THE General Radio EXPERIMENTER

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

SEARCH RECEIVERS FOR RADAR COUNTERMEASURES

Also IN THIS ISSUE

● **AN ASPECT** of the recent war that has received more and more widespread recognition, as hitherto classified information on equipment and techniques has been released, is the tremendously important role that was assumed by electronic devices.

The development of radar has been described in terms of equipment design and operating characteristics in many papers[1], and will, no doubt, be the subject of many more. Its direct relation to military operations, however, is a parallel story of equal fascination.

[1]For instance: Edwin F. Schneider, "Radar," Proc. IRE., Vol. 34, No. 8, pp. 528–578, August, 1946. Lloyd J. Berkner, "Naval Airborne Radar," Proc. IRE., Vol. 34, No. 9, pp. 671–706, September, 1946.

Figure 1. Panel view of the TYPE P-540 Receiver.

The importance of radar and of electronic aids to navigation was realized very early in the war when the Battle of Britain first demonstrated, on a grand scale, the importance of aerial warfare. The RAF's gallant few, to whom so many owed so much, could never have accomplished their seemingly hopeless task of turning back the Luftwaffe had they not been alerted and controlled by an effective radar chain.

This new weapon, which helped to defeat the enemy at a critical time, soon showed, however, that it was a two-edged sword. There was, unfortunately, no monopoly of any one country on invention of electronic devices, and the Luftwaffe, repulsed in daylight warfare, soon turned to night attacks on England with the aid of electronic navigational systems that provided unpleasantly accurate blind bombing information. It became apparent very quickly indeed that a weapon of defense in the hands of the British had become a weapon of offense in the hands of the Germans and that a further defense in the form of electronic countermeasures was vitally needed. The battle lines of a war in the laboratories of the two countries therefore began to form behind the actual battle lines as first one side and then the other gained temporary supremacy in equipment and tactics.

As the imminence of involvement of the United States in the war became more and more apparent, great interest in this technical struggle led to a consideration of our own equipment needs if we were to become participants. It was the good fortune of the General Radio Company to be able to contribute one of the first developments of equipment for this new field of military endeavor.[2]

Fundamental factors in the planning of countermeasures equipment design are the immediacy of the problems and the diversity of requirements. In contrast to radar development, in which the designer poses and solves his own problem, in countermeasures development the enemy poses the problem and the designer must solve it on terms not of his own choosing. It was a consideration of the consequent need for accurate, up-to-the-minute information on enemy equipment and tactics that led the National Defense Research Committee to place its first countermeasures contract for a search receiver.

In order to establish an effective countermeasures program, it is necessary to determine, first, what equipment the enemy may have. Much information can be gathered through conventional intelligence channels, principally interrogations of prisoners, but this information is liable to be incomplete and, quite often, inaccurate. A supplementary source of information of great value is direct information obtained by seeking out enemy stations with mobile receivers that will tune to the frequencies in use and respond with sufficient faithfulness to the modulation to make possible analysis of the nature of the emitted signal. This type of information, which has been called electronic intelligence, is, at radar frequencies, collectible only within roughly optical range of the transmitter, and the equipment is therefore most suitably carried on submarines or in airplanes that can operate in enemy waters or over enemy territory.

The requirements for a search receiver for accumulating information of this kind are readily deduced from this analysis. The receiver should, first, be capable of

[2] "Scientists Against Time," James Phinney Baxter III (Little, Brown and Company), p. 158. Chapter X of this brief official history of the Office of Scientific Research and Development is devoted to a summary of the contributions of the National Defense Research Committee to radar countermeasures.

tuning over the entire frequency spectrum within which the enemy is known to have equipment operating or in prospect. The bandwidth should be great enough to permit oscillographic analysis of modulations of various kinds, particularly short pulses. The equipment should be designed for airborne use. And, most important, the design should be flexible enough to permit rapid modification, particularly in frequency range, when changes in conditions arise.

