TABLE I
PERFORMANCE OF ARRAY DIODES

Circuit Type	Diode	Type	Peak Output Power (W)	Frequency (GHz) (Power Variation)	Max. Gain (dB)	Max. Efficiency (%)	Power Density (kW/cm^2)	Duty Cycle (%)	Pulse-width (μs)
Coupled-bar	7-array[a] p-type	KR5B	70	3.05 - 3.15 (3 dB)	5.5	26.5	155	-	0.5
Stagger-tuned	19-array[b] double-diffused	KK265	150	3.02 - 3.07	7.5	9.4	179	0.05	10
	19-array[b] double-diffused	KK265	85	3	4.5	10.9	200	1	50
	19-array[b] p-type	AK4B 2 in series	130	2.875 - 3.235 (1.15 dB) profiling	6.5	14.2	115	0.02	5
	19-array[b] p-type		120	2.95	7.2	19.2	155	0.02	10
	19-array[b] p-type		110	2.95	6.8	15.7	163	1	50

[a] Utilizing monolithically interconnected bridges.
[b] Soldering copper on top of diodes.

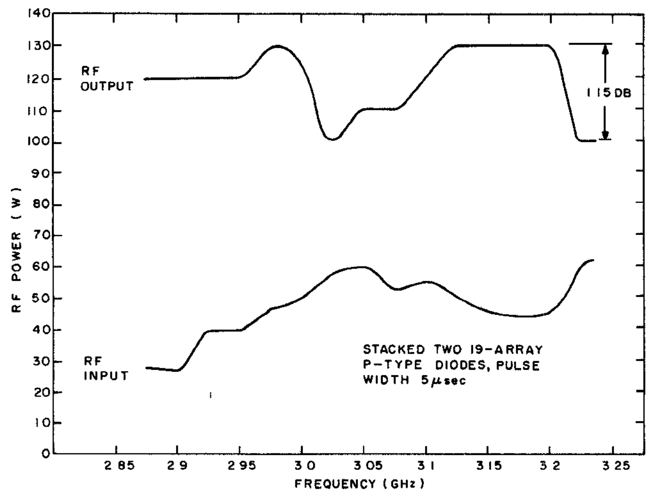

Fig. 4. Power output versus frequency from two stacked 19-diode arrays (profiling technique).

ACKNOWLEDGMENT

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Commercial Glow Discharge Tubes as Detectors of *X*-Band Radiation

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Abstract—A survey of the detection properties of various commercial glow discharge tubes to *X*-band radiation is presented, and comparisons are made with typical sensitivities of diode detectors.

Although glow discharge detection of microwave radiation has been known since at least 1952 [1], Farhat [2] was probably the first to use very inexpensive commercial indicator lamps in this

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fashion. Other advantages of these devices as detectors are large dynamic range and electronic ruggedness. Good responsivity was reported. McCain [3] used the NE-51 H and NE-2 bulbs in high-power S-band experiments and found that under certain conditions the sensitivities of the plasma detectors were superior to those of the 1 N21E crystal detector. The minimum detectable signal reported by him is −65 dBm using a 30-Hz detection bandwidth at 1-kHz modulation frequency. Kopeika and Farhat, using a novel biasing scheme to reduce plasma noise, achieved NEP's of 8×10^{-10} $W \cdot Hz^{-1/2}$ and 10^{-13} $W \cdot Hz^{-1}$ in video [4]–[6] and synchronous [7] detection at millimeter wavelengths using Signalite, Corp. TRJ250 and TRQ250 trigger tubes, respectively. The mechanism of detection is attributed to enhanced inelastic collision rates [8], [9] caused by the incident RF electric field. The purpose of this short paper is to report the results of an experimental survey of various types of commercial glow discharge tubes as detectors of X-band radiation. Sensitivities similar to those of diode detectors are easily achieved.

