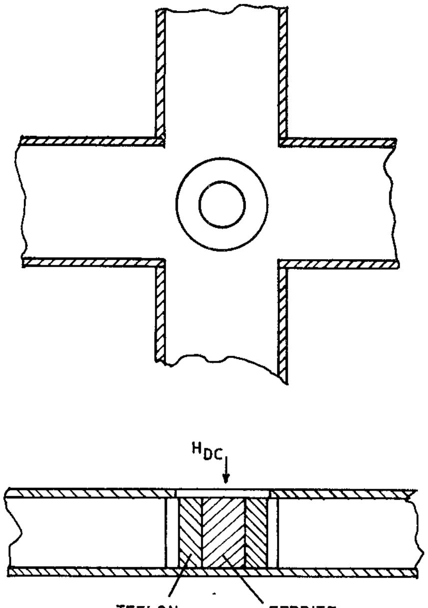

Fig. 1. Four-port X-band waveguide junction circulator.

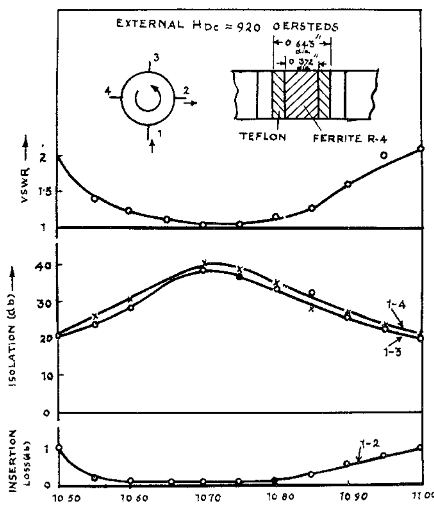

Fig. 2. Performance characteristics of the circulator.

loading on performance. Figure 3 shows the effect of adding the dielectric material to the junction. For a given diameter of the ferrite post, the circulation frequency decreases as the diameter of teflon cylinder is increased (Curve I). Teflon increases the effective diameter of the ferrite cylinder, thereby reducing the circulation frequency. Curve II shows the effect of dielectric loading on bandwidth. Bandwidth increases with increase in the diameter of teflon cylinder.

The circulator operated with a somewhat degraded performance without the teflon cylinder. Maximum isolation decreased to about 30 dB for both the isolated ports but the insertion loss remained almost the same. Bandwidth also decreased to about 240 Mc.

Teflon ($\epsilon=2.1$) was chosen for use because it was readily available. Dielectric material of higher dielectric constant ($\epsilon=6$

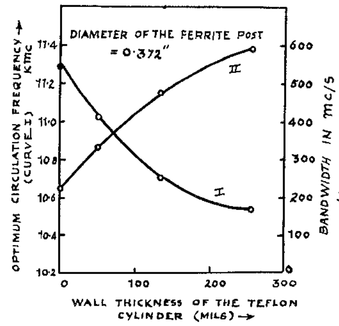

Fig. 3. Effects of dielectric loading on performance.

or 7) would have been much more effective in increasing the bandwidth.

The full height configuration has the advantage of having lower demagnetization factor that the partial height configuration because of the longer dimension along the direction of magnetization. This makes it possible to use a smaller magnet to supply the same internal magnetic field.

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Error of Doppler Radar in Target Speed Determination for Traffic Control

The purpose of this correspondence is to show the theoretical error of Doppler radar in target speed determination for traffic control due to its carrier frequency deviation. Most Doppler radars for traffic police utilize the tuning fork calibration technique immediately before monitoring the target speed.[1] In this way, the audio-frequency part of the Doppler radar is accurately calibrated. The police operator does not usually calibrate the carrier frequency before monitoring speed and no such instruction is usually given to the operator. According to the author's experience and the experience of others[2] an error due to the carrier frequency deviation is often asserted in court. Effect of short-time frequency fluctuation of the carrier frequency of a Doppler radar was investigated by Brady and found to be insignificant.[3] In this correspondence, the effect of long-time frequency deviation from the originally designed value due, for example, to a faulty power supply (such as the failure of the voltage regulator) or defected transmitter tube, is investigated. A relation among the target speed ν, carrier frequency f_0, Doppler frequency f_d, and the velocity of light c is given by the following well-known equation.[4,5,6]

$$f_d = \frac{2\nu}{c} f_0. \tag{1}$$

The output display from the Doppler radar is a speed meter which is actually a Dopper frequency counter output voltmeter. The speed scale on the output meter is calibrated in such a way that the scale is proportional to the Doppler frequency. If the proportionality constant is k, then the relation between the speed meter reading ν_m and the doppler frequency f_d is

$$\nu_m = kf_d = \frac{2k\nu}{c} f_0. \tag{2}$$

If, for some reason such as faulty power supply or a defective microwave transmitter tube, f_0 is deviated $\pm\Delta f_0$, then the meter will deviate $\pm\Delta\nu_m$.

