ARRL Periodicals Archive – Search Results
A membership benefit of ARRL and the ARRL Technical Information Service

ARRL Members: You may print a copy for personal use. Any other use of the information requires permission (see Copyright/Reprint Notice below).

Need a higher quality reprint or scan? Some of the scans contained within the periodical archive were produced with older imaging technology. If you require a higher quality reprint or scan, please contact the ARRL Technical Information Service for assistance. Photocopies are $3 for ARRL members, $5 for nonmembers. For members, TIS can send the photocopies immediately and include an invoice. Nonmembers must prepay. Details are available at www.arrl.org/tis or email photocopy@arrl.org.

QST on CD-ROM: Annual CD-ROMs are available for recent publication years. For details and ordering information, visit www.arrl.org/qst.

Non-Members: Get access to the ARRL Periodicals Archive when you join ARRL today at www.arrl.org/join. For a complete list of membership benefits, visit www.arrl.org/benefits.

Copyright/Reprint Notice

QEX Issue: Mar 2004
Title: Dominant-Element-Principle Loaded Dipoles
Author: Al Buxton, W8NX

Click Here to Report a Problem with this File

Dominant-Element-Principle Loaded Dipoles

Get rid of your old dipole traps! A new design technique makes trap look-alikes do double duty. Each sets resonance for two bands and the whole wire radiates on every band.

By Al Buxton, W8NX

This article and the accompanying computer programs introduce a new, efficient category of multiband antennas to the radio amateur fraternity. Many amateur transceivers are of the single black-box type with a built-in antenna tuner to cover all high frequency amateur bands. It would be desirable for the sake of both simplicity and appearance to connect such a multiband transceiver to a corresponding multiband antenna. Unfortunately, many hams simply sacrifice operating privileges on too many of our authorized bands for lack of a good all-band antenna.

There are many approaches to attaining a multiband antenna, all with varying degrees of success. All resonant antenna approaches suffer penalties of

2225 Woodpark Rd
Akron, OH 44333

reduced bandwidth as the price for any additional band of operation. Non-resonant antenna approaches such as random wires or loops pay the penalty of being unsuitable for low-impedance current feed provided by fully shielded coaxial feed lines. They require ladder line or open-wire feeders giving rise to feed line radiation, RF in the shack and high voltage ratings of the capacitors and inductors in the attendant transmatch. The dominant-element principle (DEP) minimizes such penalties and maximizes the number of bands that may be covered with a single antenna. Maximum bandwidth and multiband operation are attained by dominant-element-principle dipoles, which take full advantage of both the fundamental and odd-harmonic resonances of long-wire dipole antennas. Indeed, the new dominant-element-principle dipole antenna, implemented with parallel L/C load elements and

short hanging stubs properly distributed along the antenna, both shifts and doubles the number of such fundamental and odd-harmonic frequencies. A computing algorithm that feeds back antenna input reactance to adjust each respective dominant element of the antenna enables a computer to solve for the entire antenna configuration, even for antennas of high complexity. The accuracy of the computer solution is as accurate as the analytical model of the antenna input impedance.

It has long been known that every ordinary long-wire dipole antenna has a fundamental resonant frequency as well as a series of both odd and even order harmonics. Fig 1 is an idealized plot of long-wire dipole input impedance as a function of frequency. It covers a wide range of frequencies from the fundamental out to the 11th harmonic. Notice that the resistance scale is logarithmic to expand the useful

low-resistance input impedance region for clarity. Frequency increases in a clockwise motion around the spiral. Notice that the input impedance of the antenna at its fundamental resonant frequency, *F1* and all of its odd-harmonic resonant frequencies: *F3*, *F5*, *F7*, *F9* and *F11*—indicates this antenna could be suitably fed with a 75-Ω coaxial cable. Notice that the SWR on the 75-Ω feed line would be less than 3:1 at the fundamental and all odd-harmonic frequencies. The convenience and safety of fully enclosed wires and the zero RF outside shield voltage of coaxial feed lines is very desirable. The even-order harmonics with input impedances of thousands of ohms are unsuitable for operation with coaxial cable. The trick for radio amateurs is to make the fundamental and odd-harmonic frequencies match those assigned by the FCC to the Amateur Radio service. The dominant-element principle performs this trick.

Dominant-Element-Principle (DEP) Dipoles

DEP dipoles are made up of wire or tube radiating segments, hanging stubs and parallel L/C load elements, all of systematically determined values. These load elements are distributed along the dipole in a special sequence. The dipole configuration is symmetrical about the feed-line connection, having mirror symmetry of the left and right monopoles. For each monopole, the first load element out from the feed is a hanging stub—if there is one. Next comes the sequence of one or more radiating wire segments and parallel L/C load elements. Proceeding outward from the feed, the sequence of load-element resonant frequencies goes from the lowest frequency to the highest. This is the reverse order from that of ordinary trap dipole antennas. Despite the fact that every element of the dipole makes some contribution, however slight, to every resonant frequency of the dipole, one element is dominant at any speci-

fied frequency and has more effect on resonance than any other element. Therefore, the value of each dominant element may be adjusted to give antenna resonance at its corresponding operating frequency. An iterative computer algorithm using very weak negative feedback of antenna input reactance adjusts the value of each dominant element at its respective frequency. The computer program starts with an estimated antenna configuration and converges on a design solution for the antenna wherein the input reactance at all chosen operating frequencies approaches an acceptable minimum value, perhaps close to zero. The computer solution does not converge to a high-impedance even-order harmonic solution because the slope of the input-reactance function for long-wire dipoles at even harmonics is negative, whereas the slope at odd harmonics is positive.

Mathematicians studying this algorithm will immediately see the similarity of this algorithm to Newton's method of finding roots of high-order polynomial equations. However, the computer algorithm uses this method in an inverse manner: It sets the roots where we want them to be, rather than simply find the roots.

Every DEP dipole has an order of dominance of its elements in tuning the dipole to its set of operating frequencies. The orderliness of the dominance is very pronounced. The first L/C load elements (closest to the feed) induces a pair of fundamental operating frequencies. The second load elements, if used, induce a pair of third harmonic operating frequencies. The third load elements, if used, induce a pair of fifth harmonic operating frequencies, and so on. (A DEP dipole using four pairs of load elements has been designed for all-band operation from 160-10 m.[1])

The lower fundamental operating frequency sets the required inductance of the first load element, and the higher fundamental operating frequency sets its capacitance. The inductance of the third load element is fixed by the lower third harmonic frequency and the capacitance is fixed by the higher third-harmonic frequency. Proceeding from inner radiating elements to outer radiating elements, the lengths of the radiating segments are also dominant at their respective frequencies starting from the next highest odd-harmonic frequency of the load elements to still
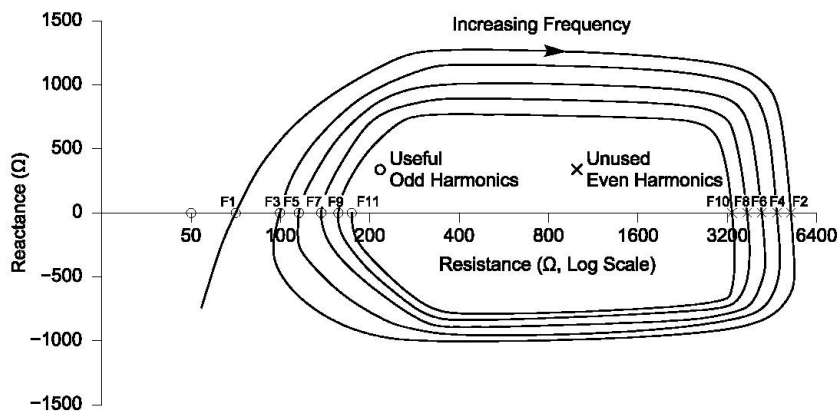
[1]Notes appear on page 30.

