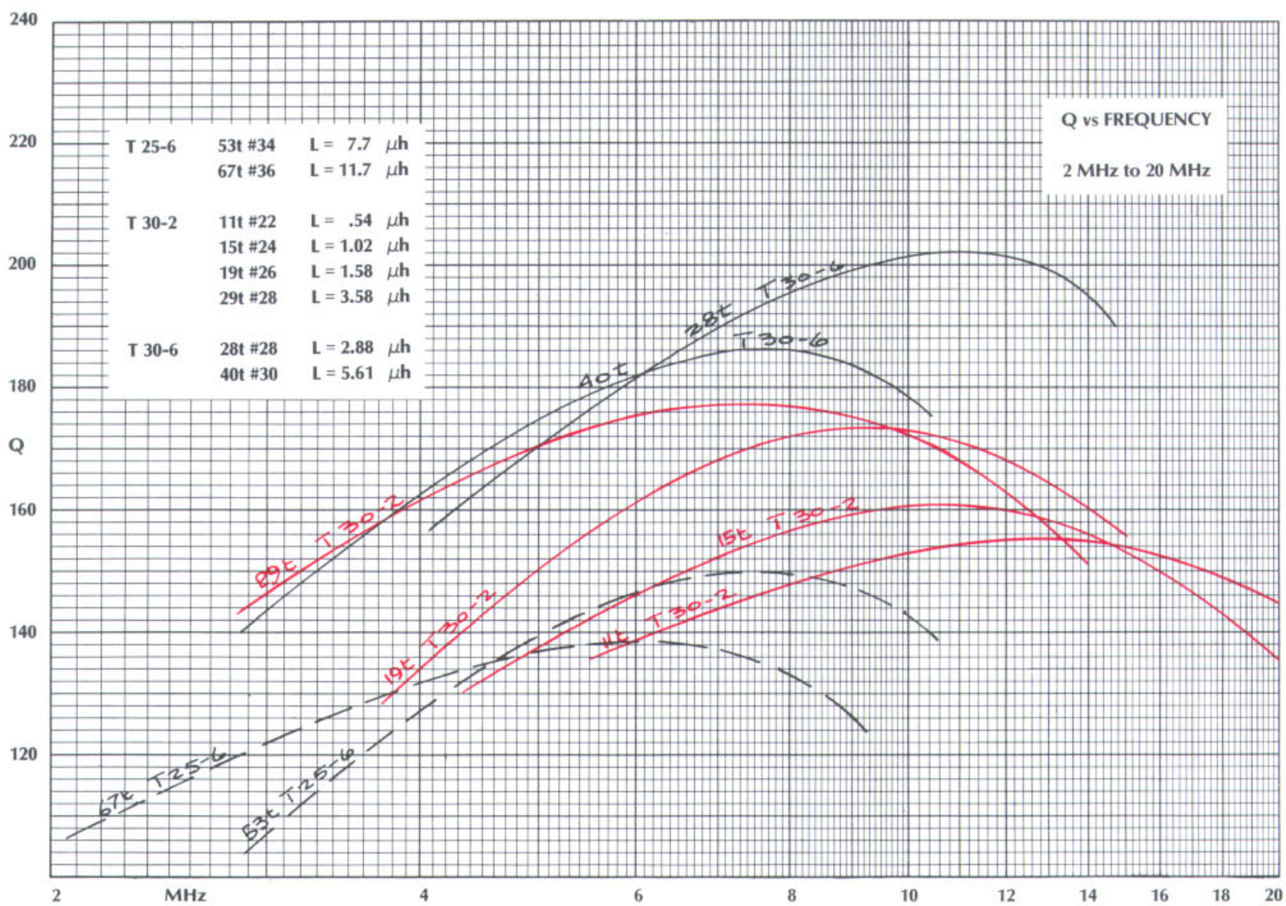

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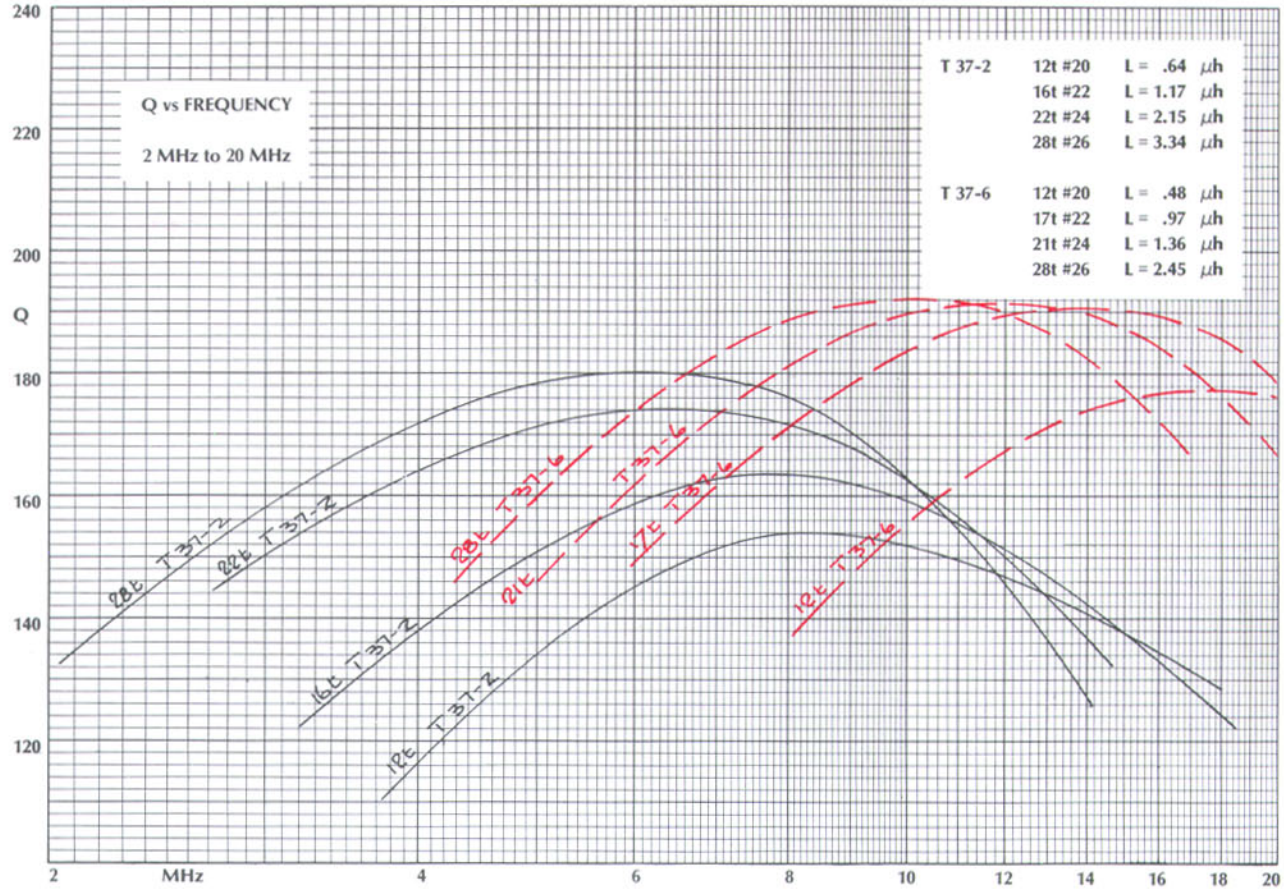

