Multiband Quads

BY L. A. MOXON*, G6XN

The Quad antenna may be used for multiband operation without reverting to individual loops for each band. G6XN presents some practical approaches and the necessary data for the construction of two and three band quads using only one loop and reflector.

THE quad is reputedly a one-band antenna and, whereas dipole-type beam-elements are commonly made to work on several wavebands, the normal "multiband" version of the quad uses separate loops for each band. This seems to be due to a misunderstanding about the properties of loops.

Some years ago the author made a rough theoretical estimate of the gain of a 14 mc quad and got a figure of 6.5 db. For the same beam energized at 21 mc the calculated gain was also about 6.5 db, and this led to the design of a reversible two-band beam with loops 17′ square, open wire stubs 36′ long, and matching on both bands, without retuning, into 100 yards of untuned line. This beam, centered on VK, has given consistently good results over a long period and reports, relative to other phone stations, have been, if anything, better on 21 mc than on 14 mc. Later developments have included several kinds of three-band arrays. The two band system described above turns into a bi-square at 28 mc; the mounting of two quads at right angles on the same pole or tree gives all around coverage by beam switching; and the use of a colinear pair of quads gives increased gain plus electrical beam rotation. We also discovered that loops can be distorted into a wide variety of shapes, such as triangular, without noticeably affecting their radiating properties. Comparisons have been made between three modes of operation, namely with a parasitic reflector, a parasitic director, and both elements driven.

As multiband beam-elements, loops have two main electrical advantages over dipoles. Firstly the radiation resistance is higher which means there is less objection to the use of long resonant feeders or stubs, and secondly if the feeder or stub is made the right length as in fig. 1 its lower end remains a point of low voltage on all bands thereby removing another objection to the use of resonant feeders. This also allows, if required, the connection with acceptable matching on each band, of a long non-resonant feeder.

One of the author's arrangements uses another property of loops to obtain tri-band matching *without* the use of long resonant lines. This enables a 21 mc loop to be resonated at 14 mc with a minimum of loading, thus keeping losses and the inevitable restriction of bandwidth to a minimum.

*1 Stoner Hill House, Froxfield, Petersfield, England

Facts About Loops

Figure 1 shows a loop plus a tuning stub, which together resonate at frequencies in the region of 7, 14, 21 and 28 mc with a voltage node at each end of the system. The resonant frequencies depend, to some extent, on how much of the wire is in the loop and how much in the stub, and are not in exact harmonic ratio, but this can be ignored for the moment.

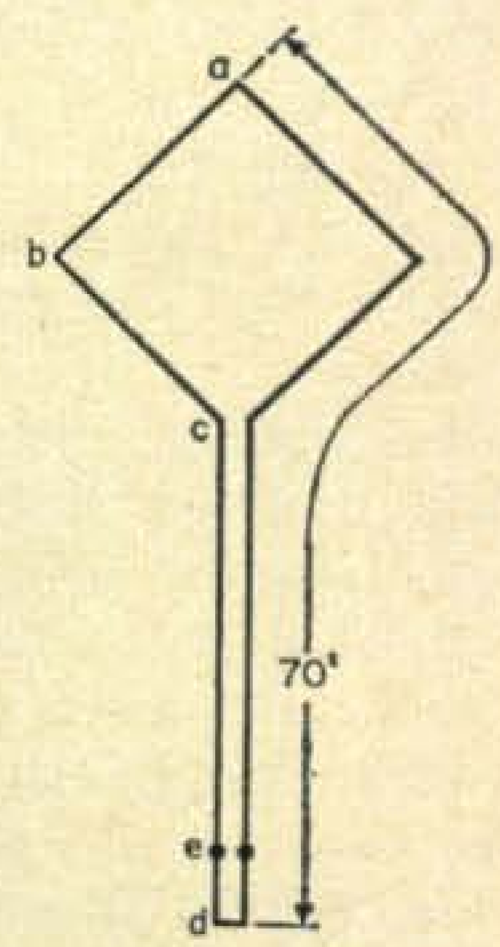

Fig. 1—A loop and stub arrangement that will resonate at 7, 14, 21 and 28 mc. A low impedance feeder may be connected at point *d* and a 600 ohm line may be attached at point e.

Figure 2 shows the current distributions round the loop when this contains ½, ¾, 1, 1½ or 2 wavelengths of wire. For a loop 17′ square this corresponds to excitation at 7, 10.5, 14, 21 and 28 mc respectively. The 1½ wavelength case, fig. 2(d), is a particularly interesting one, being that of a typical 14 mc quad operating at 21 mc or a slightly oversize 21 mc quad at 28 mc. The arrows indicate not only the direction of current flow but also the relative magnitude of field which each segment of the loop is capable of producing, a small arrow being worth only 29 percent of a large

