HIGH DYNAMIC RANGE VIDEO DETECTOR

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ABSTRACT

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A design technique yielding high dynamic range video detectors is described. Increased power handling capability is gained by combining multiple detector diodes utilizing a distributed element design approach for the impedance matching structure. Bandwidth ratios greater than 10:1 with upper passband extremes to 40GHz are realizable. VSWR of less than 2:1 has been realized covering the entire dynamic range of the detector which extends to in excess of +10dBm incident power level. The video detector is comprised of an artificial transmission line wherein the shunt capacitive elements are spaced semiconductor detector diodes and the interconnecting bonds form the series elements.

SUMMARY

A design approach for broadband high dynamic range video detectors has been presented herein. The performance data shows that video detection can be achieved for input levels exceeding +10dBm maintaining excellent VSWR performance throughout the dynamic range while retaining good sensitivity. The data presented was taken from designs implemented using MIC construction but MMIC implementation is feasible and, perhaps, preferred.

Introduction

Broadband high dynamic range video detectors are required in modern crystal video receivers. This need fostered the development of the distributed element (traveling wave) detector described in this paper. The fundamental design approach is to share the incident signal power amongst several diodes and a load resistance, thereby, increasing the detector's power handling capability. The diode's parasitic capacitance is incorporated into an artificial delay line to distribute the reactance averting restriction of the RF bandwidth. Several configurations of the basic design concept have been built. Two frequency ranges have been covered; 0.5 to 6.6 GHz and 2 to 18 GHz. Performance data presented herein demonstrates that improved power handling in crystal video receivers can be obtained utilizing the distributed element design concept. The design approach can be implemented in either MIC or MMIC format.

Technical Discussion

The fundamental relationships governing the behavior of crystal video detectors are well known. [References 1, 2, 3, 4, and 5.] The transfer characteristic of the detection process is generally divided into two regions which are referred to as square law and linear. The transition between the two regions is gradual. A typical video detector transfer characteristic is depicted in Figure 1. The detected current i in the square law range is represented by the relationship shown in Equation 1.

$i = \beta v^2$ Equation 1

i = detected current
β = Figure of merit
v = RF rms voltage impressed on diode junction

The detected current in the linear range is defined by the relationship given in Equation 2.

$i = \beta' v$ Equation 2

The voltage developed across a RF load, RL, is given by the simple relationship of Equation 3.

$V^2 = PR_L$ Equation 3

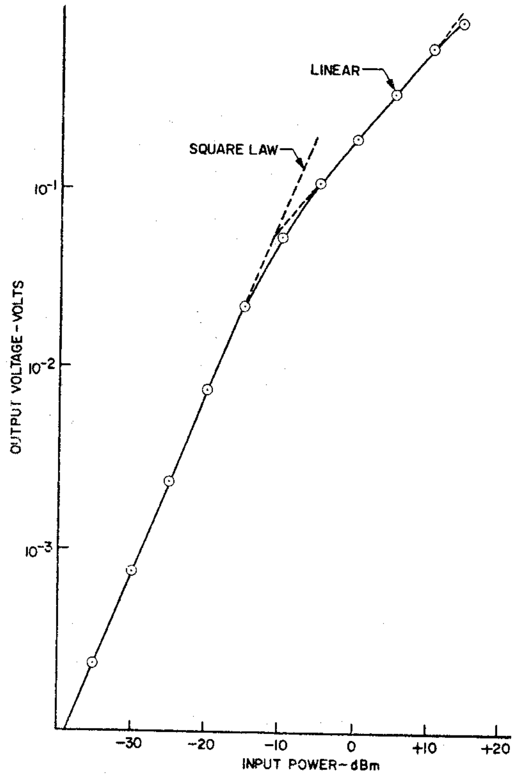
where P = incident power
R_L = load resistance

It follows then that the detected current in the square law region is as given below. Equation 4.

