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Supply Voltage Based Circuit Analysis of UBCT Cascode Amplifier

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Abstract - The Unipolar-Bipolar Composite Transistor (UBCT) cascode amplifier is a two stage amplifier circuit in which a UBCT common-source transconductance amplifier is directly coupled to a BJT common-base unity gain current amplifier. The overall voltage gain of UBCT cascode amplifier depends on the individual performance of both the constituent amplifier stages and it is mainly affected by the supply voltage because of change in the operating voltage and corresponding current of the various circuit components. The present paper describes the circuit analysis of UBCT cascode amplifier in which the effect of variation in supply voltage on the voltage across circuit components and corresponding currents are experimentally investigated and therefore, the resultant effect on voltage gain is precisely analyzed.

Keywords - Unipolar-Bipolar Composite Transistor, UBCT Amplifier, UBCT Cascode Amplifier, Wideband UBCT Amplifier, High Gain UBCT Amplifier

I. INTRODUCTION

The Unipolar-Bipolar Composite Transistor (UBCT) includes composite circuit of unipolar transistor JFET and bipolar transistor BJT. A typical UBCT is designed with n-channel JFET (BFW10), npn BJT (CL100) and source-emitter resistor pair (R_S-R_E) (100Ω-10Ω) and so designated as a three terminal composite transistor similar to JFET [1]. The circuit components of UBCT are optimized to achieve the best performance [2] and it offers high input resistance along with linear transfer characteristics [3]. The drain resistance and transconductance of UBCT are also improved up to the pinch-off voltage [4]. Thus the UBCT is found suitable for amplifier circuits due to enriched dynamic performance [5]. The best performance is achieved by a typical UBCT having JFET (BFW10), BJT (CL100) and source-emitter resistor pair (R_S-R_E) (100Ω-10Ω) as a common-source amplifier at the supply voltage of 18V [6] with maximum efficiency of 0.066dB/mW [7]. The UBCT amplifier provides mid-band voltage gain with negative feedback of 13.77dB and frequency bandwidth of 1.0MHz [8]. To improve the frequency bandwidth, UBCT cascode amplifier circuit is designed in which a UBCT common-source (CS) amplifier is directly coupled to a BJT common-base (CB) amplifier. The circuit components of UBCT cascode amplifier are optimized to achieve maximum voltage gain for a particular circuit condition [9]. It offers mid-band voltage gain with negative feedback of 14.04dB and frequency bandwidth of 3.3MHz for optimized supply voltage of 18V [10] with gain roll-off rate of -26dB/Decade [11]. The voltage gain of UBCT cascode amplifier circuit is mainly affected by the supply voltage because of change in the operating voltage and corresponding current of the various circuit components of both the constituent amplifier stages. The present paper describes the circuit analysis of UBCT cascode amplifier in which the effect of variation in supply voltage on the voltage across circuit components and corresponding currents are experimentally investigated and therefore, the resultant effect on voltage gain is precisely analyzed.

II. UBCT CASCODE AMPLIFIER

As depicted in fig.1, the UBCT cascode amplifier is a two-stage amplifier circuit in which a UBCT CS transconductance amplifier is placed at input stage and a BJT CB unity gain current amplifier at output stage. The UBCT CS amplifier is designed in self-biased arrangement with source bypass capacitor for ac grounding of source terminal and the BJT CB amplifier is in voltage divider biased arrangement with base bypass capacitor for ac grounding of base terminal. Both the amplifier stages are directly coupled and thus the output drain current of UBCT CS amplifier is directly fed to the input emitter current of BJT CB amplifier and the corresponding output collector current is then sequentially fed to the load resistor. The UBCT CS input stage attains low voltage gain because of low input resistance of the BJT CB stage. Thus the input miller capacitance and voltage gain product becomes low, which is responsible for maintaining high voltage gain at higher frequency region and hence the bandwidth is expanded. The overall voltage gain delivered by UBCT cascode amplifier is basically the voltage gain provided by

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the BJT CB output amplifier stage [12]. Therefore, the UBCT cascode amplifier circuit is designed to combine the advantages of both amplifier stages to achieve wide frequency bandwidth and high voltage gain [13].

