SVEUČILIŠTE U SPLITU
FAKULTET ELEKTROTEHNIKE, STROJARSTVA I BRODOGRADNJE

SUSTAVI ZA DIGITALNU OBRADU SIGNALA (220):

PROJEKT

IIR I FIR FILTRI

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SADRŽAJ

1. ZADATAK PROJEKTA

Tehnikom polova i nula u z-ravnini potrebno je kreirati IIR filtar, izračunati prijenosnu funkciju u z području, te odrediti odzive na jedinični impuls i jediničnu step pobudu. Zatim je potrebno kreirati ekvivalentni FIR filtar temeljem odziva prethodno kreiranog IIR filtra.

- **TESTNO OKRUŽENJE**

Kreirati dva ulazna polja duljine 512 riječi, jedno inicirati s jediničnim impulsom a drugo s jediničnim step-om. Kreirati izlazno polje duljine 512 riječi za snimanje izlaza.

- **IIR**

Napisati program za Blackfin koji izvršava jednadžbu diferencija. Testirati program s oba ulazna polja i snimiti oba izlazna rezultata.

- **FIR**

Napisati program za Blackfin koji izvršava konvoluciju. Testirati program s oba ulazna polja i snimiti oba izlazna rezultata.

- **REZULTATI GIT**

Rezultate snimiti iz izlaznog polja u tekstualnu datoteku. Program i rezultate prijaviti na lokalni git (commit). Program i rezultate poslati na centralni git repozitorij (push).

2. OPĆI PRISTUP RJEŠAVANJU ZADATKA

2.1. Razvojni sustav

Prilikom rješavanja korišten je programski paket MATLAB pomoću kojega je određen frekvencijski odziv, prikaz odabranih polova i nula u z-ravnini, izračun impulsnog odziva i odziva na step IIR i FIR filtra. Korištene su MATLAB funkcije: *zplane* (za prikaz polova i nula u z ravnini), *freqz* (za prikaz frekvencijske karakteristike), *impz* i *stepz* (za prikaz i izračun impulsnog odziva i odziva na step).

Nakon toga, kreiran je programski kod za Blackfin arhitekturu ADSP procesora. Programski kod pisan je u programskom jeziku C. Kod je testiran u Visual Studio okruženju i VisualDSP++ Simulatoru (razvojni sustav za Blackfin). Rezultati odziva FIR i IIR filtra na step i impuls koje daje kod trebaju odgovarati onima koji se dobiju u MATLAB-u.

2.2. Jednadžba diferencija

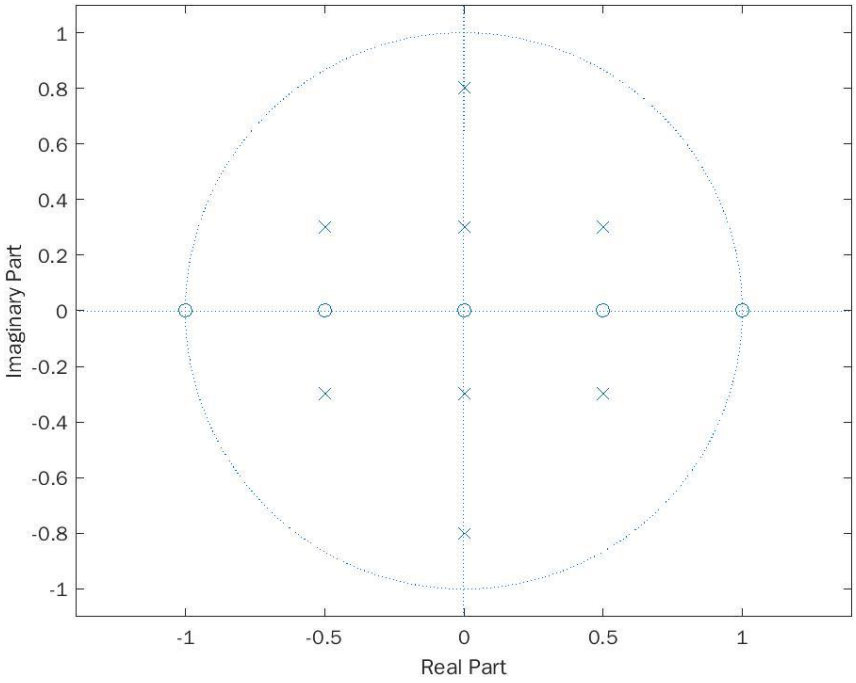
Jednadžbom diferencija opisan je rad IIR filtra. Prilikom izrade projekta, korištena je tehnika polova i nula za određivanje prijenosne funkcije, a nakon toga se iz prijenosne funkcije određuje jednadžba diferencija. Opći oblik jednadžbe diferencija:

$$\sum_{k=0}^{N} a_k y[n-k] = \sum_{k=0}^{M} b_k x[n-k]$$

Odabrani polovi i nule (prikazano na slici 2.1.):

Z = {0, 0.5, -0.5, 1, -1}

P = {0.5+0.3j, 0.5-0.3j, 0.3j, -0.3j, 0.8j, -0.8j, -0.5+0.3j, -0.5-0.3j}



Slika 2.1. Prikaz odabranih polova i nula u z-ravnini

Uvrštavanjem u jednadžbu za prijenosnu funkciju:

$$H(z) = \frac{(z - z_1)(z - z_2) \ldots}{(z - p_1)(z - p_2) \ldots}$$

I sređivanjem izraza (korištenjem programskog paketa MATLAB) dobije se:

$$H(z) = \frac{z^5 - 1.25z^3 + 0.25z}{z^8 + 0.41z^6 - 0.0604z^4 + 0.066z^2 + 0.0067}$$

Unakrsnim množenjem i korištenje inverzne z transformacije dobije se jednadžba diferencija za odabrane polove i nule:

$$\mathrm{y[n]} = \mathrm{x[n-3]} - 1.25\mathrm{x[n-5]} + 0.25\mathrm{x[n-7]} - 0.41\mathrm{y[n-2]} + 0.0604\mathrm{y[n-4]} - 0.066\mathrm{y[n-6]} - 0.0067\mathrm{y[n-8]}$$

Potrebno je izvršiti pomak za $n \to n + 8$ radi implementacije u C-u:

$$\mathrm{y[n+8]} = \mathrm{x[n+5]} - 1.25\mathrm{x[n+3]} + 0.25\mathrm{x[n+1]} - 0.41\mathrm{y[n+6]} + 0.0604\mathrm{y[n+4]} - 0.066\mathrm{y[n+2]} - 0.0067\mathrm{y[n]}$$

Ovo je potrebno učiniti kako bi osigurali da indeksi nizova počinju od nultog elementa (budući da oni mogu samo biti pozitivni cijeli brojevi). Kasnije se u kodu prilikom izračuna pomaknuti podaci preslikavaju iz privremenog niza koji počinje od osmog indeksa u odgovarajući niz za

pohranu odziva počevši od nultog indeksa (funkcija *calculateImpulseResponse* i *calculateStepResposne*).

