The fully integrated miniaturised optical electric field sensor

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1 Abstract

A new generation of miniaturised optical electric RF and Microwave field sensors is being developed. The sensors are based on the Mach-Zehnder optical interferometer and made completely by integrated optical technology. Apart from thin film metallic dipole elements of 3 to 5 mm strips, there is no other conductive material. The basic dimension of the sensor head is 5 mm to 8 mm in diameter. There is a single fibre to guide the laser beam in and out of the sensor head. The sensor is made as a single element with the polarization response either parallel, perpendicular, or at a 54.7° angle to the axis of the sensor handle. It can also be made as three orthogonal sensor elements grouped together to produce an isotropic response to the field being measured.

Since the Pockels effect of the Ti:$LiNbO_3$ has a pico-second relaxation time, this type of sensor can be made to work from intrinsically DC to millimetre waveband, to record all aspects of the RF and Microwave signal, such as amplitude, phase, modulation, frequency and polarisation – to be detected without the use of a RF and Microwave transmission line connection. Since these types of sensor can work with narrowband microwave receivers or spectrum analysers, the achievable sensitivities could be hundreds of times higher than the conventional field sensors currently available commercially. This paper will report the latest measured performance of this type of sensor, the problems encountered in its development, and also discuss their potential applications.

2 The need for new types of miniaturised implantable E-field sensors

With the need to monitor the Specific Absorption Rate (SAR) caused by the use of a mobile phone to the user's head, miniaturised implantable E-field probes have been used intensively all over the world [1][2]. The performance of the E-field probes recommended by the international standards committees is list in Table 1 bellow:

Functions:	Europe CENELEC Recommendations[1]	IEEE TC34 Recommendations[2]
Frequency range:	300 MHz – 3 GHz	300 MHz – 3 GHz
Dynamic range:	Better than 0.02 W/kg – 100 W/kg	0.01 W/kg – 100 W/kg
Modulation:	Not specified	Continuous Wave (CW)
Pulsed modulation	For pulsed signal, the integration and averaging time shall be able to yield results reproducible to within ±5.0%	Pulse repetition rate 10 Hz – 1 KHz, Duty factor greater than 4% (Included TDMA and CDMA)
Linearity	Within ±0.5 dB	Taken the measured value under recommended measurement procedure
Isotropy	Within ±1.0 dB	Taken the measured value under recommended measurement procedure
Spatial resolution	Not specified	Can be ignored if the probe dimension is less than 8 mm

Table 1. Standard body recommendation on E-field probe requirement for mobile phone SAR measurement

In fact the above probe requirement is not complete. It is a trade-off between what is needed and what is available. Due to the fact that all the miniature implantable E-field probes on the market are dipole-diode type probes [3], which have reached their performance limitation after more than 30 years of continuous development. There is a need to develop a new type of miniaturised E-field probe for better radiation safety monitoring for mobile phone and multi-media local wireless network applications, such as Bluetooth wireless digital communication.

3 The fundamental structure of a Miniaturised Optical Electric Field Sensor (MOEFS)

The trail to develop miniaturised optical electric field sensors has been reported in the literature [4,5,6]. It appears that the best suitable structure of construction is the Mach-Zehnder interferometer with a reflection scheme, which allow the use of one fibre function as both light-in and light-out routes. In contrast, the transmission scheme is not shown in the diagrams. And the integrated RF antenna could be one of the three fundamental types shown in Figs. 1A, B, and C.

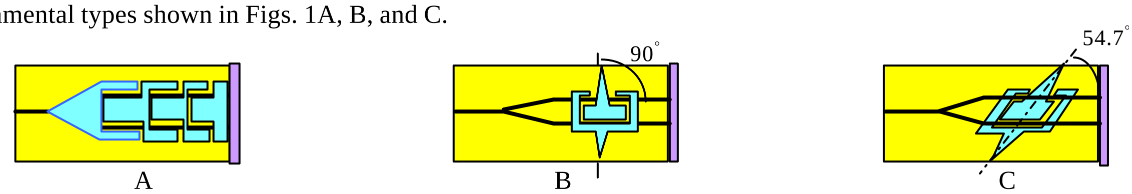

Figure 1. Basic structure of the miniaturized optic electrical field sensors

One A-type sensor with two B-type sensors could form an asymmetric isotropic sensor group. And three C-type sensors could form a symmetric isotropic group. Since the reflection scheme required only one optical fibre pigtailed to the $LiNbO_3$ chip for each sensor, the isotropic sensor could be made with the sensing elements arranged near the tip of the sensor supporting structure.

