IMPROVEMENTS IN INDUCTOR Q THROUGH THE USE OF SECTIONALIZED SPOOL WINDINGS

by W. L. McISAAC

Merrimack Valley Works

Technical Paper presented at the
Engineering Coil Conference
held at Merrimack Valley Works
June 2-3, 1964

IMPROVEMENTS IN INDUCTOR Q THROUGH THE USE OF SECTIONALIZED SPOOL WINDINGS

W. L. McIsaac

Merrimack Valley Works

INTRODUCTION

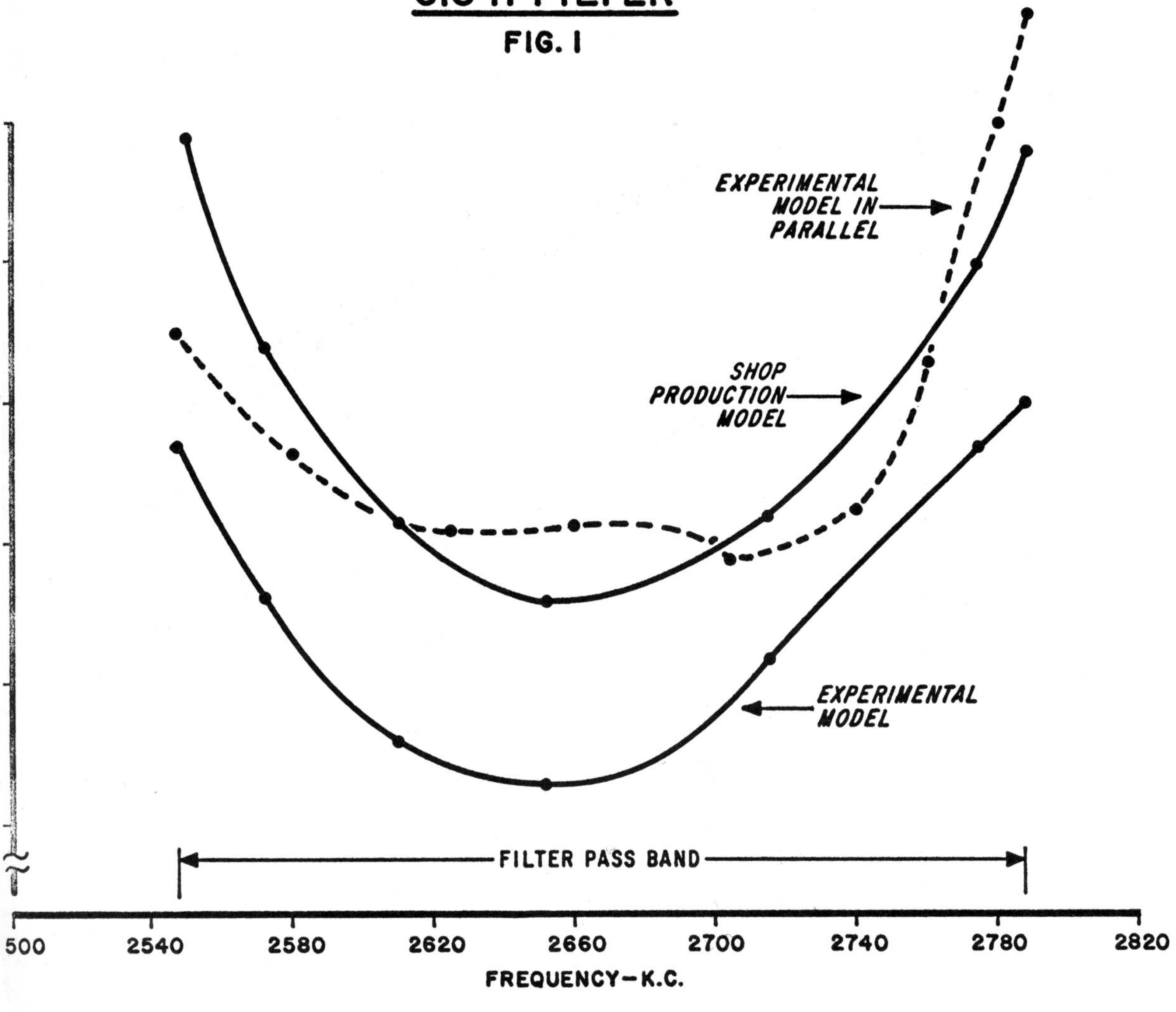
Present trends in the manufacture of communication systems are toward increased utilization of space. This trend forces the miniaturization of the system apparatus such as filters, networks and their component inductors. Development of ferrite magnetic materials has been the major factor in size redcution for inductors. One such example of this miniaturization is the 1619 type Inductor which is used primarily in the new transistorized L-1860 Multiplex System. Frequency of application is from 300 KC to 3 MC with an inductance range of 5uh to 18 mh.