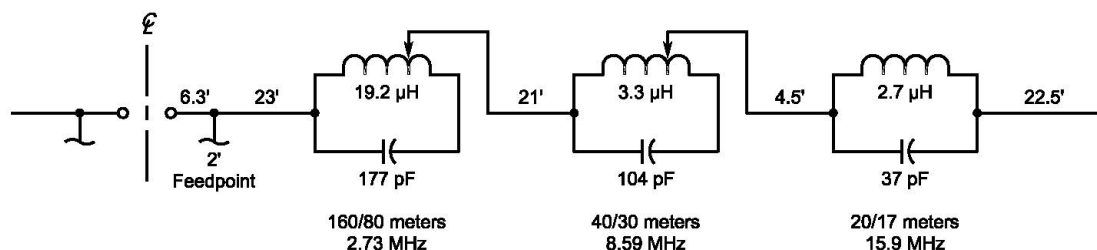Fig 1—The input-impedance spiral of a long wire dipole.

Fig 2—A DEP eight-band dipole.

higher odd-harmonic frequencies. However, the lengths of the radiating elements as dominant elements are sometimes sacrificed for the purpose of minimizing modal cross coupling in the antenna, easing the convergence to a solution. Also, sometimes there is no legally assigned amateur frequency that relates to the lengths of the radiating elements, creating unusable elements of design freedom and forcing omission of some of the odd harmonics within the sequence.

DEP dipoles are more clearly defined by example. Fig 2 shows my present eight-band working DEP dipole employing three pairs of parallel L/C loads and one pair of hanging stubs. The values shown are those after fine-tuning experimentally. As shown in Fig 2, the loads look the same as conventional traps inserted into the antenna, but they differ in an essential way. Notice also the lowest-frequency loads are closest to the feed line and the highest-frequency loads are farthest out from the antenna feed. The medium-frequency loads are located between the low and high-frequency loads. The sequence of load locations is the reverse of that in conventional trap dipoles. Moreover, the loads do not approximate open switches at the operating frequencies. With a few exceptions in the *DEP4BD* and *DEP5BD* dipoles, they are all non-resonant and simply act as either equivalent inductors or equivalent capacitors, depending on the operating frequency. At frequencies below load resonance, they are inductors, increasing the effective electrical length of the antenna. Conversely, at frequencies above load resonance, they look like capacitors, shortening the electrical length of the antenna. They do not disconnect the outboard portions of the antenna. The entire length of the antenna radiates on all bands. With certain exceptions, the load resonant frequencies are located about halfway between the frequencies of the two bands where they apply their major loading effect. Their load reactance and rate of reactance change with frequency is low in their respective bands of operating frequencies. Thus, there is less forcing or loading of the antenna than with traps and only low characteristic impedance loads (low L/C ratios) are needed. The low L/C ratios may be implemented by use of tapped output, double coaxial load elements. If you wish, open air inductors and weatherproof fixed capacitors may be used. If these three pairs of load elements were used in the classic manner of traps, the antenna could have covered only four

bands. The loading technique of this DEP loaded dipole is twice as efficient as traps in producing additional bands. Building a similar antenna using classic traps would have required seven pairs of traps and would have greatly diminished the useful bandwidth on all bands.

The dipole thus has two different fundamental frequencies as well as a series of double odd-harmonic frequencies. The eight-band DEP dipole has fundamentals at both 1.9 and 3.85 MHz, third harmonics at 7.175 and 10.125 MHz, fifth harmonics at 14.175 and 18.1 MHz, a single seventh harmonic at 21.225 MHz and finally a ninth harmonic at 28.4 MHz. In short, eight amateur bands are covered—all the HF bands between 160 and 10 meters with the exception of 12 meters.

Fig 3 shows the reactance plotted versus frequency of the 160/80 m load elements resonant at 2.72 MHz. Notice the reactance is positive (inductive) for frequencies below the 2.72 MHz resonant frequency and negative (capacitive) for frequencies above resonance. Remember inductive loading increases the equivalent electrical length of the antenna and capacitive loading shortens the electrical length of the antenna. At 1.9 MHz, they have a reactance of

460 Ω (inductive), thereby raising the electrical length of the dipole from its physical 154-foot length to an equivalent 245-foot length—the length of a standard 1.9 MHz wire dipole. Conversely, at 3.8 MHz they have a reactance of –483 Ω (capacitive), which shortens the equivalent electrical length of the dipole to 123 feet, the length of a standard 3.8 MHz dipole. The lengthening and shortening action of the other load elements is similar at their respective dominant-element frequencies.

Summarizing, only three pairs of load elements and a pair of very short 10-m loading stubs were added to the 154-ft long center-fed wire dipole to tune the antenna to its eight frequencies. If the traditional trap dipole approach had been used to create an eight-band dipole, seven pairs of traps would have been required. The DEP approach is twice as efficient as traps in creating multiband operation. The innermost pair of load elements—parallel 19.2-µH inductors and 178-pF capacitors—tune the antenna to its 160- and 80-m frequencies. The middle pair of load elements—parallel 3.3-µH inductors and 104-pF capacitors—set the 40-m and 30-m frequencies. The outermost pair of load elements—parallel 2.7-µH inductors and 37-pF
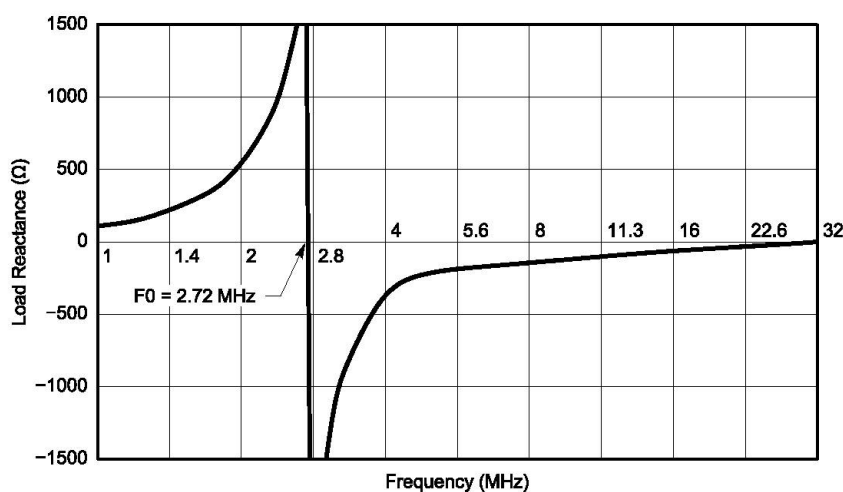

Fig 3—A plot of load reactance versus frequency for the 160/80 load element.
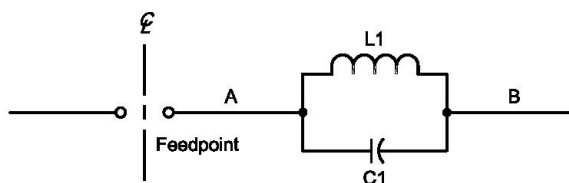

Fig 4—Various four-band DEP dipoles.

capacitors—tune the antenna to its 20-m and 17-m frequencies. The short hanging stubs tune the antenna to its 10-m frequency.