4 Testing of the single element sensor performance

The performance of an A-type sensor has been reported in Ref. [6]. The B-type and C-type of single element sensors have been tested at NPL. Based on the optical fibre leads available, the system has been configured as follows (Fig. 2):

A Kyoritsu KTC-6051 TEM cell was used to test the performance of the MOEFS sensors. This cell is a 1 m long asymmetric TEM cell, with the centre septum height h=0.188 m The field strength selected for testing was 5 V/m. This cell will work up to 1.3 GHz without causing higher order mode problems. Its first higher order mode occurred at 1.4 GHz and its second resonant mode occurred at 1.7 GHz.

A HP 8566B spectrum analyser was used as the RF receiver. For which the Resolution Bandwidth was set to 100 Hz. and the Video Bandwidth was set to 30 Hz. Under these conditions, the signal to noise ratios at 1 V/m field strength for both sensors were better than 20 dB. (***please try and stick to one tense, usually past tense in a technical report)

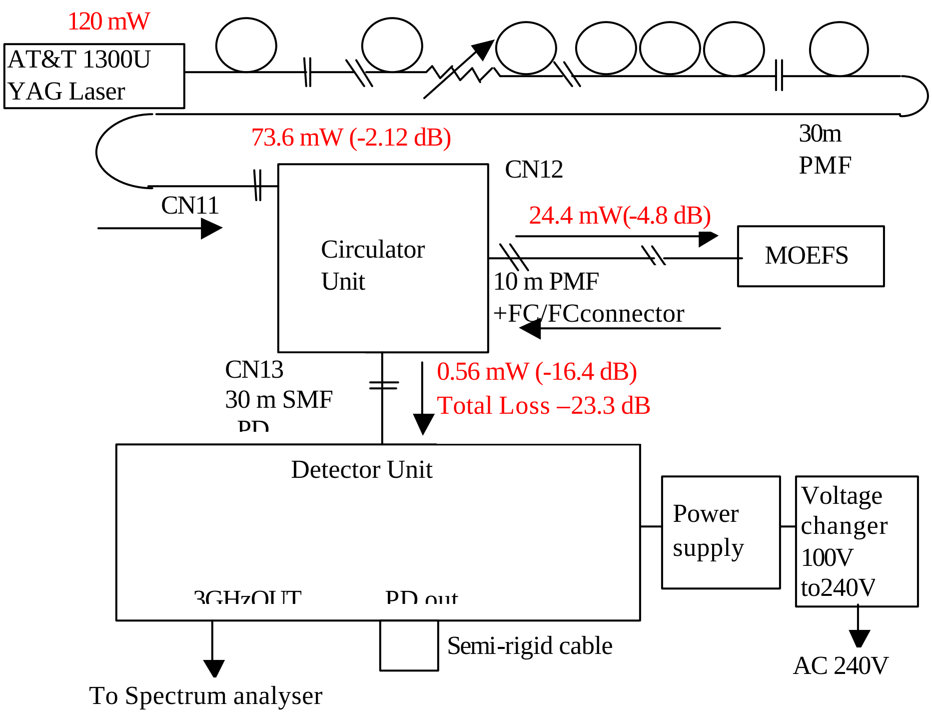

Figure 2: The MOEFS measurement system configuration schematic diagram

The frequency responses of both sensors with the frequency band between 50 MHz and 1.3 GHz are shown in Fig. 3. With the help of several NPL TEM cells and NPL tapered TEM cell (working in between 50 MHz and 2.4 GHz), and also NPL semi-anechoic camber (working between 500 MHz and 40 GHz), we have tested the B-type sensor performance up to 18 GHz. These results are shown in Figs. 4 and 5 respectively.

