UNIVERSITI PUTRA MALAYSIA

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By

SHEE YU GANG

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

ALL-OPTICAL GENERATION OF MILLIMETERWAVE CARRIER BASED ON STIMULATED BRILLOUIN SCATTERING

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March 2011

Chair: Prof. Mohd Adzir bin Mahdi, PhD

Faculty: Faculty of Engineering

The ever growing demand for delivering high speed data and networking the world fuels the interest of research on broadband access networks. As data rates increase, larger frequency bandwidths are required to support the transmission. Millimeterwave frequency has been identified as the high speed data carrier in hybrid fiber optic-millimeterwave link, or known as Radio over Fiber (ROF) systems. All-optical generation of millimeterwave carriers attracted much attention due to many advantages compared to electronic solutions. Optical heterodyning or known as optical mixing is one of the enabling technologies. Optical mixing of dual-wavelength laser source produces a beating frequency which is identical to the frequency offset between the two laser signals.

Nonlinear stimulated Brillouin scattering (SBS) is attractive in the generation of RF carriers due to its existence in the optical fiber with low threshold power. The generation of RF carriers without the utilization of high frequency signal generator is demonstrated

in this work based on nonlinear SBS. A novel configuration, namely double-Brillouin-frequency shifter (DBFS), is proposed for the generation of higher order Brillouin Stokes signals. The second order Brillouin Stokes signal (BS2) is generated from the Brillouin pump (BP) by circulating and isolating the first order Stokes signal in the fiber through a four-port circulator. Microwave carrier at frequency equivalent to twice the Brillouin frequency shift ($2\upsilon_B$) is generated by heterodyning the BP with BS2. An average carrier frequency of 21.3968 GHz with phase noise as low as -58.67 dBc/Hz is measured.

Generation of millimeterwave at 64 GHz is experimentally proven by channel filtering from a multiwavelength Brillouin-erbium fiber laser (BEFL). By incorporating the DBFS, a four-channel BEFL with channel spacing of $2\upsilon_B$ is generated. A dual-wavelength signal with ~64 GHz ($6\upsilon_B$) spacing is obtained by suppressing the two channels at the middle from the BEFL output. Millimeterwave carrier at ~64 GHz is produced after heterodyne the dual-wavelength signal at a high speed photo detector. Multiband carrier generation is also achieved by a proper design of channel demultiplexer at the output of BEFL. Microwave carriers at ~19 GHz and millimeterwave carriers at ~59 GHz are simultaneously generated from a single BEFL. System performance is investigated based on the measurement of phase noise, frequency drift and power fluctuations of the generated signals. Temperature sensitive characteristic of Brillouin frequency shift is utilized in the frequency tuning of generated RF carrier. Investigation results show a linear relationship between the output frequency and the temperature increment. This realizes the frequency tunability of the generated carriers.

With the novel configuration of DBFS, generation of microwave and millimeterwave carriers were realized through the heterodyning of Stokes signals. The cascaded Brillouin effect in DBFS enables double-Brillouin-frequency shifting at low threshold power. However, stability of stimulated Brillouin scattering in optical fiber needs to be improved with enhanced control mechanism in the future.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENJANAAN PEMBAWA GELOMBANG MILIMETER SEMUA OPTIK BERDASARKAN PENYERAKAN BRILLOUIN

Oleh

SHEE YU GANG

Mac 2011

Pengerusi: Prof. Mohd Adzir bin Mahdi, PhD

Fakulti: Fakulti Kejuruteraan

Permintaan yang senantiasa bertambah untuk penyampaian data berkelajuan tinggi dan terangkai dunia menyemarakkan minat dalam penyelidikan pada jaringan akses jalur lebar. Dengan peningkatan kadar data, jalur lebar frekuensi yang lebih besar diperlukan untuk menyokong penghantaran data. Gelombang milimeter telah dikenalpasti sebagai pembawa data berkelajuan tinggi dalam rangkaian hibrid gentian optik-gelombang milimeter, atau dikenali sebagai Radio atas Gentian Optik (ROF). Penjanaan pembawa gelombang milimeter semua optik menarik banyak perhatian disebabkan banyak kelebihannya berbanding dengan penyelesaian elektronik. Pengheterodinan optik atau dikenali sebagai penyebatian optik adalah salah satu teknologi yang merealisasikan penjanaan pembawa gelombang milimeter. Penyebatian optik sumber laser dwi-panjang gelombang menghasilkan frekuensi paluan yang seiras dengan perbezaan frekuensi di antara dua laser tersebut.