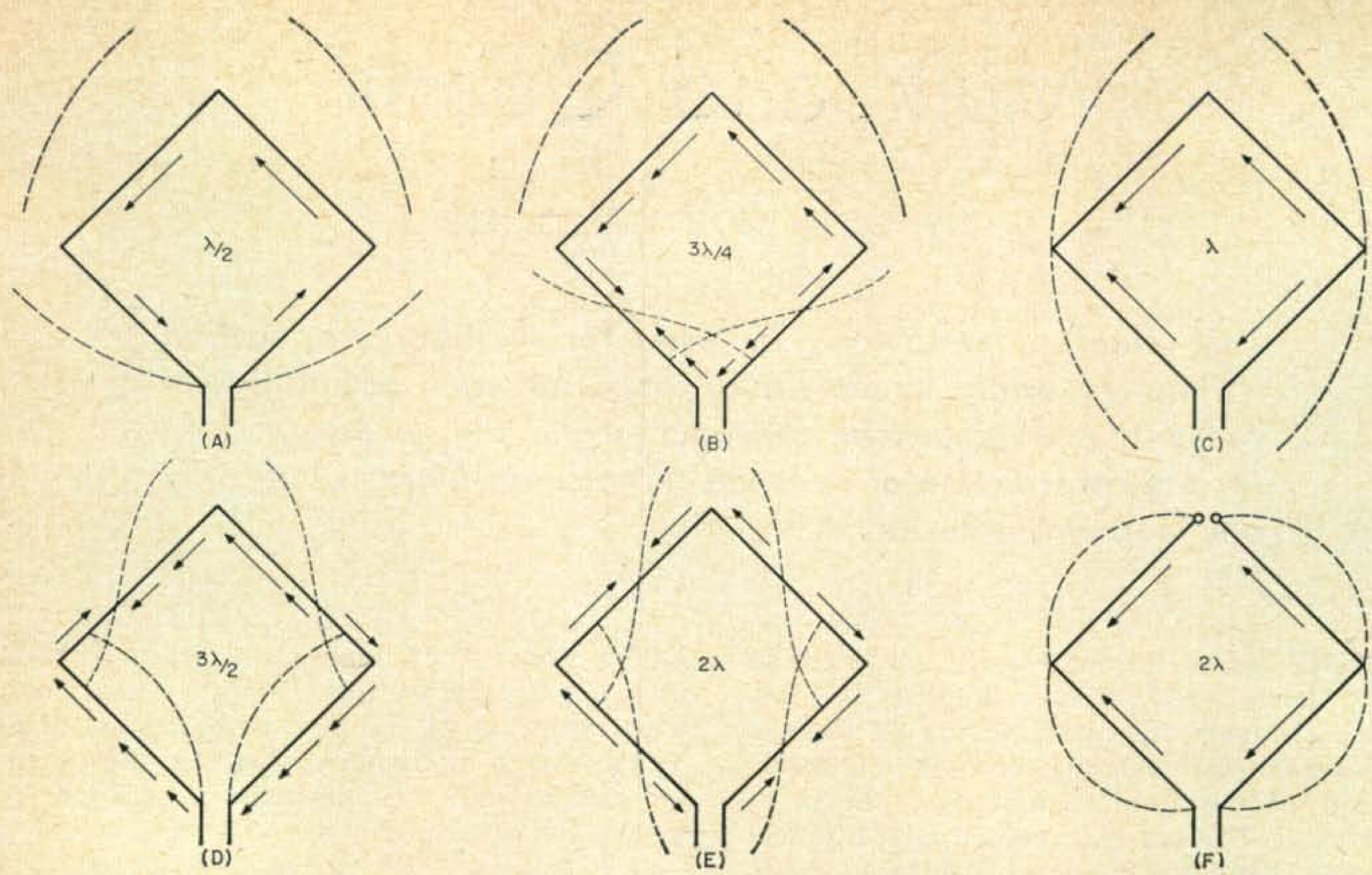

Fig. 2—Current distribution in loops of various sizes at different frequencies. The arrow lengths represent different field strengths, the smallest being 8, the next 29 and the longest 92. Illustrations (a), (c), (d) and (e) represent normal 14 mc quad antennas excited at 7, 14, 21 and 28 mc respectively. Illustrations (b) and (d) represent slightly oversized 21 mc quads at 14 and 28 mc. Illustration (f) has an insulator at the top.

one. Note that although some of the arrows cancel each other, most of them add up to produce radiation in the usual direction for quads, that is to say, at right angles to the plane of the loop. Because the three current-loops which produce most of the radiation are separated by appreciable fractions of a wavelength, the loop has a slight tendency to look like a multi-element array and the gain should be noticeably greater than that of a dipole provided there is no wastage through radiation in other directions. Further inspection shows that although there is some upward radiation, this is less than that of a dipole; in addition there is some vertically polarized radiation "off the ends" and a rough estimate suggests that about 25 per cent of the power may be wasted in this mode. With a two-element beam, however, radiation in these unwanted directions tends to cancel, and in practice the front-to-side ratio has appeared to be well up to normal standards.

Next in order of interest is the case of fig. 2(b) which shows the situation for 14 mc excitation when the loop is reduced in size to 12′ 6″ so that at 28 mc it operates as described above; at 21 mc it is slightly oversize and at 14 mc it is well below normal size. Note that three sizes of arrow have been used, their relative value in terms of field strength being 8, 29, and 92. Most of the radiation takes place from the top part of the loop which should give a useful increase of effective height, but because the dimensions are small fractions of a wavelength, the radiation pattern approximates to that of a doublet or short dipole and the possible gain from a close-spaced pair is about 5 db. The radiation resistance is about 35 ohms for a single loop, or 12-15 ohms when a reflector is added, these figures being about twice those for 21 mc dipoles operating at 14 mc so that, other things being equal, loops provide more bandwidth, easier matching and fewer losses.

Figure 2(a) shows that a 14 mc loop, when used at 7 mc radiates not only in the quad mode, but also as a "small loop" giving vertically-polarized radiation in the plane of the loop. The radiation resistance is very low, in the region of 5 ohms, and it is doubtful whether a pair of loops could be made to give useful gain as a beam. Fed in parallel, however, the two loops should give fairly efficient all-round radiation.

Figure 2(e) shows the unsatisfactory state of affairs when a 14 mc loop is fed at 28 mc. Nearly all the radiation is now in the plane of the loop with a large upwards component which reduces the gain and may also reduce the effective receiver sensitivity by increasing the level of the background noise which, at 28 mc, comes mainly from outer space. Although the two loops of a 14 mc quad can be operated as a broadside array at 28 mc, the gain is relatively small and the radiation is vertically polarized. On the other hand, if the top of the loop can be open-circuited by means of a relay, or tuning stub as in fig. 2(f), a 14 mc loop turns into a bi-square beam at 28 mc. As is well known, this has a gain of 4 db which can be increased by a second loop, acting as reflector, to about 9 db.

For 3 band operation a spacing of 8′ between loops has been found satisfactory. With increase of spacing the gain falls off rapidly at 28 mc, whereas lower spacings may lead to critical operation and reduced efficiency at 14 mc.

Tuning and Matching

Having established that loops can be made to radiate efficiently on two or more bands, there remain the problems of tuning them to resonance, or to act as parasitic elements, and of matching them to the transmitter on each band. There are several ways of doing this, the choice being largely a matter of trading simplicity of initial adjustment for convenience of operation. The beams to be described can all be tuned from ground level but if, as in the author's case, it is necessary to walk 100 yards from the shack to get to the base of the antenna, the operation of retuning when changing bands is ruled out and the job must be tackled the hard way; in other words the antenna must be made to resonate and match to an untuned line simultaneously on all bands. If the beam cannot be rotated, for example, because of tree-branches getting in the way, the next best thing is to make it reversible and this raises further difficulties if remote control is wanted.

