Letters

Comments on "The Measurement of Noise in Microwave Transmitters"

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In the recent paper, "The Measurement of Noise in Microwave Transmitters," J. R. Ashley *et al.* [1] give a review of several methods for the measurement of AM and FM noise, respectively. The section, which deals with FM noise measurements at frequencies below 5 GHz, may be the source of erroneous conclusions, as will be pointed out in this comment. In the cited paper, the authors recommend the utilization of transmission-line discriminators. These discriminators, already discussed by the same authors somewhat earlier [2], are said to have an optimum line length for maximum discriminator sensitivity where the signal is damped by 1 Np during one round trip through the discriminating line [1, (42)]. This is true, if a delay line is used as a discriminator. In the papers subject of this comment [1], [2], however, Ashley *et al.* give rise for the opinion that the optimum line length also exists for a discriminator, which utilizes a transmission-line resonator. Although the delay-line discriminator has been discussed by Cheung [3] and the discriminator implemented with a resonator is a standard laboratory equipment, we shall derive special features of the various discriminators for the sake of clarity in the following. Fig. 1 describes both the delay-line discriminator (with the slide screw tuner removed) and the transmission line (TEM) resonator-discriminator (where the slide screw tuner is used for input matching). First, we calculate the input impedance Z at the input port of the transmission line to be

$$Z = Z_0 \frac{\sinh\left(\alpha n \frac{U_0}{\nu_c}\right)}{\cosh\left(\alpha n \frac{U_0}{\nu_c}\right) + \cos\left(2\pi n \frac{\Delta\nu}{\nu_c}\right)} \left\{ 1 + j \frac{\sin\left(2\pi n \frac{\Delta\nu}{\nu_c}\right)}{\sinh\left(\alpha n \frac{U_0}{\nu_c}\right)} \right\} \tag{1}$$

where

Z_0	characteristic impedance of transmission line components,
α	transmission line attenuation factor,
n	odd number,
U_0	phase velocity on the transmission line,
ν_c	carrier frequency,
$\Delta\nu$	small deviation from the carrier frequency,
$1 = (n/2)(U_0/\nu_c)$	length of the transmission line (odd multiple of half-wavelengths at the carrier frequency).

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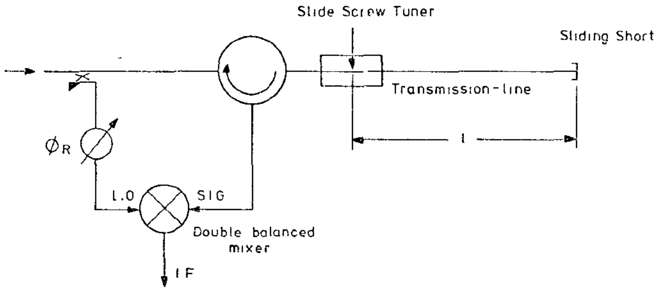

Fig. 1. Discriminator circuits.

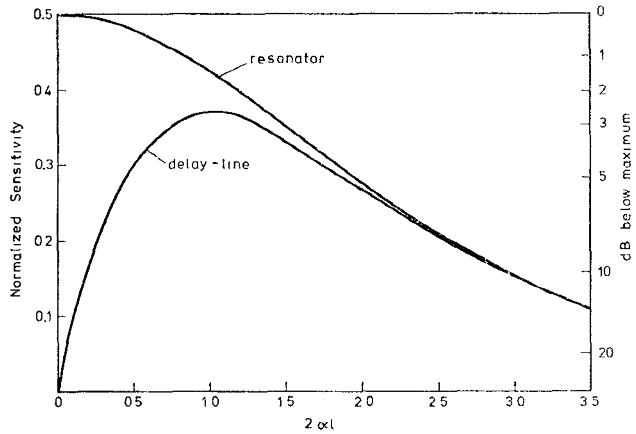

Fig. 2. Discriminator sensitivity versus length of the transmission line l for constant α.

