FREQUENCY DISCRIMINATORS FOR BROADBAND APPLICATIONS

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ABSTRACT

Frequency discriminators are widely used in electronic warfare systems for the instantaneous frequency measurement of intercepted signals, allowing rapid identification of threat emitters. This paper reviews microwave discriminator architectures based on multiple delay line, phase measurement with parallel digital processing, for operation over decade bandwidths. An alternative reflection mode discriminator architecture is introduced which exhibits the advantages of simplicity, compact realisation and can be designed over broad bandwidths. The principle of operation, circuit design techniques and frequency measurement performance are described and examples are given of mature designs which have been successfully manufactured in production quantities.

INTRODUCTION

Instantaneous Frequency Measurement receivers (IFMs) are widely used in ESM systems for rapidly identifying the frequency of pulsed signals. In dense signal environments the frequency parameter allows pulse train de-interleaving to be performed and imminent threats to be identified. The essential component used in the IFM is the frequency discriminator which converts the input microwave frequency into a quantity such as voltage which can then be further processed to give the desired frequency measurement output.

This paper outlines the architectures used in IFMs based on conventional discriminators designed with broadband coverage and goes on to describe a circuit configuration which can be easily designed for single band operation over decade bandwidths.

ARCHITECTURES

Frequency discriminators conventionally use the delay line correlator as the basic measurement element [1] as shown in figure 1.

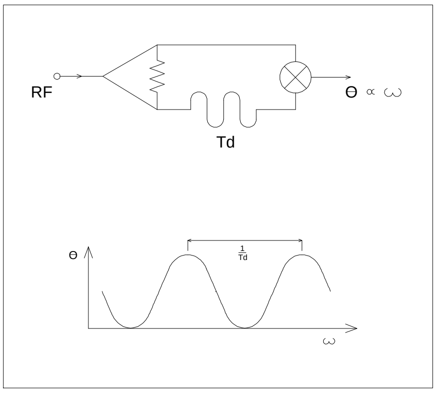

Figure 1. Basic delay line correlator

The input signal is split and fed into a phase detector via a delayed and non-delayed path respectively. The phase difference between these two paths is related to the input frequency f by

$$\vartheta = \omega T_d \quad \text{radians}$$

Where $\omega = 2\pi f$ and T_d = delay length

Figure 2. shows a realisation of such a discriminator using hybrid couplers and detectors to give four output voltages related to frequency by

$$V_1 = 1 + \cos(\omega T_d)$$
$$V_2 = 1 - \cos(\omega T_d)$$
$$V_3 = 1 + \sin(\omega T_d)$$
$$V_4 = 1 - \sin(\omega T_d)$$

And the phase angle calculated by

$$\theta = \ tan^{-1} \frac{V_1 - V_2}{V_3 - V_4}$$

For long delay lines the cyclic nature of ϑ results in ambiguous frequency measurement with unambiguous bandwidth *UBW* given by

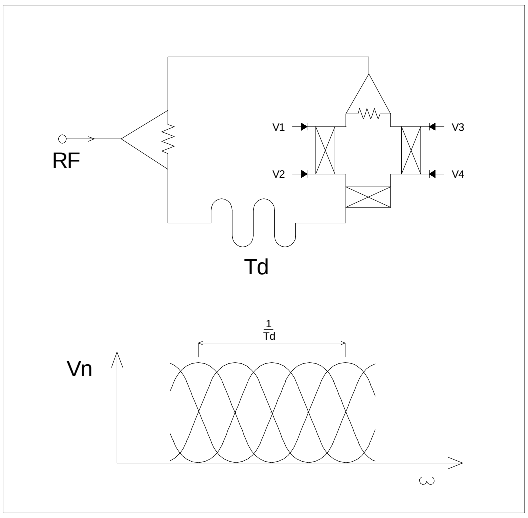

Figure 2. Delay line quadrature discriminator

$$UBW = \frac{1}{T_d}$$

For accurate frequency measurement long delays are required, whereas for unambiguous measurement over a broad band short delays are required. By using a number of discriminators operating in parallel with varying delay lengths the ambiguities can be progressively resolved by appropriate processing of the combined discriminator outputs. Figure 3. Shows a typical IFM using four tiers of discriminators with outputs combined to give a single unambiguous output.

