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A 32. 7 MC/S DIRECTIONAL COUPLER

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ABSTRACT

A reflectometer or directional coupler for use in a radar-monitoring system is described. The report contains the theory of operation, experimental results, measurement techniques, and modifications which were required to obtain couplings of 60 db and 30 db at 32.7 mc/s while maintaining a directivity of at least 15 db.

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FIGURES

A 32.7 MC/S DIRECTIONAL COUPLER

- R. Wlochowicz -

INTRODUCTION

The design of a 32.7-mc/s 20-kw pulse radar, for detection and recording of ionized trails produced by meteors, called for continuous monitoring of certain operating conditions [1]. Directional couplers were required with the following specifications:

Coupling	30 db and 60 db
Directivity	15 db, or more
Frequency range	32 mc/s - 34 mc/s
Peak voltage	1400 volts

The couplers were to operate in 50-ohm coaxial antenna feeders, and were to be sturdy and weatherproof.

Since units conforming to these specifications were apparently not available commercially, a design [2,3] based on an NRL report [4], was modified to obtain the desired properties.

THEORY OF OPERATION

The operation of the coupler depends on the fundamental phenomena of inductive coupling, capacitive coupling, and current and voltage wave reflections on a transmission line. Physically, at 32.7 mc/s, the coupler is small relative to a wavelength, and it can, therefore, be represented schematically by the lumped-parameter circuit of Fig. 1, where

C_1 = capacitance between inner and coupling conductors (a function of separation between the conductors and their diameters)
M = mutual inductance between inner and coupling conductors (a function of the separation and the dimensions of the coupling conductor)
L = inductance in coupling conductor
R_1 = principal balancing resistor
R_2 = effective detector resistance
C_2 = capacitance between outer and coupling conductors (assumed negligible)
Z_0 = characteristic impedance of feeder
i = r-f current through the detector

E = feeder voltage
I = feeder current
Load is matched to the coaxial feeder.

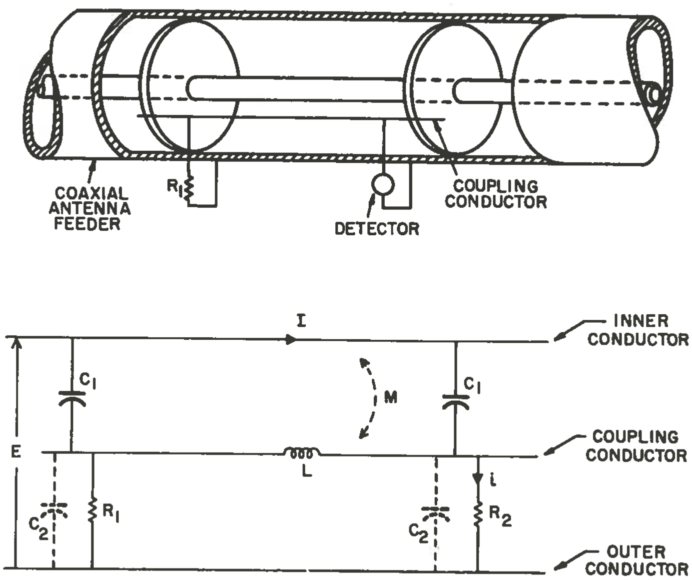

FIG. 1 SIMPLIFIED SKETCH AND EQUIVALENT CIRCUIT OF DIRECTIONAL COUPLER

In Fig. 2, branch currents are indicated with particular emphasis on the two current components I_1 and I_2, functions of line current and voltage, respectively. By suitably choosing the parameters, i, the algebraic sum of I_1 and I_2 very nearly, and hence the voltage across the detector, will be zero for the particular direction of I. Reflected energy will be detected since the phase reversal between the incident and reflected current waves will change the sign of I_1.

