Alternative Tagging Modulations

The foregoing has considered PM (or delay variation) as the tagging method with a receiver which derives error information by examining AM of the signal. Alternatively, we may tag each transmitted component with a small-percentage AM at its tag frequency, and examine the received sample for PM to find the array phasing errors. Various other forms of tagging modulation are possible. For example, a single-sideband tone can be applied to each component and a reference tone sent from one untagged element. If the timing relationship of the tones at the transmitter is known in some way (for example, a specified phase relationship at known instants of time), then their phase shifts (from reference) measured at the receiver are a direct measure of phasing errors in the transmitting array. In general, the type of modulation selected for tagging will depend on convenience in the system design. Thus, a high-power klystron cannot readily accept amplitude modulation, but is suited for tagging by phase modulation, etc.

Conclusions

The use of beam tagging for adaptive control has been verified experimentally. An X-band system was built with two stations 360 feet apart, each equipped with a 1-kw klystron and a steerable antenna. Beam tagging was used for control of RF phase. The system has acquired and adaptively tracked an aircraft target, maintaining RF coherence at ranges up to 100 miles.

Although still relatively new, it appears that beam-tagging techniques are well suited to control of the transmitting mode in nearly all systems, even when more conventional techniques are also used in the receiving mode.

Antennafier Arrays

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Summary—**The integrated transistorized dipole antennafier (antenna-amplifier) is ideally suited for use in array systems. The advantages include ease of amplitude-distribution control, low noise, high gain, high reliability and simplicity. The integration is achieved by using the antenna as a circuit element of the transistorized amplifier, thus eliminating the tuned input circuits and transmission lines commonly used.**

A four-element broadside array of antennafiers is described in which the gain of each element is varied by controlling the base bias. Binomial, uniform, edge and Dolph-Chebyshev distributions were chosen to show the wide variation of beam control possible; the resulting measured and calculated patterns, half-power beamwidths, gain over a half-wavelength dipole, and noise temperatures are presented.

A method of experimentally evaluating the noise performance, based on a theoretical development, is also described.

Introduction

MANY ADVANCED antenna designs obtain sophisticated performance from large arrays of simple elements. Often, for example, the signals from the individual elements (slots, dipoles, etc.) may be adjusted in amplitude and phase before combination, so that the array pattern could be essentially synthesized by a computer controlling the signal processing.

In these systems, great care must be exercised to minimize the RF losses in each of the controlled elements. Otherwise the radiation efficiency may be poor as a transmitting system, or the signal-to-noise ratio may be severely degraded in a receiving system.

An effective way of improving the signal-to-noise ratio is to provide amplification immediately at the point of reception in the array itself, using integrated designs of antennas and amplifiers, sometimes called "antennafiers." Such a design is said to be integrated when some portion or portions of the antenna structure serve as circuit elements in the amplifier circuitry; no division can be made which would separate the antenna from its associated circuitry without rendering the system inoperative. The concept of integrating the design of an antenna and the circuitry with which it is intended to function is an evolutionary development which, when applied properly, is capable of providing improved system performance from fewer components in more compact form than the more conventional approach of separated design [1]–[15].

This use of the antenna as a circuit element provides for the elimination of the usual matching and tuning elements between an antenna and its circuitry, and

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makes it convenient to incorporate some portions of the circuit directly in the antenna structure, dispensing with transmission lines. As a result of the elimination of these circuit elements, RF losses are reduced, and in receiving applications the operating noise temperature of the system is lowered.

The concept of integrated design has found application in transmitting, receiving and echo-area control. Tunnel-diode oscillators and varactor harmonic-generators have been combined with dipoles to form two different kinds of integrated antenna-transmitters, or "antennamitters." Mixer-diode and tunnel-diode down-converters have been combined with broad-band spiral antennas to form "antennaverters." Tunnel diodes, varactor parametric amplifiers and transistor amplifiers have been combined with slots, spirals, dipoles and arrays of dipoles to form various kinds of antennafiers. In echo-area applications, switching diodes and varactor parametric amplifiers have been used with slot antennas to modulate, increase and decrease the echo-area of simple structures with slot antennas in them.