Extensive utilization of the 1619 Inductor has been made in redesigned L-Multiplex. In some higher frequency applications, use of the inductor at the edge of design capability has produced marginal filter loss characteristics, particularly with the direct group of 613 type Filters. Problems with the 613H Filter response, together with the improvements realized through the use of higher Q inductors, can be seen in Figure 1. In fact, investigations of problems with the 613 Filters led to early thinking as to the possibilities of improving the Q and distributed capacitance characteristics of the inductor as a solution to the filter problem.

In general, more loss of signal occurs within the band pass region of a filter as the Q of the components, particularly the inductors, deteriorates. The distributed capacity of the inductor forms a part of the over-all effective inductance and generates a second undesirable variable. The filter impedance is controlled by the L to C ratio; hence, any unaccountable capacitance will adversely affect this ratio and, in turn, the filter characteristics, especially at the higher frequencies. Q and distributed capacity are directly related. Q, which is defined as $2\pi FL/E.R.$, is decreased by any amount of distributed capacitance which decreases the total inductive reactance. This can be represented mathematically as $2\pi fL_1/E.R. = X_L - X_{DC}/E.R. = X_{L1}/R$, where X_L is derived from the geometric inductance, and X_{DC} is derived from the distributed capacitance to yield the total reactance X_{L1}.

613 H FILTER

FIG. 1



There are a number of alternatives available to improve the Q of an inductor. An increase in wire size is the most obvious, although at some value of high frequency, this no longer holds true or is impractical because of skin effect. Another possibility, usually not too lucrative, is to change the configuration of the magnetic path. In this case, size was restricted so that the only dimension that could possibly be changed was the adjusting air gap. This alternative was rejected because all of the air gap was required for temperature stability.

The use of sectionalized spool windings instead of duolateral windings was selected as the best alternative to improve the Q and distributed capacity. Four areas of experimentation were investigated, mostly at the higher frequencies.

1. Duolateral versus single to four section spools.
2. Gap fringing effects.
3. Effect of various wire sizes.
4. Variation of effective inductance with distributed capacitance.