2.3. Konvolucija

Konvolucija je matematička operacija u kojoj je neki izlaz y[n] suma komponenti odziva svih dotadašnjih pobuda u tom trenutku. U diskretnoj domeni se definira kao:

$$y[n] = \sum_{k=-\infty}^{+\infty} x[k]h[n-k]$$

Vrijednost y[n] je zapravo suma impulsa pobude pomnoženih sa impulsima odziva uzetog unatrag. To je ustvari filtar gdje je obrnuti odziv zapravo skup težinskih vrijednosti faktora filtra, a sumaciju obavljamo sa desna na lijevo kao kod izračunavanja konvolucije. Konvolucijom obavljamo sintezu FIR filtra.

Napisana funkcija za obavljanje konvolucije je implementirana logikom:

- Niz h u kojemu je pohranjen odziv se okrene naopako i postavi tako da posljednji element naopako okrenutog niza nalazi na istoj poziciji kao i prvi element niza x. Pomnožimo elemente te ih zbrojimo. Dobiveni rezultat je prvi element niza y u koji se sprema rezultat konvolucije.
- Pomičemo naopako okrenuti odziv za jedno mjesto u desno. Množimo elemente i umnoške zbrajamo. Dobiveni rezultat je drugi element niza y.
- Ponavljamo drugi korak sve dok ne dođemo do posljednjeg elementa (zadnji element niza x množi prvi element naopako okrenutog odziva).

Ako je signal x[n] različit od 0 u Nx uzoraka, a signal h[n] u Nh uzoraka, tada će konvolucija ova dva signala imati Nx+Nh-1 uzoraka različitih od 0.

Za koeficijente impulsnog odziva korišten je impulsni odziv IIR filtra dobiven pomoću MATLAB-a (funkcija *impz*).

3. POTREBNI PODACI

- **JEDNADŽBA DIFERENCIJA**

$$y[n] = x[n-3] - 1.25x[n-5] + 0.25x[n-7] - 0.41y[n-2] + 0.0604y[n-4] - 0.066y[n-6] - 0.0067y[n-8]$$

Odnosno pomaknuta jednadžba:

$$y[n+8] = x[n+5] - 1.25x[n+3] + 0.25x[n+1] - 0.41y[n+6] + 0.0604y[n+4] - 0.066y[n+2] - 0.0067y[n]$$

Kao što je i prethodno spomenuto, jednadžbu diferencija koristimo prilikom implementacije IIR filtra.

- **KOEFICIJENTI IMPULSNOG ODZIVA IIR FILTRA**

Koeficijenti impulsnog odziva su dobiveni pomoću MATLAB-a za odgovarajuću prijenosnu funkciju IIR filtra. Ove koeficijente koristimo prilikom realizacije FIR filtra jer se FIR implementira pomoću konvoluciije, a za konvoluciju nam je potreban podatak o impulsnom odzivu sustava. Uzeto je prvih 100 koeficijenata.

```
double h_fir[100] = { 1.000000000000000, 0.000000000000000, -1.660000000000000,
0.000000000000000, 0.991000000000000, 0.000000000000000,
-0.572574000000000,   0.000000000000000,   0.397471740000000,   0.000000000000000,   -
0.251830883000000, 0.000000000000000, 0.158408139126000,
0.000000000000000,     -0.102554811414860,     0.000000000000000,     0.065573101903303,
0.000000000000000, -0.041846952656028, 0.000000000000000,
0.026825148965167,     0.000000000000000,     -0.017166574505281,     0.000000000000000,
0.010981093637207, 0.000000000000000, -0.007029194740280,
0.000000000000000,     0.004498493318484,     0.000000000000000,     -0.002878681753762,
0.000000000000000, 0.001842322040968, 0.000000000000000,
-0.001179029368984,   0.000000000000000,   0.000754531383072,   0.000000000000000,   -
0.000482877327900, 0.000000000000000, 0.000309025780655,
0.000000000000000,     -0.000197765935184,     0.000000000000000,     0.000126563733952,
0.000000000000000, -0.000080996616832, 0.000000000000000,
0.000051835141423,     0.000000000000000,     -0.000033172778315,     0.000000000000000,
0.000021229481345, 0.000000000000000, -0.000013586165163,
0.000000000000000,     0.000008694696311,     0.000000000000000,     -0.000005564318017,
0.000000000000000, 0.000003560979420, 0.000000000000000,
-0.000002278909020,   0.000000000000000,   0.000001458426379,   0.000000000000000,   -
0.000000933344631, 0.000000000000000, 0.000000597309685,
0.000000000000000,     -0.000000382258437,     0.000000000000000,     0.000000244632753,
0.000000000000000, -0.000000156556869, 0.000000000000000,
0.000000100191216,     0.000000000000000,     -0.000000064119064,     0.000000000000000,
0.000000041034080, 0.000000000000000, -0.000000026260453,
0.000000000000000,     0.000000016805821,     0.000000000000000,     -0.000000010755170,
0.000000000000000, 0.000000006882953, 0.000000000000000,
-0.000000004404862,   0.000000000000000,   0.000000002818966,   0.000000000000000,   -
0.000000001804045, 0.000000000000000, 0.000000001154529,
0.000000000000000, -0.000000000738860, 0.000000000000000 };
```

4. PROGRAMSKI KOD

4.1. IIR – odziv na impuls

```
#include<stdio.h>
double y_impulse[512] = { 0 };
double temp[552] = { 0 };

void calculateImpulseResponse(double* y, double* temp)
{

	int n;
	for (n = 0; n < 552; n++)
	{
		if (n == 3)
			temp[n + 8] = -0.41 * temp[n + 6] +0.0604 * temp[n + 4] - 0.066 *
temp[n + 2]  - 0.0067 * temp[n] + 1;
		else if (n == 5)
			temp[n + 8] = -0.41 * temp[n + 6] + 0.0604 * temp[n + 4] - 0.066 *
temp[n + 2] - 0.0067 * temp[n] - 1.25 * 1;
		else if (n == 7)
			temp[n + 8] = -0.41 * temp[n + 6] + 0.0604 * temp[n + 4] - 0.066 *
temp[n + 2] - 0.0067 * temp[n] + 0.25 * 1;
		else
			temp[n + 8] = -0.41 * temp[n + 6] + 0.0604 * temp[n + 4] - 0.066 *
temp[n + 2] - 0.0067 * temp[n];

		y[n] = temp[n + 8];
	}
}

void printArray(double* array, int size) {
	int i;
	for (i = 3; i < size; i++)
		printf("%0.15f, ", array[i]);
}

int main(void)
{
	calculateImpulseResponse(y_impulse, temp);
	printf("Impulsni odziv IIR filtra: \n");
	printArray(y_impulse, 512);

	return 0;
}
```