The purpose of this paper is to describe a basic type of transistorized antennafier and show one of its applications as a controlled element in an array. The element is comprised of a resonant half-wavelength dipole antenna matched directly into a controllable-gain transistor RF amplifier, whose collector tank circuit provides the output of the integrated device.

Construction

Fig. 1 shows two schematic diagrams illustrating transistorized dipole antennafiers. In Fig. 1(a) the transistor amplifier operates with fixed bias for maximum gain or minimum noise temperature, while in Fig. 1(b) the technique of "Forward AGC" has been used to provide a variable-gain antennafier for use in array applications, or elsewhere if gain control is required. Fig. 2 is a photograph of one such antennafier constructed for 146 Mc.

The active portion of the circuit is provided by the 2N1742 VHF transistor, some of whose characteristics are reproduced in Figs. 3–5. Operating unneutralized in the test circuit of Fig. 6 at 146 Mc, selected units provided up to 12.5 db gain with 4-db noise figure when optimized for best noise performance.

The antenna as shown in Fig. 1 was a resonant half-wavelength dipole with a gamma-match feed connected directly to the base of the transistor. The length of the gamma rod and resonating capacitance were both made adjustable for proper matching between the antenna and the transistor.

The output circuit was a parallel resonant tank, using the parasitic output capacitance of the transistor alone in order to achieve maximum bandwidth. The 50-Ω coaxial output was tapped part way up from the cold end of this tank circuit for an impedance match. Other tap

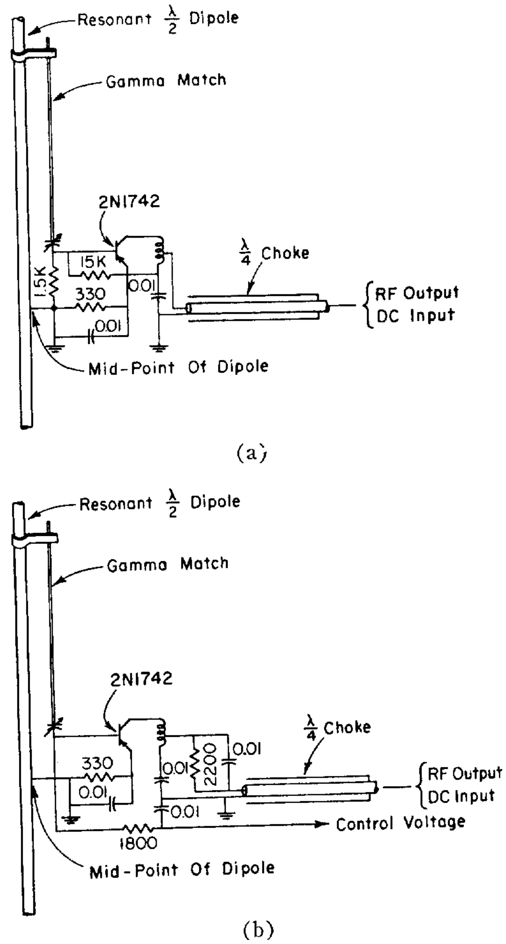


Fig. 1—The transistorized dipole antennafier. (a) Fixed gain. (b) Controllable gain.

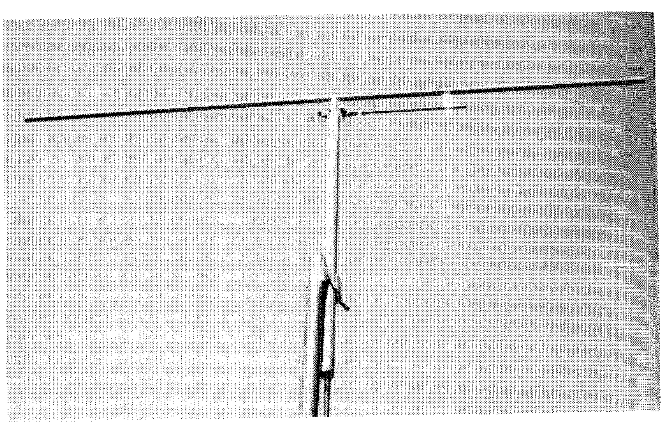


Fig. 2—A transistorized dipole antennafier for 146 Mc.

points could be used depending on whether greater or less bandwidth were desired in the output circuit at the expense of power gain, but the condition of matched impedances was chosen here. This choice resulted in a half-power bandwidth of about 20 Mc which corresponds to an operating Q of about 7.5.