Table 1 shows the relationships between the unloaded and the loaded frequencies of the dipole. The unloaded frequencies are the resonant frequencies the dipole would have if all the load elements and stubs were eliminated. The dipole would then be an ordinary dipole, each leg of 77 feet length. While every dipole element Affects every resonant frequency to some extent, the respective load elements dominate strongly in their respective bands. Note the 3.13 MHz unloaded fundamental frequency turns into two fundamental frequencies at 1.92 and 3.86 MHz, mostly because of the dominant effect of the 160/80-m load element. Similarly, the 9.52 MHz unloaded third-harmonic frequency is replaced by two third-harmonic frequencies at 7.18 and 10.125 MHz; mostly because of the dominance of the 40/30-m load element. Likewise, the 15.92 MHz fifth-harmonic frequency is replaced by two fifth-harmonic frequencies at 14.175 and 18.1 MHz; mostly due to the dominance of the 20/17-m load element. The seventh harmonic unloaded frequency at 22.32 MHz is reduced to 21.225 MHz by the combined effect of the short 10-m stubs and stray capacitance of all the load elements. The ninth harmonic unloaded frequency is slightly lowered by the stubs and load elements to 28.4 MHz.

Choices of DEP Dipoles

There are many choices of DEP dipoles available (and more may be discovered). The simplest, having four-band capability, utilize two pairs of radiating wire segments and one pair of parallel L/C load elements. The loads may be made either of coax (RG-58 or RG-58A) or open inductors in parallel with fixed high-voltage precision weatherproof capacitors. The output connection may be tapped some distance up the coil to facilitate non-standard values of capacitance.

DEP dipoles range in complexity from simple four-band antennas to those with four pairs of load elements and coverage of all nine HF bands

from 160-10 meters. The 80/40/17/10-m dipole of Fig 4 was featured in the July, 1996 *QST*,[2] but it was not recognized as a DEP dipole at the time. The full recognition and statement of the dominant-element principle, as such, was not made until 2002. This article presents its first published statement.

Fig 5 shows a group of five- and six-band DEP dipoles. The five-band dipoles differ from four-band dipoles by the addition of a pair of stubs. Also, the loads are resonant slightly above the high fundamental frequency rather than between the two fundamental frequencies. Six-band dipoles employ two pairs of load elements but use no stubs.

This configuration can theoretically cover seven bands, but unfortunately at least one will be slightly outside the closest assigned amateur band. The 160/80/40/30/20/15-m six-band dipole was used at my station for over two years before it was succeeded by the present eight-band 160/80/40/30/20/17/15/12 antenna.

The eight-band DEP dipole is again shown in Fig 6, showing the values before experimental fine-tuning. It is the best of all the DEP dipoles so far discovered. The bandwidth penalties associated with multiband operation are surprisingly less than I thought they would be. The bandwidth penalties on 30 and 17 m are mitigated by

Table 1

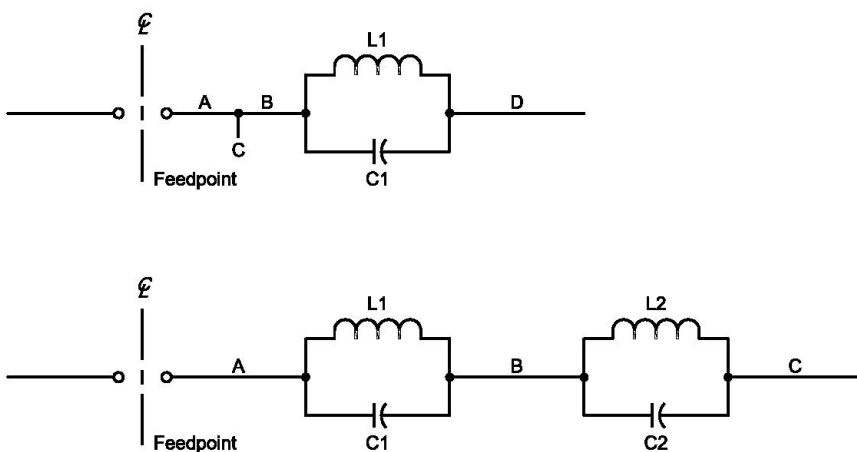| Unloaded Frequency (MHz)	Harmonic	Rin (Ω)	Loaded Frequency (MHz)	Harmonic	Rin (Ω)
3.13	1	65	1.92	1	43
			3.86	1	83
9.52	3	102	7.18	3	83
			10.125	3	270
15.92	5	124	14.175	5	128
			18.1	5	360
22.32	7	143	21.225	7	158
28.71	9	159	28.4	9	165

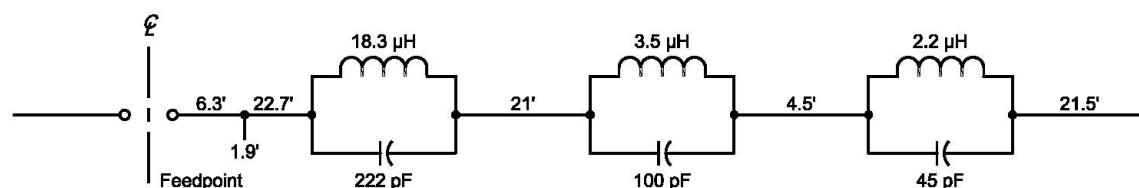Fig 5—Five- and six-band DEP dipoles.

Fig 6—The eight-band DEP dipole (160/80/40/30/20/17/15/10 m).

the very narrow bandwidth of these assigned bands. The SWRs are all manageable by the built-in automatic antenna tuner of my transceiver. The antenna is compatible with my linear amplifier when used in conjunction with my high power 1500 W antenna tuner. The antenna has the conventional multilobed radiation patterns of long wire dipoles. It is not competitive with my 20/15/10-m rotatable beam on those three bands, but it fills a gap, easily permitting me to work worldwide DX on 17 m. The coverage of the lower-frequency bands, 160-30 m, is especially desirable as we approach the downside of the 11-year sunspot cycle.

The SWR curves of the *DEP8BD* dipole are shown in Fig 7 (lower bands) and Fig 8 (higher bands). With the exception of the 30-and 17-m bands, the minimum SWRs are all below 3:1. The automatic antenna tuner in my FT-990 keeps the transmitter happy across major portions of all eight bands, with some favoring of the phone bands.

These curves are for the antenna installed as an inverted V, with heights of 47 feet at the apex and about 18 feet at each end. The bandwidth penalties were much less than I feared they would be. The worst-case SWR is for the 17-m band where the antenna's input resistance is unexpectedly above 325 Ω. However, the tuner pulls the antenna right in, so the transceiver thinks it is working into a 1:1 SWR clear across the narrow band. Similarly, on 30 m, the antenna's input resistance is higher than anticipated. The minimum SWR on 160 is slightly above 2:1, because of the low input resistance of the low, short antenna. It has an effective bandwidth of about 80 kHz on 160 m. The antenna favors the phone portion of the 80-m band, but coverage extends below 3.75 MHz into the CW portion.

This series of DEP dipoles would not be complete without showing the nine-band DEP dipole covering every band from 160-10 m. All-band coverage requires four pairs of load elements but no stubs. Unfortunately, the fourth pair of load elements adds 12 m but significantly decreases bandwidth on both 15 and 10 m. The tradeoff for going from eight-band operation to all-band operation is not advantageous. The law of diminishing returns seems to have taken over at nine-band operation. However, somebody may want to build it anyway. After all, it truly is an all-HF-band ham antenna with genuine low-impedance current feed. Making and testing one would provide further confirmation of the dominant-element principle.