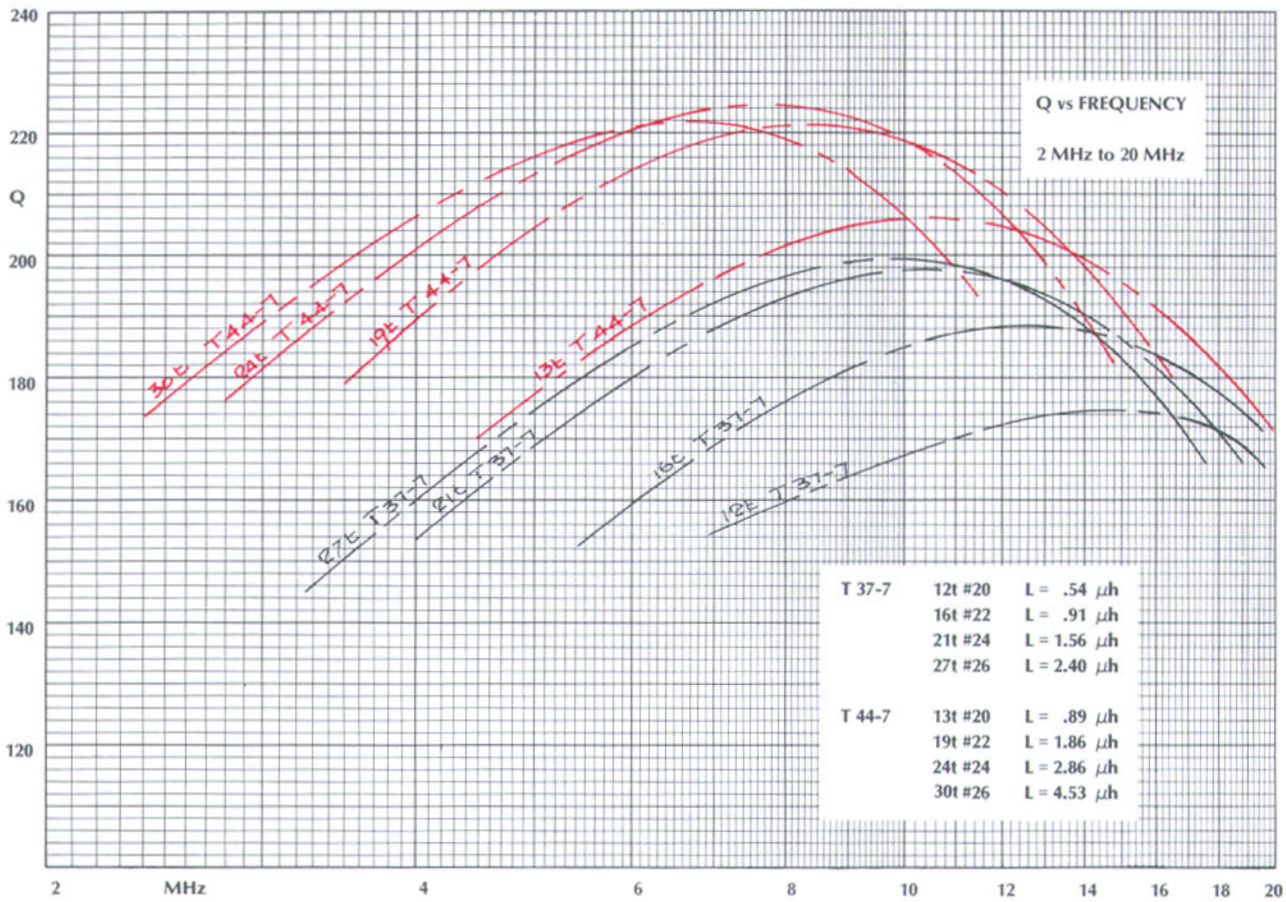

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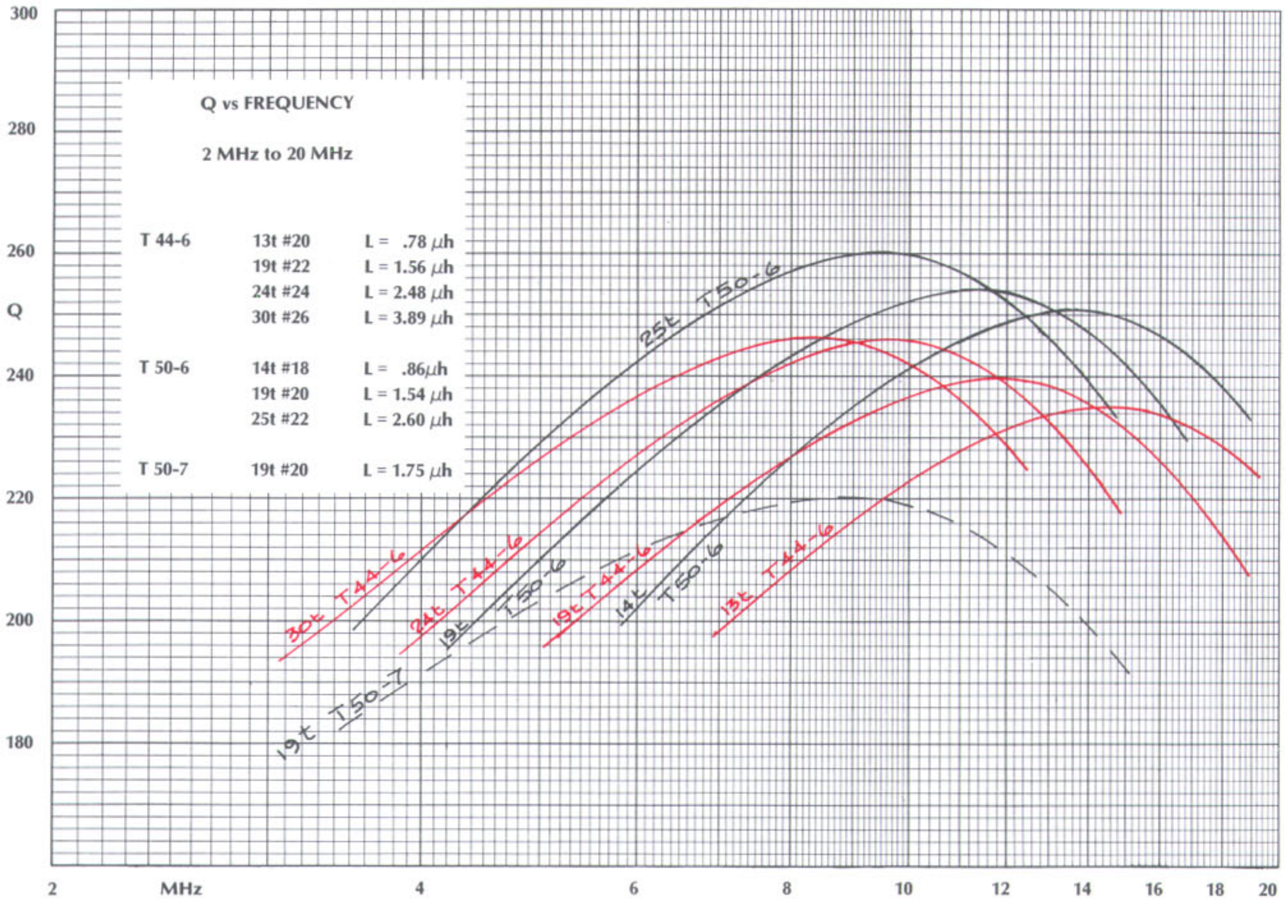
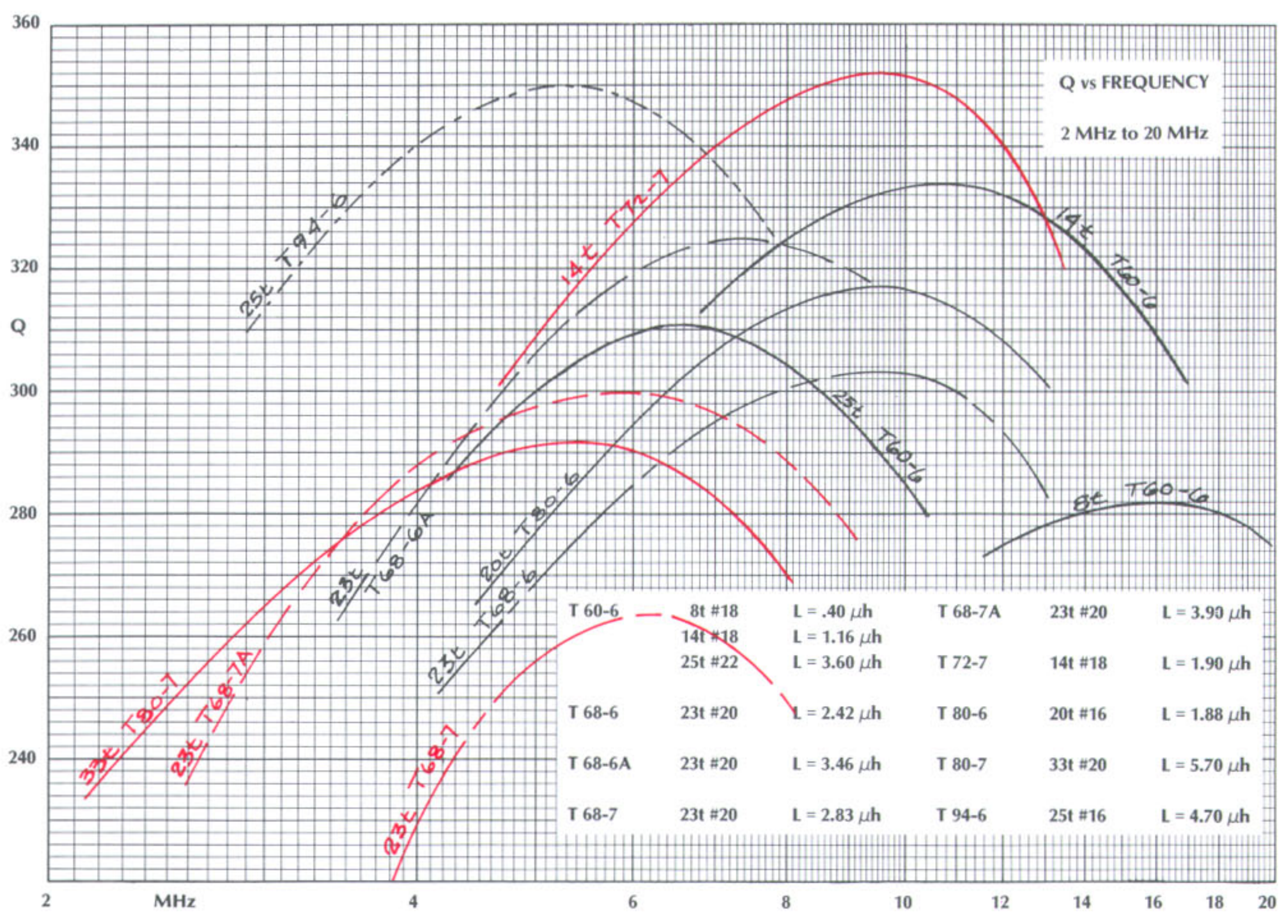
2 MHz to 20 MHz





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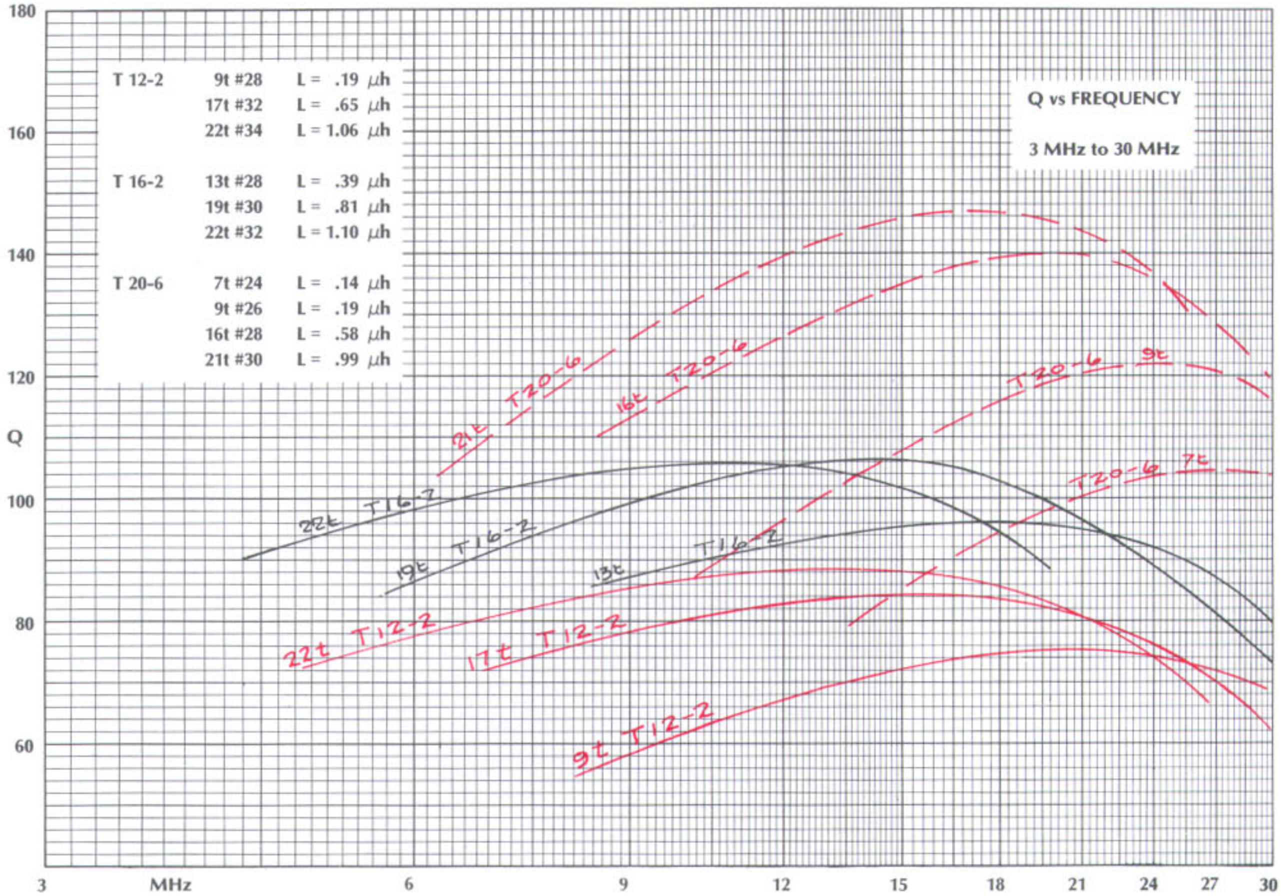

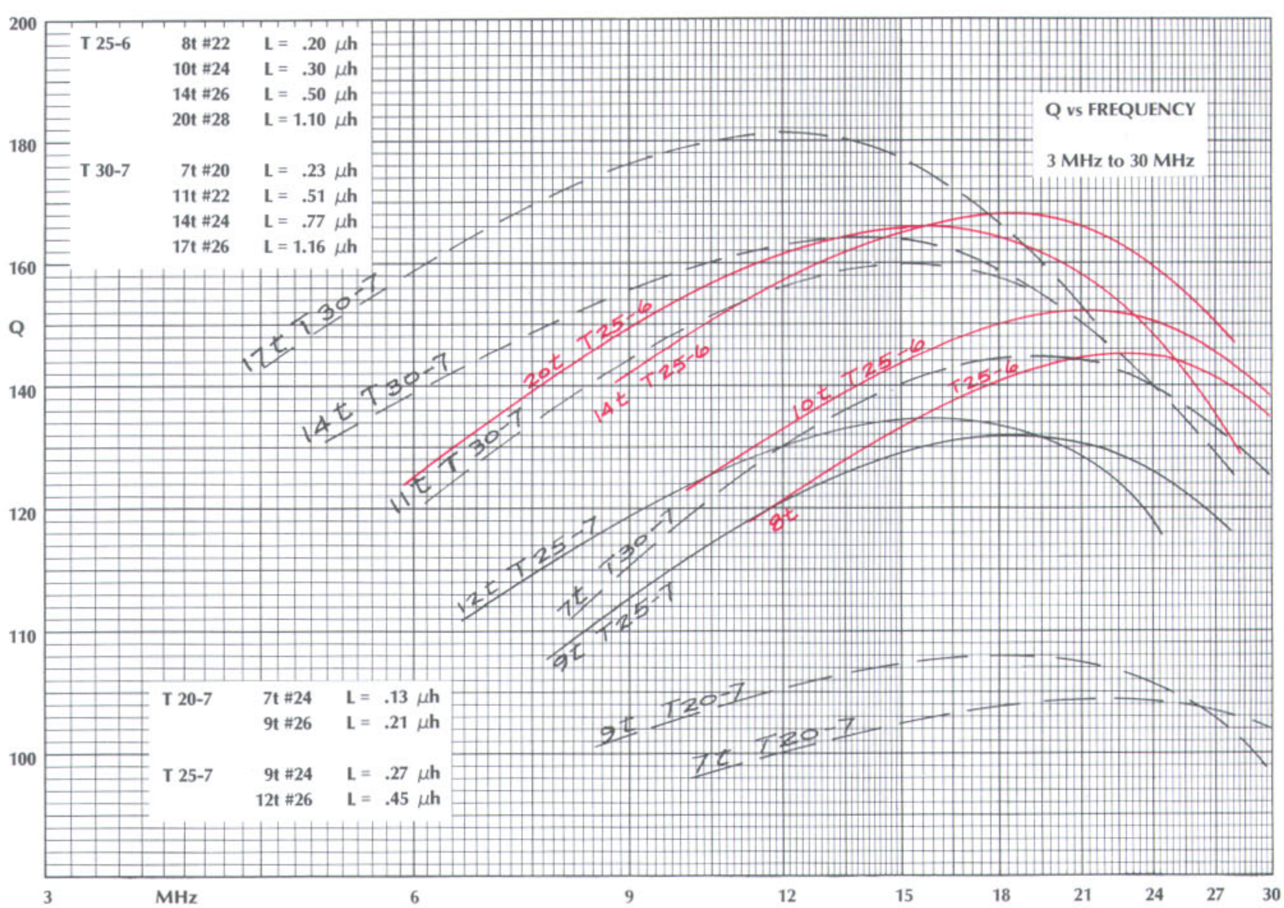

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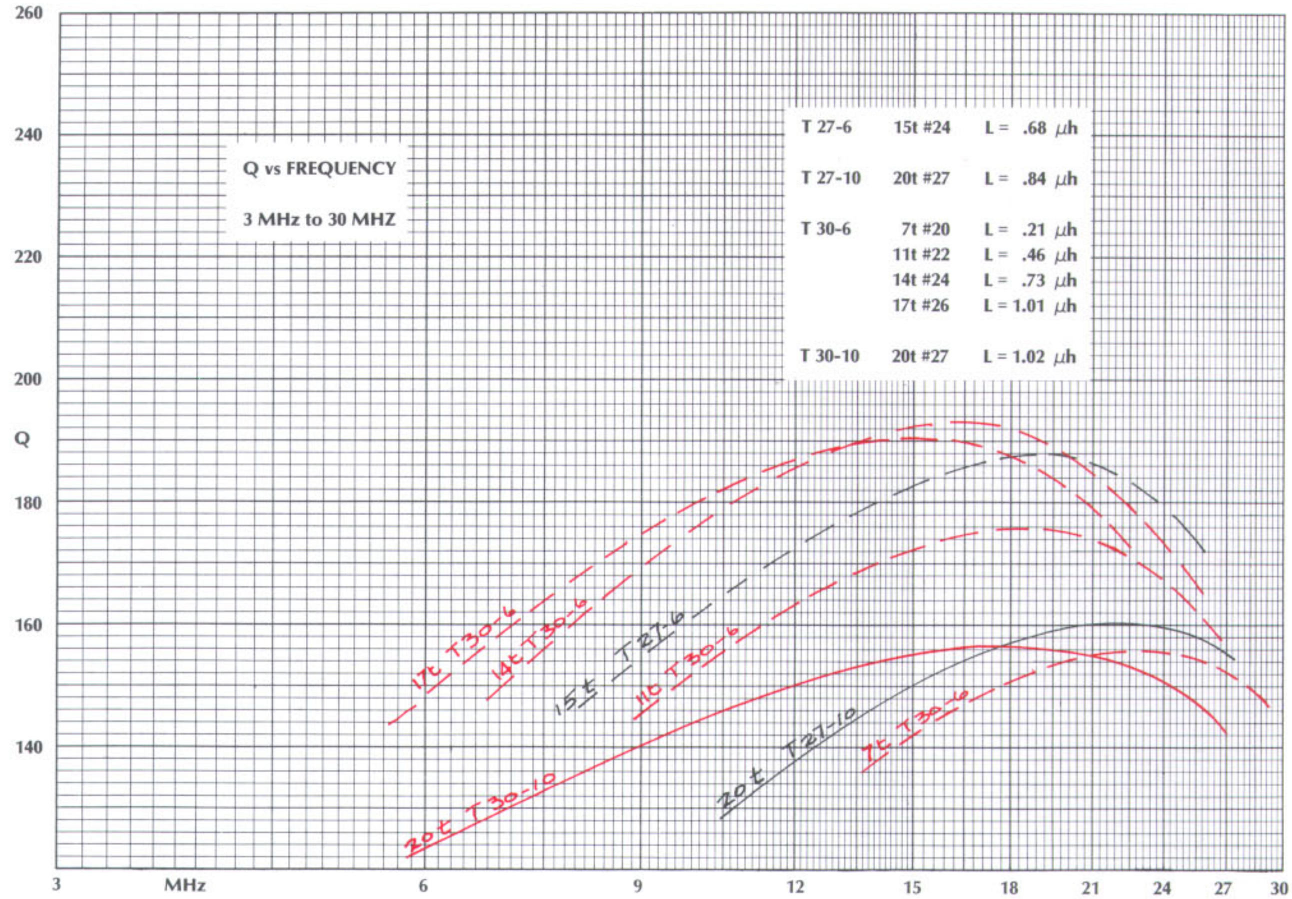