All tubes were tested under the same circumstances. They were placed in the far field of a 10-dB X-band transmitting antenna. The geometrical orientation of the glow tubes was such that the plane of the electrodes was perpendicular to the direction of the RF energy flow and parallel to the RF electric field. The effect of geometric orientation on responsivity will be discussed in a future paper.

The gas in the glow lamp was broken down with a dc field from the relatively quiet Lambda LPD 425-A-FM power supply and the detected signal amplified 40 dB by a Brookdeal-type 452 precision amplifier over a 10–100-kHz range. A 1-kΩ load resistor was used in parallel with the glow discharge lamp as indicated in Fig. 1. The circuit for triode tubes is shown elsewhere [5], [6]. The X-band radiation consisted of a 9.32-GHz carrier sine wave modulated at a 50-kHz rate. Two 20-dB variable attenuators in series were used to measure NEP, as indicated in Fig. 2. The transmitter power, generally about 20 mW, was continuously monitored through use of a 40-dB directional coupler, a bolometer, and a Hewlett-Packard 432 A power meter. The modulation was achieved using a function generator connected to a Hewlett-Packard 716 B klystron power supply in the external modulation mode. The signal from the function generator was increased until it was somewhat less than the value where distortion began to be seen in the detected signal, so that the

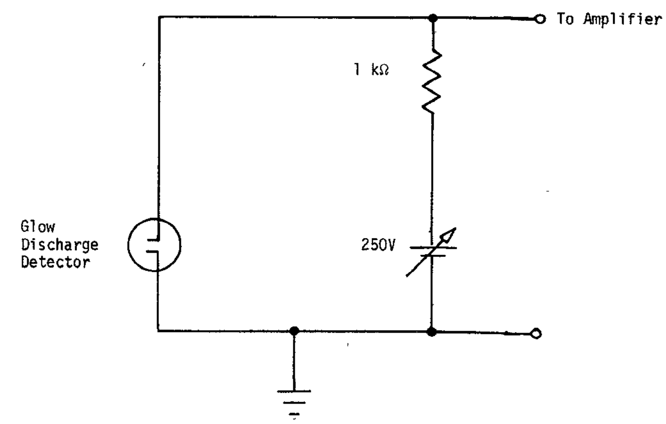

Fig. 1. Glow discharge detector biasing circuit.