4.2. IIR – odziv na step

```
#include<stdio.h>
double y_impulse[512] = { 0 };
double temp[552] = { 0 };


void calculateStepResponse(double* y, double* temp)
{
	int n;
	for (n = 0; n < 552; n++)
	{
		if ((n >= 3) && (n < 5))
			temp[n + 8] = -0.41 * temp[n + 6] + 0.0604 * temp[n + 4] - 0.066 *
temp[n + 2] - 0.0067 * temp[n] + 1;
		else if ((n >= 5) && (n < 7))
			temp[n + 8] = -0.41 * temp[n + 6] + 0.0604 * temp[n + 4] - 0.066 *
temp[n + 2] - 0.0067 * temp[n] - 1.25 + 1;
		else if (n == 7)
			temp[n + 8] = -0.41 * temp[n + 6] + 0.0604 * temp[n + 4] - 0.066 *
temp[n + 2] - 0.0067 * temp[n]+ 1 - 1.25 + 0.25;
		else
			temp[n + 8] = -0.41 * temp[n + 6] + 0.0604 * temp[n + 4] - 0.066 *
temp[n + 2] - 0.0067 * temp[n] + 1 - 1.25 + 0.25;

		y[n] = temp[n + 8];
	}
}

void printArray(double* array, int size) {
	int i;
	for (i = 3; i < size; i++)
		printf("%0.15f, ", array[i]);
}

int main(void)
{

	calculateStepResponse(y_step, temp);
	printf("Odziv na step IIR filtra: \n");
	printArray(y_step, 512);

	return 0;
}
```

4.3. FIR

```
#include<stdio.h>

double x_impulse[512] = { 0 };
double x_step[512] = { 0 };
double y_impulse[512] = { 0 };
double y_step[512] = { 0 };

double h_fir[100] = { 1.000000000000000, 0.000000000000000, -1.660000000000000,
0.000000000000000, 0.991000000000000, 0.000000000000000,
-0.572574000000000, 0.000000000000000, 0.397471740000000, 0.000000000000000, -
0.251830883000000, 0.000000000000000, 0.158408139126000,
0.000000000000000, -0.102554811414860, 0.000000000000000, 0.065573101903303,
0.000000000000000, -0.041846952656028, 0.000000000000000,
0.026825148965167, 0.000000000000000, -0.017166574505281, 0.000000000000000,
0.010981093637207, 0.000000000000000, -0.007029194740280,
0.000000000000000, 0.004498493318484, 0.000000000000000, -0.002878681753762,
0.000000000000000, 0.001842322040968, 0.000000000000000,
-0.001179029368984, 0.000000000000000, 0.000754531383072, 0.000000000000000, -
0.000482877327900, 0.000000000000000, 0.000309025780655,
0.000000000000000, -0.000197765935184, 0.000000000000000, 0.000126563733952,
0.000000000000000, -0.000080996616832, 0.000000000000000,
0.000051835141423, 0.000000000000000, -0.000033172778315, 0.000000000000000,
0.000021229481345, 0.000000000000000, -0.000013586165163,
0.000000000000000, 0.000008694696311, 0.000000000000000, -0.000005564318017,
0.000000000000000, 0.000003560979420, 0.000000000000000,
-0.000002278909020, 0.000000000000000, 0.000001458426379, 0.000000000000000, -
0.000000933344631, 0.000000000000000, 0.000000597309685,
0.000000000000000, -0.000000382258437, 0.000000000000000, 0.000000244632753,
0.000000000000000, -0.000000156556869, 0.000000000000000,
0.000000100191216, 0.000000000000000, -0.000000064119064, 0.000000000000000,
0.000000041034080, 0.000000000000000, -0.000000026260453,
0.000000000000000, 0.000000016805821, 0.000000000000000, -0.000000010755170,
0.000000000000000, 0.000000006882953, 0.000000000000000,
-0.000000004404862, 0.000000000000000, 0.000000002818966, 0.000000000000000, -
0.000000001804045, 0.000000000000000, 0.000000001154529,
0.000000000000000, -0.000000000738860, 0.000000000000000 };

void generateImpulse(double* impulse, int size)
{
	impulse[0] = 1.0;
	int i;
	for (i = 1; i < size; i++)
		impulse[i] = 0;
}
void generateStep(double* step, int size)
{
	int i;
	for (i = 0; i < 100; i++)
		step[i] = 1;
	for (i = 100; i < size; i++)
		step[i] = 0;
}

void convolve(double* x, double* h, double* y, int x_size, int h_size)
{
	int N = x_size + h_size - 1;
	int n, i;
	for (n = 0; n < N; n++)
		for (i = 0; i < x_size; i++)
```

```
                        if (((n - i) >= 0) && ((n - i) < h_size))
                                y[n] += x[i] * h[n - i];
}


void printArray(double* array, int size) {
        int i;
        for (i = 0; i < size; i++)
                printf("%0.15f, ", array[i]);
}

int main(void)
{
        generateImpulse(x_impulse, 512);
        generateStep(x_step, 512);
        convolve(x_impulse, h_fir, y_impulse, 512, 100);
        printf("Impulsni odziv FIR filtra: \n");
        printArray(y_impulse, 512);
        convolve(x_step, h_fir, y_step, 512, 100);
        printf("\nOdziv na step FIR filtra: \n");
        printArray(y_step, 512);

        return 0;
}
```

5. REZULTATI ODZIVA

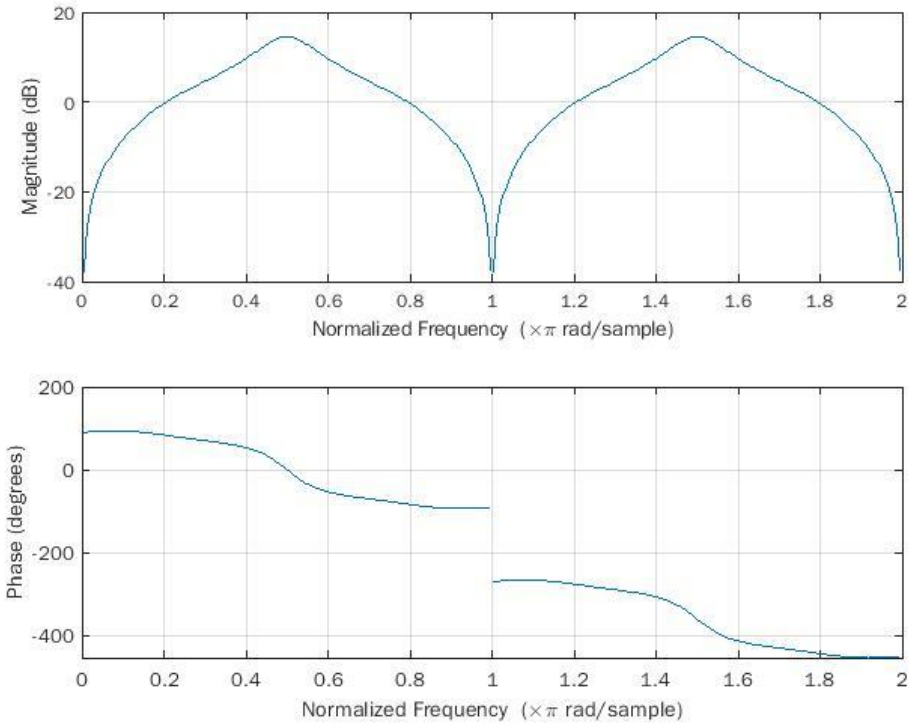
Odzivi su izračunati u MATLAB-u i programski. Svi rezultati su postavljeni u *.txt* datoteku na git. Ovdje samo navodimo one programski dobivene rezultate. Pojedini odzivi su prikazani i grafički.