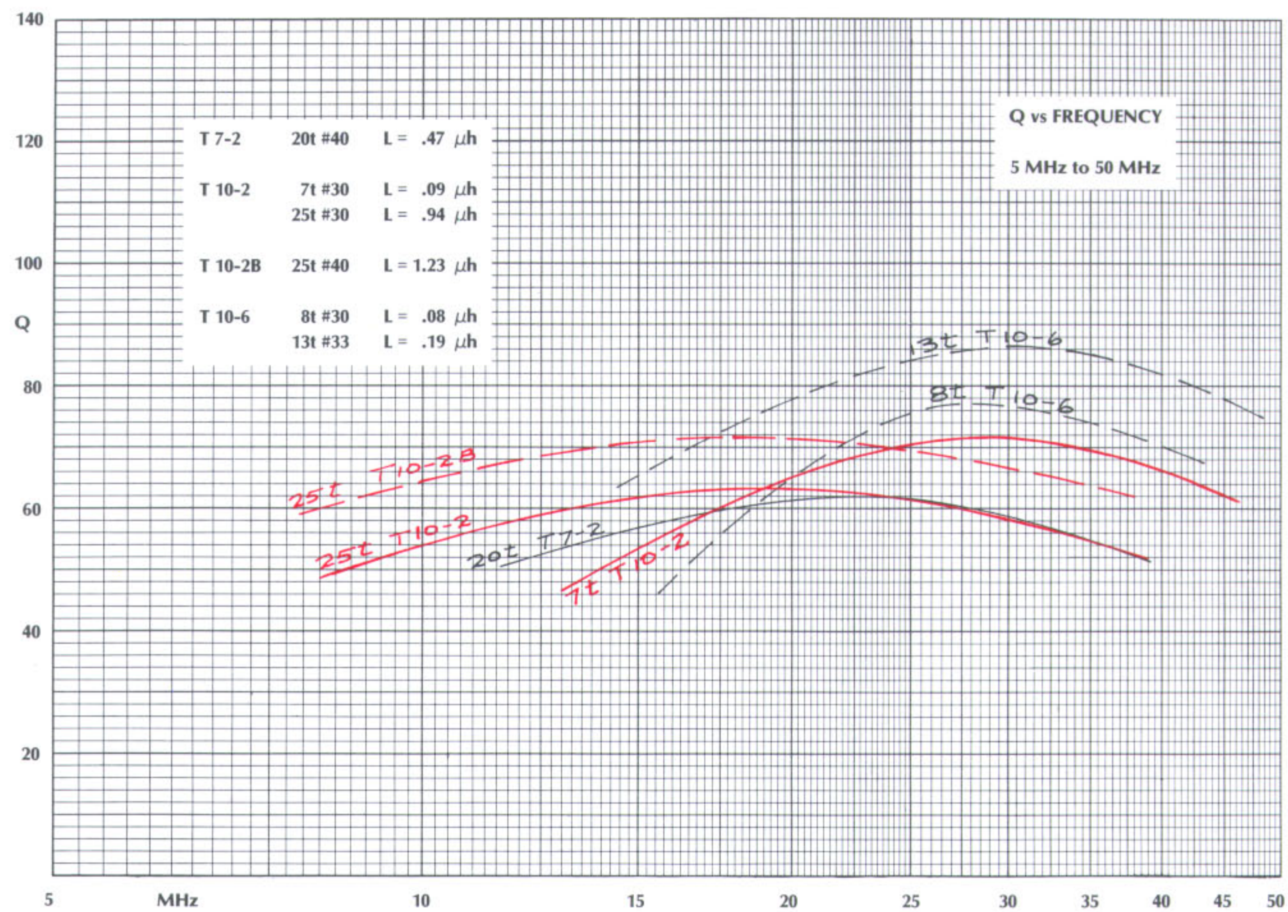

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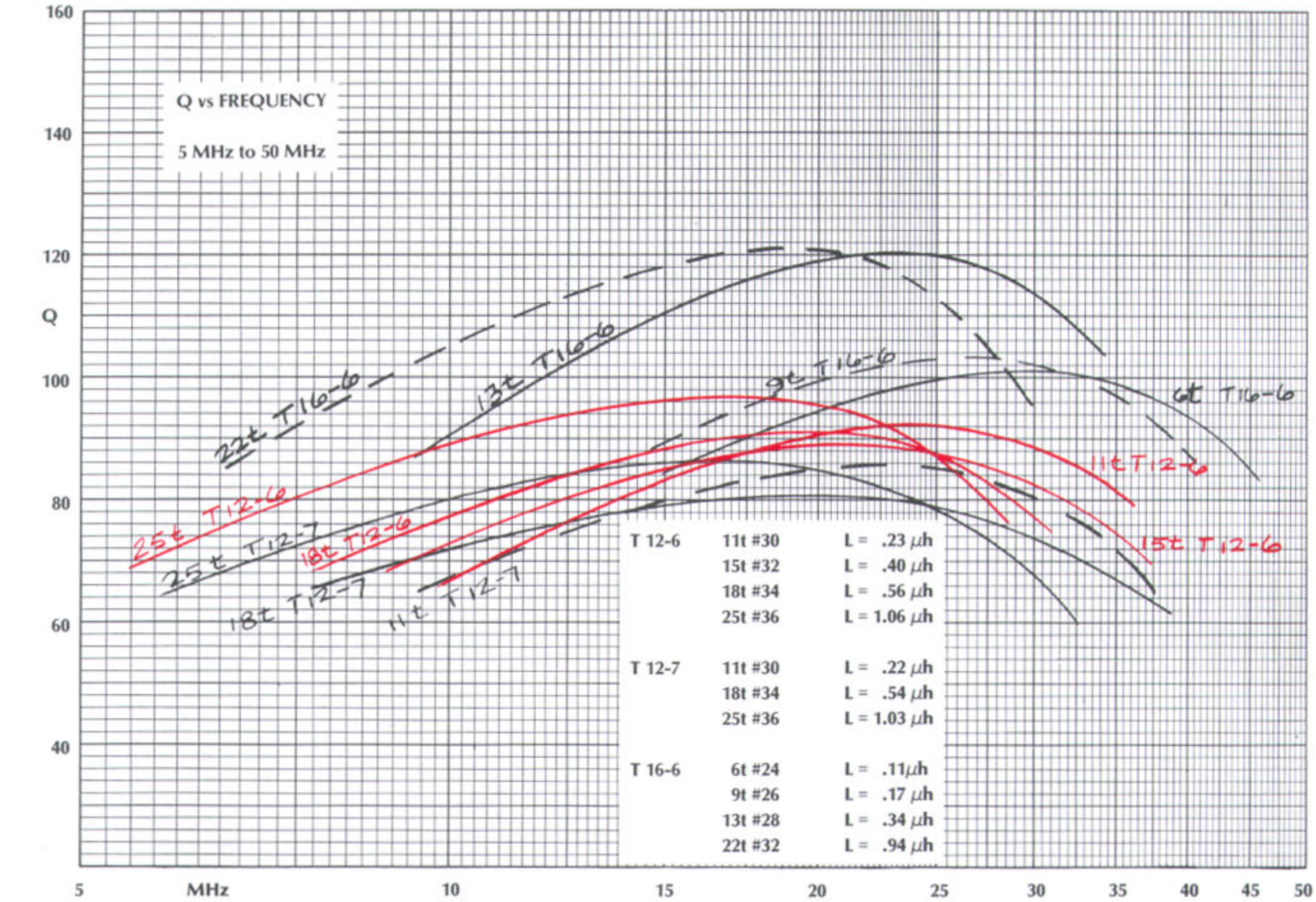