The simplest method is to use tuned feeders of any length up to say 40 or 50′ with suitable tuning units. Instead of tuning units, the feeders can be made the "right length" as in fig. 1 which, as already indicated, is a first step towards all-band matching to an untuned feeder. The second step is to bring the resonances into exact harmonic ratio; for two bands this is easy and the method shown in fig. 3 for a 14/21 mc beam has given good service at G6XN over many years. The tuned circuits resonate at about 17 mc and have the effect of increasing the feeder length by 18 inches at 14 mc and decreasing it by 13 inches at 21 mc. The tuned circuit of fig. 3b is used in place of a shorting bar and if adjusted to give maximum gain on either frequency should be found correct for both.

It was originally expected that, due to increase of radiation resistance with frequency, the required length of stub *e d* would be the same for both bands but, although a length of 3′ 4″ was found to give tolerable matching in each case, the optimum was about 15 per cent less at 21 mc and correspondingly greater at 14 mc. This implies a radiation resistance of about 70 ohms on both bands so that better matching would be obtained by replacing the open wire feeder with a low impedance line connected at *d*. Moreover, since lower radiation resistance means larger currents in the loops and, other things equal, more gain, it seems likely that the gain at 21 mc has been underestimated. It will be noticed that at 14 mc the above arrangement differs from a normal quad only by the inclusion of half a wavelength of resonant feeder plus the compensating circuits. This increases the losses, but only by a very small fraction of a db, and roughly halves the bandwidth which still remains adequate from the standpoint of gain and radiation efficiency.

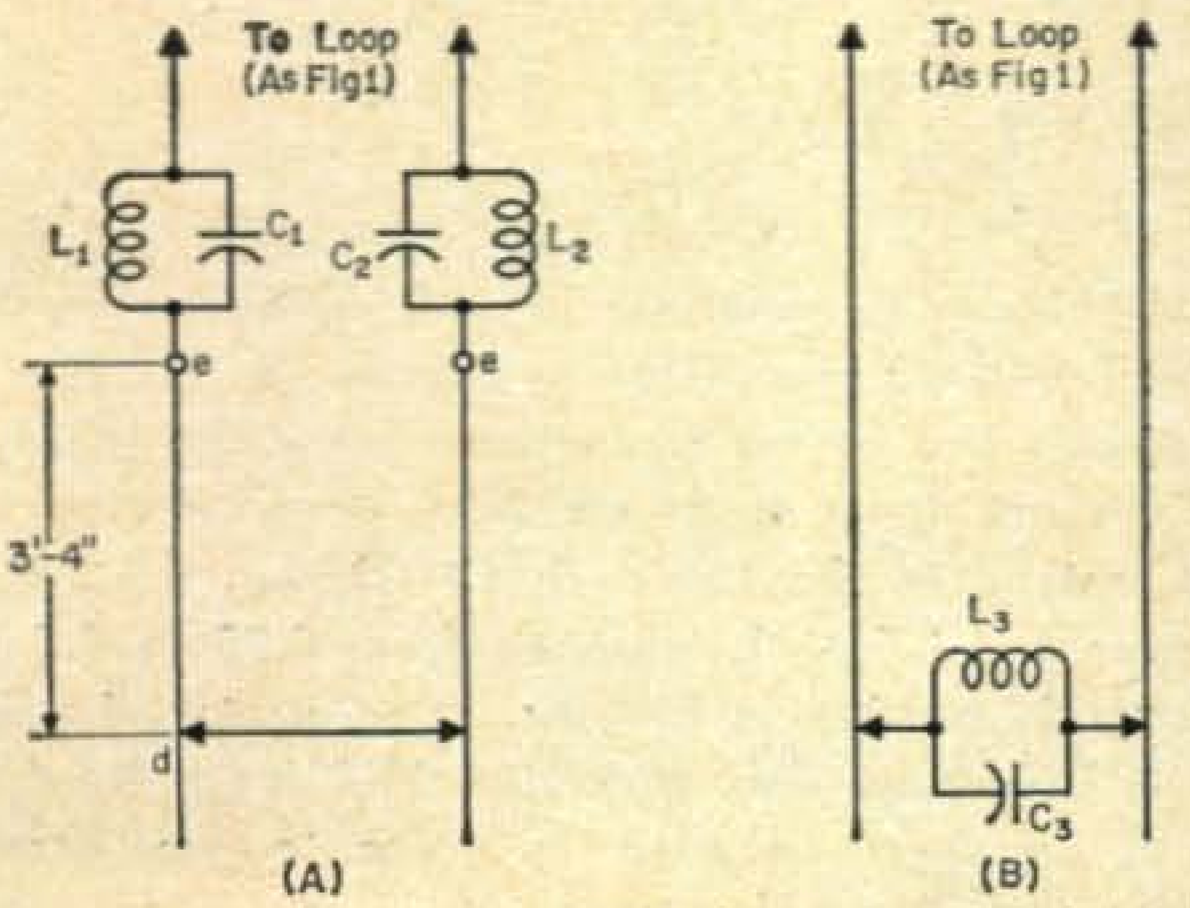

Fig. 3—Compensating circuits for a 14/21 mc version of the antenna shown in fig. 1, assuming 16′8″ loops. In (a), a high impedance feeder may be attached at e with a shorting bar at *d*, or a low impedance feeder may be used at *d*. An alternate arrangement for the reflector is shown in (b).

L_1, L_2—2 turns, 1⅜″ diam., spaced about 1″.
L_3—3 turns, 1¾″ diam., spaced about 1¼″.
C_1, C_2—500 mmf
C_3—250 mmf

Three Band Quad

The author's first attempt at producing a three-band quad was also based on fig. 1, but the loop size was reduced to 12′ 6″ square. The exact length, *abcd*, for 28 mc was found by taking ¾ of the length previously found correct for 21 mc, and then adding half a

