The Match Checker—A Simple Instrument for Matching Impedances in Waveguide and Coaxial Systems

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Abstract—The match checker [1] is a self-contained passive device, which, when inserted between ports of a waveguide or coaxial-line system, provides an indication of the mismatch at each port.

It does not require tuning, and internal reflections from components of the match checker do not limit the accuracy of the match which may be obtained. It is therefore suitable for use in matching ports with the high precision needed for calibration systems.

INTRODUCTION

When making measurements in waveguide and coaxial-line systems, it is often necessary to ensure that parts of the system are accurately matched to the guide or line impedance. For example, when an attenuator is being calibrated, it must be connected between a matched "source" and a matched "receiver." In practice, each of these ports may be connected to a combination of tuner and isolator which must be removed from the calibration system and attached to a reflectometer, adjusted to an exact match, and replaced. Alternatively, a reflectometer [2], [3] and its auxiliary equipment has to be brought to the ports. As the match has to be checked from time to time, and always when the frequency is changed, there has been a long-standing need for a simple device which, when inserted between two ports, would show, for each port separately, the degree of mismatch from the characteristic impedance of the coaxial line or waveguide.

DESCRIPTION AND OPERATION

The match checker, shown schematically in Fig. 1, consists essentially of a piece of waveguide or coaxial line, several wavelengths long, containing a movable bilaterally matched attenuator and a movable reflector. The waveguide or line must be accurately made, because it serves as the impedance standard to which the source and receiver will be matched. The reflector may be mechanically locked in positions at either end of the attenuator as shown in Fig. 1(a) and (b), and the combination may be moved backwards and forwards along the waveguide by the operator. Throughout their travel, the attenuator and reflector retain a fixed separation.

The match checker is used in two different modes, one for coarse, and one for fine matching. For coarse matching the attenuator is first set to face (say) the receiver port with the reflector at the opposite end facing the source, as shown in Fig. 1(a). The attenuator-and-reflector combination is then left stationary while the tuner of the receiver port is adjusted for maximum power transfer. The reflector is then moved to the position shown in Fig. 1(b) and the source port is adjusted similarly.

To fine-tune the receiver, the reflector is left as in Fig. 1(b) and the operator observes the rise and fall in the transmitted power as the attenuator-and-reflector combination is moved along the guide. The receiver tuner is then adjusted until the minimum variation is observed. The reflector is then moved to face the source as in Fig. 1(a) and the source is fine-tuned in the same way.

It may be necessary to repeat this procedure, but the two adjustments are almost independent and the correct settings may be found rapidly.

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Match checkers of this kind have been constructed in two different ways. In one form, an attenuating vane and a reflecting metal ring, designed to have a reasonably constant reflection over the band, are inserted through the slot in the center of the broad wall of a precision waveguide and are moved along the central plane by guides attached to an external carriage. To change ends, the reflector is withdrawn from the slot and reinserted at the opposite end of the attenuator.

The second method of construction avoids the need for slotting the guide. In this form, both the attenuator and the reflector are less than half waveguide height and are held in position and moved by thin dielectric cords which enter and leave the waveguide through small holes near the ends. These cords are held under tension around drums which may be rotated by the operator. The attenuator is a double-ended wedge of lossy material, shaped for low reflection, and the reflector is a ball-bearing, supported on a Teflon (polytetrafluoroethylene) carriage. A ball is used because it has a comparatively constant reflection over the band [4].

When checking a port, the two drums are locked together so that the reflector remains fixed in relation to the attenuator while the combination is moved up and down the waveguide. To match the second port, the drums are first rotated relative to each other to bring the reflector to the other end of the attenuator and then locked.

Whichever construction is used, the reflector must be constrained to move accurately along a path parallel to the internal surfaces of the guide; departures show up as spurious variations in the output. To ensure this, the moving components are supported on Teflon pads, pressing lightly against the inner walls.