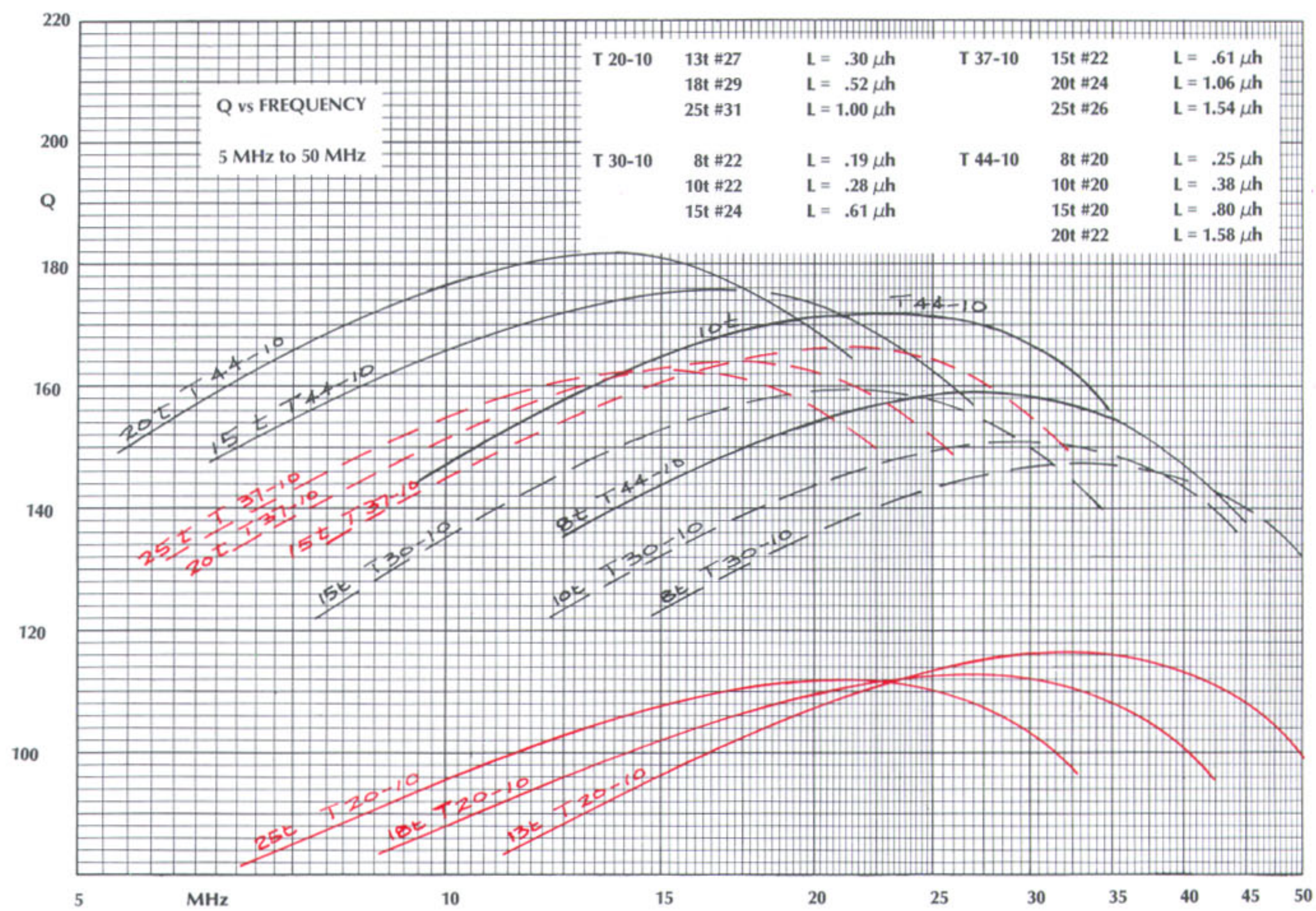

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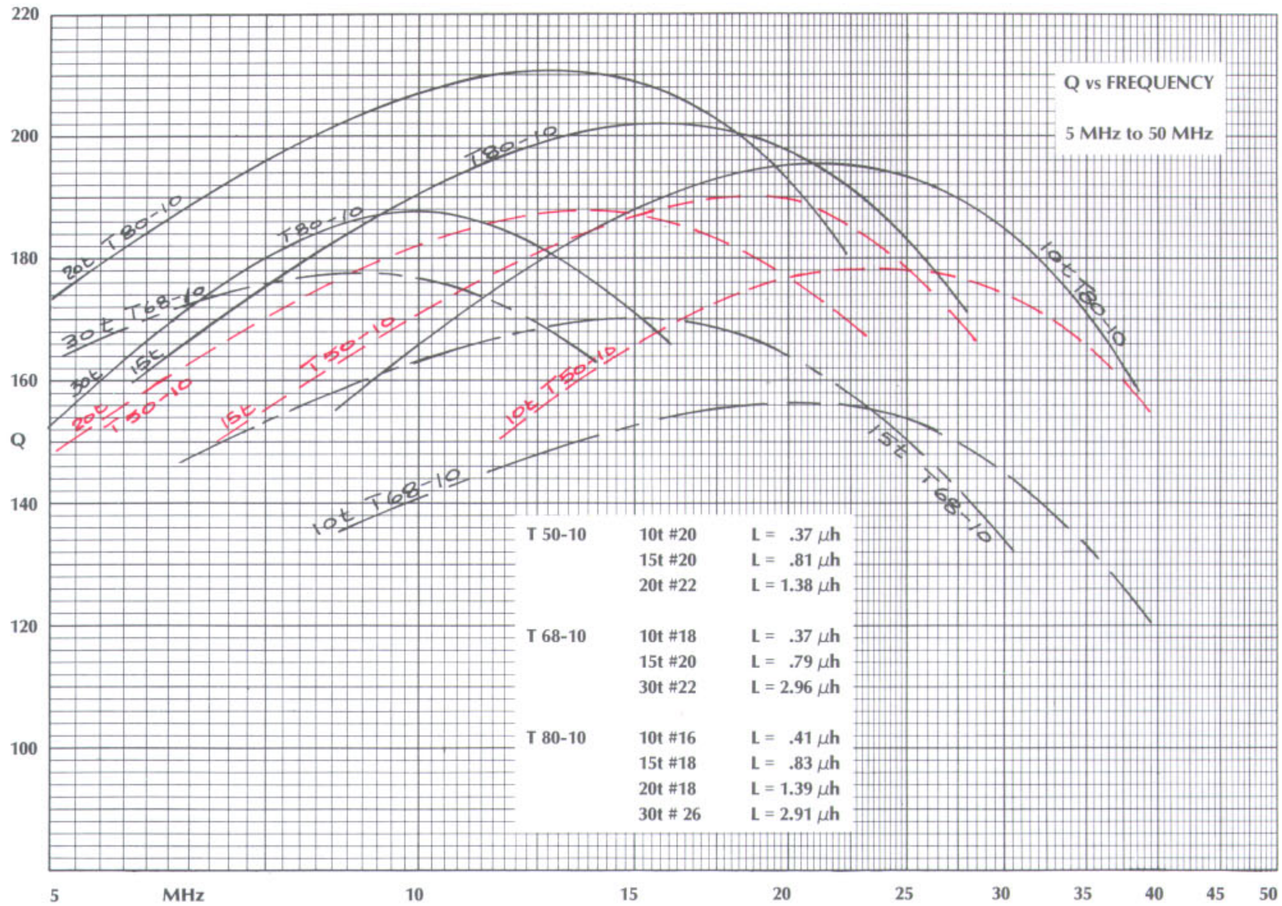
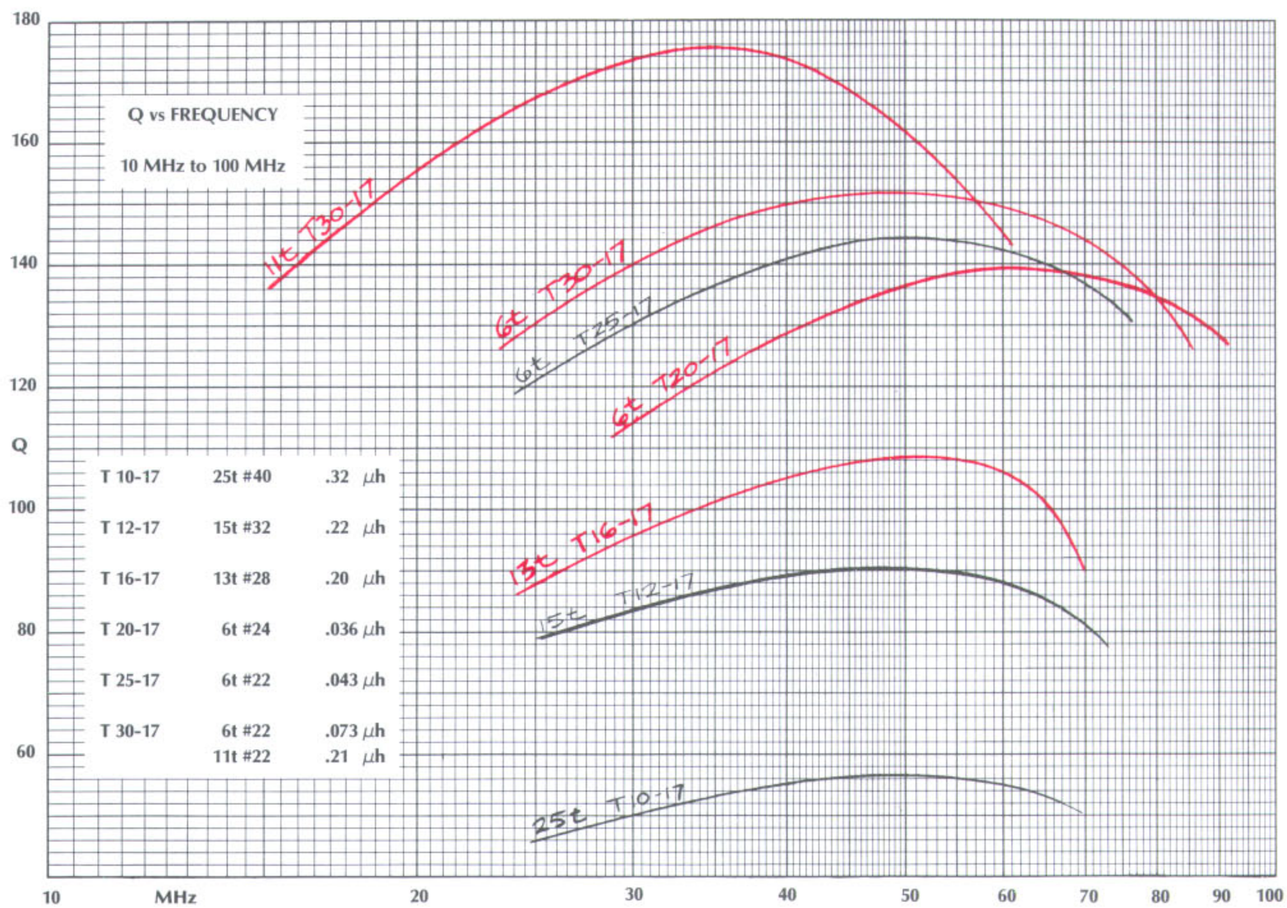
5 MHz to 100 MHz





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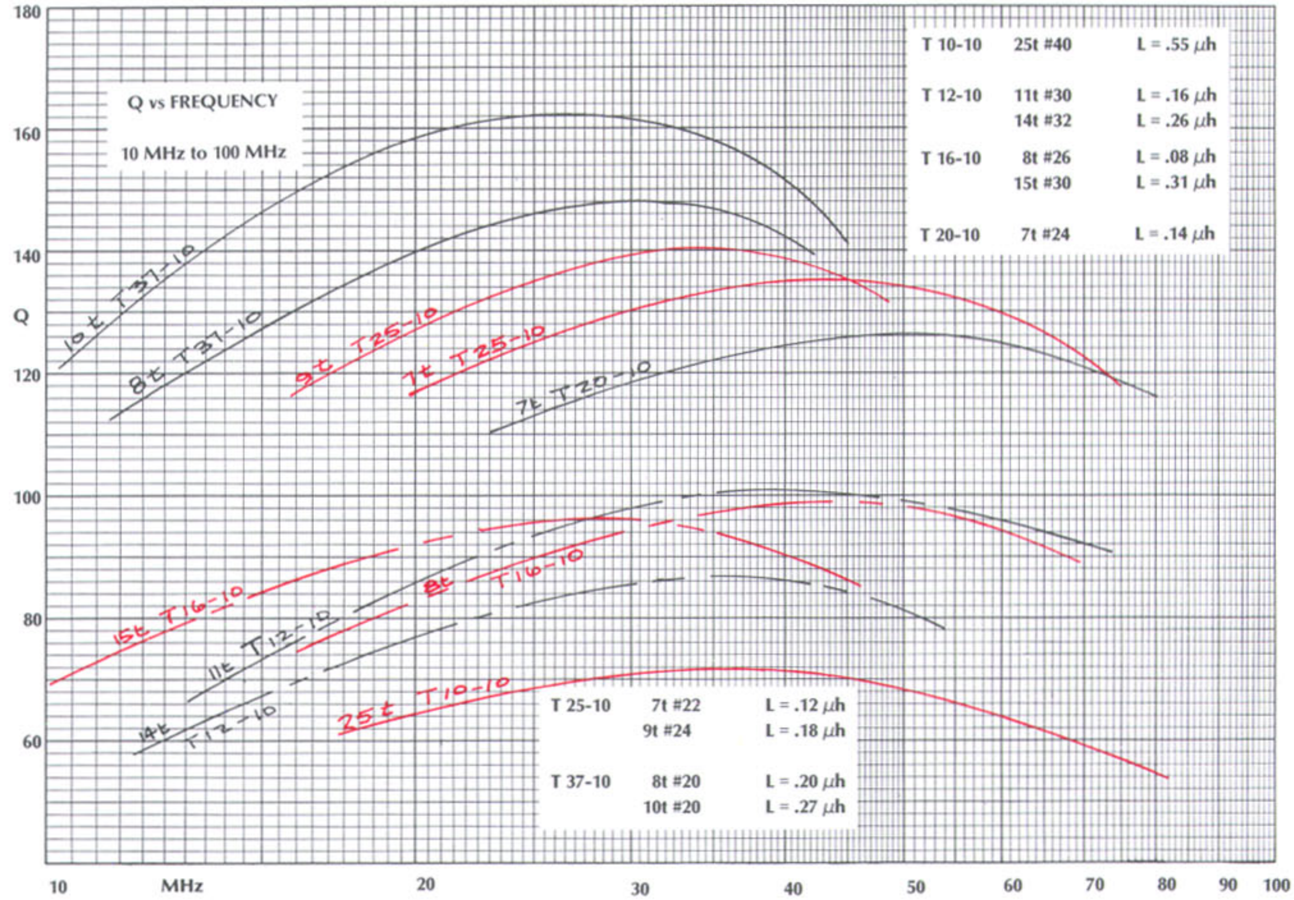

