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SUPER REGENERATIVE PULSE RADAR

BY

F. H. SHEPARD, Jr.

also

THE WRITING OF RADIO HISTORY--A PROJECT FOR R. C. A.

BY

I. S. COGGESHALL

THE RADIO CLUB OF AMERICA, INC.

11 West 42nd Street ★ ★ ★ New York City

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The Radio Club of America

ORGANIZED FOR INTERCHANGE OF KNOWLEDGE OF THE RADIO ART, THE PROMOTION OF GOOD FELLOWSHIP AMONG THE MEMBERS THEREOF, AND THE ADVANCEMENT OF PUBLIC INTEREST IN RADIO.

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PROCEEDINGS OF THE RADIO CLUB OF AMERICA

Volume 37 Winter 1960-61 No. 1

SUPER REGENERATIVE PULSE RADAR*

by

F. H. Shepard, Jr.**

Super-regeneration was invented and developed to become a valuable tool by our fellow Radio Club member, the father of radio as we know it today, the late Edwin Howard Armstrong. All who have worked with this concept have been awed by its simplicity, stability and exceptional sensitivity. When using super-regeneration, some of us have been frustrated by our inability to obtain signal-to-noise ratios in communications equipment equal to those that can be obtained with complex high gain amplifiers operating by other principles.

Since many of us have not analyzed physically and basically how super-regeneration operates, I would like to offer the following considerations:-

(1) Assume a parallel tuned circuit with an A.C. voltage source connected across it through a switch, the circuit being tuned to the same frequency as the A.C. source.

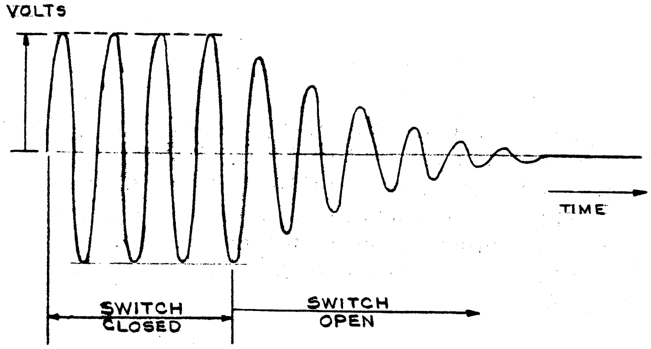


FIG 1

(2) Now if we open the switch at some particular instant, we observe the voltage across the tank circuit will decay in amplitude, not instantaneously on the opening of the switch, but at some rate, determined by the losses in the tuned circuit. Figure No. 1 shows an oscillogram looking across such a tuned circuit. In Figure No. 2 the amplitude of the A.C. voltage is plotted logarithmically against a linear time scale. The slope is linear on this scale because the energy stored in the tuned circuit is dissipated at an exponential rate just as the D.C. energy stored in a condenser is discharged by a shunt resistor, i.e., the power dissipated in the resistance in either case is proportional to the square of the voltage.

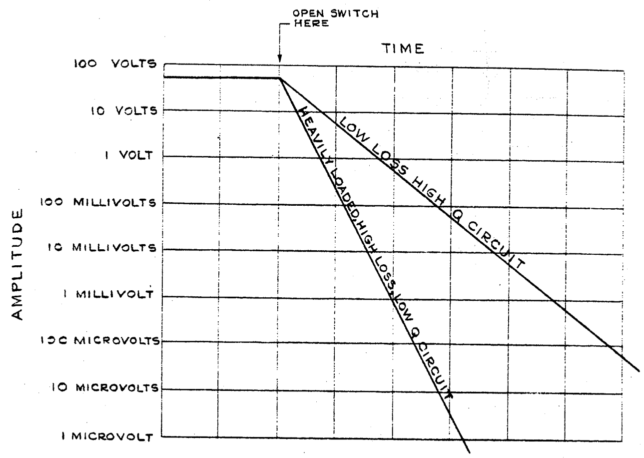


FIG 2

(3) A hypothetical tuned circuit of infinite Q, zero losses, would ring at some voltage amplitude that would be constant as long as the losses remain zero.

(4) If we connect a resistance across the circuit at some instant in time, the curves in Figures No. 1 and No. 2 would obtain, the lower curve in Figure No. 2 being for a lower valued shunt resistor.

(5) As is well known, the circuit having the higher "Q" (with the lower losses) and the higher effective resistance will tune more sharply, i.e., will have the narrower bandwidth and higher selectivity. Conversely, the circuit with the lower shunt resistance will have the broader bandwidth and less selectivity.