THEORY

Fig. 1(c) shows a flowgraph of the match checker fitted between source and receiver ports having reflection coefficients Γ_s and Γ_r, respectively. The attenuator is assumed to have a small mismatch Γ_a at a distance x from the source and a voltage attenuation ratio α. On the receiver side, the small reflection from the attenuator and the reflector together are represented by Γ_m at the distance $l - x$ from the receiver.

The voltage transferred through the match checker S_{21} is

$$S_{21} = \frac{\epsilon^{-j\beta l}\alpha(1 - \Gamma_a)(1 - \Gamma_m)}{1 - \epsilon^{-j2\beta(l-x)}\Gamma_r[\Gamma_m + \alpha^2\Gamma_a(1 - 2\Gamma_m)] - \epsilon^{-j2\beta x}\Gamma_s[\Gamma_a + \alpha^2\Gamma_m(1 - 2\Gamma_a)] - \epsilon^{-j2\beta l}\Gamma_r\Gamma_s[\alpha^2(1 - 2\Gamma_m)(1 - 2\Gamma_a) - \Gamma_a\Gamma_m] - \alpha^2\Gamma_a\Gamma_m}. \quad (1)$$

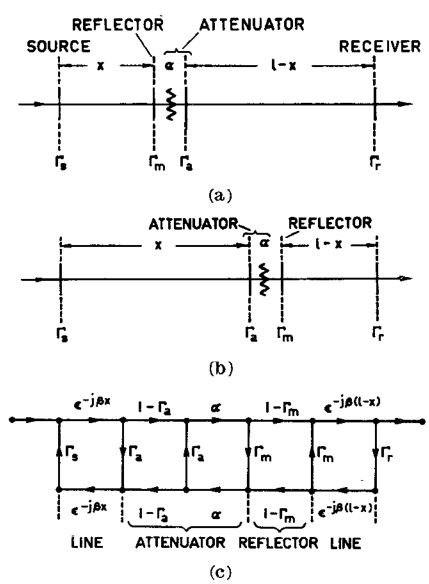

Fig. 1. The match checker inserted between source and receiver ports in a transmission system. (a) The relative positions of the reflector Γ_m and the attenuator α for fine-tuning the source port. (b) For fine-tuning the receiver port. (c) A flowgraph of the match checker arranged as shown in (b).

As α^2 and $\Gamma_a \ll 1$,

$$S_{21} \simeq \frac{\epsilon^{-j\beta l}\alpha(1 - \Gamma_a)(1 - \Gamma_m)}{1 - \epsilon^{-j2\beta(l-x)}\Gamma_r\Gamma_m}. \tag{2}$$

When the attenuator–reflector combination is moved along the guide, only x is varied, and the output exhibits a fluctuation having a maximum to minimum ratio w, where

$$w \simeq (1 + |\Gamma_r\Gamma_m|)/(1 - |\Gamma_r\Gamma_m|). \tag{3}$$

Fig. 2 is a plot of this relation which represents the sensitivity of the match checker.

Equations (1)–(3) apply when the reflector is set to face the receiver port. When the reflector is in its second position, facing the source, Γ_r and Γ_s must be exchanged. Because w increases with Γ_m, the reflected voltage should be made large. However, a large mismatch reduces the transmitted signal, and also is difficult to keep constant during its travel along the guide; for these reasons $|\Gamma_m| \simeq 0.5$ has been used.

Superimposed upon w is a much smaller fluctuation which results from interactions between the source Γ_s and the attenuator Γ_a and also Γ_s and Γ_m through the attenuator, as shown by the third term in the denominator of (1). This fluctuation is reduced as α is made smaller until a value is reached which makes the two terms of the unwanted fluctuation roughly equal, i.e., $\Gamma_a \simeq \alpha^2\Gamma_m(1 - 2\Gamma_a)$. If $|\Gamma_a| = 0.03$ and $|\Gamma_m| = 0.5$, then $\alpha^2 \leq 0.064$ and the attenuation should be at least 12 dB.

The unwanted fluctuation is proportional to the reflection from the port facing the attenuator, not the port being tuned; therefore, to ensure that it remains small in comparison with the wanted fluctuation, the two ports should be tuned in turn.

