harmonics of the microwave spectra and allowing for the additional line broadening arising from the 100 ns long pulse modulation of the laser diode. Locking of the pulse train at a range of frequencies between 0·5 and 4 GHz has been achieved, this range of frequencies having been limited by the electrical sources available.

To achieve encoding of generated pulse trains the output of a 2 Gbit/s pseudorandom pattern electrical generator has been applied to the centre contact of the laser. Here control of the loss is sufficient to suppress pulses which are not required and yet not to disrupt the generation of later pulses. The generated pulses have similar durations and powers to those reported above, the action of the pseudorandom drive being primarily to inhibit pulse generation and not to modify it. This scheme thus not only permits a reduction in the jitter, but also enables data to be encoded. Fig. 3 shows different pulse trains observed using a high speed photodiode and sampling oscilloscope. Here successful bit modulation is achieved at frequencies up to the maximum allowed by the electrical generator, the observed jitter and noise of the trace being due to limited detection system capability.

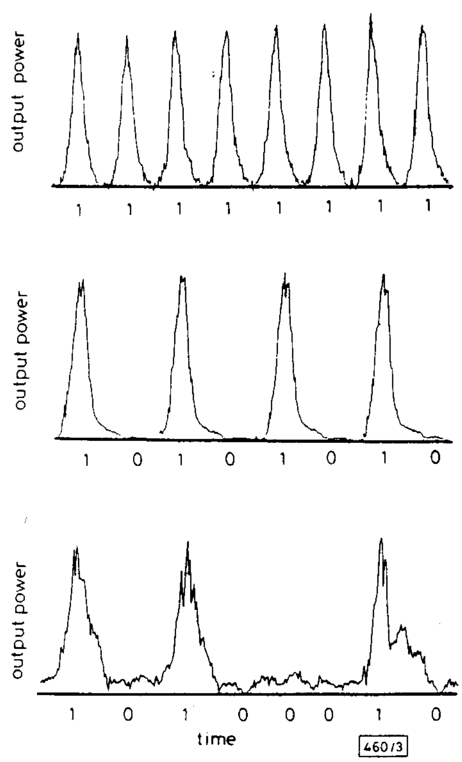

Fig. 3 *Examples of 2 Gbit/s optical data streams for various pattern inputs*

In this Letter, the reduction of jitter and direct encoding of high power self-Q-switched pulses trains generated by a GaAs/GaAlAs diode laser have been reported. Despite the generation of peak powers in excess of 1 W, jitter levels have been reduced to less than 300 fs, thus allowing the devices to be used in a wide variety of applications. Direct encoding of data has been achieved at 2 Gbit/s by direct modulation of the loss in cavity.

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NOISE FIGURE MEASUREMENT OF RECEIVING ACTIVE MICROSTRIP ANTENNAS

H. An, B. Nauwelaers and A. Van de Capelle

Indexing terms: Antenna noise, Microstrip antennas, Active antennas, Antenna measurements

A novel technique for the measurement of the noise figure is proposed for an amplifier embedded in a receiving active microstrip antenna, where direct measurement is impossible. The proposed technique is a combination of the transducer power gain measurement of the amplifier and the absolute noise power measurement of the active antenna. The measured results of a receiving active microstrip antenna show the validity of the measurement technique. This enables the characterisation of the noise performance of active antennas.

Introduction: In the literature, little attention has been paid to amplifier-type receiving active microstrip antennas. Although some primary attempts have been made [1–3], the noise performance, which is of great importance in practical applications, has been ignored. The major difficulty is probably due to the lack of measurement techniques to characterise the noise performance of such antennas.