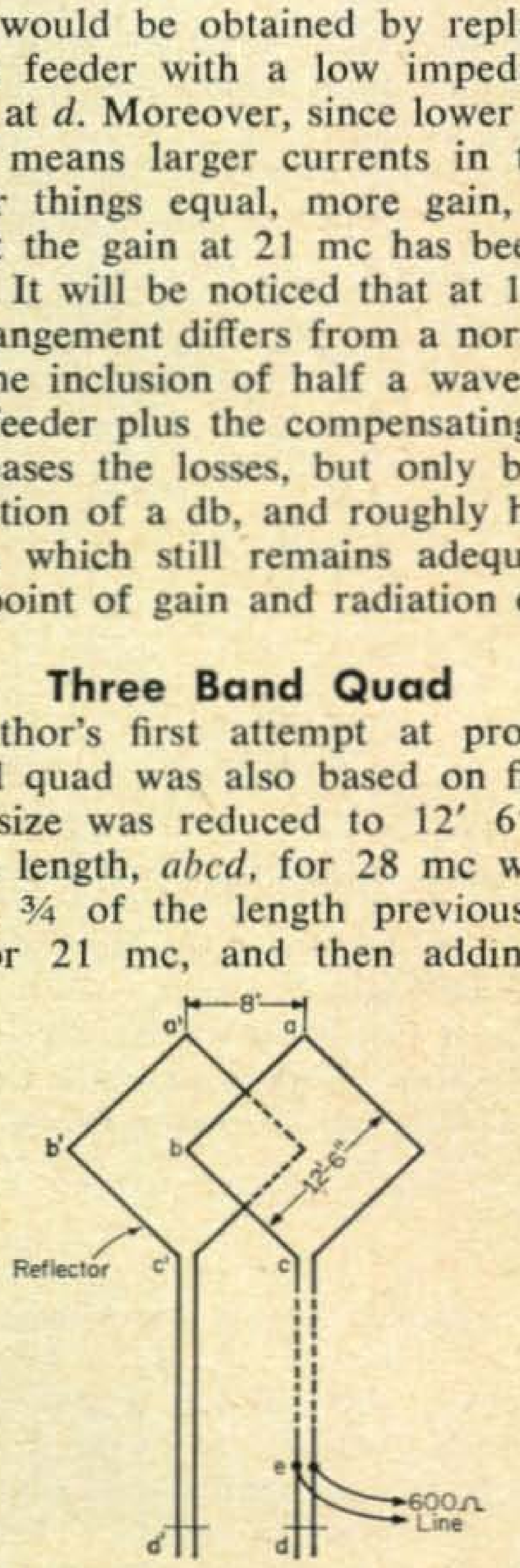

Fig. 4—A bandswitched 3 band beam based on the antenna shown in fig. 1. The length *a b c d* is approximately 72′ long and the shorting bars at *d* and *d′* are adjusted for resonance at 14.12 mc. The location of the shorting bar is then referred to as *P* in the table below and the location of the feeder and shorting bar may be determined for each band. These figures are intended as a guide only.

Band mc	Distance of *d* up from *P*		Distance of *e* from *P*
	Driven Element	Reflector	
14	at *P*	at *P*	3′1″
21	3′3″	2′2″	6′1″
28	3′7″	2′2″	6′1″

wavelength to restore approximate coincidence of the three resonances. Even so, the shorting bar had to be re-adjusted on changing bands, as shown in fig. 4. This was inconvenient, and another drawback was the narrow bandwidth and excessive losses estimated to be about 2 db, at 14 mc. However, even on 14 mc, DX phone reports were mostly flattering and included two of "the only signal from Europe." These experiments proved that, with normal distances between shack and antenna, the use of tuned feeders would be a practical and simple method of obtaining multiband operation.

Triband matching, together with minimum losses and maximum bandwidth at 14 mc, was achieved as shown in fig. 5 which was evolved from fig. 4 by subtracting 34′ of stub and arranging for an open circuit instead of a short

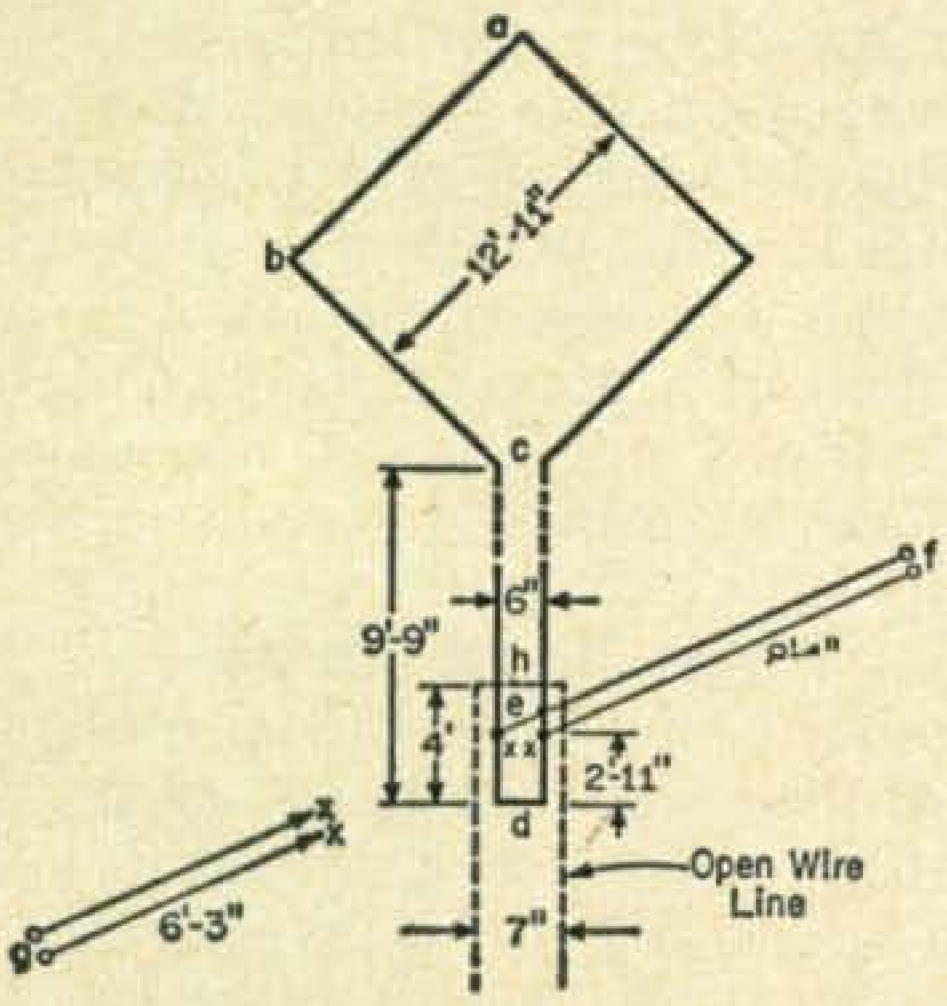

Fig. 5—A 3 band beam with simultaneous tuning and matching on all bands. The main feeder overlaps the 9′9″ stub for a distance of 4′. The 6′3″ stub is connected to the main feeder at xx where the stub of ef is connected. Only one element is shown.