5.1. IIR - odziv na impuls

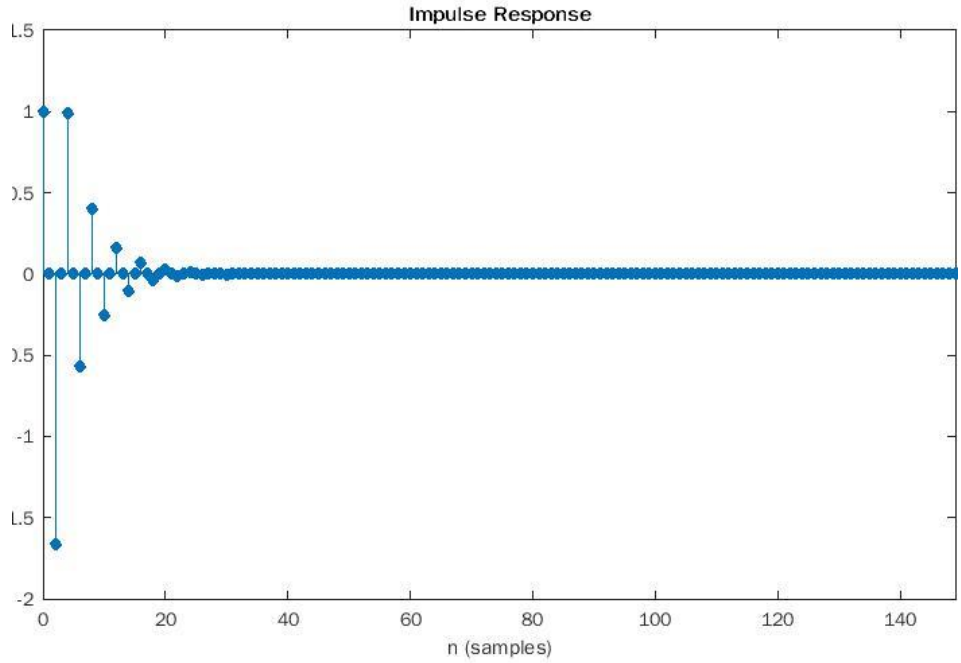
Odziv na impuls:

$$h[n] = \delta[n-3] - 1.25\delta[n-5] + 0.25\delta[n-7] - 0.41h[n-2] + 0.0604h[n-4] - 0.066h[n-6] - 0.0067h[n-8]$$

Na slici 5.1. prikazana je frekvencijska i fazna karakteristika IIR filtra, a na slici 5.2. prikazan je impulsni odziv IIR filtra.



Slika 5.1. Frekvencijska i fazna karakteristika IIR filtra



Slika 5.2. Impulsni odziv IIR filtra

Impulsni odziv IIR filtra y[512] (dobiven iz programa):

1.000000000000000, 0.000000000000000, -1.660000000000000, 0.000000000000000,
0.991000000000000, 0.000000000000000, -0.572574000000000, 0.000000000000000,
0.397471740000000, 0.000000000000000, -0.251830883000000, 0.000000000000000,
0.158408139126000, 0.000000000000000, -0.102554811414860, 0.000000000000000,
0.065573101903303, 0.000000000000000, -0.041846952656028, 0.000000000000000,
0.026825148965167, 0.000000000000000, -0.017166574505281, 0.000000000000000,
0.010981093637207, 0.000000000000000, -0.007029194740280, 0.000000000000000,
0.004498493318484, 0.000000000000000, -0.002878681753762, 0.000000000000000,
0.001842322040968, 0.000000000000000, -0.001179029368984, 0.000000000000000,
0.000754531383072, 0.000000000000000, -0.000482877327900, 0.000000000000000,
0.000309025780655, 0.000000000000000, -0.000197765935184, 0.000000000000000,
0.000126563733952, 0.000000000000000, -0.000080996616832, 0.000000000000000,
0.000051835141423, 0.000000000000000, -0.000033172778315, 0.000000000000000,
0.000021229481345, 0.000000000000000, -0.000013586165163, 0.000000000000000,
0.000008694696311, 0.000000000000000, -0.000005564318017, 0.000000000000000,
0.000003560979420, 0.000000000000000, -0.000002278909020, 0.000000000000000,
0.000001458426379, 0.000000000000000, -0.000000933344631, 0.000000000000000,
0.000000597309685, 0.000000000000000, -0.000000382258437, 0.000000000000000,
0.000000244632753, 0.000000000000000, -0.000000156556869, 0.000000000000000,
0.000000100191216, 0.000000000000000, -0.000000064119064, 0.000000000000000,
0.000000041034080, 0.000000000000000, -0.000000026260453, 0.000000000000000,
0.000000016805821, 0.000000000000000, -0.000000010755170, 0.000000000000000,
0.000000006882953, 0.000000000000000, -0.000000004404862, 0.000000000000000,
0.000000002818966, 0.000000000000000, -0.000000001804045, 0.000000000000000,