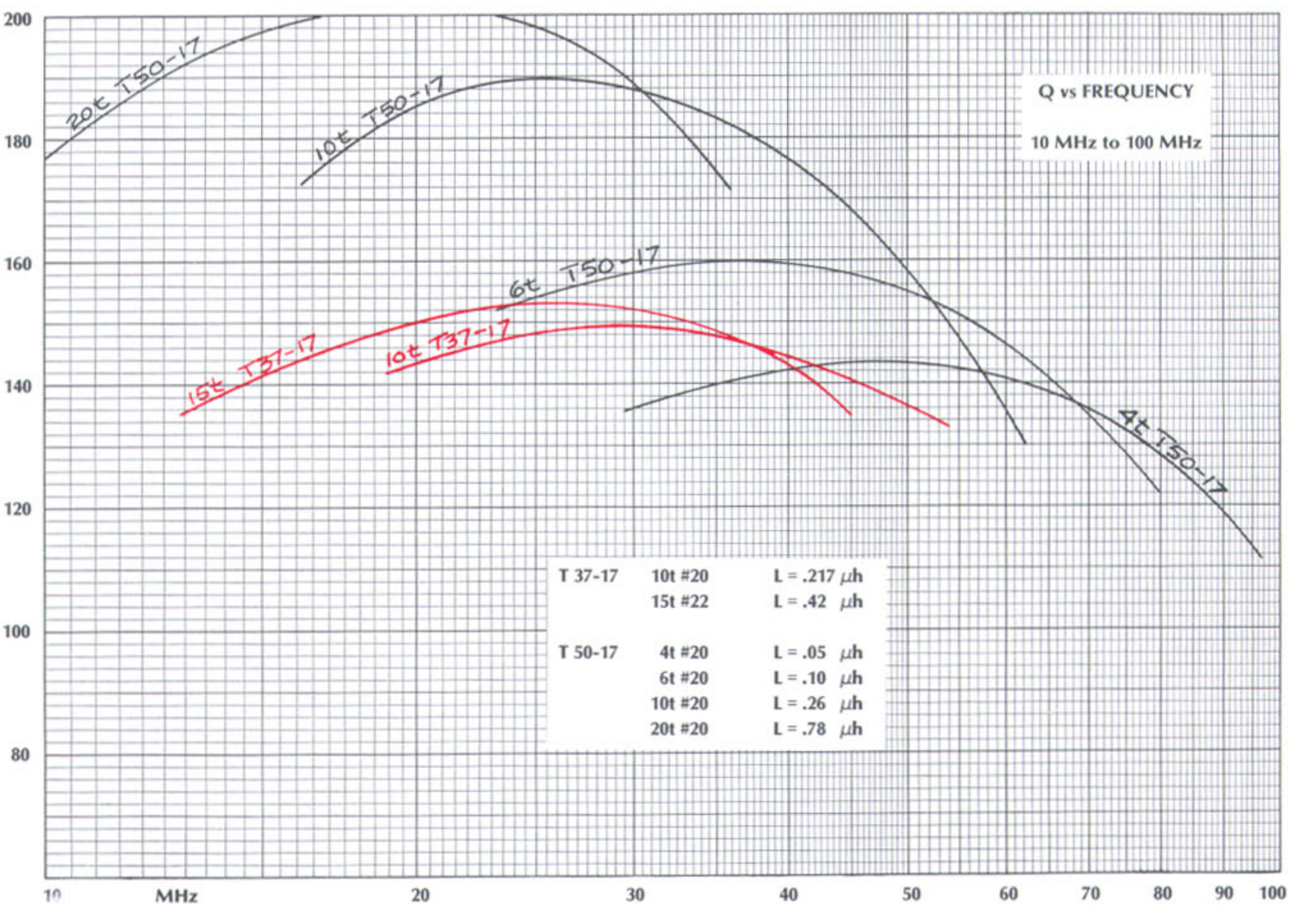

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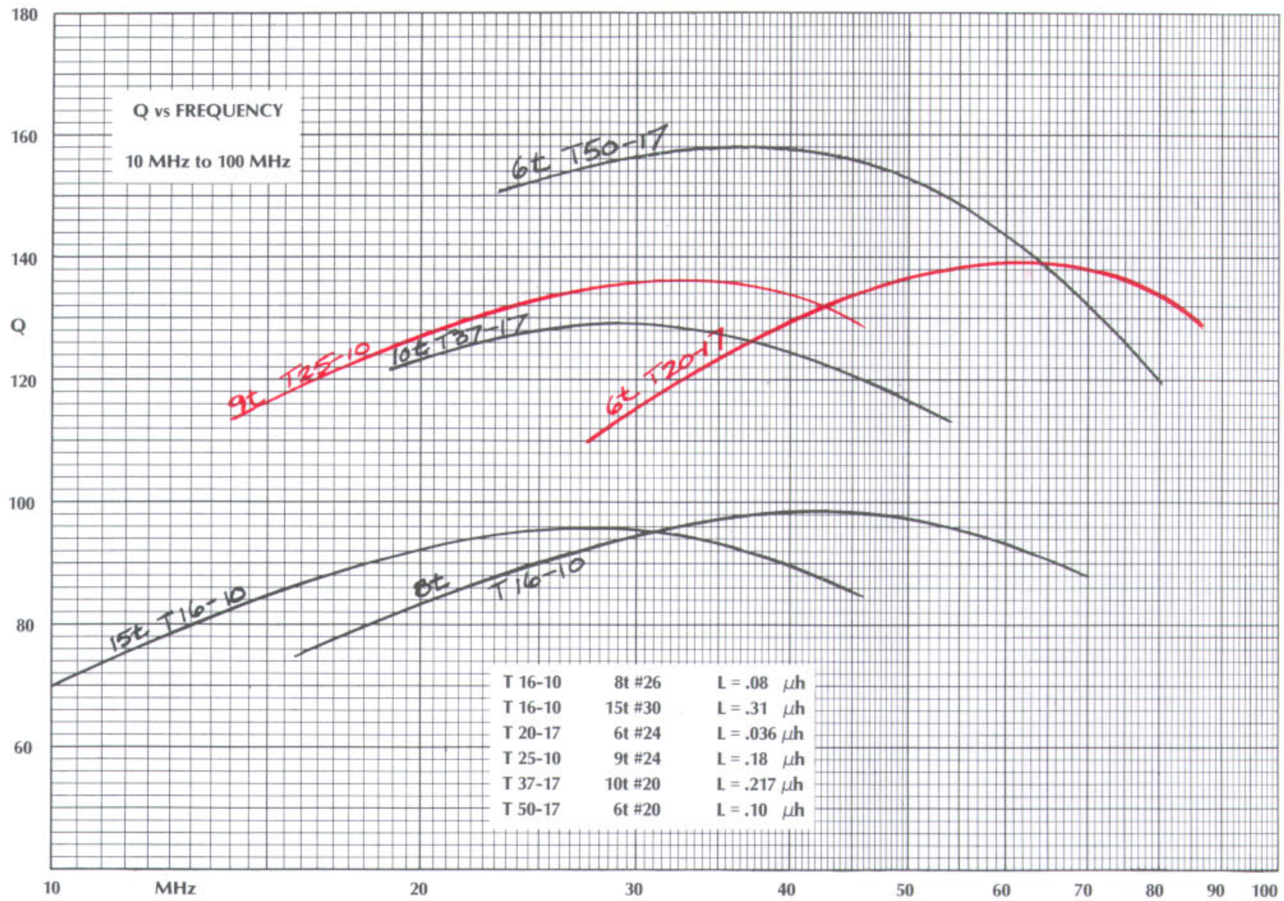
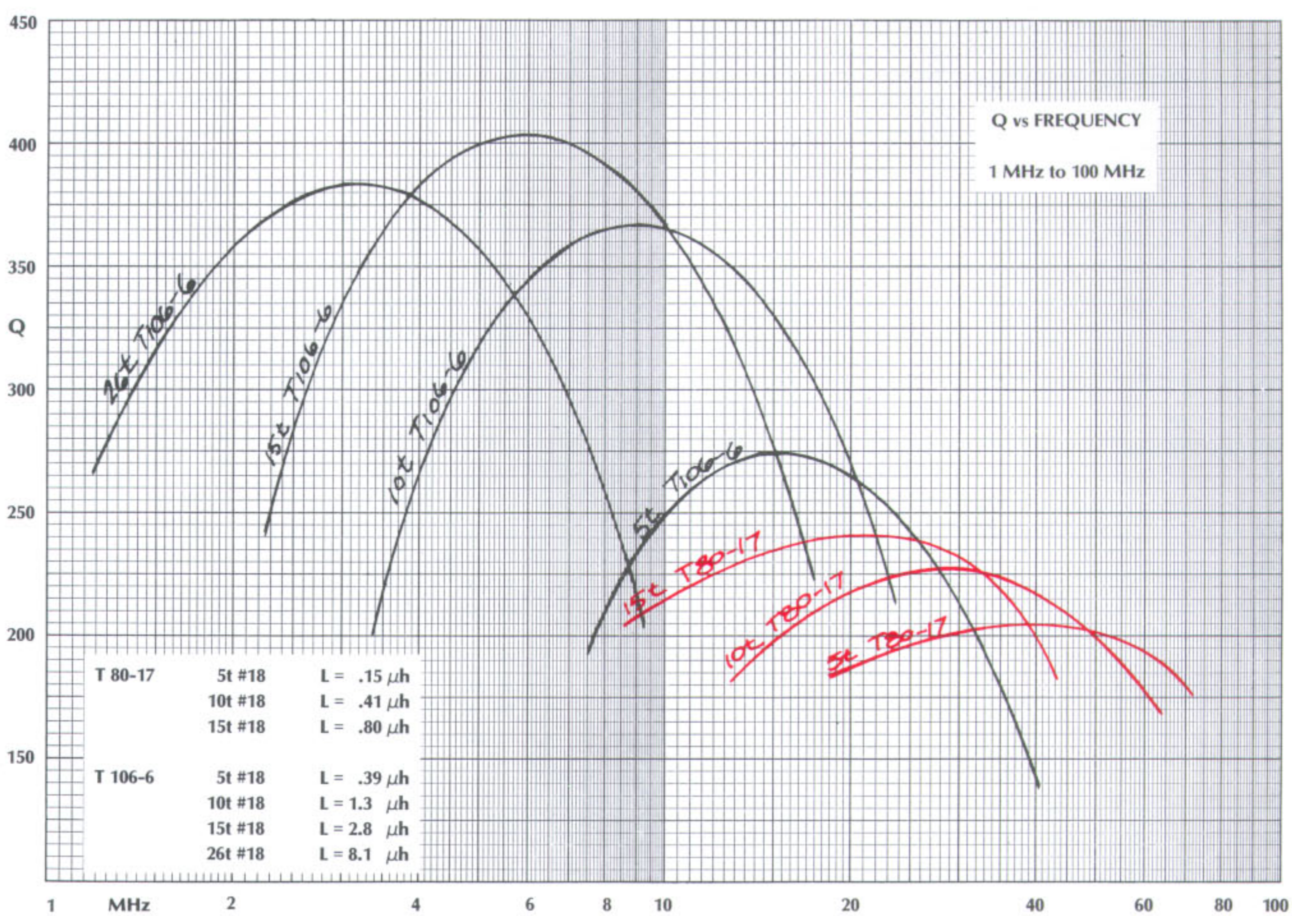
10 MHz to 100 MHz





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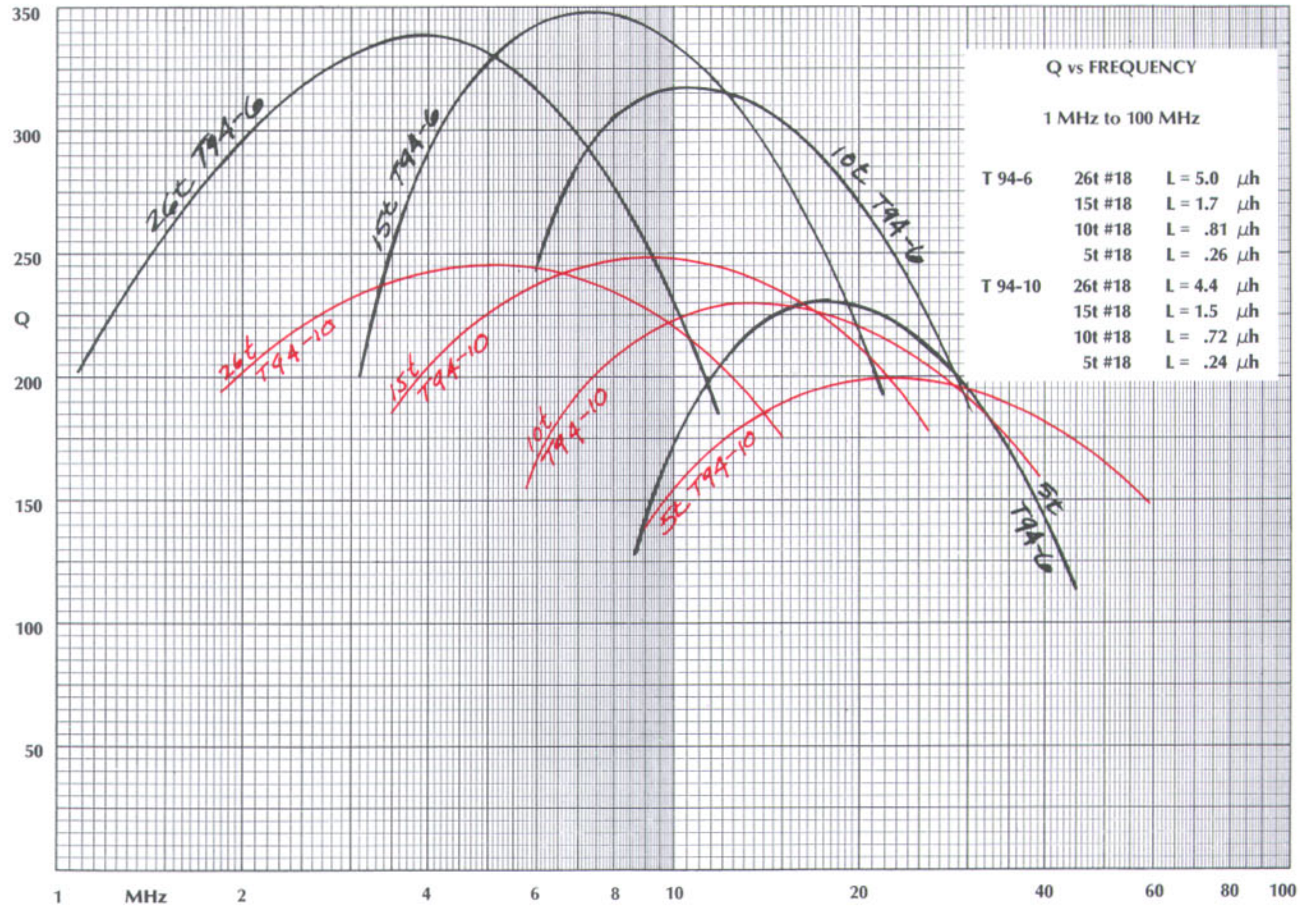