The General Radio Company TYPE P-540 Receiver, from which many of the search receivers used in the war were derived, was designed to meet these needs. The first butterfly circuits[3] had just been developed and applied in the design of field-strength measuring equipment for the frequency range from 300 to 1000 Mc[4], and the wide tuning range of these units made feasible the design of a superheterodyne receiver having characteristics similar to those of low-frequency receivers. As early as the summer of 1941, when work was begun, it was known that the Germans were using radar frequencies between 120 and 565 Mc. The first design was therefore made to cover this frequency range with ample margins at both ends.

It was found that, with a 30 Mc intermediate frequency, the range from 75 to 1000 Mc required only two bands.

The first of these was covered with a Type 955 acorn triode in a butterfly-circuit local oscillator, tuning from 105 to 300 Mc; the second was covered with a Type 955 triode in a butterfly-circuit local oscillator tuning from 135 to 485 Mc. On the first band, mixing was done at the oscillator fundamental and yielded a tuning range from 75 to 300 Mc; on the second band, mixing was done at the second harmonic of the local oscillator and yielded a tuning range from 300 to 1000 Mc. On both bands, the antenna was tuned by butterfly circuits of appropriate range.

The need for as much flexibility in design as possible was recognized from the outset. Not only was there no guarantee that enemy frequencies outside the tuning range might not suddenly appear, but new developments were occurring at such rapid rate that there seemed good reason to suppose that frequent changes in the receiver itself might be desirable to keep it abreast of requirements. A unit-construction design was therefore chosen in which complete r-f tuning units could be plugged into a chassis that comprised the intermediate-frequency, second-detector, video-amplifier, and power-supply assemblies. Figure 1 shows the general nature of the design that was evolved for mounting in a standard ATR rack.

The basic correctness of this approach is well illustrated by the fact that, except for changes in controls and other minor modifications dictated by operational experience, no changes were made in the general chassis design throughout the war. Many substantial changes were made in tuning units, however, and improved performance obtained from receivers already in the field with newly designed units that could be inserted in place of obsolete ones.

The operating characteristics of the receivers as originally designed are now largely of historical interest and will be mentioned only as they are basic to the particular application and as they led to later improvement. The i-f bandwidth was 2 Mc, and about 90 db of i-f gain was obtained with five double-tuned overcoupled stages. This was sufficient gain to

[3]E. Karplus, "Wide-Range Tuned Circuits and Oscillators for High Frequencies," Proc. IRE, Vol. 33, No. 7, pp. 426–441, July, 1945.

[4]E. Karplus, "Components of UHF Field Meters," *Electronics*, Vol. 19, No. 11, pp. 124–129, November, 1946.

get down into the noise level and to realize as much sensitivity as could be obtained with the r-f circuits. The r-f circuits, themselves, were elementary by modern receiver standards. No r-f amplifier was used, and the antenna and the local-oscillator tuning were separate. This simple design led to very rapid development, and models were submitted that were accepted for production within two months of the time the contract was let. The over-all sensitivity of the receiver was not extremely high, an r-f level of 5 to 15 μv generally being necessary to produce an audible signal; but it should be emphasized that sensitivity is not often important in radar-intercept work since direct signals at a given distance from a transmitter are so much stronger than signals reflected back over a path as long again to the radar receiver itself.

A few words about the subsequent history of the development of search receivers are of interest, particularly as they bring out the coordinated effort of industry. Much has been said about the interchange of information in the aircraft industry during the war. Less highly publicized has been the extent to which the same cooperation developed in the electronic industry.

By the summer of 1941 it was obvious that production facilities at the General Radio Company were going to be fully taken up by the manufacture of measuring equipment and that receiver production should be undertaken by a company better able to handle it. As a consequence, the Philco Corporation took the design and, by the spring of 1942, produced a small quantity of a Navy Bureau of Ships version of the receiver (Navy Model ARC-1). This was followed shortly afterward by a small quantity of an Air Corps version (Model SCR-587).