Using (1) we derive the reflection coefficient at the input port of the transmission line for the delay line discriminator as

$$r_d = -e^{-\alpha n(U_0/\nu_c)} e^{-j2\pi n(\Delta\nu/\nu_c)}. \tag{2}$$

When using the TEM line of length $1 = n(\lambda/2)$ (λ is the wavelength) as a resonator, matching is established between the resonator and the adjacent (lossless) transmission line of characteristic impedance Z_0 by means of a slide screw tuner. Hence we obtain from (1) the input reflection coefficient of the resonator

$$r_r = \frac{1}{2} \frac{\sin\left(2\pi n \frac{\Delta\nu}{\nu_c}\right)}{\sinh\left(\alpha n \frac{U_0}{\nu_c}\right)} e^{j(\pi/2)} \tag{3}$$

where $\cos\left(2\pi n(\Delta\nu/\nu_c)\right) \approx 1$ is assumed.

From (2) and (3) we calculate the output amplitude of the double balanced mixer. The output voltage is optimized by a proper choice of the reference phase ϕ_R at the LO input of the mixer. Equation (2) yields for the delay line discriminator

$$v_d = Ae^{-\alpha n(U_0/\nu_c)} \sin\left(2\pi n \frac{\Delta\nu}{\nu_c}\right) \tag{4}$$

and (3) for the discriminator with a resonator

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$$v_r = \frac{A}{2} \frac{\sin\left(2\pi n \frac{\Delta\nu}{\nu_c}\right)}{\sinh\left(\alpha n \frac{U_0}{\nu_c}\right)} \tag{5}$$

respectively, where

- v_d output voltage of the delay-line discriminator,
- v_r output voltage of the resonator discriminator,
- A incident amplitude at the circular input.

Finally, we obtain the sensitivity for the delay-line discriminator

$$S_d = \frac{dv_d}{d(\Delta\nu)} = Ae^{-\alpha n(U_0/\nu_c)} \cos\left(2\pi n \frac{\Delta\nu}{\nu_c}\right) \frac{2\pi n}{\nu_c} \tag{6}$$

and for the discriminator with a resonator

$$S_r = \frac{dv_r}{d(\Delta\nu)} = \frac{A}{2} \frac{\cos\left(2\pi n \frac{\Delta\nu}{\nu_c}\right)}{\sinh\left(\alpha n \frac{U_0}{\nu_c}\right)} \frac{2\pi n}{\nu_c}. \tag{7}$$

Both sensitivities are maximum at $\Delta\nu = 0$, and we can write in a normalized form

$$s_d = \frac{S_d}{\frac{1}{\alpha} \frac{2\pi}{U_0} A} = e^{-2\alpha l} 2\alpha l \tag{8}$$

and

$$s_r = \frac{S_r}{\frac{1}{\alpha} \frac{2\pi}{U_0} A} = \frac{1}{2} \frac{2\alpha l}{\sinh(2\alpha l)}. \tag{9}$$

It should be stressed that neither the sensitivity s_d nor s_r depend on frequency ν_c, as may be deduced from [1] (especially (39) and some remarks at p. 308). The sensitivities from (8) and (9) are plotted in Fig. 2 versus the line length. It is seen, that the sensitivity for a discriminator with a resonator is always better than the sensitivity of a delay line. The best choice in line length for the first one is $l = (\lambda/2)$ $(n = 1)$, if losses at the ends of the transmission-line resonator are neglected. The maximum sensitivities are in the ratio

$$\frac{s_r}{s_d} = \frac{e}{2} \tag{10}$$

that means the delay line discriminator is about 2.6 dB worse in sensitivity.

References

[1] J R. Ashley, T. A. Barley, and G. J. Rast, "The measurement of noise in microwave transmitters." *IEEE Trans., Microwave Theory Tech.*, vol. MTT 25, pp. 294–318, Apr. 1977.

[2] ——, "Transmission line discriminators for FM-noise measurements," in *Proc. IEEE* (Letters), vol. 64, pp. 578–580, Apr. 1977.

[3] W. N. Cheung, "The measurement of FM-noise from Gunn oscillators using a microwave interferometer," *Int. J. Electronics*, vol. 3, pp. 809–815, 1974.