0.000000001154529,	0.000000000000000,	-0.000000000738860,	0.000000000000000,
0.000000000472846,	0.000000000000000,	-0.000000000302606,	0.000000000000000,
0.000000000193658,	0.000000000000000,	-0.000000000123935,	0.000000000000000,
0.000000000079314,	0.000000000000000,	-0.000000000050758,	0.000000000000000,
0.000000000032484,	0.000000000000000,	-0.000000000020788,	0.000000000000000,
0.000000000013304,	0.000000000000000,	-0.000000000008514,	0.000000000000000,
0.000000000005449,	0.000000000000000,	-0.000000000003487,	0.000000000000000,
0.000000000002232,	0.000000000000000,	-0.000000000001428,	0.000000000000000,
0.000000000000914,	0.000000000000000,	-0.000000000000585,	0.000000000000000,
0.000000000000374,	0.000000000000000,	-0.000000000000240,	0.000000000000000,
0.000000000000153,	0.000000000000000,	-0.000000000000098,	0.000000000000000,
0.000000000000063,	0.000000000000000,	-0.000000000000040,	0.000000000000000,
0.000000000000026,	0.000000000000000,	-0.000000000000016,	0.000000000000000,
0.000000000000011,	0.000000000000000,	-0.000000000000007,	0.000000000000000,
0.000000000000004,	0.000000000000000,	-0.000000000000003,	0.000000000000000,
0.000000000000002,	0.000000000000000,	-0.000000000000001,	0.000000000000000,
0.000000000000001,	0.000000000000000,	-0.000000000000000,	0.000000000000000,
0.000000000000000,	0.000000000000000,	-0.000000000000000,	0.000000000000000,
0.000000000000000,	0.000000000000000,	-0.000000000000000,	0.000000000000000,
0.000000000000000,	0.000000000000000,	-0.000000000000000,	0.000000000000000,
0.000000000000000,	0.000000000000000,	-0.000000000000000,	0.000000000000000,
0.000000000000000,	0.000000000000000,	-0.000000000000000,	0.000000000000000,
0.000000000000000,	0.000000000000000,	-0.000000000000000,	0.000000000000000,
0.000000000000000,	0.000000000000000,	-0.000000000000000,	0.000000000000000,
0.000000000000000,	0.000000000000000,	-0.000000000000000,	0.000000000000000,
0.000000000000000,	0.000000000000000,	-0.000000000000000,	0.000000000000000,
0.000000000000000,	0.000000000000000,	-0.000000000000000,	0.000000000000000,
0.000000000000000,	0.000000000000000,	-0.000000000000000,	0.000000000000000,
0.000000000000000,	0.000000000000000,	-0.000000000000000,	0.000000000000000,
0.000000000000000,	0.000000000000000,	-0.000000000000000,	0.000000000000000,
0.000000000000000,	0.000000000000000,	-0.000000000000000,	0.000000000000000,
0.000000000000000,	0.000000000000000,	-0.000000000000000,	0.000000000000000,
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0.000000000000000,    0.000000000000000,    -0.000000000000000,    0.000000000000000,
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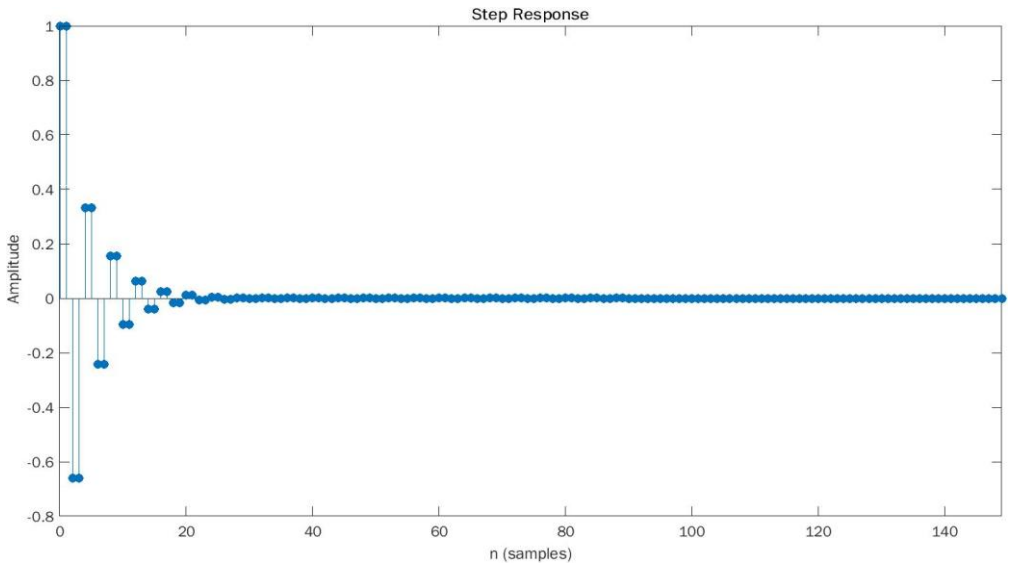
0.000000000000000,    0.000000000000000,    -0.000000000000000,    0.000000000000000,
0.000000000000000
```

5.2. IIR -odziv na step

Odziv na step:

$$s[n] = u[n-3] - 1.25u[n-5] + 0.25u[n-7] - 0.41s[n-2] + 0.0604s[n-4] - 0.066s[n-6] - 0.067s[n-8]$$

Na slici 5.3. prikazan je odziv na step IIR filtra.



Slika 5.3. Odziv na step IIR filtra

Odziv na step IIR filtra y[512] (dobiven iz programa):

```
1.000000000000000,    1.000000000000000,    -0.660000000000000,    -0.660000000000000,
0.331000000000000,    0.331000000000000,    -0.241574000000000,    -0.241574000000000,
0.155897740000000,    0.155897740000000,    -0.095933143000000,    -0.095933143000000,
0.062474996126000,    0.062474996126000,    -0.040079815288860,    -0.040079815288860,
0.025493286614443,    0.025493286614443,    -0.016353666041585,    -0.016353666041585,
0.010471482923583,    0.010471482923583,    -0.006695091581699,    -0.006695091581699,
0.004286002055509,    0.004286002055509,    -0.002743192684771,    -0.002743192684771,
0.001755300633713,    0.001755300633713,    -0.001123381120049,    -0.001123381120049,
```

```
0.000718940920919,   0.000718940920919,   -0.000460088448065,   -0.000460088448065,
0.000294442935007,   0.000294442935007,   -0.000188434392893,   -0.000188434392893,
0.000120591387762,   0.000120591387762,   -0.000077174547422,   -0.000077174547422,
0.000049389186530,   0.000049389186530,   -0.000031607430302,   -0.000031607430302,
0.000020227711122,   0.000020227711122,   -0.000012945067193,   -0.000012945067193,
0.000008284414151,   0.000008284414151,   -0.000005301751011,   -0.000005301751011,
0.000003392945300,   0.000003392945300,   -0.000002171372718,   -0.000002171372718,
0.000001389606702,   0.000001389606702,   -0.000000889302318,   -0.000000889302318,
0.000000569124061,   0.000000569124061,   -0.000000364220570,   -0.000000364220570,
0.000000233089115,   0.000000233089115,   -0.000000149169322,   -0.000000149169322,
0.000000095463431,   0.000000095463431,   -0.000000061093438,   -0.000000061093438,
0.000000039097779,   0.000000039097779,   -0.000000025021285,   -0.000000025021285,
0.000000016012795,   0.000000016012795,   -0.000000010247659,   -0.000000010247659,
0.000000006558163,   0.000000006558163,   -0.000000004197007,   -0.000000004197007,
0.000000002685946,   0.000000002685946,   -0.000000001718916,   -0.000000001718916,
0.000000001100050,   0.000000001100050,   -0.000000000703995,   -0.000000000703995,
0.000000000450534,   0.000000000450534,   -0.000000000288327,   -0.000000000288327,
0.000000000184520,   0.000000000184520,   -0.000000000118086,   -0.000000000118086,
0.000000000075571,   0.000000000075571,   -0.000000000048363,   -0.000000000048363,
0.000000000030951,   0.000000000030951,   -0.000000000019807,   -0.000000000019807,
0.000000000012676,   0.000000000012676,   -0.000000000008112,   -0.000000000008112,
0.000000000005192,   0.000000000005192,   -0.000000000003322,   -0.000000000003322,
0.000000000002126,   0.000000000002126,   -0.000000000001361,   -0.000000000001361,
0.000000000000871,   0.000000000000871,   -0.000000000000557,   -0.000000000000557,
0.000000000000357,   0.000000000000357,   -0.000000000000228,   -0.000000000000228,
0.000000000000146,   0.000000000000146,   -0.000000000000093,   -0.000000000000093,
0.000000000000060,   0.000000000000060,   -0.000000000000038,   -0.000000000000038,
0.000000000000024,   0.000000000000024,   -0.000000000000016,   -0.000000000000016,
0.000000000000010,   0.000000000000010,   -0.000000000000006,   -0.000000000000006,
0.000000000000004,   0.000000000000004,   -0.000000000000003,   -0.000000000000003,
0.000000000000002,   0.000000000000002,   -0.000000000000001,   -0.000000000000001,
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5.3. FIR – odziv na impuls

Na slikama 5.4. i 5.5. dane su frekvencijske i fazne karakteristike FIR filtra s 20 koeficijenata i s 10 koeficijenata. Na slikama 5.6. i 5.7. prikazan je odziv na impuls FIR filtra s 20 i 10 koeficijenata.