DUOLATERAL AND SECTIONALIZED SPOOLS

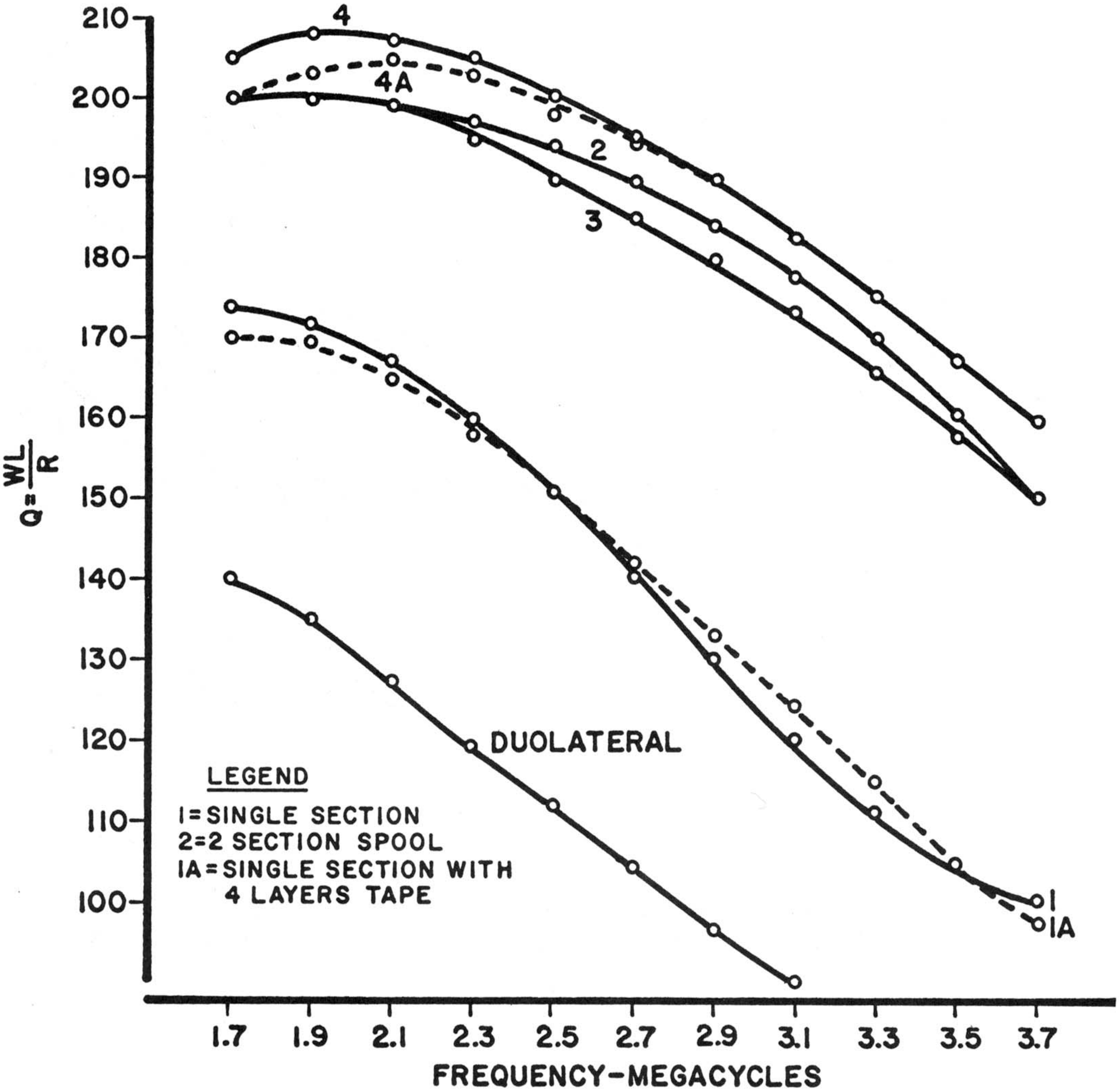
The inductor design selected for the experiment consisted of 50 uh or a duolateral winding of 50 turns of 9/44 wire. For purposes of comparison, all experimental samples were set at an effective inductance of 50 uh at 2.7 m.c. A 50 uh coil is one of the larger values of inductance used at this higher frequency range.

The experimental results are depicted in Figure 2. A considerable improvement is realized with the single section spool over that of the duolateral winding. Two and three section spools provide the next greatest increase in Q. A much less spectacular gain in Q is realized when the coil is wound with four sections. These well-defined stages of improvement in Q are understandable from the nature of distributed capacity. The total winding may be regarded as a lumped capacitance. Sectionalizing the winding reduces this larger capacitance to a number of smaller capacitances in series, and since capacitance in series adds like resistance in parallel, the total capacitance is smaller than any one of the series elements. Four sections of winding would normally present less distributed capacitance and higher Q than the single section spool. As for the difference in Q exhibited between the duolateral and single section spool, it can be deduced that the mean distance between turns of the compact duolateral is less than the mean distance for the spool, and since capacitance is inversley proportional to the separating distance. This capacitance is represented in mathematical proportion as $C_d = K A/d$ wherin C_d is the capacitance between two conductors, d is the separation and A is the effective conductor area. It is also logical that something approaching half of the distributed capacitance might be accomplished with a two-section spool.

A compromise between the number of spool sections, the number of turns, wire size and cost is often necessary. A four-section spool would seem to be a practical limit for an inductor the size of the 1619 which uses 5/8" ferrite cores. Cost is a primary factor, since sectionalized spools are more expensive than the paper cylinder for the duolateral winding, and require a more elaborate winding operation.