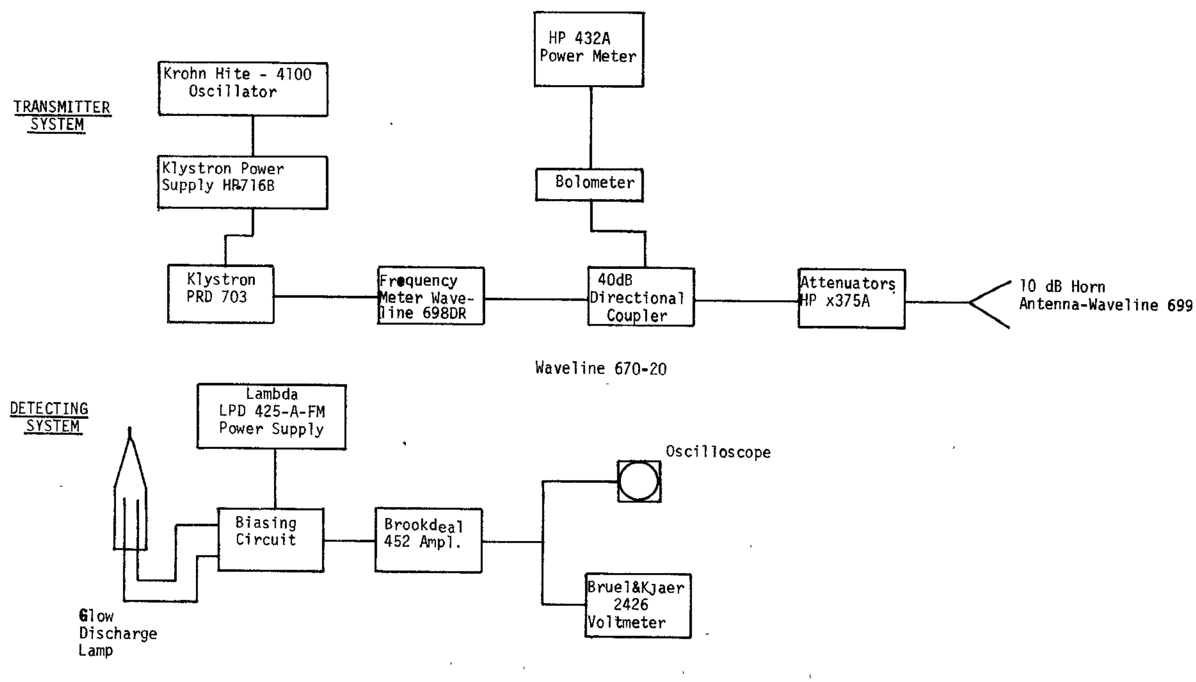

Fig. 2. Test setup for measuring sensitivity of glow lamps to X-band radiation.

modulation index was effectively 100 percent. Square-wave modulation was used for rise time measurements, which were taken with an oscilloscope but without the amplifier in the test system.

The responsivity and NEP were determined according to [4], [6]

$$R = \frac{4\pi r^2 V_a}{P_t G G_a A_r} \quad \mathrm{V \cdot W^{-1}} \tag{1}$$

and

$$\mathrm{NEP} = \frac{P_t G A_r}{4\pi r^2 A_{tt} B^{1/2}} \quad \mathrm{W \cdot Hz^{-1/2}} \tag{2}$$

where r is the distance from the transmitting antenna (30 cm), P_t the transmitted sideband power, G the transmitting antenna gain, G_a the postdetection amplifier gain (40 dB), A_r the effective detecting area of the tube, V_a the detected signal after amplification, A_{tt} the attenuation at which the signal voltage is equal to the noise voltage, and B the postdetection bandwidth (90 kHz). To determine V_a and A_{tt} a Bruel & Kjaer-type 2426 rms voltmeter was used. Even at unity signal-to-noise ratio, as determined with the voltmeter, the signal could still be recognized through the noise as seen on the oscilloscope display. The attenuation required to remove the signal from the oscilloscope display was generally 2–3 dB more than that used in the NEP calculations. The effective detecting area of each tube was taken to be the product of electrode length and separation.

No receiving antenna was used in these measurements. The results for each tube depend greatly on the biasing arrangements. Typical variation of responsivity and NEP with discharge current are shown in Fig. 3, where data for the NE-84 glow lamp are displayed. The dependence of responsivity upon discharge current is believed to stem from the role of the electron-neutral molecule elastic collision frequency in the detection process [6], [8], [9]. This parameter is a function of the discharge current. The maximum in the responsivity curve is believed to occur when this electron momentum transfer frequency is equal to that of the incident RF energy. Thermal noise in a plasma is associated with the electron temperature [6] and decreases with increasing current. At high currents sputtering effects increase and result in increased noise [10], [11]. Thus at low and high current extremes the lamps are relatively noisy. This is reflected in the NEP curve of Fig. 3. Sputtering changes the lamp characteristics and should be avoided.

The best detection results for each tube are compared with typical values for diode detectors in Table I. The glow tubes are listed according to NEP.

Responsivity and NEP were measured independently. Measurement of the noise voltage V_n afforded a check on the NEP and responsivity results since

$$\mathrm{NEP} = \frac{V_n}{R B^{1/2}}. \tag{3}$$

The calculated and measured NEP's closely resemble each other.

Utilization of external electrodes [6], [13] at X-band wavelengths with these small commercial tubes was limited by waveguide cutoff frequency effects.

Comparisons of the responsivities of the NE-24 and LT2-24-2 tubes, or the LT2-27-2 and LT2-32-1 tubes in the light of manufacturer specifications [14] suggest that radioactive additives to reduce the dark effect result in improved responsivities. In general, the more responsive tubes contain such additives.