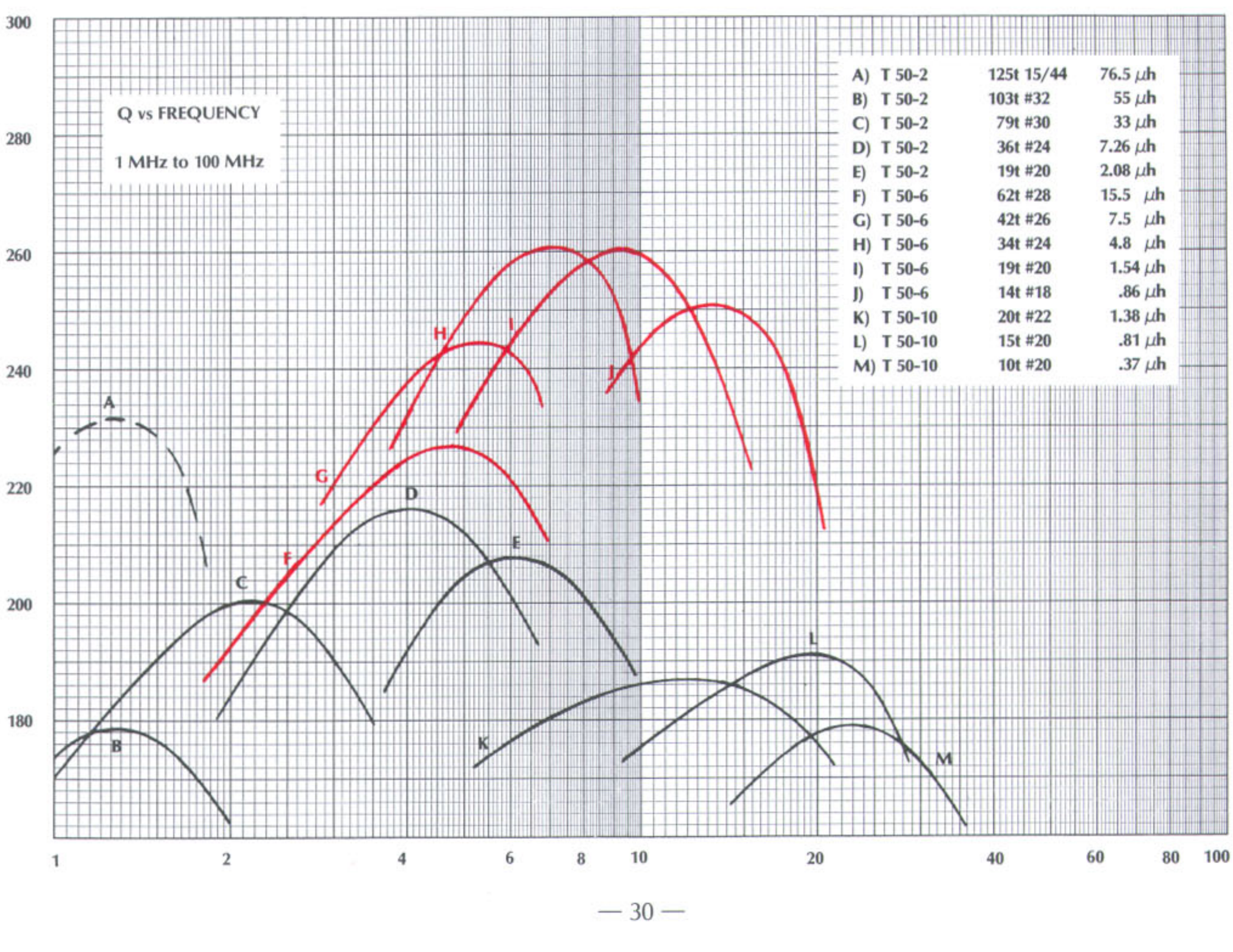

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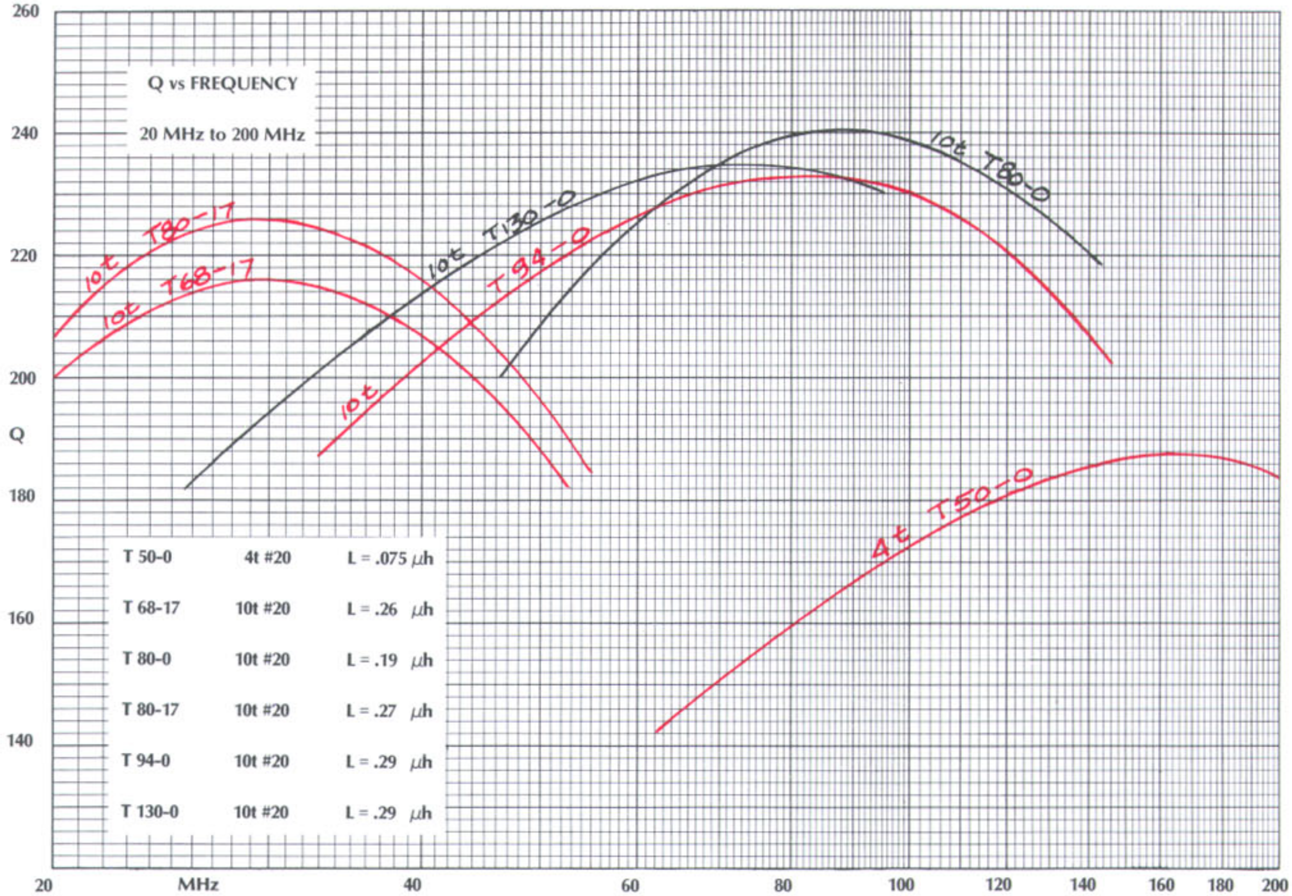
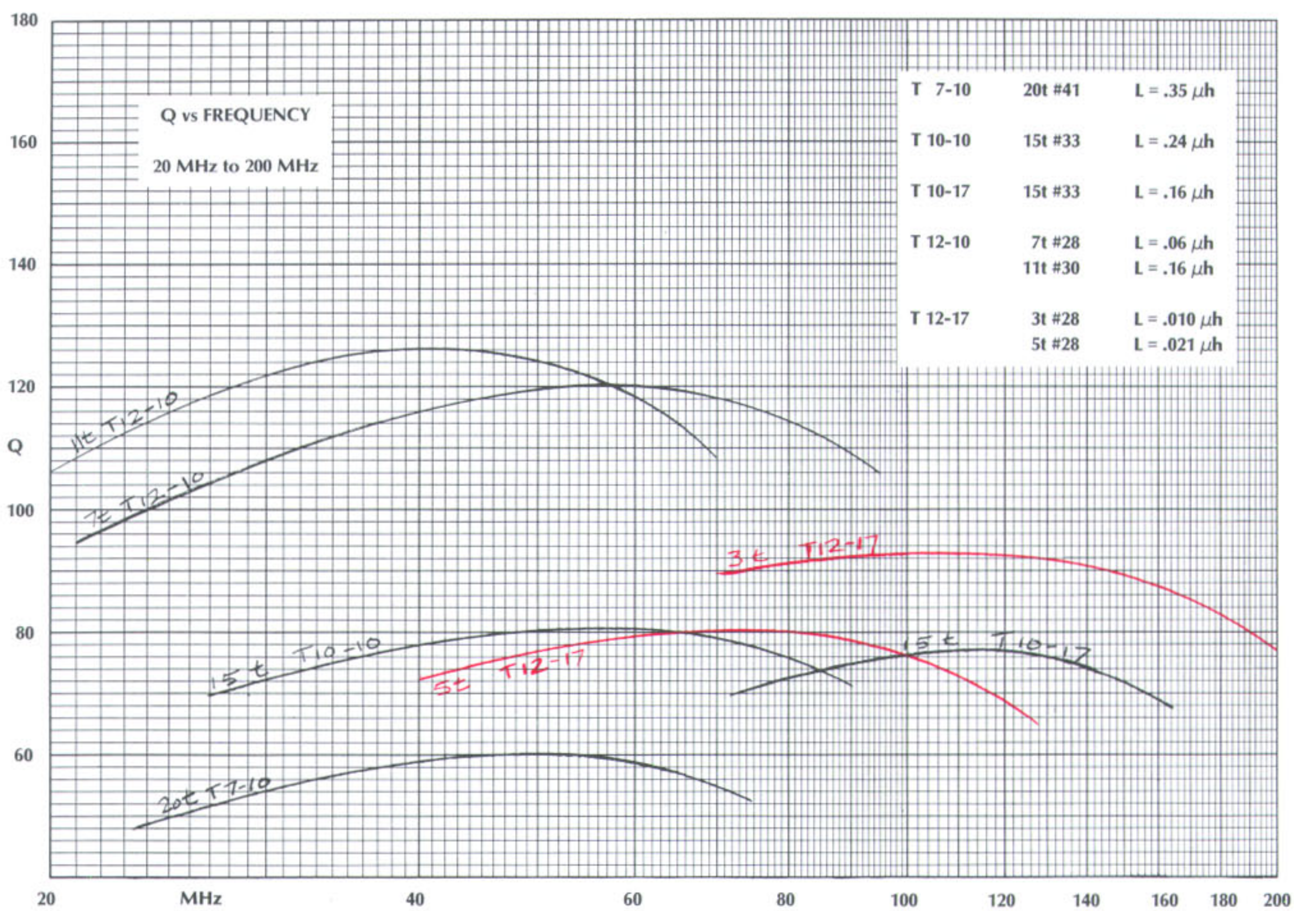
20 MHz to 200 MHz





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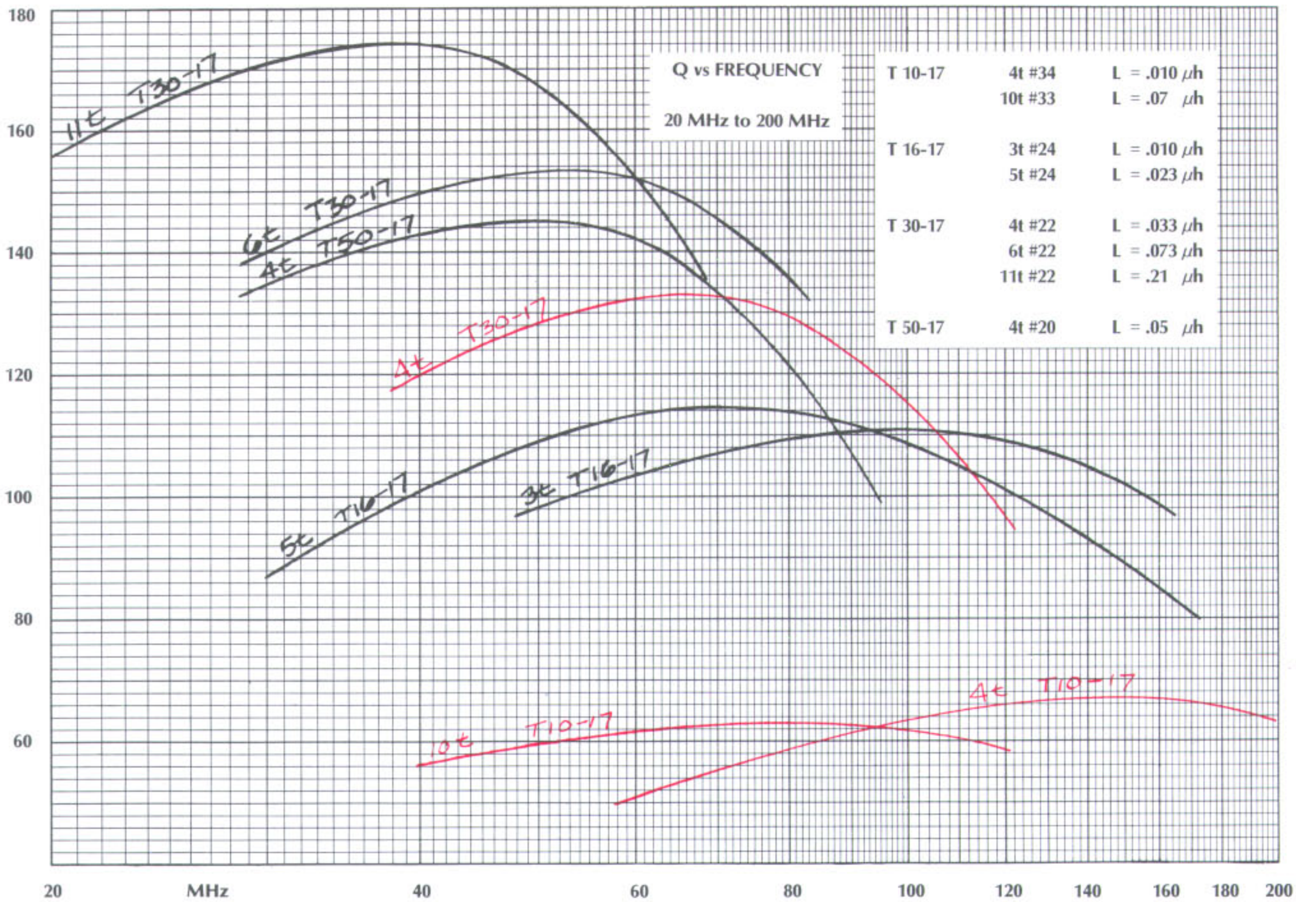