$$\nu_m \pm \Delta\nu_m = \frac{2k\nu}{c}\cdot(f_0 \pm \Delta f_0). \tag{3}$$

Therefore, the error in the speed meter reading is

$$\Delta\nu_m = \frac{2k\nu}{c}\cdot\Delta f_0. \tag{4}$$

From (2), the proportionality constant is

$$k = \frac{c}{2f_0}\cdot\frac{\nu_m}{\nu}. \tag{5}$$

The scale of the speed meter was made in such a way that, if there is no fault, the reading ν_m is exactly equal to the target vehicle's speed ν. Therefore,

$$\frac{\nu_m}{\nu} = 1. \tag{6}$$

Substituting (6) to (5)

$$k = \frac{c}{2f_0} = \frac{\lambda_0}{2}. \tag{7}$$

It is interesting to note that *the proportionality constant between the speed meter reading and the Doppler Frequency is equal to the half wavelength* ($\lambda_0/2$) *of the carrier wave.* Substituting (7) into (4)

$$\Delta\nu_m = \nu\frac{\Delta f}{f_0} \tag{8}$$

or

$$\frac{\Delta\nu_m}{\nu} = \frac{\Delta f_0}{f_0} \tag{9}$$

applying (6) to (9)

$$\frac{\Delta\nu_m}{\nu_m} = \frac{\Delta f_0}{f_0}. \tag{10}$$

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[1] For example, *Manual, Stephenson Transistor Radar Speed Analyzers T-62A and T-63 Series*, Stephenson Corp., Red Bank, N. J.

[2] For example, an unpublished undated private copy of an article entitled, "Reprinted from Dicta, Radar Evidence in the Courts," by P. J. Carosell of the Denver Bar, Colo., and W. C. Coombs of the Denver Research Inst., University of Denver, Colo. This document was brought to the author's attention by T. H. Schaus, Attorney at Law, Milwaukee, Wis., before November 25, 1964.

[3] Brady, M. M., Frequency stability requirements on coherent radar oscillators, *Proc. IRE* (*Correspondence*), vol 47, May 1959, pp 1001–1002.

[4] Ridenour, L. N., *Radar System Engineering*, vol I, Radiation Lab. Ser. New York: McGraw-Hill, 1947.

[5] Barlow, E. J., Doppler radar, *Proc. IRE*, vol 37, Apr 1949, pp 340–355.

[6] Skolnik, M. I., *Introduction to Radar Systems.* New York: McGraw-Hill, 1962, p 72.

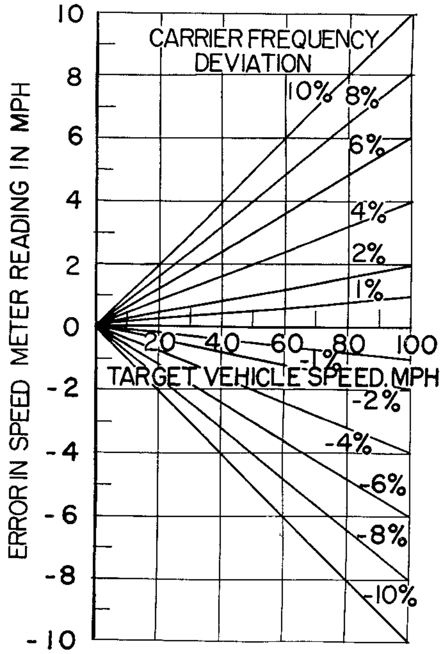

Fig. 1. Error in speed meter reading of a Doppler radar due to carrier frequency deviation.

This means that if the carrier frequency is deviated $(\Delta f_0/f_0)$ per cent then the error in the speed meter reading $(\Delta\nu_m/\nu_m)$ per cent is equal to $(\Delta f_0/f_0)$ per cent.

Equation (8) shows that the magnitude of the error is proportional to the product of both the target vehicle speed and the carrier frequency deviation. It should be noted that the error becomes greater for a high speeding target vehicle. The error of speed meter $\Delta\nu_m$ is plotted against the target speed ν for various carrier frequency deviation $\Delta f_0/f_0$ in Fig. 1. This figure is useful for any carrier frequency. The results shown in Fig. 1 and (10) suggest that if the carrier frequency deviation is less than one per cent which is normally the case (FCC Rules and Regulations Section 89.115), the error in the speed reading is less than one per cent. The previously stated analysis may have been carried out individually on private basis before[7] but to the author's knowledge the analysis shown in this correspondence has never been published as yet in a professional publication as a public document. Considerable effort was devoted to a search for such a document. There were many articles about Doppler radars for military and navigation applications but none of these were about police radar. Those found did not deal with the error analysis due to the long-time frequency deviation of the carrier. For example, Kelly's analysis[8] was about the pulsed Doppler radar error due principally to the signal to noise ratio and his theoretical equations are not directly applicable to this case. Goetz and Albright[9] discussed frequency stability of airborne Doppler radar but the accuracy was that of range accuracy and not of speed accuracy. The previously mentioned articles were for pulsed radar and not for the CW radar which is used by the police. Craig, Fishbein, and Rittenbach[10] discussed the error of a continuous wave Doppler radar. This error analysis was not due to the carrier frequency deviation but was rather a comparative study of a proposed new method of speed determination compared to other conventional methods. Doppler radar was analyzed for air navigations by Mayer[11] and Feurstein, Safran, and James.[12] Airborne Doppler radar was discussed in these articles, but error was not due to the long term deviation of carrier frequency. These articles are *not* directly related to the police's continuous wave Doppler radar. This is the reason why this writer presented the error analysis of the police's continuous wave Doppler radar for traffic speed determination due to the long-time deviation of the carrier frequency.