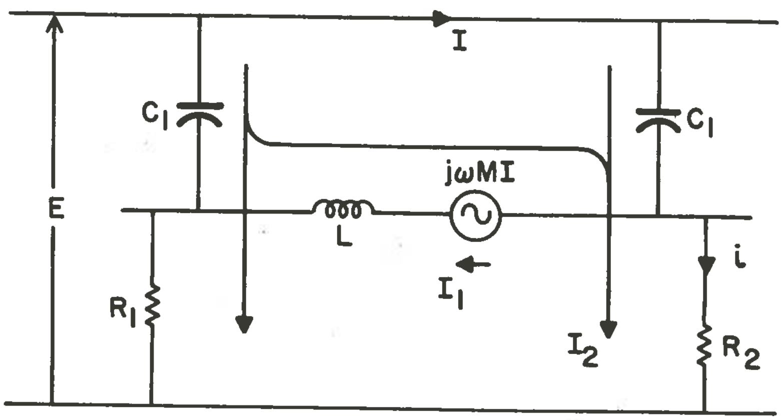

FIG. 2 INDUCED CURRENTS FOR A PARTICULAR OPERATING CONDITION

A mathematical analysis [4] of the coupler yields the following useful equations:

$$M = 2R_1 C_1 Z_o = \frac{LZ_o}{R_1} \qquad \text{(from balance condition } i = o) \qquad (1)$$

$$\frac{|i|}{|I|} = \frac{2\omega L Z_o}{(R_1 + R_2) R_1} \qquad (\text{for } i \neq o) \qquad (2)$$

$$\text{Coupling (db)} = 20 \log \frac{2\omega M}{R_1 + R_2} \qquad (\text{for } R_2 = Z_o) \qquad (3)$$

EXPERIMENTAL WORK

The internal structure of the coupler consisted of a cylindrical conductor between two grounded parallel plates with two coupling wires, diametrically opposite and equidistant from the plates, for the measurement of direct and reflected waves (Figs. 4 and 5). The experimental coupler had provision for variation of plate width; length, diameter, and distance of coupling wire from inner conductor; and value of balancing resistor. The resistor and the conductor separation behaved as coarse and fine null adjustments, respectively, while coupling appeared to be governed, in order of importance, by conductor separation, coupling wire diameter, and plate width.

Characteristic Impedance

The characteristic impedance of a conductor between parallel plates is:

$$Z_o = \frac{138}{\epsilon^{\frac{1}{2}}} \log 10 \frac{4h}{d}, \quad \text{for } d/h < 0.75,$$

where ϵ = permittivity of free space
h = separation between plates
d = diameter of inner conductor.

For $d/h = 0.5$, the impedance is approximately 50 ohms. To allow sufficient insulation to withstand a peak r-f potential of 1400 volts, 0.375-inch-diameter brass rod was selected as inner conductor.

The value of the characteristic impedance was verified by inserting the coupler into a bridge balanced on a 50-ohm termination, and noting the changes required to restore a null. Observed changes were less than ±2 ohms reactance, and it was concluded that, for practical purposes, the coupler matched the line.

Design Data

The design data, obtained by trial and error, are given in the Appendix. The components, and partially and fully assembled couplers, are shown in Figs. 4 and 5. The plates, center and coupling conductors, and cover spacers were heavily silver plated; the 4-inch brass-tubing casing and the $\frac{1}{4}$-inch brass covers were cadmium plated. Watertight construction was achieved by utilizing Vellumoid gaskets beneath the covers, and lead gaskets (chosen for electrical conductivity and malleability) beneath the connectors. As further precautions, assembling screws were dipped in Seal-All and casing ends were sprayed with clear plastic after assembly. Note in Fig. 5, the lead washer, the heavy insulation on the HN type connector, the two $\frac{1}{2}$-watt resistors comprising R_1, the BNC connector for the external detector R_2, and the long shielded conductor.

MEASURING PROCEDURE AND RESULTS

The requirements of the measuring apparatus were that it simulate the 50-ohm system, be capable of detecting power level changes of the order of 60 db, and retain a sensitivity of ± 1 db at these high attenuations. The arrangement in Fig. 3 proved satisfactory. The 32.7-mc/s source was modulated at 1000 cps, and the attenuating pads were inserted to present to the coupler its characteristic impedance.

