Conclusions: We propose a cost-effective CFC circuit that uses a small number of components. By accumulating the charges produced by repetitive charge integration, the difference between two capacitances can be converted to an output frequency with good linearity. Experimental results show that the circuit has a conversion gain of 6.8293 kHz/IF, which makes it possible to detect small changes in differential capacitance.

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Magnetic field tunable 75–110 GHz dielectric phase shifter
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A magnetic field tunable W-band phase shifter based on dielectric resonator type harmonic ferrite has been designed and characterised. A phase shift of 60° with low losses is demonstrated at low bias magnetic field.

Introduction: Tunable phase shifters are among the crucial components in phased array radars for beam formation and steering, as well as in wireless and satellite communication systems [1]. Phase shifters for the frequency range 75–110 GHz are of interest for use in phased array transmitters and receivers for automobile radars [2]. Among the available options, ferrite phase shifters have the advantages of low insertion loss and high power handling capability. Traditional ferrite phase shifters exploit the fast variation of magnetic permeability near ferromagnetic resonance (FMR) frequency; hence their operating frequency is defined by the FMR frequency range of a ferrite material. Spinel ferrites or garnets are not suitable for millimetre-wave phase shifters owing to the large external magnetic field necessary to operate at high frequencies.

Pure or Sc-doped barium, or strontium hexagonal ferrites with M-type structures, have high uniaxial anisotropy fields and are appropriate materials for phase shifters in the Ka- and V-bands [3]. However, devices at higher frequencies, such as W-band, would still require a very large bias magnetic field.

One possible solution for phase shifters in the W-band is the use of Al-substituted M-type hexaferrites [4], which have a much larger uniaxial magneto-crystalline anisotropy field than BaFe$_2$O$_4$ (BaM), but substitution of Al for Fe increases losses. An alternative to FMR-based devices is the utilisation of dielectric resonances BaM. Such resonances occur at a much higher frequency than FMR in gyrotropic resonators with rotational symmetry and could be tuned with an external bias field $H$ to achieve a differential phase shift. Magnetic field dependence of dielectric resonance frequency is well understood in garnets and spinel ferrites [1, 5, 6], but has not been studied in any detail in hexaferrites.

Design: A waveguide phase shifter, as in Fig. 1, is proposed. A single crystal BaM with a uniaxial anisotropy field of 16.8 kOe was used. A disk with diameter $D = 1.24$ mm and thickness $S = 0.28$ mm was chosen since rotational symmetry for the sample is a key requirement. The above dimensions ensure the lowest-frequency of dielectric resonances to be in the W-band. The sample was mounted in a WR-10 waveguide flange and sandwiched between a 30 µm-thick dielectric polyethylene layer and a foam slab. The dielectric layer serves two purposes; by moving the BaM disk away from metal surface one decreases the high frequency losses and slightly increases the frequency of the main $E_{115}$ dielectric mode.

Fig. 1 Zero-field frequency of $E_{115}$ dielectric resonance against dielectric layer thickness
Transmitted wave has magnetic field dependent phase shift relative to incident wave
Inset: Schematic of phase shifter cross-section with magnetic system

For $H = 0$, the frequencies $\omega$ of $E$-type dielectric modes are derived to be

$$\tan(\beta_{\omega}S) = \left(\frac{\tanh(\beta_{1,1}d_1) + \tan(\beta_{1,2}d_2)}{1 + \frac{\beta_{1,1}^2}{\beta_{1,2}^2}}\right)\left(\frac{\beta_{1,1}e_{\perp}}{\beta_{1,1}e_{\parallel}} + \frac{\beta_{1,2}^2}{\beta_{1,2}^2}\right)$$

$$\tan\left(\frac{\beta_{1,2}d_1}{\tan(\beta_{1,2}d_2)}\right)$$

(1)

Here

$$\beta_{1} = \sqrt{\frac{\frac{2\pi}{\mu_0}c^2}{e_{\perp} - e_{\parallel}^2}}$$

$$\beta_{1} = \sqrt{\frac{\frac{2\pi}{\mu_0}c^2}{e_{\parallel}^2 - e_{\perp}^2}}$$

and $e_{\perp}$ and $e_{\parallel}$ are the transverse and longitudinal dielectric permeability, respectively, $c$ is the speed of light, $d_1$ and $d_2$ are thickness of air space between the resonator and metal planes above and below, $\beta = 2A_{mn}/D, A_{mn}$ is an $n$th root of Bessel functions $J_n(\alpha) = 0$.

Owing to the nonreciprocity of a magnetised ferrite medium with respect to two rotation directions the degeneracy is removed for $H \neq 0$ and their frequencies become magnetic field dependent [1, 5, 6]. When the resonator centre point is placed at a quarter-width from the waveguide sidewall, the polarisation of waveguide $H_{0w}$ wave across the resonator is predominantly circular (left or right, depending on the direction of propagation). Hence, the direct wave at a given frequency excites the clockwise rotation mode, e.g. the reverse wave cannot excite either the counterclockwise mode (owing to unfavourable polarisation) or the clockwise mode (polarisation is appropriate but the frequency is different). Therefore, such an arrangement ensures operation with only one of the split modes and the phase shifter becomes nonreciprocal [7].