Initial Configuration Estimating

Design of DEP dipoles starts with an appropriate configuration and estimated values of all the load and radiating elements. These estimates are not obtained by pure guesswork even though there remains trial and error in making them. For the computer design programs to converge to a solution from the initial estimates, several constraints exist that must be accepted and used as guidelines. First, a design solution must exist. Not all desirable antennas can have a physical reality. For instance, the laws of physics fix the rate of change of input reactance with frequency. Therefore, chosen bands of operating frequencies must have proper constraining limits on their separation. Further, the chosen set of operating frequencies must be within those frequency bands that
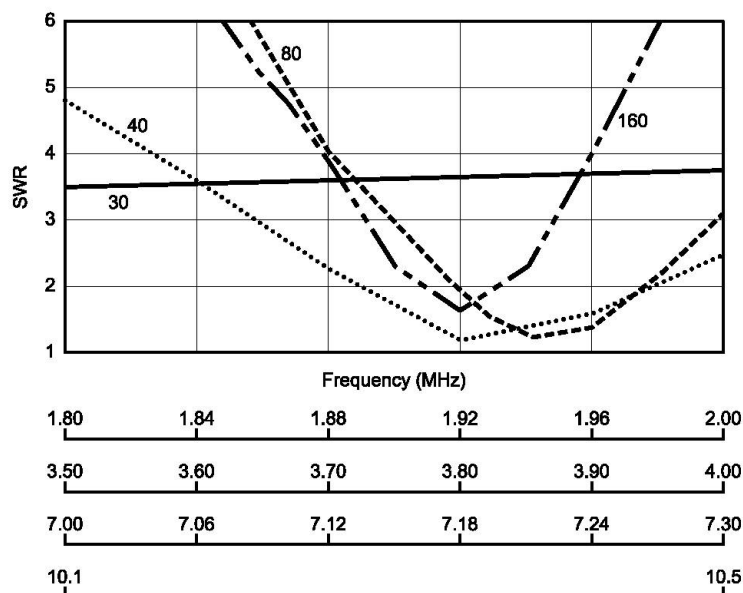
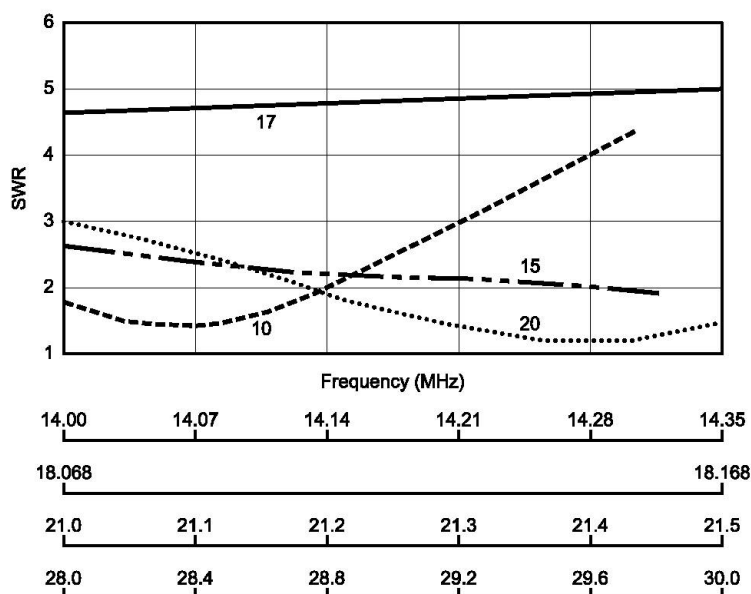Fig 7—Low-band SWR curves for the eight-band DEP dipole.

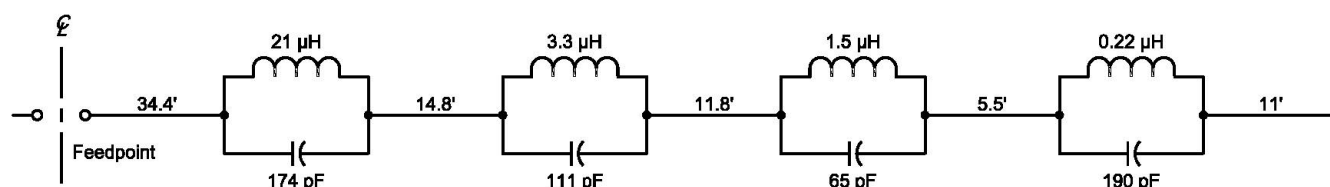Fig 8—High-band SWR curves for the eight-band DEP dipole.

Fig 9—A nine-band DEP dipole (160/80/40/30/20/17/15/12/10 m).

the FCC rather arbitrarily assigned to the Amateur Service years ago. One may ask what is the probability that the FCC-assigned bands would have the proper frequency separation? It is just serendipitous that proper separation exists for the amateur bands for a large number of DEP dipoles.

First, consider the compatibility of the set of operating frequencies with each other. This constraint shows up in the following empirical monopole equivalent-electrical-length equation:

$$meel = \frac{983.57(n - 0.05)}{4 f_{MHz}}$$ (Eq 1)

$$= Zphysical + Zloading$$

where:

meel = the monopole equivalent electrical length of each monopole, in feet.

Zphysical = the physical height of an equivalent vertical radiator above a perfect ground plane, in feet.

Zloading = the contribution in electrical height made by the load elements, in feet.

983.57 = wave propagation velocity, in feet/microsecond.

f_{MHz} = the frequency in megahertz.

n = the order of the harmonic frequency.

$(n–0.05)$ = the nominal length factor where the –0.05 term is caused by fringing of the electrical field at the end of the antenna.

Of course, *meel* is also equal to the physical height of an unloaded vertical monopole of the same frequency above a perfect ground plane. If the *meel*s for the various operating frequencies are spread too far apart, then convergence may be impossible. The load elements may simply be unequal to the task of pulling the antenna into resonance.

Further constraint is imposed by the desirability to equalize the loading bandwidth penalty in the two dominant-frequency bands by keeping the resonant frequency of all loads near the geometric mean of their two respective dominant frequencies. However, the dominant-element principle is still applicable and usable where the loads are tuned a few per-
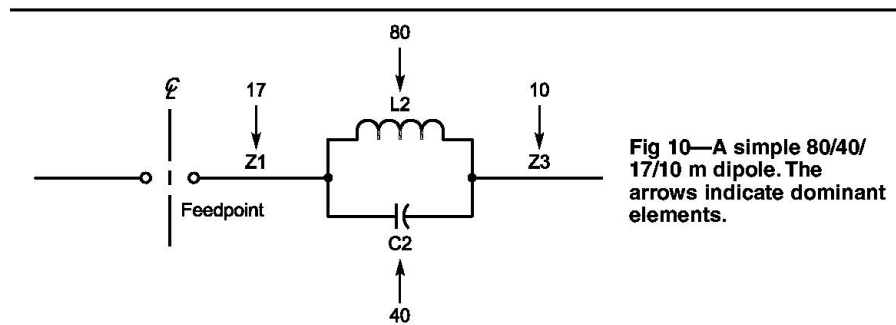

Fig 10—A simple 80/40/17/10 m dipole. The arrows indicate dominant elements.

cent above the high fundamental frequency, as will be illustrated later in this section. Likewise, there is the desirability of using very low characteristic-impedance loads to reduce the bandwidth penalty in both bands. Hopefully, the L/C ratios of all load elements may be made to correspond to a characteristic impedance of less than 500 Ω—where lower is better from a bandwidth-conservation point of view. These constraints are met by the convergence algorithm, which sets the exact values of L and C for each load. Thus, they are useful guidelines for estimating the initial configuration needed by the convergence algorithm. These constraints give us the following equations for the initial values of L and C for the loads:

$$L = \frac{Z_0}{2\pi f_{MHz}}$$ (Eq 2)

$$C = \frac{1,000,000}{2\pi Z_0 f_{MHz}}$$ (Eq 3)

where:

L = inductance of the load, in microhenries.

C = capacitance of the load, in picofarads.

Z_0 = assumed trial characteristic impedance, generally between 100 and 500 Ω.

f_{MHz} = geometric mean of the two dominant load frequencies in megahertz.