In the meantime the Radio Research Laboratory had been set up at Harvard University to deal directly with the development of countermeasures equipment. Intensive development work was commenced there in the spring of 1942 on an improved model, which incorporated a single-dial control of antenna tuning and local-oscillator frequency, a motor drive for sweeping any desired frequency band within the frequency range of the tuning units, improved image rejection, and an additional tuning unit to cover the frequency range from 40 to 100 Mc. This work culminated in the RRL Type D100 receiver, which was manufactured with some modifications by the Galvin Manufacturing Company for the Navy as the Type AN/APR-1 and by the Crosley Radio Corporation for the Army Air Forces as the Type AN/APR-4, large-quantity delivery beginning late in 1943.

In conjunction with this work, the General Radio Company also developed a Type P540-P3 tuning unit to cover the

Figure 2. Panel view of the TYPE P-540-P3 Tuning Unit.

frequency range from 1000 to 3000 Mc. This tuning unit, shown in Figure 2, also used butterfly circuits. A scaled-down butterfly circuit was used for antenna tuning over the range from 1000 to 3000 Mc, and a local-oscillator butterfly circuit of more conventional dimensions for generating a fundamental frequency range of 500 to 1100 Mc with a Western Electric Type 703-A triode.

This tuning unit was produced in small quantity but was not so satisfactory as the lower-frequency units because serious difficulties were encountered with anomalous resonances in the antenna-tuning circuit. The Crosley Radio Corporation therefore undertook the development of two new tuning units using a similar local oscillator design but replacing the antenna-tuning butterfly by a tuned coaxial transmission line. The tuning of this line was ganged successfully with the oscillator drive to produce tuning units having single-dial control and frequency ranges from 1000 to 2200 Mc and 2200 to 4000 Mc.

The ultimate receiver secured from so much joint effort, therefore, covered with convenience and flexibility a frequency range from 40 to 4000 Mc, which was ultimately found to encompass all the radar frequencies used operationally by both the Germans and Japanese. It first found service in helping to spot enemy radar installations for the planning of the amphibious assault on Sicily and later found great use in the operations of the 8th Air Force over Germany and the 20th Bombing Command over Japan. Its appearance more recently among the electronic devices used at Bikini seems to indicate that advances in the art have not yet rendered it obsolete.