It will be shown later that at these bandwidth limits the antenna VSWR is so low that the total bandwidth

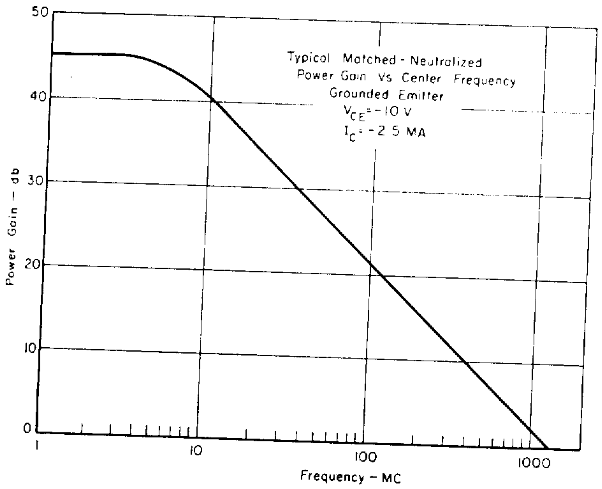


Fig. 3—Frequency capability of Philco 2N1742 transistor.

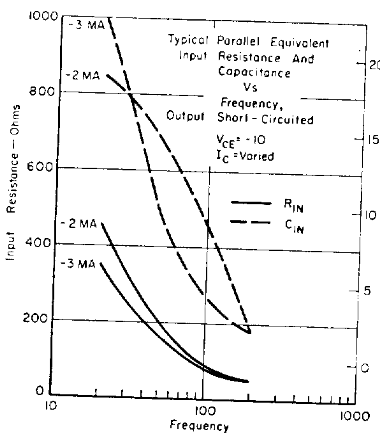


Fig. 4—Input characteristics of Philco 2N1742 transistor.

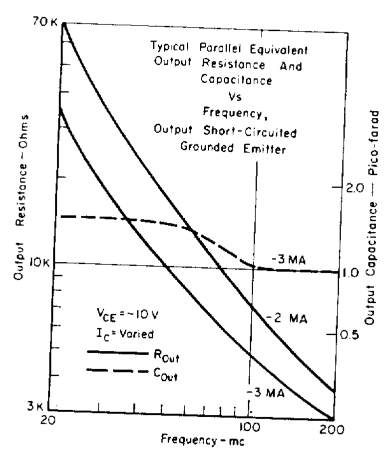


Fig. 5—Output characteristic of Philco 2N1742 transistor.

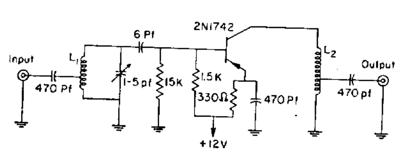


Fig. 6—146-Mc test circuit for 2N1742 transistor.

is determined primarily by the operating Q of the collector circuit.

The $\lambda/4$ sleeve balun shown in Figs. 1 and 2 was required only to prevent antenna currents from flowing on the supporting structure of the dipole. This is a common fault of the gamma-match type of unbalanced feed arrangement, and if uncorrected can lead to asymmetrical radiation patterns of the dipole.

The power supply used for the 2N1742 transistor amplifier was 12-v dc connected to the RF output line with an RF choke and dc block arrangement for isolation. A Microlab HW-02N monitor tee was well suited to this purpose.

Performance

The parameters of interest in the specification of an antennafier are pattern, gain and noise temperature. Patterns are easily measured and are interpreted in the same way as ordinary antenna patterns. Gain and noise temperature are not always easy to specify, however.

The gain of an antennafier is a function of both antenna gain and circuit gain, and is usually measured in terms of gain over a half-wavelength reference dipole. In simple examples such as the present case, the circuit gain can be more or less separated from the antenna gain, but in more complicated cases such as antennafier arrays, this separation becomes difficult and it is necessary to specify pattern and gain independently.