circuit at 21 mc. The open circuit is provided by using the 2′ 11″ of excess length *de*, required for 14 mc, as an inductance and tuning it to resonance at 21 mc by a capacitance in the form of the stub, *ef*. By a lucky chance this stub puts a short circuit nearly in the right place for 28 mc whereas at 14 mc it is not long enough to have any appreciable adverse effect. There is no electrical contact between the feeder and the loop, power being transferred to the aerial through the mutual inductance formed by placing the end of the open-wire feeder close to the end of the stub, *cd*. The overlap is 4′ and the spacing roughly ¾ in. To achieve a sufficiently tight coupling it is necessary for the inductance on one side or the other to form part of a fairly high *Q* tuned circuit although the *Q* can and must be low enough to allow adequate coverage of the amateur bands. Due to the comparatively low radiation resistance at 14 mc, the loop has just about the right *Q* for correct matching with a reasonable value of overlap. At 21 mc *f e d* constitutes a high *Q* resonator, appropriately damped by the radiation resistance of the loop which presents a parallel impedance of several thousand ohms at *e*. At 28 mc the *Q* of the aerial is too low to provide efficient coupling, and this is resolved by adding the stub *eg* to the main feeder, *heg* being approximately λ/4 but adjusted to compensate for the slight residual error in the tuning of the loop. The stub *eg* has negligible effect at 21 or 14 mc.

The method of adjustment on 14 and 21 mc was to excite the loops from another aerial and tune each in turn, for maximum current, first at 14 mc using the shorting bar at *d* and then at 21 mc by altering the length of the stub *ef*, finally rechecking at 14 mc. The loop not being adjusted was detuned by a suitable shorting bar so that no measureable current flowed in it. At 28 mc the stub *eg* was adjusted to give the best value of v.s.w.r. Finally, with one element driven, the other was tuned as reflector by means of a feeder extension at a convenient height with a shorting bar being moved along this extension to give maximum field strength in the desired direction.

From the positions of the shorting bar it was possible to calculate a compact three band termination for the feeder going to the reflector as shown in fig. 6. Beam reversal was obtained by a 2 pole changeover relay as shown, and the v.s.w.r. improved rather than deteriorated by leaving the reflector termination attached to the driven element.

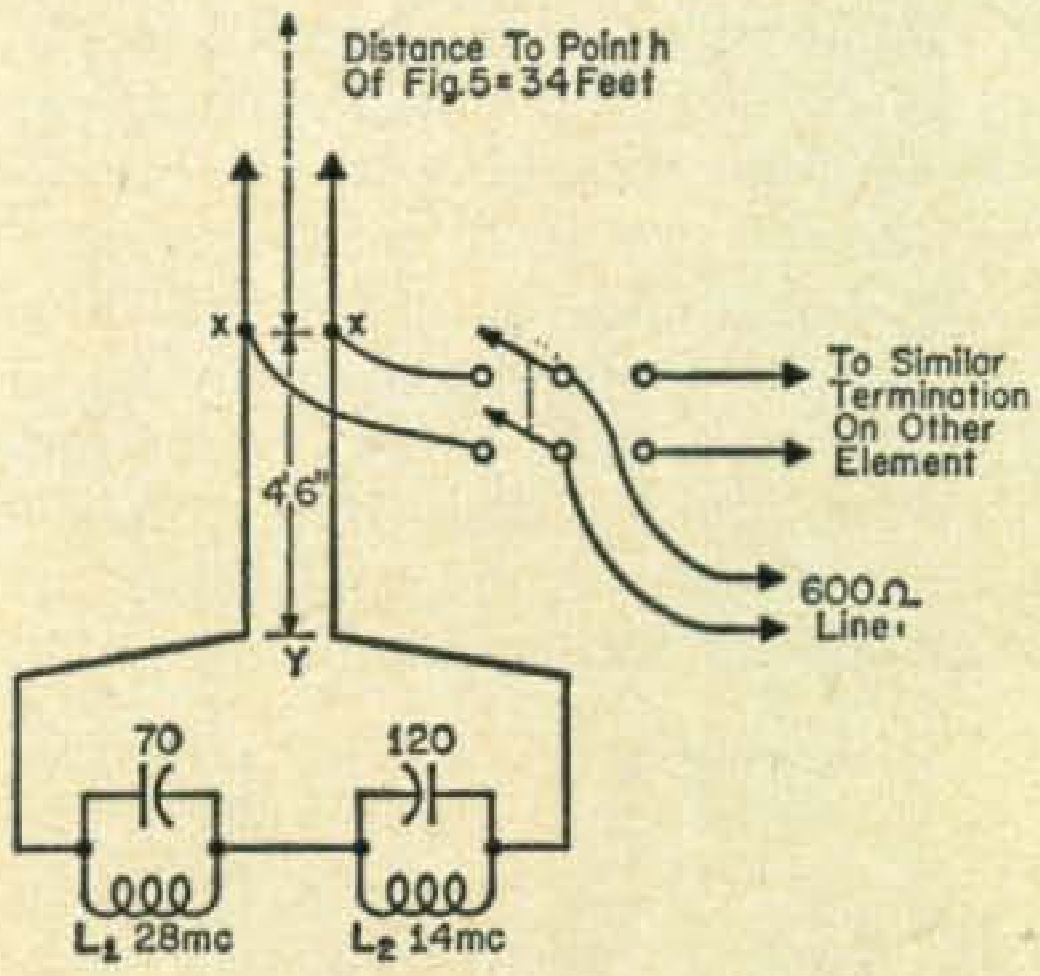

Fig. 6—Feeder terminations for a 2 element reversible beam based on the antenna showin fig. 5. The requirements are for an open circuit at *y* on 14/28 mc and a short circuit on 21 mc. If switches or relays are used instead of the tuned circuits shown, the 28 mc reflector bandwidth is widened from 0.25 to 0.5 mc. Inductor L_1 consists of 5 turns, 1″ diameter, 1″ long and L_2 is 6 turns, 1¾″ diameter, 1¾″ long. Points *xx* should be short circuited in order to use another beam mounted on the same pole.