(6) Let us assume that we have a tuned circuit with a small A.C. voltage source connected across it. Upon disconnecting the A.C. voltage source and connecting a resistor across the tank circuit at some instant in time the conditions in Figure No. 3 result. If the added resistor has a negative value lower than the effective positive resistance of the circuit the resultant resistance of the circuit will be negative and the amplitude of the A.C. voltage will increase at an exponential rate. If the shunt resistance is negative and equal in value to the circuit resistance, the A.C. voltage across the tank will remain constant. If the shunt resistance is negative but higher than the positive resistance, the voltage will decay. The rate of increase or decrease will be an

* Patents Applied for.

** Consulting Engineer;
President, Shepard Laboratories, Inc.

inverse function of the effective resistance value of the parallel combination. In the extreme case, when the shunt resistance varies infinitesimally minus or plus with respect to zero, the rate of increase goes from plus infinity to minus infinity.

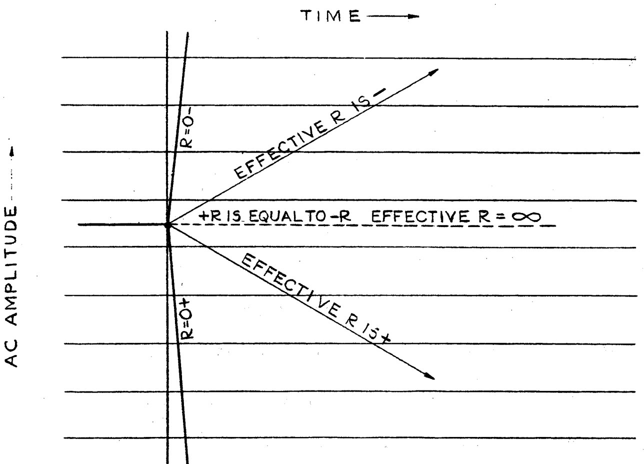


FIG 3

Figure No. 4 shows how the effective circuit-loading resistance varies as the shunt is varied through zero in both directions. The curve in Figure No. 5 illustrates how the selectivity varies as the shunt resistor is varied. The curve in Figure No. 6 shows how the bandwidth of the tuned circuit varies with the external shunt resistor. This curve is effectively the reciprocal of selectivity.

