Beam swing by phase-changing in a microwave array

Watson, W. H.; Guptill, E. W.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/21273990
PRA; no. PRA-87, 1943-08

[redacted]

SECRET

PRA-87

COPY NO. 18

NATIONAL RESEARCH COUNCIL OF CANADA

RADIO BRANCH

BEAM SWING BY PHASE-CHANGING IN A MICROWAVE ARRAY

OTTAWA

AUGUST, 1943

NATIONAL RESEARCH COUNCIL OF CANADA
RADIO BRANCH

S E C R E T — PRA-87

BEAM SWING BY PHASE-CHANGING IN A MICROWAVE ARRAY

This report presents proposals for the design of a microwave array the beam for which can be traversed at a rate suitable for a number of practical applications.

The phase-changer, on which the method proposed depends, has been described in our second report on Resonant Slots in Wave Guides. The feature which commends this phase-changer is that it may be incorporated in the wave-guide feed of the array itself, for it occupies no more length of array than an individual radiator. Each of the bays of which the array is composed comprises a suitable number of radiating slots cut in the main feeder guide, to be determined by the necessary conditions which are well known in the theory of antennas.

Since the phase-changer will produce the desired phase-shift according to a simple law of plunger displacement only when it works into a load matched to the guide, some provision must be made to allow for this. At the present time three procedures are known to us by which this may be effected:

1. The individual radiators may be slots inclined to the axis of the guide, so that each behaves as a π-section reflecting no energy (see Figure 1). With this arrangement, it will not be possible to satisfy simultaneously arbitrarily imposed restrictions on the gabling along the array, spacing of the elements and on the amount of radiation of unwanted polarisation. For, to secure the first, the individual bays will comprise radiating slots tilted at different angles with the axis and therefore radiating with different resultant polarisation and phase. Nevertheless, with centre feed to the long array, it may be possible to secure a simple, practical compromise in the following way. Imagine that all the slots are identically disposed along the guide so that each abstracts the same fraction of the feeder-guide energy passing it, this arrangement will lead to a 'natural gabling' while at the same time preserving the polarisation. Provided that the figure of merit of the array is not insisted on unduly, this should lead to good beam width without unreasonable misuse of the length of the array.

2. In order to allow effect to be given to a chosen gabling distribution along the array, one may transform the impedance presented to each phase-changer so as to produce the necessary matching. This proposal is somewhat inelegant in that it uses up part of the array length to accommodate the transformers. The principle can be made effective however by modification of the phase-changer, described in the next paragraph.

3. It will be recalled that the phase-changer is effectively a π-section in the transmission line equivalent to H wave propagation in the guide. This section is achieved by cutting on the broad face of the guide a series (transverse) slot, coupling series-series the feeder guide to a parallel auxiliary guide (A), the length of which can be varied by means of a plunger at one end, the other end being closed $\lambda_g/2$ from the slot. As the plunger is moved, the series reactance presented to the feeder guide is varied. Opposite the series slot is a shunt (longitudinal) slot cut in the narrow side of the feeder guide. This slot couples shunt-shunt the feeder to another parallel auxiliary guide (B) closed at one end $\lambda_g/4$ from the slot centre and with a plunger at the other. In consequence, a shunt reactance is coupled to the feeder. In a matched guide, provided that these reactances are conjugate, the pair of slots acts as a non-reflecting phase-changing network, the phase-change being determined by the position of the plungers which, once adjusted, can be clamped and moved as a single unit to secure different phases under the condition of conjugacy mentioned.

It is shown in the mathematical appendix to this report that if the series reactance is increased in the ratio m:1 and the shunt decreased in the ratio 1:m the resulting network is equivalent to a π-section preceded by the step-up transformer (1:m) and followed by the step-down transformer (m:1). To secure the required transformation of the series and shunt reactances of the phase-changer all that is necessary is to change the narrow dimension of the auxiliary guides A and B. The two plungers will then still move in unison to produce phase-change, and impedance transformation can be achieved without any loss of space on the array.

We believe that the arrangement just described can be simplified to a single inclined slot cut in the feeder guide and coupling it to a parallel guide closed at one end $\lambda_g/2$ from the slot centre and the other by a plunger. The coupling from the feeder to the auxiliary guide will be π-series and, if the slot is cut with the proper dimensions, a single variable plunger in the auxiliary guide will control the phase of the wave passing the slot in the feeder guide. Transformation will be secured by choosing the narrow dimension of the auxiliary guide.

It is obvious that procedure (1) involves much loss designing than procedure (3). On the other hand (3) leads to freedom in gabling which (1) does not permit. Further in (3) standing waves can be permitted in the bays themselves and this feature is desirable from the point of view that the phase distribution along the array is the most important single factor determining the quality of the pattern.