Prijenosna funkcija se dobije iz relacije:

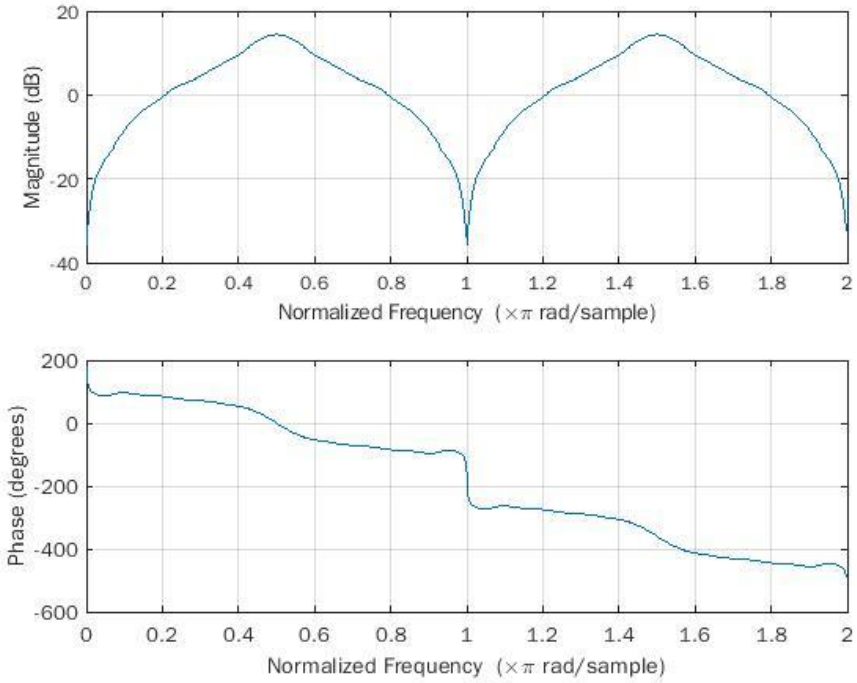
$$H(z) = \sum_{n=0}^{\infty} h[n] z^{-n} = \sum_{k=0}^{\infty} b_k z^{-k}$$

Gdje b_k (koeficijenti FIR-a) zapravo odgovara impulsnome odzivu h[n] koji smo prethodno dobili iz IIR filtra.

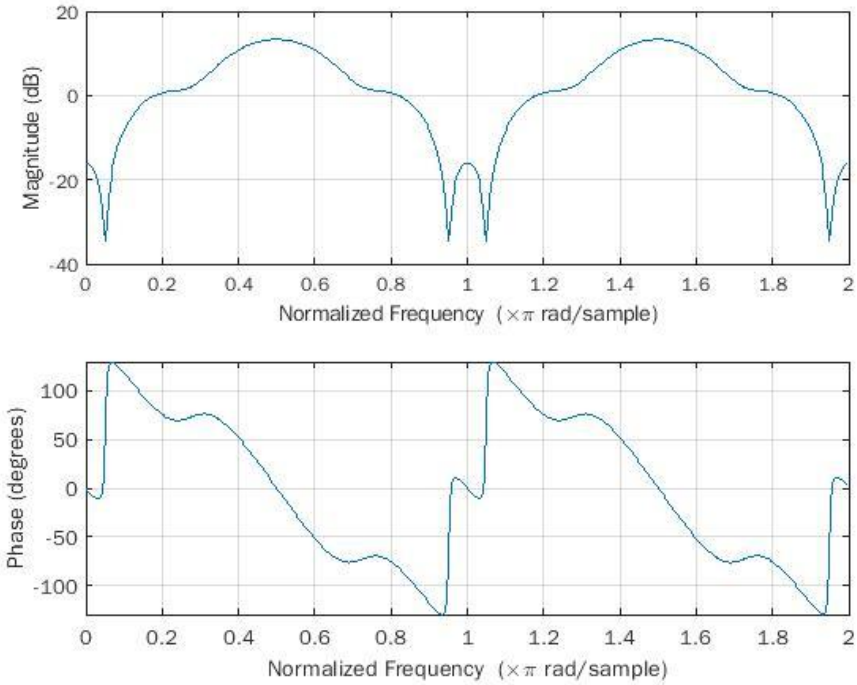
Koeficijenti FIR-a (20 i 10 koeficijenata):

b_k = { `1.000000000000000, 0.000000000000000, -1.660000000000000, 0.000000000000000,`
`0.991000000000000, 0.000000000000000,-0.572574000000000, 0.000000000000000,`
`0.397471740000000, 0.000000000000000, -0.251830883000000, 0.000000000000000,`
`0.158408139126000,0.000000000000000, -0.102554811414860, 0.000000000000000,`
`0.065573101903303, 0.000000000000000, -0.041846952656028, 0.000000000000000` }

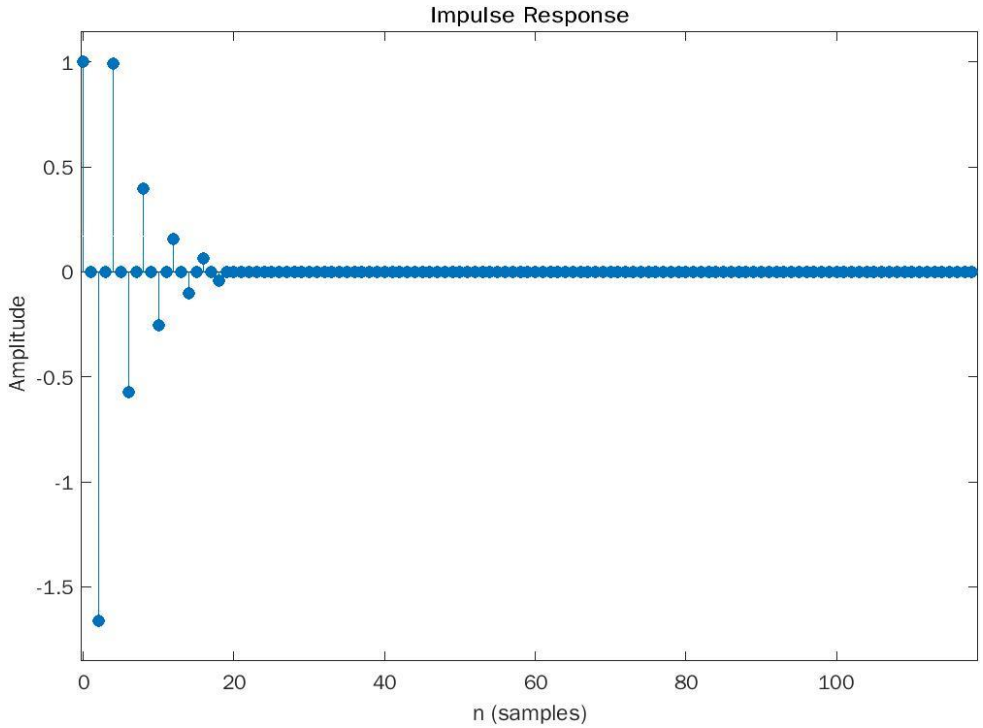
b_k = { 1.000000000000000, 0.000000000000000, -1.660000000000000, 0.000000000000000, 0.991000000000000, 0.000000000000000,-0.572574000000000, 0.000000000000000, 0.397471740000000, 0.000000000000000 }



