the *SEED* antenna — a *S*hort, *E*fficient *E*nd-fed *D*ipole

Achieve good efficiency while covering 80/160 meters

In 1978 I needed a very short antenna for the 80 and 160 meter bands. Because I was not satisfied with popular designs, I developed a very small antenna which, I hoped, might be better. For the last several years, the result of this effort has been my regular station antenna. I can find nothing like it described in the Amateur literature.

The antenna measures 20 feet (6 meters) long, and its center is 14 feet (4.2 meters) above the ground. Input SWR is less than 1.15:1 from 3.5 to 4.0 MHz (160 meter data is comparable).

If the interest in small antennas is as widespread as it appears to be, and if the numerous popular designs are as inefficient as I believe them to be, then the story of the SEED antenna, whether useful, amusing, or controversial — might be worth telling. My design considerations, measurement techniques, performance data, and evaluation are included: if they were flawed in any way, experts are welcome to set the record straight, but the antenna *does* work . . . and it has advantages I've never seen in any other ham antenna, large or small.

initial design

The first task was to decide what features were considered most important, and what their order or priority should be. They were:

- operation in the 80 and 160-meter bands
- small size
- efficiency
- feed point impedance of 50 ohms
- simplicity of operation

The first two would be mandatory; optimizing the others would be the job at hand.

Since short radiators have low radiation resistance, good efficiency requires even lower loss resistance. The possibilities of a vertical monopole antenna operated against ground were not explored because an adequate radial system is not small and, without one, ground losses are excessive. Similarly, capacitive end loading structures, to be effective, would also be too big. A short dipole, fed at its center, would require loading inductance, which would necessarily have too much resistance to be acceptable.

However, when viewed from its ends, a short dipole exhibits inductive reactance. This can be resonated with capacitance, and the losses in capacitors can be quite small.

The efficiency of such a short antenna could also be enhanced if the radiation resistances were maximized. This could be done by causing more current to flow in a greater part of the length of the radiator. The end-fed design would provide maximum current in the full length of the radiator and maximum radiation resistance for the length available. The antenna would then be a short, efficient, end-fed dipole.

With these thoughts in mind, a 20-foot (6.1 m) piece of 1-inch (25.4 mm) copper pipe was selected for the radiating element corresponding to a length of 0.08 wavelength or 29 degrees at 3.950 MHz, and half that at 1.9 MHz. A tapered transmission line of two 20-foot pieces of 1/2-inch (12.7 mm) copper pipe are used to end feed the driven element while providing closely spaced points for connection of the other parts. This approximates an equilateral triangle, with the narrow end of the transmission line separated by only a few inches. At this point the reactance would still be highly inductive.

Air dielectric tuning capacitors from each side of the transmission line establish resonance. By placing a low

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reactance loading capacitor between them, the two connecting points provide a low impedance, balanced feed point. By proper selection of the loading capacitor value, this becomes a 200 ohm feedpoint, nonreactive when the system is tuned to resonance, and appropriate for a conventional 4:1 balun to match to 50-ohm coaxial cable.

Inherent in this design philosophy is the distinction between the radiator and the transmission line functions. The radiator is a linear elementary dipole in which current is essentially the same at all points along its length, and voltages at its ends are equal and opposite in phase.

The transmission line section consists of two adjacent, straight conductors in which current and voltage are equal and opposite. It is tapered, and therefore its characteristic impedance varies throughout its length. Its center line is perpendicular to the radiator, and all elements lie in the same plane.

If the radiator is mounted vertically, its intrinsic radiation will be vertically polarized and maximum toward the horizon, while the center line of the transmission line will be horizontal, as will the polarization of its radiation.

The inductive reactance present at the open end of the transmission line section is the combination of that at the ends of the radiator and the effects of the line itself. This total was considered the inductive component of the resonant circuit, and no attempt to separate the factors appeared to be necessary.

construction

The antenna assembly is illustrated in **fig. 1**. The pipe was joined using standard soldered plumbing fittings to minimize junction losses. The ends of the transmission line were connected with half inch silver plated braid to rather large feedthrough insulators on the box containing the other parts. A wooden "T" frame supports the pipe and box, and is mounted on a 14-foot (4.27 m) high wooden 4 × 4 inch (100 × 100 mm) pole. The copper pipe weighs about 18 pounds (8.16 kg) and is not self supporting.