Let's apply these guidelines in a couple of examples. First is the simplest DEP dipole: a four-bander with only

four elements of design freedom, one for every band of operation (see Fig 10). The dipole is symmetrical about the feed line. The arrows show the dominant relations. The input reactance of the antenna at the 80-m design frequency is reduced to zero by adjusting the size of the load inductance *L2*. Similarly, the input reactance of the antenna at the 40-m design frequency is reduced to zero by adjusting the load capacitance, C2. Likewise, the length of the innermost radiating element, *Z1*, tunes the antenna to resonance on 17 m; and the length of the outer elements, *Z3*, brings the antenna into tune on 10 m. These adjustments are all cross coupled to some extent, but the orderly element dominances of DEP dipoles permit us to unscramble the cross coupling effects via a computer program incorporating very weak, iterative negative-feedback algorithm.

Begin the task of making the estimates of the initial values of the four elements of each monopole. First, choose preferred operating frequencies in the four bands. For this example, let's choose 3.8, 7.15, 18.1 and 28.6 MHz. The antenna will have two fundamental frequencies at 3.8 and 7.15 MHz. There will be third-harmonic operation on 18.1 MHz and fifth-harmonic operation on 28.6 MHz. Phone operators may prefer different design frequencies from those of CW operators. If you don't like those frequencies, choose your own and redo the calculations.

Since the L/C load elements will be tuned to about 5.2 MHz (the mean

of 3.8 and 7.15 MHz), they will have very little loading effect on 10 m at 28.6 MHz, giving *zloading* = 0. Therefore, the overall length of each monopole is best estimated by the *meel* of Eq 1 applied for fifth-harmonic 10-m operation at 28.6 MHz:

$$meel \quad Z1 + Z3 \quad \frac{983.57(5-0.05)=}{4(28.6)=} \quad 42.5 \text{ ft}$$
(Eq 4)

Next, assuming the loads will be located somewhere near the middle of each monopole, giving *InitialZ1*= *InitialZ3*= 42.5/2= 21 feet in rounded off numbers for initial estimates of the length of each radiating element.

You may wish to calculate the *meel*s for the other operating frequencies with the same equation to get an estimate of the amount of loading equivalent lengths:
at 3.8 MHz,

$$meel \quad \frac{983.57(0.95)=}{4(3.8)=} \quad 61.5 \text{ ft} \quad \text{(Eq 5)}$$

at 7.15 MHz

$$meel \quad \frac{983.57(0.95)=}{4(7.15)=} \quad 32.7 \text{ ft} \quad \text{(Eq 6)}$$

at 18.1 MHz,

$$meel \quad \frac{983.57(0.95)=}{4(18.1)=} \quad 40.1 \text{ ft} \quad \text{(Eq 7)}$$

These *meel*s tell us that the inductive loading for 3.8-MHz operation must add 61.5 – 42.5 = 19 ft of length to each monopole. On 7.15 MHz, the capacitive loading must be the equivalent of 32.7 – 42.5 or – 9.8 ft. On 18.1 MHz, the load element is only very slightly capacitive, changing the length by 40.1 – 42.5 = –2.4 ft. Experience shows that all of these loading values are acceptable without sacrificing too much bandwidth on any of the bands.

Next, determine estimates of the *L* and *C* of the load. Assuming a characteristic impedance of 350 Ω for the load and using Eq 2, we get:

$$InitialL2 \quad \frac{350}{2\pi 5.2} \quad 10.7 \text{ µH} \quad \text{(Eq 8)}$$

and using Eq 3:

$$InitialC2 \quad \frac{1,000,000}{2\pi(350)5.2} \quad 87.4 \text{ pF}$$
(Eq 9)

Of course, we would probably round off the numbers to, say, 10 µH and 90 or even 100 pF. These initial estimates

are close enough to permit successful convergence to the accurate final values of the four elements of each monopole. If successful convergence had not been achieved, we would have repeated the calculations using either higher or lower assumed values of characteristic impedance. It is interesting to compare the final solved values of the load and radiating elements with the initial estimated values to get a feel for the tolerance of the DEP method to initial configuration errors. To make this comparison, use the print option during the computer run to print the specifications of the designed antenna. Unfortunately, more complex antenna configurations have less tolerance to errors in the estimated initial configuration.

When making a computer run, you may also choose the option to monitor the convergence process on an iteration-by-iteration basis. This may give clues to why convergence was not attained, such as conflict between harmonic operation of differing orders. Watch the individual antenna input reactance for such conflicts. These conflicts can sometimes be eased by appropriate changes of operating frequency—or watch the overall convergence parameter, σ, which is the rss of the antenna's input reactance for the entire set of operating frequencies. However, monitoring step-by-step is a slow and tedious process, and you may prefer not to monitor in this manner. With lower gains in the negative-iterative-feedback algorithm, the algorithm is more tolerant of highly inaccurate initial configuration estimates. The expense is slower convergence, requiring more iteration to reach the solution. Up to 1000 iterations are used for the most complex antenna configurations.

Let's look at another, more complex example of initial configuration estimating: a six-band DEP dipole using two pairs of load elements and three

pairs of radiating elements (see Fig 11). This configuration is interesting because the configuration has seven elements of design freedom with only six operating bands. If amateurs still had the 11-m band, this antenna could have covered seven bands. The extra element of design freedom is used to minimize a cross coupling conflict between the fifth-harmonic 20-m band and the seventh-harmonic 15-m band. That saves a little bandwidth in each band, aids the convergence process and slightly relaxes the tolerances on the estimated initial configuration.

The inner pair of load elements dominates on 160-m and 80-m operation, the outer pair on 40-m and 30-m operation. The 15-m band is the most removed from the effects of the loads and therefore the overall length of each monopole is set by the *meel* at 21.15 MHz, giving:

$$meel \quad Z1 + Z3 + Z5$$
$$\frac{983.57(6.95)}{4(21.225)} \quad \text{(Eq 10)}$$
$$80.8 \text{ ft}$$

and

$$meel \quad \frac{983.57(4.95)}{4(14.25)} \quad 85.4 \text{ ft} \quad \text{(Eq 11)}$$

These two *meel*s show a basic conflict between 15 and 20-m operation. Both the 160/80 and 40/30 load elements are being operated well above their resonant frequency so their shortening effect is slight. However, what is needed is a relative lengthening effect on 20 m of about five feet. The way out of this dilemma comes through the stray capacitance of both pairs of load elements acting as shunt capacitance to ground. The stray capacitance of the 160/80 load is about 4.5 pF, that of the 40/30 load about 3 pF. These stray capacitances sufficiently lengthen the antenna on 20 meters, both loads in close enough proximity of 20-m voltage maximums.
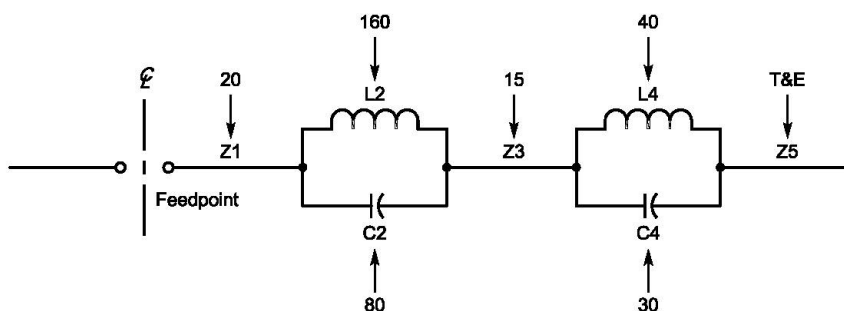

Fig 11—A six-band DEP dipole (160/80/40/30/20/15 m). The arrows indicate dominant elements.

The choice of a 33-ft length for Z5 and the 28-ft length of Z3 determined by the convergence algorithm thus supplies the lengthening needed on 20 m. These load stray capacitances, acting as hidden shunt elements to ground, become additional useful lengthening loading elements.