As microwave engineers it is important for us to know the foregoing fact and to inform the public.

ACKNOWLEDGMENT

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[7] An unidentified person who reviewed this author's unpublished note stated that he had tried similar analysis independently with this author before, and the unidentified person claimed that similar results were obtained.

[8] Kelley, E. J., The radar measurements of range, velocity and acceleration, *IRE Trans. on Military Electronics*, vol MIL-5, Apr 1961, pp 51–47.

[9] Goetz, L. P., and J. D. Albridgt, Airborne pulse-Doppler radar, *IRE Trans. on Military Electronics*, vol MIL-5, Apr 1961, pp 116–126.

[10] Graig, S. E., W. Fishbein, and O. E. Rittenbach, Continuous-wave radar with high range resolution and unambiguous velocity determination, *IRE Trans. on Military Electronics*, vol MIL-6, Apr 1962, pp 153–161.

[11] Mayer, R. H., Doppler navigation for commercial aircraft in the domestic environment, *IEEE Trans. on Aerospace and Navigational Electronics*, vol ANE-11 Mar 1964, pp 8–15.

[12] Feurstein, E., H. Safran, and P. N. James, Inaccuracies in Doppler radar navigation systems due to terrain directivity effects, nonzero beamwidths and eclipsing, *IEEE Trans. on Aerospace and Navigational Electronics*, vol ANE-11, Jun 1964, pp 101–111.

Optimum Transducer Coupling Coefficient of a Multiple Reflection Pulsed Microwave Delay Line

Delay lines have been made which propagate pulses of sonic waves at microwave frequencies,[1] and transducers are required to convert electromagnetic waves to sonic waves.

With a finite length of line, a long delay time can be obtained by multiple reflections. The coefficient of coupling of the transducers in a multiple-reflection microwave delay line cannot have any arbitrary value; the limit of zero coupling is trivial, and the other limit of total coupling will not produce a reflection.

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[1] Tehon, S. W., and S. Wanuga, Microwave acoustics, *Proc. IEEE*, vol 52, Oct 1964, pp 1113–1127.

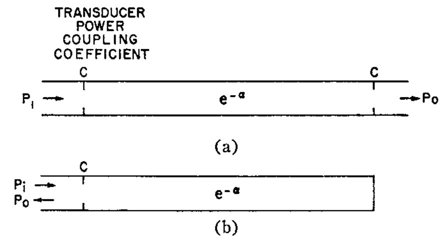

Fig. 1. Multiple reflection delay lines. (a) Two-transducer delay line. (b) One-transducer delay line.

The purpose of this correspondence is to present a short analysis on the optimum coupling coefficient for any desired number of reflections. The results differ depending on whether the delay line has either one or two transducers. A schematic representation of multiple-reflection delay lines is shown in Fig. 1. The two-transducer delay line may be referred to as a transmission-type delay line. The one-transducer delay line requires a ferrite circulator to prevent the outgoing delayed signal from appearing at the generator.

In this analysis it is assumed that a) the transducers are lossless, and b) the pulse length is short compared to the one-way sonic delay time in the medium.

SYMMETRICAL TWO-TRANSDUCER DELAY LINE

By referring to Fig. 1(a), the output power P_0 after n transits (n odd) within the symmetrical two-transudcer delay line is given by:

$$P_0 = P_i C^2 (e^{-\alpha})^n (1 - C)^{n-1}$$

where

P_i = input power

C = power coupling (or transmission) coefficient, equal value for input and output transducers

$e^{-\alpha}$ = single-transit sonic attenuation in delay medium.

If the derivative of P_0/P_i with respect to C is equated to zero, the following nontrivial solution is obtained:

$$C = \frac{2}{n+1}.$$

For example, if the signal is to be reflected 100 times, i.e., $n = 100$, then the optimum C is 0.02 or −17 dB; the VSWR of this transducer is about 200.

ONE-TRANSDUCER DELAY LINE

By referring to Fig. 1(b), the output power P_0 of a one-transducer delay line after n transits (n even), is given by:

$$P_0 = P_i C^2 (e^{-\alpha})^n (1 - C)^{(n/2)-1}.$$

If the derivative of P_0/P_i with respect to C is equated to zero, the following nontrivial solution is obtained:

$$C = \frac{4}{n+2}$$

For example, if the signal is reflected 100 times, i.e., $n = 100$, then the optimum transducer coupling is −14 dB.

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