A weatherproof box at the end of the transmission line houses the capacitors, balun, and selsyn. The circuit within the box is shown in simplified form in **fig. 2**.

The tuning capacitors, "ganged" by a shaft coupling, are controlled from the operating position by a pair of surplus selsyns connected by a multi-conductor cable. A small reversible, slow speed motor might have been a better choice. The loading capacitors are mounted and connected with copper strap and banana plugs.

The assembly is mounted with the radiating element vertical. The supporting boom is hinged at the top of the pole to allow it to be tilted 90 degrees to bring the control box down to shoulder level for substitution of capacitors during evaluation.

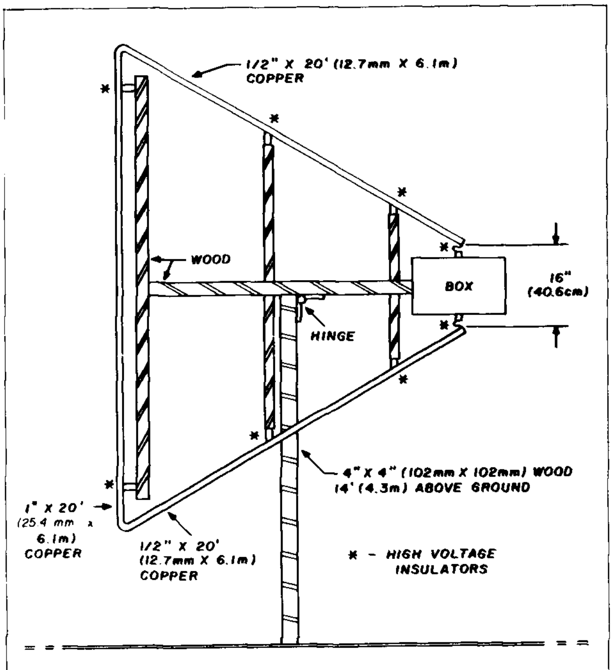

fig. 1. The structure of the SEED antenna and its mounting (not to scale).

After the initial selection, the loading capacitor does not require adjustment to provide a low SWR across a single band. However, a different value is required for each band. Because of the high current to be carried, use of relays or switches is avoided and plug-in units are substituted when changing bands.

circuit description

The basic circuit as originally envisioned is a parallel resonant circuit as shown schematically in **fig. 3A**. The series resonating capacitors, C_{S1} and C_{S2}, and the loading capacitor, C_L, all in series, are across the inductance of the pipe structure, L. There is also a significant distributed capacitance, C_D, across the inductor. This is the capacitance between the sides of the pipe structure plus the stray capacitance of leads to and within the component box. The inductance is 20 μH and the distributed capacitance is 19 pF. The resistance, R, is the sum of the radiation resistance and the loss resistance of the pipe (including joints) and capacitors.

Selection of the series resonating capacitors determines the operating frequency. The value required for the loading capacitor will depend, to some extent, on the physical characteristics of the antenna structure, its mounting and environment, and the adjacent ground. The balun is a standard commercial unit with a cylindrical core and an impedance ratio of 4:1, and is rated for full Amateur power.

The practical circuit now in use is shown in **fig. 3B**. C_{S1} and C_{S2} are, in fact, series or parallel connected assemblies of fixed units, as required by band selec-