COMPARISON OF Q VALUES FOR DUOLATERAL VS SECTIONAL SPOOL WINDINGS

FIG. 2



EFFECTS OF FLUX FRINGING UPON Q

The adjustable range of the inductor is produced by moving a slug of the magnetic material to shunt an air gap in the inductor core structure. The flux at this gap spreads beyond the confines of the magnetic core. The over-all flux linkages with the turns of the winding are then decreased; consequently, the available inductance is reduced. To produce an equivalent or desired inductance under this condition requires additional turns of wire or insertion of the adjusting slug further into the core, both of which decrease Q. Experiments with varying spool diameters to determine the relative effects of flux fringing are presented graphically in Figures 2 and 3. An improvement in Q did not occur with increased spool diameters for the 50 uh inductor. In fact, Figure 2 shows that the Q actually deteriorated somewhat. Further examination of the four-section spool with various diameters produced the results of Figure 3. It remains that the spool without tape added to increase the diameter presents the best Q characteristic for a 50 turn coil or 50 uh inductor. One possible reason for the lack of improvement is that the larger number of turns tends to increase the mean distance of the winding to the gap. Increase of the spool diameter is this instance does not aid significantly in avoiding the fringing flux of the gap, but adds copper loss as more wire is required to span the larger diameter.

The second half of the experiment was done with a 22 turn winding of 21/44 wire or 20 uh inductance. In this case, an improvement in Q did occur with the larger spool diameter. This result supports the theory that the windings with larger numbers of turns are less affected by air gap fringe flux. In summary, the limit for improving the Q of the inductor appears to be 25 turns or approximately 25 uh and below.

VARIANCE OF Q WITH WIRE SIZE

As previously stated, one obvious solution to the improvement of Q is to increase wire size. The number of strands will not only determine the resistance, but also will vary, to a degree, the distributed capacity of a particular winding. At the higher frequencies, above 1 m.c. for instance, it is found that an increase in wire size does not always increase Q since hysteresis and eddy current losses in the copper or core material can be the major factors in determining Q rather than the wire resistance.

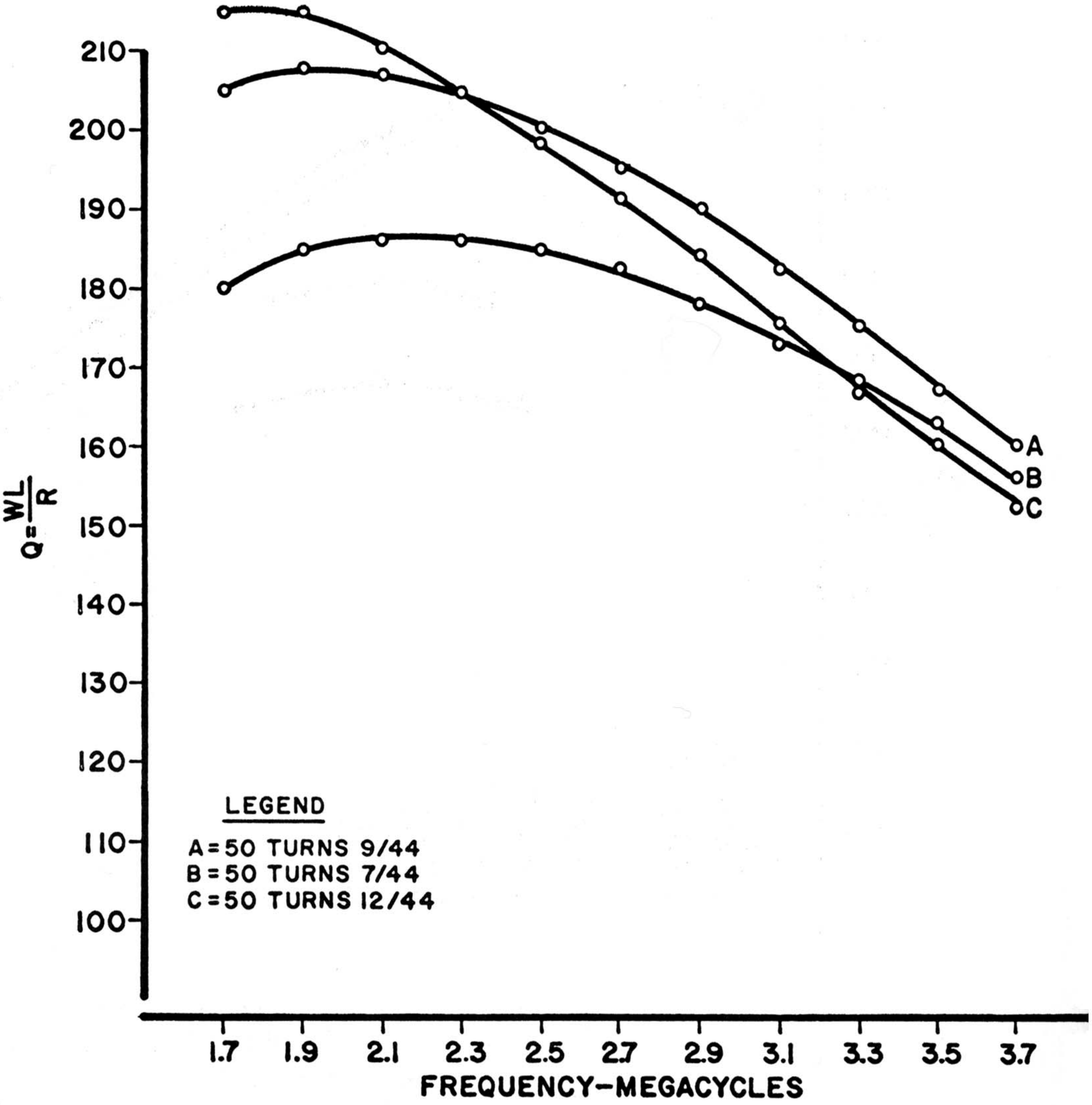
The comparisons of Figure 4 show the values of Q resulting from use of wire sizes above and below that originally specified for the 50 uh inductor. Higher peak values of Q occur for a larger wire size, but a sharper decline in value is apparent as frequency increases as opposed to the nominal wire size which exhibits a lower peak value and less of a Q decline with frequency. As would be expected, the smaller wire size produces a lower over-all Q characteristic. Choice of wire size then depends somewhat on the frequency range of application.