$$i = \beta PR_L \quad \text{Equation 4}$$

whereas the linear range is given by the expression in Equation 5.

$$i = \beta' \sqrt{PR}_L \quad \text{Equation 5}$$



Conventional video detector design approaches utilize the barrier resistance of the diode as the RF load resistance. This approach produces maximum sensitivity. An undesirable product of this design approach is the fact that the barrier resistance (RF load resistance) is a function of the incident power level. Exiting the square law region of the detection process results in the onset of dramatically increased VSWR. Poor VSWR is detrimental to the overall receiver performance. A previous approach countering this problem used a fixed resistor paralleling the diode impedance to serve as the primary RF load [Reference 6]. This design approach is marginally acceptable. Sensitivity is sacrificed in that some of the incident power absorbed in the fixed resistance and not available for the detection process. More troublesome, however, is the fact that the technique has RF bandwidth limitations which are a function of the parasitic elements of the diode.

The video detector design approach described herein shares the incident power with multiple diodes in addition to a fixed resistance. Multiple diode detectors have been previously reported [Reference 7]. The authors did not, however, disclose any attempt to distribute the parasitic diode capacitance which is the key to wide bandwidth.

Embedding multiple diodes in a distributed element structure permits them to be effectively paralleled. This structure yields a high dynamic range video detector with broad RF bandwidth, wide video bandwidth capability, excellent VSWR and good sensitivity. One example of a distributed element multi-diode detector is shown in the schematic of Figure 2. Periodically spaced diodes in an artificial transmission line structure are depicted.

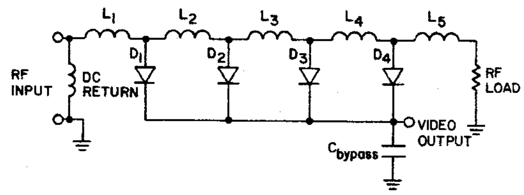


FIGURE 2. SCHEMATIC DIAGRAM, DISTRIBUTED DETECTOR

The structure averts deleterious accumulation of the parasitic junction capacitance which ordinarily restricts the RF bandwidth capability. The equivalent circuit of this structure is shown in Figure 3. Any number of diodes can be employed in the arrangement but an arbitrary practical limit exists.

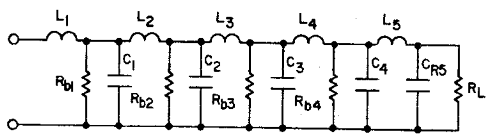


FIGURE 3. RF EQUIVALENT CIRCUIT, DISTRIBUTED DETECTOR

As stated above, the primary RF load is a fixed resistor rather than the diode barrier resistance. This aspect of the design reduces the input impedance dependency on incident power level. Additionally, the diodes can be lightly biased reducing the generated shot noise. The transmission line characteristic impedance should be as high as possible from the viewpoint of sensitivity, but if different from the system impedance, a mismatch developes. Secondly, more of the incident power is shared with the diode barrier resistance increasing the detector's behavior sensitivity to the incident power level.

The network is formed using the diode junction capacitance coupled with an inductance taking the form of either a lumped element or section of high impedance transmission line. Unless the diodes are heavily biased, the diode's series resistance can be ignored since it proves to be negligible with respect to the barrier impedance. Each section of the transmission line follows the relationship.

$$Z = \sqrt{L/C} \quad \text{Equation 6}$$

The detected signal is developed across the parallel combination of the barrier resistances and RF load resistance as was indicated in Figure 3. The equivalent circuit from video point of view is shown in Figure 4.