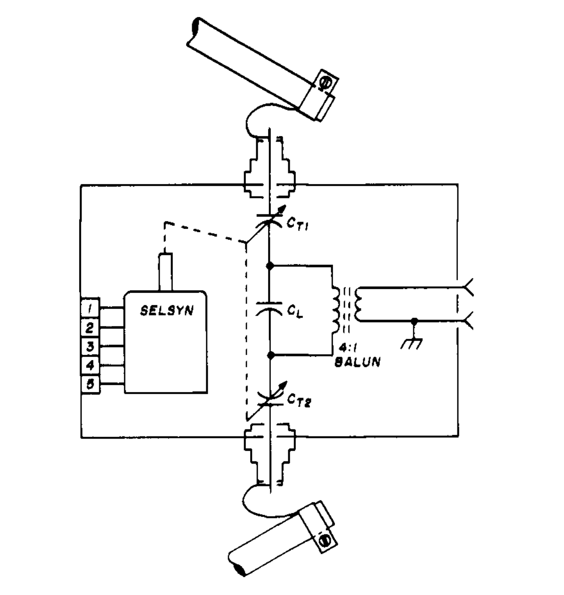

fig. 2. Simplified diagram of the contents of the control box on the boom of the antenna.

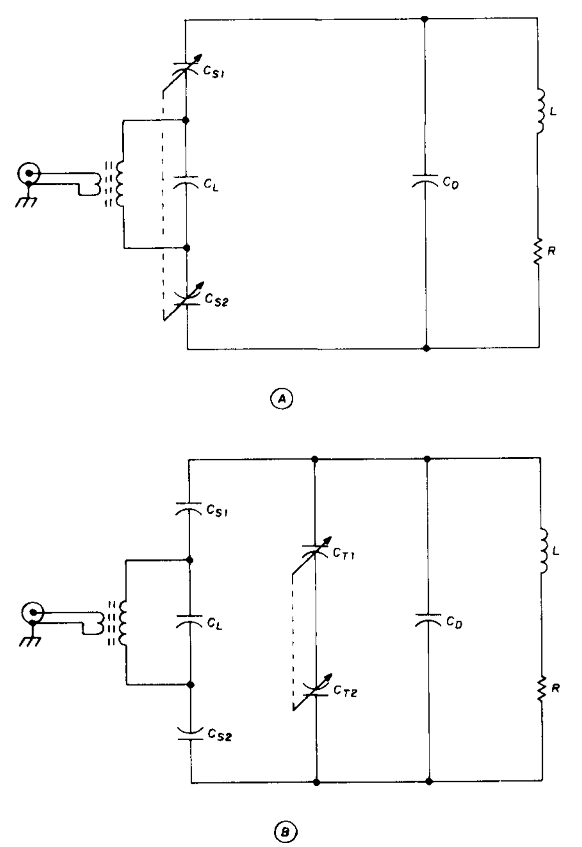

fig. 3. Circuit of the SEED antenna: (*A*) the elementary circuit originally envisioned, and (*B*) the practical circuit in use. (Component designations are explained in text.)

tion and parts availability. In early experiments, each of the variable tuning capacitors was connected in parallel with the related series resonating capacitor. This isolated the distributed capacitance, C_D, and facilitated its measurement. Under these conditions, SWR was 1.5:1 or less from 3.5 to 4.0 MHz. It later developed that connecting the tuning capacitors in series across the entire circuit, as shown, would significantly improve the SWR at the band edges.

Under operating conditions, the total resistance, R, also included the effects of ground and environment. This measured 0.64 ohms at 1.9 MHz and 2.21 ohms at 3.950 MHz.

The tuning capacitors are 10-100 pF, 4500 volt units. When each is paralleled with a fixed series capacitor of 680 pF at C_{S1} and C_{S2}, the circuit tunes from 1.813 to 1.907 MHz. The optimum value of C_L was 7450 pF, and maximum SWR was 1.3:1 in this range. Bandwidth for an SWR of 2:1 without retuning was 3.75 kHz with a loaded Q of about 370. At 200 watts to the antenna, the tuning capacitors each had 2000 volts, RMS, across them and the current in the circuit was 18 amperes, RMS. The benefits of the revised connection of the tuning capacitors had not yet been recognized when 160 meter tests were made.

Using the same tuning capacitors but in the revised circuit, and with fixed 100 pF units at C_{S1} and C_{S2}, the circuit could be tuned from 3.300 to 4.095 MHz. The optimum value of C_L was 1250 pF for an SWR of less than 1.15:1 from 3.5 to 4.0 MHz. The bandwidth for an SWR of 2:1 without retuning was 14 kHz, with a Q of about 225. At 200 watts to the antenna, each tuning capacitor had 2250 volts, RMS, across it, and current in the circuit was 9.5 amperes, RMS.