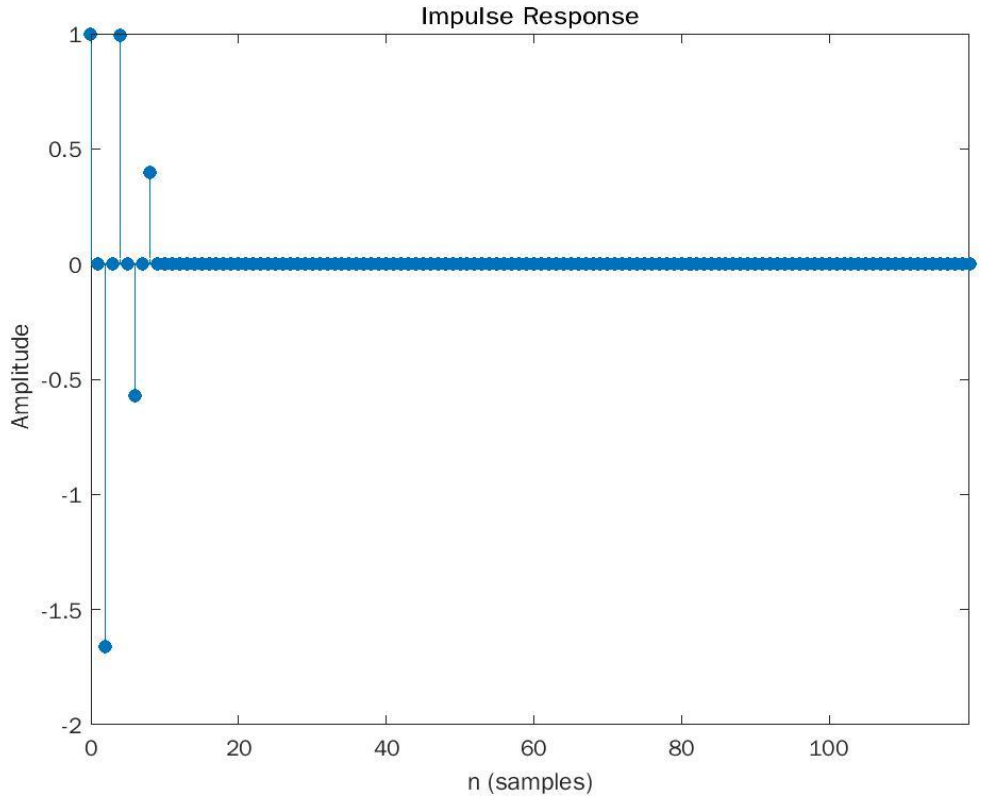
Slika 5.4. Frekvencijska i fazna karakteristika FIR filtra (s 20 koeficijenata)



Slika 5.5. Frekvencijska i fazna karakteristika FIR filtra (s 10 koeficijenata)



Slika 5.6. Impulsni odziv FIR filtra (20 koeficijenata)



Slika 5.7. Impulsni odziv FIR filtra (10 koeficijenata)

Odziv na impuls FIR filtra y[512] (dobiveni programski):

1.000000000000000,	0.000000000000000,	-1.660000000000000,	0.000000000000000,
0.991000000000000,	0.000000000000000,	-0.572574000000000,	0.000000000000000,
0.397471740000000,	0.000000000000000,	-0.251830883000000,	0.000000000000000,
0.158408139126000,	0.000000000000000,	-0.102554811414860,	0.000000000000000,
0.065573101903303,	0.000000000000000,	-0.041846952656028,	0.000000000000000,
0.026825148965167,	0.000000000000000,	-0.017166574505281,	0.000000000000000,
0.010981093637207,	0.000000000000000,	-0.007029194740280,	0.000000000000000,
0.004498493318484,	0.000000000000000,	-0.002878681753762,	0.000000000000000,
0.001842322040968,	0.000000000000000,	-0.001179029368984,	0.000000000000000,
0.000754531383072,	0.000000000000000,	-0.000482877327900,	0.000000000000000,
0.000309025780655,	0.000000000000000,	-0.000197765935184,	0.000000000000000,
0.000126563733952,	0.000000000000000,	-0.000080996616832,	0.000000000000000,
0.000051835141423,	0.000000000000000,	-0.000033172778315,	0.000000000000000,
0.000021229481345,	0.000000000000000,	-0.000013586165163,	0.000000000000000,
0.000008694696311,	0.000000000000000,	-0.000005564318017,	0.000000000000000,
0.000003560979420,	0.000000000000000,	-0.000002278909020,	0.000000000000000,
0.000001458426379,	0.000000000000000,	-0.000000933344631,	0.000000000000000,
0.000000597309685,	0.000000000000000,	-0.000000382258437,	0.000000000000000,
0.000000244632753,	0.000000000000000,	-0.000000156556869,	0.000000000000000,
0.000000100191216,	0.000000000000000,	-0.000000064119064,	0.000000000000000,
0.000000041034080,	0.000000000000000,	-0.000000026260453,	0.000000000000000,
0.000000016805821,	0.000000000000000,	-0.000000010755170,	0.000000000000000,
0.000000006882953,	0.000000000000000,	-0.000000004404862,	0.000000000000000,
0.000000002818966,	0.000000000000000,	-0.000000001804045,	0.000000000000000,
0.000000001154529,	0.000000000000000,	-0.000000000738860,	0.000000000000000,
0.000000000000000,	0.000000000000000,	0.000000000000000,	0.000000000000000,
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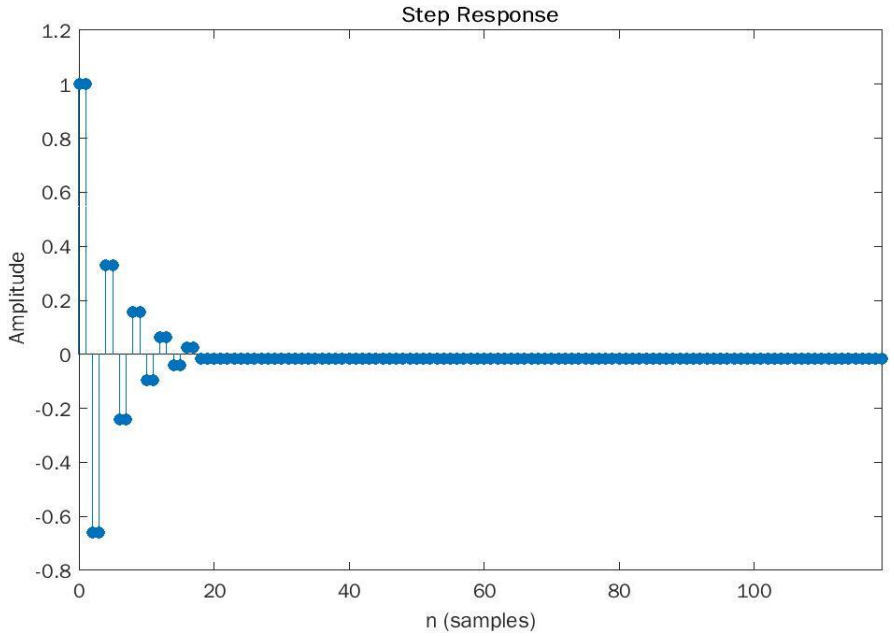
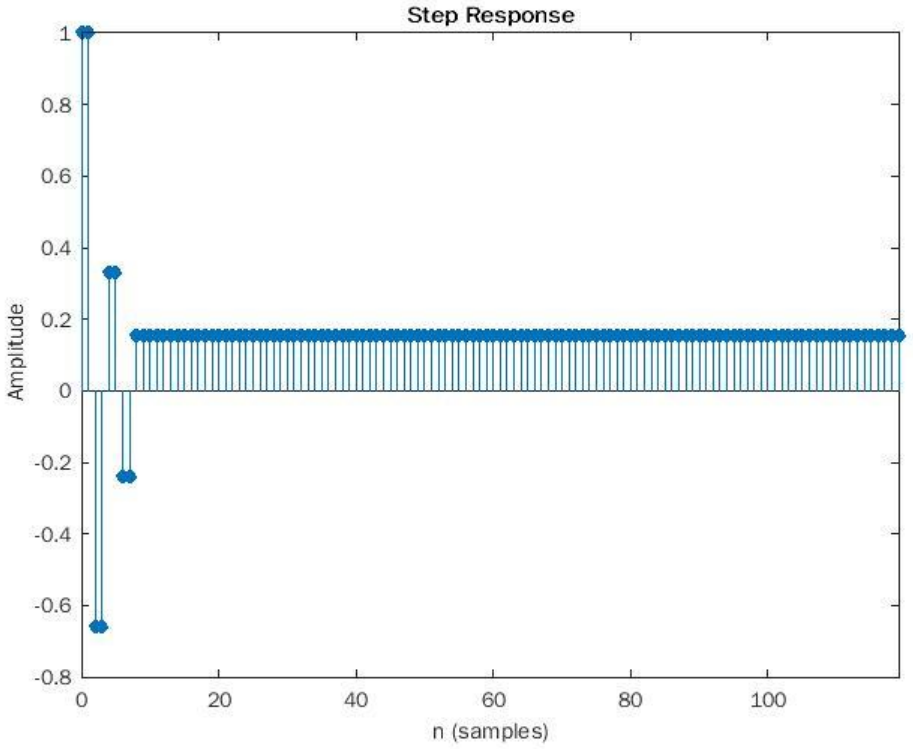
5.4. FIR – odziv na step