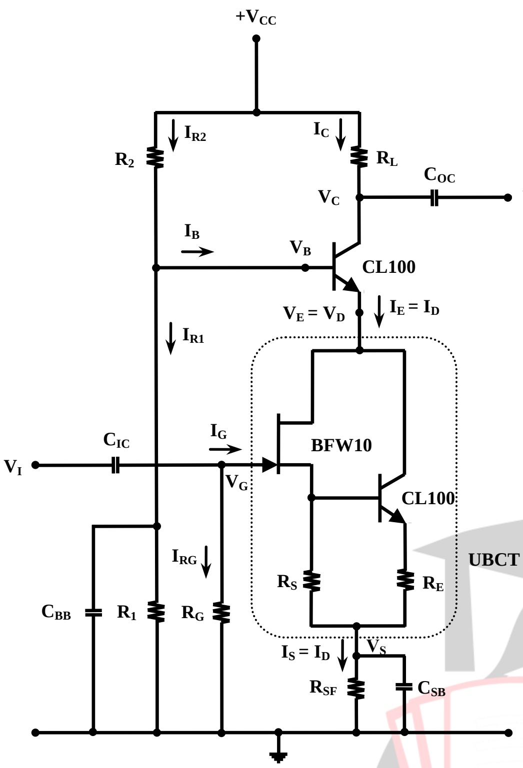

Fig.1. UBCT Cascode Amplifier Circuit

The UBCT cascode amplifier is designed with circuit components of UBCT amplifier having JFET (BFW10), BJT (CL100) and source-emitter resistor pair (R_S-R_E) (100Ω-10Ω) with gate resistor R_G=1MΩ, load resistor R_L=1kΩ, source feedback resistor R_{SF}=100Ω, input & output coupling capacitors C_{IC}=C_{OC}=10μF and source bypass capacitor in No-Connection mode C_{SB}=N/C (to obtain voltage gain with negative feedback) along with circuit components of BJT amplifier having an additional BJT (CL100) with BJT biasing resistor pair (R_1-R_2) (4.7kΩ-10kΩ) and base bypass capacitor C_{BB}=10μF [14].

III. CIRCUIT ANALYSIS

In the experimental observations, the voltage across all the circuit components and corresponding currents are investigated for a range of supply voltage from 9V to 21V. Also an input signal ac voltage (sine wave) of 100mV(p-p) having fixed frequency of 1kHz is applied to the UBCT cascode amplifier circuit and corresponding output voltage is measured to obtain voltage gain for the normal operating temperature range of 30°C to 33°C.

The fig.2 depicts the voltage distribution in BJT biasing resistor pair (R_1-R_2) and corresponding currents for a particular range of supply voltage. For variation in supply voltage from 9V to 21V, the voltage across resistor R_2 increases linearly from 6.28V to 14.59V with corresponding increment in current I_{R2} from 0.628mA to 1.459mA and also voltage across resistor R_1 increases linearly from 2.72V to 6.41V with corresponding increment in current I_{R1} from 0.579mA to 1.364mA. A very small difference is observed between currents I_{R2} and I_{R1} because of very low value of base current I_B of BJT and thus I_{R1} is slightly less than I_{R2}.

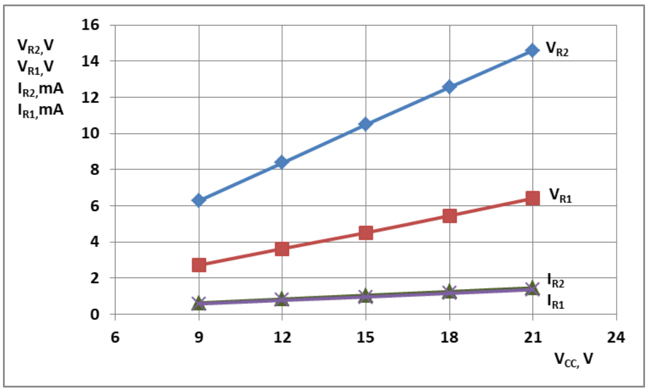

Fig.2. Voltage across Resistor R_2 and R_1 (V_{R2} and V_{R1}) and corresponding Currents (I_{R2} and I_{R2}) versus Supply Voltage (V_{CC})

As depicted in fig.3, the base to emitter voltage of BJT shows a very small variation from 0.64V to 0.66V with corresponding variation in base current from 0.049mA to 0.095mA for change in supply voltage from 9V to 21V. The change in base current of BJT is then responsible for change in collector current and emitter current of BJT amplifier.