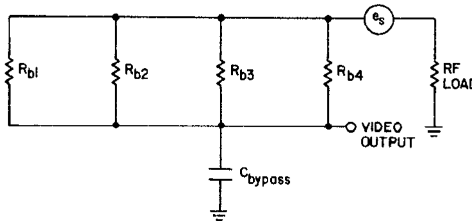


FIGURE 4. VIDEO EQUIVALENT CIRCUIT, DISTRIBUTED DETECTOR

Note that the diode impedances are effectively in parallel which reduces the effective source impedance. Maximum sensitivity is achieved when operating into a high impedance load for voltage amplification and into a short circuit impedance for current amplification. A schematic of the equivalent video circuit, when including the shot noise sources, is shown in Figure 5. The Johnson noise is negligible in comparison to the shot noise, therefore, it is not included. Since the current sources are in parallel, the x currents sum in the following manner.

$$i^2_{nsum} = i^2_{n1} + i^2_{n2} + \dots i^2_{nx} \quad \text{Equation 7}$$

Note that less noise current is produced from a plurality of diodes in parallel than from a single diode with equal total bias current. This condition results from the fact that the phase of the noise from each diode is random and independent. The

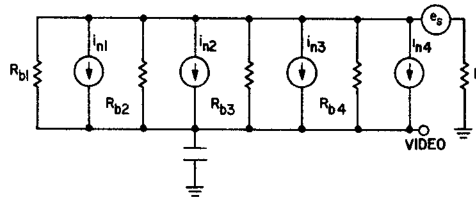


FIGURE 5. NOISE EQUIVALENT CIRCUIT, DISTRIBUTED DETECTOR

detected signal currents, however, are in phase. Thus, the resulting tangential sensitivity is not dramatically affected by the fact that much of the incident rf signal is dissipated in the fixed load resistance rather than the diode junctions. The noise current from each generator is given in Equation 8.

$$i^2 = 2qBI \quad \text{Equation 8}$$

q = charge of an electron 1.6×10^{-19}

I = diode current - amperes

B = video bandwidth

Minimization of the bias current produces the least noise. The detector can be operated over a wide range of bias current without markedly affecting its performance. Good VSWR is also achieved over a wide range of bias current. Consideration must be given to the desired video bandwidth requirement, however, since the bias current selection affects the video source impedance.

A variety of circuit configurations can be selected for the detector using the distributed element concept. While each diode represents an independent source of detected signal, the detected voltages do not sum when they are paralleled. A circuit configuration has been devised to, in effect, have the voltages add to develop an improved detector figure-of-merit. A schematic diagram of this circuit configuration is shown in Figure 6. The circuit is a

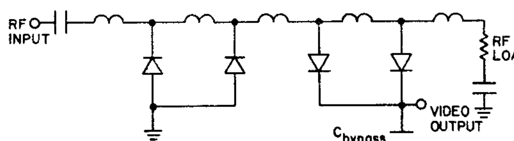


FIGURE 6. SCHEMATIC DIAGRAM, DISTRIBUTED DETECTOR OPPOSITE POLARITY DETECTOR

variation of the voltage doubler concept which has existed for many years (Reference 4, pg. 66.). The scheme uses opposite polarity diodes to obtain the voltage doubling feature. This scheme produces a detector figure-of-merit on the order of 1000 mv/mw.

The frequency response and return loss for various incident signal levels are given in Figures 7 thru 10. The performance of a 2-18 GHz detector is given in Figures 7 and 8. Figures 9 and 10 depict the performance of a 0.5 to 6.6 GHz detector design. The +5dBm signal level represents the maximum output level of the test apparatus. The detector has been exposed to power levels in excess of +20 dBm with no indication of performance degradation in the operating dynamic range.