Cautions

Now for some words of warning. To obtain optimum gain and a v.s.w.r. better than 3, simultaneously on all three bands for both directions, required a lot of time and patience. The job would have been easier if more care had been taken to make the two loops and their stubs exactly the same. Small variations in the tuning of the loops make large differences in the reflector terminations and there is no certainty that the author's values would be optimum in another installation. These terminations operate via the mutual couplings to give vernier adjustment of loop tuning and will not compensate for large errors in the adjustment of the loops. A suggested alternative alignment procedure is to tune the loops for maximum gain as reflectors with the tuned circuits of fig. 6 replaced by a short circuit at 21 mc and open circuits at 14 and 28 mc. The circuits can then be adjusted to produce equivalent results without switching and the v.s.w.r. checked. Comparing the fig. 5 scheme with that of fig. 4, improved performance at 14 mc has been obtained at the expense of increased losses and narrower bandwidth on 21 and 28 mc. For these losses to be negligible, thick wire must be used for the stub *fed* and all joints must be soldered and taped. A calculated figure for the stub-loss at 21 mc is 0.5 db for 12 S.W.G. wire, and the adverse effect of using 16 S.W.G. in the first experimental hook-up was very noticeable, particularly in terms of back-to-front ratio.

As compared with a full sized quad at 14 mc, voltages are much higher, and to avoid deterioration in wet weather it is advisable to use good insulation and keep tree branches, etc., well away from high voltage points in the system. Bandwidth on 14 and 21 mc is only just adequate and is not symmetrical. To cover the whole of each band it is recommended that adjustments be made at about 14.12 and 21.15 mc. Coverage on 28 mc is somewhat restricted unless the reflector is retuned, which can be done, however, at ground level by adjusting the termination shown in fig. 6.

Rotary Quad

Some thought has been given to a rotary version of the above beam. With 360° rotation, one feeder can be discarded but disposal of the stubs remains a problem. For the driven element the stub *eg* (fig. 5) can be replaced by a fixed capacitance. Similar replacement of *ef* is a possibility but increases the circulatory current in *ed* at 14 mc and may cause appreciable losses. Possibilities for the reflector, if disposal of stubs proves difficult, include separate loops for each band, or a two band loop plus a one band loop, and an experiment has shown that loops resonating at 14 and 21 mc can be spaced a few inches apart without serious interaction.

Three Band Compensating Circuit

Figure 7 shows the 3 band version of fig. 3. The shorting bar at *d* is first adjusted for resonance at 21 mc with the stub *eg* disconnected. The stub is then connected and its length adjusted for resonance at 28 mc. On 14 mc the stub *eg* acts as a capacitance, thereby increasing the effective length of *ed* by about the right amount. The larger the *LC* ratio of the 21 mc trap-circuits the greater the length-

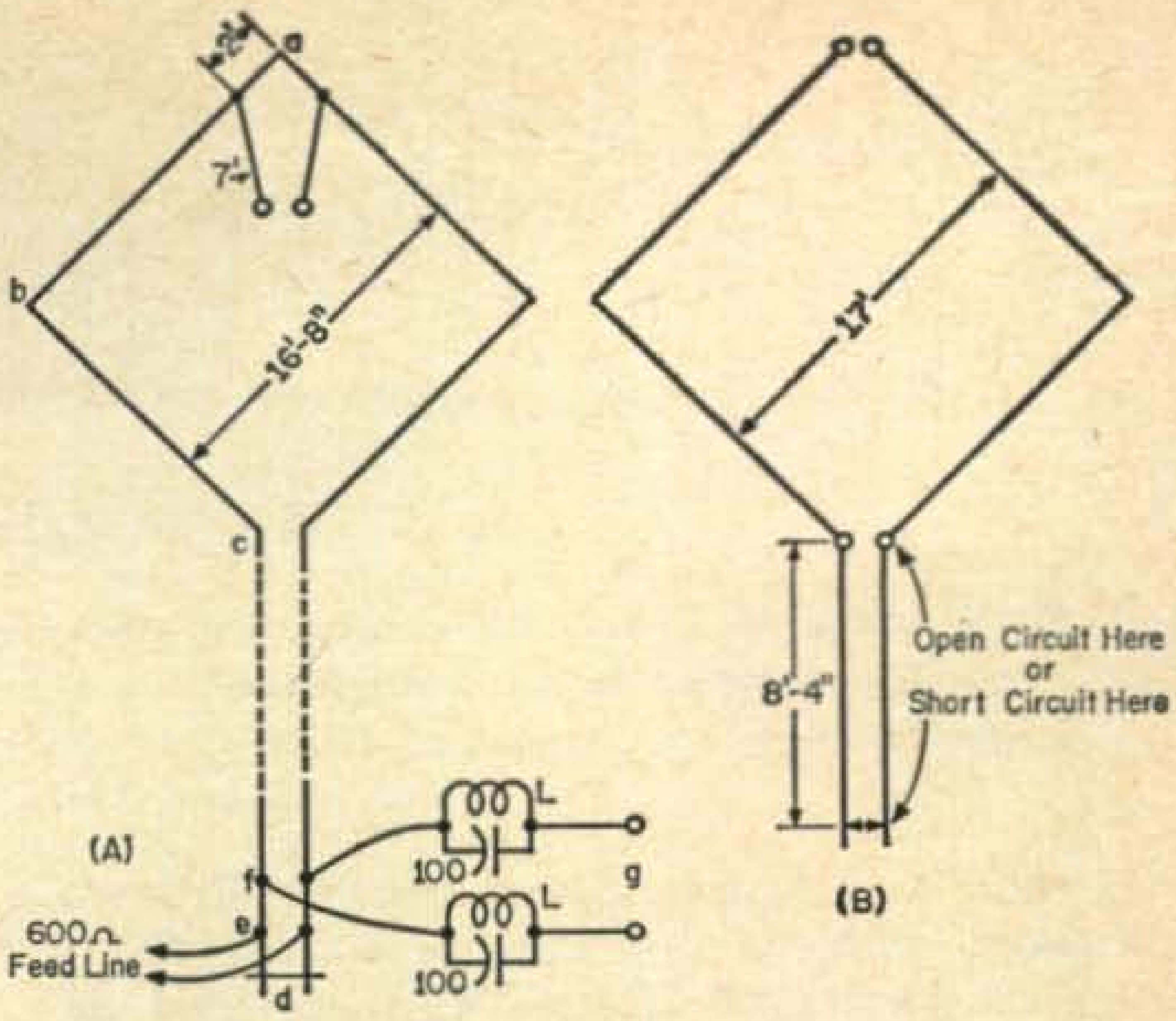

Fig. 7—Compensating circuits for a 3 band beam using 14 mc loops. A recommended design is the use of 2 loops, as in (a), spaced 8' to 10' as a reversible 14/21 mc beam with a separate 28 mc reflector, shown in (B), spaced midway between the two main loops. The lengths are as follows: *cd*, 36'; *ed*, 34'; *ef*, 22"; *fg*, 5'6". The inductors are each 6 turns, 1" diameter, 1" long, resonated at 21 mc.