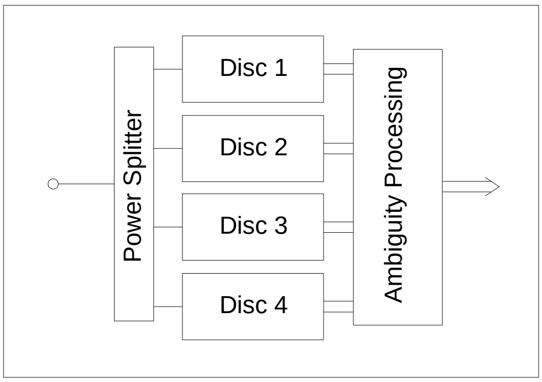

Figure 3. Multitier Discriminator

ALTERNATIVE DISCRIMINATORS

The quadrature discriminator described above using hybrid couplers generates very accurate frequency characteristics, but can be difficult to design and manufacture for extremely wide bandwidths and can consume large areas of microwave real estate [2]. In multi-tier architectures the lower resolution discriminator tiers do not require such high measurement accuracy, so an alternative circuit configuration can be used which offers inherent broad bandwidth, simplicity and small size. Known as the reflection mode discriminator its operation is described as follows.

Consider a series connection of a resistor and a length of transmission line terminated in a short circuit as shown in figure 4. At frequencies where the line is a multiple of a half wavelength the incident power can be dissipated in the resistor, whereas at odd multiples of a quarter wavelength the resistor sees no RF power. Figure 5. Shows the power in the resistor vs frequency is cyclic with period $1/2T_d$.

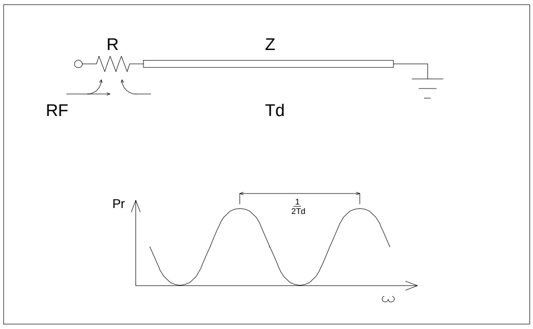

Figure 4. Reflection discriminator

Now by introducing two more resistors and lines with ideal phase shifters of 60 and 120 degrees respectively, three interleaved characteristics suitable for a discriminator can be generated as shown in figure 5.

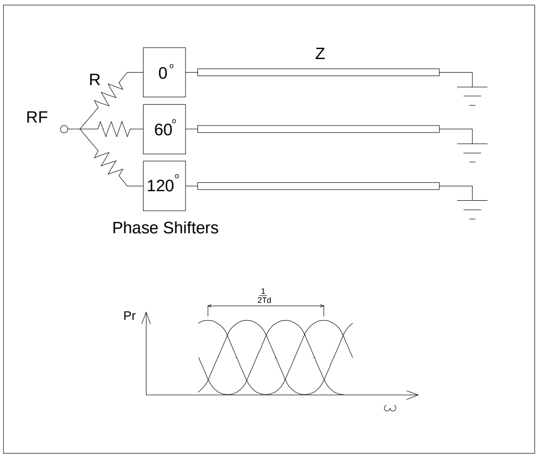

Figure 5. Three phase discriminator

By choosing the resistor values and line impedances to be 75 ohms, all of the incident power from a 50 ohm source is divided between the resistors, giving a perfect input match. Now replacing the resistors by square law detectors three output voltages are generated:

$$V_1 = 1 + sin(\omega T_d)$$

$$V_2 = 1 + sin\left(\omega T_d + \frac{2\pi}{3}\right)$$

$$V_3 = 1 + sin\left(\omega T_d + \frac{4\pi}{3}\right)$$

Taking the appropriate ratios of differences, the phase angle can be derived which is independent of amplitude.