2-meter model

A 1:36 scale model of the design was made and operated in the 2-meter band in an effort to determine the free space radiating characteristics of the design. Under much less than ideal conditions, scans of 360 degrees of azimuth were made for both horizontally and vertically polarized radiation, with the antenna in three attitudes.

The most informative patterns occurred when the radiator was horizontal and the center line of the feedline section vertical, as shown in **fig. 4A**. This separated the horizontal radiation of the radiator from the vertical radiation of the feedline section, and facilitated consideration of each separately from the other. It emphasized that the maximum signal from the radiator was at right angles to it, whereas that from the feedline section was concentrated in the directions in the plane of the structure and perpendicular to its center line.

With the plane of the assembly horizontal, a plot of the horizontal radiation, as shown in **fig. 4B**, shows essentially a circular pattern, decreasing about 2 dB off the ends of the radiator. Radiation from the feedline section nearly fills in the nulls at the ends of the radiator. Vertical radiation was not detectable in any direction.

With the radiating element vertical, the vertical radiation pattern, as shown in **fig. 4C** shows lobes in directions in the plane of the antenna which were about 6 dB above the nulls at 90 degrees from them (broadside). There was no measureable horizontal radiation.

orientation

The model tests simulated operation of the SEED antenna in free space. To that information must be added the effects of the proximity of ground. Even though they could not be measured with available facilities, the nature and relative magnitude of the distortions to be expected could be estimated.

Mounted horizontally, the SEED design might be an excellent antenna if it were about 140 feet (42.67 m) above ground. At a height appropriate to its size, its radiation resistance would be reduced, decreasing efficiency. Very little low angle radiation would exist. Ground losses would be severe.

If it were mounted with the plane of the structure vertical and the radiator horizontal, the horizontal radiation would be degraded as described above. The feedline section would produce some vertically polarized radiation.

By mounting the SEED with the radiating element vertical, ground losses might be less and low angle radiation should be improved. Since selection of polarization could not be based on comparison of measurable losses, vertical polarization was chosen to favor lower vertical radiation angles.

