The Effect of Windings on ADSL Transformer Insertion Losses

JIANG Xiao-na¹, LAN Zhong-wen¹, CHEN Sheng-ming², ZHANG Huai-wu¹, SU Hua¹
1. State Key Laboratory of Electronic Thin Films and Integrated Devices, University of Electronic Science and Technology of China Chengdu 610054 China
2. Center of Magnetic Material and Device Engineering Technology of Jiangsu Wuxi 214199 Jiangsu China

Abstract Insertion loss (IL) is one of the important parameters of asymmetrical digital subscriber loop (ADSL) transformers. In different frequency bands, the factors that affect insertion loss are different. Windings mainly affect insertion loss in mid and high frequency bands. The effects of winding ways, winding wire diameters and winding turns on insertion loss were discussed. The presented experiment shows that the insertion loss of an ADSL transformer could be under 0.4 dB in mid frequency band when the winding is 30 turns, in which the ADSL transformer satisfies the requirement of total harmonic distortion (THD). Our experiments also show that the sandwich winding structure is better than the side by side winding structure and the twisted-pair winding structure, and the increase of winding diameter is one means to reduce insertion losses of an ADSL transformer in mid frequency band.

Key words asymmetrical digital subscriber loop; insertion loss; transformer; winding

In an asymmetrical digital subscriber loop (ADSL) system, the ADSL transformer, as an interface between transceivers and transmission lines, can be used in the chipset of modems or isolation devices. ADSL transformers are low power and linear, and they are different from power transformers. The main function of ADSL transformer is coupling the transmission information between transceivers and transmission lines. So ADSL transformers should have high qualities so as to transmit information with low loss and distortion[1]. At the same time, ADSL transformers should supply DC isolation, impedance match, electric insulation, and accurate ratio of voltage or current between the both sides of ADSL transformer, etc.

An ADSL transformer will bring insertion loss when it is put in system circuits. In different frequency bands the factors that affect insertion loss are different. Insertion loss relates to the winding ways, winding wire diameters, winding turns, working voltages, and magnetic fields[2]. In this paper, we mainly study winding ways, winding wire diameters and winding turns.

1 Experiment

THD is generated when a sine wave magnetic field induces a non-sinusoidal flux density. This is due to a non-linear relation between flux density and magnetic field in the ferrite core of a transformer[3]. In order to reduce total harmonic distortion (THD) of ADSL transformers, we adopt EPX/EOP type ferrite cores, which have high permeability (µ_i = 10 000) and are the most suitable cores for ADSL transformer at present. We introduce an air-gap in the core set to improve THD. The primary winding inductance is 100 µH, and the turn ratio between the primary and secondary windings is 1:1. According to the requirement of THD and the following Eq.(1), we account winding turns of ADSL transformers with different flux densities.

\[
B = V_{rms}/(4.44fNA_e)
\]

where B is the magnetic flux density, V_{rms} is the root mean square work voltage, N is the turns of primary windings, and A_e is the effective core area.

Fig.1 Three kinds of winding ways of ADSL transformers
In our experiment, four kinds of primary winding turns are adopted. The winding turns are separately 30 Ts, 40 Ts, 48 Ts, and 60 Ts. By considering the working frequency, the high transmit rate, and the skin effect, four kinds of winding wires are used. The diameters of these winding wires are 0.1 mm, 0.13 mm, 0.15 mm, and 0.18 mm, separately. The bobbins are EPX/EOP type. They determine the winding shape. Three kinds of winding ways are applied as shown in Fig.1.

2 Analysis

The insertion losses, leakage inductances, and distributed capacitances are tested by Voltech AT3600, and the THD by ATS-1. The test voltage is 100 mV. The load resistance is 100 Ω. The THD is under −82 dB at 30 kHz. Winding turns not only affect THD but affect insertion losses. The relationship between insertion losses and frequencies with different winding turns is shown in Fig.2.

In the low frequency band, the key parameter that affects insertion loss is the inductance of primary winding. Insertion loss will be high when the primary inductance is small. The primary inductance we designed is 100 µH, so the insertion loss would be high. In this paper, we mainly analyze the insertion losses in mid and high frequency bands.

