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Research Article

An Efficient Algorithm and Its Implementation for Armstrong's Indirect Method of Conversion of Narrowband FM to Wideband FM: A Valuable Tool for Communication System Designers

Syed Waqar Shah[1], Mazhar Sher[2], Talha Khan[2], Tariqullah Jan[1*], Haseeb Zafar[1],Syed Riaz ul Hassnain[2], Gulzar Ahmad[1] and Sahibzada Majid Ashraf[1]

[1]Department of Electrical Engineering, University of Engineering and Technology, Peshawar, Pakistan

[2]Department of Electronics Engineering ,University of Engineering and Technology, Abbottabad Campus, Pakistan

Abstract. A novel algorithm is presented to calculate the most appropriate frequency multipliers for the conversion of NBFM to WBFM. This algorithm makes the communication system designer job easier and calculates most accurately the best possible frequency multiplying factors in least possible time. The carrier frequency and frequency deviation of NBFM signal can be increased by the application of these frequency multipliers. The algorithm is implemented in C++ programming language and is applied to various practical design problems. The best possible results are generated with least possible errors. The algorithm can be used for either frequency Doublers or frequency Triplers or frequency Quintuplers or 1000* frequency or combination of them like frequency Doublers and Triplers, frequency Doublers and Quintuplers, frequency Triplers and frequency Quintuplers, etc.

Keywords: Narrowband frequency modulation, wideband frequency modulation, algorithm, communication system

1. INTRODUCTION

FM signal can be generated by two methods namely: Direct Generation and Indirect Generation. The Direct Generation of FM signal involves voltage-controlled oscillator (VCO) in which message signal is used as a control signal and VCO frequency varies linearly with the modulating signal. The severe concern with Direct Generation method is the poor frequency stability. The drift of the carrier frequency is intolerable in commercial FM broadcastings [1]. The indirect method of FM generation consists of two steps:

1. Generation of NBFM signal from the message signal; and
2. Conversion of NBFM to WBFM using frequency multipliers.

The indirect method is preferred in commercial radio broadcasting due to its frequency stability property [2]. Frequency multipliers are of utmost importance in communication system. They are actually non-linear devices used for generation of FM signals [3] with band pass filter to extract desired frequencies. If x(t) is the input signal and it is provided to a non-linear system so that the output obtained from this system is y(t) where

$$y(t)= b_2[x(t)]^2$$

Let $x(t) = \cos(\omega_c t + k_f\int m(t)dt)$ is a FM signal, then y(t) will consist of a dc component 0.5 b_2 and a signal $0.5b_2 \cos(2\omega_c t + 2k_f\int m(t)dt)$. A bandpass filter centered at $2\omega_c$ can be used to extract the FM signal whose frequency is twice as compared to original input signal.

This approach can be extended to get signals at $\omega_c, 2\omega_c, 3\omega_c, 4\omega_c, \ldots, n\omega_c$ with frequency deviations

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*Corresponding author: Tariqullah Jan: Email: tariqullahjan@nwfpuet.edu.pk

ranging from Δf, 2Δf, 3Δf,…, nΔf. Thus by the application of frequency multipliers it is possible to increase the carrier frequency and frequency deviations of composite FM signal.

An nth multiplier will increase the carrier frequency to $n\omega_c$ and frequency deviation to nΔf. This concept is used to obtain WBFM from NBFM. The NBFM signal can be approximated by the following equation:

$$\varphi_{NBFM}(t)=A[\cos \omega_c t - k_f\, a(t) \sin \omega_c t]$$

The next process involves the use of frequency multipliers to increase the carrier frequency and frequency deviation. When Δf and fc is multiplied by a multiplying factor of n, the tremendous increase in fc is undesirable and frequency heterodyning operation is used to down shift the carrier frequency [4].

Edwin Armstrong is the pioneer and inventor of Wideband FM systems [5] and his major interest was in the suppression and possible elimination of various atmospheric disturbances [6]. WBFM signals have distinct characteristic that their bandwidth not only depends upon the bandwidth of the message signal f_m but also on the modulation index β. WBFM has modulation index having value β>>1 and by varying the value of this β, we can control the bandwidth of the WBFM .