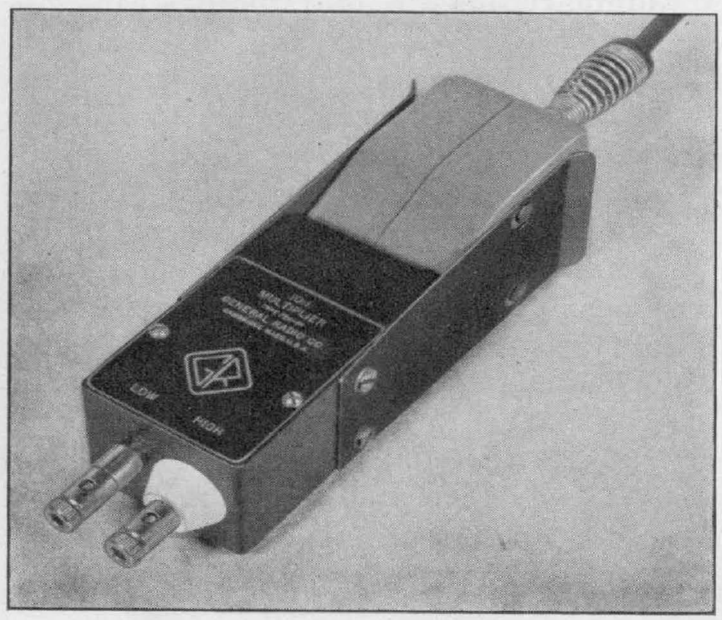
—D. B. Sinclair

IN STOCK—TYPE 726-P1 MULTIPLIERS

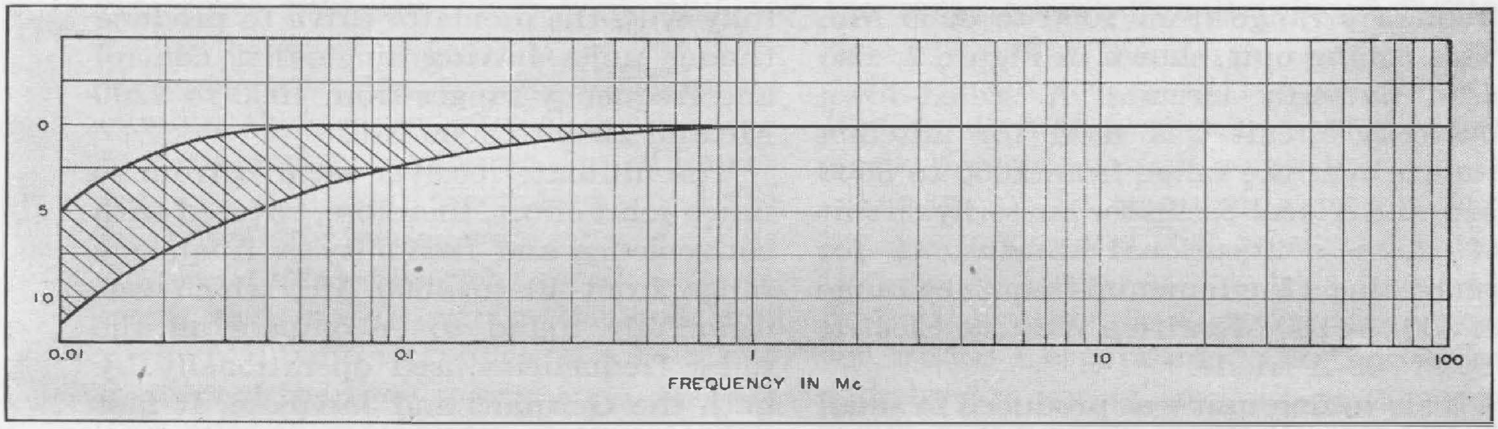
Although the Type 726-A Vacuum-Tube Voltmeter has been superseded by the recently announced Type 1800-A, thousands of the older instruments are still in use in radio and electronic laboratories. The usefulness of these can be greatly increased through the use of the Type 726-P1 Multiplier, which extends the voltage range of the instrument to a maximum of 1500 volts.

The multiplier is a capacitive voltage divider, which provides a 10:1 reduction between the voltage applied to the multiplier and the voltage appearing across the voltmeter terminals. The multiplier fits snugly to the voltmeter probe, adding about three inches to the effective probe length. The flanges which secure the multiplier to the probe also act as an electrostatic shield.

This useful accessory is still available and a quantity has only recently been completed in our factory. Shipment can be made from stock.



View of the TYPE 726-P1 Multiplier attached to the Voltmeter probe.



Frequency characteristic of the multiplier.

SPECIFICATIONS:

Multiplier Ratio: 10 to 1, within $\pm 1\%$.

Input Impedance: From 1 Mc to 100 Mc, the input impedance is effectively that of a 4.5 $\mu\mu$f condenser of less than 0.5% power factor.

Frequency Error: The frequency error is shown in the plot. No appreciable error occurs between 1 Mc and 100 Mc. The multiplier is not recommended for frequencies below 1 Mc.

Net Weight: 12 ounces.

Type		*Code Word*	*Price*
726-P1	Multiplier	ALOUD	$18.00

Add 10% to price listed above.

IMPROVEMENTS IN THE PRECISION WAVEMETER

The tuned-circuit wavemeter, long since displaced for highly precise work by crystal standards, nevertheless remains one of the most useful general-purpose instruments in the radio laboratory. This is particularly true of the Type 724 Precision Wavemeter, which has been for many years an accepted standard in the industry.