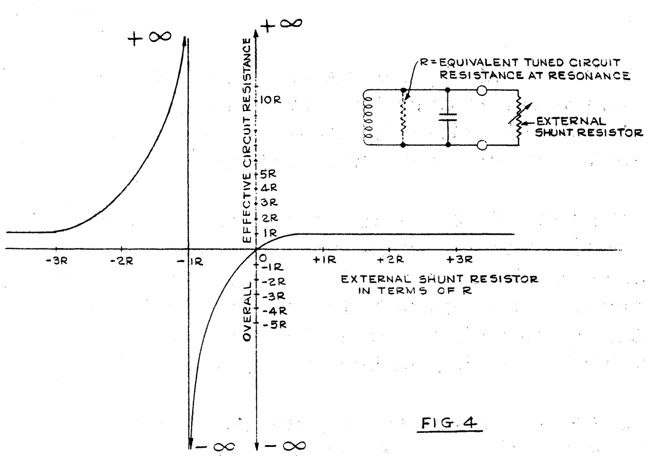


FIG 4

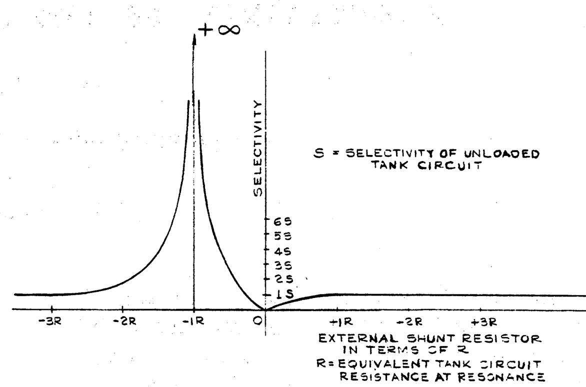


FIG 5

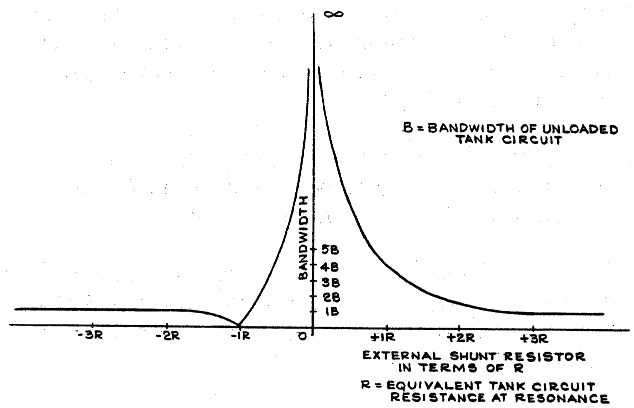


FIG 6

(7) Now when signals of various amplitudes are present in the tank circuit at the time that a negative resistance is connected across it, Figure No. 7 shows, for two values of negative shunt resistance, the voltage time curves for three input voltages. I have arbitrarily shown all values of negative resistance limiting at about 50 volts. This could be any level depending on the characteristic of the negative resistance. If the negative resistor is allowed to remain connected for only a specific number of time units, 4-1/2 time units for instance, and we observe that as long as saturation has not been reached, the peak tank circuit voltages attained are directly proportional to the input voltages and are many times these input voltages. The maximum gain, if sufficient time is allowed, is limited only by the ratio of saturation level to noise level. The lines with negative slope represent the decay rate of the tuned circuit with the negative resistance removed.

If the negative shunt resistor is left connected to the tank circuit for a sufficiently long period of time, the amplitude of oscillations (the AC) will always saturate. If the starting voltage is high, saturation will occur sooner, and conversely, if the starting voltage is low, saturation will occur later. If we measure the area under the A.C. envelope, we will see that this area is proportional to the logarithim of the starting voltage. This is known as the logarithmic mode of operation.

If the time units on Figure No. 7 are in tens of microseconds and the negative resistance is reapplied say every ten units, i.e. every 100 microseconds, and the peak detector is filtered with a time constant of say 200 microseconds, response to signal modulation frequencies as high as 5,000 cycles can be had. The

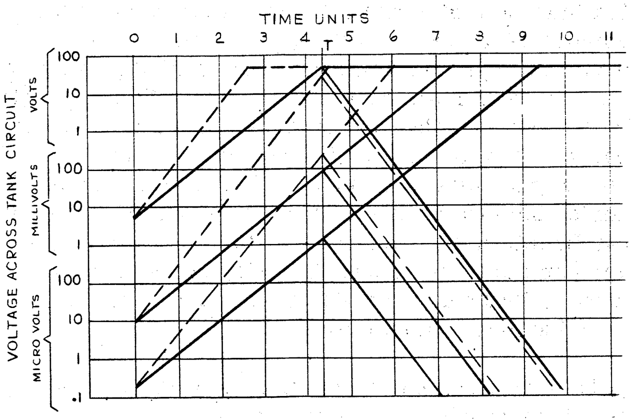


FIG 7

response of the tank circuit to input signals will take place during a part of the first time unit. This means that, using a rate of rise necessary to obtain the desired gain within the available 4.5 time units during which the negative resistance is placed across the tank circuit, the selectivity bandwidth of the circuit will be over 100 kilocycles per second. This is unfortunate because the circuit noise level is controlled by the 100 kilocycle selectivity bandwidth, while the intelligence bandwidth is limited by the repetition rate. This means that, for modulated-signal amplification, super-regeneration is at best only about one twentieth as good as an amplifier having the same selectivity and intelligence bandwidths. However, to amplify pulses of say 1/10 of a time unit duration (1 microsecond), a conventional amplifier needs not less than a 1 megacycle bandwidth to handle such a pulse. If this microsecond pulse is fed to our tuned circuit at the instant the negative resistance is applied, it will need a rise rate that will set its bandwidth at one megacycle to respond. Thus when used for pulse reception, the super-regenerative receiver has the same selectivity and intelligence bandwidths as found with any other type receiver, i.e., the signal-to-noise ratio for pulse reception can be as good for super-regeneration as for any other type of receiver. Using light-house tubes in cavity-type oscillators, noise factors of 6 db at 600 megacycles and 10 db at 3,200 megacycles have been obtained. (At 600 megacycles noise measurements were made with a Measurements Corporation Model 84 signal generator, and at 3,200 megacycles noise measurements were made with a Navy "S" Band signal generator Model TS-403/U.)

In practice, the negative shunt resistance switched across the tank circuit can be supplied by a vacuum tube, a magnetron, a klystron, a transistor, a tunnel diode or any other amplifying device that will operate at the desired frequency.

Even though the receiver gating pulse may last for many microseconds to obtain the desired gain, the sensitivity to signal varies inversely as the logarithm of time after the start of the receiver pulse. Also, since the signal voltage in the receiver tank, before application of the minus R, decays directly as the logarithm of time after the input signal is removed, the range definition can be measured in fractions of a microsecond. Figure No. 8 illustrates a typical Expanded "A" scope curve, range in microseconds versus response.