FM commercial transmitter is shown in Fig. 2, where message/modulating signal is first converted to approximate NBFM signal and then multipliers and frequency converters are employed to obtain the WBFM signal. Frequency multipliers are incorporated to change the carrier frequency, modulation index β and frequency deviation [7]. Crystal oscillator having frequencies ranging from 9 MHz to 11 MHz and frequency mixing circuits are employed to perform the frequency down conversion.

3. ALGORITHM DESCRIPTION

The flow chart of the proposed algorithm for the conversion of NBFM to WBFM is presented in Fig. 3. The algorithm [8] is used to determine the most appropriate frequency multiplying factors with the best possible accuracy and in least possible time. This algorithm is used to determine the multipliers works on the following logic:

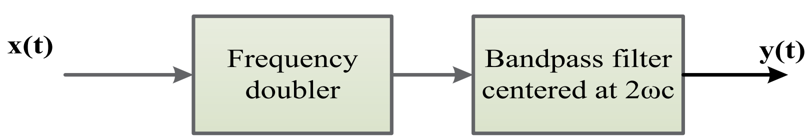

Fig. 1. The block diagram of frequency doubler.

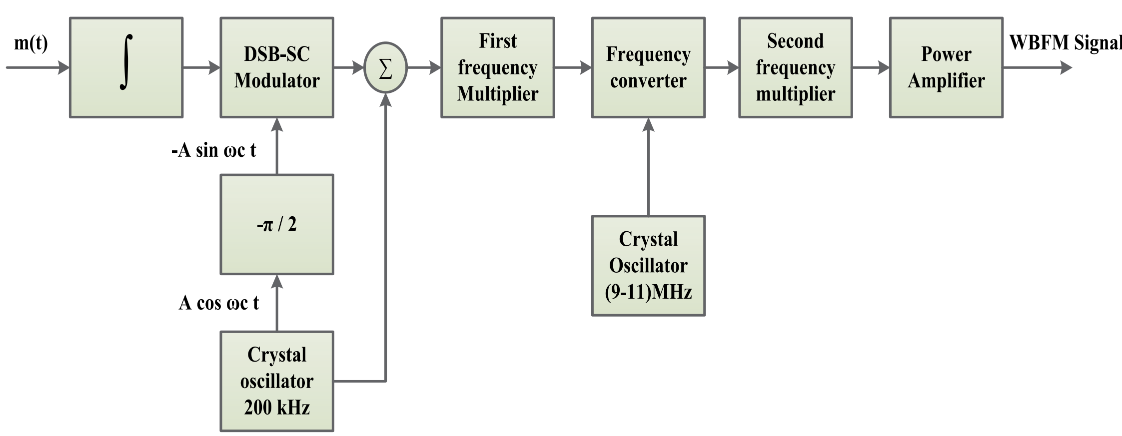

Fig. 2. Block diagram of Armstrong Indirect FM transmitter.