This phenomenon shows the vital necessity for having an accurate representation of the load stray capacitance in the analytical model of the antenna. The load stray capacitance effect is also magnified further when the loads have parasitic resonances not far enough above their normal resonant frequency. Large, low-frequency loads may thus have a surprisingly great effect at much higher frequency operation, especially if the stray capacitance is magnified by parasitic resonance.

The length Z5 being 33 feet leaves (80.8 − 33 = 47.5) or 47.8 feet for the sum Z1 + Z3, which if split evenly gives:

$$InitialZ1 \quad InitialZ3 \quad 23.9 \text{ ft} \qquad \text{(Eq 12)}$$

A trial of these values shows they do not give good convergence, so try shortening InitialZ1 to 20 feet and lengthening InitialZ3 to 28 feet.

The initial L and C values for the loads will now be determined. First, the 160/80 load, whose resonant frequency is assumed to be the mean of 1.9 and 3.8 MHz, or 2.68 MHz. Also, assume a characteristic impedance of this load of 250 Ω. Applying Eq 2 gives:

$$L2 \quad \frac{250}{2\pi \, 2.68} \quad 14.8, \text{say} \, 15 \, \mu\text{H} \qquad \text{(Eq 13)}$$

Applying Eq 3 gives:

$$C2 \quad \frac{1,000,000}{2\pi \, (250)2.68} \quad 237.5, \text{say} \, 230 \, \text{pF}$$
$$\text{(Eq 14)}$$

Repeat these calculations for L4 and C4 of the 40/30-m load element using your own set of assumed load resonant frequency and characteristic impedance. Trial and error will show the initial values for L4 and C4 are near 4 μH and 100 pF, respectively.

You now are set for a DEP6BD program run either using these initial estimates for the configuration or accepting the default values for the default antenna in the program. You may want to calculate some other estimated initial values based on other assumed load characteristic impedances.

Two DEP dipoles employing the alternative method of tuning the loads to a frequency slightly above the high fundamental frequency will now be discussed. They both satisfy the meel,

criteria, differing only in the load-tuning criteria from other DEP dipoles. Consider the 80/40/20/15-m dipole of Fig 4. Notice the L is 6.6 μH and C is 69.2 pF, corresponding to a load resonant frequency of 7.447 MHz, about 4 % above the middle of the 40-m band. Similarly, the 80/40/20/15/10-m five-band DEP dipole of Fig 6 has a load inductance of 6.3 μH and a load capacitance of 77.7 pF. The load resonant frequency is 7.193 MHz, about 0.6 % above the middle of the 40-m band. One might consider these DEP dipoles as ordinary trap dipoles. However, they were designed according to the dominant element principle; and with the exception of the high fundamental frequency, the loads do not truncate the outboard radiating elements. The entire length of all the elements on all other bands act as radiators. Unfortunately, the loads of the 80/40/20/15-m dipole tuned 4% above the middle of the 7.15 MHz frequency cause rather rapid change of load reactance with frequency, and there is significant loss of bandwidth on 40 m.

Tweaking the Design

As is the case with all antenna design, experimental fine-tuning can improve upon DEP designed antennas. The accuracy of the DEP design programs is limited by the accuracy of the input impedance analytical model of the programs. There are simply too many unknowable factors for the analytical model to have absolute accuracy. The model assumes free-space operation, and this is a cause of error, especially for the lower frequency bands where ground effects can lower the frequency by two or three percent. Thus a 160-m design frequency at 1.9 MHz will usually result in resonance at perhaps 1.85 MHz when the antenna is installed at, say, 40 or 50 feet. However, the ground will much less affect the higher frequencies of the antenna. A second source of error is the stray capacitance of the loads to ground, which is empirically approximated in the analytical model to an accuracy of perhaps one picofarad. This small amount of capacitance error can produce small but significant error at the higher frequencies of the antenna. Thirdly, a small but significant error arises in the assumption of standard "lossy" transmission-line theory, where transmission-line losses simulate the antenna radiation resistance. Other unknown errors are also believed to exist. Thus, most DEP antenna designs should be tweaked or fine-tuned experimentally.

A few tricks can be valuable during experimental fine-tuning of the an-

tenna. First, the higher-frequency loads may be space wound, so that they may be adjusted by compressing or further expanding the turns. This type of fine-tuning the load must be done before you have stabilized the windings with PVC glue. If you have already stabilized the windings with glue, you can raise the load frequency by shorting a single turn that can be moved by sliding the bar along the turns of the load winding. Screwing the turn to the center of the load will raise the frequency a maximum amount. Screwing it to either end will raise the frequency a minimum amount. Lengthening or shortening the hang-down stubs will have maximum effect on the highest antenna frequency but slight effect on the other frequencies. Raising or lowering the ends of the antenna will have maximum effect at the antenna's lowest frequency but some effect at all frequencies.

The most sophisticated approach to tweaking the design of the antenna is to build and install the antenna exactly as specified by the computer. High accuracy in fabrication of the antenna is a requirement if this approach is to be successful. Then measure the exact minimum SWR frequencies during antenna performance and calculate the design frequency error by taking the differences between the design frequencies and the actual measured frequencies. Then make a second totally new design at frequencies adjusted for these design frequency errors. For example, if your original frequency was 1.9 MHz and the actual minimum SWR was at 1.86 MHz, make a second antenna design frequency 1.94 MHz on 160 m. Similarly, adjust all the other design frequencies.

Making Double Coax Loads

The load elements may be either double coax loads or open inductors in parallel with fixed weatherproof capacitors. However, the inherent ruggedness and weatherproof characteristics of the double coax loads is very
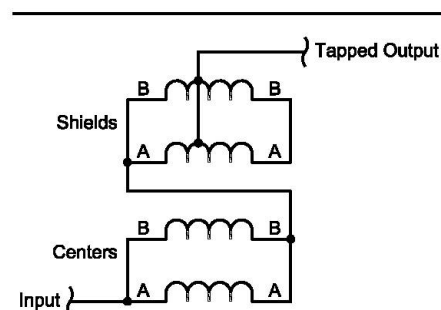

Fig 12—A schematic diagram of double coax loads.

desirable despite their somewhat greater losses. Both approaches require a tapped output to provide the necessary L/C ratios. The required value of capacitance seldom fits those available in the standard EIA capacitor values. However, the transformation capability provided by the output tap eliminates the difficulty. The transformation equations for the Ls and Cs referred to the output tap, sufficiently accurate for our purposes, are based on the usual square of the turns relationship. They are embedded in the computer design for both categories of loads. Run the floppy disk program, *DOUBCOAX*, for the design of double coax loads. Also, run the conventional load program, *CONVLOAD*, to familiarize yourself with it. The schematic diagram of double coax loads is shown in Fig 12.

The inductors are wound on schedule 40 PVC pipe. The pipe diameter is the builder's choice. Notice the series connection of the inner and outer shield windings constituting the inductance of the load. Also notice the parallel connections of both center conductors and both shield windings. These parallel connections and the tapping of the output permit the increased value of capacitance that is necessary to obtain the low L/C ratio loads required by the dominant-element principle. The capacitance of the load comes from the capacitance between the inner conductors and outer shield conductors, not shown because it is not essential to connection of the load. Solid center conductor, Belden RG-58 (#8240), is the preferred cable. However, stranded-center-conductor cable, Belden RG-58A (#8259), may also be used where the greater ruggedness of the stranded center conductor gives less danger of breaking the connections of the load.

Fig 13 shows the general appearance of a double coax load with wide spacing between turns. Turn spacing is recommended, at least for the higher harmonic bands, to give flexibility in making fine-tuning adjustment of the load resonant frequency. Compressing the turns lowers the frequency, expanding them raises the frequency. However, turn spacing is not a requirement and close spacing may be desirable especially for the low-frequency loads such as those intended for 160/80-m operation, where the frequency tolerance of the loads is easy to meet. Studies of optimum configuration show the diameter-to-length ratio of the loads should be close to one.