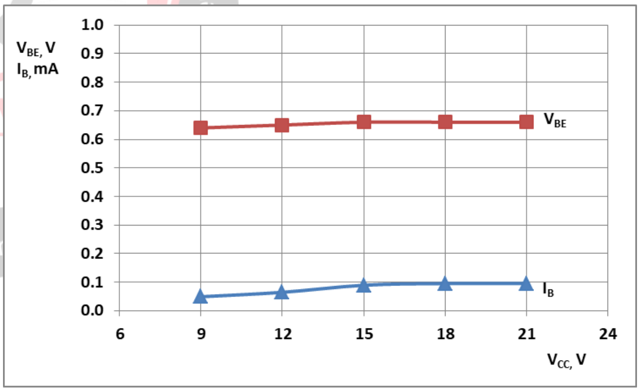

Fig.3. Base to Emitter Voltage (V_{BE}) of BJT and corresponding Base Current (I_B) versus Supply Voltage (V_{CC})

As depicted in fig.4, the gate to source voltage of UBCT changes from -0.54V to -1.12V with increase in supply voltage from 9V to 21V. The UBCT exhibits very large input resistance and thus the corresponding gate current becomes very small which often assumed to be zero. Therefore, the source current becomes almost equal to the drain current for UBCT amplifier circuit. As far as the gate resistor current I_{RG} is concerned, the gate terminal voltage V_G is at virtual ground condition because of large gate resistor R_G and having corresponding zero gate resistor current I_{RG}.

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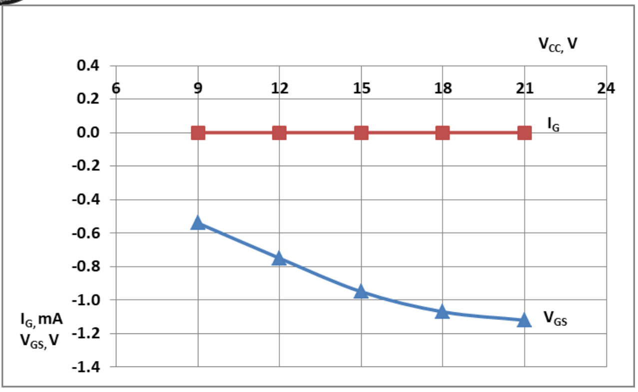

Fig.4. Gate to Source Voltage (V_{GS}) of UBCT and corresponding Gate Current (I_G) versus Supply Voltage (V_{CC})

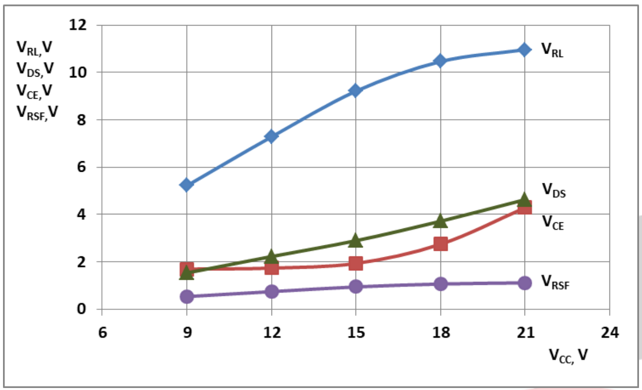

Fig.5. Load Resistor Voltage (V_{RL}), Drain to Source Voltage (V_{DS}) of UBCT, Collector to Emitter Voltage (V_{CE}) of BJT and Source Feedback Resistor Voltage (V_{RSF}) versus Supply Voltage (V_{CC})

As depicted in fig. 5, for variation in supply voltage from 9V to 21V, the load resistor voltage varies from 5.22V to 10.96V, the drain to source voltage of UBCT increases from 1.54V to 4.63V, the collector to emitter voltage of BJT varies from 1.70V to 4.29V and source feedback resistor voltage increases from 0.54V to 1.12V. The variation in drain to source voltage of UBCT shows small degree of non-linearity, whereas the collector to emitter voltage of BJT exhibits large degree of non-linearity. The load resistor voltage increases almost linearly in the range of supply voltage from 9V to 18V and thereafter it is nearly saturated in the range of 18V to 21V.

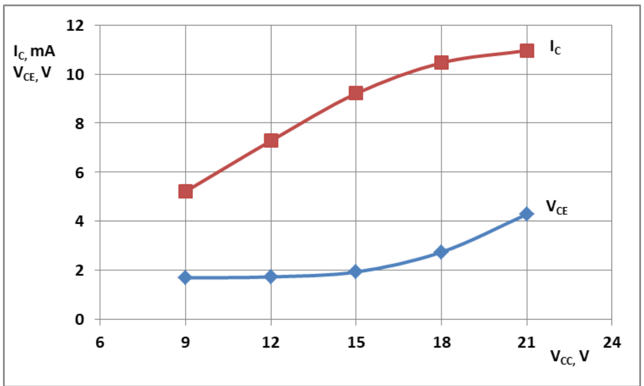

Fig.6. Collector to Emitter Voltage (V_{CE}) of BJT and corresponding Collector Current (I_C) versus Supply Voltage (V_{CC})

The fig. 6 shows that collector to emitter voltage of BJT increases from 1.70V to 4.29V and the corresponding collector current from 5.22mA to 10.96mA for variation in supply voltage from 9V to 21V. The collector current increases largely with small increment in collector to emitter voltage in the range of supply voltage from 9V to 18V and thereafter collector current is almost saturated in the range of 18V to 21V.