The noise temperature of an antennafier is even more difficult to measure. In conventional receiving systems, a direct measurement of noise temperature with respect to input terminals can be made on a receiver, and the effective noise contribution due to losses in the antenna and matching circuits can be measured and added. However, this approach is inapplicable to antennafiers generally, because no such set of input terminals to the receiver exists.

The only related parameter which can be measured easily is the field-strength sensitivity, defined as the power density of the electromagnetic wave in which the antennafier must be immersed in order to provide signal output equal to noise output:

$$FSS = \left| \overline{P}_{\text{inc}} \right|]S_{\text{out}} = N_{\text{out}} \tag{1}$$

where $\overline{P}_{\text{inc}}$ is the incident Poynting vector, S_{out} is signal power output, N_{out} is noise power output.

This measurement is then repeated using the reference dipole and a receiver of known noise temperature. The resulting ratio of field-strength sensitivities, along with the measured power gain of the antennafier and the effective antenna temperatures, is sufficient to determine the effective noise temperature of the antennafier:

$$T_a = T_e(R - 1) + T_r(R - 1/G) \tag{2}$$

where

T_a = antennafier noise temperature

T_e = antenna noise temperature

T_r = noise temperature of the receiving system following the antennafier

G = circuit gain of the antennafier

R = field-strength sensitivity ratio.

This type of measurement has been discussed in greater detail [10].

The gain of the transistorized dipole antennafier was measured as 12.5 db relative to the reference dipole. The pattern was identical to the reference dipole pattern as shown in Fig. 7. The 12.5-db gain difference was removed for better comparison of the two patterns. It was found that the controllable-gain antennafier of Fig. 1(b) could be adjusted over the range from 20-db loss to 12.5-db gain by variation of the control voltage.

Fig. 8 shows the frequency response of the antennafier. This curve was obtained from comparison with the response of a reference dipole constructed to the same dimension as the antennafier, with an identical reference dipole used as the transmitting antenna. Fig. 9 shows a VSWR curve of the two identical reference dipoles. In this way the frequency behavior of the transmitting antenna was known and accounted for in the frequency-response measurements.

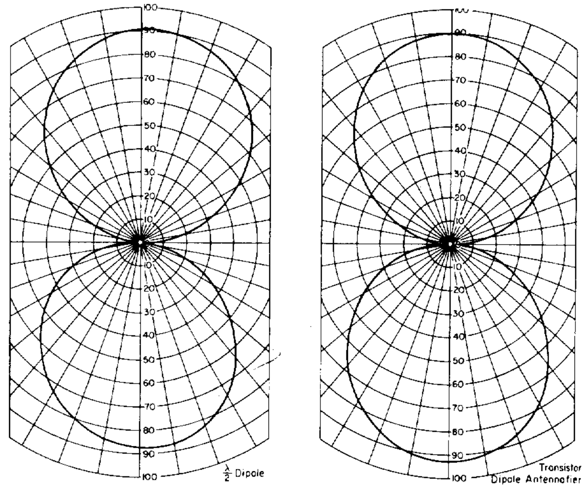
As mentioned earlier, since the half-power bandwidth of the antennafier corresponds to VSWR limits of less than 2 on the antenna (a VSWR of 5.8 would correspond to a half-power mismatch), the bandwidth of the antennafier is determined principally by the choice of loaded Q in the collector circuit.

The spot noise temperature measured at 146 Mc by the method described above indicated about 350°K for the complete antennafier. This turns out to be slightly better than the approximately 425°K measured for the same transistor in the amplifier test circuit. This difference is believed to arise from the losses which inevitably occur in the input circuit of the conventional amplifier, and which have been eliminated in the integrated design.

It is interesting to note that even at this frequency of 146 Mc, the noise temperature of the antennafier approximates the lowest level of cosmic noise temperature to be found in the coldest regions of the sky, and this element is therefore well suited to VHF communications applications.

Four-Element Array

In order to illustrate the usefulness of this antennafier in array applications, four identical transistorized dipole elements with controllable gain were arranged in a broadside array using $\lambda/2$ spacing at 148 Mc, as sketched in Fig. 10. A corporate feed structure was



(a) (b)

Fig. 7—Field patterns of transistorized dipole antennafier and reference dipole antenna.