initial observations

A unique feature of the SEED design is a feed point

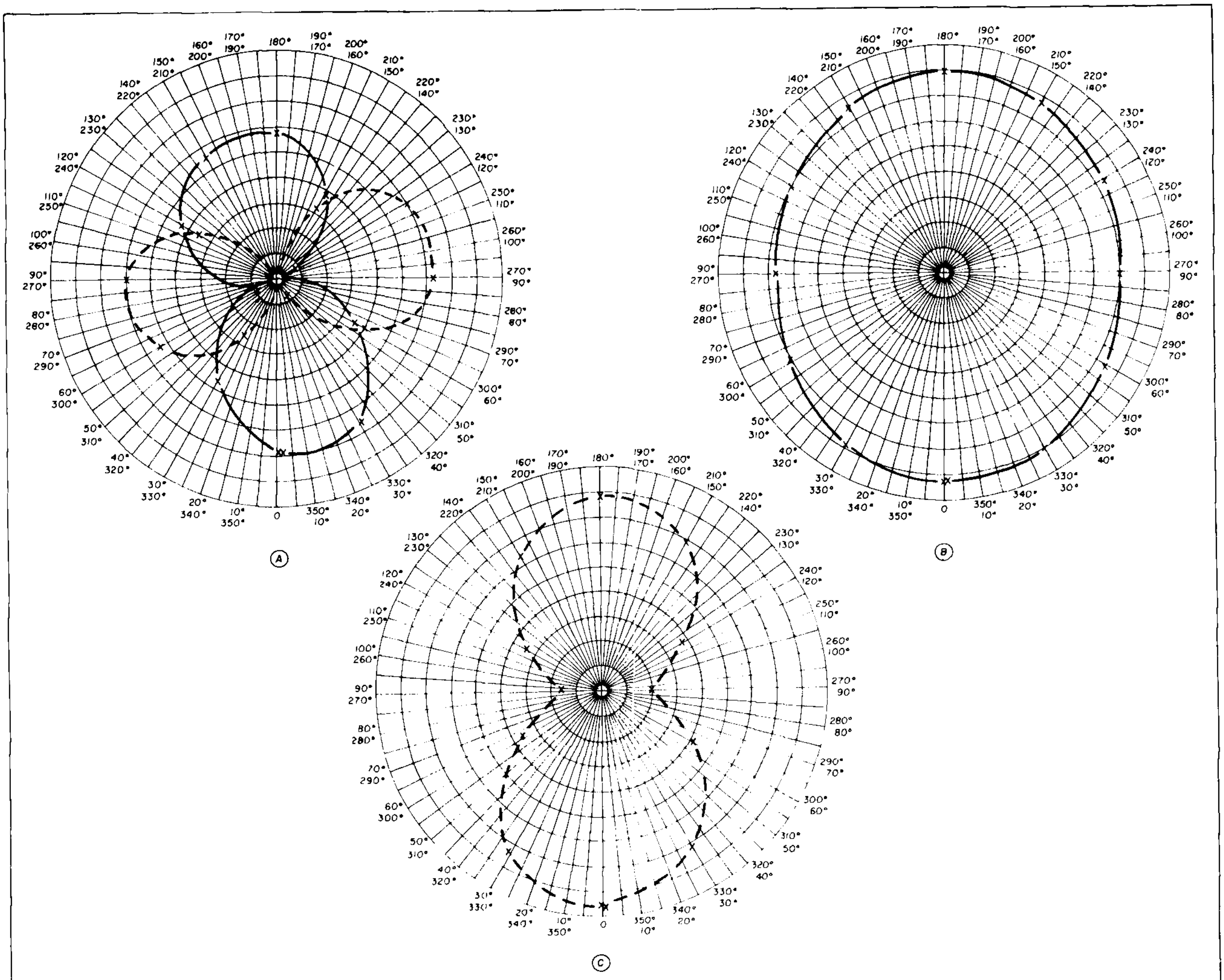

fig. 4. Free space radiation patterns of the 2-meter model SEED: (*A*) with plane of antenna vertical and radiator horizontal, (*B*) with plane of antenna horizontal, and (*C*) with radiating element vertical. Zero degrees in *A* is perpendicular to the plane of the antenna; in *B* and *C*, perpendicular to the radiator in the plane of the antenna, feed point at 180 degrees. Solid line shows horizontally polarized radiation, dashed line, vertical.

impedance of exactly 50 ohms, non-reactive. Other resistive or complex impedances may be obtained if desired. The resistive component is continuously variable by adjusting the value of the loading capacitor, and reactance may be introduced or eliminated by the main tuning control. With the loading capacitor optimized at mid-band, SWR did not exceed 1.15:1 from 3.5 to 4.0 MHz.

Since the loading capacitance is "set-and-forget," only one operating control is needed. A noise bridge or other low power indicator of resistance and reactance at the operating position will show when the antenna is resonant at the desired frequency, and causes no harmful interference. Under power, any device which will show maximum forward or minimum reflected power in the feed line will indicate proper tuning. But accurate tuning is critical to optimum antenna performance as well as feed point impedance. Error in tuning of 8 kHz at 3.950 MHz results in SWR of 2:1 and degrades efficiency, and at 160 meters much more care is necessary. CAUTION: A matching network or "antenna tuner" should not be used with the SEED antenna; neither it nor any controls in the transmitter can compensate for mis-adjustment of this antenna.

If a slow speed, reversible motor is used for remote tuning, a drive shaft speed of 1 RPM is a little too fast for convenience and accuracy, while a slower rate increases the time required for wide frequency excursions.

The very high loaded, operating Q of this circuit, 225 at 3.950 MHz and 370 at 1.900 MHz, probably attenuates harmonics and many other spurious emissions very effectively, but this effect could not be assessed. The resulting high current in the full length of the radiator is the good news. High current and voltage in the other parts of the circuit require special attention. Many hams may not be familiar with antenna parameters of 16,000 volts, peak, or 42 amperes of RF.