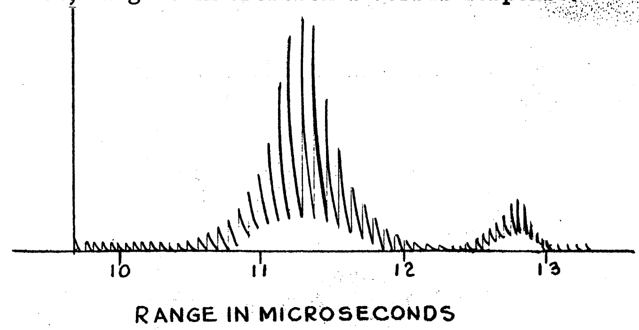


FIG 8

Up to this point, I have discussed only the operation of super-regeneration as a receiver. Since oscillations are permitted to build up to large amplitudes, and since the tank circuit is coupled to an antenna, energy will be radiated. This makes possible the use of a single circuit as a transmitter and receiver. The circuit in Figure No. 9 shows a single-circuit Super-regenerative Radar Transmitter-Receiver that operates in the logarithmic mode. In

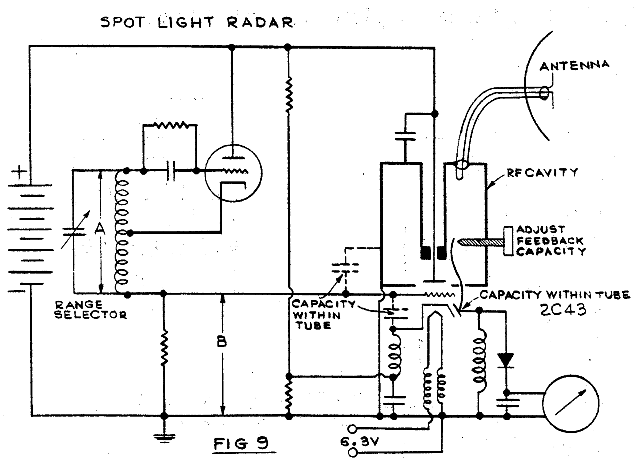


FIG 9

operation, the antenna is aimed at a target, much as a flashlight would be aimed, and the range selector is adjusted until a maximum response is observed on the meter. Figure No. 10 shows the signals at the labeled points in Figure No. 9. This unit was developed to replace optical rangefinders on early anti-aircraft guns, and is probably the simplest form of radar system possible.

The negative resistance supplied by a lighthouse tube is periodically switched on and off by the plate-current surges of the low-frequency class-C oscillator. Since oscillations are always allowed to build up to saturation, high-level radiation is obtained. The time between successive applications of the -R is varied by manually adjusting the frequency of the low-frequency class-C oscillator. The tuning capacitor is calibrated in range.

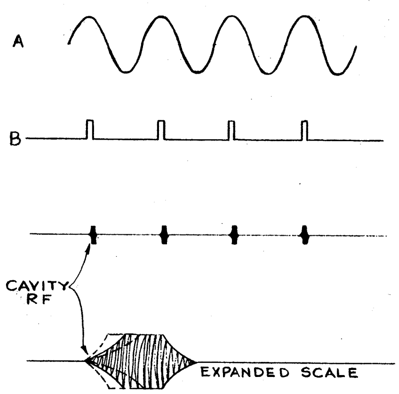


FIG 10

The manner in which a vacuum tube is coupled as a negative resistance to a tuned circuit to obtain the best noise factor in a Super-regenerative receiver is important. Figure No. 11 shows how the effective circuit resistance and the bandwidth vary as the feedback is changed by moving the cathode tap along the tank circuit. Note that there are two points of adjustment for every desired bandwidth. This is done practically in the circuit shown in Figure No. 9 by means of the adjustable cathode-to-plate capacity shown.