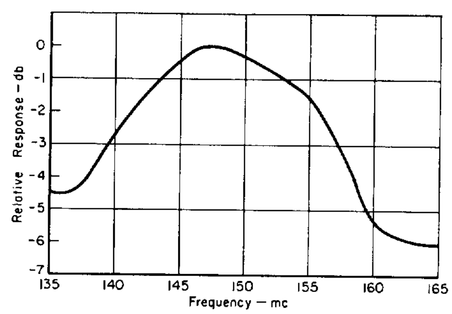


Fig. 8—Frequency response of the transistorized dipole antennafier.

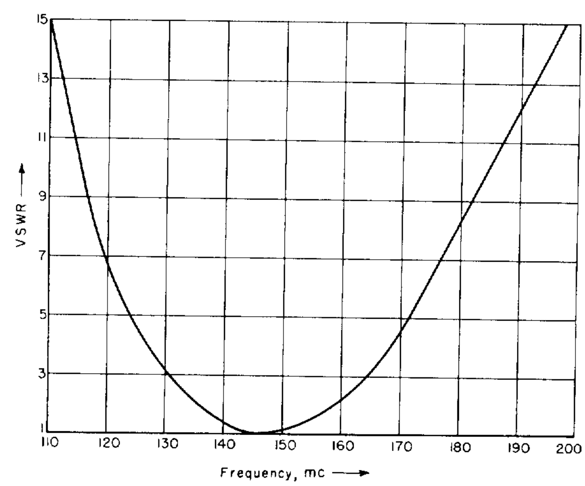


Fig. 9—VSWR of reference dipole antenna.

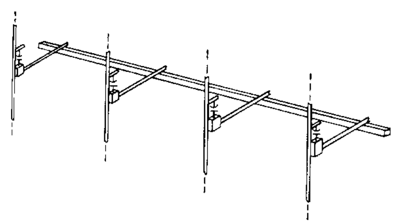


Fig. 10—Four-element antennafier array.

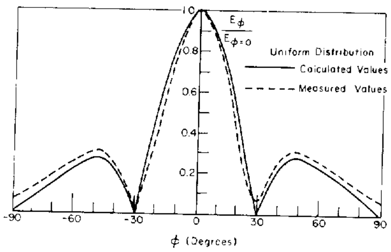


Fig. 11—Pattern of uniform distribution (1:1:1:1).

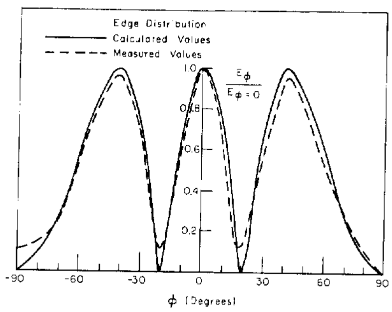


Fig. 12—Pattern of edge distribution (1:0:0:1).

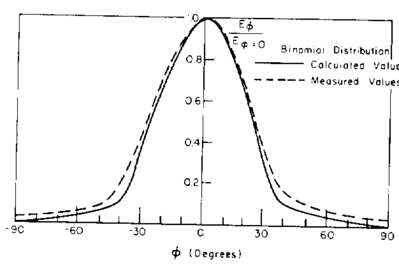


Fig. 13—Pattern of binomial distribution (1:3:3:1).

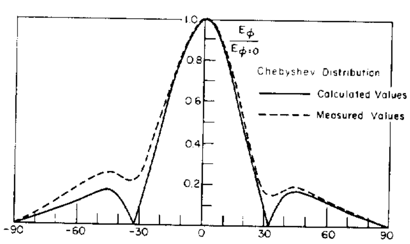
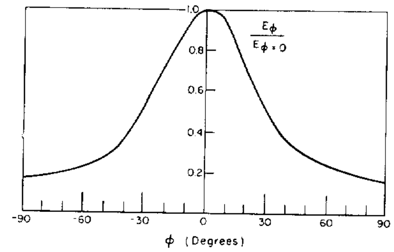
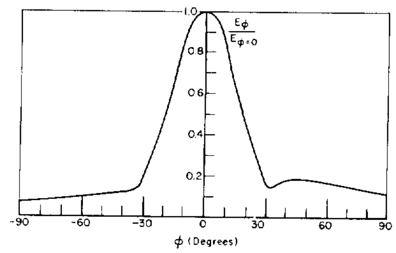


Fig. 14—Pattern of 15-db Dolph-Chebyshev distribution (1:1.72:1.72:1).