Run the *DOUBCOAX* program before studying the next few figures to get a feel for the details of double coax

loads. The two coaxial cables are first laid out flat together and cut to length according to the layout in Fig 14. The dimensions marked A and B, calculated by the computer run, determine the overall length of the cable and the location of the output tap. The tabulation above the cables is for the loads of the eight-band 160/80/40/30/20/17/15/10-m DEP dipole.

Make the tap and apply the cable ties while the winding is still laid out flat in

accordance with Fig 15. The taps are made from a short cannibalized length of the shield braid from the same kind of coax. Be sure the tap makes a taut encirclement of the double coax holding the tap in tension as you crimp the connector about the tap.

The tap connection is tinned copper pressing tightly on tinned copper and therefore no solder is required. If you chose to solder the tap, you may damage the polyethylene dielectric of the
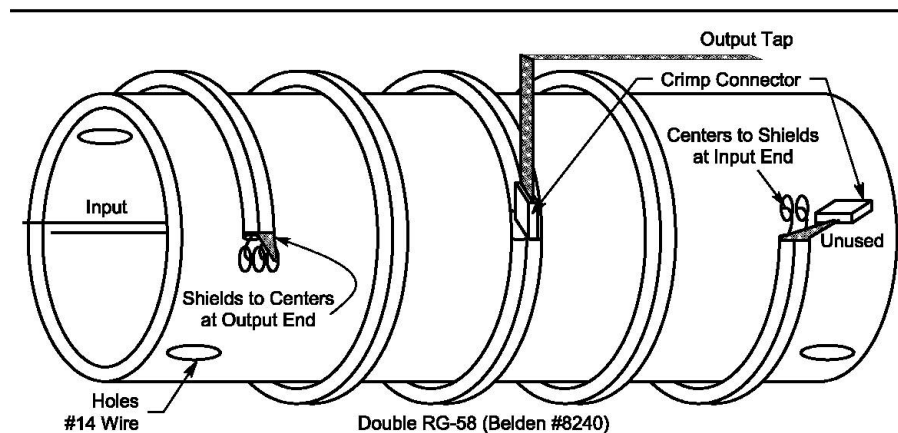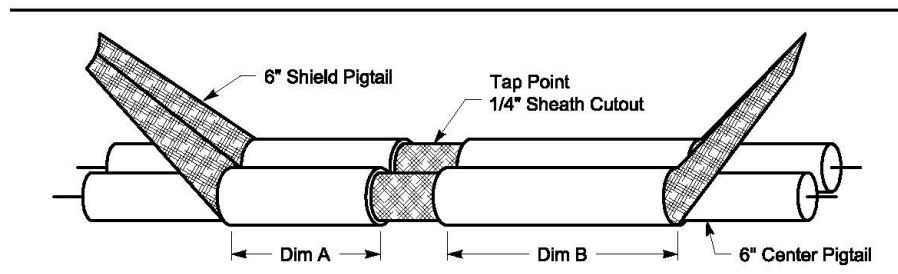

Fig 13—A double coax load (not to scale).

Fig 14—Layout of double coax loads. Forms are Schedule 40 PVC pipe. Coaxial cable is Belden #8240. Cable ties are not shown. Not to scale.

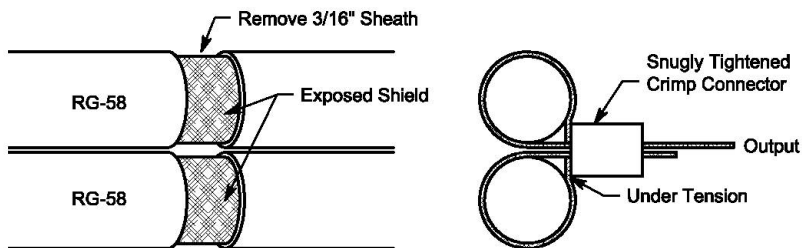| Load	Form Diameter (Inches)		Form Length (Inches)	F_0 (MHz)	Dim A (ft)	Dim B (ft)
	OD	ID				
160/80	3.5	3.0	5.6	2.73	7.7	1.96
40/30	2.378	2.0	5.0	8.55	2.1	1.95
20/17	1.875	1.5	4.33	15.9	1.8	0. 65

Fig 15—Details of the tap connection. The tap is made by tightly wrapping each exposed cable shield with a length of braid take from the same cable and securing the wrap ends with a crimp connector.

double coax or at least degrade the breakdown voltage of the load. I chose not to apply solder and the taps continue to make good contact after nearly two years of service. Inspection shows no corrosion or other problems developing at the tap connection. After the double cables are joined at the output tap point, lace the two cables together with plastic cable ties every few inches. You may wish to regard the cable ties as temporary aids. You can remove them after construction of the load is complete and the load windings have been stabilized by application of PVC glue to the windings and PVC-pipe coil form. If you want greater confidence in maintaining a low tap contact resistance, make the tap encircle the two cables two or more times for greater surface contact area.

Fig 16 shows the details of the forms. The tabulation applies to the forms for the eight-band DEP dipole. Notice that there are three $^3/_{16}$-inch holes in the forms at the left, or input, end of the load and only two holes at the right end. These holes are reamed into an oval shape for appearance.

Fig 17 shows the loads as they should be installed in the antenna. Notice that the input-end, consisting of the two inner conductors of the double coax leads, is toward the feedpoint of the antenna, and the output tap leads are toward the far end of the antenna. The antenna will be slightly detuned if the load terminals are reversed during installation because of the asymmetry of the load stray capacitance. Check the resonant frequency of the loads with a dip meter, and fine-tune them to within 0.5 percent accuracy by varying the spacing between turns before application of stabilizing PVC glue to the turns and forms. If you measure the Q of the loads on a Q meter, be sure to multiply the indicated Q by the factor $(1 + Cload / CQmeter)$ to get the true Q of the load. This factor may be rather large, approaching as much as five or six for double coax cable loads. This multiplying factor must be applied because the current in the load capacitor bypasses the Q-meter current sampling resistor. It is probable that coaxial traps and loads have a bad reputation because people put them on a Q meter and were unaware of this multiplying factor.

Making Conventional Loads

Some amateurs may prefer the use of open inductors and fixed capacitors for the loads because they may have lower losses than double coax loads. However, they are significantly less rugged and are susceptible to rain, ice and snow problems causing frequency

change and possible detuning of the antenna in inclement weather. Moreover, coax loads are considerably less costly. High voltage and high accuracy fixed capacitors are very expensive.

Conventional loads may be used in place of double coax loads providing their primary L and C values are equal to those of the coax loads as well as having an equivalent stray capacitance to ground. The latter equivalence means

that the outer dimensions of the conventional load must be roughly equivalent to those of double coax loads. The *CONVLOAD* program may design conventional loads. Make a trial run of the program using your selected type of open inductors and fixed, high-voltage weatherproof capacitors.

The nomenclature for the design program is given in Fig 18. Fig 18A shows the loads as the maker of the
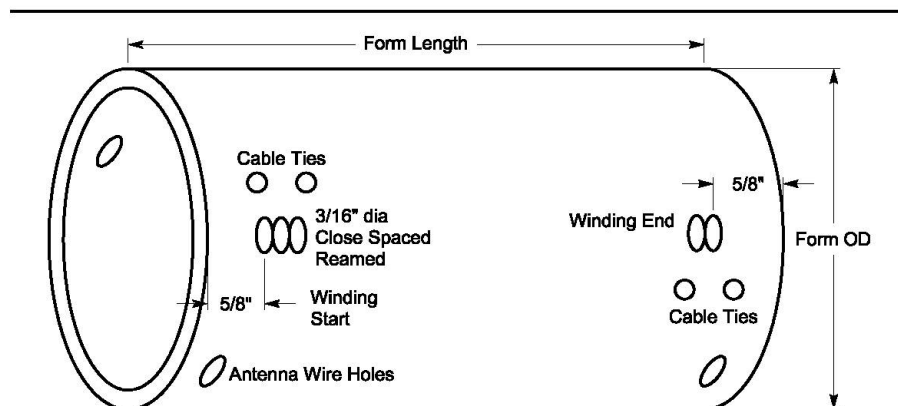

Fig 16—Load form details.