PHASE SHIFTER DESIGN

A number of microwave structures can be used to provide frequency independent phase shifts, such as schiffman sections and meander lines [3], however these also introduce a significant electrical length in order to produce the phase shifts required. For discriminators with large unambiguous bandwidths a shorter structure would be useful, and given that we have a reflective line which can be either open or short circuit the concept of a reflection mode phase shifter is suggested. By stepping the impedance of the lines and terminating in both open and short circuits as shown in figure 6. the reflection differential phase shifts which are constant vs frequency are generated as shown. The impedance values may be derived by synthesis for equidistant linear phase approximation to a constant phase shift [4], however these do not exhibit equiripple phase, so the designs here were derived by computer aided optimization. Smaller unambiguous bandwidths are produced by adding equal Z_0 lengths to each arm.

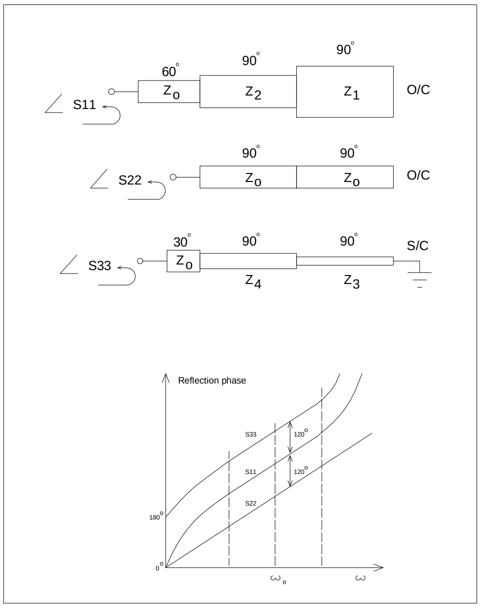

Figure 6. Stepped impedance phase shifters

DESIGN EXAMPLE

Figure 7. shows an example of a decade bandwidth reflection mode, three phase discriminator designed to cover 1.8 to 18 GHz. The phase shifters use three section stepped impedance lines, giving equiripple phase error of less than +/-2 degrees.