It should be noted that as the tuning proceeds, and Γ_r and Γ_s approach zero, both wanted and unwanted fluctuations diminish; therefore the residual imperfections do not prevent a perfectly matched condition of Γ_r and Γ_s from being achieved.

In the theoretical treatment above it was assumed that Γ_m and α are constant; however, in practice, both vary slightly in magnitude during movement along the waveguide. It was found that for the X-band match checker the combination of these imperfections resulted in a standard deviation of w representing an uncertainty in Γ_r and Γ_s of 0.0008. This is attributed to lack of uniformity in the commercial waveguide used. If it is required to reduce residual reflections to this order of magnitude, lapped precision flanges must be used.

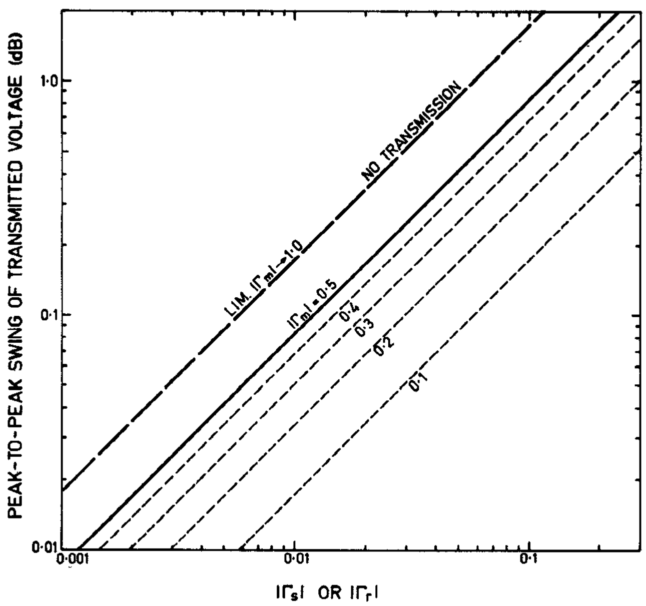

Fig. 2. The rate of maximum to minimum transmitted voltage produced by moving the reflector-and-attenuator combination along the waveguide. For example, if the reflector $|\Gamma_m| = 0.5$ is set facing the source, and the source mismatch $|\Gamma_s| = 0.01$, the indicated output will vary by ~0.08 dB.

CONCLUSION

The match checker has proved to be a useful and practical device for tuning component parts of any transmission system whenever an accurate match is required. It is a portable passive device, requiring no tuning and thus may be used in the laboratory or in the field.

When it is inserted between ports to be matched, the variation in transmitted signal on sliding the reflector–attenuator combination is a measure of the mismatch of the port facing the reflector; thus no auxiliary equipment is required, as the original signal source and detector are used. Active and passive ports are checked by the same procedure, with active ports in the active condition, which distinguishes the match checker from slotted lines and reflectometers in their usual modes of operation.

As constant reflections caused by imperfection in the instrument do not in any way prevent an accurately matched condition from being achieved, it is suitable for obtaining the degree of match required for precision measurements.

ACKNOWLEDGMENT

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Design Equations and Bandwidth of Loaded-Line Phase Shifters

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***Abstract*—Design equations for a loaded-line phase shifter are derived for any susceptance spacing. An analysis based on these relations shows that maximum bandwidth is obtained when the spacing between the switched susceptances is 90°.**

INTRODUCTION

The digital loaded-line phase shifter shown in Fig. 1(a) remains a popular and useful device for obtaining small-bit phase shifts up to approximately 45°. Recently, there has been some discussion over whether the optimum shunt susceptance separation θ should be 75 or 90°. Garver [1], on the basis of his lossless diode model, states that $\theta = 90°$, gives the widest bandwidth, while Opp and Hoffman [2] and Yahara [3], using lossy diodes find that smaller phase error, standing-wave ratio (SWR), and loss is achieved using $\theta = 75°$. A rigorous evaluation of the tradeoff between these performance parameters and bandwidth has been hindered by the

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