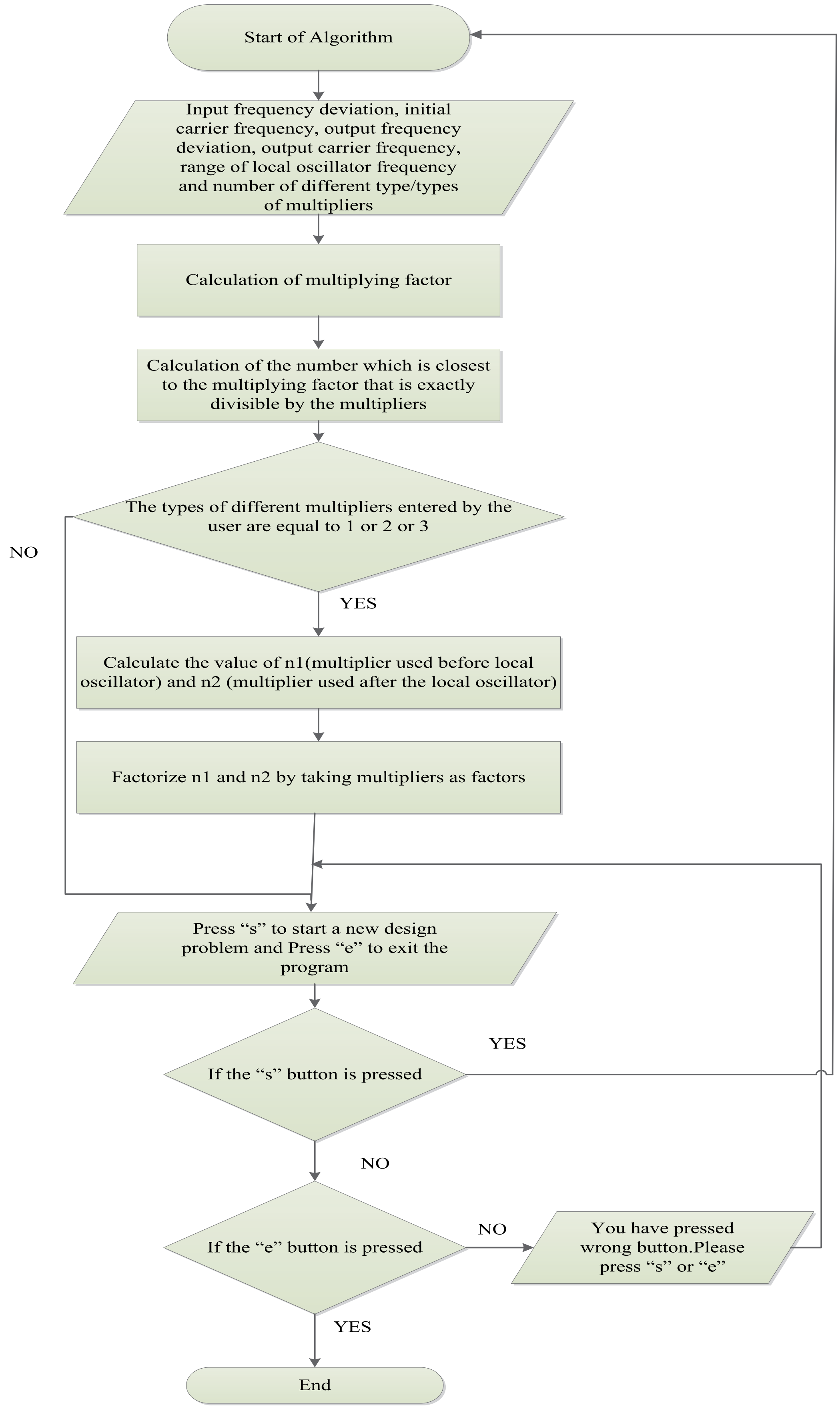

Fig. 3. Flow chart of the proposed algorithm.

To convert a NBFM to WBFM we have to increase the frequency deviation and carrier frequency of the NBFM. For example if we have a NBFM having frequency deviation of 25 Hz(df1) and carrier frequency of 200 kHz(fc1) and we want to change it WBFM having the frequency deviation of 75 kHz(df4) and carrier frequency of 12.8 MHz(fc4).

To perform this task we multiply the frequency deviation and carrier NBFM with a certain number. The multiplication factor is found by dividing the final frequency deviation i.e. 75000 by initial frequency deviation i.e. 25 Hz and we get the number 3000.We have to multiply the NBFM signal with 3000 to change it to WBFM signal.

We do not have any electronic device that can directly multiply the frequency up to some value i.e. 3000 in this case that's why we convert the multiplication factor to some smaller factors so that available electronic devices like doublers, triplers andquintuplers or their combinations can be used to accomplish the required task.

If we utilize only doublers and triplers for the above case to get the multiplication factor of 3000. And the possible combination of doublers and triplers for the number closest to 3000 is 3072 which can be accomplished using 10 doublers and 1 tripler.

The first part of algorithm consists of finding the most suitable multiplying factor in terms of doublers, triplers, quintuplers etc. The algorithm checks whether the number is completely divisible by any combination of the different type of multipliers provided by the user. Let for the above case the program will check whether 3000 is completely divisible by the multiplication of any possible combination of doublers and triplers. If not then it will find the closest possible number completely divisible by the multiplication of any combination of doublers and triplers.

The algorithm determines the closest number by the following logic:

Algorithm copies the number (3000) into two different variables (num1 and num2) and increases the number (3000) by 1 using one variable num1 (3001 in the above case) and then checks that whether that number is completely divisible by the multiplication of any combination of doublers or triplers and in the next step it will decrease that number by 1 using other variable num2 (2999 in the this case) and then checks the same condition. If the condition does not meet it again increases the previously increased number num1 by 1(the number will be 3002) and the checks the condition if it is not satisfied then will decrease the previously decreased number by 1 (the number n_2 will be 2998) and then checks the condition and so on.