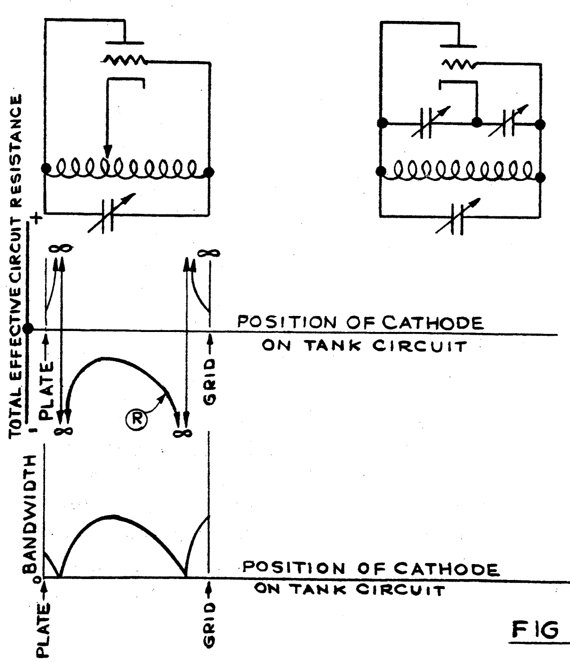


FIG 11

A vacuum tube has a considerable amount of thermal noise associated with the flow of its plate current. If the cathode is tapped all the way towards the grid end of the tank circuit, all the plate-circuit noise is coupled into the tank circuit. On the other hand, if the cathode is tapped all the way towards the plate end, none of the plate-circuit noise is coupled into the tank circuit. Maximum amount of induced grid noise will be coupled into the circuit under this latter condition but this is of secondary importance because the induced grid noise is substantially less than the plate noise. Obviously, significantly superior noise factors can be attained by operating with the cathode tapped as near the plate as possible. Careful attention to these adjustments resulted in the favorable signal-to-noise ratios mentioned above.

To obtain the maximum amount of radiated energy as a transmitter,it is desirable to pulse the tube with as high a voltage as it will stand. However, this is not the best condition for operating the circuit as a receiver. Therefore, the oscillator should be pulsed with a high-amplitude short-duration pulse for transmission; at range-time later, it should be pulsed with a lower-amplitude longer-duration pulse to give optimum performance as a receiver. During the transmit pulse, the detector should be gated off. This manner of operation is known as the double-pulse technique.

If the range delay is varied for successive pairs of pulses, and the detected signal is displayed on a scope while the horizontal spot position is controlled in accordance with the range delay, an "A" scope presentation results.

Since the detector output can be tens or even a hundred volts, no additional amplification is needed between the detector and the deflection plates of the oscilloscope. Also, since the signal pulses can be stretched in the detector circuit, and because the range sweep is slow, neither a wide-band deflection amplifier nor a high-intensity oscilloscope is needed. A few hundred supply volts is all that is required to develop a brilliant presentation. The reduced oscilloscope supply voltage reduces the necessity for high deflection voltages.

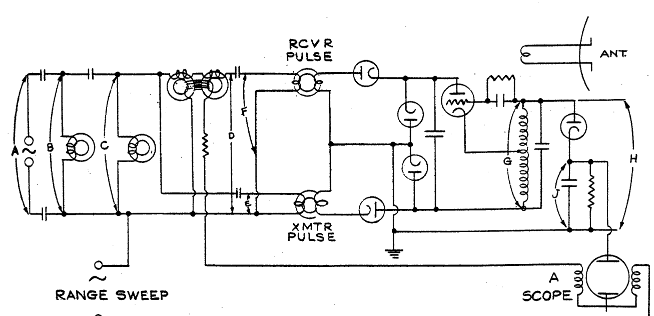


FIG 12

The circuit of Figure No. 12 shows a complete "A" scope radar, utilizing the double pulse technique. The double pulses and the range delay are generated by saturable "Deltamax" toroids directly from a 400 or

2,000 cycle power supply. The range delay is controlled by a premagnetizing current through the range delay reactor. This same current is used to deflect the beam horizontally on the "A" scope, hence no horizontal scope amplifier is necessary.