Kesan tak linar penyerakan Brillouin (SBS) adalah menarik dalam penjanaan pembawa RF disebabkan kewujudannya dalam gentian optik dengan kuasa ambang yang rendah.

Penghasilan pambawa RF berdasarkan kesan ketidaklelurusan SBS ditunjukkan dalam kerja ini tanpa penggunaan penjana isyarat frekuensi tinggi. Satu konfigurasi novel, iaitu penganjak gandaan frekuensi Brillouin (DBFS), adalah dicadangkan untuk penghasilan isyarat Brillouin Stokes tertib lebih tinggi. Isyarat Brillouin Stokes tertib kedua dihasilkan daripada isyarat masukan dengan pengaliran dan pemencilan isyarat Stokes tertib pertama dalam gentian optik melalui peranti kawalan aliran empat liang (*four-port circulator*). Pembawa gelombang mikro dengan frekuensinya bersamaan dua kali ganda frekuensi anjakan Brillouin dihasilkan oleh pengheterodinan isyarat pam Brillouin dengan isyarat Brillouin Stokes tertib keduanya. Purata frekuensi pembawa pada 21.3968 GHz dengan hingar fasa serendah -58.67 dBc/Hz diukur.

Penghasilan gelombang milimeter pada 64 GHz terbukti secara eksperimen dengan penapisan saluran dari laser gentian optik Brillouin-Erbium berbilang panjang gelombang (BEFL). Dengan menggabungkan DBFS, satu BEFL dengan empat saluran dan jarak di antara salurannya sebanyak $2\upsilon_B$ dihasilkan. Satu isyarat dwi-panjang gelombang dengan jarak di antara salurannya ~64 GHz ($6\upsilon_B$) diperolehi dengan menindas dua saluran tengah dari keluaran BEFL. Pembawa gelombang milimeter pada ~64 GHz dihasilkan selepas heterodin isyarat dwi-panjang gelombang di pengesan foto berkelajuan tinggi. Penghasilan pembawa berbilang jalur (multiband) juga dicapai dengan rekaan penyahmultipleks saluran yang sesuai pada keluaran BEFL. Gelombang mikro pada ~19 GHz dan gelombang millimeter pada ~59 GHz dihasilkan serentak dari satu BEFL. Prestasi sistem disiasat berdasarkan ukuran hingar fasa, hanyutan frekuensi dan perubahan kuasa isyarat yang dijanakan. Sifat anjakan frekuensi Brillouin yang sensitif kepada suhu digunakan dalam menala frekuensi pembawa RF yang dijanakan.

Hasil siasatan menunjukkan satu perhubungan linear antara frekuensi keluaran dan peningkatan suhu. Ini merealisasikan penalaan frekuensi pembawa yang dihasilkan.

Dengan konfigurasi novel DBFS, penghasilan pembawa gelombang mikro dan millimeterwave telah direalisasikan melalui pengheterodinan isyarat Stokes. Kesan Brillouin melata dalam DBFS membolehkan anjakan frekuensi Brillouin berganda pada kuasa ambang rendah. Bagaimanapun , kestabilan penyerakan Brillouin dalam gentian optik perlu diperbaiki dengan peningkatan mekanisme kawalan pada masa akan datang.

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I certify that an Examination Committee has met on 8 March 2011 to conduct the final examination of **Shee Yu Gang** on his **degree** thesis entitled "**All-Optical Generation of Millimeterwave Carrier based on Stimulated Brillouin Scattering**" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Examination Committee were as follows:

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of **Doctor of Philosophy**. The members of the Supervisory Committee were as follows:

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

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SHEE YU GANG

Date: 8 March 2011

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