Notes added 10th August 1943

1. The arrangement of guide B (§ 3 above) has shown us that the laws of guide coupling are not as simple as we first supposed on the basis of experiments with slots to which both guides showed the same aspect. Shunt-shunt coupling in which the coupling slot occupies different positions in the cross-section of the coupled guides involves that when impedance is transferred from one guide to the other, it is multiplied by a constant factor dependent on the position of the slot in both guides. With the arrangement shown in Figure 3 it should be possible to correct for this by altering the narrow dimension in the cross-section of guide B, so as to achieve the same motion for both plungers.

2. Initial power tests have been made. These required us to cover the edges of the slots to avoid breakdown when the stubs become resonant. With resonant slots 3/8" wide covered by 1/4" diameter silver tube slotted to slip over the slot edges (long sides only), the complete phase cycle was possible at 30 KW, and at 150 KW phase change up to $\pm 60^{\circ}$ was achieved without breakdown.

Finally, it is hardly necessary to point out that the set of phase-changers would be mechanically coupled so that all the plungers once adjusted would be moved together from one end of the array (see Figure 2). With either of the arrangements proposed here, one escapes the mechanical enormity of moving transversely a long plunger forming the side of the feeder guide, for the plungers to be moved in the proposed system are light and are to be moved parallel to the length of the guide. At the same time a decent regard is paid to the electrical principles which govern the feeding of arrays.

Possibility of High-Speed Electrically-Controlled Phase Change

If a tube such as thyratron REL 20 were connected to an antenna in the guides A or B it would be possible to vary the reactance at the coupling slot without moving a plunger. This tube however could not handle the u.h.f. power from a magnetron but it could handle the output of a klystron. The speed in the beam swing would then be limited only by the speed at which the plate current in the tube can be varied.

W. H. Watson

July 1943
McGill University

E. W. Guptill

APPENDIX

In the matrix notation which has been employed in several reports from this laboratory starting with N.R.C. PRA-71

let $P = E + \alpha U_1$ and $S = E + \beta U_2$

The matrix representing a step-down transformer (right - left) of ratio m is

$$T = mU_2U_1 + \frac{1}{m} U_1U_2$$

$$\text{and } T^{-1} = mU_1U_2 + \frac{1}{m} U_2U_1$$

Let

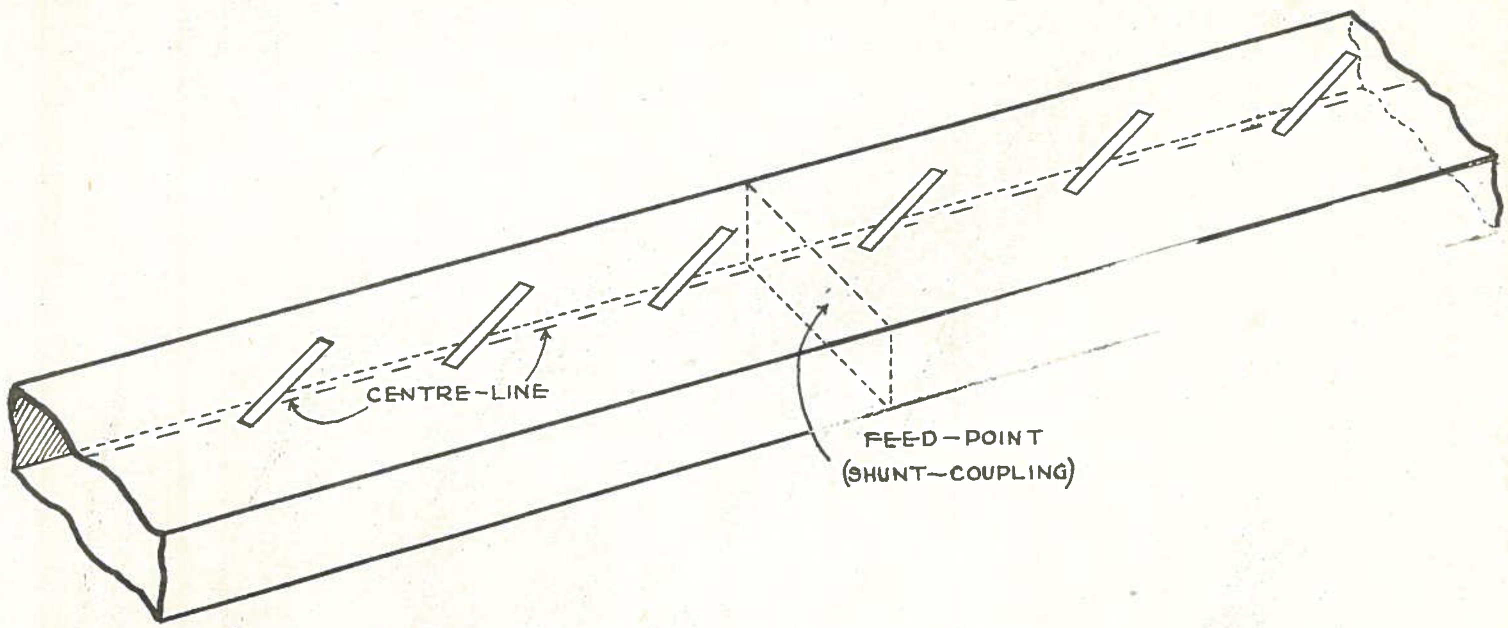
$$S' = T^{-1} ST = E + \frac{\beta}{m^2} U_2$$