In this way a number can be obtained that is closest to original number (3000 in this case) and is completely divisible by the multiplication of the combination of different type of multipliers given (doublers and triplers in this case).

The direct multiplication by the help of doublers and triplers will result in increase of carrier frequency beyond the permissible value. This difficulty can be resolved by incorporating the frequency mixing process.

Initially we multiply both initial frequency deviation and carrier frequency of NBFM by an appropriate combination of multipliers (doublers and triplers in the our case) from the total combination of multipliers and then we will translate the carrier frequency using local oscillator and then again multiply the frequency deviation and carrier frequency with the remaining combination of doublers and triplers.

If we consider the above case, and let we have oscillators available in inventory stock having frequency range from 10 MHz to 11 MHz. We multiply the initial frequency deviation with 64(using six doublers) and the carrier frequency shifts to 12.8 MHz.

By the application of a local oscillator having frequency 10.9 MHz, the carrier frequency is shifted to 1.9 MHz (fc3). Then this frequency fc3 is multiplied by 48 (which is the remaining combination of multipliers having four doublers and one tripler) to obtain the final carrier frequency of 91.2 MHz.

Our proposed algorithm automates the above challenging task of finding the suitable factor of 3072 by using the following logic:

This novel algorithm splits the original number n into two numbers n_1 and n_2. The values of n_1 and n_2 greatly depend on the availability of different oscillators.

First of all, we will use only one type of multiplier and increase its power up to the last permissible power. As in the above example we choose n_1=3072, n_2=1 and check the condition that the resulting carrier frequency is in the range of local oscillator or not. If not then we swap the values assigned to n_1 and n_2 so that the new values are n_1=1 and n_2=3072 and check the range of the carrier frequency.

The next step involves the division of fc_4 by the first type of multiplier (the factor 2 in this example) and check of carrier frequency for the range of available local oscillators, for n_2=2 and n_1=1536 and in case of failure, the condition will be rechecked after swapping n_1 and n_2. After this step the power of the 1st multiplier (doubler in this case) is increased continuously up to its last value and after increasing every time we also swap the numbers. Here for each case, the program also checks the condition that whether resulting carrier frequency fc is in the range of the local oscillator's frequencies. If it does not then we will take n_2 the 2nd multiplier (tripler in the above case) and then n_1=n/n_2. If the condition does not fulfill, then the algorithm will multiply 1st multiplier with n_2 and will take the modified value of n_2 and each time will check the validity of condition and also swaps the numbers (the program swap the numbers every time when they are changed and also checks the condition). Then the power of first multiplier is increased up to its last value (10 in this case). If during this process, the condition does not meet it will make n_2 the square of 2nd multiplier and the multiply it with the 1st multiplier up to its last power and if condition does not satisfy it will make n_2 the cube of 2nd multiplier and will check the condition and in case condition of carrier frequency in permissible range does achieve then multiply it with the 1st multiplier up to its last power and so on (depending on n_2 it is also modifying n_1 by n_1=n/n_2). This process is continued for each possible factor of the resulting number (3072 in this case) by using the multipliers given (by using doublers and triplers in this case).

The algorithm successfully finds the two possible values of n_1 and n_2 which will result in the desired frequency deviation and carrier frequency.

A. Design Problem # 1

The task is to design an Armstrong indirect FM modulator which is capable of generating a wide band FM signal with carrier frequency 97.3 MHz and frequency deviation 10.24 kHz. A NBFM generator having output carrier frequency fc = 20 kHz and frequency deviation Δf = 5 Hz is available in inventory store. To convert this NBFM to WBFM the only multipliers available are doublers. The available local oscillators have adjustable frequency range of 400 kHz to 500 kHz for frequency mixing purposes.

B. Design Problem # 2

Design an FM modulator capable of generating an FM carrier with a carrier frequency of 96 MHz and frequency deviation Δf = 20 kHz. A NBFM generator with output carrier frequency fc = 200 kHz and frequency deviation Δf = 9.7656 Hz is available. A local oscillator with adjustable frequency in the range of 9 to 10 MHz and only frequency doublers are available.

C. Design Problem# 3

Design a commercial FM transmitter using Armstrong indirect method. The final output specifications are following:

1) Carrier frequency= 91.2 MHz
2) Frequency deviation = 75 kHz.
3) A narrowband FM generator with fc = 200 kHz and Δf = 25 Hz is available.
4) Local oscillator with adjustable frequency in the range of 9 to 11 MHz
5) Only frequency doublers and Triplers are available.