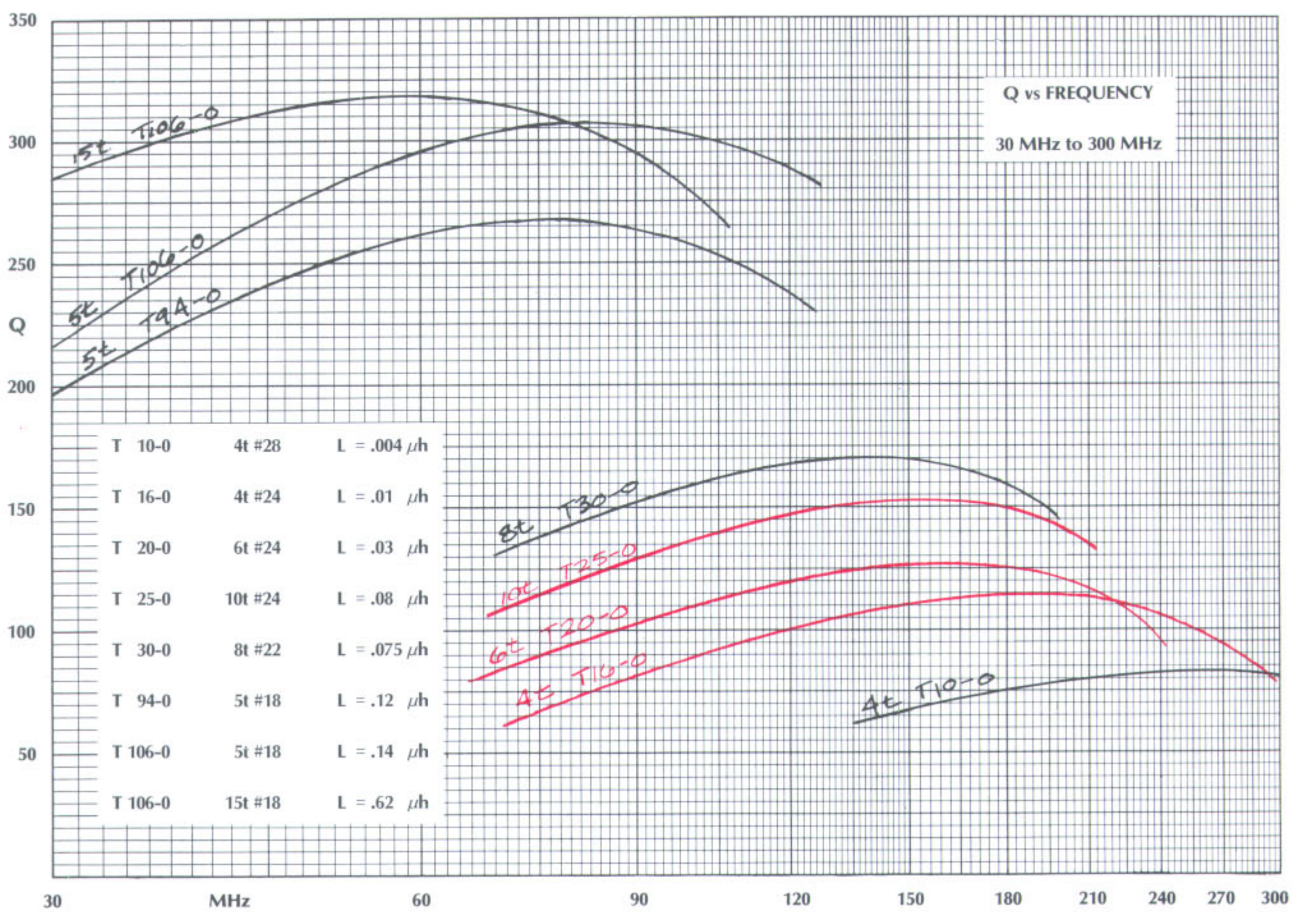

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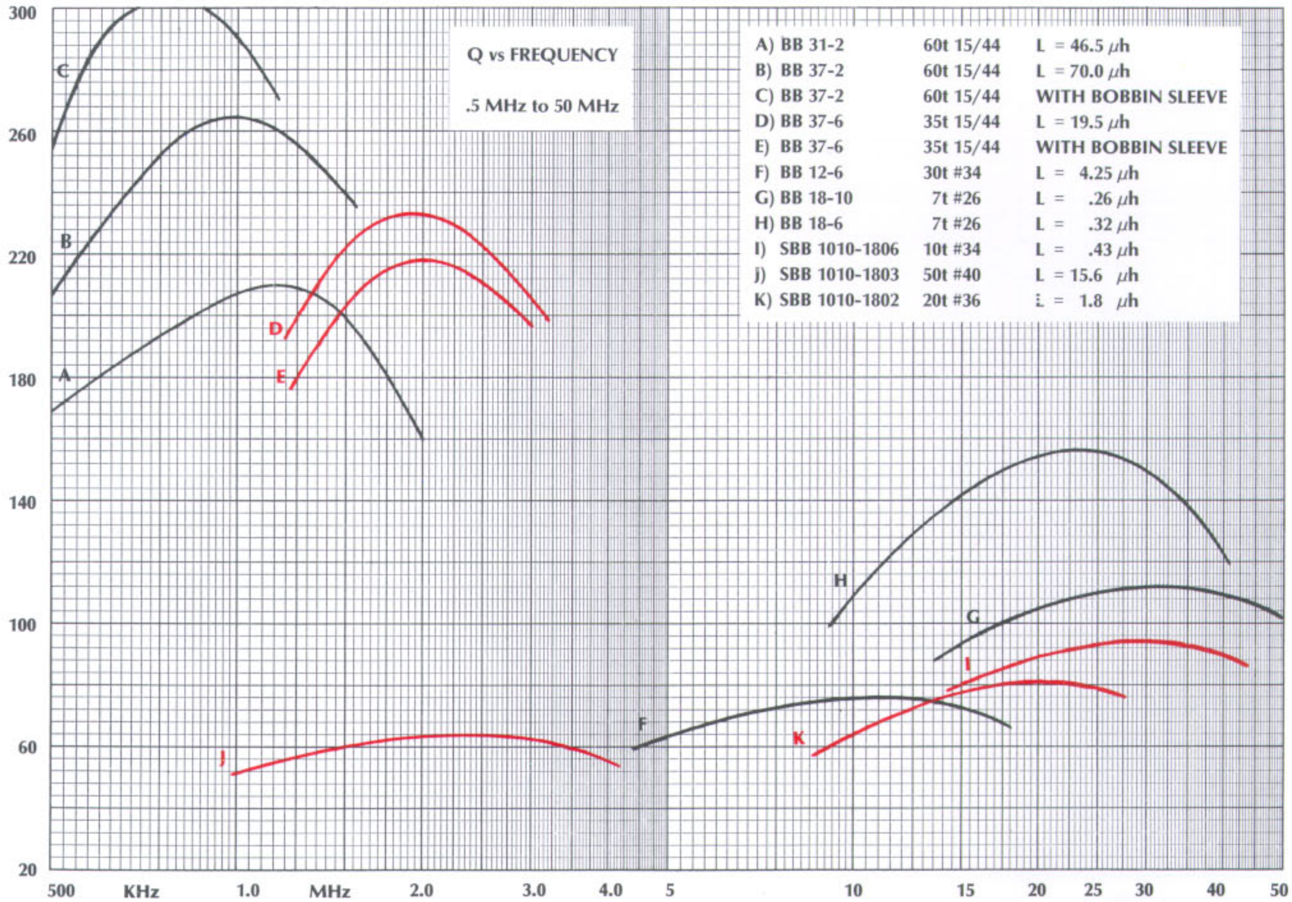
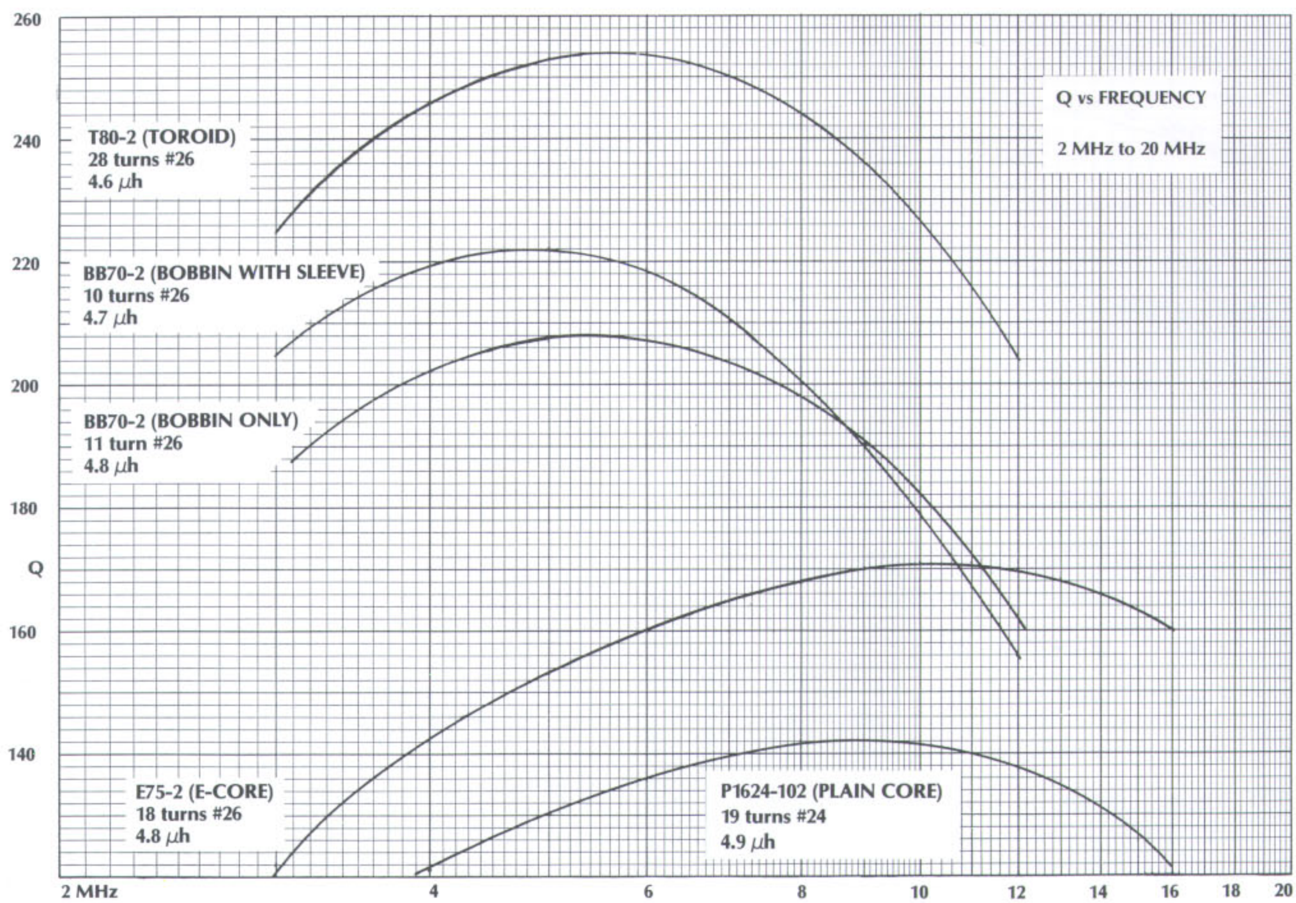
NON-TOROIDAL SHAPES





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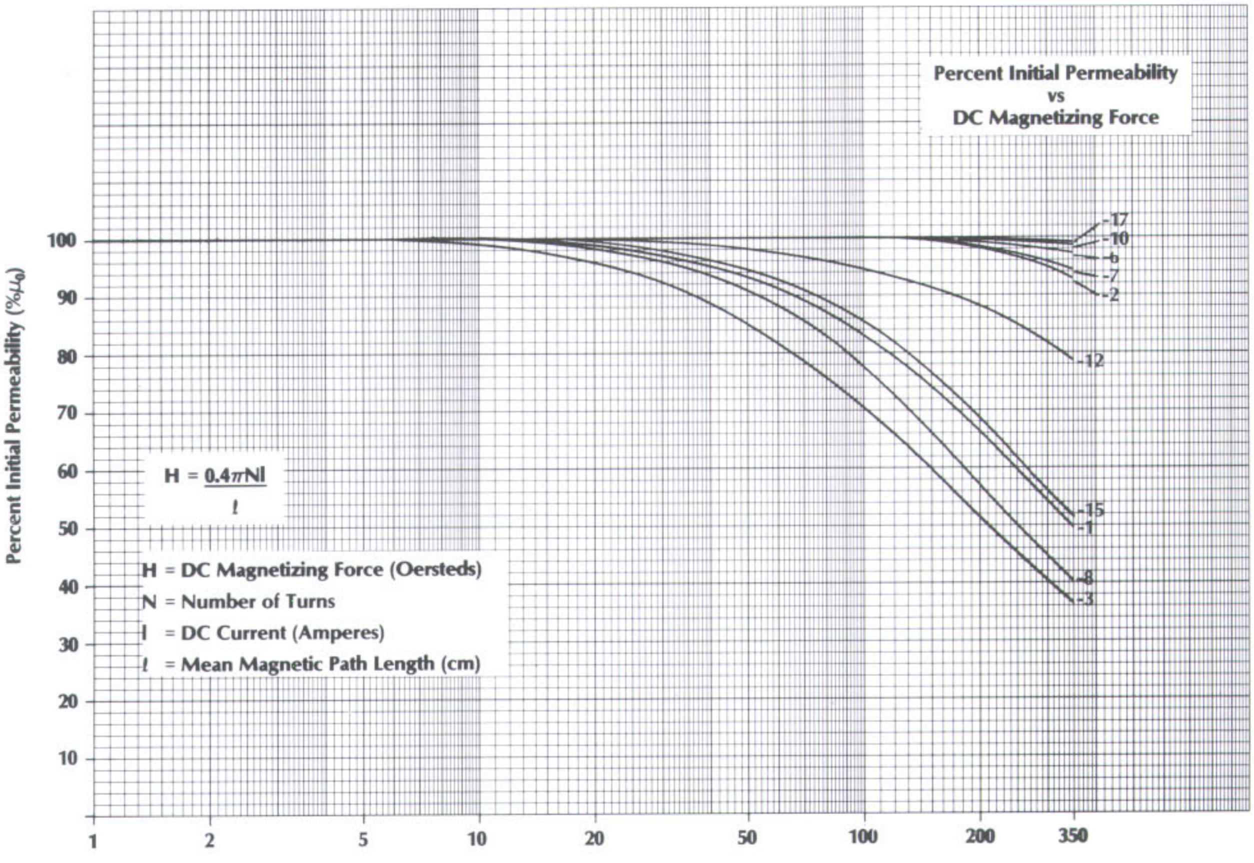