ening effect on 14 mc so that the design can be rectified, if, as might happen with a different installation, the best positions of the shorting bar at *d* for 14 and 21 mc fail to coincide. This matching arrangement can also be used for a two-band system in place of the one previously described (fig. 3) and has the advantage that the system can be tuned to resonance on 14 mc by adjusting the length of *eg* (or an equivalent lumped capacitance) without affecting the 21 mc adjustment which must, however, be carried out first.

A useful feature of all these beams has been the ability to reverse them merely by changing over the main feeder from one element to the other without retuning, the elements having been first tuned up for maximum gain as reflectors. Optimum adjustments for reflectors and radiators do not always coincide exactly but it has usually been possible to reverse the beam in the above manner without losing gain or making the v.s.w.r. worse than about 2 or 3. The capacity of the reversing switch or relay with its leads tends to have a lengthening effect on the reflector stub and the tendency for the optimum adjustments to coincide can usually be improved by altering the lead lengths.

Practical Results

The arrangement of fig. 3 was the first to be tried and was fixed in an East-West direction. The mean height was 45' and the spacing about 12'. The array was mounted at the top of a tree with its lower half partly buried in the branches. Tested on 14 mc using another local station as a yardstick, performance was roughly equal to that of an earlier 4-element array which used two half-waves in phase with reflectors. Phone reports over the

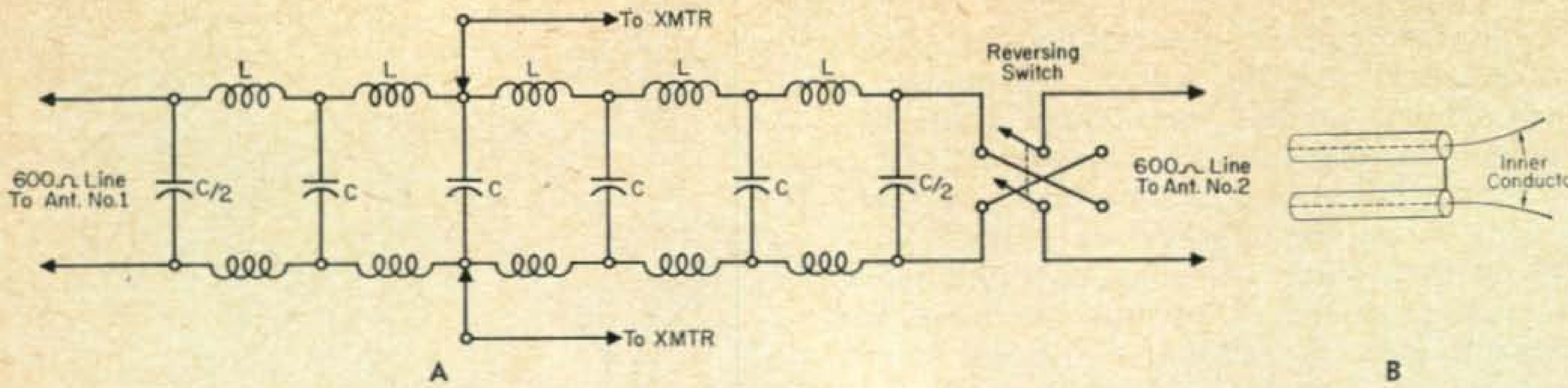

Fig. 8—An artificial line for phasing two antennas is shown above. The line is wrapped around a 2 pole 6 position switch. Each inductor is 6 turns, ⅜" diameter 1¼" long. The capacitors are formed from two 5" lengths of 72 ohm, ½" diameter coax wired as shown in B, except for the first and last. These two are 2½" each.

long route to VK were about one S-unit down compared with results from a former QTH where a steep ground-slope had provided an assisted take-off. Reports of "the best G signal" were received occasionally on 14 mc and more frequently on 21 mc. At this stage the method of beam reversal consisted of retuning the reflector to act as a director, which proved very inefficient. The current in a director was found to be less than half that in a reflector, and the gain appeared to be at least 3 db less, although this was offset by the advantage of having a slight ground slope in the reverse direction. The reason for the loss is that the mutual coupling between loops is more inductive than that between dipoles. Parasitic directors and reflectors only give equal performance if the mutual coupling is non-reactive as in the case of dipoles spaced about $\lambda/8$. Inductive coupling increases the current in a reflector making it more nearly equal to that in the driven element, thus increasing the gain slightly, and front-to-back ratio considerably. Similarly a capacitive mutual impedance favors directors at the expense of reflectors.

The next development was the erection of a second similar array, the two being used as a collinear pair spaced 35' giving an additional gain of about 3 db. The two were phased by connecting the feeders to opposite ends of an artificial line wrapped round a 2 pole, 6 circuit wafer switch as shown in fig. 8. This arrangement allowed the beam to be swung ±45° for a loss of up to 3 db, adjustment being made for *minimum* signal strength on reception followed by operation of the reversing switch. Theory requires unity v.s.w.r. in the feeders and predicts insufficient phase-shift on 14 mc and too coarse an adjustment of phase on 28 mc. In practice, however, the arrangement has been successfully used over many years with different antennas, v.s.w.r.'s of up to 3, and differences in performance between the two antennas of up to 1 S-unit. It has usually been possible to obtain a gain of ½ to 1 S-unit from the pair.