(a)



(b)

Fig. 15—(a) Pattern of 15-db Dolph-Chebyshev at 130 Mc. (b) Pattern of 15-db Dolph-Chebyshev at 170 Mc.

used to insure in-phase excitation from all elements, maintaining the main beam at broadside.

The corporate feed used equal power division at each tee, so that a uniform effective amplitude distribution across the array would be obtained when all antennafier elements operated with equal gain. This condition is shown in the field pattern of Fig. 11. Good agreement with the calculated pattern for four equal in-phase isotropic sources was obtained.

Any other effective amplitude distribution could be obtained, however, by bias adjustments of the individual antennafier elements, thereby varying their gain. This is illustrated in Figs. 12, 13 and 14, which show measured and calculated field patterns for edge, binomial and 15-db Dolph-Chebyshev distributions respectively. In all cases the same equal-amplitude corporate feed was used, and the only adjustments were the dc control voltages on the transistor bases. The actual patterns are chiefly of academic interest, of course, because only four elements were used. The important feature is the great amount of beam control available through antennafier design.

The bandwidth over which good patterns could be obtained with reasonable gain was about 25 per cent in all cases. For example, Fig. 15 shows the Dolph-Chebyshev pattern taken at 130 Mc and at 170 Mc. This represents approximately the useful bandwidth of the elements themselves, beyond which the array patterns begin to deteriorate sharply.

The power gain of the array was measured with respect to a half-wave passive dipole constructed similar to the antennafier elements. Since both directivity and circuit gain contribute to the over-all gain, the convention of specifying patterns, gains and noise temperatures as separate parameters has been adopted. These measurements are summarized in Table I.

TABLE I

PERFORMANCE OF 4-ELEMENT BROADSIDE ANTENNAFIER ARRAY WITH $\lambda/2$ SPACING, MEASURED AT 148 Mc

Distribution	Half-power beamwidth	Gain over $\lambda/2$ dipole, db	Noise temperature
Uniform	29°	9.0	850° K
Binomial	37°	9.0	1020° K
Edge	18°	7.0	455° K
15 db Dolph-Chebyshev	29°	9.5	1090° K
Maximum gain	29°	17.0	515° K

Two distinct methods of gain adjustment in the individual antennafier elements were investigated: reverse and forward bias techniques. Reverse-gain control reduces gain of the transistor amplifier by reducing the amount of forward bias normally applied between emitter and base, thus operating the transistor close to cutoff bias. Forward-gain control, on the other hand, increases the forward bias, driving the transistor toward saturation. However, a bypassed resistor is used in series with the collector circuit, and the resulting dc drop across it at high currents forces the transistor to operate at very low collector potential, greatly reducing its gain [see Fig. 1(b)].

Forward-gain control has the advantage of being inherently much more resistant to overload than reverse control, but phase shift through the amplifier was found to change enough as a function of gain to alter the array patterns somewhat. This effect was almost entirely absent for reverse control, so the latter was used for all measurements shown here. The pattern distortion was of such minor nature, however, that forward-gain control would be recommended for any application requiring the additional resistance to high-signal overload.

Noise performance of antennafiers is the most difficult property to measure accurately. As mentioned previously, good results have been obtained by comparing the noise performance of a given antennafier to an identically constructed passive antenna. This method has the advantage of not requiring a measurement of effective antenna aperture.

For the array measurements, however, it was inconvenient to construct the identical passive antenna array, so comparisons were made to a single half-wave dipole antenna, and the array directivity was computed from the patterns. It was necessary to know the directivity because the total output noise is the amplified input noise plus the excess noise. The input noise is amplified only by the circuit gain, however, so the total gain of the antennafier array must be reduced by the array gain factor in order to evaluate the excess noise of the amplifiers.

It should be noted that the noise temperatures shown in Table I are derived from the excess noise divided by circuit gain, and represent the input temperature of an equivalent lumped amplifier.