An important parameter for describing the noise characteristic of large aperture antennas for Earth stations in satellite communications is the figure of merit (G/T), which is defined as the ratio of the gain of the antenna and the antenna noise temperature towards the cold sky plus the effective noise temperature of the receiver [4]. However, for mobile communications or applications where the size and cost are prime considerations, the directivity of the antennas is usually low. Therefore G/T is not a proper parameter for characterising the noise performance of such antennas: the external noise received by the radiator is much greater than that from the large aperture antennas directed to the cold sky and it strongly depends on the environment and the orientation of the antenna. Also, the effective noise temperature of the receivers connected to these antennas differs from applications.

The noise in active antennas consists of two parts: the external noise received by the raditors and the internal noise produced by the active circuitry. It could be very useful to define a parameter describing the internal noise because it only depends on the active circuits and is independent of the environment. The noise figure of the attached amplifier in an active antenna provides such a measure. However, as the amplifier is integrated with the passive radiator and therefore is a nonseparable part of the active antenna, it is impossible to measure the noise figure directly.

This Letter presents a measurement technique for determining the noise figure of the attached amplifier in a receiving active antenna by combining the transducer power gain measurement [5] and absolute noise power measurement.

Measurement technique: If the passive radiator temperature is T_a, and the effective noise temperature of the attached amplifier in an active receiving antenna is T_e, the absolute noise power density P_n in the output of the antenna referred to 290 K (−174 dBm/Hz) is

$$(P_n)[\text{dB}] = 10 \log \frac{k(T_a + T_e)G_T}{k \,.\, 290}$$

$$= 10 \log \frac{(T_a + T_e)G_T}{290} \qquad (1)$$

where k is the Boltzmann constant, and G_T is the transducer power gain of the amplifier in the active antenna. P_n can be directly measured by a noise figure meter.

If the noise temperature T_a of the radiator and the transducer power gain G_T of the amplifier are known, the effective noise temperature of the amplifier can be calculated from

$$T_e = 290 \frac{P_n}{G_T} - T_a \qquad (2)$$

Therefore the noise figure of the amplifier is

$$F = 1 + \frac{T_e}{290} = 1 + \frac{P_n}{G_T} - \frac{T_a}{290} \qquad (3)$$

The transducer power gain G_T of the amplifier in the active antenna can be determined with the technique reported in Reference 5 by measuring the transmission coefficient $S_{21(a)}$ between the active antenna and a standard antenna, and also the transmission coefficient $S_{21(p)}$ between a reference (passive) antenna (with a patch identical to that of the active antenna) and the standard antenna. The gain is thus given by

$$(G_T)[\text{dB}] = (S_{21(a)})[\text{dB}] - (S_{21(p)})[\text{dB}] + 10 \log (1 - |\Gamma_p|^2) \qquad (4)$$

where Γ_p is the return loss of the reference antenna.

The noise measurement could be carried out inside an anechoic chamber with a well-controlled ambient temperature T_r. Therefore the noise temperature T_a of the radiator is equal to T_r, and

$$F = 1 + \frac{P_n}{G_T} - \frac{T_r}{290} \qquad (5)$$

Thus the noise figure of the attached amplifier in an active antenna can be determined from this formula.

Measured results: Several amplifier-type receiving active microstrip antennas have been designed, realised and tested, and the results are compared with the simulation [6]. Here we show the result of one example. The active antenna was designed with a one-stage amplifier configuration in a two-sided structure which is similar to the antenna structure reported in Reference 7. The series source inductance feedback technique is employed to obtain simultaneous power match and noise match. The details of this antenna can be found in Reference 6.

Fig. 1 shows the measured transmission coefficient between the standard gain (horn) antenna and the active antenna against frequency. That of the reference (passive) antenna is also given in this Figure for comparison. The realised gain of the active antenna has a flatness of ±0·78 dB in the band 3·03–3·48 GHz, and 11·9 dB gain improvement compared to the reference antenna. This shows clearly that the active antenna has high gain performance. Fig. 2 illustrates the comparison of the measurement (solid line) and calculation (dotted line) for the transducer power gain of the amplifier embedded in the active antenna with the technique reported in Reference 5. We found that the measured transducer power gain has a wider bandwidth but a worse flatness than the calculated power gain. This is mainly due to the diversity of the parameters of the transistor.