The author is well aware that the gain should only have been 2-3 db and that an S unit is supposed to be 6 db; in the course of long experience, however, it has been found that 3, or at most 4, genuine db are equal to one S-unit in average signal report, or anywhere between 6 and 20 db if signals are "over S9". Perhaps someone can explain this! Either way, we do not know how to improve much on this result short of buying a few more acres of land and erecting a great number of large rhombics. Results should, of course, improve over the years as the trees get taller, so perhaps by the year 1980 or thereabouts we may get around to winning that DX contest!

To improve performance on the short route to VK, the beams were altered so that both elements were driven, using a pet scheme which we wrote up some years ago[1].

The two elements were tuned to resonance, connected in antiphase 8JK fashion, and fed about 2' off center in the desired line-of-shoot. This worked quite well and gave a very large front-to-back ratio on both hands. Unfortunately, the optimum off center displacement was not the same on both bands and the strain of having to decide whether to accept a 1 db loss or walk 100 yards to shift the feed-point proved too great. It was decided that a large back-to-front ratio is of little use anyway, because its holds over such a small angle that the chance of an interfering signal being in that direction is just about nil. Eventually, a parasitic reflector was used for both directions with plug and socket connections for beam reversal.

Tests with the smaller beams have been mainly in a North-South direction, i.e. at right angles to the larger ones, but for a short time one of the latter was replaced by the beam shown in fig. 5. Results were comparable except for a drop of about half an S-point on 14 mc. It had been hoped that the extra effective height would make up for the theoretical drop of 1 or 2 db in gain, but this just didn't work out.

The beam of fig. 5 was first tried out using triangular loops, the idea being to mount it on spreaders between two trees. During adjustments at ground level a number of phone contacts were made including ZS on 21 mc (QSA5 S7) and CN8 on 14 mc. After adjusting the stubs the loops were altered to a square shape with the diagonal vertical. The

[1]Moxon, L. A., "Two Element Driven Arrays," *QST*, July, 1952, page 28.

effect of this on the adjustments, and on the radiation resistance, was very small.

With a fig. 3 beam and a fig. 4 beam mounted at right angles on the same tree some very serious interaction was found at 14 mc, but was removed by placing shorting bars on the unused feeders some 3 or 4′ up from the normal position. The same trouble was found on replacing the fig. 4 by the fig. 5 beam, but on this the position for the shorting bars was much more critical and exactly $\lambda/2$ at 14 mc from the antenna end of the feeder. The same position was satisfactory for all bands, the interaction on 21 and 28 mc being in any case small.

The most recent development has been the conversion of one of the original 14/21 mc beams to a three-band beam in accordance with fig. 7, and the mounting of another similar beam at right angles to it on the same tree. These modifications have had no perceptible effect on the 14/21 mc performance, subject to de-tuning of whichever beam is not in use. Without this precaution, interaction was so bad at 14 mc that the reflector appeared completely dead, having no measurable current and no effect on field strength readings! Checks on 28 mc have included good reports from VK, VQ and ZS and confirm that the beam is operating in the intended mode, although the gain from the reflector is rather poor, being in the region of 3 db only. This is not surprising in view of gale damage which has caused uneven and excessive spacing.

Other Experiments

As is well known, a Quad can be mounted with either a diagonal vertical or the sides vertical, results being identical for the same mean height. This does not necessarily apply to multiband operation and rough calculations indicated that a 14 mc Quad might be about 1 db worse at 21 mc with the sides vertical. This arrangement has been tried and gave good results, but it was not possible either to prove or disprove the suspected loss.

From the fact that a square loop can be distorted into a triangular shape without upsetting it, one might argue, why stop at a triangle? How about squashing it completely flat? It then turns into a folded dipole which is also reputed to be a single-band antenna and like the quad, can also be used as a two or three band antenna. A 14 mc folded dipole was tried on 21 mc and found to work equally well, the v.s.w.r. in a 600-ohm feeder being rougly 3 on both bands, although it was more difficult to support and down slightly in gain compared with a loop. A 28 mc folded dipole, tuned and matched with a stub at 21 mc and only 24′ high, produced a report of Q5 S8 from VS1.

A brief trial was made of a single loop at 7 mc. Although c.w. DX was worked, results were poor and the loop was later found to have excessive resistance. This would, of course, have been much more harmful at the lower frequency.

Recommendations

The resonant-feeder method can be applied to two or three-band quads having between 45 and 70′ of wire in each loop, the efficiency of the larger loops at 28 mc being greatly increased by adding a stub or other form of open circuit at the top to turn them into a bi-square, as discussed above. This is a good scheme for anyone who wants to try out the idea with a minimum of trouble, or who doubts his ability to tackle the more complex multiband matching devices.

The small three band beam (fig. 5) is advised only for use when space or pole-height is restricted, and may prove tricky for the novice. The beam of fig. 7 is comparatively simple, and adjustment is less critical on all bands. With either of these beams two can be mounted at right angles on the same pole or tree, one of them two or three feet below the other, and used to give all round coverage by beam-switching. An obvious improvement not yet tried out is to connect the two beams in parallel for the 45° directions to prevent the performance drop which would otherwise occur. Elements of either of these types can be assembled to form multi-element arrays in any of the usual ways. Another obvious but untried improvement is to mount a "28 mc only" reflector element midway between the two triband elements; this gets over the difficulty that the minimum acceptable spacing for 14 mc is a little wide for 28 mc and may simplify beam reversal since the element not being driven no longer has to turn into a reflector on all three bands.

Finally, one of the main objects of this article is to stimulate further experiments from which it is hoped that new and better designs will emerge. While on the subject of progress, a few words of warning may be in order. Accurate measurement of antenna performance is difficult and even a bad beam may work well in a good location. Some standard of comparison is necessary such as another antenna, at the same height if possible, or another station willing to take part in three-way QSO's and act as a yardstick, but findings should anyway be checked against theoretical expectations and regarded with suspicion if they do not fit. "Theory" does not mean pages of mathematical formulae, just a few simple rules and common sense, as I have tried to show in another article, "Evaluating Aerial Performance," *Wireless World*, February and March 1958 which provides most of the theoretical background for the Quad experiments described above[2]. The author's gain figure (6.5 db for the Quad is less than is usually quoted, but is supported by his own and other measurements, *e.g.* as reported by G3HRH/G3GOZ in the *R.S.G.B. Bulletin* for April 1959. ■

[2] See also, p. 50, *CQ*, this issue—*Ed.*).