Na slikama 5.8. i 5.9. prikazan je odziv na step FIR filtra s 20 i 10 koeficijenata.



Slika 5.8. Odziv na step FIR filtra (20 koeficijenata)



Slika 5.9. Odziv na step FIR filtra (10 koeficijenata)

Odziv na step FIR filtra y[512] (dobiveni programski):

1.000000000000000, 1.000000000000000, -0.660000000000000, -0.660000000000000,
0.331000000000000, 0.331000000000000, -0.241574000000000, -0.241574000000000,
0.155897740000000, 0.155897740000000, -0.095933143000000, -0.095933143000000,
0.062474996126000, 0.062474996126000, -0.040079815288860, -0.040079815288860,

0.025493286614443, 0.025493286614443, -0.016353666041585, -0.016353666041585,
0.010471482923582, 0.010471482923582, -0.006695091581699, -0.006695091581699,
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6. KOMENTARI NA ODZIVE

6.1. Impulsni odziv

Impulsni odzivi IIR i FIR filtara dobiveni programski se poklapaju s onima dobivenim iz MATLAB-a kao što smo i očekivali. Na temelju odziva dobivenog iz IIR filtra realiziramo FIR filtar sa određenim brojem koeficijenata. Uzeta su dva slučaja: s 20 i s 10 koeficijenata za izračun odziva u MATLAB-u. Vidimo kako frekvencijski odziv FIR filtra sa 20 koeficijenata gotovo odgovara frekvencijskom odzivu IIR filtra dok je 10 koeficijenata premalo. S većim brojem koeficijenata postigli bi točniji odziv. Ova dva slučaja služe čisto radi ilustracije da se većim brojem koeficijenata postiže i veća točnost.

U programskome kodu za FIR filtar, uzeto je 100 koeficijenata impulsnog odziva za izračun odziva putem konvolucije.

6.2. Odziv na step

Kod odziva na step IIR i FIR filtra, rezultati dobiveni u MATLAB-u se također poklapaju s onima dobivenim programski. Mala odstupanja su moguća zbog različitih formata podataka u MATLAB-u i C-u. Odziv na step često koristimo jer ima veću energiju u odnosu na impuls. Kod FIR filtra također je ilustriran primjer s 20 i 10 koeficijenata u MATLAB-u, dok je u programu korišteno 100 koeficijenata impulsnoga odziva.

7. ZAKLJUČAK

U ovome projektu prikazan je postupak realizacije IIR i FIR filtra. Korišten je programski paket MATLAB za grafički prikaz rezultata kao i za usporedbu odziva s onima koji se dobiju programski. Funkcionalnost napisanog koda je testirana u Visual Studio okruženju te u VisualDSP++ Simulatoru za Blackfin.

IIR filtar je realiziran tehnikom polova i nula, nakon čega je izračunata njegova prijenosna funkcija iz koje se dobije jednadžba diferencija na temelju čega se računaju odgovarajući odzivi ovog filtra. Izračun jednadžbe diferencija se vrši na osnovu prijenosne funkcije i korištenje inverzne z transformacije. Potrebno je i pripaziti na indekse nizova koji se koriste budući da indeksi nizova u programskom jeziku C mogu biti samo pozitivni cijeli brojevi zbog čega je potrebno izračunati pomaknutu jednadžbu. Prilikom implementacije u C jeziku potrebno je također paziti koji se koeficijenti jednadžbe diferencija uključuju u proračun za određeni indeks. U MATLAB-u su izrađeni grafički prikazi pojedinih odziva kako bi se rezultati usporedili. IIR filtar se ostvaruje rekurzivno i u pravilu imaju beskonačan impulsni odziv i beskonačan broj koeficijenata. Nakon određivanja frekvencijskog odziva, moguće je korigirati položaj polova i nula kako bi realizirali željeni filtar. Pri tome treba paziti na utjecaj polova i nula na frekvencijski odziv. Dakle, nulama se guši signal određene frekvencije, dok polovi pojačavaju signal te određene frekvencije.

Kod realizacije FIR filtra koristimo dobivene vrijednosti impulsnoga odziva IIR filtra kako bi dobili koeficijente impulsnoga odziva h[n] (odnosno koeficijente FIR-a b_k). Koeficijente FIR-a zapravo dobivamo množenjem impulsnoga odziva IIR-a s kvadratičnim prozorom određene duljine ovisno o broju koeficijenata FIR-a koji želimo. Potrebno je pripaziti na broj uzoraka odziva kako bi postigli što veću preciznost odziva. Odziv FIR-a se zatim računa kao konvolucija impulsnog odziva i ulaznog signala (step ili impuls). FIR se realizira nerekurzivno i ima konačan broj elemenata kao i konačan odziv.

8. LITERATURA

- Materijali sa predavanja kolegija: „Sustavi za digitalnu obradu signala“ (220)
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