Fig.2 shows that in mid and high frequency bands the insertion losses rise sharply when winding turns increase, furthermore, insertion the losses rise more obviously in high frequency band than that in mid frequency band. The reason is that increasing winding turns induce both increasing winding resistances and increasing leakage inductances and distributed capacitances. So the insertion losses will increase. The relationship between leakage inductances and distributed capacitances with frequencies is shown in Fig.2. The results in Fig.2 show that the leakage inductances and the distributed capacitances increase when winding turns increase. The reason is that winding widths and thicknesses increase when winding turns increase. The winding shape may induce high leakage inductances and distributed capacitances. Leakage inductances is affected by characteristics of core materials, winding shapes, winding turns, and the coupling of primary and secondary windings. The relation of leakage inductances, winding turns and the winding shape is described as

\[ L_i \propto \frac{N^2 l_w h_w}{b_w} \]  \hspace{1cm} (2)

where \( l_w \) is the winding height, \( b_w \) is the winding width, \( h_w \) is the winding mean length of each turn.

When winding turns increase, the capacitances between turns and the capacitances between layers will both increase. If the requirement of THD is satisfied, less winding turns should be chosen. In addition, the diameters of winding turns should be considered. Because the transmit rate is high in ADSL systems, we have to consider not only the skin effect but also the effect of wire diameters on insertion losses. The characteristics of ADSL transformers with four kinds of winding wire diameters are shown in Fig.3.

From Fig.3 it can be found that wire diameters heavily affect the insertion losses in mid frequency band, and the insertion losses reduce when wire diameters increase. Because the main factor that affect insertion losses in mid frequencies band is winding
As it is well known, winding resistances will reduce when wire diameters increase. So insertion losses will reduce too. In high frequencies band, the effect of wire diameters on insertion losses should be considered from leakage inductances and distributed capacitances. When wire diameters increase, winding wires may distribute unevenly, the distances between winding turns will increase and the thickness of windings will increase. So all these may induce leakage inductances and distributed capacitances to increase. If ADSL transformers meet the requirement of insertion losses, we should select thin winding wires in order to weaken skin effects.

In addition, winding ways play an importance role for insertion losses. In our design, three kinds of winding ways are applied and the same magnetic core with different lengths of air-gaps is used. The test results are showed in Fig.4.

In mid and high frequency bands insertion losses change more greatly for the side by side winding structure compared with that for the sandwich winding structure and the twisted-pair winding structure, because the side by side winding structure will induce large leakage inductances. This can also be seen from Fig.4(b). For the side by side...
winding structure, winding wires in the same winding distribute more tightly than that in other winding ways. Under the circumstances, though distributed capacitances are only 7 pF, the coupling between primary and secondary windings is bad, so leakage inductances can reach 16 μH. For the twisted-pair winding structure, leakage inductances are under 1 μH because of the good coupling, but distributed capacitances reach 80 pF. Furthermore, it is very hard to introduce insulators which are benefit to improve the dielectric intensity. Though for the twisted-pair winding way insertion losses are low, we should not choose it. As regards the sandwich winding structure, leakage inductances and distributed capacitances are treated well, and it is easy to introduce insulators between the windings. So ADSL transformers can meet the safe requirement easily[7].

3 Conclusions

The effects of winding on insertion loss are the effects of winding resistance, leakage inductance and distributed capacitance. But leakage inductance and distributed capacitance are contradictory in the same transformer. Through experiments we find the sandwich winding structure is benefit to treat leakage inductance and distributed capacitance. This structure is the best one of the three winding structures discussed in this paper. Generally, the side by side winding structure can make insertion losses rise sharply and therefore transmit characteristics become deteriorative. Selecting thick winding wire diameter can reduce winding resistance, so insertion loss in mid frequency band can be reduced. But when winding wire diameter is too thick, skin effect will get serious and winding wire could not distribute evenly, and leakage inductance and distributed capacitance rise. So the perfect winding wire diameter should be in the range of 0.1 mm ~ 0.15 mm.

References

Brief Introduction to Author(s)

JIANG Xiao-na (蒋晓娜) was born in Henan, China, in 1977. She received the M.S. degree from University of Electronic Science and Technology of China (UESTC) in 2005. Her research interests include magnetic material and device.

LAN Zhong-wen (兰中文) was born in Sichuan, China, in 1963. He received the M.S. degree from UESTC in 1986. He is currently a professor with UESTC. His research interests include electronic material and device.

CHEN Sheng-ming (陈盛明) was born in 1956. He is a senior engineer. His main research field is ferrite material application.

ZHANG Huai-wu (张怀武) was born in Xian, China, in 1959. He received the B.S. degree from UESTC in 1992. He is currently a professor with UESTC. His research interests include electronic material and device.

SU Hua (苏 楠) was born in Sichuan, China, in 1977. He received the M.S. degree from UESTC in 2001. His research interests include electronic material and device.