Comparisons of the noise voltages of the 5AB series tubes suggest that preaging [15] them has hardly any noticeable effect.

From Table I it is seen that ordinary glow discharge lamps, when used as detectors of X-band radiation, display sensitivities quite comparable to those of diode detectors. The advantages of the latter are much faster speed of response (on the order of nanoseconds) and little or no power dissipation. The advantages of the former are low purchase price and electronic ruggedness, i.e., the glow tubes are able to operate under much greater incident power levels [6], [8], [16] and are less sensitive to environmental temperature effects.

It should be pointed out that these commercial indicator lamps are not designed to be detectors. The results reported here are therefore also an indication of the potential sensitivity of this mechanism.

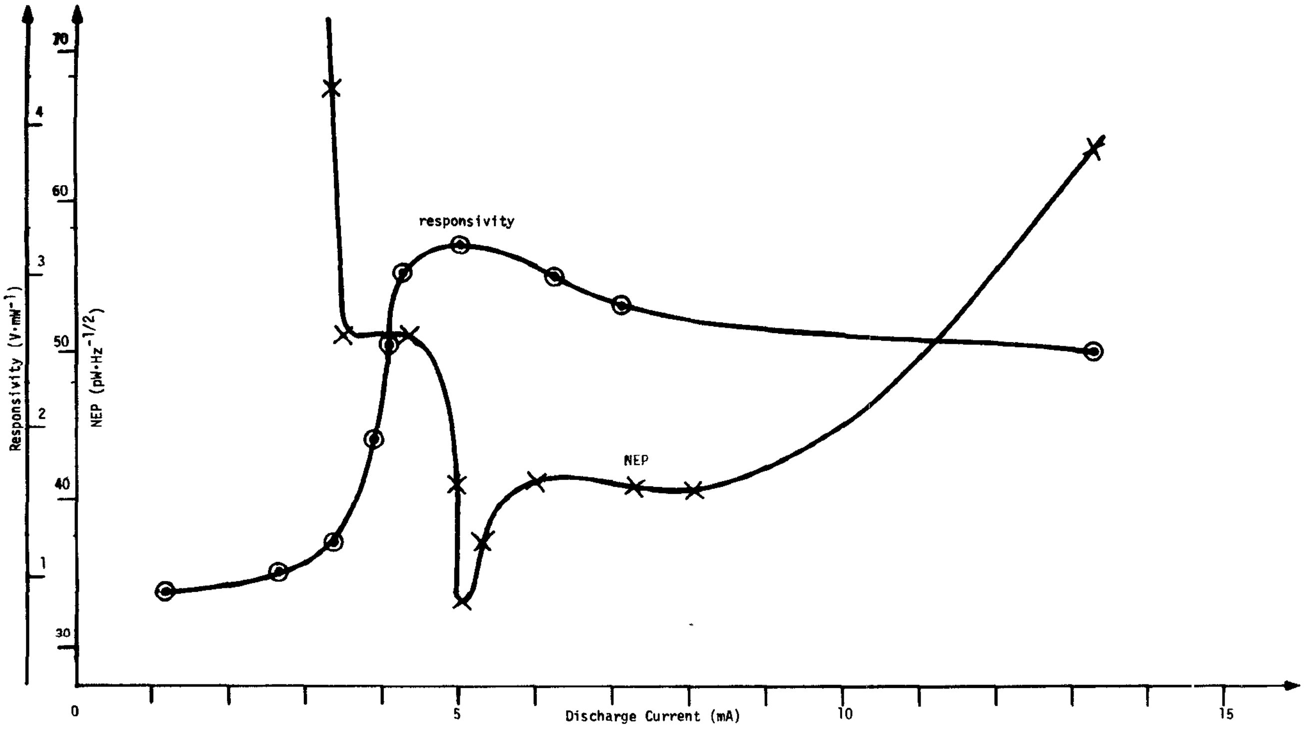

Fig. 3. Responsivity and NEP for X-band radiation as a function of discharge current in the NE-84 glow lamp.