The measured and simulated noise figures of the active antenna are shown in Fig. 3. In the design band between 3·1 and 3·5 GHz, the measured noise figure is below 1·2 dB. The maximum difference between the measurement and calculation is 0·4 dB in this band. In the frequency band 3·0–3·58 GHz, the noise figure is below 1·2 dB. It is evident that this active antenna has excellent noise performance.

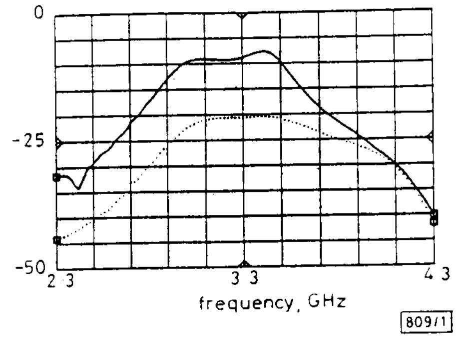

Fig. 1 *Measured transmission coefficients of two microstrip antennas with identical patches*

——— active antenna
······ reference antenna

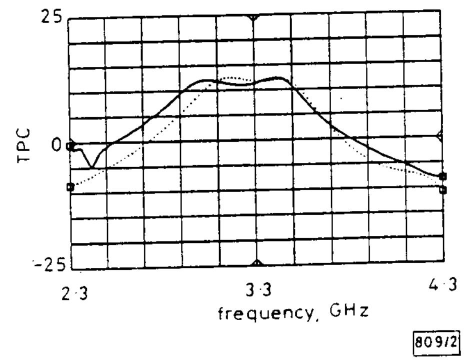

Fig. 2 *Transducer power gain of the amplifier embedded in an active microstrip antenna*

——— measured
······ calculated

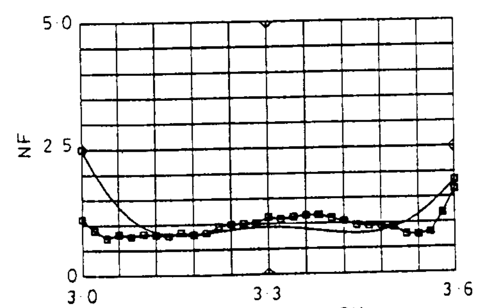

Fig. 3 *Noise figure of the amplifier embedded in an active microstrip antenna*

—□— measured
——— calculated

Conclusions: This Letter presents a novel technique for the measurement of the noise figure of the amplifier embedded in a receiving active microstrip antenna. The proposed technique is the combination of the transducer power gain measurement of the amplifier and absolute noise power measurement of the active antenna. The other parameters such as the bandwidth and the gain improvement of the active antenna can also be determined with the proposed technique. The measured results of a receiving active microstrip antenna show the validity of the measurement technique. This enables the noise performance of active antennas to be characterised.

 19th July 1993

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FIELD-DEPENDENCE OF THE AREA-DENSITY OF 'COLD' ELECTRON EMISSION SITES ON BROAD-AREA CVD DIAMOND FILMS

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Indexing terms: Field emission electron microscopy

A high area density of field-induced electron emission sites has been observed on broad-area (12 mm in diameter) CVD diamond films deposited on molybdenum substrates. Furthermore, it was found that the density increased with the electric field applied to the surface of the films. These findings indicate that the CVD diamond film has to be seen as a potentially favoured candidate among electronic materials for the development of new types of cold cathode electron source.

Previous authors [1] have reported that 'cold' electron emission can be obtained at fields as low as 3 MV/m from various types of CVD diamond film. These findings enhance the view that CVD diamond film has to be considered as a potential material for fabricating broad-area cold-cathode electron sources. In this context, it is desirable to be able to examine how the constituent electron emission sites are distributed over the surface of a broad-area sample, and in particular how this distribution varies with the electric field applied to the surface. This Letter reports new findings from 15 mm diameter CVD diamond films deposited on Mo substrates with an emphasis on the issue of how the area density of emission sites varies with the applied electric field.