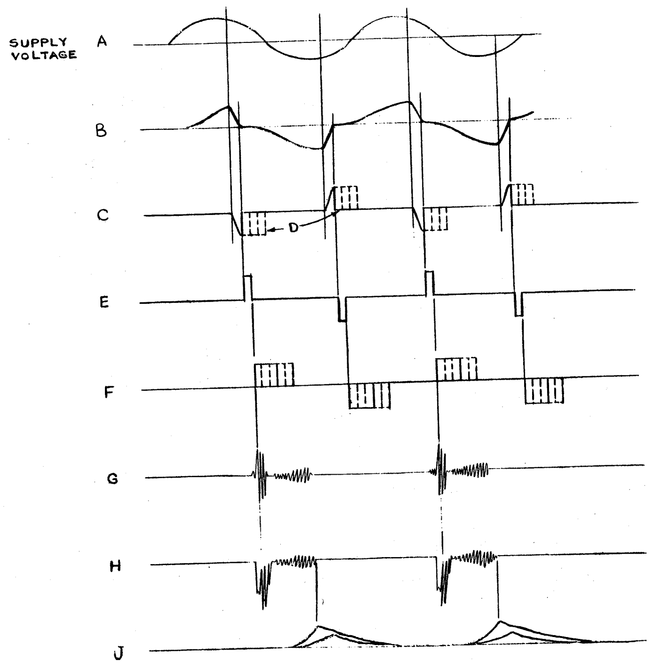


FIG 13

Figure No. 13 shows ideally how saturating reactors are used to create the desired transmit, receive and gating signals. In operation the reactors have high impedance until they saturate, whereupon they suddenly have very low impedance. When these reactors are used as chokes or transformers, voltage can exist across their windings only as long as the flux is changing and will collapse when the flux is limited by saturation. The time it takes a given reactor to saturate is inversely proportional to the applied voltage and is also an inverse function of the amount of premagnetization before the application of the voltage. This is how the receiver pulse time modulation is obtained. A reactor having relatively much iron and many turns is used to form the Wave "B" from the supply voltage. "B" is not an infinitely steep Wave because this reactor after saturation still has substantial inductance. Therefore another stage using a reactor with fewer turns and less iron is needed to develop a wave form having fractional microsecond rise times. The transmit pulses generated by the small tape-wound Deltamax cores may be of the order of a quarter microsecond duration, so that tens or hundreds of volts per turn can be developed. Consequently, very few turns are needed. The toroids used with the equipment were easily wound by hand. The operation of the receiver and the transmit-receive gate should be obvious from the circuit of Figure No. 12 and the curves of Figure No. 13.

SETTABLE RANGE BOMB FUZE

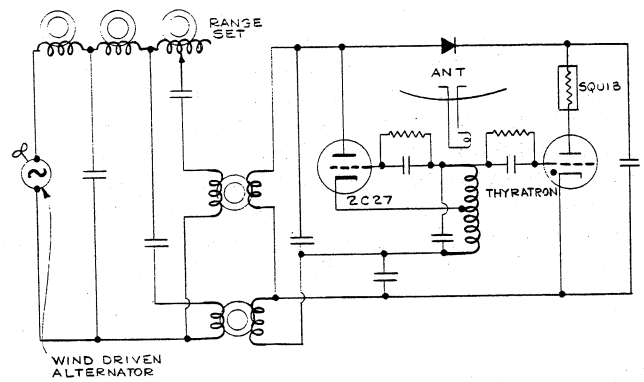


FIG 14

Figure No. 14 shows a typical circuit for a setable range bomb fuze powered by a small wind driven alternator. The mechanical construction of this unit was such that everything shown in the circuit of Figure 14 except the alternator, the squib, and the antennae was contained in a space of approximately two cubic inches. Filaments were energized by a separate low-voltage winding on the alternator (not shown).

EDITORIAL

In future issues of the Proceedings we will be reviving an old custom as when the Proceedings were being handled by Larry Horle. Additional space beyond that needed by the technical papers will be devoted to the carrying of news about activities of our members; reports of interesting projects relating to our fields; and actions by the Board of Directors and Officers that are of interest. Keep this in mind if you hear of such items from correspondence with others, AND keep us informed about yourself.

JOHN H. BOSE, Past President of the Club, and recent winner of the Armstrong Medal, recently participated in the Tenth Anniversary celebration of the Electronics Research Laboratory, a part of Columbia University established to conduct advanced research in a number of electronic fields. John is in charge of one of the six basic areas of study: Frequency Modulation. Research projects involving several millions of dollars are being handled at ERL.

CORRECTION TO YEARBOOK LISTING:

Somebody muffed the spelling of the old Holland Dutch name of Bloodgood as the middle name of Howard Day, and we will rest easier if you will correct your copy.

THE WRITING OF RADIO HISTORY—A PROJECT FOR R. C. A.

by

I. S. Coggeshall*

By and large those whom the Radio Club of America has chosen to present papers for its Proceedings have been too busy making radio history to write it.

This is not to say that the papers collected by title in your Jubilee Golden Book of 1959 are not historical gems -- far from it! Radio history flashes from their facets. It would be difficult to find their match as a collection, to pour through the fingers and catch up, one by one, radio's vast spectrum of colors.

But the compilation of useful radio history is more than a recounting of its bits. It involves a systematic, philosophical explanation of their relationships -- the interplay of cause and effect -- what led to what. It is the stringing of the beads into a necklace by means of a vital but hidden strand. It results in the creation of a thing better thought out, more unified, hence more precious, than the fistful of gems from which it was created -- a whole, if you will, greater in value than the sum of its parts.