No inherent frequency limitations on the SEED design were observed. The 144 MHz model performed well, but both selection and adjustment of low loss, small capacitors were tedious. The total length of the radiator plus both elements of the feedline section should not exceed about 0.4 wavelength at the highest frequency to be used for fundamental operation.

At lower frequencies, through the broadcast band and below, it appears that a structure of this design, but still less than 0.1 wavelength long, would operate well and might have advantages. Elimination of the need for an extensive field of ground radials as an integral part of the circuit may be beneficial in some cases.

operational testing

The test site for the SEED is in a ravine nearly surrounded by ground 130 feet higher. The surface slopes about 8 degrees and is completely covered by trees. There are seven houses within a half wavelength of the antenna. A full length horizontal dipole 35 feet high and a 48-foot vertical are available for comparison. A single knob permits instant selection of any antenna and disabling of the others so they will not act as parasitic radiators. All antennas were matched to accept the same power. Most tests were conducted at frequencies near 3.950 MHz.

A lengthy effort was made to obtain dependable numerical comparative performance data, but results were inconclusive. Subjectively, less formal signal reports and innumerable listening tests over a three-year listening period were encouraging. At distances of less than 100 miles, the consistent superiority of the horizontal dipole confirmed the predominantly low-angle radiation of both the SEED and the vertical. At distances up to about 550 miles, the SEED and the horizontal dipole exceeded each other as conditions varied, while the vertical whip was consistently inferior. The immediate terrain prevents investigation of the probable superiority of the SEED and the vertical at greater distances, where predominantly low-angle radiation is most effective.

The antenna was resonated and matched in the 160 meter band and operated for about three weeks in early April. Power to the antenna was about 160 watts, PEP, on Single Sideband. Most contacts were made between 6 and 10 PM and at distances of 300 to 600 miles. No apology was offered for the size of the antenna and good reports were received. Those who asked and were told that the radiator was 20 feet long expressed surprise and curiosity.

The most frustrating aspect of these experiments was the inability to obtain satisfactory "on the air" performance data. It is hoped that someone with a suitable test site will investigate and report the low angle, long distance capability of the SEED which could not be determined at this location.

measurements

Several years of dredging at surplus outlets and hamfests had provided a supply of nondescript capacitors for this project. It soon became apparent that knowing the capacitance of those in the circuit would be necessary, and accuracy would be important. A Dynascan digital capacitance meter was obtained and used for measurements. A popular noise bridge was found to be inadequate for critical, repeatable, measurements. By modifying a published design, a noise bridge with suitable accuracy and resolution was made and calibrated. A secondary station receiver was dedicated to the project, and a signal generator and frequency counter provided signals of known amplitude and frequency.

One of the useful features of the SEED design is that it is a parallel resonant circuit with easily measurable components. The series, loading and tuning capacitors can be measured directly. The value of the distributed capacitance and the inductance of the structure, including the connecting leads, can be computed directly from these measurements and the frequency of resonance, as explained in **appendix A**.

With this data, it is possible to determine the series resistance of the antenna in position, as shown in **appendix B**. This is the sum of the radiation resistance, the loss resistance of the components, and the effects of absorption and reflection of adjacent ground and other objects. The loaded Q of the circuit can also be found, and measurement of the bandwidth for an SWR of 2:1 can be confirmed as in **appendix C**.

efficiency

The books say that the radiation resistance at 3.950 MHz of the SEED antenna in free space would be about 5 ohms. Loss resistance in the primary circuit has been determined to be about 0.1 ohm. Under these conditions, efficiency would be $\frac{5}{5 + 0.1} \times 100 = 98$ *percent*. This shows success in obtaining some of the design and construction goals, but usefulness of the figure is limited.

When the real secondary effects of ground and environment loss and reflection are added, the measured total resistance is 2.21 ohms at 3.950 MHz. Facilities were not available to divide this total between loss and radiation resistance, so a real efficiency percentage cannot be determined. However, the portion which represents total losses cannot exceed 2.21 ohms and must be somewhat less because useful radiation has been observed.