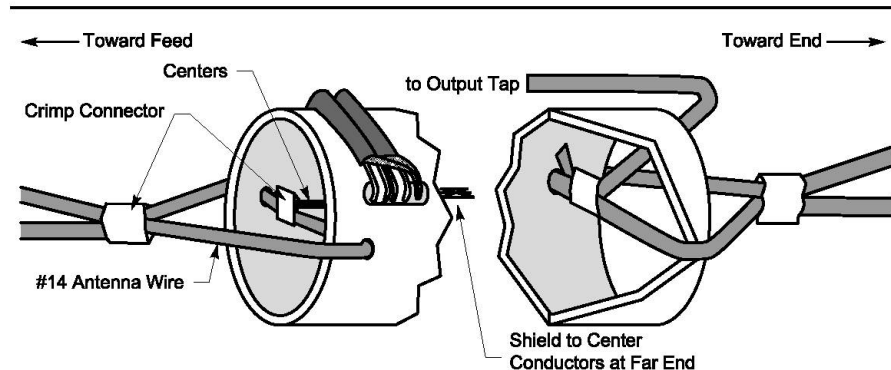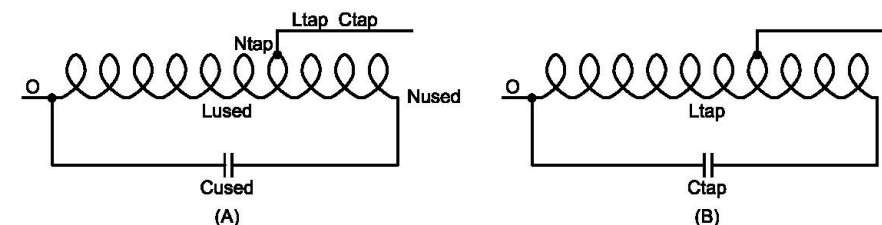| Load	F_0 MHz	Form OD Inches	Form Length Inches	Number Turns	Tap Turns	Spacing Inches
160/80	2.73	3.5	5.6	10	8	0
40/30	8.55	2.378	5.0	6	3.1	0.16
20/17	15.9	1.875	4.33	4.5	4.5	0.195

Fig 17—Load installation.

Fig 18—Nomenclature of conventional loads: (A) as built. (B) as shown in diagrams.
Lused = total inductance (µH); *Ntap* = turns to tap; *Ltap* = inductance referred to tap, µH. *Cused* = external capacitance, pF; *Nused* = total turns used; *Ctap* = capacitance referred to tap, pF.

loads would see the values of *L* and *C* with which he works. Fig 18B shows how they appear in the figures of the various DEP diagrams of this article, specifying the *L* and *C* values referred to the output tap. Since output is taken at a tap on the inductor, the tapped output inductance will always be smaller than the total inductance used for load. In addition, you must select a capacitor whose capacitance value is less than the required *C* of the load. The inductance is stepped down by tapping whereas the capacitance is stepped up by tapping.

Load-Element Stray Capacitance

Stray capacitance of the load elements is a very important consideration vitally affecting the accuracy of the analytical model of the antenna. Fig 19 shows the analytical model of stray capacitance of the loads. The combined effect of the stray capacitances of all the load elements can contribute a substantial increase to the effective electrical length of the antenna. It must therefore be accurately represented in the antenna analytical model. The load-element stray capacitance is the self-capacitance caused by the rather large bulk size of the loads. First, there is the ordinary distributed self-capacity associated with the outside dimensions of the loads. The 160/80-m loads of the *DEP8BD* dipole have a self-capacity of about 4.3 pF without considering parasitic resonance of the loads. There is a dynamic increase in this self-capacitance to 5.3 pF when it resonates in series with the distributed self-inductance of the outside shield windings of the loads. The parasitic resonance may be observed with a dip meter at a frequency perhaps 20 to 25 times higher than the primary load-element frequency. For instance, the aforementioned 160/80-m load element of the *DEP8BD* antenna has a primary resonant frequency of 2.72 MHz and a parasitic resonance at 59 MHz. The effective stray capacity of the 160/80-m loads at 28.6 MHz thus becomes[3]:

$$C_{stray} = \frac{1.05\left(diam^2 \times len\right)^{0.333}}{1-\left(\frac{f_{MHz}}{f_{parasitic}}\right)^2} \text{ pF}$$

$$= \frac{1.05\left(3.695^2 \cdot 4.35\right)^{0.333}}{1-\left(\frac{28.6}{59}\right)^2} = 5.3 \text{ pF} \quad \text{(Eq 15)}$$

where:
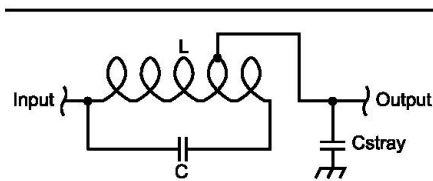*diam* = center diameter of cable on the form, in inches

Fig 19—The load equivalent circuit.

Table 2

GW-BASIC programs for designing DEP dipoles
DEP4BD
DEP5BD
DEP6BD
DEP7BD
DEP8BD
DEP9BD
SINGCOAX
DOUBCOAX
CONVLOAD
LOADZ

len = length of the winding on the form, inches
C_{stray} = stray capacitance of the load to ground, pF
f_{MHz} = operating frequency, in megahertz
$f_{parasitic}$ = parasitic resonance frequency, in megahertz

This stray capacity is the approximate equivalent of that of a two-foot stub of #14 AWG wire hanging from the end of each of the 160-m load elements. These equivalent stubs thus have the potential to make a significant contribution to the 28.6-MHz antenna resonant frequency, depending on their proximity to voltage maximums on the antenna. The stray capacitance will have a similar, but lesser, effect on lower

frequencies. The stray capacitance effects of all load elements at all frequencies are appropriately accounted for in the analytical model of all the antennas in the DEP series.

DEP Dipole Programs

The computer programs listed in Table 2 are available from ARRL (see Note 1). These programs are in *GW-Basic* 3.12,[4] otherwise known as *BASICA*, permitting the easiest and most rapid dissemination of the DEP technology. Hams are free to revise and upgrade the programs as they see fit. Leaving the programs in common *BASICA* gives immediate access to the source code and listing of the programs. Six different programs permit designing DEP dipoles of varying complexity, from the simplest four-band to the most complex nine-band dipoles. All six programs may be run using default data to demonstrate the dominant-element principle very quickly and dramatically. Programs for the design of both single and double coax load elements as well as conventional parallel inductor/capacitor load elements are supplied. A program for the calculation of the impedance of load elements is also included.

Notes
[1]Look for *DEP9BD* in the software package. You can download the package from the ARRLWeb at **www.arrl.org/qexfiles/**. Look for **0403Buxton.ZIP**.
[2]A. Buxton, W8NX, "An Improved Multiband Trap Dipole Antenna," *QST*, Jul 1996, p 32.
[3]From Fig 16, *diam* = (3.5 + 0.195) = 3.695 (0.195 inches is the diameter of Belden #8219), and *len* = 5.6 − 0.625 − 0.625 = 4.35 because the winding begins 0.625 inches in from each end of the 5.6-inch form.
[4]*GW-BASIC* is available on the Web. One source is **www.geocities.com/KindlyRat/GWBASIC.html**. □□