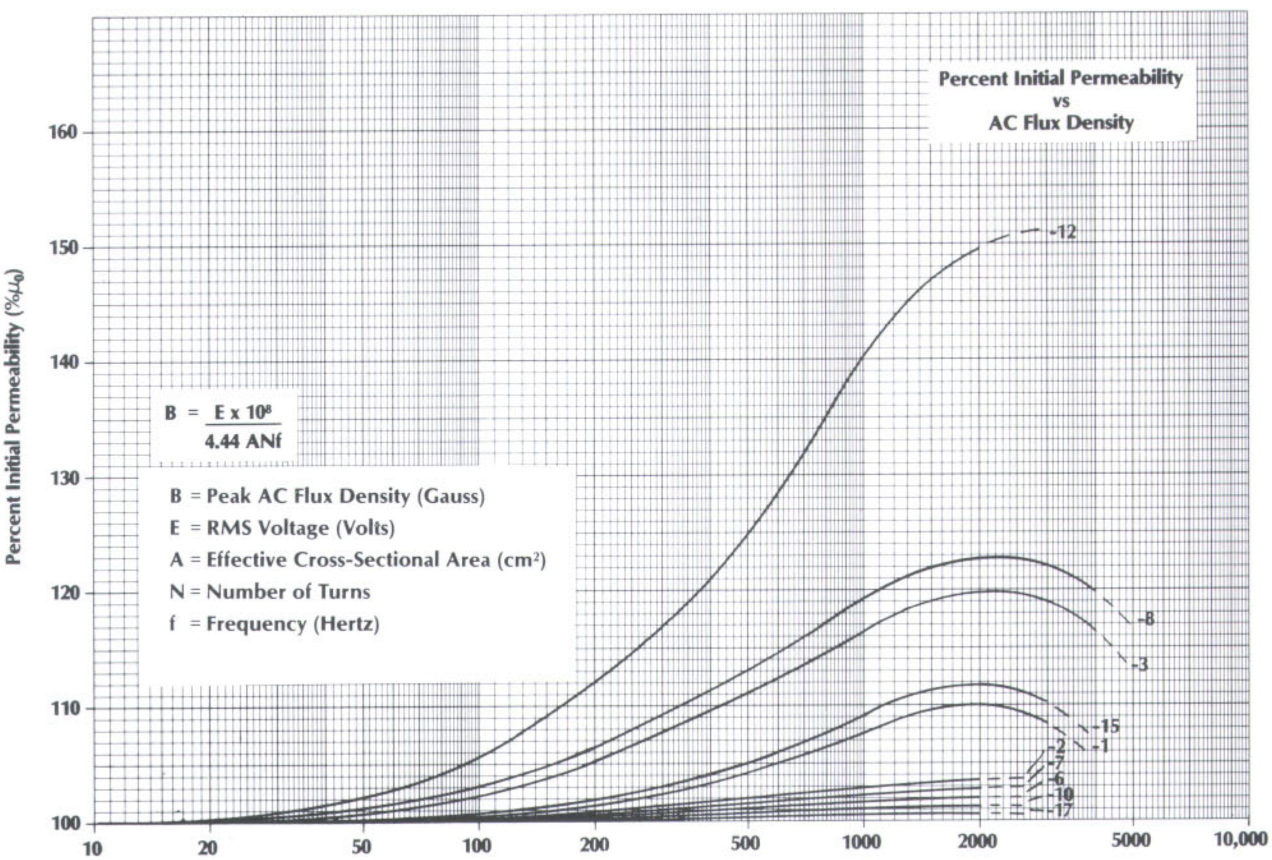

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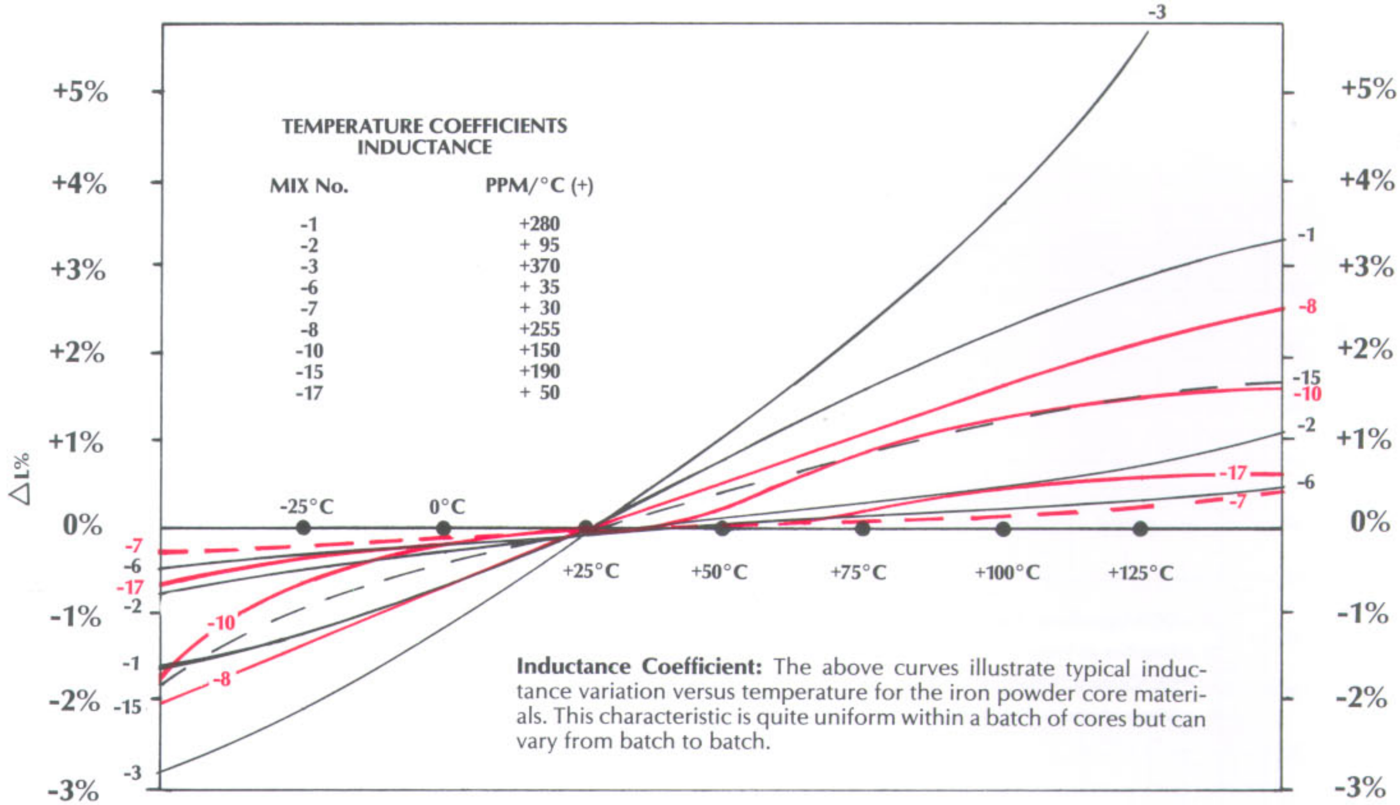
TEMPERATURE CONSIDERATIONS



TEMPERATURE COEFFICIENTS
INDUCTANCE

MIX No.	PPM/°C (+)
-1	+280
-2	+ 95
-3	+370
-6	+ 35
-7	+ 30
-8	+255
-10	+150
-15	+190
-17	+ 50

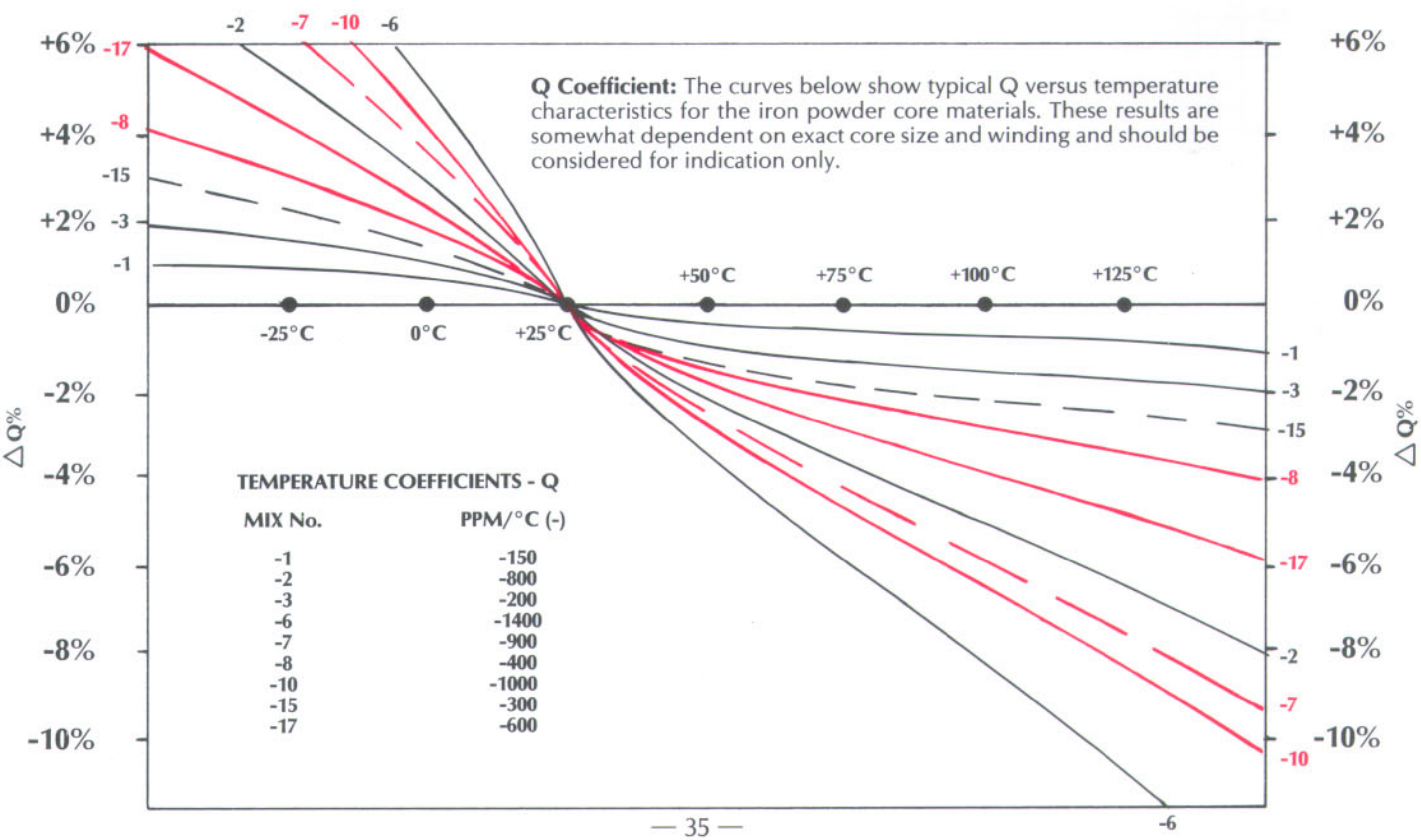
Inductance Coefficient: The above curves illustrate typical inductance variation versus temperature for the iron powder core materials. This characteristic is quite uniform within a batch of cores but can vary from batch to batch.

TEMPERATURE EFFECTS

Micrometals iron powder cores have an organic content and undergo thermal aging. When the cores are exposed to or generate elevated temperatures, a permanent decrease in both inductance and quality factor will gradually occur. The extent of these changes are highly dependent on time, temperature, core size, frequency, and flux density. It is essential that these properties are considered in any design operating at or above 75°C. Iron powder cores tolerate temperatures down to -65°C with no permanent effects.

In high power applications where core loss is contributing to the total temperature, a decrease in quality factor will translate into an increase in eddy current losses which will further heat the core and can lead to thermal runaway. Designs where core loss exceeds copper loss should be avoided. Hysteresis losses are unaffected by the thermal aging process.

Micrometals is continuing to characterize and model these thermal aging characteristics. Please refer to our Web Page at http://www.micrometals.com. for the latest information or contact us directly. We are pleased to provide free design consultation.



Q Coefficient: The curves below show typical Q versus temperature characteristics for the iron powder core materials. These results are somewhat dependent on exact core size and winding and should be considered for indication only.

TEMPERATURE COEFFICIENTS - Q

MIX No.	PPM/°C (-)
-1	-150
-2	-800
-3	-200
-6	-1400
-7	-900
-8	-400
-10	-1000
-15	-300
-17	-600

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SINGLE LAYER WINDING TABLE

Part No.	MTL cm/turn	Surface Area (cm2)	40	38	36	34	32	30	28	26	24	22	20	18	16	14	12	10
Wire Size (AWG)			40	38	36	34	32	30	28	26	24	22	20	18	16	14	12	10
Resistivity (mΩ/cm)			35.4	21.3	13.6	8.57	5.32	3.40	2.13	1.34	.842	.530	.330	.210	.132	.083	.052	.033
			NUMBER OF TURNS															
T5	.283	.089	12	8	6	4	2											
T7	.349	.154	20	15	11	8	5	3	2									
T10	.416	.248	28	21	16	12	8	6	4	2								
T12	.564	.445	43	33	26	20	15	11	8	5	3	1						
T12B	.523	.415	43	33	26	20	15	11	8	5	3	1						
T16	.799	.800	48	37	29	22	17	13	9	6	4	2	1					
T20	.956	1.16	57	44	34	27	20	15	11	8	5	3	2	1				
T22	1.38	1.84	64	50	35	31	23	18	13	10	7	4	2	1				
T25	1.19	1.88	84	65	52	41	31	24	18	14	10	7	5	3	1			
T27	1.36	2.46	110	86	69	54	42	33	25	20	15	11	7	5	3	1		
T30	1.44	2.79	110	86	69	54	42	33	25	20	15	11	7	5	3	1		
T37	1.53	3.77	156	122	98	78	60	48	37	29	22	17	12	9	6	4	2	1
T44	1.84	5.23	177	138	111	88	69	55	43	34	26	20	15	11	7	5	3	1
T44A	1.69	4.80	177	138	111	88	69	55	43	34	26	20	15	11	7	5	3	1
T50	2.01	6.86	239	187	151	121	94	76	59	47	37	28	22	16	12	8	6	3
T51B	2.89	8.44	152	118	95	76	59	47	36	28	22	16	12	9	6	4	2	
T60	2.48	9.84	267	209	169	135	106	85	67	53	41	32	25	19	14	10	7	4
T68	2.47	11.2	296	232	187	150	117	94	74	59	46	36	28	21	16	12	8	5
T68A	2.77	12.5	296	232	187	150	117	94	74	59	46	36	28	21	16	12	8	5
T72	3.15	13.3	220	172	138	110	86	69	54	43	33	26	19	14	11	7	5	3
T80	2.80	15.5	402	316	255	204	161	129	103	82	64	51	39	30	23	17	13	9
T80B	3.44	18.7	402	316	255	204	161	129	103	82	64	51	39	30	23	17	13	9
T94	3.44	22.0	458	359	290	233	183	148	117	94	74	58	45	35	27	21	15	11
T106	4.49	31.0	462	362	293	235	185	149	118	95	74	59	46	36	27	21	15	11
T130	4.75	42.2	640	503	406	326	257	208	165	133	105	83	65	51	40	31	23	17
T157	5.89	63.2	784	616	499	401	316	256	204	164	129	103	81	64	50	39	30	23
T175	6.58	79.1	886	697	564	453	357	289	230	186	147	117	92	73	57	44	34	26
T184	7.54	89.2	780	613	496	398	314	254	202	163	129	102	81	63	50	38	29	22
T200	6.50	90.9	1035	814	658	529	418	338	270	217	172	137	108	86	67	53	41	31
T200B	8.78	120	1035	814	658	529	418	338	270	217	172	137	108	86	67	53	41	31
T225	6.93	109	1167	917	742	597	471	382	305	245	195	155	123	97	76	60	46	36
T225B	9.21	143	1167	917	742	597	471	382	305	245	195	155	123	97	76	60	46	36
T300	7.95	173	1612	1268	1027	826	653	529	422	341	271	216	171	136	108	85	66	52
T300D	10.5	223	1612	1268	1027	826	653	529	422	341	271	216	171	136	108	85	66	52
T400	11.1	301	1884	1482	1200	966	763	619	494	399	317	254	201	160	126	100	78	61
T400D	14.4	384	1884	1482	1200	966	763	619	494	399	317	254	201	160	126	100	78	61
T520	17.7	629	2589	2037	1650	1328	1050	852	680	550	437	350	278	221	176	139	109	86

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PART NUMBER/Q CURVE INDEX

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