This justifies the original premise that even small amounts of loss resistance in the primary circuit could seriously degrade the output signal. As an example, substitution of No. 10 wire for the pipe which was used would increase primary resistance by 1.1 ohms and would just about double the total loss of the operating antenna. In other words, the increased resistance of the wire would be more or less equivalent to the power of the radiated signal.

evaluation

The initial design goals were all satisfactorily met or exceeded. A 20-foot radiator which can be operated without apology on either 160 or 80 meters is certainly small, and the SEED appears to be much more effective in use than would be expected. An SWR of less than 1.15:1 across the entire 3.5-4 MHz band may be one of the best solutions available for modern transceivers with transistor output stages. Elimination of the usual "antenna tuner" in the shack, and a single control to resonate the system, is operating convenience which approaches the ultimate (automatic sensing and resonating of the circuit could be provided).

However, CAB's Law is that "A problem solved is a problem created." At full legal Amateur power, a very short antenna must carry very high current, as do the associated capacitors. In the process of developing that current, high voltages are created. Ham-type handbooks and reference data available here provide very little theoretical or practical information about capacitors under conditions of high voltage, high current, high frequency, and high capacitance values.

The SEED antenna operates at 200 watts on either band with surplus capacitors that cost less than $25. The air variables are currently advertised at about twice that, but all others are obsolete and not now available. The capacitors in SEED Mk IV, a rather different version, are more than is needed, but they will take a full kilowatt without strain. They could be bought new, now, but for well over $1,000.

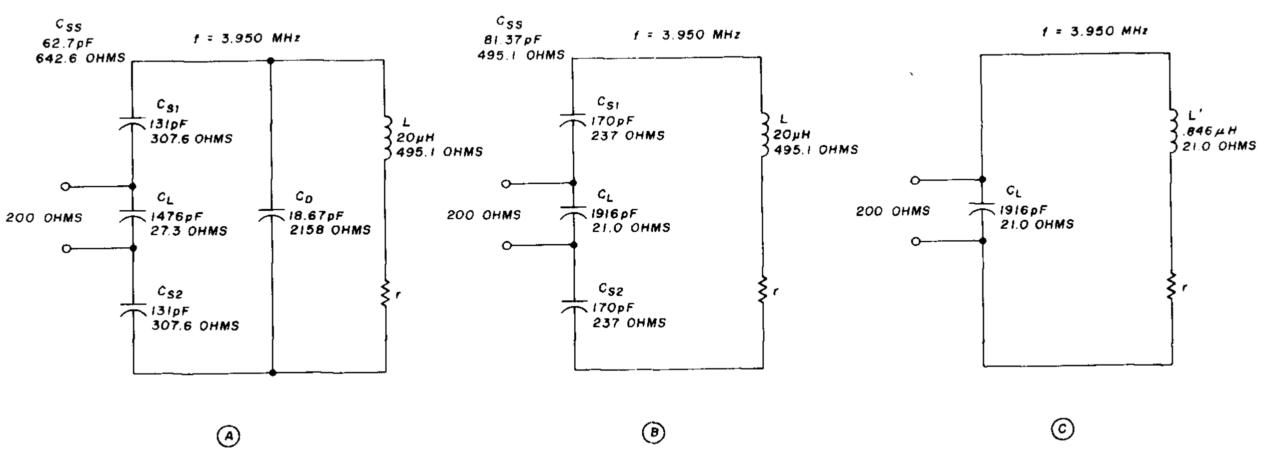

fig. 5. Transposition of the actual circuit of the SEED antenna (*A*); to the equivalent circuit (*B*); and to the simplified equivalent (*C*), as described in *appendix B*.