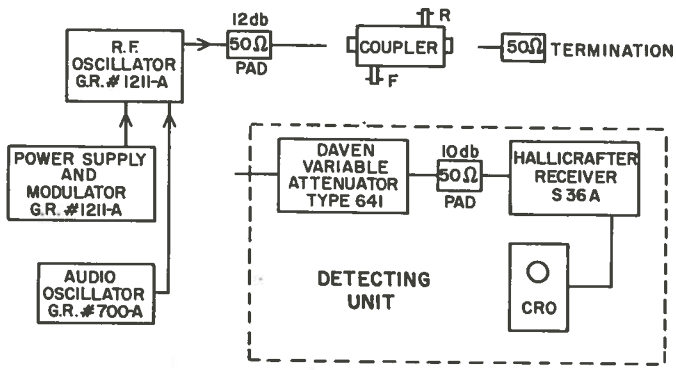

FIG. 3 BLOCK DIAGRAM OF APPARATUS FOR MEASURING COUPLING AND DIRECTIVITY

Measurement of Coupling

With the coupler terminated in 50 ohms, the detecting unit connected to the forward coupling loop terminal, F (Fig. 3), and the variable attenuator set at zero, the receiver and oscilloscope gains were adjusted to obtain a pattern of convenient amplitude. The termination was replaced by the detecting unit, and attenuation was added until the previous pattern was reproduced. The added attenuation, in decibels, is then the coupling of the loop.

Measurement of Directivity

With the coupler terminated and fed in the forward direction, and the detecting unit on the reverse coupling loop terminal, R, the gains were adjusted as above. Without removing the detecting unit, the power flow through the coupler was reversed, and attenuation was added to reproduce the initial pattern. The inserted attenuation represents the directivity very nearly.

In adjusting the gains, a check was made to determine that leakage was negligible, and that the amplifiers were not saturating, by adding 1 db at 60 db and noting that the pattern amplitude definitely decreased. Table I summarizes the results of the initial measurements on the units.

TABLE I

SUMMARY OF COUPLER PROPERTIES

Coupler	Nominal Coupling (db)	Nominal Directivity (db)	Actual Coupling		Actual Directivity	
			Forward (db)	Reverse (db)	Forward (db)	Reverse (db)
1	30	20	27	30	30	28
2	30	20	27	30	25	29
3	60	20	60	59	20	16

CONCLUSION

It was observed experimentally that the directivity was greater at the higher coupling impedance; however, the opposite proved true in the final product — the discrepancy being tentatively attributed to the relative proximity of the coupler casing and the long shielded lead of the reverse loop output (C_2 being no longer negligible). At the time of writing this report, the couplers have had two years of service, and, except for a possible 1-db decrease in coupling on one of the 30-db units, they have provided trouble-free operation throughout that period.

APPENDIX

DESIGN DATA

30-db Coupler

Center Conductor: 0.375 ± 0.005" dia. × 6"
Coupling Conductor Diameter: 0.064"
Coupling Conductor Length (between taps): 4.25 ± 0.02"
Separation between Conductors (center to center): 0.295 ± 0.010
Plates: 0.250 ± 0.010" × 6.75"
Plate Separation: 0.750 ± 0.05"
R_1 : 125 ± 5 ohms

60-db Coupler

Center Conductor: 0.375 ± 0.005" dia. × 6"
Coupling Conductor Diameter: 0.064"
Coupling Conductor Length: 4.75 ± 0.01"
Separation between Conductors: 1.31 ± 0.02"
Plates: 3.5" × 6"
Plate Separation: 0.750 ± 0.05"
R_1 : 280 ± 5 ohms