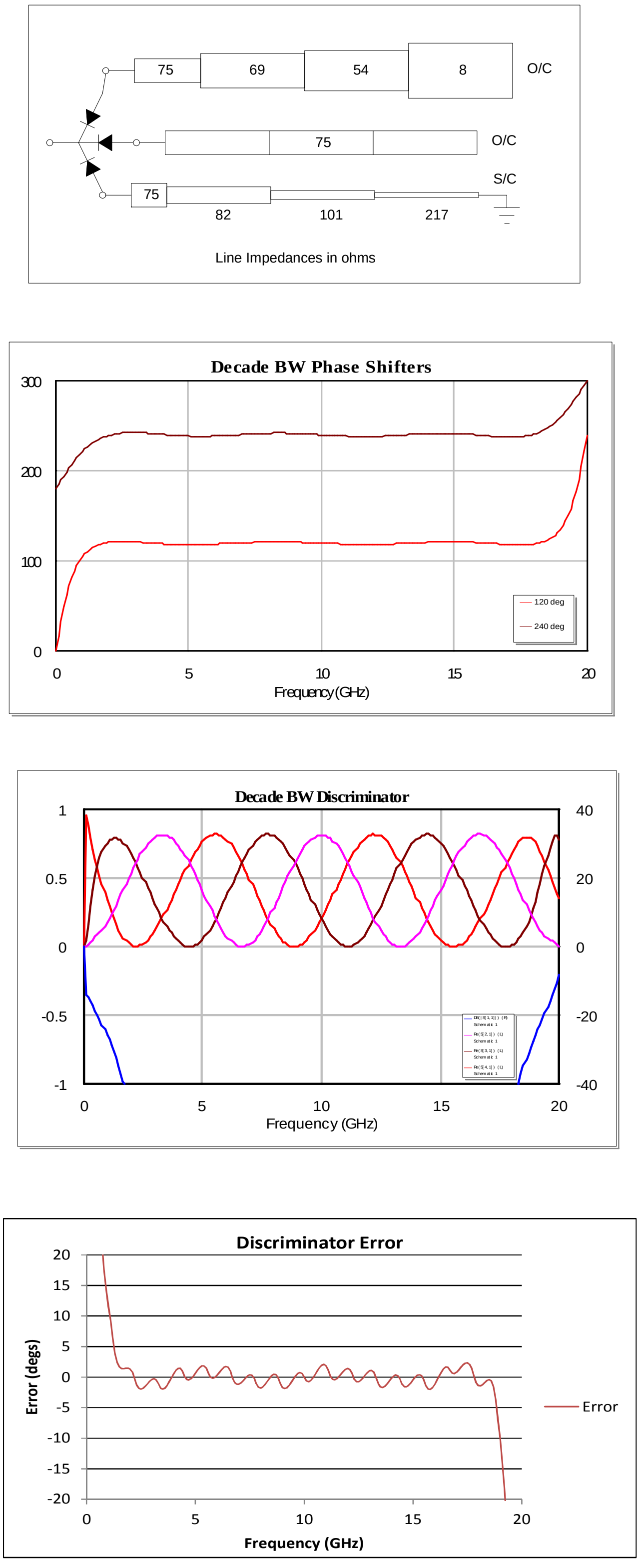

Figure 7. Decade Bandwidth Discriminator Design Example

PRACTICAL CIRCUIT ISSUES

Three phase discriminators have been realized in suspended substrate stripline which provides a convenient means of achieving the high impedances, and with backside metalisation, the low impedance sections also. The video outputs from the detectors are extracted from the terminated ends of the lines via wound chokes for the open circuit lines and chip or microstrip capacitors for the shorted line. Low parasitic schottky detectors in beam lead packages can be mounted on chip resistors which act as carriers and also pad off the high detector impedance down to the required 75 ohms. A dc return choke to ground or some bias voltage at the RF input completes the detector circuit.

Figure 8. shows a photo of a discriminator used in a 2-18 GHz multi-tier IFM for an airborne application. The line lengths give this design an unambiguous bandwidth of 2.5 GHz.

The top line steps to low impedance, the centre line to a high impedance and the lower line a uniform 75 ohms.
Video chokes can be seen on the right hand side, the three detectors on the left and the dc return coil on the feed line.
The holes shown in the grounded areas are plated through to provide a solid ground connection between the cover lid and base, forming isolated cavities around the lines.

CONCLUSIONS

The use of multiple discriminator tiers for wideband IFMs is described with reference to ambiguity resolution and conventional delay line phase correlator discriminators outlined. An alternative compact discriminator architecture is developed and shown to operate over extremely wide bandwidths which can be used to advantage for the ambiguity resolving tiers. The design principles are demonstrated with a decade bandwidth example and a brief mention given on some of the practical circuit issues.

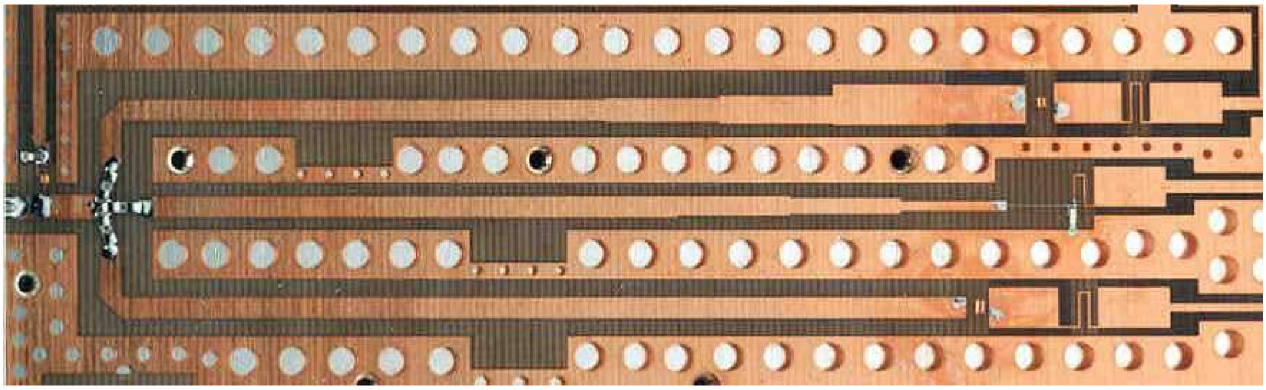

Figure 8. Photo of a reflection mode discriminator

ACKNOWLEDGEMENT

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This and other discriminator designs were originally used in IFM products manufactured by Filtronic Components Ltd and are now manufactured by Teledyne UK Ltd

The paper is published with kind permission of Teledyne UK.

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