The study involved applying a transparent anode imaging technique [2] to record the spatial distribution of emission sites. As illustrated in Fig. 1, this technique employed an anode consisting of a 30 mm diameter glass disc that is coated with conducting tin oxide, and is normally set 0·5 mm apart from, and in parallel with, a cathode surface. Electrons emitted from the cathode surface cause an impact on the tin oxide, and so generate visible transition radiation. Thus, the position of an emission site on the cathode surface is directly 'marked' on the anode by this light. The distribution of these 'light' centres can be recorded by some form of photographic technique to give a 'map' of emission sites.

Fig. 2 presents two optical images corresponding to the spatial distributions of emission sites obtained at applied field levels of 5 and 10 MV/m, respectively. Three important findings emerge from a study of these distributions that confirm CVD diamond film is a potentially favourable material for use in the development of broad-area cold cathode electron sources.

(i) Field emission can be obtained at fields as low as 5 MV/m.

(ii) Emission sites are distributed over a large area of the surface of the diamond films.

(iii) The area density of the sites is high, in particular when compared with that obtained from other coatings such as Langmuir–Blodgett films reported in previous related works [3]; more importantly, the area-density increases with increasing applied field.

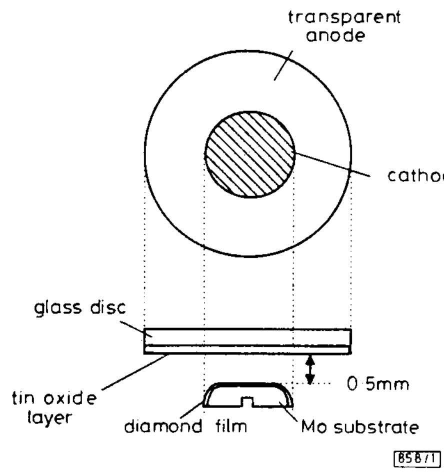

Fig. 1 *Basic configuration of the electrode assembly employed for the present study, which consists of a transparent anode for imaging the spatial distribution of emission sites*

Two specific properties of CVD diamond films are believed to be favourable to field electron emission. These are: the likely negative electron affinity of the (111) facets of diamond crystallites [4], and the presence of a high density of localised graphite carbon inclusions [5]. The former gives rise to a low

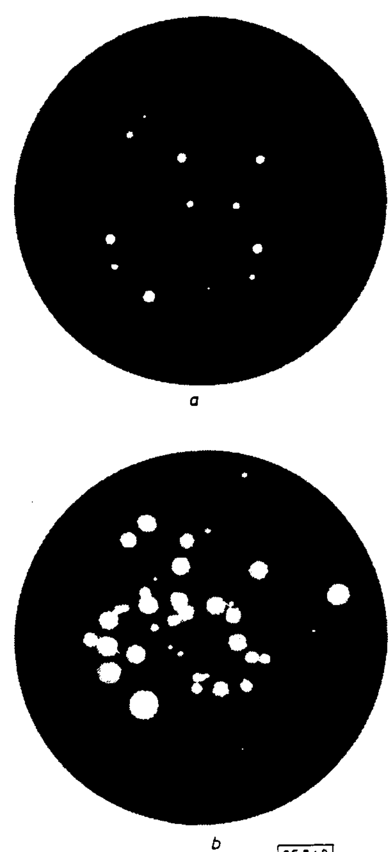

Fig. 2 *Spatial distributions of electron sites recorded at fields of 5 and 10 MV/m applied to CVD diamond films on Mo substrates*

Note: diameter of both images is 12 mm
a 5 MV/m
b 10 MV/m