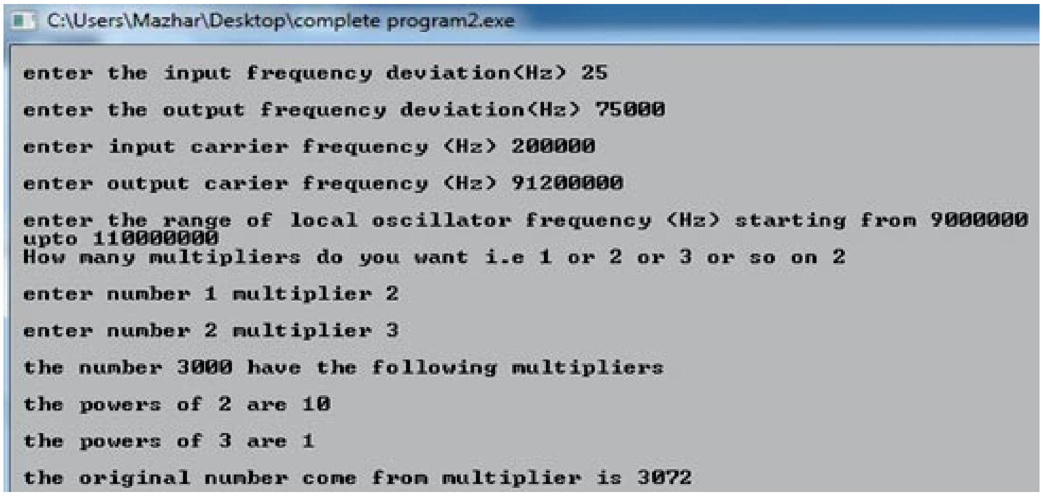

Fig. 4. The screen visual showing the execution of proposed algorithm.

Table 1. The results obtained for various design problems.

Serial #	Input Frequency Deviation	Output Frequency Deviation	Input Carrier Frequency	Output Carrier Frequency	Range of Local oscillator	Multipliers	First Multiplier	Second Multiplier
Design Problem # 1	5	10240	20000	97300000	400000-500000	only doublers	16	128
Design Problem # 2	9.7656	20000	200000	96000000	9000000-10000000	only doublers	64	32
Design Problem # 3	25	75000	200000	91200000	9000000-11000000	Doublers and Triplers	64	48
Design Problem # 4	10	75000	100000	98100000	10000000-11000000	doublers, triplers and 5 times multiplier	124	60
Design Problem # 5	12	22000	200000	99100000	9000000-11000000	Triplers and 5 times multipliers	74	25
Design Problem # 6	30	76000	200000	101000000	7000000-11000000	Doublers and Triplers	54	48
Design Problem # 7	15	75000	200000	10100000	9000000-11000000	Doublers and Triplers	54	96
Design Problem # 8	20	75000	200000	100000000	9000000-11000000	Doublers and Triplers	54	72
Design Problem # 9	18	75000	200000	97000000	9000000-12000000	doublers	64	64
Design Problem # 10	40	75000	200000	106000000	9000000-11000000	Doublers and Triplers	72	27

D. Design Problem# 4

Design an Armstrong indirect FM modulator to generate a WBFM signal having fc = 98.1 MHz and Δf = 75 kHz. A narrowband FM generator with fc=100 kHz and Δf = 10Hz. The local oscillator available in the stock room has an adjustable frequency in the range of 10 to 11 MHz. Any multiplier like doublers, triplers, quintuplers etc can be used.

4. TEST OF PROPOSED ALGORITHM AND RESULTS

The algorithm was implemented in C++ programming language [9,10] and the above mentioned four design problems were tested .The screen shot for one of the problems is presented in Fig. 4.

The overall results are summarized in the form of table 1. The algorithm is also tested for 6 different design problems and the following results were obtained.

5. CONCLUSIONS

The proposed algorithm not only makes the lengthy and tiresome process of conversion of NBFM to WBFM much easier but is very accurate too. The overall accuracy of the algorithm is 97.62%. The task of communication system designer is made easier by implementing this algorithm. This algorithm can be implemented on printed circuit board in near future to compare its performance.

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