When Ralph Batcher asked me to give the address this evening, the shortcomings of engineers as historians occurred to me as a fit subject for discussion. He had said that, in addition to entertaining you, I ought to seize the opportunity to make some detached suggestion which would give your Club additional purpose. So I do suggest that you set a goal of making your Proceedings a recognized repository of the world's most frequent and outstanding articles on the history of radio. To such a repository, scientists, engineers, the industry, the profession, historians, and others would instinctively turn, either to settle questions of the past, or at least to find satisfactorily documented the noble controversies of Who Got There First which have enraged the principals and enlivened the bystanders. I can think of a number of reasons why you should do this.

First, your records already constitute a good beginning. Apart from papers which themselves represent disclosures, I count in your Proceedings at least a dozen papers which, from their titles, are sources of historical material. You also have a number of recordings, in addition to the priceless record by Rounds and Armstrong brought out in connection with your 50th Anniversary.

Second, your relationships with Columbia University are so close that you have unusual access to source material available there in the form of memorabilia recorded on tape by Old Timers, some of them your members.

Third, the roster of your Club membership contains an unusual number of men whose roots tap historic soil all the way from 1959 back fifty years to 1909, and some of them prior to that date.

Fourth, the very detachment of your Club commends it as a mentor and repository of history. While the engineering societies are not beholden to vested corporate interests, their memberships do include blocs of loyal company employees who perceive the inconveniences and diversionary aspects of making historical claims in engineering papers; such statements are, therefore, left by common consent to the House organs. By contrast, your smaller organization is not concerned with grinding out current papers by the hundreds for national consumption. Your debt to units of the industry for support is closer to zero. You therefore have fewer people to offend when your researches are so rigorous that they turn up facts not entirely slanted toward vested interests.

Fifth, you can nicely take a mid-position between engineering and science. These branches of learning have more or less separate literatures, hence they tend to become departmentalized. The Radio Club of America can dip into both disciplines without diluting any obligation it may hold its members to specialize on the one side or the other.

Sixth, because your membership contains younger and older members in an ideal mix, you can produce authorities capable of evaluating history within its various decades. It is a mistake to assume that radio history is concerned alone with the Marconis, Fessendens, and de Forests. Profitable historical papers might be written right now on developments which took place under cover of secrecy in World War II, such as radar, proximity fuzes, printed circuits, and so on. The same goes for radio receiver circuits, loud speakers, modulation, feed-back, and such matters of an earlier generation. The burgeoning out of electronics in its audio, industrial, and other forms, is a subject of manifold interest. Going farther back, we run into such questions as who was first to think of putting amplifying stages in cascade; who started the C-biasing of filaments. All these subjects, of course, are to be found buried in the technical literature. It is one of the duties of historians to make the proper selection and interpretation of such facts and to cite their authorities so that statements may be substantiated by later researchers.

Seventh, what we have by way of history is inadequate. Biographies and memoirs are notoriously one-sided. The books we have are valuable as to some of their features and periods of time covered, but they stop too soon and often omit salient facts. A periodical, like your Proceedings, offers a great advantage in that in it history can be continuously produced, and controversial points may be cleared up by letters to the editor or supplementary articles which will give all sides a fair hearing.

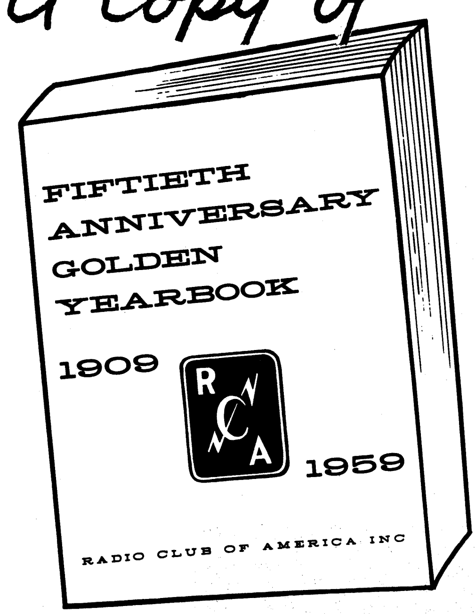
Eighth and last, the continuum of a periodical affords the required space to spread out. Even an encyclopedia, though calling for precision in every statement, lacks room to support its assertions or for the contributor to cite his authorities. A history not documented isn't worth much to future historians -- nor for that matter to contemporary disbelievers.

*Extracted from the 51st Anniversary Banquet speech at Columbia University Club, December 16, 1960. Dr. Coggeshall was President of IRE in 1951.

If embarked upon by your Club, such a program would require a lot of working up. Papers -- as in other situations -- would have to be obtained the hard way, by dint of persuasion. It would not be easy but, in my opinion, the project would be eminently worth while.