For such applications as the preliminary line-up of radio transmitters and the rapid checking of oscillator frequencies, this precision wavemeter fills a definite need in the frequency measurement field. The variable capacitor is a General Radio Type 722, specially designed for the purpose, with plates shaped to give a scale that is linear in frequency. The precision of setting is better than one part in 25,000. The plug-in coil mounting allows the coil to be rotated to obtain different degrees of coupling.

Newly developed crystal rectifiers and newly derived design formulae for inductors have made it possible to improve the performance of the wavemeter considerably. In the latest model, Type 724-B, the vacuum-tube detector has been replaced by a germanium crystal, thus eliminating the need for batteries and considerably simplifying the maintenance problem. Both selectivity and sensitivity are enhanced owing to a 2:1 improvement in the loading effect of the detector on the tuned circuit.

Selectivity and sensitivity are also greatly improved by a complete redesign of the inductors to obtain higher values of the storage factor, Q. All inductors have considerably higher Q's than formerly, with the greatest gain obtained on the 16 to 50 kilocycle coil, where the improvement is of the order of 6:1. As a result, this coil is now calibrated to the same accuracy as the others, namely, 0.25%.

SPECIFICATIONS

Frequency Range: 16 kilocycles to 50 megacycles.

Accuracy: ±0.25%.

Calibration: The calibration is supplied in the form of a table of calibrated points. Linear interpolation between these points is used to obtain settings for other frequencies.

Condenser: Precision worm-drive type similar to TYPE 722. The condenser setting is indicated on the dial and drum and is controlled from the front of the panel. There are 7500 divisions for the entire 270-degree angular rotation of the condenser rotor. The precision of setting is better than one part in 25,000. The plates are shaped to give an approximately linear variation in frequency with scale setting.

Inductors: Coils are wound on isolantite forms and enclosed in molded phenolic cases. Seven coils are used to cover a frequency range between 16 kilocycles and 50 megacycles.

Resonance Indicator: A germanium crystal rectifier is used with a microammeter to indicate resonance. The indicator is coupled to the tuned circuit through a capacitive voltage divider.

Crystal: TYPE 1N34 germanium crystal rectifier is used.

Mounting: A wooden storage case, fitted with lock and carrying handle, is furnished. This has compartments for holding the condenser, inductors, and calibration charts.