INDUCTANCE AND DISTRIBUTED CAPACITANCE

The distributed capacitance in parallel with the inductance of the winding of an inductor may be regarded as a composite reactance or effective inductance as opposed to a geometric inductance which neglects C_D since it is measured at very low frequency. Effective inductance, then, is a function of frequency

COMPARISON OF Q VALUES FOR VARIOUS WIRE SIZES ON FOUR SECTION SPOOLS

FIG. 4



and will vary with frequency.

Figure 5 illustrates measurements of inductors constructed with duolateral, single, two and four-section spools in which all of these have different values of distributed capacitance. The sample with the least variation of effective inductance is, of course, that of the four-section winding. Measurements of the distributed capacitance have been made at 30 m.c. where the inductance is, for all practical purposes, an open circuit. Duolateral windings average 7-12 picofarads, and the four-section spool inductors average 1.5 to 3 picofarads, or a reduction of 75% in capacitance.

CONCLUSIONS

These experiments with the winding of the 1619 Inductor have substantiated that the usefulness of the inductor can be extended by significant improvements in Q and distributed capacitance. The case is practically illustrated in the experimental trials with the higher frequency 613 Filters. The inductor with the sectionalized spool will be more costly, but still less expensive than designs utilizing larger inductors or additional components.

Future demands and trends for miniaturized designs are inevitable. Improvements in magnetic materials can make ever further progress possible. However, as frequency spectrums of operation become higher, in the search for more information carrying capacity, accuracy in component design becomes more of a problem.

There will be problems in manufacturing sectionalized spool windings, particularly from the winding standpoint. Special winding machines and revised techniques are now desirable and will be required to make the cost competitive. One approach, under present investigation, is to wind several interconnected duolateral sections on a core tube, thereby eliminating the cost of the sectionalized spool and decreasing the winding time. Nevertheless, the objective is to utilize all possible capabilities of the present design at a reasonable cost.

W. L. McIsaac
Merrimack Valley Works

INDUCTANCE VS FREQUENCY
FOR VARIOUS COIL TYPES

FIG. 5