$$P' = T^{-1} PT = E + \alpha m^2 U_1$$

then

$$P' S' P' = T^{-1} PSPT$$

This proves the result, for αm^2 is the shunt admittance presented by the shunt slot and the series slot presents the series reactance of the equivalent T-section which likewise will be m^2 times its untransformed value.



Array of Non-Reflecting Tilted Slots

Figure 1

SECRET

SECTION OF LINEAR ARRAY WITH PHASE CHANGERS

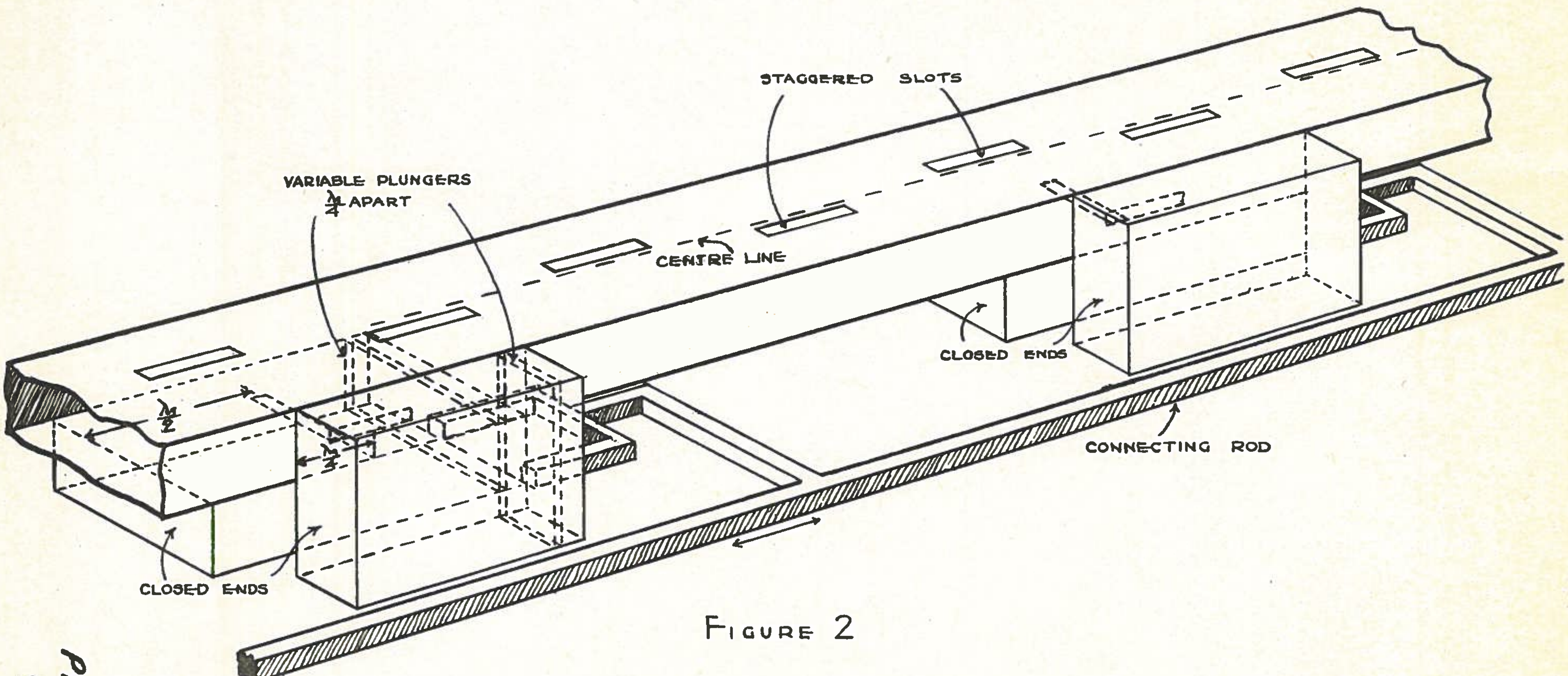


FIGURE 2

PRA-87
448

SECRET