I would be naive and unrealistic indeed were I to propose that a sense and pursuit of history is all-sufficient for your members, or that a recounting of history alone is a satisfying program for a Club like this. But there is a certain momentum gained in pursuing the past into the present which carries over usefully into a projection of the future. And a constant looking ahead is a source of dynamism which will attract the youth of our industry and profession, and perpetuate the vitality and influence of the Club for many years to come.

A review of the achievements of only the one year now ending is replete with possibilities of extrapolation into the Sixties and far beyond that. This has been going on ever since the Radio Club of America was founded, 51 years ago. We have the "feel" of having been swept up in the stream of history. What could be more interesting than to define its banks, identify its shoals and channels, and plot its course onward towards the sea?



MEASUREMENTS "FAMOUS FIRSTS" in *Laboratory Standards*

1939	MODEL 54 STANDARD SIGNAL GENERATOR—Frequency range of 100 Kc. to 20 Mc. The first commercial signal generator with built-in tuning motor.
	MODEL 65-B STANDARD SIGNAL GENERATOR—This instrument replaced the Model 54 and incorporated many new features including an extended frequency range of 75 Kc. to 30 Mc.
1940	MODEL 58 UHF RADIO NOISE AND FIELD STRENGTH METER—With a frequency coverage from 15 Mc. to 150 Mc. This instrument filled a long wanted need for a field strength meter usable above 20 Mc.
	MODEL 79-B PULSE GENERATOR—The first commercially-built pulse generator.
1941	MODEL 75 STANDARD SIGNAL GENERATOR—The first generator to meet the need for an instrument covering the I.F. and carrier ranges of high frequency receivers. Frequency range, 50 Mc. to 400 Mc.
1942	SPECIALIZED TEST EQUIPMENT FOR THE ARMED SERVICES.
1943	MODEL 84 STANDARD SIGNAL GENERATOR—A precision instrument in the frequency range from 300 Mc. to 1000 Mc. The first UHF signal generator to include a self-contained pulse modulator.
1944	MODEL 80 STANDARD SIGNAL GENERATOR—With an output metering system that was an innovation in the field of measuring equipment. This signal generator, with a frequency range of 2 Mc. to 400 Mc. replaced the Model 75 and has become a standard test instrument for many manufacturers of electronic equipment.
1945	MODEL 78-FM STANDARD SIGNAL GENERATOR—The first instrument to meet the demand for a moderately priced frequency modulated signal generator to cover the range of 86 Mc. to 108 Mc.
1946	MODEL 67 PEAK VOLTMETER—The first electronic peak voltmeter to be produced commercially. This new voltmeter overcame the limitations of copper oxide meters and electronic voltmeters of the r.m.s. type.
1947	MODEL 90 TELEVISION SIGNAL GENERATOR—The first commercial wide-band, wide-range standard signal generator ever developed to meet the most exacting standards required for high definition television use.
1948	MODEL 59 MEGACYCLE METER—The familiar grid-dip meter, but its new design, wide frequency coverage of 2.2 Mc. to 400 Mc. and many other important features make it the first commercial instrument of its type to be suitable for laboratory use.
1949	MODEL 82 STANDARD SIGNAL GENERATOR—Providing the extremely wide frequency coverage of 20 cycles to 50 megacycles. An improved mutual inductance type attenuator used in conjunction with the 80 Kc. to 50 Mc. oscillator is one of the many new features.
1950	MODEL 111 CRYSTAL CALIBRATOR—A calibrator that not only provides a test signal of crystal-controlled frequency but also has a self-contained receiver of 2 microwatts sensitivity.
1951	MODEL 31 INTERMODULATION METER—With completely self-contained test signal generator, analyzer, voltmeter and power supply. Model 31 aids in obtaining peak performance from audio systems, AM and FM receivers and transmitters.
1952	MODEL 84 TV STANDARD SIGNAL GENERATOR—With a frequency range of 300-1000 Mc., this versatile new instrument is the first of its kind designed for the UHF television field.
1953	MODEL 59-UHF MEGACYCLE METER—With a frequency range of 420 to 940 megacycles, the first grid-dip meter to cover this range in a single band and to provide laboratory instrument performance.
1954 1955	FM STANDARD SIGNAL GENERATOR. Designed originally for Military service, the commercial Model 95 is engineered to meet the rigid test requirements imposed on modern high quality electronic instruments. It provides frequency coverage between 50 Mc. and 400 Mc.
1956	MODEL 505 STANDARD TEST SET FOR TRANSISTORS. A versatile transistor test set which facilitates the measurement of static and dynamic transistor parameters.