It was found that the measured sky temperature was almost independent of antenna orientation at the time of measurement. Therefore the same sky temperature was assigned to the array as that measured with the reference dipole. The sky temperature was deduced by comparing the output noise of the dipole to the output noise of a 50-Ω load at 290°K. The input noise temperature of the receiver was measured with a Hewlett-Packard 342-A noise-figure meter.

A schematic representation of the measurement is shown in Fig. 16. In both cases a Hewlett-Packard Model 608-C signal generator was used as a transmitter. Since it was necessary to known only the ratio of the two signals, the ratio was read directly from the attenuator dial. In each case the attenuator was adjusted so that the signal and noise output of the receiver were equal; *i.e.*

$$S'_{01} = N'_{01} \quad (3)$$

$$S'_{02} = N'_{02}. \quad (4)$$

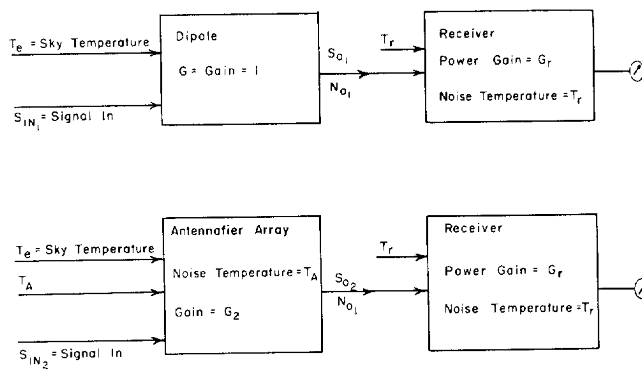


Fig. 16—Measurement system.

The gain of the integrated array may be written as

$$G_2 = (\text{array gain})(\text{circuit gain})$$

or

$$G_2 = G_{ANT} G_A \quad (5)$$

where G_A is the power gain of an equivalent amplifier located at the passive array output terminals.

The output noise terms are

$$N'_{01} = (T_r + T_e) G_r k B \quad (6)$$

$$N'_{02} = (T_r + G_A T_A + G_A T_e) G_r k B \quad (7)$$

where k is Boltzmann's constant.

The output signals are

$$S'_{01} = G_r S_{\text{in}_1} \quad (8)$$

$$S'_{02} = G_r G_2 S_{\text{in}_2}. \quad (9)$$

Substituting (3), (4), (8) and (9) into (6) and (7) and dividing, yields the field strength sensitivity ratio as defined previously

$$R = \frac{S_{\text{in}_2}}{S_{\text{in}_1}} = \frac{T_A + T_e + \dfrac{T_r}{G_A}}{(T_r + T_e) G_{ANT}} \cdot \quad (10)$$

Solving for T_A

$$T_A = T_e(R\,G_{ANT} - 1) + T_r\left(R\,G_{ANT} - \frac{1}{G_A}\right) \quad (11)$$

which is an extension of (2). Since T_r, T_e, G_A, G_{ANT} and R are measured quantities, T_A may be evaluated from (11).

Conclusions

The concept of integrated antenna-circuitry design is one of combining certain antenna functions with certain circuit functions in a single structure. Some of the advantages offered by integrated design over conventional separated design are improved electrical performance, increased reliability, reduced number of components and more compact packaging.

An example of a practical and useful integrated design is the transistorized dipole antennafier, which is the combination of a resonant half-wavelength dipole antenna with a simple and completely stable VHF transistor amplifier. The device is compact, inexpensive, features high gain with low noise, and is suitable for use singly or in arrays with similar elements, all of whose gains may be controlled independently.

In such arrays rapid and automatic beam control may be achieved electronically without the sacrifice of signal-to-noise ratio which inevitably occurs in all-passive arrays. The four-element array described here was intended only to demonstrate an application of antennafier elements in larger systems. The economies in weight, size, complexity, and cost shown here, along with the sophisticated performance, can be of very considerable value when multiplied by the great number of elements now being used and proposed for new receiving arrays.

Future work in this direction will include electronic phase control, as well as amplitude control, for complete beam control including steering as well as shaping.

Acknowledgment

The idea of integrating antennas and circuit devices was first suggested to the authors by E. M. Turner of the U. S. Air Force Aeronautical Systems Division. The advice of Dr. C. H. Walter and the help of R. L. Riegler, who performed many of the measurements, are also gratefully acknowledged.

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