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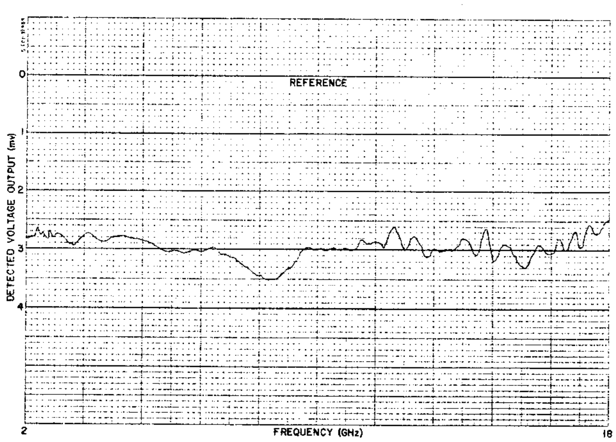

FIGURE 7. MEASURED DETECTOR FREQUENCY RESPONSE WITH (−)20dBm INCIDENT SIGNAL INPUT WITH 100 MICROAMPERES OF BIAS

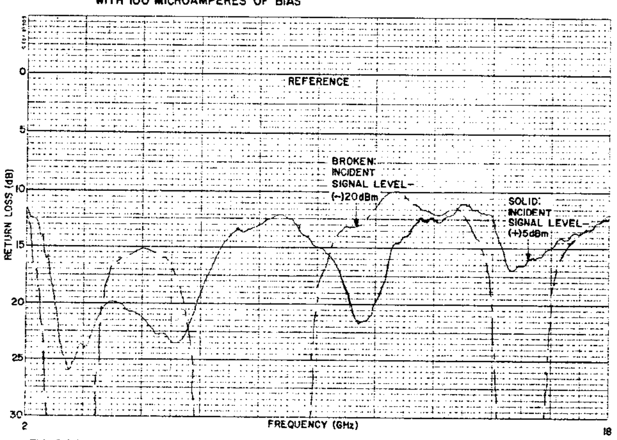

FIGURE 8. MEASURED RETURN LOSS AT INCIDENT INPUT POWER LEVELS OF (−)20dBm AND +5dBm WITH 100 MICROAMPERES BIAS

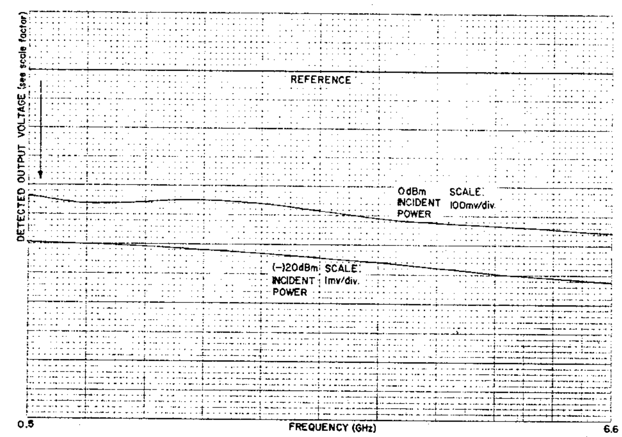

FIGURE 9. MEASURED FREQUENCY RESPONSE FOR INDICATED INCIDENT POWER LEVELS BIAS: 100 MICROAMPERES VIDEO LOAD RESISTANCE: 330Ω

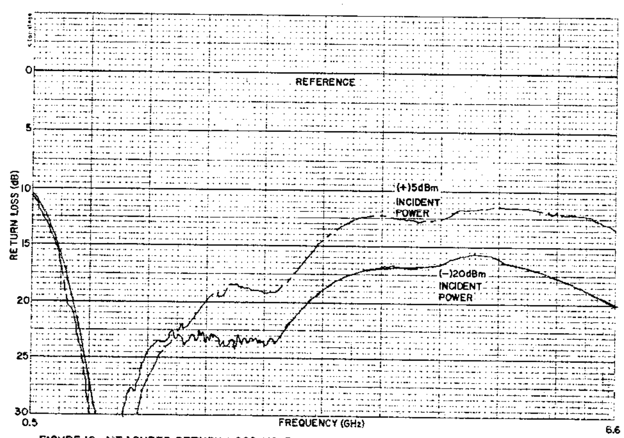

FIGURE 10. MEASURED RETURN LOSS VS. FREQUENCY FOR INDICATED INCIDENT POWER LEVELS BIAS: 100 MICROAMPERES