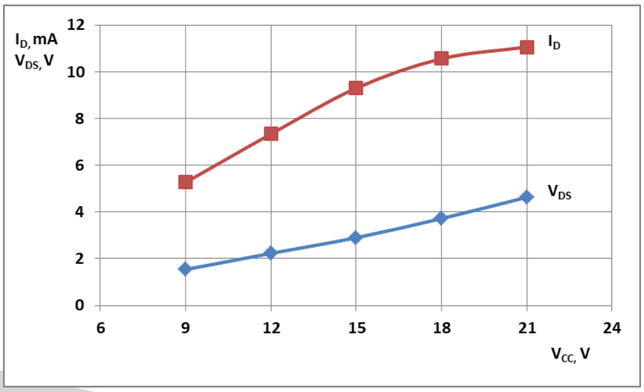

Fig.7. Drain to Source Voltage (V_{DS}) of UBCT and corresponding Drain Current (I_D) versus Supply Voltage (V_{CC})

The fig. 7 shows that drain to source voltage of UBCT increases from 1.54V to 4.63V and the corresponding drain current increases from 5.27mA to 11.06mA for variation in supply voltage from 9V to 21V. The drain current of UBCT also increases almost linearly with similar increment in drain to source voltage in the range of supply voltage from 9V to 18V and thereafter the drain current tends to be almost saturated in the range of 18V to 21V.

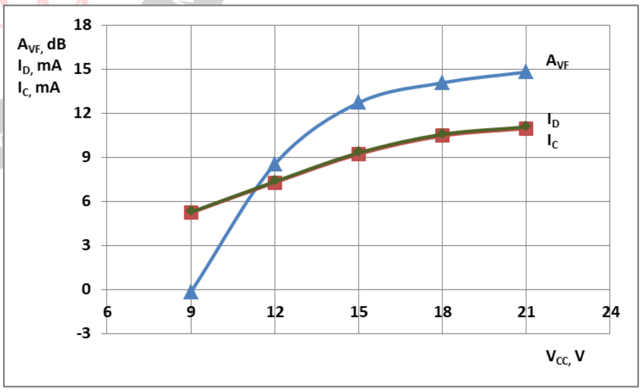

Fig.8. Voltage Gain with Negative Feedback (A_{VF}) of UBCT Cascode Amplifier, Drain Current (I_D) and Collector Current (I_C) versus Supply Voltage (V_{CC})

As depicted in fig. 8, the drain current of UBCT and collector current of BJT are unable to be distinguished due to having almost similar value. The drain current of UBCT is basically the emitter current of BJT, which is slightly larger than the collector current. Both the drain current and the collector current show approximately linear increment for a range of supply voltage from 9V to 18V with large non-linear increment in voltage gain with negative feedback of UBCT cascode amplifier from -0.18dB to 14.07dB. For

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supply voltage in the range of 18V to 21V, the drain current of UBCT CS transconductance amplifier and the collector current of BJT CB unity gain current amplifier both tend to saturate and therefore, the voltage gain with negative feedback of UBCT cascode amplifier is ultimately almost saturated with a small variation from 14.07dB to 14.80dB.

IV. CONCLUSION

In the UBCT cascode amplifier circuit, as the supply voltage increases from 9V to 18V, the voltage across various circuit components and corresponding currents of both the constituent amplifier stages are increased. However in the range of supply voltage from 18V to 21V, the input quantity of UBCT CS transconductance amplifier and BJT CB unity gain current amplifier both tend to saturate and thereafter the resultant output quantities are also approximately saturated. As a result, the input gate to source voltage and corresponding output drain current for UBCT CS transconductance amplifier along with input emitter current and corresponding output collector current for BJT CB unity gain current amplifier are independently attained the saturation levels. Therefore, the overall voltage gain of UBCT cascode amplifier circuit is almost saturated as the main output collector current achieves its saturation for the supply voltage ranging from 18V to 21V.

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