Calculations of zero-field $E_{115}$ resonance frequency against $d_1$ using (1) with $e_{\perp} = e_{\parallel} = 16$ for a series of thicknesses $S$ are shown in Fig. 1. Here we assumed that the sample lies in a WR-10 waveguide with dimensions $a = 2.54$ mm and $b = 1.27$ mm so that $d_2 = b - S - d_1$. As can be seen from Fig. 1, one can easily control the zero-field frequency of the $E_{115}$ mode, hence the phase shifter operating point in the whole W-band by just varying $d_1$.

Results: Microwave measurements were carried out using a 75–110 GHz Agilent vector network analyser with the standard calibration procedure performed before measurements. A swept input signal was applied to the sample mounted flange that was inserted between two reference planes of WR-10 waveguides. This ensured that only contributions from the phase shifter were measured. The bias magnetic field $H$ was aligned parallel to the disk axis. Profiles of $S_{21}$ amplitude and differential phase shift against $f$, for a series of $H$, are shown in Fig. 2. High-frequency split mode $E_{115}$ was chosen because it provides larger phase shift compared with low frequency $E_{116}$. The operating
frequency of 80 GHz is a compromise between insertion losses and phase shift. Data on the differential phase shift $\Delta \varphi = \varphi(f, H) - \varphi(f, H = 0)$ against $H$ is shown in Fig. 3. A maximum $\Delta \varphi$ of 60° for $H = 3200$ Oe and an insertion loss of 1.5–4 dB are obtained. This phase shifter is indeed nonreciprocal with $\Delta \varphi$ up to $-250°$ in the reverse direction, while the losses are 10 dB. Note that on the contrary to the work in [3] where ferrite needs to be saturated, our resonator is based on dielectric resonance, hence it can operate in the unsaturated regime.

Fig. 2 Dielectric resonance absorption profiles and differential phase shift of BaM gyromagnetic resonator at different values of applied magnetic field

Fig. 3 Direct phase shift and insertion losses of phase shifter at 80 GHz

If we consider the resonator as a pure dielectric with quality factor $Q$ and resonant frequency $f_0$, the transmission coefficient $T$ is given by [8]:

$$T(f) = \frac{1 + i \xi}{1 + K + i \xi}, \quad \xi = Q \left( \frac{f_f - f}{f_f} \right).$$

$$S_{21} = -20 \log(T).$$

(2)

Here $K$ is the coupling coefficient defined by $K = (1 - T_s)/T_r$, where $T_r$ is the transmission coefficient at resonance. From (2) one can find the phase

$$\varphi(f, H) = \arctan \left( \xi(H) \frac{1 - T_r}{1 + T_r \xi(H)} \right).$$

(3)

In (3) $\xi(H)$ stands for $Q(f_r/H) - f_r(H)/f_r$. By estimating values of $Q$, $T_r$, and $f_r$ obtained from data and used in (3), we obtained theoretical $\Delta \varphi$ against $H$ shown in Fig. 3, which is smaller than the measured values by a factor of 3, which is probably owing to the gyrotropic nature of the resonator and the presence of split modes.

Conclusion: A magnetic field tunable W-band ferrite phase shifter utilizing dielectric resonances in barium ferrite has been demonstrated. It was shown that the magnetic field dependence of dielectric resonance frequencies creates possibilities for using high-quality hexaferrite materials at frequencies much higher than for traditional FMR devices.

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Experimental study on effect of second-harmonic injection at input of classes F and F−1 GaN power amplifiers


This presented study focuses on the impact of gate-source voltage waveforms on power added efficiency performances of GaN HEMTs for the design of class F and class F−1 amplifiers. It is shown that second-harmonic signal injection at the gate port of transistors can lead to efficiency improvements in the case of class F operation and efficiency deteriorations in the case of class F−1 operation. This work is applied to a 15 W GaN HEMT die from Cree at a fundamental frequency Fo equal to 2 GHz. Measured on-wafer time domain measurements are reported.

Introduction: AlGaN/GaN HEMT technology offers good potentialities for high-efficiency high power microwave amplification because of high current densities and high breakdown voltage. High efficiency performances of microwave power amplifiers are reached when fundamental and harmonic frequency components (Fo, 2Fo, 3Fo) are terminated into appropriate impedances. High efficiency harmonic tuned microwave power amplifiers have been widely reported during the past few years [1–6].

In this Letter, we focus on class F and class F−1 operation modes and examine a possible way to increase efficiency performances using active second-harmonic signal injection at the gate port of GaN HEMTs. An appropriate control of both first and second harmonics of the gate-source voltage results in a quasi-half sine wave shape having a DC level close to or a little above the pinch off voltage of the transistor. Such a gate-source voltage shape results in an aperture time reduction of the drain-source current. Consequently a decrease of the DC drain current and an improvement of efficiency can be obtained. In the following, we demonstrate by experimentation that this technique can be successfully applied to class F amplifiers but is not compliant with class F−1 amplifiers.