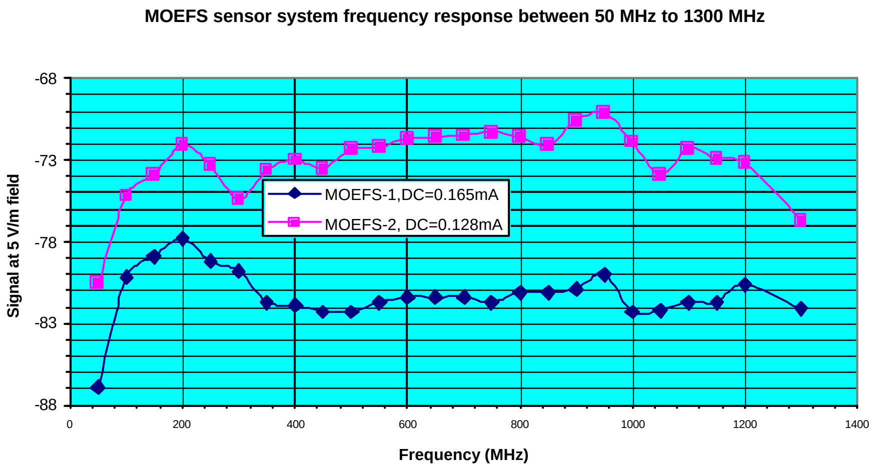

Fig. 3: MOEFS system frequency response between 50 MHz and 1300 MHz

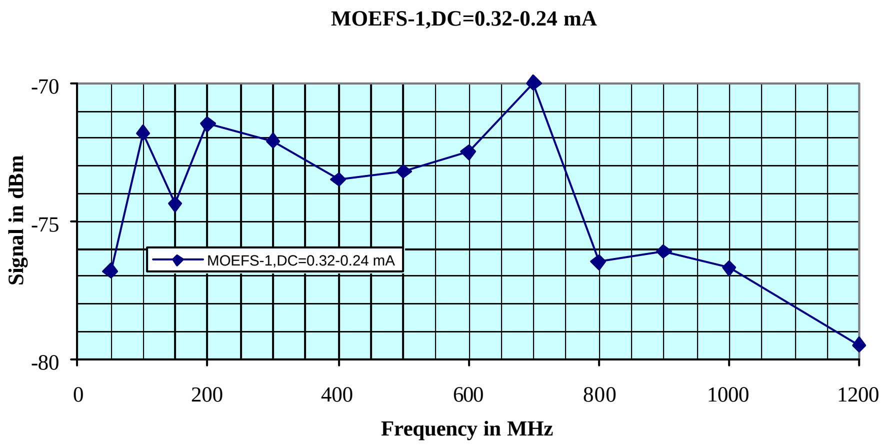

Fig. 4 MOEFS-1 sensor response measured between 50 MHz and 1.2 GHz at 20 V/m field strength inside NPL TEM cells.

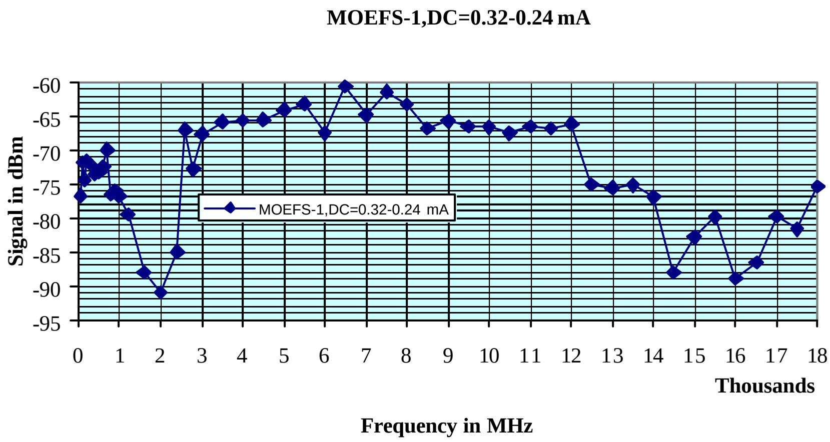

Fig. 5 MOEFS-1 sensor response measured between 50 MHz and 18 GHz at 20 V/m field strength inside NPL TEM cells and NPL semi-anechoic chamber

Fig. 3 shows that the two types of sensor have similar performance between 50 MHz and 1.3 GHz, with the C-type (MOEFS-2) 6 dB more sensitive than the B-type (MOEFS-1). For a field strength of 5 V/m, their signal to noise ratios are better than 35 dB. This means they can detect field strengths as low as 0.1 V/m. This is more than 20 dB better than the conventional diode-dipole type of miniaturised sensors.

Fig. 5 shows there is a sensitivity gap between 1 GHz and 2.6 GHz for the sensor system. This is caused by the anti-phase interference RF signal getting into the RF pre-amplifier of the photo-detector unit. When we switch off the laser source, we can see this interference signal on the spectrum analyser.

5 Conclusions

We have shown that this new type of MOEFS field sensor could work between 100 MHz and 12 GHz with 20 dB higher sensitivity than the conventional miniaturised E-field probes. More stringent requirements will need to be met on EMC performance of the photo-detector and RF receiver system.(***perhaps compare the achieved specification with that in Table 1) Mention again the fast response time, see attached application for measurement prize)

An isotropic type of MOEFS sensor system is under development with the NPL-Tokin collaboration. Mechanical as well as optical construction difficulties have to be overcome before the prototype performance can be tested under laboratory conditions. Stability may be a problem for this type of MOEFS. But the performance advantage will be much better than the conventional type of miniaturised E-field sensors. It is aimed to have the sensors available in the Spring of next year.

6 References

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