ACKNOWLEDGMENT

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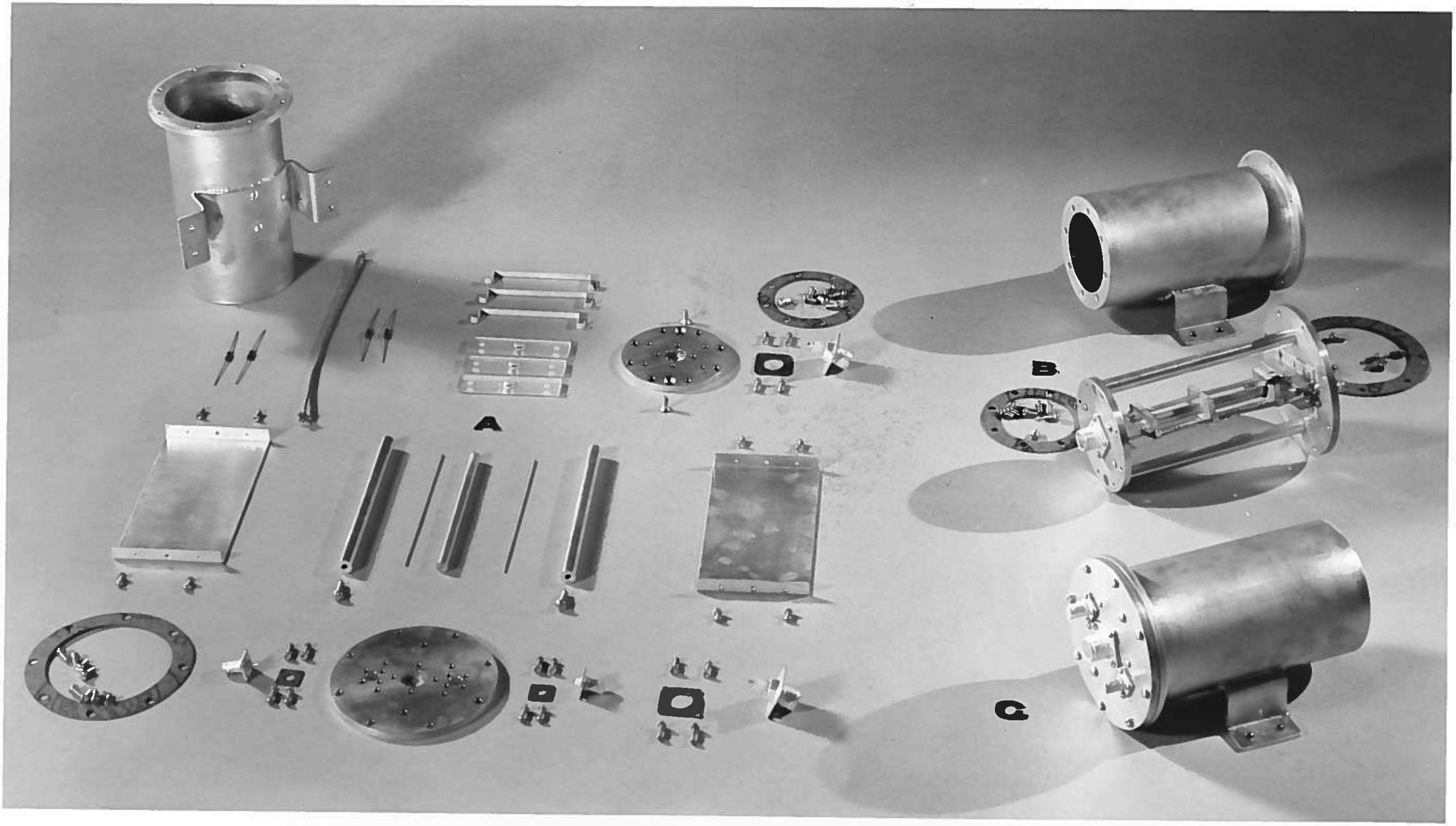

FIG. 4 — A: COMPONENTS OF 60 db COUPLER
B: PARTIALLY ASSEMBLED 30 db COUPLER
C: ASSEMBLED COUPLER

FIG. 5 CLOSE-UP OF 30 db COUPLER