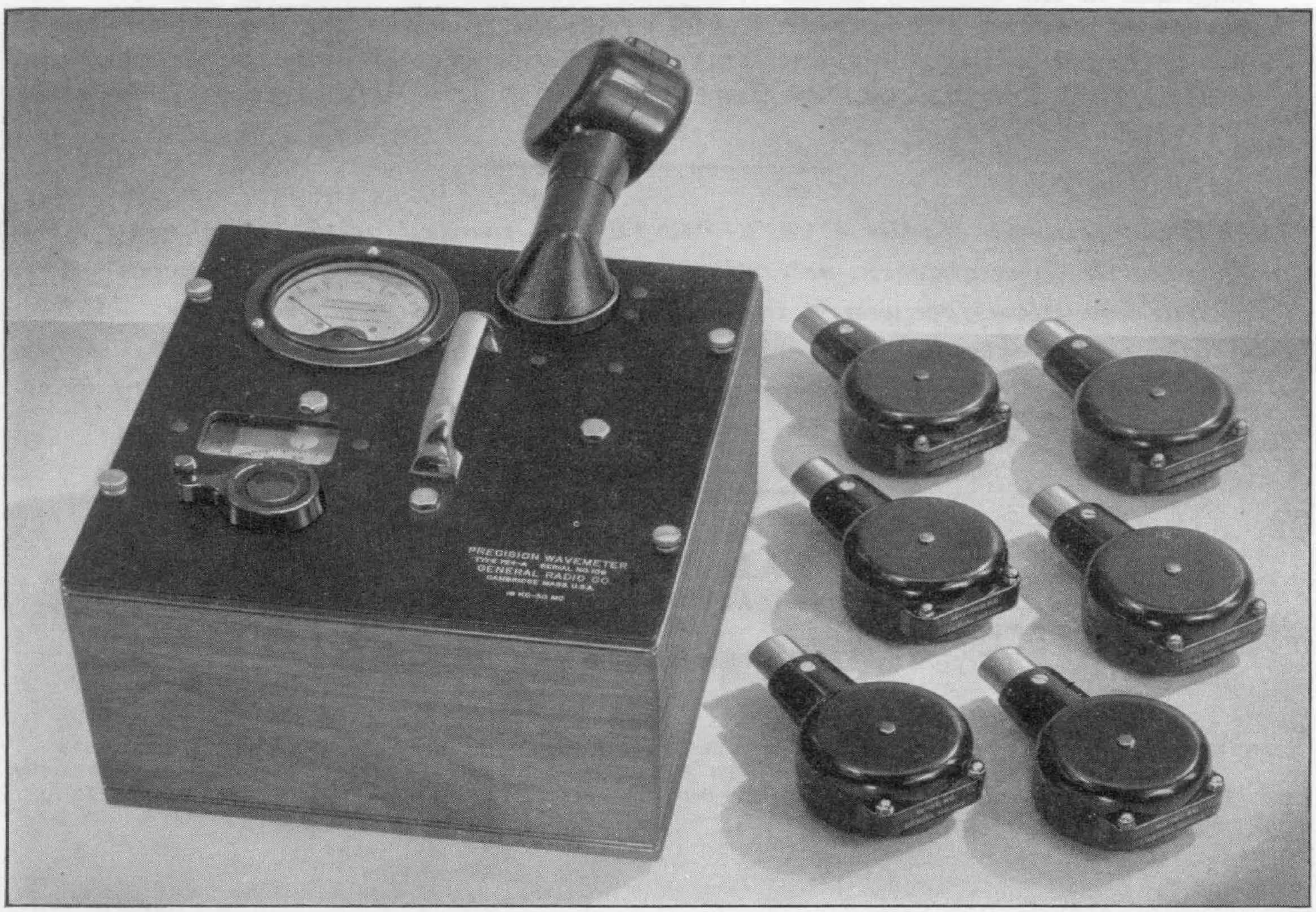
Dimensions: Carrying case, 17⅞ x 13 x 12½ inches, over-all.

Net Weight: With carrying case, 35¼ pounds; without carrying case, 20 pounds.

Type		*Code Word*	*Price*
724-B	**Precision Wavemeter**	WOMAN	**$230.00**

Add 10% to price listed above.

The TYPE 724-B Precision Wavemeter is identical in appearance with the TYPE 724-A shown here.



MISCELLANY

TWENTY YEARS AGO in the EXPERIMENTER, March, 1927 — The feature article is entitled, "A Discussion of Condenser Plate Shapes," by C. T. Burke. Three types of plates are discussed, giving linear variations in capacitance, wavelength, and frequency, respectively, and their advantages for particular uses are pointed out. Also mentioned is the fact that the straight-line-wavelength plate was first used commercially by the General Radio Company in the TYPE 124 Wavemeter, introduced in 1916.

A second article deals with the design plate supply units to achieve good regulation, and a third announces the TYPE 415 Laboratory Amplifier for use with bridges and oscillographs.

Another article, entitled "How Good is GOOD?" deals with the quality of reproduction obtainable from audio-frequency amplifiers and reproducers. It is pointed out that there is little advantage in designing amplifiers to cover a wider frequency range than can be reproduced by existing speakers.

A handy copper wire table is also published which gives the mechanical and electrical properties of wire for B and S gauges between 1 and 40.

Donald B. Sinclair, author of the article on search receivers, is Assistant Chief Engineer of the General Radio Company, where the TYPE P-540 Receiver was developed under his direction. As head of the Receiver Group of the Radio Research Laboratory, Harvard University, he supervised both the development of the D100 Receiver and its first field tests in the Mediterranean Theater of Operations.

THE General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in communication-frequency measurement and control problems. When sending requests for subscriptions and address-change notices, please supply the following information: name, company address, type of business company is engaged in, and title or position of individual.

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