TABLE I
GLOW DISCHARGE TUBE AND DIODE SENSITIVITIES TO X-BAND RADIATION

Tube	V_n(μV)	A_r(mm^2)	I (mA)	R(V·mW^{-1})	NEP(pW·Hz$^{-1/2}$)	t_r(μs)
A059-2	40	8	2	4.45	1.44	2.1
NE-4	46	13	3	3.69	2.17	3.0
NE-76	50	8	3	3.10	2.23	2.0
A 215	153	5	2	15.4	3.25	1.3
T2-32-1	65	13	6	2.20	3.81	2.0
NE-3	39	9	3.4	3.81	6.20	2.4
NE-7	57	25	40.0	3.29	6.59	4.5
AR-9	84	12	2.5	4.26	7.51	2.5
NE-51-H	21	12	1.8	0.09	9.82	4.0
5AB-A	57	11	8.0	4.24	9.86	10.0
5AB-B	54	10	13.0	2.86	11.0	2.3
5AB	57	11	12.0	4.11	11.4	2.4
NE-81	73	14	15.0	3.67	15.9	2.0
LT2-24-2	52	6	10.0	0.33	19.1	0.8
A059-9	57	7	8.0	3.31	24.5	2.1
LT2-32-1	13	11	20.0	2.56	25.7	1.6
LT2-27-2	73	7	9.0	0.47	25.7	0.8
5AH-D	46	17	6.5	1.92	28.2	2.4
NE-2U	77	7	17.0	1.67	29.8	1.4
NE-84	137	7	4.2	2.32	30.7	1.0
AIB	72	6	17.0	4.46	34.9	0.8
5AHA	40	14	4.5	3.07	37.6	1.6
5AH	54	16	15.0	1.98	39.4	2.0
TRJ250	10	4	I_1 = 2, I_2 = 0.5	0.50	39.5	2.5
AIC	70	4	12	9.00	41.1	2.0
IN238 Crystal * Diode (Sylvania)	7	15	-	211.0	0.318	-
MA-40207 [12] Schottky-barrier diode	-	-	0.02	5.0	1.1	-

Note: I is current and t_r is rise time.
* Parameters measured in test setup.

Redesign of these indicator lamps for detector applications should improve their sensitivities and speed of response further.

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Light Transmittance and Microwave Attenuation of a Gold-Film Coating on a Plastic Substrate

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***Abstract*—Light transmittance and microwave attenuation of a gold-film coating on a plastic substrate is investigated. The dependence of the transmittance of visible light upon the thickness or resistivity of a gold-film coating on a plastic substrate is analyzed numerically. The microwave attenuation produced in the far field over the frequency range of 100 MHz–30 GHz by the gold film is calculated and compared with experimental data. An optimum condition is established between the light transmittance and the microwave attenuation. The results are applicable to any transparent glass coated with any thin metallic film.**

I. INTRODUCTION

In certain engineering applications, it is often desirable to use a metallic-thin-coated glass to transmit optimum light intensity at visible-light frequencies and also to attenuate as much of the EM radiation as possible at microwave frequencies. For example, the head of a missile may be formed of a plastic–glass dome coated on its concave surface by a gold film which is designed so that the optimum amount of light be transmitted into the dome for picture taking by cameras while, at the same time, the microwave radiation is attenuated sufficiently to eliminate its interference with the electronic systems inside the dome.

The microwave attenuation of a metallic-film-coated glass was investigated by several workers in the near field [1], [2]. Their work was carried out at a distance of 1 in away from the power source. This is not a complete treatment of the problem. This short paper presents the microwave attenuation in the far field.

II. OPTICAL PROPERTIES OF GOLD FILM

The optical properties of materials are usually characterized by two parameters, the index of refraction n and the extinction coefficient k. The complex refractive index is given by

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