Maybe someone who reads this can publish information on how to economically obtain capacitors which can handle any of the following requirements:

7500 pF, 42 amperes, at	500 volts RMS, at 2 MHz
680 pF, 42 amperes, at	4,700 volts RMS, at 2 MHz
100 pF, 24 amperes, at	5,600 volts RMS, at 4 MHz

appendix A

With reference to **fig. 3A**, the parallel tuned circuit consists of an inductance, L, a distributed capacitance, C_D, and a series combination of tuning and loading capacitors, C_{SS}. The values across C_{SS} were measured as follows:

1.900 MHz	333 pF
3.950 MHz	62.7 pF

In each case, the distributed capacity must be added to that measured to resonate with L.

The formula for resonance,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

can be rewritten:

$$\frac{\left(\frac{1}{2\pi f}\right)^2}{C} = L$$

Substituting appropriate numbers,

$$\frac{\left(\frac{1}{6.28 \times 1.9 \times 10^6}\right)^2}{333 \times 10^{-12} + C_D} = L$$

$$= \frac{\left(\frac{1}{6.28 \times 3.95 \times 10^6}\right)^2}{62.7 \times 10^{-12} + C_D}$$

which can be solved for C_D (18.67 pF) and then for L:

At 1.900 MHz: $333\ pF + 18.67\ pF$
$= 351.67\ pF$ *or* $238.2\ ohms$
and $238.2\ ohms = 19.953\ \mu H$ *for* L
at 3.950 MHz: $62.7\ pF + 18.67\ pF$
$= 81.37\ pF$ *or* $495.2\ ohms$
and $495.2\ ohms = 19.952\ \mu H$ *for* L

appendix B

With the antenna resonant at 3.950 MHz, the value of the loading capacitor was adjusted for 50 + j0 ohms at the end of about a half wavelength of new RG 213/U cable. Subject to any imperfections in the balun, this indicated an impedance of 200 + j0 ohms across the loading capacitor. The measured value of this capacitor was 1476 pF for a reactance of 27.3 ohms. The reactance across the series combination of C_{S1}, C_{S2}, *and* C_L, or C_{SS}, was 643 ohms.

The ratio of X_{CSS} to X_{CL} is 643 to 27.3 or 23.553 to 1. The impedance ratio is the reactance squared, or 554.75 to 1. Therefore, the impedance across C_{SS}, at resonance, is the impedance across C_L, 200 ohms, multiplied by 554.75 or 110,950 ohms. This is the impedance across the parallel tuned circuit and, at resonance, it is purely resistive. Since the relationship of the series resistance, r, to the parallel resistance, R, is:

$$r = \frac{X^2}{R}$$

where X is the reactance of either the inductor or total capacitance of $C_{SS} + C_D$, or 495.1 ohms. Then

$$r = \frac{245{,}124}{110{,}950} = 2.2093\ ohms$$

or the total series resistance of the antenna is 2.21 ohms.

Alternatively, the circuit may be considered by transposing it as shown in **fig. 5**. The circuit was modified and measured at 3.950 MHz, as shown in **fig. 5A**. In the absence of C_D, the total of C_D and C_{SS} would need to be combined to resonate at the same frequency. Retaining the same ratio between C_S and C_L, the values can be computed and would be as given in **fig. 5B**.

It can then be seen that the net reactance of C_{S1}, L, C_{S2}, in series, is inductive and equal to the capacitive reactance of C_L. Considering this combination, L', the circuit can be redrawn as in **fig. 5C**. This is a simple parallel tuned circuit, and it is known that its parallel impedance at resonance is 200 + j0 ohms and may be expressed as R. Then, since the equivalent series resistance, r, is given by $r = \frac{X^2}{R}$ and X is the reactance of C_L, which is 21 ohms. Then $r = \frac{441}{200} = 2.205\ ohms.$

appendix C

The loaded Q of the antenna at 3.950 MHz can be found by dividing the reactance of L by the series resistance. Then $Q = \frac{495}{2.21} = 224$. It can be shown that for a Q of 224, the bandwidth for an SWR of 2:1, would be 13.225 kHz at this frequency.

Tests of the SEED at 3.800 kHz, where the coax was electrically a half wavelength long, measured the bandwidth for a SWR of 2:1 of 13.950 MHz. This tends to corroborate other tests and computations.

ham radio